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Assessment of existing and future emissions reduction from the coal sector toward the implementation of the Minamata and Stockholm Conventions

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UN environment programme

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LIST OF ABBREVIATIONS

ACT	Accelerating Coal Transition
ADB	Asian Development Bank
AERS	Alternative Early Retirement Scenario
AMAP	Arctic Monitoring and Assessment Programme
APCD	Air Pollution Control Device
ASEAN	Association of Southeast Asian Nations
BAT	Best Available Techniques
BAU	Business-As-Usual
BCRC-SEA	Basel Convention Regional Centre for South-East Asia
BEP	Best Environmental Practices
CFPP	Coal-Fired Power Plant
CFIB	Coal-Fired Industrial Boiler
CIDP	Coal Industry Development Plan (Vietnam)
CIF	Climate Investment Fund
CO_2	Carbon Dioxide
COP	Conference of the Parties
DMC	Developing Member Countries
DoE	Department of Energy (the Philippines)
EREA	Electricity and Renewable Energy Authority
ERIA	Economic Research Institute for ASEAN and East Asia
ESP	Electrostatic Precipitator
ETM	Energy Transition Mechanism
FGD	Flue Gas Desulphurisation
GDP-PPP	Gross Domestic Product based on Purchasing Power Parity
GDP-USD	Gross Domestic Product based on United States Dollar
GEM	Global Energy Monitor
GFANZ	Glasgow Financial Alliance for Net Zero
GMA	Global Mercury Assessment
GW	Gigawatt
ICSC	International Centre for Sustainable Carbon
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
IPG	International Partners Group
JETP	Just Energy Transition Partnership
LNG	Liquefied Natural Gas
LT-LEDS	Long-Term Low Greenhouse Gas Emission Development Strategies
MEMR	Ministry of Energy and Mineral Resources (Indonesia)
MIA	Minamata Initial Assessment
MOIT	Ministry of Industry and Trade (Vietnam)
MWh	Megawatt Hours
NDC	Nationally Determined Contributions
NOx	Nitrogen Oxides
PCD	Vietnam Pollution Control Department
PDP	Power Development Plan (Vietnam)
PLN	Perusahaan Listrik Negara (Indonesian power utility)

PM	Particulate Matter
RUEN	Indonesian National Energy General Plan
RUPTL	Government of Indonesia and PLN Electricity Business Plan
SCR	Selective Catalytic Reducer
SO_2	Sulfur Dioxide
TWh	Terawatt Hour
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VEA	Vietnam Environment Administration
WBG	World Bank Group
WEO	World Energy Outlook

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Scope of the report

This report evaluates current and future estimates from coal-fired utility and industry plants in specified emerging economies. Using coal characteristics and plant-specific data, projections have been created for emissions of carbon dioxide (CO_2), and mercury (Hg) under different future energy scenarios. The scenarios considered are business as usual, early retirement, and the installation of air pollution control devices, taking current and planned energy policies as well as potential future strategies into account.

The report summarises a project of work to assess how emissions of concern could be affected by potential changes in regional and national energy strategies and related policies in emerging economies.

The target countries – Bangladesh, China, India, Indonesia, Pakistan, Philippines, South Africa and Vietnam - are all currently heavily reliant on coal for energy production. These countries have growing populations and/or populations which are likely to increase their per capita energy demand as they move through industrialisation. The potential for emissions to increase in these regions is therefore significant and the overall result – emission increase, control or reduction – will depend on the stringency and efficacy of current and future policies and legislation.

This report considers the energy sector in the target regions and projects potential emission values under different assumptions:

- BAU: where future emissions are projected according to current or impending action within the country
- AERS: where future emissions are projected on the assumption that some plants may be retired earlier than their planned 40-year lifetime
- Retrofit: where future emissions are projected assuming different installation rates of various emission control technology retrofits.

These projections allow an understanding of potential emission futures in these countries and could inform potential changes or amendments to policies in future to maximise emission reduction.

The feasibility of the various coal fleets to reach Paris Agreement climate goals, along with the potential to mitigate pollutants such as mercury, is explored. The report identifies areas where intervention may have the highest impact on mitigating national, and ultimately, global emissions of greenhouse gas and mercury into the atmosphere from the coal sector in these regions.

Executive Summary

This final project report presents and summarises the results of a Global Environment Facility (GEF) funded medium sized project (MSP), GEF10748. The objective of the project is to demonstrate mercury and POPs emissions reduction potential from coal fired power plants and industrial boilers in order to support governments in implementation control and reduction strategies for new and existing sources. The project quantifies potential future emissions of mercury and POPs for both the current baseline scenario and for a range of development scenarios. This data will underline the benefits that will accrue from targeted international action embedded in the Paris Agreement targets and the Stockholm and Minamata Conventions.

This summarising report includes main findings, conclusions, and recommendations regarding (a) the Global emissions outlook from coal-fired power plants (CFPPs), (b) target country profiles, (c) Possible solutions, including strategies on coal phase-out and air pollution control improvements, and (d) future project recommendations and policy guidance. The summarising report is supported by a range of appendices which present greater detail for the individual target or focus countries, gender considerations, and POPs.

Main conclusions:

Development of the process and engagement of stakeholders throughout

- This project is unique in its depth and analyses, combining a detailed analysis of published data, enhancing this with new emission calculations, and then combining this all with feedback from national stakeholders attained through face-to-face and online events.

Results from the analyses

- For most if not all countries, coal use is expected to peak in or by 2030.
- Emissions of all pollutants – CO_2, mercury etc – from these coal fleets will follow the trajectory of coal use in each country, peaking by 2030 and then declining as the coal fleets are phased out.
- Countries such as China have managed to decouple emissions of mercury from the trajectory of coal use due to the application of advanced APCDs across the fleet. If this approach were copied in some other countries, emissions of mercury could be reduced in terms of tens of tonnes.
- For all countries, early retirement of the coal fleet is the most effective means of accelerating emission reduction. However, for many countries, especially Indonesia, Vietnam and China, the young age of the coal fleet means that 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 which rely on decades of operation to achieve their return on investment.
- For most countries, the commitment to reducing emissions, through Paris and Minamata ratification, is clear. However, many face significant challenges with respect to the affordability and practicality of moving away from conventional coal plants in the timelines expected. Significant international support and investment is necessary to keep these aims on track.

Individual country insights:

- 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 APCD systems. China has significantly reduced emissions of mercury as a co-benefit of more stringent controls on the emissions of fine particles, and fine particle precursors (the acid gases NO_x and SO_2). The result has been reductions in atmospheric PM2.5 concentrations with significant economic and health benefits.
- 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. Although India has agreed to ambitious climate goals and has set emission limits to match those set in developed countries, its progress towards compliance is slow at best and risks stalling further. The emission limits and reduction goals are potentially too expensive and too challenging for a coal fleet which is already operating in extreme flexing mode whilst being asked to co-fire biomass. Assessment of the Indian coal fleet to determine best practice on a unit-by-unit basis would ensure strategic and efficient fleet operation whilst accelerating emission reduction.
- 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. Further, the total capacity of coal continues to rise. As coal plants age and retire, the total capacity should decline to 40 GW by 2050 – however, this is only slightly less than the current capacity. Indonesia has also expanded the use of coal through captive use with dedicated power plants being operated and utilised by industry for mineral processing. It is estimated that almost 25% of the operating coal capacity in Indonesia is for captive use, often with less stringent emission limits than electricity generating plants. Assuming that all plants will install sulfur control by 2030, emissions of mercury could decline significantly as a result. However, without further mercury-specific policies, the complete control of mercury will follow the trajectory of plant closure, continuing past 2050 before lowering to even 50% of current emission levels.
- Vietnam has significant renewable energy (including hydropower) but still relies on fossil fuels for around 43% of the energy capacity. Total capacity continues to grow and will reach 146 GW by 2030. The future of the energy sector in Vietnam will be determined by the continued uptake and deployment of renewable power and the development of energy storage solutions. Coal use is predicted to double between 2020 and 2030. Early retirement is therefore intrinsic to reducing emissions. As with China, the age of the coal fleet in Vietnam is the major challenge. The current plants may well operate for 40 years and, even with emission control technologies for the major pollutants, the emissions from the sector will be significant for decades.
- For South Africa, the challenges are largely economic and technical. Coal is critical to the country's grid but the fleet has been in decline for years, with plant accidents (fires and turbine failures) becoming more frequent. But without any alternative power sources, the coal fleet will remain essential. Investment is needed.
- 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 to 2030. And, as for the other regions with many plants which are still new, the major challenge is

accelerating emission reduction from a coal fleet which has, theoretically, 40 years of operation left.

- Pakistan and Bangladesh have been included because of future plans to significantly increase the installed capacity of the 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. There are some major issues in renewable energy generation for these countries, e.g., challenges with Pakistan's hydropower generation, so it is possible that CFPP projects under a pre-construction stage will proceed to construction. As a result these plants could potentially operate for another 40+ years, past 2060. If renewables development does accelerate however, this increase in CFPP capacity may represent a stranded asset risk.

Legacy of the project

- Need for the maintenance of the dataset as a living document and the importance of updating the data, especially the potential to improve the emission factors
- Indication of a clear path forward – focussing on strategic operation of the remaining coal fleets to ensure the cost-effective application of APCD versus the selection of plants most appropriate for early retirement. Help to manage coal fleets on their glide path to retirement through a holistic approach which considers plant age, efficiency and, often more importantly, their importance to energy security – without energy security in the short-term, the move to renewable energy options will stall.
- This current project has demonstrated that, despite the potential peak of coal use in the next 5 years, emissions from the coal sector will continue for decades. This is particularly true for countries such as China, Indonesia and Vietnam whose coal fleets are young and have decades of planned operation ahead. Accelerating coal fleet closure is part of the Paris commitment for many countries and is vital to the aims of the convention.

A major outcome of the project has been the development of a proposed new GEF project. The proposed project aims to address the operation of coal fleets with the aim of strategic management to accelerate emission reduction. The project will not require the installation of control technologies but rather will address the operation of the existing fleet. If funded, the project would work with target regions to promote best practice in coal use in utility fleets as they transition towards retirement, by working with governments and utilities to strategize coal plant use on the glide path to complete closure of the existing coal fleet.

1. Background

Electricity is critical to the establishment and maintenance of a national population. The World Energy Council (World Energy Council 2024) has defined the energy trilemma as the balance between:

- energy security – the delivery of dispatchable and reliable power to sustain a growing economy
- energy affordability – ensuring that energy is accessible to industry and populations
- energy sustainability – minimising the impact of energy use on the environment

Energy security will always dominate – governments will prioritise the delivery of power to their populations to maintain standards of living and to ensure access to vital resources such as education, healthcare, and other daily needs. Affordability and sustainability have historically been lower priorities than energy security and this is still evident today. When regions face external issues such as conflict and pandemics which change the dynamics of the economy, electricity costs will inevitably increase and environmental goals may be delayed or even abandoned as priorities and funding are focussed elsewhere. The International Energy Agency (IEA) World Energy Outlook report of 2023 (IEA 2023) opens with the warning of the "fragile" state of the energy sector in the face of unpredictable but ever-present threat of national and international crises.

The challenge is therefore to move to energy grids which are based on reliable, affordable and clean power although these options rarely exist together: coal is reliable and affordable but not clean; renewable energy is clean but, until energy dispatchability and storage challenges are solved, it can be relatively unreliable and expensive. Economically challenged countries which have grown on a coal-based economy are likely to continue to do so until alternatives become feasible, technically and economically. Some regions may be unlikely to take on the challenge of making significant changes to their energy sector unless they are forced to or, more likely, they are assisted (financially) in making the transition.

The sections below provide a pragmatic assessment of the challenges in energy use globally and in the countries of focus of this project. Potential barriers to the energy transition are discussed, including the challenge of changing the dominant source of power (coal) to lower-emission options as well as the challenges of not only developing emission reduction strategies and policies but ensuring that they work in practice.

1.1. Global energy outlook and challenges

There is a global trend to increase the volume of renewable energy within the energy sector in response to the need for emission reduction, climate action, and sustainable energy production. However, geopolitical and socioeconomic challenges must also be considered. While there has been a decline in the proportion of coal-fired power capacity relative to other energy sources globally (Figure 1A), this reduction is not due to an accelerated retirement of coal-fired power plants (CFPPs) worldwide, but rather to the reduction in the expansion of new coal-fired power plant infrastructure on a global scale (Figure 1B). The total amount of global coal use continues to increase.

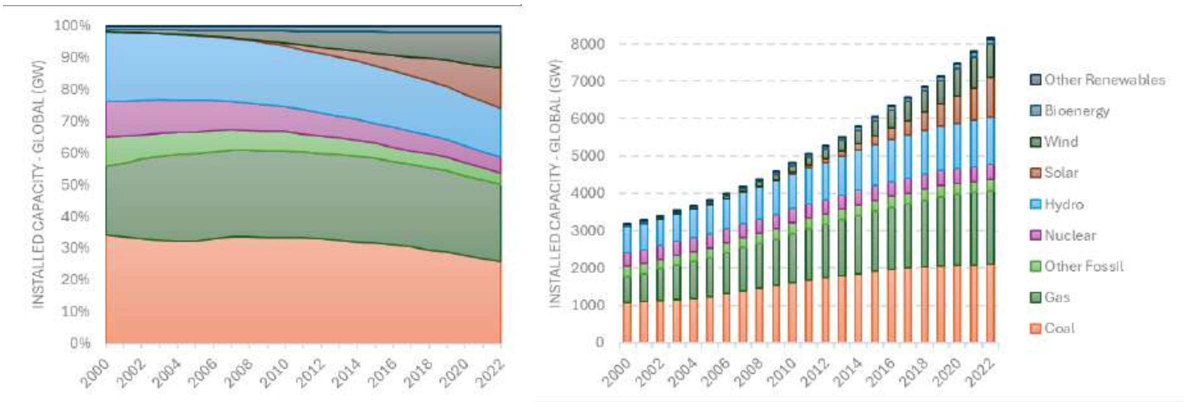

Figure 1: Global share (A) and absolute amount (B) of installed power capacity by source (data from Ember database, updated March 2024 (1)

In recent years, Asia has been the most active global area in terms of changes within the energy sector. In 2022, Asia had a 50% share of the total global electricity demand and it currently holds around 60% of the global population. Furthermore, Asia has a 75% share of the total global capacity of CFPPs, with China alone hosting around 52%[1]. Rapid adoption and deployment of cleaner and more sustainable energy alternatives are therefore vital in the region if emission reduction is to be achieved.

Fossil fuels have historically been regarded as the most viable (affordable and available) resources to fulfil energy needs in many emerging and developing countries. However, increased awareness of climate issues and the health effects of pollutants emitted by fossil fuels has created a growing push towards cleaner and more efficient power production. For emerging economies, the challenge is to facilitate population growth and industrial advancement and the associated increased energy demands with a cleaner energy sector, which often comes at a significant economic cost.

1.2. The continued reliance on coal

The challenge is greatest for those countries with the largest population and highest rate of population growth - China and India. In 2022, these nations collectively accounted for a substantial portion of global electricity demand, with China alone representing 37%. They hold significant shares in global electricity generation from coal (66%) and installed CFPP capacity (63%) according to the latest data from EMBER (2024). Table 1 shows **t**he top 10 ranked countries by total fossil fuel consumption, coal production, coal consumption, per capita energy consumption from coal, and the share in primary energy from coal in 2019[1].

Table 1 The top 10 ranked countries by total fossil fuel consumption in 2019[1]

Rank	Total electricity demand (TWh) – World (28771)	Total electricity generation from fossil fuels (TWh) – World (17652)	Total electricity generation from coal (TWh) – World (10266)	Installed capacity – CFPPs (GW) – World (2106)	Share in electricity generated from coal (%) – World (36)
#1	China (8831)	China (5761)	China (5398)	China (1095)	Kosovo (93)
#2	United States (4328)	United States (2557)	India (1380)	India (234)	Mongolia (91)
#3	India (1856)	India (1431)	United States (832)	United States (212)	South Africa (84)
#4	Russia (1154)	Japan (755)	Japan (348)	Japan (53)	India (74)

[1] EMBER, 2024. Yearly electricity database. Updated 11 March 2024. https://ember-climate.org/data-catalogue/yearly-electricity-data/.

#5	Japan (1034)	Russia (738)	South Korea (211)	South Africa (46)	Morocco (73)
#6	Brazil (700)	Saudi Arabia (401)	Indonesia (205)	Indonesia (45)	Poland (70)
#7	South Korea (620)	South Korea (393)	South Africa (202)	Germany (40)	Kazakhstan (67)
#8	Canada (618)	Iran (332)	Russia (192)	South Korea (39)	Bosnia (66)
#9	Germany (540)	Germany (281)	Germany (180)	Russia (39)	Serbia (66)
#10	France (484)	Indonesia (268)	Australia (131)	Poland (29)	Moldova (64)

China dominates the ranking, generating over twice as much electricity from fossil fuels as the next highest-ranking country, the USA.

China is already working to reduce the environmental effects of its power generation sector. The conclusion of China's 13th Five-Year Plan (FYP-13) for energy development coincided with a commitment to achieve 'climate neutrality' by 2060, as announced during the 26th Conference of the Parties (COP26) of the United Nations Framework Convention on Climate Change (UNFCCC). FYP-13 initiated a change in China's coal consumption pattern through the decommissioning of smaller, inefficient coal-fired power plants and widespread adoption of air pollution control devices (APCDs). These devices, targeting particulate matter (PM), sulfur dioxide (SO_2), and oxidized nitrogen (NOx), were installed in both existing and new coal utility plants which led to a significant co-reduction in pollutants such as mercury and greenhouse gases. The Sino-German Energy Transition Project, as outlined by the German Federal Ministry for Economic Affairs and Energy (BMWi), reported China's success towards meeting the energy development targets outlined in their FYP-13 (Sino German Energy Transition Project 2021). The installed capacity of CFPP fell below 40% of the total energy capacity in 2023 but in terms of actual generation, coal still delivered over 56% of the demand. Despite the progress made under FYP-13, demonstrating a commitment to emission reduction, the continued reliance on coal, at least up to 2050, is still evident under existing Chinese policies (CNPC Economics & Technology Research Institute (CNPC ETRI) 2018).

India recently overtook China in terms of total national population and India's dependence on coal is also significant. Currently, as can be seen in Table 1, India has an electricity demand which is less than 25% of that in China, despite having a similar population. This difference is due to the lower standard of living of most of the Indian population. It is important to consider that, as Indians move towards greater industrial growth and development, the per capita demand for electricity is likely to increase, causing further demand on the power sector.

While China has made significant steps to increasing efficiency and reducing emissions from the CFPP, India is at least a decade behind. Despite the introduction of emission standards for CFPPs in India in 2015, compliance through the installation of APCDs remains low (below 10%) and many CFPP in India continue to pollute at a significant level (Sloss *et al.* 2023).

Over the past two decades, other countries in Southeast Asia have experienced rapid economic expansion, resulting in a surge in energy demand (IEA, 2022)[2]. Many still rely heavily on coal for power generation, primarily due to its affordability and accessibility and, since the move to cleaner alternatives is complex and expensive, there are significant obstacles for a clean energy transition. The International Energy Agency (IEA) World Energy Outlook report of 2021 and 2022 confirms the persistence of coal as a primary energy source in Southeast Asia, driven by current policies. However, recent commitments to sustainable development and climate action indicate a potential peaking in electricity demand around 2030, followed by a rapid reduction in demand by 2050. As shown in **Error! Reference source not found.**, the region must decouple from the previous trajectory

[2] IEA Southeast Asia Energy Outlook 2022, https://www.iea.org/reports/southeast-asia-energy-outlook-2022/key-findings

and commit to significant action if it is to meet the announced climate action pledges by the end of this decade.

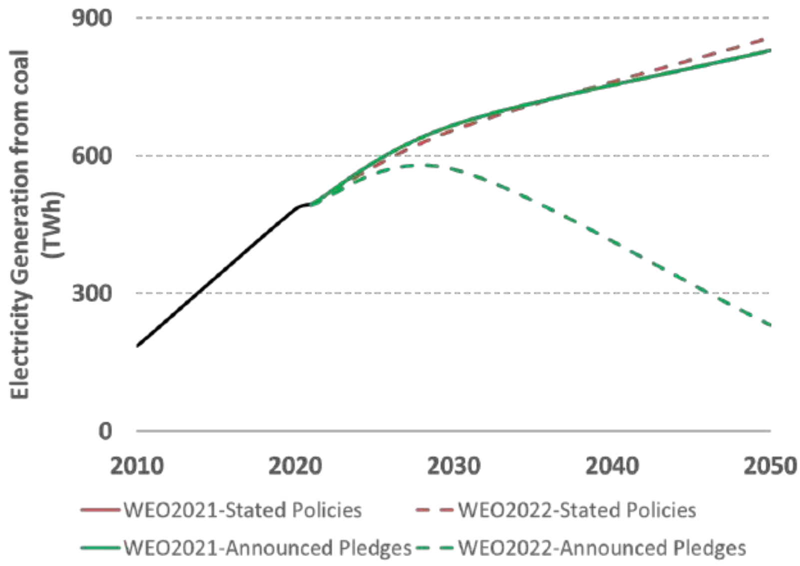

Figure 2 Projected electricity generation from coal in Southeast Asia as recorded by the stated policies and announced pledges scenarios from the IEA World Energy Outlook reports of 2021 and 2022

The five largest ASEAN countries - Indonesia, Vietnam, Malaysia, the Philippines, and Thailand - are also still reliant on CFPP for power generation. However, there are signs of decline observed in Vietnam, Malaysia, and Thailand (Figure 3, data from the Ember Electricity Data Explorer Platform[3]). The predicted increase in coal use in these regions could mean a concomitant increase in emissions from the power sector, especially in countries such as Indonesia. Since coal plants have an average lifetime of 40 years, CFPPs under planning and construction will contribute to global emissions for decades. It is therefore imperative that action is taken as soon as possible to promote alternative sources of energy as well as to encourage strategies to reduce emissions from existing and potential new coal-build.

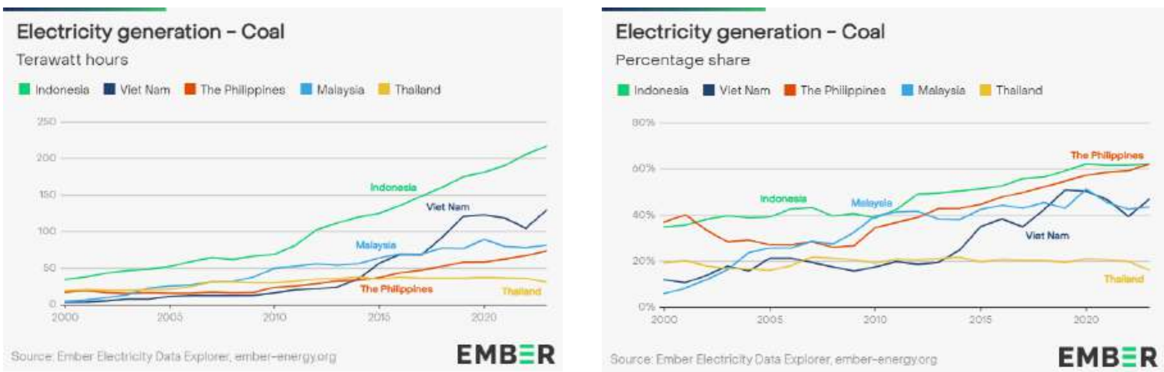

Figure 3 Electricity generation from coal-fired power plants in Southeast Asia[3]

Whilst coal use for power generation may be slowing or even declining in some regions, it is important to acknowledge that coal use in the industrial sector is still significant. Coal as a captive source of power is seen as an advantage for industries as they can control costs and output, independent from any issues on the national grid. Coal is still used in the nonferrous metal industry

[3] EMBER Electricity Data Explorer platform (https://ember-climate.org/data/data-tools/data-explorer/)

as well as the cement sector. Somewhat ironically, coal use is often still intrinsic to the production of various materials (graphite, nanotubes, rare earth elements) which are critical to the development of renewable energy systems and related battery storage. These are outside the scope of this current report but are important in the wider context of the significant challenge of achieving a complete move away from coal and related emissions.

The United Nations Environment Programme (UNEP) Emissions Gap report (UNEP 2023) emphasised the following concerns:

- emissions are still rising globally and the emission gap, between current levels and those required to avoid significant climate change, remains high
- emissions remain unequally distributed globally, reflecting global inequality
- there has been “negligible” movement on achieving the National Determined Contributions under the Paris Agreement to reduce greenhouse gas emissions
- commitments this decade will determine the feasibility of achieving the goals of the Paris Agreement, with the current increase in temperature predicted to reach 3°C
- all countries, high-income and low-income, must accelerate action but the lower-income countries face a greater economic and institutional challenge

The global dependency on coal internationally is starting to decline but it is clear that significant efforts are needed, especially in more coal-dependent emerging regions, to make a determined move away from fossil fuels and to reduce emissions from remaining sources. However, it is important to note that, even if new coal built were to cease immediately, existing coal fleets would continue to operate in order to provide power through the energy transition and also, perhaps more critically for utility companies, to recoup on investment costs and to avoid stranded assets.

In this context it is revealing to examine the age and potential operating lifetimes of CFPPs in countries who are likely to rely on coal as an energy source in the coming decades. **Error! Reference source not found.** and Figure 5 show the age ranges of CFPPs in operation in China and India[4].

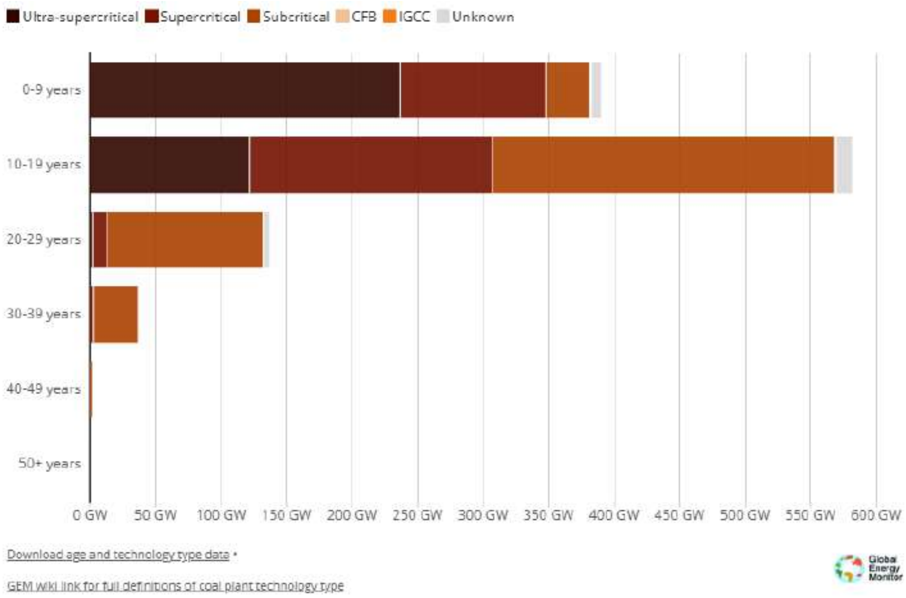

Figure 4: Distribution of CFPPs in China by age (data from the Global Energy Monitor 2023 Coal Plant Tracker Database (https://globalenergymonitor.org/projects/global-coal-plant-tracker/[4])

[4] Coal Plant Tracker Database, Global Energy Monitor; https://globalenergymonitor.org/projects/global-coal-plant-tracker/

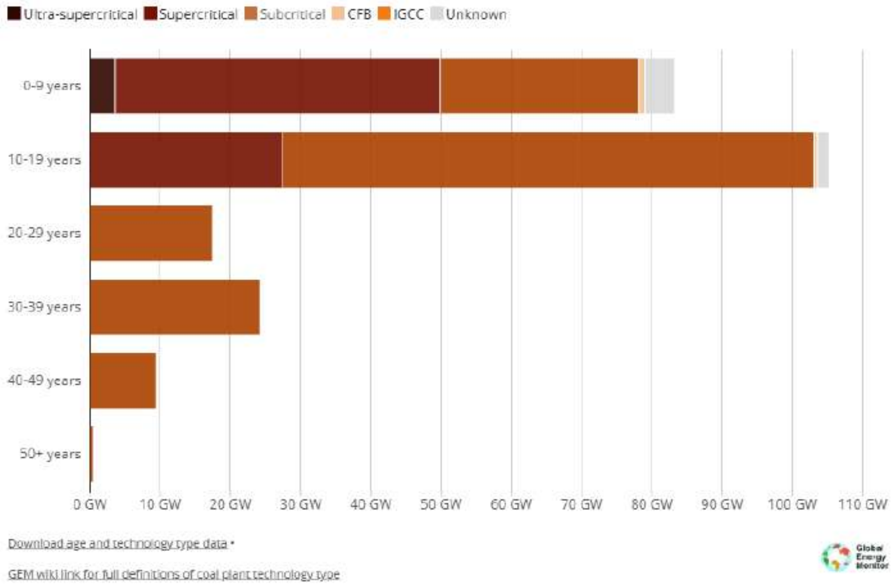

Figure 5: Distribution of CFPPs in India by age (data from the Global Energy Monitor 2023 Coal Plant Tracker Database (https://globalenergymonitor.org/projects/global-coal-plant-tracker/[4])

The vast majority of Chinese coal plants are younger than 30 years old. Whilst plants over 20 years old may have recovered investment cost, this is less likely for plants under 10 years old. And since most power plants operate for 40 years or more, the majority of Chinese plants could feasibly continue to operate for several more decades. The same is even more true for India, where almost half of the existing fleet is considered new, at under 10 years of age.

Figure 6 shows the same information for several Southeast Asian countries and, again, the majority of the coal fleet is relatively young, with a significant predicted remaining lifetime. In order for these coal units to retire early, there would likely be a need for funding to avoid stranded asset issues as well as a need for appropriate consideration of associated just energy transition issues for those employed within the industry.

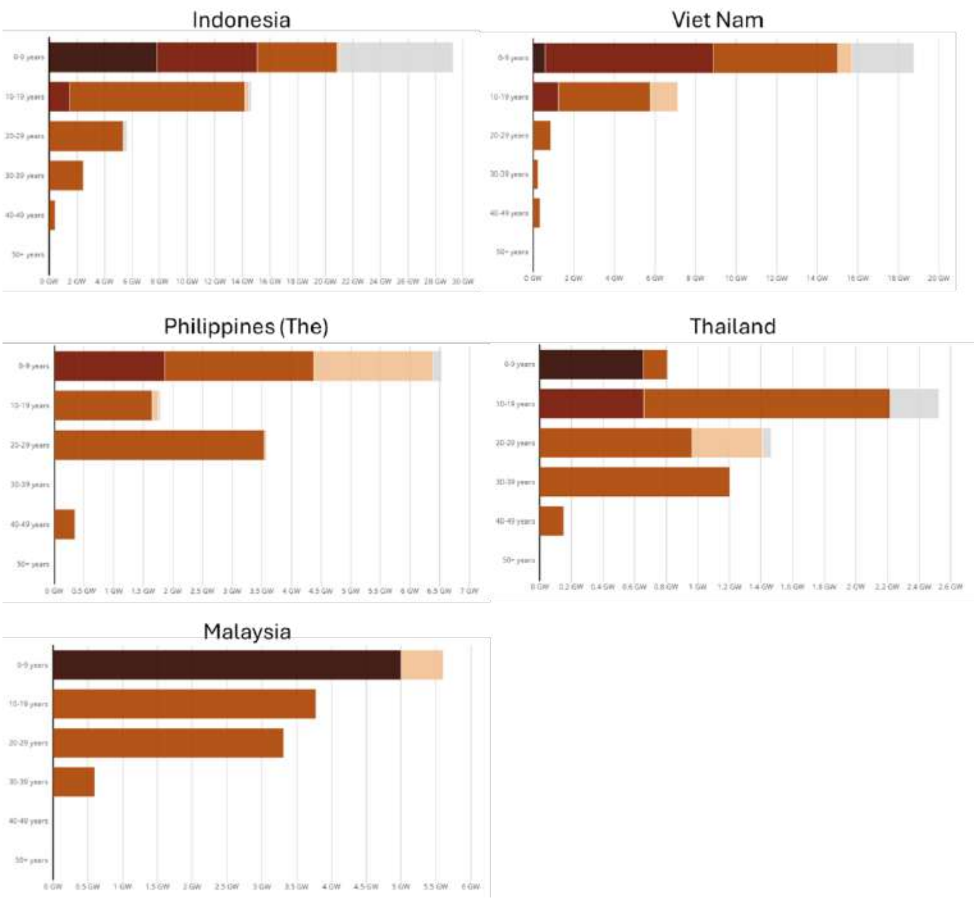

Figure 6: Distribution of CFPPs in various Southeast Asian countries by age (data from the Global Energy Monitor 2023 Coal Plant Tracker Database (https://globalenergymonitor.org/projects/global-coal-plant-tracker/[4])

Vietnam has the youngest fleet of coal-fired generators in Southeast Asia, with 82% of power plants less than ten years old. Indonesia has the greatest capacity of young plants and, based on the continued investment in new coal build in the country (see later) this disparity could increase.

Approximately 8% (166.5 GW) of all operating CFPPs have already exceeded a lifetime of 40 to 50 years, with an additional 9.7% (202.4 GW) operating for over 50 years. Most of these aging units are in countries such as the Czech Republic, Russia, Ukraine, the United Kingdom, the United States, and South Africa.

1.3. Implications on health and climate - relevant international policies and action

Concern over pollutant emissions from human activities continues to grow, especially around long-lived atmospheric species such as mercury and greenhouse gases (GHG) which pose significant threat to human health. In response to this, nations have come together to agree on coordinated efforts to control and where feasible reduce emissions, through international agreements and conventions. The following sections review the international instruments most likely to have an effect on emissions from coal-fired power generation.

GHGs and the Paris Agreement

The United Nations Framework Convention on Climate Change (UNFCCC) entered into force on 21 March 1994, with 198 countries currently Parties to the Convention. The Paris Agreement, a legally binding treaty on climate change under the UNFCCC, was adopted in December 1995 (COP21) and entered into force on the 4th of November 1996. The implementation of the Paris Agreement requires economic and social transformation that is based on the best scientific information to guide strategies and set goals for the abatement of anthropogenic pollution that contributes to climate change. Country-specific goals for the Parties are mainly structured around their national climate action plans through the submission of Nationally Determined Contributions (NDC) and Long-Term Low Emissions and Development Strategies LT-LEDS.

Error! Reference source not found. shows an analysis of the NDCs of the top 20 fossil fuel producers by the International Institute for Sustainable Development (IISD) for 2024[5].

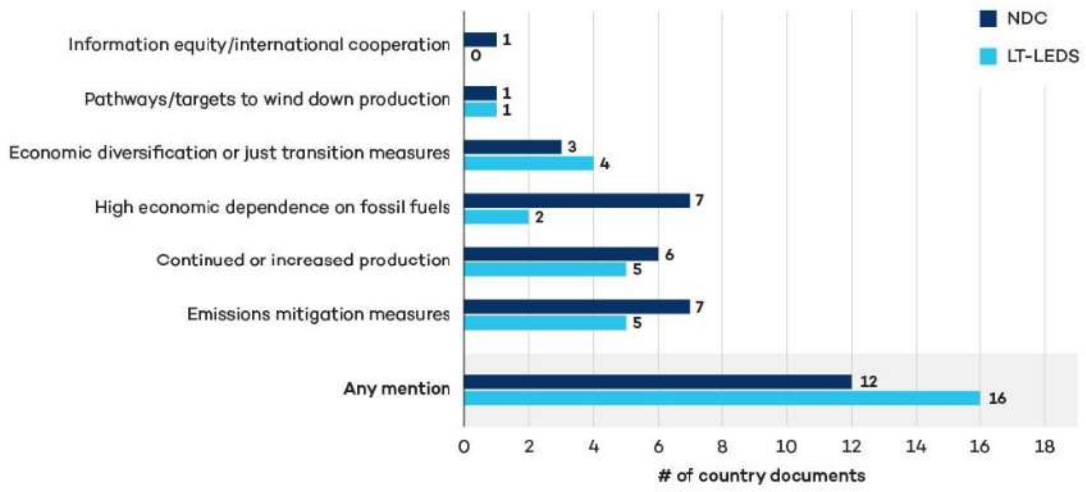

Figure 7: Overview of references to fossil fuel production in climate documents of the 20 largest fossil fuel producers (IISD, 2024)

Together the 20 nations reviewed (Algeria, Australia, Brazil, Canada, China, Germany, India, Indonesia, Iran, Iraq, Kuwait, Norway, Poland, Qatar, Russia, Saudi Arabia, South Africa, Turkey, United Arab Emirates, and the United States) account for 93% of global coal production. The study notes that seven of these countries, a third of the total, do not mention coal production in their NDCs, six stated plans to continue or increase production, and only Germany and Poland mention any intention to decrease coal production. Emission mitigation measures are mentioned, relating to energy efficiency and emission control strategies. The Paris Agreement is not the only legislative framework affecting GHG emissions from the coal sector – many developed countries have their own separate national policies and reduction strategies. However, for many emerging regions, the Paris Agreement is the only commitment they have made to tackling climate change. Without strengthening this commitment, ideally with international financial support, there is a significant risk that the Paris Agreement will have a limited effect on emissions from the coal sector in regions such as Southeast Asia.

The Paris Agreement references gender equality issues within climate action, acknowledging that the consequences of climate change are not gender neutral – in situations of economic stress and hardship, women and children are the most vulnerable. Article 7 of the Paris agreement includes

[5] IISD, 2024 https://www.iisd.org/articles/press-release/report-calls-fossil-fuel-producers-map-transition-away-ndcs

references to gender-responsive adaptation and relevant capacity building. COP 29, in November 2024, reviewed the gender action plan which was adopted at COP28[6].

The UN Minamata Convention on Mercury

The Minamata Convention is a global treaty adopted in 2013 and entered into force in 2017 to protect human health and the environment from the harmful effects of mercury. It is named after the Japanese city of Minamata, where severe mercury poisoning occurred in the mid-20th century due to industrial pollution.

In the context of reducing mercury emissions from the coal-fired power plant and coal-fired industrial boiler (CFPP/CFIB) sector, the Minamata Convention sets out several key provisions and objectives:

- Emission Limitations: The Convention calls for the development and implementation of national strategies to reduce emissions of mercury from anthropogenic sources, including CFPPs and coal-fired industrial boilers (CFIBs).
- Best Available Techniques (BAT) and Best Environmental Practices (BEP): Parties to the Convention are encouraged to promote the use of BAT and BEP to minimize mercury emissions from CFPPs and CFIBs. This includes the adoption of appropriate technologies and practices for mercury control.
- Monitoring and Reporting: Parties are required to establish monitoring programs to track mercury emissions from CFPPs and CFIBs and report their findings to the Convention's governing body.
- Phasing Out of Mercury-Added Products: The Convention aims to phase out the use of mercury-added products, such as mercury-containing fuels used in CFPPs and CFIBs, where technically and economically feasible alternatives exist.
- Technology Transfer and Capacity Building: The Convention promotes international cooperation to facilitate the transfer of environmentally sound technologies for mercury control in the CFPP/CFIB sector. It also supports capacity-building efforts to assist developing countries in implementing mercury reduction measures.

Overall, the Minamata Convention serves as a comprehensive framework for addressing mercury emissions from various sources, including CFPPs and CFIBs, by promoting the adoption of emission reduction measures, fostering international cooperation, and enhancing monitoring and reporting mechanisms.

The Convention includes a call for processes to evaluate the effectiveness of the Convention in eliminating or reducing mercury emissions and releases to the environment (Article 22). Guidelines have been developed in some cases to assist Parties in identifying and quantifying emissions and releases; for example, for emissions from industrial sources included in Article 8 (UNEP 2019a) including CFPPs and CFIBs.

The timeline for implementation of the goals of the convention currently runs to 2032, where primary mercury mining must cease in all signatory countries. Inventories and national plans are required for each signatory country are required from 2022 onwards (or five years after the date of entry into force of the convention for the relevant country). BAT/BEP for new plants are also

[6] UNFCC Gender and climate change brief for the adaptation committee https://unfccc.int/sites/default/files/resource/Brief_Gender%20in%20the%20work%20of%20the%20AC.pdf

required within this time frame and existing plants have until 2027 (or ten years after the date of entry into force of the convention[7].

Article 8 of the Convention focuses on emissions from point sources, with Annex D defining the major sources – CFPPs, CFIBs, smelting and roasting of non-ferrous metals, waste incineration and cement production[8]. For CFPPs, guidelines are provided on BAT/BEP for mercury emission reduction. However, the selection of technique or technology used, including co-benefit effects through the introduction of APCDs for other pollutants such as particulate matter or sulfur dioxide (SO_2) is not prescribed. Rather the signatory country can determine its own strategy to "control and where feasible reduce" emissions of mercury, taking technological, geographical and economic challenges into account. Individual countries, such as Canada, the USA, the EU, Japan and China, have set stringent emission standards for mercury emissions from CFPPs. Other countries, such as India and Indonesia, have also set emission limits but these are somewhat lax and unlikely to result in any requirement for action to be taken at CFPPs. In these situations, mercury control at CFPPs falls to co-benefit effects, and the ability of APCDs for other major pollutants to capture mercury.

The Convention also addresses gender equality, recognising that women and children are more susceptible to the potential health effects of mercury and that they make up a large proportion of the vulnerable population. Document 4/22 of the Convention focusses on mainstreaming gender in the work of the Minamata Secretariat as well as ensuring gender considerations in all project development, review, reporting and evaluation[9].

POPs and Stockholm Convention

The Stockholm Convention was adopted in 2001 to address emissions of potentially harmful and persistent organic pollutants (POPs) from human activities. As set out in Article 1 of the Convention, the objective is to protect human health and the environment from POPs, due to their persistence, wide geographically dispersal, and their potential to bioaccumulate and present adverse health effects in both humans and ecosystems[10](UNEP 2019b). The Stockholm Convention, while primarily focused on regulating POPs emissions and release, also encompasses gender issues by recognizing the heightened risk of POPs exposure in women due to their frequent engagement in activities involving these chemicals, and the potential transference of POPs to their offspring due to their bio-accumulative and persistent nature.

It is important to note that organic emissions such as POPs are not commonly significant from high-temperature combustion systems such as CFPPs and so they do not feature much in Stockholm Convention-focussed activities. However, inefficient combustion systems, which are more common in emerging regions, can release unburnt carbon and organic species. Promoting clean and efficient CFPPs could contribute to a small but important reduction in POPs globally. As mentioned earlier, the younger CFPP fleet faces a significant risk of becoming stranded assets considering the global commitment under the Paris Agreement to achieve carbon neutrality or net zero emissions between 2050 and 2070. Eight focus countries, primarily in Asia (China, India, Indonesia, Vietnam, Thailand, Malaysia, Philippines) and Southern Africa (South Africa), are anticipated to continue relying heavily

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[7] Minamata Convention - Timeline https://minamataconvention.org/en/about/timeline
[8] Minamata Convention – Text and Annexes https://minamataconvention.org/en/documents/minamata-convention-mercury-text-and-annexes
[9] Minamata Convention – Mainstreaming gender in capacity building projects: practical approaches https://minamataconvention.org/sites/default/files/documents/2024-03/MO7March24-Presentation.pdf
[10] Convention on Persistent Organic Pollutants https://www.pops.int/

on coal-fired power in the foreseeable future, and Pakistan and Bangladesh have indicated further additions to their coal-fired plants in the near future.

1.4. Comments

Many of these focus countries have revised and enhanced their nationally determined contributions (NDCs) under the Paris Agreement, accompanied by long-term low greenhouse gas emission development strategies (LT-LEDS) aimed at achieving carbon neutrality.

The establishment of a Just Energy Transition Partnership (JETP) between wealthier countries and coal-reliant nations like South Africa and Indonesia signals efforts to expedite their transition away from coal-fired power generation. However, the announced commitments of USD 8 billion for South Africa and USD 20 billion for Indonesia are acknowledged as insufficient, as noted in their national action plans.

Initiatives such as the Energy Transition Mechanism (ETM) aim to secure stakeholders and funds to retire and repurpose 50% of CFPPs in Vietnam, Indonesia, and the Philippines. However, the implementation of this mechanism is still pending finalization. These developments highlight the complex challenges and evolving strategies associated with transitioning away from coal-fired power generation, emphasizing the need for concerted international efforts, substantial investments, and innovative mechanisms to facilitate a just and sustainable energy transition.

A recent analysis (Ordonez *et al.* 2024) analyses JET partnerships (JETPs) with South Africa, Indonesia and Vietnam and assesses their alignment with global climate targets. These analyses show that the JETP targets result in considerable alignment with a 1.5°C trajectory by 2030 compared to the BAU scenario. However, the authors also note that climate policy and diplomacy efforts to prevent coal expansion will be needed to support existing JETPs and prevent the emergence of new coal-dependent economies.

2. Methodologies and assumptions

This project used publicly available data and information to analyse potential future emissions from CFPPs in target countries, based on different future energy sector 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.

2.1. 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[4]. 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 CO_2 emissions. The database was updated in January 2023. Country-specific scenarios were built from the database with the addition of country- or plant-specific information generated from government databases, scientific literature and/or reports from consultancy agencies.

Three scenarios were assumed for this project:

- Business as usual, BAU
- Alternative early retirement, AERS
- APCD retrofit, RETROFIT

Each of these is discussed separately below.

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. CFPP projects under construction are expected to be commissioned/operational by 2025, if not indicated otherwise on the GEM database, and are assumed to continue to operate for a 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 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 under pre-construction will continue.

Alternative early retirement scenario (AERS)

This scenario assumes that coal-fired power plants can retire early, ceasing operation before they reach the end of their designed 40-year lifespan. This scenario can be modified at a country-specific level, taking into account the remaining lifetime for existing plants, and the design lifetime for newly constructed plants.

- A threshold date is set. Plants build before or after this date stamp can be proposed to retire a certain number of years earlier than indicated on the GEM database.
- This scenario does not consider any air-pollution control retrofits and so does not differentiate on a plant/unit-specific level which units should considered for early retirement other than by their year of commissioning. For example: All plants that were built before 2015 will retire 3 years earlier than their remaining design lifetime while those built after 2015 will retire 10 years earlier than their design lifetime.

Air pollution control device retrofit scenario (RETROFIT)

This scenario can be modified at a country-specific level to consider options for units to be fitted with additional APCDs under additional pre-determined conditions.

- This scenario only assesses future mercury/POPs reduction based on the effects of installed APCDs. It does not consider total CFPP capacity projections or early retirement options. It does not calculate the improved CO_2 reducing capability which may be achieved through plant upgrades during APCD installation.
- Assumptions must be made for plants where there is no published information on the current status of APCDs installed. In these situations, units above 600 MW operating under subcritical combustion conditions are assumed to be fitted with particulate matter and SO_2 control (electrostatic precipitators, ESP, + flue gas desulphurisation, FGD), while those operating under 600 MW are assumed to be fitted only with particulate matter controls (ESP only). Units above 600 MW that operate under (ultra)supercritical combustion conditions are assumed to be fitted with particulate matter control and SO_2/NOx control (selective catalytic reduction, SCR + ESP + FGD), while those operating under 600 MW are assumed to be fitted with particulate matter and SO_2 control (ESP + FGD). These conditions can be modified on a country-specific level using information from each country. For example, India is shown to have limited SO_2 control technologies while China is known to have SO_2 control technologies fitted to most of their CFPP fleet.

It is significantly challenging to estimate global emission reductions under the RETROFIT scenarios as the status of APCDs globally has a high level of uncertainty. This uncertainty is exemplified by the significant variance in APCD configurations observed across different regions and countries.

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 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 configuration 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 ton/yr),
IF mercury input factor of the feed coal (in mg/kg)
RF mercury retention factor (%) according to the CFPP unit's APCD configuration.

A relative 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.

2.2. Global emission outlook

In order to determine the assumptions used for this project, it is important to understand the trends in energy production as well as the factors which can affect those trends.

Fossil fuels are responsible for the largest contribution to the global atmospheric emissions of greenhouse and pollutant gases (CO_2, CH_4, N_20, NOx and SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), and other adverse health pollutants such as mercury. In 2022, global CO_2 emissions from energy generation and industrial processes reached an all-time high of 36.8 billion tons (Figure 7).

Emissions from developing economies in Asia (excluding China) grew more than for any other region in 2022, from which more than 50% of the recorded emissions are from coal-fired power generation alone (Figure 8).

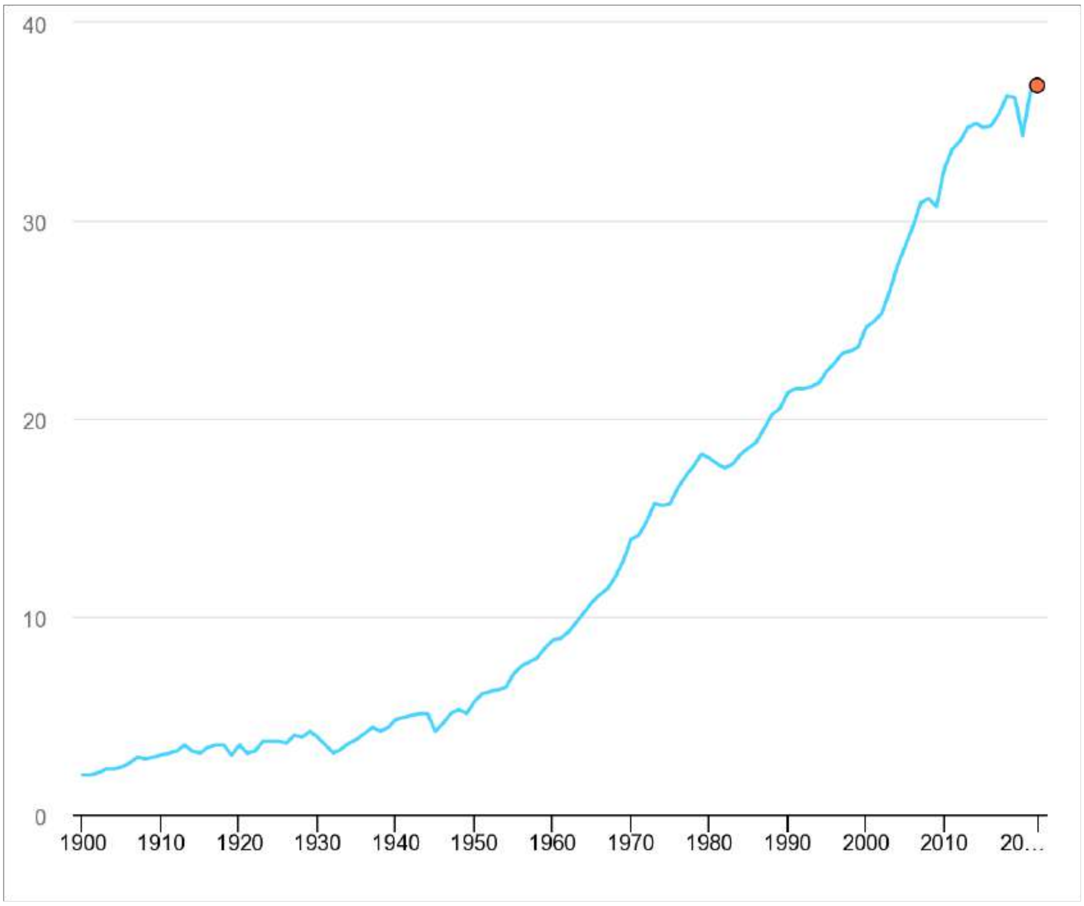


Figure 8: Global CO_2 emissions (Billion tons) from energy production and industrial sources, 1900-2022[11]

It is challenging to implement a just energy transition whilst ensuring energy security and economic growth during the current global conditions. External factors such as the COVID-19 pandemic and various sites of national and international conflict result in volatile energy resource markets and economic instability at a global scale. For this reason, a multi-faceted approach that includes policy reforms, investment in infrastructure, and technological innovation is key to executing a positive outlook in sustainable energy generation and climate action. Therefore, it is acknowledged that a complete transformation of the global energy system is required to meet carbon neutrality in the future (IEA 2021a; IEA 2021b; Ordonez *et al.* 2024).

2.3. Trends in coal use

Asia is currently the region with the highest global appetite for coal-fired energy, from which China alone accounts for almost 60% of CO_2 emissions in the Asia-Pacific region in 2022[12].

In the CFPP sector, China and India alone account for around 80% of CO_2 emissions in Asia (Figure 9).

[11] IEA, 2023 License: CC By 4.0

[12] Statista. Carbon dioxide emissions from energy worldwide from 1965 to 2022, by region. https://www.statista.com/statistics/205966/world-carbon-dioxide-emissions-by-region/#:~:text=The%20Asia%2DPacific%20region%20produced,percent%20of%20the%20global%20total.

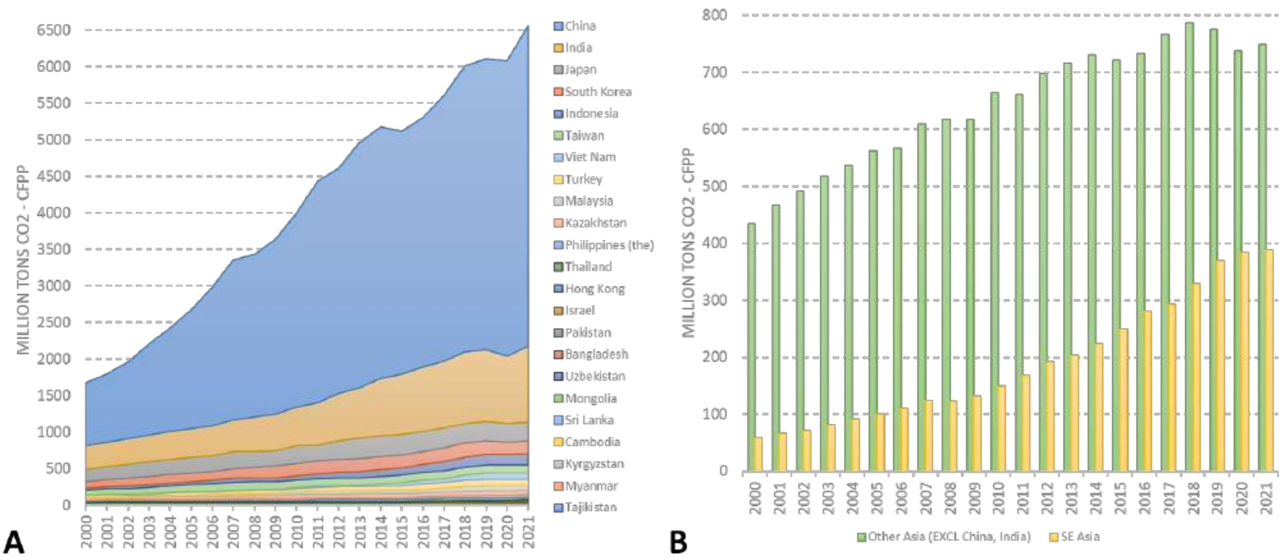


Figure 9: Emissions of CO_2 from power generation, Mt, in Asia (A) and combined emissions for Southeast Asia, excluding China and India (B) [3]

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 (Figure 9B). For this reason, efforts should be focused on reducing the dependence on coal in these regions.

Additional data from the Global Energy Monitor (GEM) shows that Indonesia, Vietnam, Malaysia, the Philippines, and Thailand are operating a young CFPP fleet. These countries combined currently have 421 operating units (89.8 GW capacity), of which 344 units (71.3 GW capacity) are less than- or equal to 20 years of age (Figure 10). This suggests that investment in coal-fired power generation in these countries is high and that most of the currently operating fleet is expected to continue to operate for the next two to three decades (assuming a design lifetime of around 40 years). This does not even consider all projects under construction and in the pre-construction phase for these countries. For this reason, the early retirement of existing CFPPs, and the potential cancellation of new projects, could be vital for these countries to reach decarbonization of their power sectors by 2050.

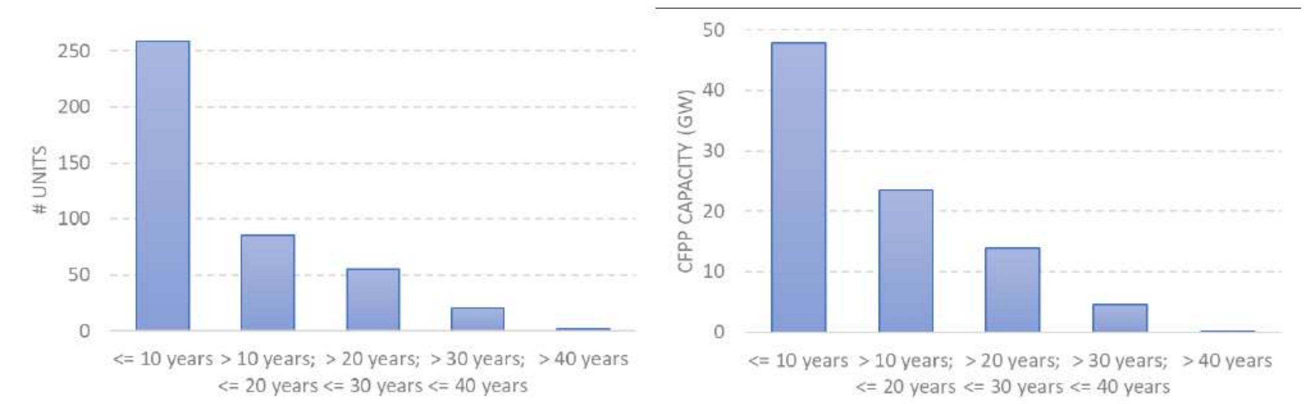


Figure 10: Combined number of units and operating capacity of CFPP in Indonesia, Vietnam, Malaysia, the Philippines, and Thailand, ordered by age[3]

Total coal consumption (utility and industry) has continued to increase since the 1980s especially in Indonesia, as shown in Figure 11.

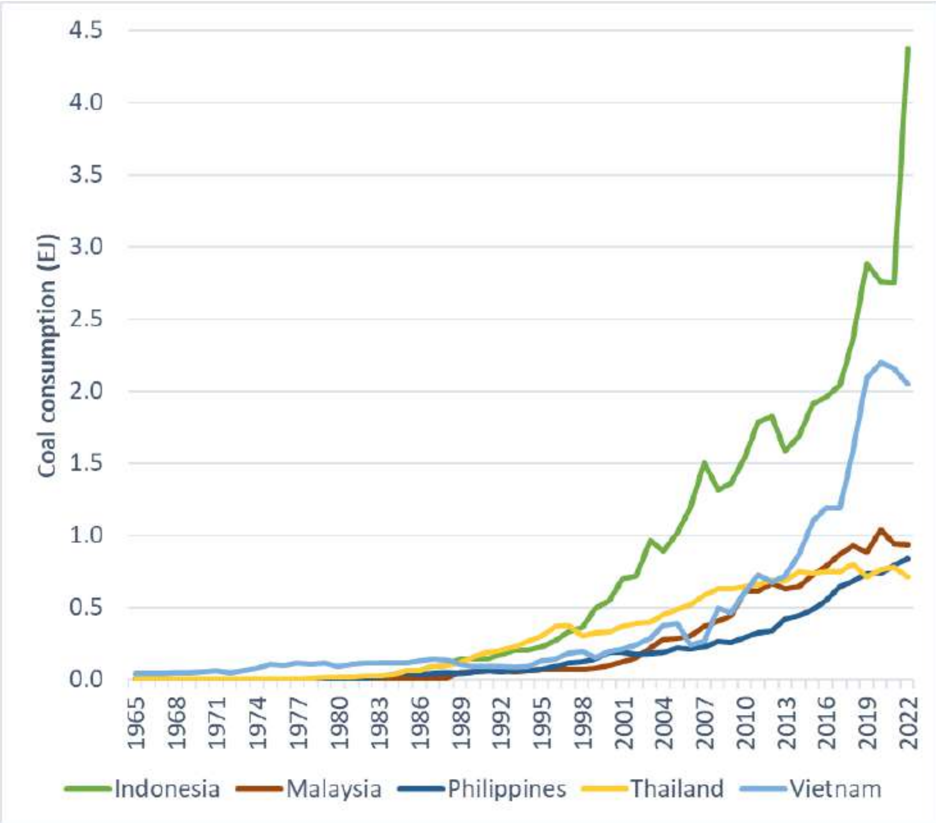


Figure 11: Increase in coal consumption for primary energy generation in Indonesia, Vietnam, Malaysia, the Philippines, and Thailand, 1965-2022[13]

The growth in coal use in Indonesia has been partly attributed to the expansion of Indonesia's nickel industry. Although Vietnam has shown reducing coal consumption for 2021 and 2022 (Figure 11), it is recently reported that thermal coal imports for the country have surged due to increased power demand. These trends pose challenges for SE Asian countries to reach their nationally determined contributions (NDC) under the Paris Agreement.

From the five SE Asian countries mentioned above there have been varied approaches and levels of commitment to the Paris Agreement:

- the Philippines committed to an ambitious NDC to reduce greenhouse gas (GHG) emissions by 75% by 2030, but this commitment assumed that 72.3% of this would be on a conditional basis (i.e., through international support).
- Malaysia proposed to reduce its GHG emissions intensity of its Gross Domestic Product (GDP) by 45% (unconditional) by 2030, relative to 2005 levels.
- Indonesia has made a commitment to reduce its emissions from 2020 to 2030 by 29% (unconditional) to 41% (conditional) compared to the 2030 business-as-usual (BAU) scenario, as outlined in the country's National Medium-Term Development Plan (RPJMN) 2020-2024 to implement its NDC strategy.

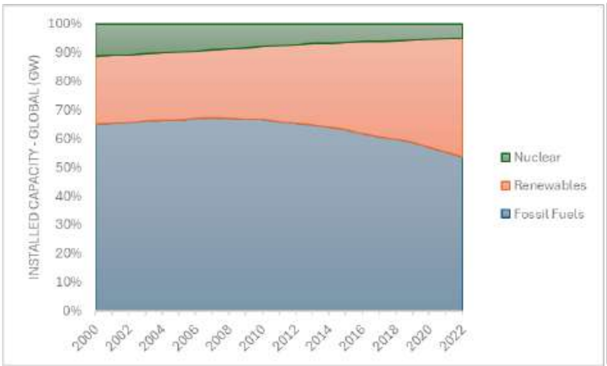
[13] Energy Institute, 2023 https://www.energyinst.org/statistical-review

- Thailand has committed to reducing its greenhouse gas emissions by 20% (unconditional) to 25% (conditional) by 2030 compared to its projected BAU level.
- Vietnam has committed to an unconditional greenhouse gas emissions reduction of 8% by 2030 in the period from 2021 to 2030, compared to the BAU, which could be increased up to 25% under a conditional basis.

It is therefore evident that the majority of the commitment to reduce GHG emissions from these countries is stated under a conditional basis - requiring climate finance, technology transfer, and capacity building from developed countries. For this reason, the mechanisms involved in a sustainable energy transition system must be considered in terms of their applicability and efficacy, as they will be critical to the success of the Paris Agreement.

2.4. Coal-Fired Power Plant Capacity

Analysis of global energy trends reveals a gradual but significant shift in the composition of power generation sources, particularly evident in the declining share in the installed capacity of fossil fuels compared to other energy sources (Figure 12).



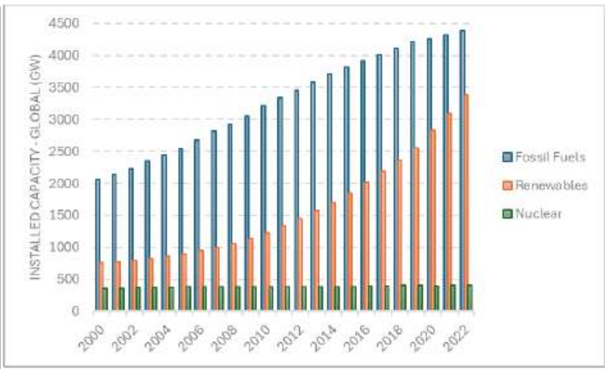


Figure 12: Global share of fuel capacity share over time

Between 2000 and 2021, the proportion of CFPP capacity relative to the total energy mix decreased from 35.1% (1,087.8 GW) to 33.6% (1,606.4 GW) in 2010, further dropping to 27.1% (2,074.3 GW) by 2021[3].

Despite this decline in CFPP capacity, the share of global CFPP electricity generation, measured in terawatt-hours (TWh), has remained consistently above 35% between 2000 and 2022 (Figure 13)[13].

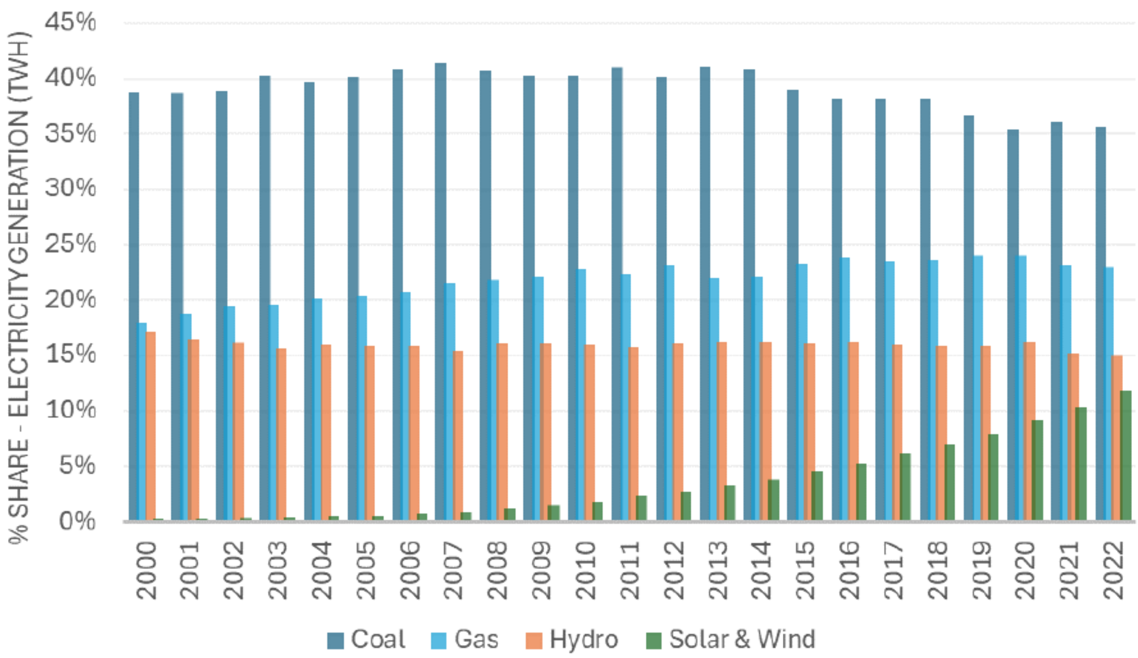


Figure 13: Global share (%) of electrical generation for different energy sources

These trends confirm the continued reliance on coal despite a noticeable reduction in relative capacity during the same period. This underscores the complex dynamics at play within the global energy landscape, signalling both a transition towards cleaner energy sources for future decades and the enduring significance of coal-fired power generation in meeting current electricity demand.

One of the major reasons that coal remains within these energy mixes is due to its reliability and dispatchability. Strong and secure national energy grids require power that can immediately ramp up or down to meet demand. Utilities firing coal and gas, and even nuclear plants and pumped hydro power, can almost immediately ramp their electrical output up or down to meet the demand from the population. This is not true for renewable sources such as wind and solar, which produce a limited amount of power over an often-unpredictable time period. Currently, the power from wind and solar is required when these systems can be stored for use at other times but only with expensive battery storage systems. The increased capacity of renewable energy sources such as wind and solar will therefore not replace conventional power until these dispatchability and storage issues are resolved. In some regions, even as renewable energy and associated energy storage make advances, the grid distribution system is another factor which can hinder reliable energy delivery. Renewable power, associated energy storage, and grid upgrades are all expensive investments.

The rise in dependence on coal-fired energy is evident in the Asia Pacific, where the global share in electricity generation and primary energy consumption from coal in this region reached 79% and 81% respectively by 2022 (

Figure 14).

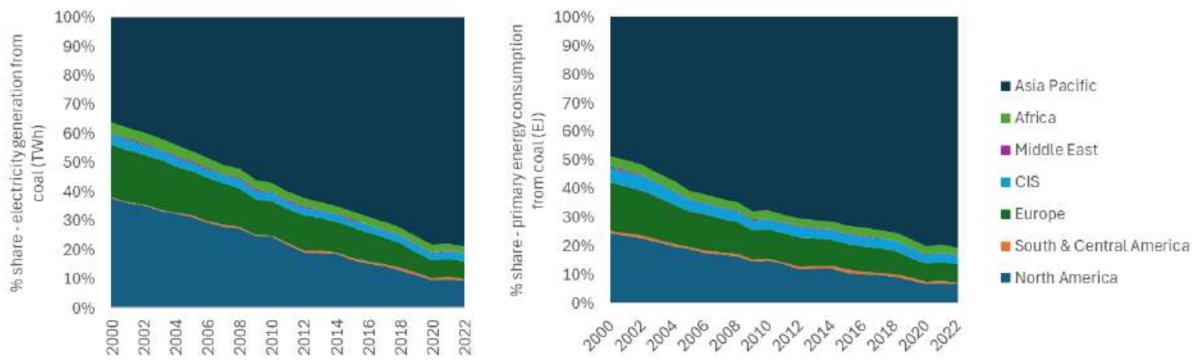


Figure 14: Change in primary energy generation and consumption from coal (%)[13]

Although some moderate reduction in coal-fired power capacity is shown for Asia during the past decade, it still remains at a total electricity generation share above 50% for this region, with above 40% increased slightly from 43.3% (365.9 GW) in 2000 to 51.8% (879.9 GW) in 2010, but then decreasing to 42.5% (1 535.3 GW) in 2021 (Figure 15). However, the share of coal-fired electricity generation (in TWh) in Asia increased from 49.5% (1 995.8 TWh) in 2000 to 59.9% (4 784.6 TWh) in 2010 and then decreasing slightly to 57.7% (7 843.12 TWh) in 2021 (Figure 15)[2].

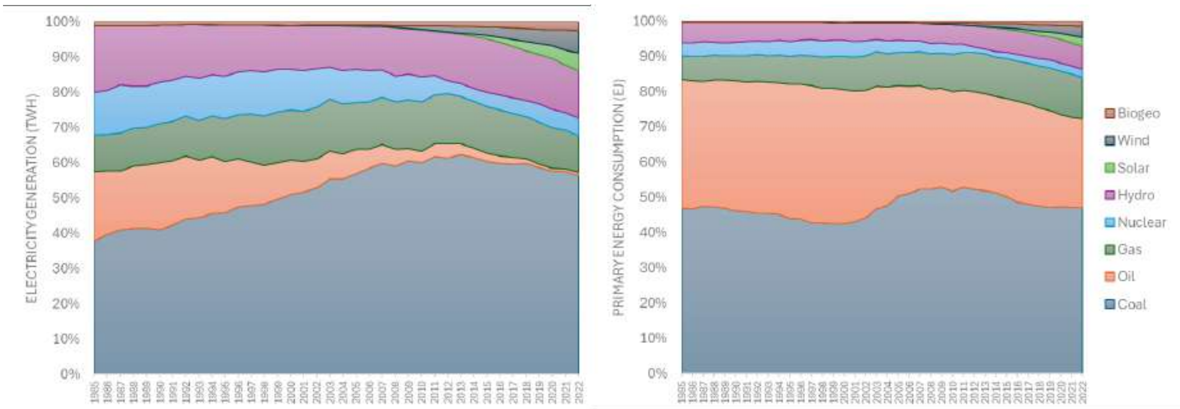


Figure 15: Share of power plant capacity (A) and electricity generation (B) for coal, hydropower and solar/wind in Asia

The Asian continent makes up a 74.0% global share in coal-fired power capacity, and a 78.4% global share in coal-fired electricity generation as of 2012.

2.5. Global emission outlook

According to the Global Energy Monitor Global Coal Plant Tracker database, updated as of July 2023, the current global fleet of Coal-Fired Power Plants (CFPPs) possesses an estimated capacity of 2,083 gigawatts (GW).

China and India collectively hold the majority share in CFPP capacity, accounting for 52.7% and 11.9% of the global capacity, respectively. Projections indicate that China's global share is expected to increase to 55.5% by 2030 before slightly decreasing to 48.6% by 2050 under the BAU-1 scenario. Similarly, India's global share is forecasted to rise to 13.8% by 2030, followed by a slight reduction to a 12.7% share by 2050 under the BAU-1 scenario.

The total CFPP capacity is anticipated to decrease by 10% (209 GW) from 2023 levels by 2030 under the BAU-1 scenario (operating + construction). Conversely, it is projected to increase by 6% (131 GW) from 2023 levels by 2030 under the BAU-2 scenario (operating + construction + pre-construction).

Looking ahead to 2050, the total CFPP capacity is expected to undergo a substantial reduction, declining by 55% (1,144 GW) from 2023 levels under the BAU-1 scenario (operating + construction) and by 39% (804 GW) under the BAU-2 scenario (operating + construction + pre-construction). These projections highlight significant shifts in CFPP capacity over the coming decades, influenced by various factors including policy decisions, technological advancements, and market dynamics.

Figure 16 shows the historic CFPP capacity (in GW)[3] and projection of global CFPP capacity (in GW) considering the remaining lifetime of existing plants and if all projects under construction (BAU-1) and pre-construction (BAU-2) is expected to be commissioned. Data on future CFPP capacity are derived from the Global Energy Monitor's Global Coal Plant Tracker database (updated January 2023)[14].

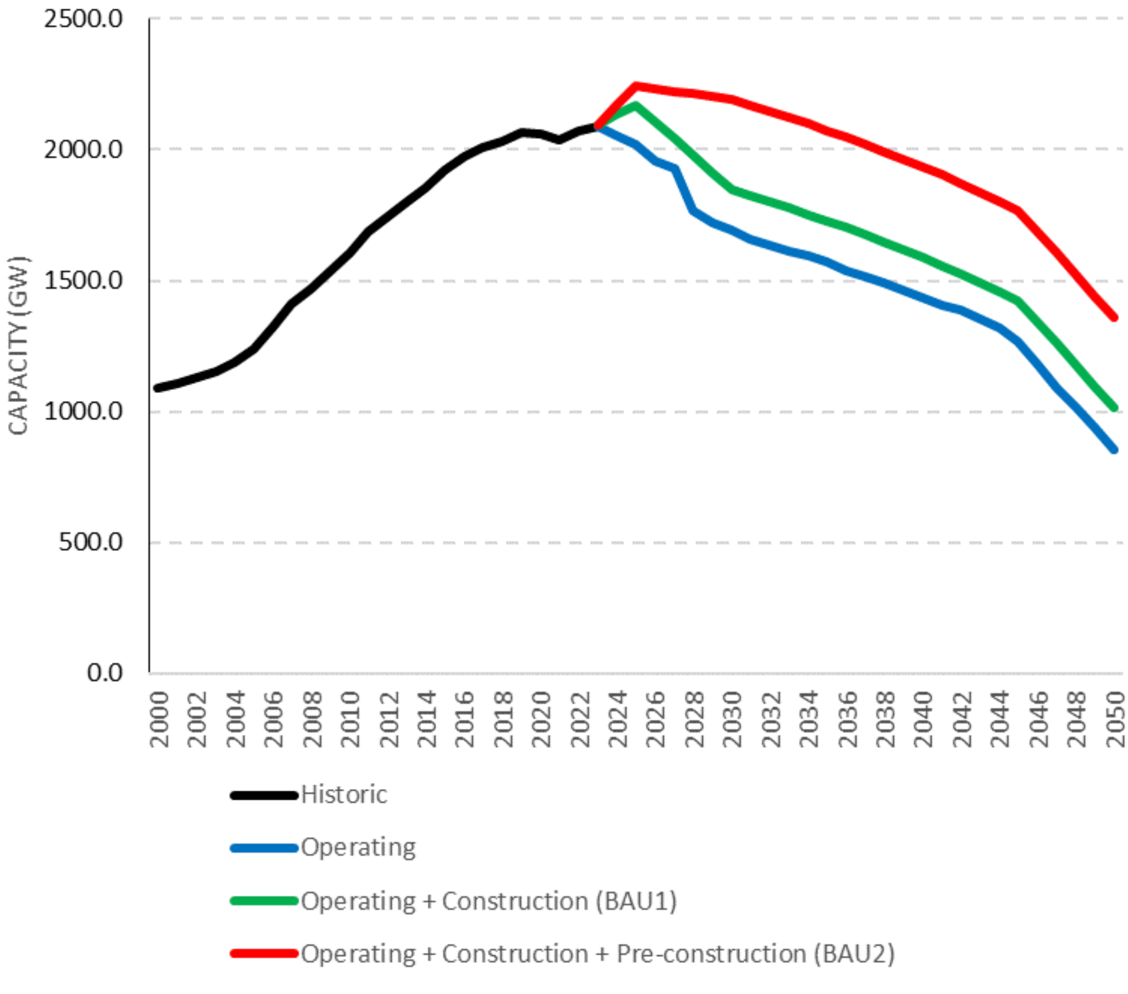


Figure 16: Historic and projected global CFPP capacity under BAU-1 and BAU-2

[14] https://globalenergymonitor.org/projects/global-coal-plant-tracker/?gclid=CjwKCAiA_6yfBhBNEiwAkmXy5-vRgJqTXykaEN_B4LxqIpRe_TvPgCvQIRCmbntFgKPuDzspyK4i3hoCYIcQAvD_BwE

Figure 16 shows the historic rise of CFPP capacity, potentially peaking around 2020-2025, depending on the scenario. Operating plants (in blue) will phase out as they move towards retirement at 40 years old. Including plants in construction, the green line, delays the peaking of coal and adds several years to the phase out timeline. By including plants in pre-construction, both coal peaking and phase out are delayed further. This delay in peaking and phase out means a concomitant delay in the reduction of related emissions from the coal sector.

2.6. Emission assumptions within the scenarios

Carbon Dioxide (CO_2)

Figure 17 shows historic CO_2 emissions from global CFPPs (in million tonnes per year)[3] and projection of future global CO_2 emissions from CFPPs (in million tonnes per year) considering the remaining lifetime of existing plants and if all projects under construction (BAU-1) and pre-construction (BAU-2) are expected to be commissioned. Data on future CFPP capacity is derived from the Global Energy Monitor's Global Coal Plant Tracker database (updated January 2023)[15].

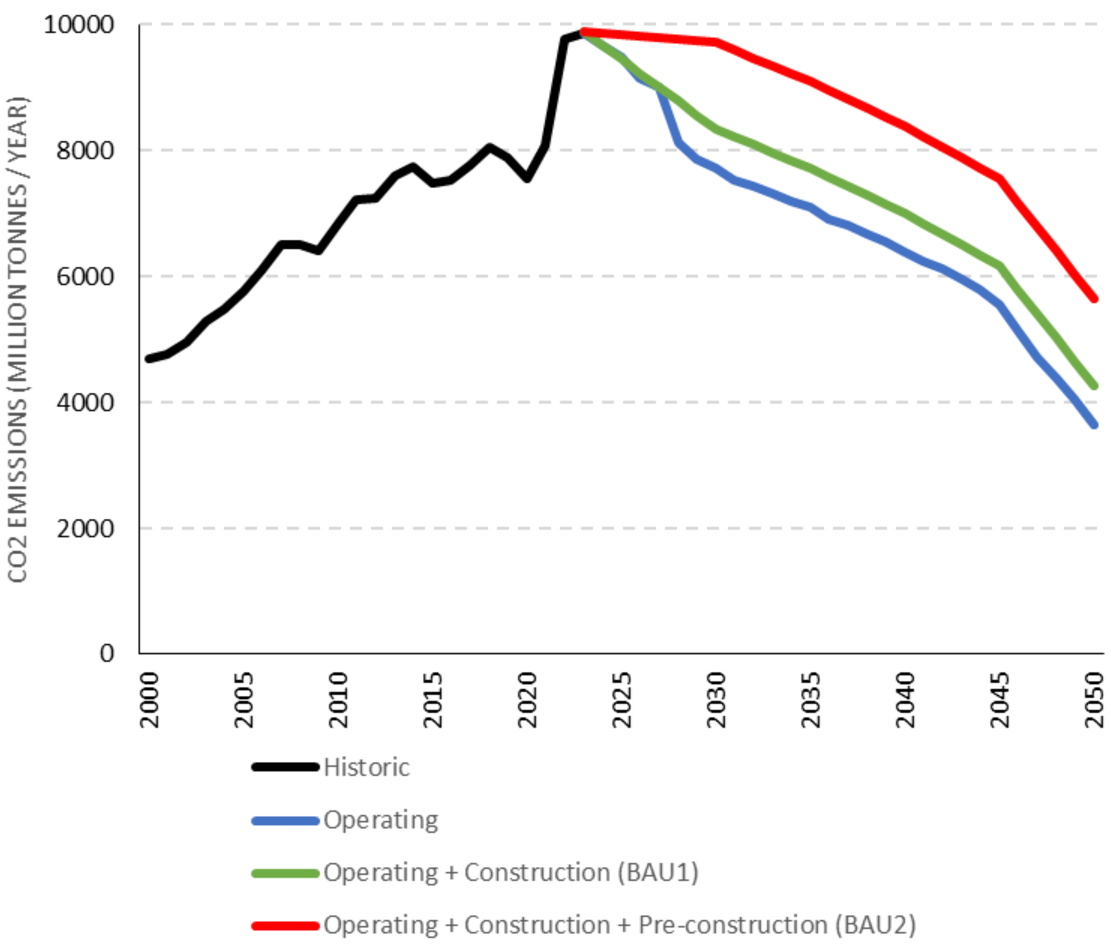


Figure 17: Historic and projected global CO2 emissions under BAU-1 and BAU-2

[15] https://globalenergymonitor.org/projects/global-coal-plant-tracker/?gclid=CjwKCAiA_6yfBhBNEiwAkmXy5-vRgJqTXykaEN_B4LxqIpRe_TvPgCvQlRCmbntFgKPuDzspyK4i3hoCYIcQAvD_BwE

The projected trends indicate a 12% reduction in global CO_2 emissions from CFPPs by 2030 compared to 2023 levels under the BAU-1 scenario (operating + construction). However, under the BAU-2 scenario (operating + construction + pre-construction), emissions are anticipated to increase by 1% by 2030.

Looking further ahead, by 2050, global CO_2 emissions from CFPPs are expected to decline significantly, with a 55% reduction from 2023 levels under the BAU-1 scenario (operating + construction) and a 42% reduction under the BAU-2 scenario (operating + construction + pre-construction). These projections highlight the potential for substantial emissions reductions over the coming decades, albeit with variations based on different scenarios and factors influencing CFPP development and operation.

The BAU projections do not incorporate improvements in existing infrastructure or the installation of additional Air Pollution Control Devices (APCDs) or Carbon Capture, Utilization, and Storage (CCUS) technologies. They focus solely on the potential to accelerate the decommissioning CFPPs or transition to carbon-neutral energy generation to achieve a global carbon-neutral future in the CFPP sector by 2050.

The International Energy Agency's (IEA) 2022 World Energy Outlook forecasts a modest reduction of 11% in global electricity production from coal by 2030 compared to 2021 levels (9,044 TWh), followed by a more substantial 35% reduction by 2050 (5,892 TWh). This projection underscores the imperative to limit or halt CFPP capacity additions for projects under pre-construction.

Mercury

The AMAP Global Mercury Assessment for 2018 (AMAP/UNEP 2019), based on data from 2015 to 2017, provides insights into mercury emission levels from CFPPs and CFIBs, and these are summarised in Figure 18.

For CFPPs, the assessment recorded mercury emission levels ranging from 291.9 metric tons per year (t/y) (low estimate: 179.4 t/y; high estimate: 535.7 t/y). Notably, the top ten mercury-emitting countries in the CFPP sector, in descending order, are China, India, South Africa, the US, Germany, Indonesia, Poland, Turkey, Russia, and Kazakhstan. These countries collectively account for a substantial share, ranging from 71% to 81% of the global emissions estimate.

For CFIBs, the assessment reported mercury emission levels of 126.2 t/y (low estimate: 77.9 t/y; high estimate: 198.4 t/y). Similarly, the top ten mercury-emitting countries in the CFIB sector, in descending order, are China, India, South Africa, Vietnam, the US, Indonesia, Thailand, Pakistan, Kazakhstan, and Turkey. These countries collectively contribute significantly, comprising 90% to 93% of the global emissions estimate.

These findings highlight the predominant role of a select group of nations in contributing to global mercury emissions from both CFPPs and CFIBs. Addressing mercury emissions in these key countries is crucial for effective global mercury reduction efforts and mitigating the associated environmental and health impacts.

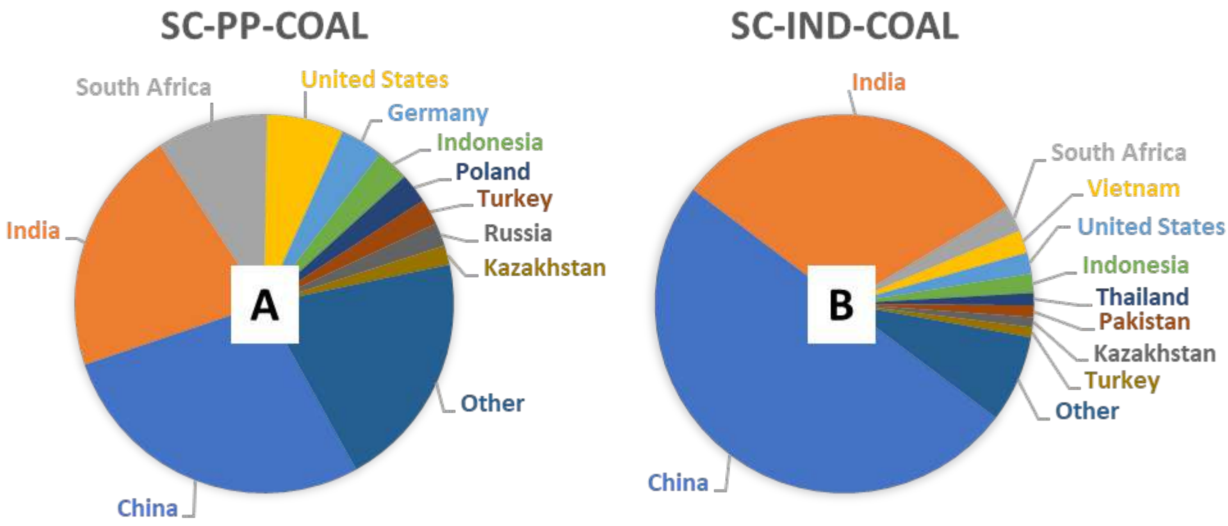


*Figure 18: Share of global mercury emissions from CFPP (A) and CFIB (B) for the top ten countries**Error! Bookmark not defined.***

Mercury emission estimates for CFPPs, particularly in more recent years (2020 to 2023), exhibit a notable decrease, especially in China. This reduction can be attributed to various factors, including the accelerated phasing-out of small and outdated CFPPs, the substitution of some plants with natural gas alternatives, and the widespread adoption of high-efficiency sulfur- or nitrogen-reducing technologies in industrial coal-fired infrastructure. For example, in China, mercury emissions from the CFPP sector decreased from 81 t/y in 2015 to 48 t/y in 2017. This significant decline reflects concerted efforts to modernize and upgrade CFPPs, resulting in improved emission control measures. These changes are also discussed in detail in the section on health impacts of fine particles above.

Conversely, other countries such as the United States, Germany, Russia, and Kazakhstan have recorded reductions in CFPP capacity between 2015 and 2021. However, nations like India, China, South Africa, Indonesia, Pakistan, Bangladesh, Poland, and Turkey have witnessed increases in CFPP capacity during the same period[3].

Despite the anticipated substantial reduction in emissions from China, a global mercury emissions estimate of 423 t/y was calculated for 2023 based on certain assumptions:

- CFPPs operating under subcritical combustion conditions with a capacity exceeding 600 MW are equipped with particulate matter and SO_2 control technologies (ESP + FGD), while those under 600 MW utilize only particulate matter control technologies (ESP).
- CFPPs operating under supercritical- and ultra-supercritical combustion conditions with a capacity exceeding 600 MW employ particulate matter, SO_2, and NOx control technologies (ESP + FGD + SCR), while those under 600 MW utilize particulate matter and SO_2 control technologies (ESP).

Under the BAU scenarios, emissions are projected to decrease between 338 t/y (BAU-1) and 378 t/y by 2030 (BAU-2), representing a 20% and 11% reduction, respectively, from the 2023 emissions estimate, as shown in Figure 19. Furthermore, emissions are forecasted to decline to between 184 t/y (BAU-1) and 224 t/y by 2050 (BAU-2), constituting a 56% and 47% reduction, respectively, from the 2023 emissions estimate.

Under the AERS scenarios, assuming all subcritical CFPP units will retire 10 years earlier than recorded in the BAU scenario, the emissions are projected to decrease between 279 t/y and 318 t/y by 2030, representing a 34% and 25% reduction, respectively, from the 2023 emissions estimate, as shown in Figure 19. Furthermore, emissions are forecasted to decline to between 102 t/y and 142 t/y by 2050, constituting a 76% and 66% reduction, respectively, from the 2023 emissions estimate.

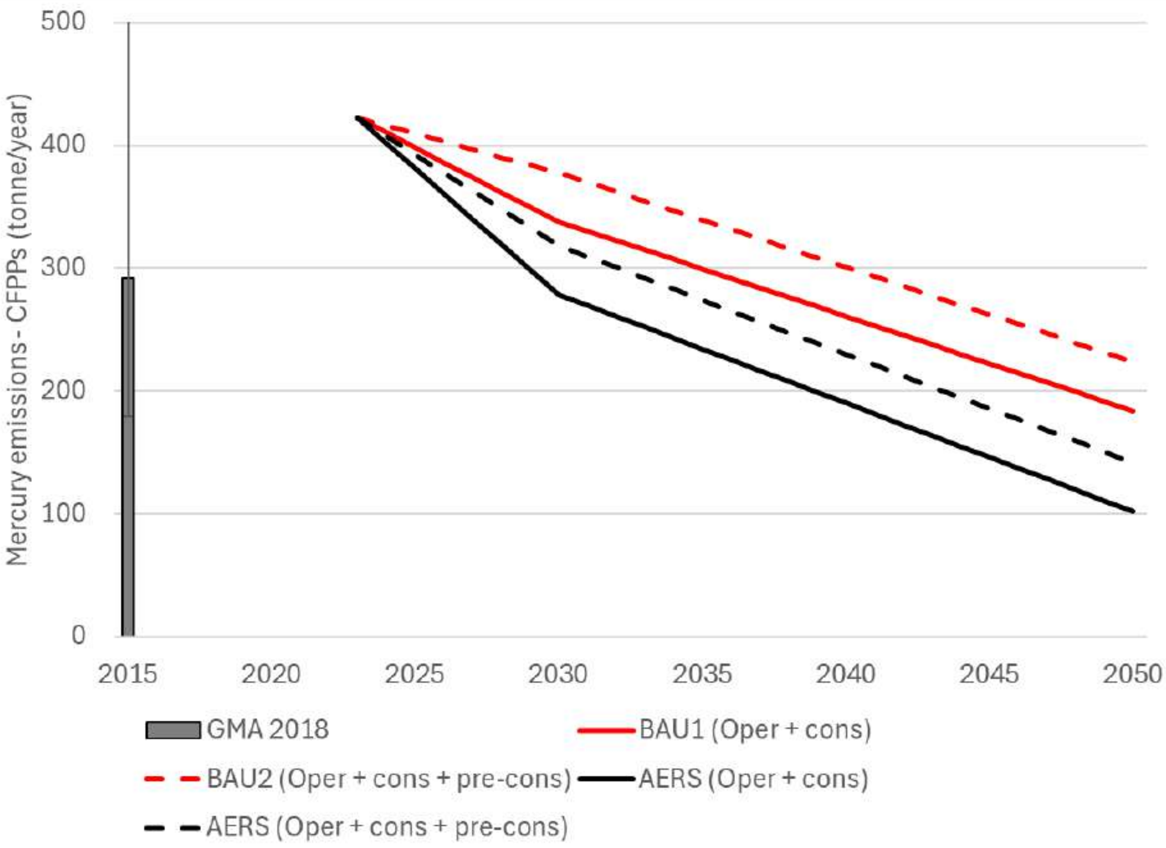


Figure 19: Estimated mercury emission reduction from the global CFPP fleet under the BAU scenarios and AERS scenarios. The AERS scenario assumes that all subcritical CFPP units will retire 10 years earlier than recorded in the BAU scenario.

These projections highlight the potential for significant emissions reductions in the CFPP sector over the coming decades, driven by advancements in technology, policy interventions, and shifts towards cleaner energy sources. However, continued efforts and sustained commitments are essential to realizing these emission reduction targets and mitigating the environmental impacts associated with coal-fired power generation.

Within the AERS scenario, assuming early retirement, there is the need to consider the Just Energy Transition mechanism (Ordonez *et al.* 2024). This mechanism would entail the early decommissioning of candidate CFPPs before reaching their designated end-of-life expectancy. By expediting the retirement of these facilities, emissions from CFPPs can be significantly curtailed, contributing to a more sustainable and environmentally conscious energy transition.

This approach not only addresses the immediate need for emissions reduction but also aligns with broader sustainability goals by facilitating the transition towards cleaner energy sources. Moreover, it underscores the importance of ensuring a just transition, wherein the impacts on affected communities and workers are carefully considered and mitigated.

By implementing a Just Energy Transition mechanism, policymakers can accelerate progress toward achieving emission reduction targets while fostering a fair and equitable transition to a more sustainable energy future. This proactive approach will be instrumental in mitigating the environmental impacts of CFPPs and advancing towards a cleaner, greener energy landscape.

The results above demonstrated potential global emission reductions under the BAU and AERS scenarios. It is significantly more challenging to estimate global emission reductions under the RETROFIT scenarios as the status of APCDs globally has a high level of uncertainty. This uncertainty is exemplified by the significant variance in APCD configurations observed across different regions and countries. 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.

Figure 20 shows the estimated mercury emissions reduction from the global CFPP fleet under the business-as-usual scenario of existing plants and those under construction (BAU-1), along with the added scenario where all plants are fitted with air pollution control devices having the highest possible co-benefit for mercury reduction.

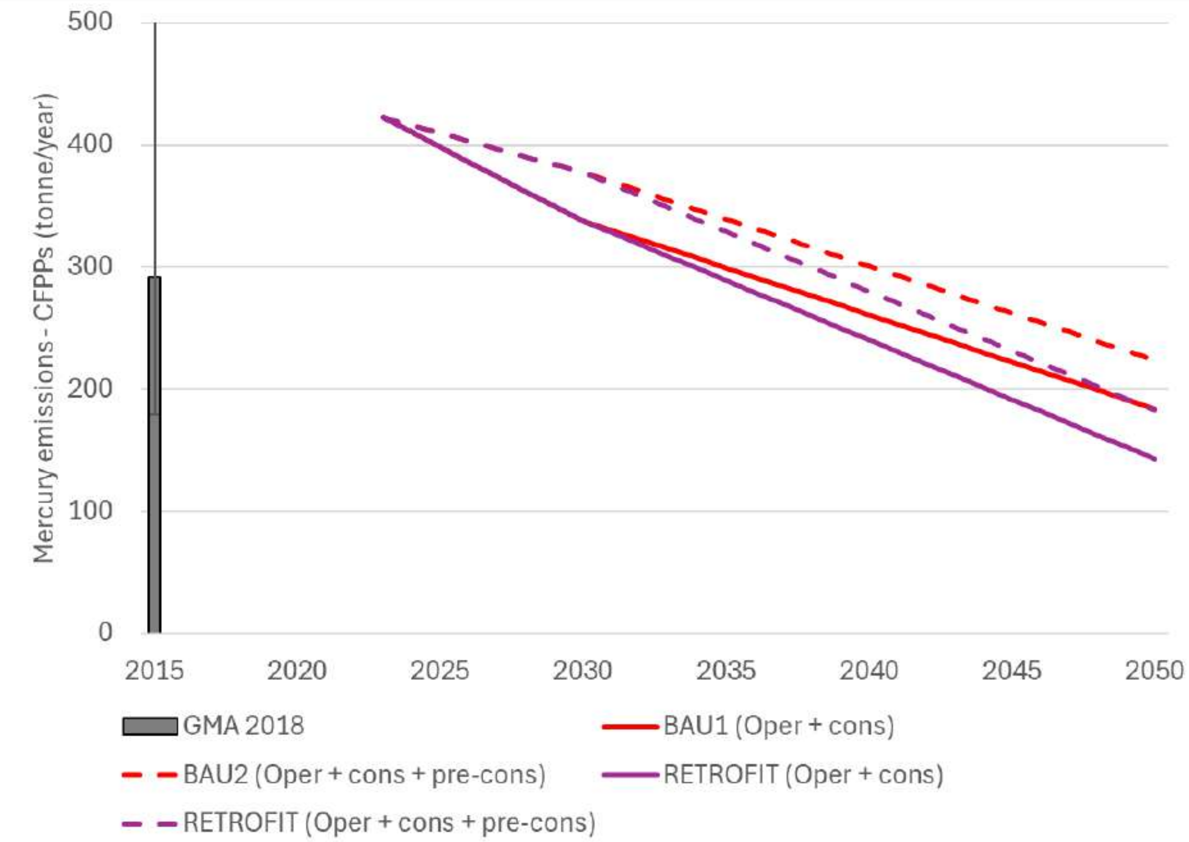


Figure 20: Estimated mercury reduction under the BAU and RETROFIT scenarios. The RETROFIT scenario assumes CFPP units with ESP technologies and with a remaining plant lifetime of at least 20 years will also be fitted with FGD technologies.

Under a best-case scenario, assuming all CFPP units with current ESP technologies alone and with a remaining plant lifetime of at least 20 years will be fitted with the highest co-benefit for mercury reduction in stack emissions (ESP + FGD + SCR) by 2040, , an additional 10% reduction in emissions from the BAU-1 scenario could be achieved by 2050 (Figure 20). However, achieving such a scenario is improbable due to limitations such as unavailable land for expansion or plant designs incompatible with retrofitting additional APCD technologies. Therefore, uncertainties surrounding CFPP configurations for APCDs require a cautious approach, with country-specific analyses crucial for accurate emission projections. While optimistic scenarios present potential emissions reductions, practical constraints must be addressed to achieve meaningful progress in emissions mitigation within the coal sector.

From Figure 20 it is clear that retrofitting CFPPs with the most viable APCDs will not achieve complete mercury emissions abatement by 2050. However, significant reductions from estimated 2023 levels can still be expected if the remaining operational lifespan of the coal fleet is adhered to.

3. Persistent Organic Pollutants (POPs)

This project also included a consideration of Persistent Organic Pollutants (POPs) from the coal sector which are included in the Stockholm Convention. The concern with POPs in the environment has a long history at least from the 1960s (Jones 2021), culminating in the Stockholm Convention entering into force in 2004 as a global response to this concern.

Utility and industrial boilers are designed to burn fuel to heat water or to produce steam for use in electricity generation or in industrial processes. Concentrations of the chemicals included in the Stockholm Convention in the emissions from fossil fuel-fired boilers are generally very low and can be difficult to measure and quantify. The scale of fossil fuel combustion, in terms of both tonnage and distribution, for electricity generation and heat or steam production, may result in emissions of interest.

In carefully controlled combustion systems, such as those in large coal-fired power stations and industrial boilers, organic compounds are exposed to high temperatures for enough time, with adequate oxygen and mixing, to achieve complete combustion. In some cases those conditions may not be present and potentially toxic airborne emissions of the POPs, polychlorinated dibenzo-*p*-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), polychlorinated biphenyls (PCB) and hexachlorobenzene (HCB) can be produced in or survive the combustion process (Van Remmen 1998; UNEP 2013).

As a consequence, it has proved very difficult to make highly accurate inventories of emissions of POPs from power stations and industrial boilers as these emissions largely depend on furnace operating conditions and can be highly variable depending on how the combustion system is designed and maintained.

Control measures to decrease the formation and release of POPs include:

- maintenance of efficient combustion conditions within the boiler and ensuring sufficient time is available to allow complete combustion to occur.
- undertaking measures to ensure fuel is not contaminated with PCB, HCB or chlorine, and is low in other components known to act as catalysts in the formation of PCDD and PCDF.
- use of appropriate gas-cleaning methods to lower emissions that may contain entrained pollutants; and appropriate strategies for disposal, storage or ongoing use of collected ash.

Lemieux (1998) summarizes work at the United States Environmental Protection Agency that shows, in decreasing order of importance, the parameters that can be controlled to reduce PCDD/PCDF emissions:

- Combustion quality as indicated by carbon monoxide (CO), total hydrocarbons, soot formation;
- Particle entrainment and burnout;
- Air pollution control temperatures; and
- Fuel/waste parameters (sulphur; metals; chlorine)

These can be achieved by the following conditions (Lemieux 1998): Uniform high combustor temperature; good mixing with sufficient air; minimize entrained, unburnt particulate matter; feed rate uniformity; active monitoring and control of CO and total hydrocarbons.

PCDD/PCDF air emission levels associated with best available techniques can be significantly lower than 0.1 ng I-TEQ/m^3. In fact, there is significant evidence from measurements at large scale plants that efficient combustion results in very low emissions, although combustion in less efficient furnaces could result in higher emissions (Sloss and Smith 2001).

A similar approach to that used for mercury emissions was used to estimate POPs, using the Global Energy Monitor Coal Plant Tracker (GCPT) database (updated July 2023)[16]. The database is updated bi-annually and contains worldwide information on CFPP unit locations, design capacity, combustion technology, build status, coal type used, etc. Along with the general CFPP unit information, the database includes an estimated remaining lifetime of each unit, along with calculated heat rate values (HRV; Btu/lb) that are based on combustion technology and coal type.

The PCDD/F emission estimate for all operating CFPPs in the defined country was expressed in grams toxic equivalence per year (gTEQ/yr) using two estimation approaches, namely using default emission factors based on (1) micrograms TEQ produced per tonne coal consumed (µgTEQ/t) of 0.2 µgTEQ/tonne, or (2) micrograms TEQ per terajoule energy produced (µgTEQ/TJ) as stipulated in the UNEP POPs emissions inventory toolkit (UNEP 2013).

Examples for China and India of these calculations are given in Figure 21 and Figure 22.

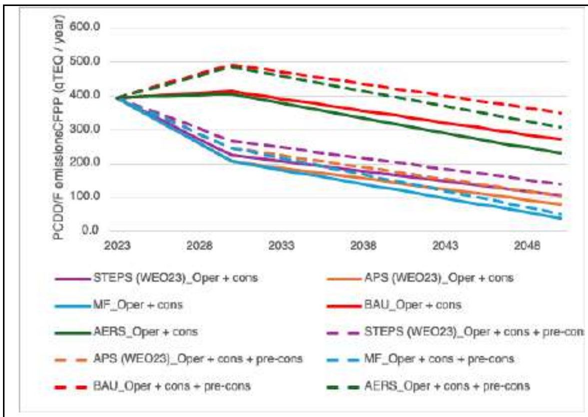


Figure 21: PCDD/F emissions for coal-fired power stations in China for a range of emission scenarios

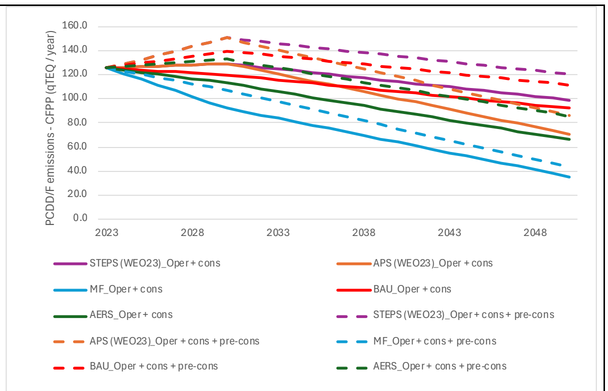


Figure 22: PCDD/F emissions for coal-fired power stations in India for a range of emission scenarios

[16] https://globalenergymonitor.org/projects/global-coal-plant-tracker/?gad_source=1&gclid=Cj0KCQiAh8OtBhCQARIsAIkWb6_yMVOD-KqFeAnDgJ0wBRnX5KGQ4o1uvA2d4dFcERtQpFnq82cCPZkaAgTlEALw_wcB

There are clearly inherent limitations within these calculations, such as the various generalized assumptions (such as coal consumption and APCD configurations) and variability in CFPP operation and feed coal type (source and/or blending). The capacity factors of energy generation units exhibit significant variability at both unit and country levels, stemming from a multitude of factors such as routine plant maintenance (planned or unplanned) or flexing operations as renewable resources are increasingly introduced in the power grid, all having variability on a unit level.

However, within these limitations it is clear that significant reductions in POPs emissions require reduced coal consumption and/or the installation of improved air pollution control devices, which have a co-benefit for POPs control, on operating plants. Further details of these issues are given in the Appendices for individual focus countries.

4. Fine particles pollution from the coal sector and the global burden of disease

It is important that the development of policies and strategies to address global pollutants including greenhouse gases (GHGs), mercury and persistent organic pollutants (POPs) does not neglect other local and regional pollutants which have significant impacts on human health and the global burden of disease. Some parties to the Minamata Convention have pursued a holistic and coordinated approach to the management of the inter-related issues of energy security and the transition to renewables, GHGs reductions, mercury and POPs management, and traditional local and regional air pollutants, especially fine particles ($PM_{2.5}$). The health impacts of the latter must be a high priority in ensuring population health.

Exposure to ambient air pollution increases morbidity and mortality and is a leading contributor to global disease burden. Air pollution is a major cause of premature death and disease and is the largest environmental health threat globally (Lelieveld *et al.* 2015; Cohen *et al.* 2017; Landrigan *et al.* 2018; Manisalidis *et al.* 2020). Besides endangering health and shortening lifespan, air pollution also affects economic productivity (Zivin and Neidell 2012; Taghizadeh-Hesary and Taghizadeh-Hesary 2020; Fisher *et al.* 2021). The Sustainable Development Goals (SDGs) call for reduction of the burden of deaths and diseases from air pollution. Targets of particular relevance to ambient and household air pollution include:

- SDG target 3.9.1, which calls for a substantial reduction in deaths and illnesses from air pollution.
- SDG target 7.1.2, which aims to ensure access to clean energy in homes
- SDG target 11.6.2, which aims to reduce the environmental impact of cities by improving air quality

The Global Burden of Disease (GBD) Study[17, 18] offers a powerful resource to understand the changing health challenges facing people across the world in the 21st century. Compelling results from this study include the following:

- Ambient $PM_{2·5}$ was the fifth-ranking mortality risk factor in 2015
- Exposure to $PM_{2·5}$ caused 4·2 million deaths and 103·1 million disability-adjusted life-years (DALYs) in 2015, representing 7·6% of total global deaths (Cohen *et al.* 2017)
- In China, 1·24 million (95% UI 1·08–1·40) deaths in China were attributable to air pollution in 2017, including 851 660 (712 002–990 271) from ambient $PM_{2·5}$ pollution (Yin *et al.* 2020); Pollution from ambient $PM_{2·5}$ and household burning of solid fuels decreased markedly in recent years in China, after extensive efforts to control emissions. However, $PM_{2·5}$ concentrations still exceed the WHO Air Quality Guideline for the entire population of China, with 81% living in regions exceeding the WHO Interim Target 1, and air pollution remains an important risk factor (Yin *et al.* 2020).
- In India, 1·67 million deaths were attributable to air pollution in India in 2019, accounting for 17·8% of the total deaths. The majority of these deaths were from ambient particulate

[17] https://www.thelancet.com/gbd
[18] https://www.healthdata.org/research-analysis/gbd

matter pollution (0·98 million) and household air pollution (0·61 million) (India State-Level Disease Burden Initiative Air Pollution 2021)

Figure.23 shows results for ambient $PM_{2.5}$ burden, population-weighted mean $PM_{2.5}$ mass and fractional source sector, fuel, and disease contributions globally and for the nine countries with the largest burden (McDuffie *et al.* 2021a). Five of the focus countries from the present study (China, India, Indonesia, Pakistan and Bangladesh) are included in this figure and make up 65% of the global disease contributions (China (36%) and India (23%) are the major contributors.

It is important to note that the industrial coal sector is only one source of fine particulate pollution, as illustrated in Figure.23, and hence of the GBD in these countries. However, the power and industrial sector are prominent.

Given these results it is clear why many countries have developed specific strategies to reduce the $PM_{2.5}$ disease burden from the dominant sources in their locations.

A comprehensive evaluation of sector- and fuel-specific contributions to this disease burden across 21 regions, 204 countries, and 200 sub-national areas has been developed (McDuffie *et al.* 2021b). This study (McDuffie *et al.* 2021b) revealed that globally, 1.05 million deaths were avoidable in 2017 by eliminating fossil-fuel combustion (27.3% of the total $PM_{2.5}$ burden), with coal contributing to over half.

In South Asia, for example (Chatterjee *et al.* 2023), 1.02 million deaths were attributable to ambient $PM_{2.5}$ in 2019 primarily from three leading sectors: residential combustion (28%), industry (15%), and power generation (12%); and solid biofuel is the leading combustible fuel contributing to the $PM_{2.5}$-attributable mortality (31%), followed by coal (17%), and oil and gas (14%) (Chatterjee *et al.* 2023). These results are summarised in Figure 24.

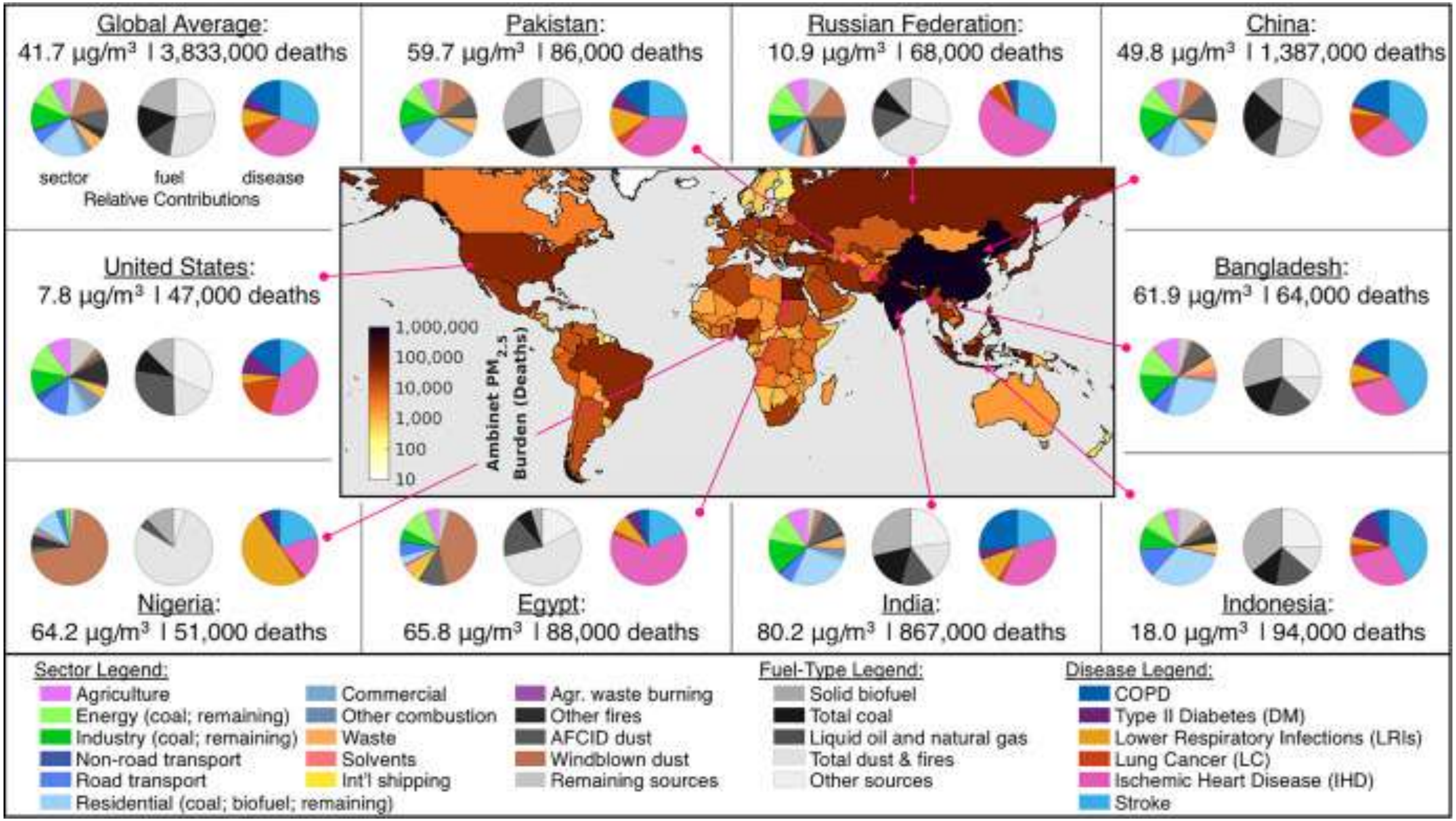


Figure.23: Ambient $PM_{2.5}$ burden, population-weighted mean $PM_{2.5}$ mass and fractional source sector, fuel, and disease contributions globally and for the nine countries with the largest burden (From McDuffie et al. (2021a)

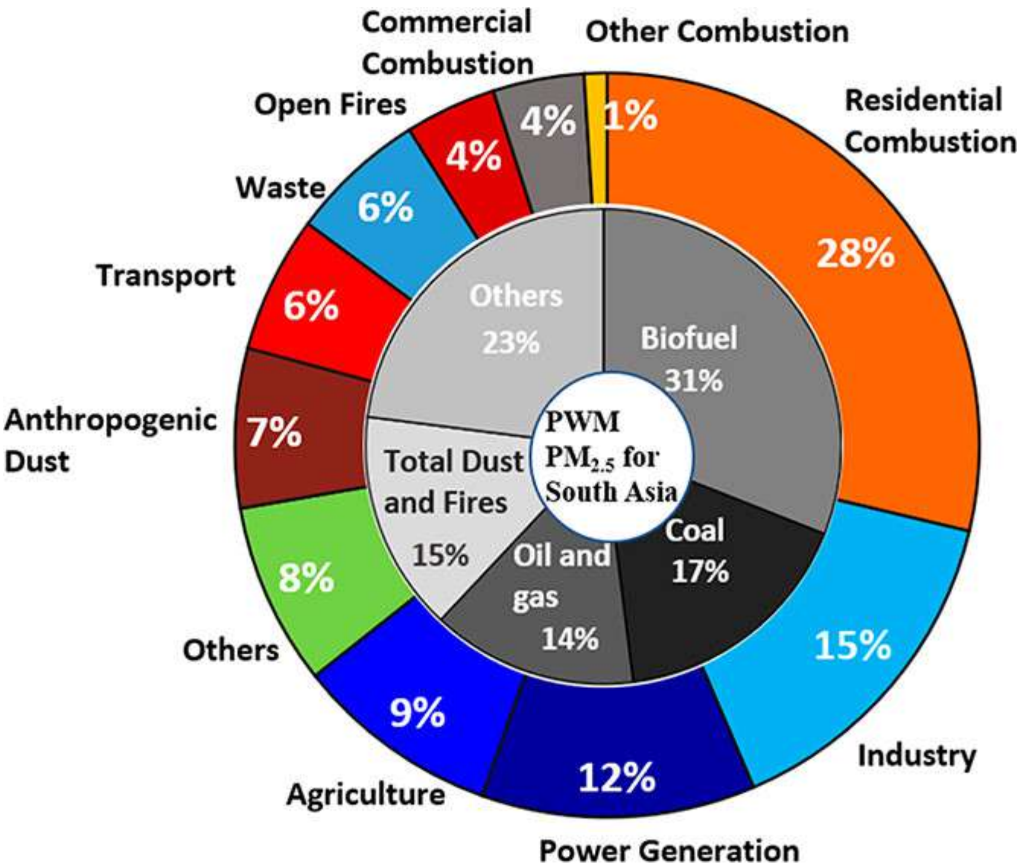


Figure 24: The contribution of emission sectors and fuels to fine particulate matter (population weighted annual mean $PM_{2.5}$,) for South Asia (Chatterjee et al. 2023)

4.1. Air Pollution Control Initiatives in China – particularly for PM

China has implemented comprehensive emission initiatives, strategies and controls since 2010 (Zheng *et al.* 2018). These include a new air quality standard for $PM_{2.5}$, strengthened emission standards, and in 2013 a new Action Plan on the Prevention and Control of Air Pollution (denoted as the Clean Air Action) was implemented (China State Council 2013). The Clean Air Action radically tightened air pollution targets for particulate matter pollution reduction requiring 15-25% reductions in $PM_{2.5}$ by 2017 (Zheng *et al.* 2018).

The Action included commitments to reducing $PM_{2.5}$ pollution in 2013 for the first time and developed eight pollution control measures that were more stringent and ambitious than ever before. These new measures not only reduced emissions but also improved energy efficiency (Zheng *et al.* 2018).

The measures relevant to the coal sector included:

1. *"Ultralow" emission standard for power plants*.

In 2017 emissions from coal power were required to be reduced by an additional 60% by 2020 compared to the 2012 standard using the ultralow emission technique. The emission limits for SO2, NOx, and particulates are respectively 35, 50, and 10 mg/m^3, similar to those achieved by gas-fired plants. It is estimated that more than 70% of the current power plants operated close to ultralow emission levels in 2017 (Zheng *et al.* 2018)

2. *Phase out of outdated industrial capacity and phase out or replacement of small high-emitting factories*. Small and inefficient factories that cannot meet efficiency, environmental, or safety standards have been phased out resulting in improvements in the average efficiency of coal- fired power units.

3. *Strengthen industrial emission standards*. Since 2013, all industrial emission standards have been strengthened. All the emission-intensive industries in China, including iron and steel making, cement, brick, coke, glass, and chemical industries, which make extensive use of coal-fired industrial boilers are included. The new emission standard also decreased the limit values for existing coal-fired industrial boilers.

4. Eliminate small coal-fired industrial boilers.

China shut down all coal boilers with capacities less than 7 MW in urban areas by the end of 2017. Some remained in suburban and rural areas but are in the process of closure.

5. *Replace residential coal use with electricity and natural gas*.

The benefits of the Clean Air Action have been substantial. China's anthropogenic emissions are estimated to have declined by 62% for SO_2, 17% for NOx, 27% for CO, 38% for PM_{10}, 35% for $PM_{2.5}$, 27% for black carbon (BC), and 35% for organic carbon (OC) since 2010 (Zheng *et al.* 2018).

Figure 25 also demonstrates that these emissions are also decoupling from growth measures such as coal usage, GDP, and population. The emission reductions are also supported by measurements of ambient atmospheric pollutant concentrations. (Zheng *et al.* 2018; Geng *et al.* 2024). Supporting evidence for the effectiveness of the control of industrial emissions also comes from estimates of highly resolved inventories of mercury emissions (Liu *et al.* 2018; Liu *et al.* 2019; Liu *et al.* 2021), and measurements of atmospheric concentrations of mercury (Liu *et al.* 2019) and mercury and nitrogen deposition (Liu *et al.* 2019; Liu *et al.* 2024).

The Clean Air Action was implemented in two phases (2013-2017, and 2018-2020). National population-weighted mean $PM_{2.5}$ concentrations decreased by 19.8 μg/m^3 and 10.9 μg/m^3 in the two phases, and the contribution of clean air policies in Phase II (2.3 μg/m^3/y) was considerably lower than that of Phase I (4.5 μg/m^3/y) (Geng *et al.* 2024), suggesting that abatement measures in phase 1, including closure of older plants had proportionally larger impacts.

There is also compelling evidence that these initiatives have resulted in very substantial health and economic benefits. For example (Ban *et al.* 2024), the short-term $PM_{2.5}$-related excess incidence of stroke and heart disease (CHD) is projected to be reduced to 3,352 cases compared with 34,485 cases under a medium-emissions scenario (SSP245)—and is expected to be accompanied by a 95% reduction in the related economic burden.

Similarly, due to co-deployment of air pollution control and climate policies more than 2 million avoided premature deaths per year by 2060 are predicted (Cheng *et al.* 2023). Air pollution control is the leading factor of death reduction up to 2030, while carbon-neutrality policies contribute more between 2030 and 2060 (Cheng *et al.* 2023).

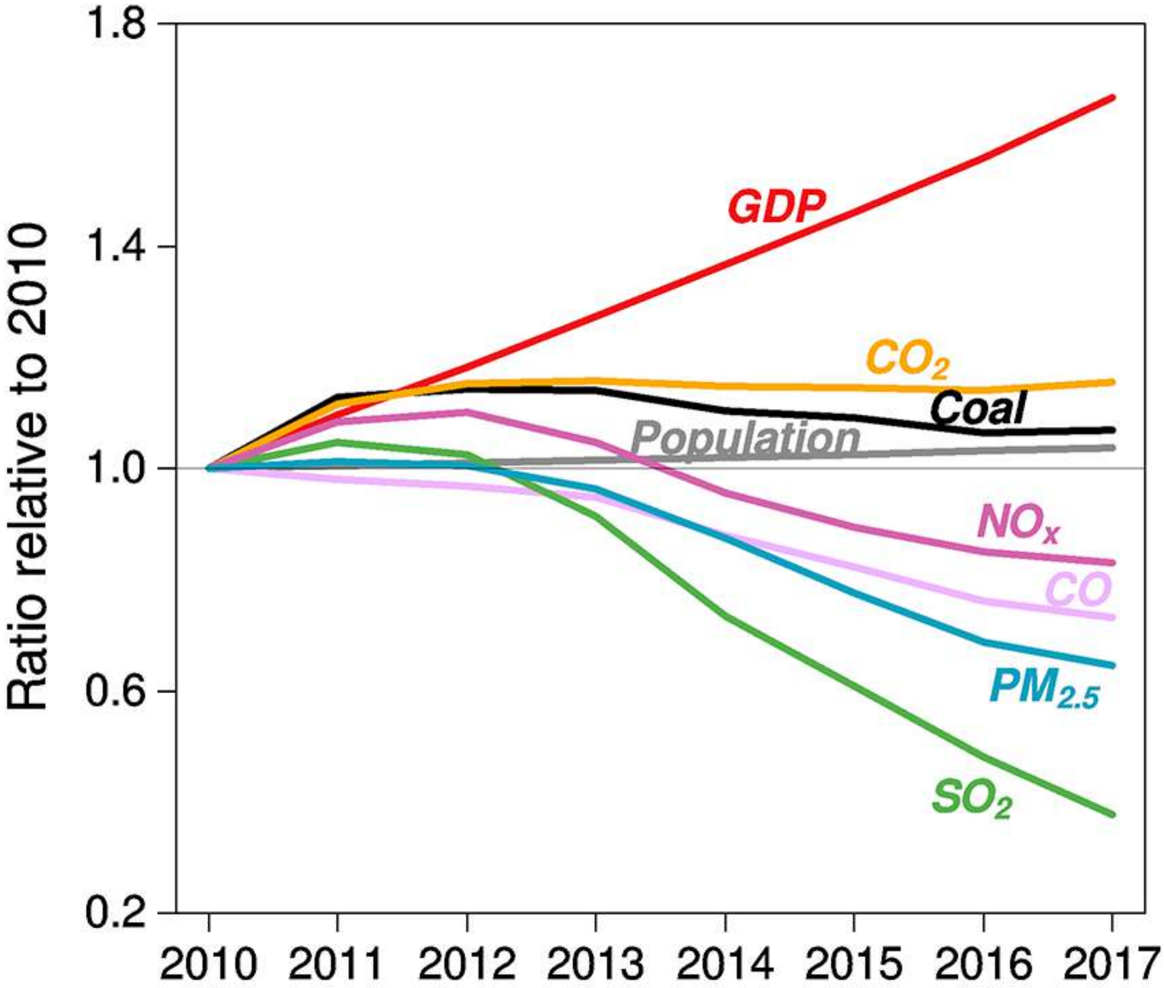


Figure 25: Emission trends and underlying social and economic factors in China from 2010-2017 (Zheng et al. 2018). Coal usage, GDP and population data is based Chinese National Bureau of Statistics.

4.2. Co-benefit effects on mercury reductions

Importantly for the Minamata Convention there is now emerging evidence that the initiatives implemented in the Clean Air Action measures have also resulted in major reductions in mercury emissions and atmospheric mercury concentrations in China, and by extension globally. The measures to reduce the criteria air pollutants (SO_2, NOx, and particulates) are well known to have a co-benefit for mercury control; hence it might be expected that the measures would also result in reductions in mercury emissions and resulting atmospheric concentrations.

Feng *et al.* (2024) argue that combating air pollution has significantly reduced atmospheric mercury concentrations at four Chinese monitoring sites by almost 40% during the period from 2013 to 2022 and coincided with the decreasing concentrations of criteria air pollutants in China. Figure 26 summarises this data for 2008-2022 and compares it with similar data at other locations. The figure illustrates the large decreases in China and shows that they are much larger than changes at other locations.

It is also clear that anthropogenic emission reduction is the driver of these changes in atmospheric concentrations (Feng *et al.* 2024; Liu *et al.* 2024).

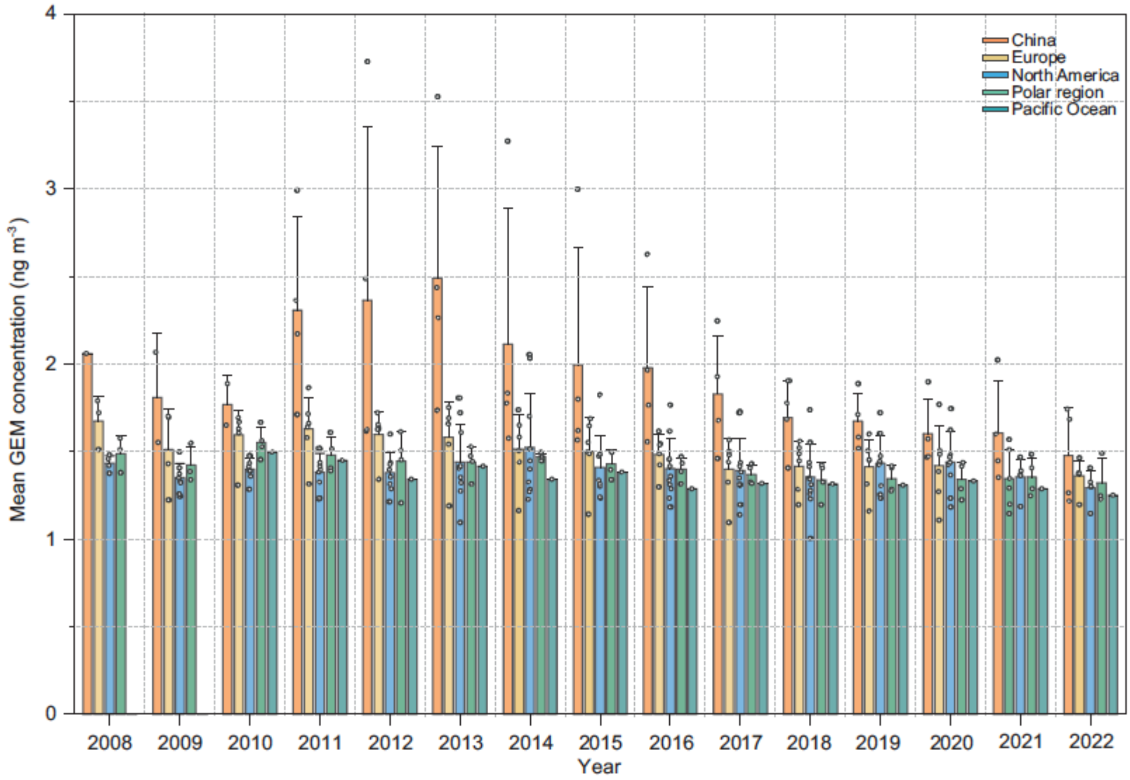


Figure 26: Comparison of annual mean GEM concentrations between China and other regions in the northern hemisphere. From (Feng et al. 2024).

4.3. Benefits of integrated energy-environment-economic strategies

The developments in Chinese strategies to reduce emissions of CO_2, air pollutants, and toxic mercury have relied heavily on integrated energy-environment-economic assessment modelling (Pan *et al.* 2024; Qin *et al.* 2024). These assessments suggest that carbon neutrality strategies will achieve near-zero emissions of mercury by 2060 (Pan *et al.* 2024). integrating carbon neutrality strategies with air pollution controls is predicted to also save 384 million CNY in 2060 illustrating the benefits of integration of all three issues. Figure 27**Error! Reference source not found.** describes the model and the outcomes for a range of scenarios to 2060.

Similar conclusions were reached by Qin *et al.* (2024). Using an integrated cross-disciplinary modelling framework that can capture the feedback of changing aerosols on meteorology, the amplified air quality, human health and renewable energy self-reinforcing synergies of China's carbon neutral target in comparison to the baseline in 2015 and 2060 was determined. These authors found that achieving China's carbon neutrality in 2060 reduces $PM_{2.5}$ concentrations by around 39 μg/m^3 and associated premature deaths by 1.13 million (Qin *et al.* 2024). The integrated approach illustrates the benefits of including carbon measures with pollutant controls and economic costs. The conceptual model used in this case is shown in Figure 28.

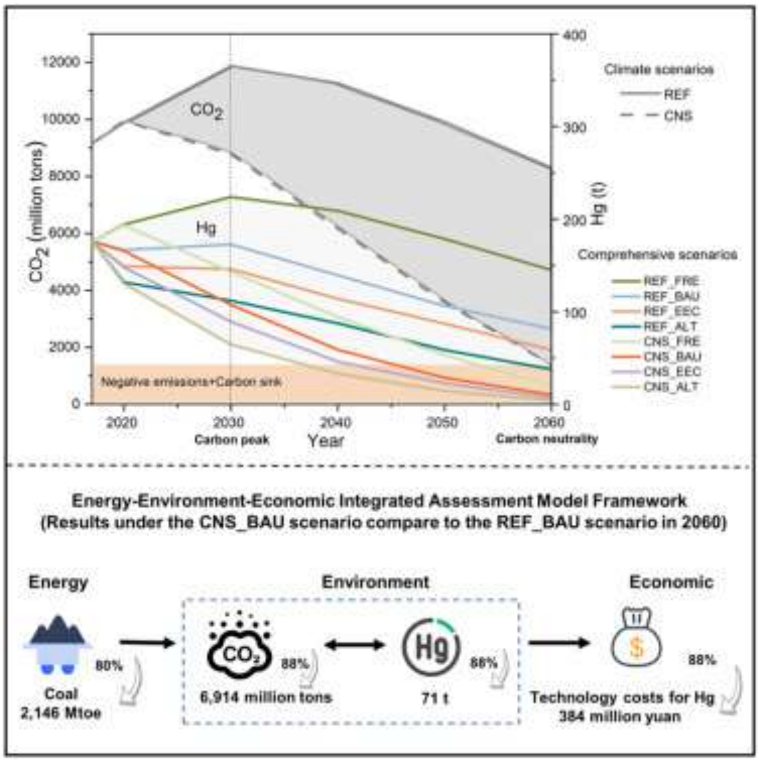


Figure 27: The integrated energy-environment-economic assessment modelling approach used to predict future CO_2 and mercury emissions for a range of climate and air pollutant scenarios (From (Pan et al. 2024)

Figure 28: Conceptual model of multi-aspect synergies and renewable self-reinforcing effect (From (Qin et al. 2024)

The power of these integrated modelling approaches is necessary to address the complexities of inter-related issues in energy supply and security, zero carbon or neutrality strategies, air pollutants and their major effects on the global burden of disease, and reductions in mercury, and also represent great potential in assisting other parties to the Minamata Convention to address these issues for the coal sector.

It is recommended that a future GEF project incorporates this approach and includes extensive related knowledge transfer and capacity building in countries with high reliance on coal for future energy needs.

5. Executive Summary: Gender-Responsive Perspectives in Emissions Mitigation

The relationship between gender and atmospheric emissions from coal-fired energy generation is characterized by complex socio-ecological impacts that extend far beyond immediate health risks. A more detailed considerations of these issues is presented in Appendix E; here the major findings are presented and summarised.

A complex landscape of health, governance, and economic dimensions operate differently across gendered lines. The full gender report examines these relationships through an intersectional lens, focusing on greenhouse gas (GHG), mercury (Hg), and persistent organic pollutants (POP) emissions in the context of gender-sensitive approaches to global environmental governance. This section provides an overview of gender and gender-related considerations central to assessing and implementing existing and future emissions reductions toward the implementation of the Minamata and Stockholm Conventions (with a primary focus on the coal sector). Integrating social outcomes with ecological outcomes, the full gender report (provided separately) sets out considerations for shaping scientific project scoping and development, framing policy and governance initiatives, and devising effective analytical models.

In addition to immediate health effects, coal-fired energy generation emissions cause complex socio-ecological impacts with health, governance, and economic dimensions. Through an intersectional and socio-ecological lens, this report examines how greenhouse gas (GHG), mercury (Hg), and persistent organic pollutants (POP) emissions interrelate with gender-sensitive approaches to global environmental governance, particularly in implementing the Minamata and Stockholm Conventions' coal sector provisions. We conclude that effective frameworks for scientific project development, policy initiatives, and analytical modelling must comprise an intersectional approach to social and ecological outcomes across project scoping, development, implementation, and assessment.

5.1. Context and Core Findings

Effective implementation of the Paris Agreement, Minamata and Stockholm Conventions requires understanding gender within broader socio-economic contexts. All three conventions acknowledge that climate change impacts and energy-related emissions affect groups differently. Direct health impacts from mercury, POPs, and GHGs interact with broader environmental, social, and economic factors through gendered social networks and norms. These effects are further shaped by intersecting forms of disadvantage, including socio-economic status, ethnicity, indigeneity, disability, age, and sexuality. Evidence shows that vulnerability to environmental impacts results from these factors working in combination rather than in isolation.[19]

Drawing on gender-focused expertise across academic, institutional, and industry sources to trace these complex social networks and norms, it is clear that:

[19] See broad overviews in, for example, Kaijser, A., & Kronsell, A. (2013). Climate change through the lens of intersectionality. *Environmental Politics*, 23(3), 417–433; Gunnhildur, L., & Kronsell, A. (2021), *Gender, Intersectionality and Climate Institutions in Industrialised States*, Routledge.

vulnerability to environmental impacts is shaped by multidimensional factors working in combination, rather than any single characteristic in isolation.

As discussed several times in this report, the global energy landscape demonstrates a fundamental tension between the international pressure to reduce coal dependency and meeting diverse energy needs across diverse contexts. This challenge extends beyond techno-economic considerations, encompassing significant socioeconomic implications (including but not limited to gender considerations) that remain understudied. Gender-focused research has proven that effective energy sector governance requires integrating the energy-climate-gender nexus into climate policy foundations and implementation frameworks to prevent exacerbating complex existing inequalities[20].

The Global Environmental Facility's implementation of Minamata demonstrates a strategic shift from harm-minimisation to proactive empowerment, emphasising gender equality and gender mainstreaming[21] .This report builds on this approach by examining gender through its intersection with other forms of disadvantage, analysing impacts across health, livelihood, and agency dimensions. The resulting socio-ecological framework recognises three key advances:

- **Intersectional Analysis**. Gender intersects with socio-economic status, ethnicity, indigeneity, age, disability, and sexuality; these factors converge differently across time and location; understanding these intersections is crucial for effective policy development[22].
- **Moving Beyond Traditional Gender Approaches.** Rejecting binary understandings where "gender considerations" simply mean "women's concerns", to examine how environmental governance frameworks interact with social hierarchies and multiple and interconnected types of disadvantages, and compound disadvantages.
- **Agency Over Vulnerability.** Recognising marginalised communities as active agents of change rather than passive victims of climate crises, while valuing diverse knowledge systems, especially from black, indigenous, and global south perspectives.

To this end, the full gender report (Appendix E) identifies three key priorities:

1. Implementing enhanced air pollution controls where rapid transition from fossil fuels is not immediately feasible.
2. Developing intersectional, gender-responsive energy policy recommendations that consider and incorporate downstream socioeconomic impacts (country-specific where appropriate).
3. Promoting sector-wide diversity, especially gender diversity, to advance both environmental and social progress through an integrated approach.

Energy security and employment stability are crucial considerations in transition pathways. Gender-responsive strategies must be tailored to support government and private sector decisions concerning the energy generation mix in each country. Understanding how gendered social

[20] Mohr, K. (2021). Breaking the Dichotomies: Climate, Coal, and Gender. Paving the Way to a Just Transition. The Example of Colombia. *Energies*, *14*(17), 5457.
[21] See, for example, GEF2020 Strategy (https://www.thegef.org/sites/default/files/publications/GEF-2020Strategies-March2015_CRA_WEB_2.pdf) and recent Gender Action Plan and Gender Mainstreaming set out in the Conference of the Parties to the Minamata Convention on Mercury Fifth meeting (2023).
[22] See, for example, Rao, N., Lawson, E. T., Raditloaneng, W. N., Solomon, D., & Angula, M. N. (2017) Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Climate and Development*, *11*(1), 14–26. Examples of application of this approach to regional and country-specific analyses include Marty, E., Segnon, A. C., Tui, S. H. K., Trautman, S., Huyer, S., Cramer, L., & Mapedza, E. (2023). Enabling gender and social inclusion in climate and agriculture policy and planning through foresight processes: assessing challenges and leverage points. *Climate Policy*, *24*(8), 1034–1049; Ahmed, S., Eklund, E., & Kiester, E. (2022). Adaptation outcomes in climate-vulnerable locations: understanding how short-term climate actions exacerbated existing gender inequities in coastal Bangladesh. *Journal of Environmental Planning and Management*, *66*(13), 2691–2712.

structures and norms influence energy consumption and usage patterns makes gender-sensitive project development and community engagement essential for sustainable energy practices.

5.2. Critical Challenges and Analysis

5.2.1. Health Impacts and Bio-amplification

Women face disproportionate health risks in relation to mercury, POPs, and GHGs, through both biological and social pathways. For example:

- Higher deposition rates of inhaled particles in lung tissue[23].
- Increased sensitivity to toxicological exposure due to higher prevalence of anaemia[24].
- Maternal health vulnerabilities affecting birth outcomes (e.g. increased risks of stillbirths and birth defects)[25].

Social factors amplify exposure and impact of exposure:

- Extended exposure to indoor air pollution through domestic duties. Women spend 3-6 hours daily on cooking/fuel collection in Africa and Asia, which is the fifth leading risk factor for morbidity among women in low-income countries (and higher than for men)[26], and 60% of premature deaths from household air pollution occur in women and children[27].
- Resulting maternal and reproductive health impacts. Placental exposure to pollutants leads to increased risks of stillbirths and congenital birth defects[28]; 13% of global maternal deaths linked to unsafe conditions during climate-related events[29]; 47% increase in hypertensive disorders of pregnancy per 5 $\mu g/m^3$ increment of fine particulate matter[30].

5.2.2. Regional Disparities and Impacts

Global access gaps:

- Nearly 770 million people lack access to electricity (majority in Sub-Saharan Africa)[31].

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[23] Chen, L. H., Knutsen, S. F., Shavlik, D., Beeson, W. L., Petersen, F., Ghamsary, M., et al. (2005). The association between fatal coronary heart disease and ambient particulate air pollution: are females at greater risk? *Environ. Health Perspect*. 113, 1723–1729.

[24] Sorensen C, Saunik S, Sehgal M, Tewary A, Govindan M, Lemery J, Balbus J. (2018). Climate Change and Women's Health: Impacts and Opportunities in India. *Geohealth*. 2(10), 283-297.

[25] Krishnan, V., & Safe, S. (1993). Polychlorinated biphenyls (PCBs), dibenzo-p-dioxins (PCDDs), and dibenzofurans (PCDFs) as antiestrogens in MCF-7 human breast cancer cells: Quantitative structure-activity relationships. *Toxicology and Applied Pharmacology*, 120, 55-61; USEPA, 1997. Locating and Estimating Air Emissions from Sources of Dioxins and Furans. Office of Air Quality Planning and Standards, Office of Air And Radiation, U.S. Environmental Protection Agency, Washington, D.C. EPA-454/R-97-003.

[26] Haddad Z., Williams KN, Lewis JJ, Prats EV, Adair-Rohani H. (2021) Expanding data is critical to assessing gendered impacts of household energy use. *The BMJ*. Oct 14;375:n2273.

[27] Sorensen C, Murray V, Lemery J, Balbus J. (2018). Climate change and women's health: Impacts and policy directions. *PLoS Med.* Jul 10;15(7):e1002603.

[28] Sorensen C. et al.

[29] Chukwumalu, K., Gallagher, M. C., Baunach, S., and Cannon, A. (2017). Uptake of postabortion care services and acceptance of postabortion contraception in Puntland Somalia. *Reprod. Health Matt.* 25, 48–57.

[30] Conway F, Portela A, Filippi V, Chou D, Kovats S. (2024). Climate change, air pollution and maternal and newborn health: An overview of reviews of health outcomes. *J Glob Health*. May 24;14:04128.

[31] https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

- About a third of people worldwide rely on polluting open fires and inefficient fuels, even in areas where electricity infrastructure is available[32].
- .In both domestic and non-domestic settings, this significantly impacts a community's access to socio-economic development. The disparity between domestic and productive energy access creates significant economic barriers. E.g. the Women Empowerment Index shows that while 75% of women have unrestricted access to household energy technologies, only 25% can access energy-dependent assets for income generation. This gap limits not only individual economic opportunities but also broader household and community development potential.
- Emerging economies, particularly in Asia and Africa, face distinct energy challenges. While energy consumption is rapidly growing, heavy fossil fuel dependence creates gendered impacts:
    - 2.4 billion people still rely on polluting open fires and inefficient fuels.
    - Women in rural areas provide 91% of household fuel and water collection effort.
    - Collection activities consume up to 10 hours of women's time weekly.

  This pattern highlights how energy access disparities disproportionately affect women's time, health, and economic opportunities[33].

5.2.3. Indigenous communities' challenges

- Governance and representation: limited representation and voice in governance structures; double discrimination as indigenous people and women; loss of customary self-government systems and economic displacement which forces migration to urban areas.
- Environmental health impacts: disproportionate exposure from environmental contamination, particularly in relation to traditional practices (e.g. traditional food preparation roles that increase exposure to contaminants, and reliance on contaminated water sources); higher levels of toxics in breast milk and increased reproductive health risks; limited access to culturally appropriate and affordable healthcare services.
- Climate vulnerability: heightened gender-based violence during environmental disasters; forced migration increasing trafficking risks; displacement threatening traditional livelihoods; disruption of women's traditional roles in meeting community needs.
- Knowledge and policy gap: indigenous ecological knowledge remains undervalued in policy-making, exacerbating immediate health impacts, structural barriers, and broader social and economic disadvantages[34].

5.2.4. Intersectional factors compound emissions-related impacts through multiple pathways

Key vulnerability patterns:

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[32] See, for example, https://www.unep.org/news-and-stories/story/cooking-smoke-kills-millions-every-year-heres-what-world-can-do-about; IEA. 2023. Tracking SDG 7: The Energy Progress Report. World Bank, Washington DC. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=CN

[33] https://cleancooking.org/the-issues/women-and-clean-cooking/

[34] See, for example, Bhattachan, K. B., Thapa, K., & Magar, S. K. T. (2020). *Climate justice for Indigenous women: urgency and way forward.* Policy Brief AIPP, Bangkok; Carmen, A., & Waghiyi, V. (2012). Indigenous Women and Environmental Violence: A Rights-Based Approach Addressing Impacts of Environmental Contamination on Indigenous Women, Girls and Future Generations, submitted to the United Nations Permanent Forum on Indigenous Issues Expert Group Meeting, January 18-20; Race, D., Gentle, P., & Mathew, S. (2023). Living on the margins: Climate change impacts and adaptation by remote communities living in the Pacific Islands, the Himalaya and desert Australia. *Climate Risk Management*, *40*, 1-7; Race et al.

- Rural/urban disparities (e.g. rural women face increased pollutant exposure through extended fuel collection, as compared to urban counterparts).
- Socio-economic unevenness (e.g. lower-income women experience higher emissions exposure due to solid fuel dependence).
- Multiple levels of culture, socio-economic, and geographical marginalisation (e.g. indigenous women face elevated toxic exposure through traditional practices.

These intersecting factors create distinct patterns of vulnerability. They demonstrate that siloed energy policy frameworks (e.g. those that afford basic energy access) are alone insufficient for achieving gender equality goals.

Case study: China's energy paradox
China offers a useful example to illustrate. China's energy landscape means that, despite universal electrification, intersecting socioeconomic and gender factors create 'energy poverty' as socioeconomic and gendered disparities intersect to amplify biological and health impacts:

- Many (largely rural) households continue using solid fuels due to cost.
- Women bear disproportionate health impacts as social norms and socioeconomic constraints place the burden of domestic duties (e.g. cooking) on them.
- Women face limited options for alternative work due to lack of electricity access (further compounding emissions-related health impacts, but also those related to socio-economic disadvantage more broadly).
- Rural areas face reduced access to (acute and preventative) healthcare and environmental health information.

There are, therefore, compounding disadvantages in emissions exposure as women in emerging economies face a triple burden:

- Higher biological sensitivity to toxics
- Increased exposure through social structures and norms
- Limited access to decision-making processes about emissions management

The example above is instructive and illustrates the ways in which an intersectional gender-responsive analytical framework is essential for maximizing the success of emissions reduction projects. For example, China's carbon neutral strategy is expected to achieve near-zero emissions of mercury by 2060 (See Section 4. Our framework reveals critical intersectional considerations that must inform implementation:

- Economic impacts:
    - Women in traditional energy sectors may face disproportionate job losses during transition.
    - Rural women, particularly in agricultural sectors, could experience increased economic vulnerability.
    - The transition is likely to exacerbate existing wage gaps.
- Social impacts:
    - Rural women are likely to bear increased domestic burdens during energy transitions.
    - Traditional gender roles could be reinforced rather than transformed.
    - Indigenous and minority women will face particular challenges in accessing new technologies.

Opportunities for intersectional gender-responsive approaches include:

- Policy integration:
    - Combine climate initiatives with social protection measures.
    - Ensure gender-responsive financing mechanisms.
    - Develop targeted support for women entrepreneurs in clean energy.

- Capacity building:
    - Provide vocational training for women in renewable energy sectors.
    - Support women's leadership development in environmental governance.
    - Create opportunities for women in new green jobs.

5.3. Sector-Wide Structural Challenges

The energy sector has had persistent gender-based obstacles. There are significant structural obstacles, and the sector is not only male-dominated but also deeply masculinist in its culture and working practices.

Workforce disparities:

- Women represent only 16% of the traditional energy workforce despite comprising 39% of the global labour force and face a 19% pay gap.
- Only 20% of senior leadership roles are held by women[35].
- Digital literacy gaps compound existing barriers in emerging economies in particular[36].

Governance barriers:

- Institutional "sticky pathways" perpetuate existing power structures and restrict meaningful participation from marginalised groups (women often face double, triple, or more discrimination).
- Masculinist culture in extractive industries and STEM fields limits women's participation. Even ‘benign’ working practices make participation from marginalised groups difficult (organisational cultures, frequent travel, long hours).
- Environmental governance frameworks often reinforce existing power structures. E.g. decision-making bodies continue to allow all-male delegations despite gender policy commitments. Language and resource constraints limit access to and participation in global governance institutions (particularly problematic for women from emerging economies)[37].

This results in limited access to decision-making processes, but also means decision-making lacks the diversity that informs effective policy development and implementation across different social, cultural, and economic contexts.

5.4. Summary of Recommendations

Future energy projects aimed at reducing emissions in coal-dependent countries should integrate gender perspectives into their projects from the scoping stage, through to project design, data analysis frameworks, and implementation plans, and assessment tools. This requires engaging with gender-responsive experts from the earliest stages of strategy, framework, and project development, and leveraging their connections with industry and communities. Expertise in this area should offer technical emissions experts a well-informed set of perspectives that move beyond traditional gender approaches and ensure genuine integration of diverse perspectives in emissions management governance and strategies.

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35 See for example, Bellesi, V., S. Ramos Magaña and D. Xynou (2023), "Gender mainstreaming in environmental policies", in *Joining Forces for Gender Equality: What is Holding us Back?* OECD Publishing, Paris; World Economic Forum. 2022. *The Global Gender Gap Report 2022*.

36

37 Magnusdottir, G. L., & Kronsell, A. (2024). Climate institutions matter: The challenges of making gender-sensitive and inclusive climate policies. Cooperation and Conflict, 59(3), 361-378.

Designing and delivering effective gender-focused projects requires:

- analysing gender dynamics to understand the unique challenges and opportunities faced by different genders, involving stakeholders from diverse backgrounds
- providing defined training and capacity-building programs to enhance gender equality within organisations responsible for decision-making in future energy development plans
- collecting gender-specific data to inform policymaking, and
- fostering gender-responsive communication strategies throughout the project life cycle.

Shaping future projects along these lines also aligns with increasingly *intersectional* gender concerns in energy policies and national GAPs under the various UN Conventions.

Below is a summary of key recommendations from the full report, based specifically on the areas of focus of this GEF project on Emissions Reduction for the Minamata and Stockholm Conventions.

1. Embed Intersectional Gender Analysis

- Integrate comprehensive gender analysis into project inception and implementation.
- Consider existing inequalities, socio-cultural norms, and power dynamics.
- Develop targeted interventions with community support.

2. Enable Inclusive Decision-Making

- Address systemic barriers to participation.
- Engage underrepresented groups as key contributors and beneficiaries.
- Challenge institutional structures that limit diverse participation.

3. Create Context-Specific Frameworks

- Develop principles that inform locally tailored guidelines.
- Test approaches through pilot country programs.
- Triangulate community feedback with expert input.
- Consider broader political, social, and economic contexts.

4. Recognise Agency Over Vulnerability

- Value women's insights and knowledge in project development and identify and include specific intersectional perspectives that are most relevant to the project.
- Acknowledge existing sustainable practices expertise.
- Support transition from resource dependency to empowerment.

5. Leverage Private Sector Innovation

- Learn from agile corporate approaches to intersectional gender inclusion.
- Study successful case studies from emerging economies.
- Engage with existing private sector initiatives.
- Build on shared stake and interest in environmental governance.

6. Country profiles

Detailed information on the most important of the focus countries is included in Appendices A-D attached to this report. Here the major findings and issues are summarized.

6.1. China

Importance of coal to energy security

Coal is critical to energy security in China, providing 60% of the country's energy supply. The country's dependence on coal shows no sign of slowing in the near term - the fleet of new CFPP plants in pre-construction and construction phase is equivalent to the entire Indian coal fleet - >390 GW.

> *One out of every four tonnes of coal use globally is used to produce electricity in China*

However, China has acknowledged that it continues to build new coal plant as a means to support the expansion of renewable energy. Since renewable energy sources are not yet dispatchable or able to provide baseload power on a consistent basis, coal is being used to support the expansion of these systems, along with supportive energy storage solutions, until the removal of coal from the energy mix is no longer a risk to energy security.

Relevant environmental legislation – is it working?

It is not surprising that emissions of CO_2 from China make up around 50% of all emissions from Asia. However, China has some of the tightest emission standards in the world. It is critical that China continue to focus on reducing emissions from coal combustion and to replacing fossil fuels with alternative sources of power. Most units in the coal fleet are less than 20 years old and state-of-the-art with respect to efficiency and emission reduction. The trajectory of emissions from the coal sector has already decoupled from the trajectory of coal use due to the move towards cleaner combustion systems and the significant installation of APCD. The challenge for China will be controlling emissions from a continually growing coal fleet.

New insight from the GEF dataset

Coal use is predicted to peak by 2030 and then decline to potentially reduce capacity by 50% by around 2050. However, the predicted capacity in operation in 2050 could still be 3-4 times larger than the current capacity in India (236 GW).

> *China could account for around 65% of the remaining CFPP capacity still in operation in 2050 under the BAU scenario*

Emissions of CO_2 from the coal sector are predicted to reach 5.4 Gt/y by 2030 and then to decline to around 2.8 Gt/y by 2050.

Due to the application of state-of-the-art emission controls for all major pollutants, emissions of mercury from Chinese CFPP began to decline in 2010, despite the continued increase in coal use, as shown in Figure 29.

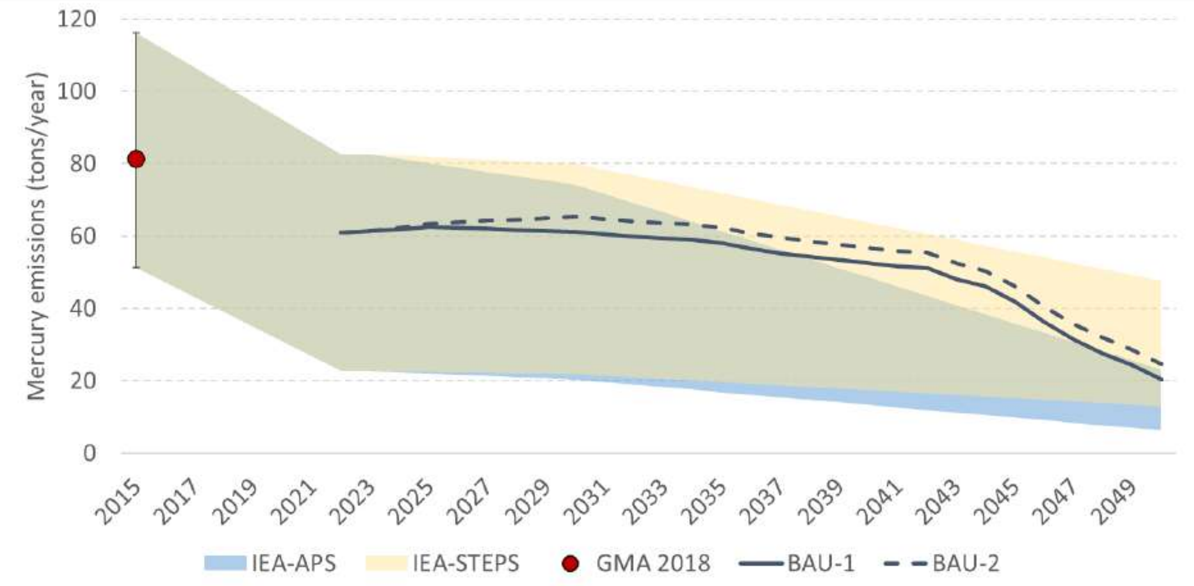

Figure 29 Estimated mercury emissions from Chinese CFPP under different scenarios

However, the downward trend has somewhat stalled, with emissions likely to remain relatively constant from now until around 2040. This is due to the reduction in mercury emissions from plants reaching the maximum technically possible versus the continued expansion of the coal sector. Mercury control factors for many plants in China are above 88%. This is exemplary and the expertise and experience gained from achieving this should be shared widely with other coal-dependent nations.

As described above in Section 4, China has significantly reduced emissions of mercury as a co-benefit of more stringent controls on the emissions of fine particles, and fine particle precursors (the acid gases NO_x and SO_2. The result has been reductions in atmospheric PM2.5 concentrations with significant economic and health benefits.

Outcomes for POPs are more difficult to estimate but the predictions using simplified assumptions about POPs emission factors (see Figure 21) show significant reductions in yearly emissions are possible for a range of coal use scenarios.

Unique challenges

China is leading the development and evolution of industrial processes which can operate either from renewable sources or directly from the electricity grid, thus solving the issue of continued coal use in the sector and simultaneously reducing the effects of localised air pollution, which can be significant from industrial sources. However, it must be noted that, whilst the movement of industrial sources onto the grid will reduce localised use of coal, unless the source of baseload power also moves away from coal, the end result could be the increase of coal use in the utility sector to provide the extra power needed. Despite this, even if industrial coal use is transposed onto the grid, the emissions would reduce on a mg/m^3 basis for all pollutants simply due to the higher combustion efficiency of CFPP compared to CFIB.

Effective paths for future emission reduction

Since China is already applying effective APCD systems, the most appropriate means of emission reduction from the coal sector is early retirement. However, since the majority of the coal fleet is under 20 years old, there may be issues with stranded assets. As mentioned above, the growing coal fleet is seen as a supporting bridge to cleaner energy, including moving industrial practices from less efficient onsite coal combustion onto the grid. But once renewable energy is ready to provide baseload power to a large population, the existing coal fleet can be phased out. Ideally this would be through repurposing of the majority of the fleet – using existing grid infrastructure to create renewable energy sites whilst reusing as much of the technology, infrastructure and staff as possible. This would reduce the impact of stranded asset risk and conform with the aims of the Just Energy Transition

Biggest advantage vs biggest challenge

China's current big challenge is aligning its goals for emission reduction with the continued, hugely significant, growth in coal use. For China, the aim is to maximise the energy security and affordability of a large coal fleet to support the development of a renewable energy fleet that will ultimately, and potentially swiftly, replace it. This relies heavily on success in the development of affordable renewable energy and the associated energy storage required to ensure dispatchability. Whilst this could be seen as a somewhat clumsy approach to ultimately reducing emissions (using one of the dirtiest fuels available to support clean power) there is a clear strategy and one which is affordable and achievable, especially since China is leading the world in terms of clean energy technology.

6.2. India

Importance of coal to energy security

In 2023, India's population surpassed that of China's as the largest in the world. Coal provides just under 50% of the country's total energy production and just over 70% of its electricity. Although India has plans to reduce its dependence on coal, there are still over 30 GW of units in construction and 36 GW in the planning stage. The status of coal sector – whether it will continue to grow or not – is still unclear with conflicting information on whether the planned new capacity will materialise or face cancellation.

Indian coal is of poor quality, containing up to an order of magnitude more incombustible ash than other coals. Indian coal plants therefore often run below design efficiency and face significant challenges with respect to corrosion and pollution control. Over and above this, the Indian government has recently required that utility plants operate in flexing mode to meet capacity demands and to balance the power on the grid from intermittent renewable energy. Indian coal plants are now flexing and cycling more often than any other coal fleet in the world and, as a result, their performance and efficiency is being negatively affected, causing an increase in emission factors for all pollutants. This change in emission factors has not been considered in any previous emission projections nor could it be included in this study. However, the effect of this potential variation is significant and has led to the proposal of a follow-up GEF program/project, which is discussed in more detail at the end of this report.

The Indian government has recently required that all coal plants begin to investigate biomass co-firing at coal plants. Whilst this can reduce emissions from coal, the addition of a new fuel feed with variable characteristics to coals which are already high in ash will lead to additional problems with corrosion and ash production at plants. Depending on the composition and other properties of the biomass, co-firing may also lead to increases in POPs.

The instability of the Indian electricity grid means that many industrial activities rely on captive coal plants, which provide onsite power without having to comply with the strict emission limits faced by larger utility plants. Although emissions from the industrial sector in India have not been quantified due to lack of data on coal use in this sector, it is known that these emissions may be large – for example, in 2013, emissions of CO_2 from coal for energy were 900 Mt/y whereas emission from iron and steel were 189 Mt/y.

Relevant environmental legislation – is it working?

Under its Paris commitments, India aims to produce 50% of its power from non-fossil sources by 2030 and to reach carbon neutrality by 2070. This does not align with the significant number of new plants which are in the pre-construction or planning stage, as mentioned above.

In 2015, India leapt from having minimal emission standards (relatively lenient limits for PM) to requiring all coal plants to comply with standards equivalent to those in Europe and North America. Considering the scale of this challenge, the large number of plants affected, it should not be a surprise that these limits have not been met. Almost 10 years later, the level of compliance with these norms remains below 10% as plants continue to stall and derogate on their compliance obligations. Attempts by the Indian government to make the limits more achievable, such as phased implementation and targeting of more polluting plants in urban areas first, do not seem to have accelerated compliance. In fact, the continued flexibility within the legislation suggests that the norms are not yet fixed and that delays will continue. Plants are therefore hesitant to spent millions of dollars to comply with legislation which they argue is still not final.

Adding in the issues with flexing and co-firing, as mentioned above, and the Indian coal utility fleet is recognised as facing the “perfect storm” of demands – they must operate outside their design parameters, use fuel for which the plant was not designed, and install expensive control systems that have not yet proven effective on Indian coals. If much of the coal fleet must, potentially, also start planning for retirement to meet Paris Commitments, is not surprising that the sector is currently in a state of confusion as to the best path forward.

New insight from the GEF dataset

This project projects that coal use in India will peak around 2030. The decline in emissions after that will vary by up to 50% depending on the scenario. Under BAU, where plants in the preconstruction phase are completed, the coal plant capacity will not return to even current levels until after 2050. Early retirement strategies are required to achieve anything approaching a 50% reduction in capacity by 2050 at the earliest.

Figure 30 shows the trajectory of mercury emissions under different scenarios.

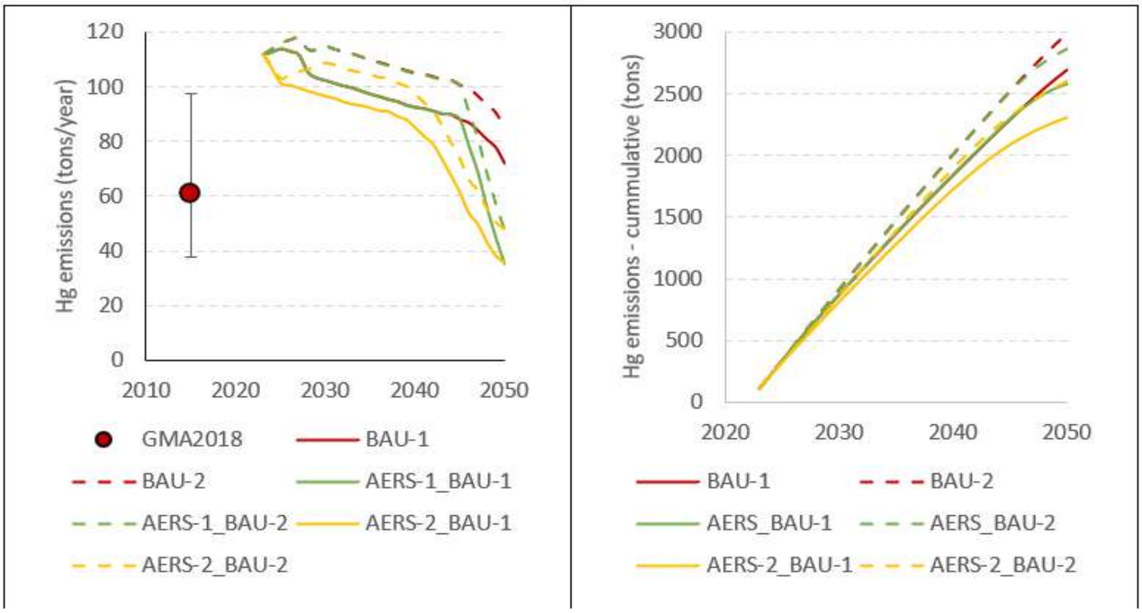

Figure 30 Mercury emission projections for India under different scenarios

On the left in Figure 30, mercury emissions are shown to decline from around 2030 onwards, depending on the status of new build plants. The reduction in emissions could be significant if plants retire early, resulting in the avoidance of up to around 750 t of mercury by 2050.

Retrofitting control technologies on the Indian coal fleet could reduce emissions by around an additional 20% by 2050, avoiding a further 500-600 t of mercury by 2050.

Unique challenges

As discussed above, there is uncertainty as to whether India has peaked its coal use of whether the significant number of new plants in construction or planning will reach completion and operation. This will determine whether India's emission decline will start from its current level or whether the capacity of the fleet could increase by 100 GW. The decline path of emissions will therefore be very dependent on what happens in India's coal sector in the next few years. New plants are designed to operate for 40 years, so every new plant that is built will lock in potential new emissions over this time frame.

Although India has agreed to ambitious climate goals and has set emission limits to match those set in developed countries, its progress towards compliance is slow at best and risks stalling further. The emission limits and reduction goals are potentially too expensive and too challenging for a coal fleet which is already operating in extreme flexing mode whilst being asked to co-fire biomass.

Effective paths for future emission reduction

The environmental policies in India are, at best, confused and, in practice – chaotic. In order to move forward, the Indian government must confirm the environmental goals for the coal utility fleet and then stand firm to enforce compliance. Clarity and simplicity would be advised. There is also potential to consider an approach which prioritises different goals across the Indian fleet. For example:

- Should new plants proceed to construction, older less efficient plants could close earlier (a strategy which has proven effective in China)

- Younger plants should be prioritised for retrofitting APCD as they are most likely to achieve a return on investment before closure
- Not all plants should have to provide both flexible operation and biomass co-firing. The newest plants should flex whilst older units, who are less likely to be negatively affected by changes in operation since they are already running at below design efficiency, should co-fire biomass. No plant should be doing both without significant investigation into how to achieve this without potential detrimental effects on performance and emissions.

Assessment of the Indian coal fleet to determine best practice on a unit-by-unit basis would ensure strategic and efficient fleet operation whilst accelerating emission reduction.

6.3. Indonesia

Importance of coal to energy security

Coal provides just over 60% of Indonesia's electricity. Over 80% of the 45 GW (2023) of coal plants in operation are younger than 10 years old, implying a long potential phase out path. Further, the total capacity of coal continues to rise to reach a predicted 52 GW in 2030. As coal plants age and retire, the total capacity should decline to 40 GW by 2050 – however, this is only 5 GW less than the current capacity, suggesting that emissions will not decline significantly in the near future unless action is taken.

Indonesia has also expanded the use of coal through captive use with dedicated power plants being operated and utilised by industry for mineral processing. It is estimated that almost 25% of the operating coal capacity in Indonesia is for captive use (Parapat and Hasan 2023). These coal plants may face more lenient emission control requirements that coal utility plants and therefore release proportionally greater emissions, often in more densely populated areas. Recent government policies and announcements have revealed a strategy for increasing in country mineral processing rather than export of mineral concentrates which may exacerbate this issue.

Relevant environmental legislation – is it working?

Under Paris commitments, Indonesia has announced that it will retire 9.2 GW of capacity by 2030 and that new build may be cancelled. However, this does not apply to independent power producers who may proceed with 5 GW of new capacity. The government has introduced new emission limits for pollutants such as SO_2 and NOx which may accelerate mercury emission reduction through co-benefit effects.

New insight from the GEF dataset

Figure 31 shows the potential future emissions of mercury under different scenarios.

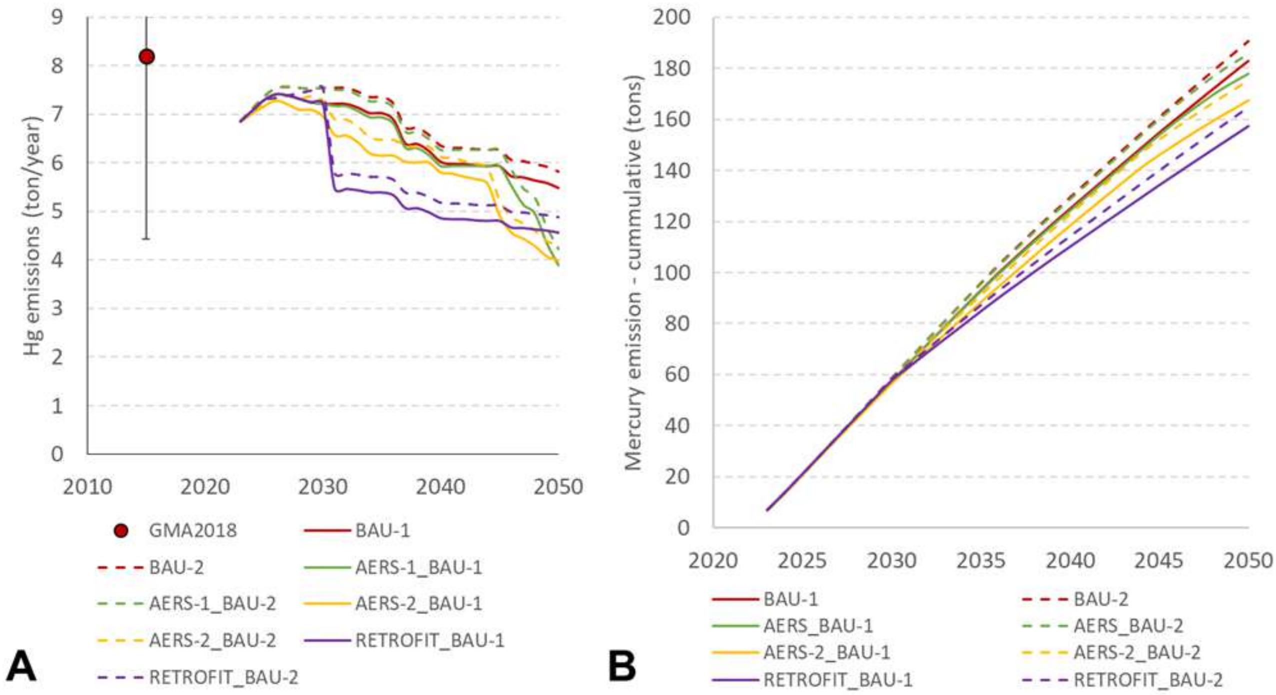

Figure 31 Estimated mercury emissions from the Indonesia coal utility fleet

Assuming that all plants will install FGD for sulfur control by 2030, emissions of mercury could decline significantly as a result. However, without further mercury-specific policies, the complete control of mercury will follow the trajectory of plant closure, continuing past 2050 before lowering to even 50% of current emission levels.

This study showed that fitting FGD to plants with a remaining lifetime of over 20 years would have the same effect on mercury emissions as a 7-year early retirement plan for all plants. A combination of both approaches could accelerate emission reduction further.

Unique challenges

Currently it is unclear whether Indonesia will commit to its Paris agreement and halt new coal plant build or whether it will allow new plants, especially private sector utilities, to proceed. This decision will have a significant effect on future emissions, determining whether coal has already peaked or whether capacity could increase by a further 10% or more by 2030. All new coal plants add to the total emissions for 40 years or more, based on the design lifetime of a coal plant. The application of emission control systems for sulfur, which have recently become compulsory on all plants, could reduce mercury emissions before 2030. However, beyond that, emissions of all pollutants will correlate with the continued operation of the coal fleet. Early retirement strategies are critical for Indonesia to decouple from the current trajectory, which suggests that emissions of mercury will not be reduced by more than 50% from current levels, even by 2050.

Indonesia is currently one of the countries with a potential JET project, aiming to reduce emissions from the coal sector. However, there continues to be debate and controversy over whether the existing project, which plans to close the largest plant, Cirebon, 10-15 years early (replacing it with an equivalent capacity of renewable energy with energy storage) will proceed. The financing, like many international projects, is in the form of a loan rather than a grant. This adds to Indonesia’s already significant financial burden and therefore risks issues with affordable implementation.

Effective paths for future emission reduction

A complementary study by the ICSC for the USDOS provided a unit-by-unit assessment of emissions from the Indonesian coal fleet. This level of insight could inform a strategic approach to emission reduction, prioritising action at those plants where the greatest effects can be achieved in a cost-effective manner.

6.4. South Africa

Importance of coal to energy security

South Africa uses coal to provide almost 90% of its electricity demand and is the most carbon-intensive electricity producer in the world.

South Africa faces a combination of unique challenges with respect to supplying power for its growing population and populations in surrounding regions. Unlike the countries in southeast Asia discussed earlier, South Africa has not been building many new coal plants, and the majority of the fleet is now over 40 years old and operating at or well beyond the design lifetime. Demand for energy in the country exceeds capacity – loadshedding and blackouts are common. Further, there are many reports of fires, breakdowns and unsafe operating conditions. Eskom, the country's major power provider, has faced financial issues for years and cannot afford to take plants offline for major refurbishment.

Relevant environmental legislation – is it working?

The country's NDC aims for 20 GW of renewable power by 2030. However, this is still only less than a third of the capacity supplied by coal. Moving from coal is a challenge for all coal-dependent regions but South Africa is more coal-dependent than any other nation. A significant portion of the population works in the coal sector, which is why it has been a priority target for one of the first JET projects. The project aims to improve the country's energy infrastructure, focussing on decommissioning and repurposing of the existing coal fleet. This will include green hydrogen, which is still relatively developmental.

New insight from the GEF dataset

Coal capacity in the country has been relatively stable since 2000 at around 40-45 GW. The current fleet, which is already at or near the end of its planned life, should glide towards closure before 2050. However, without an alternative sources of affordable baseload power, the practicality of a coal phase out, even for plants that are due to retire, is problematic.

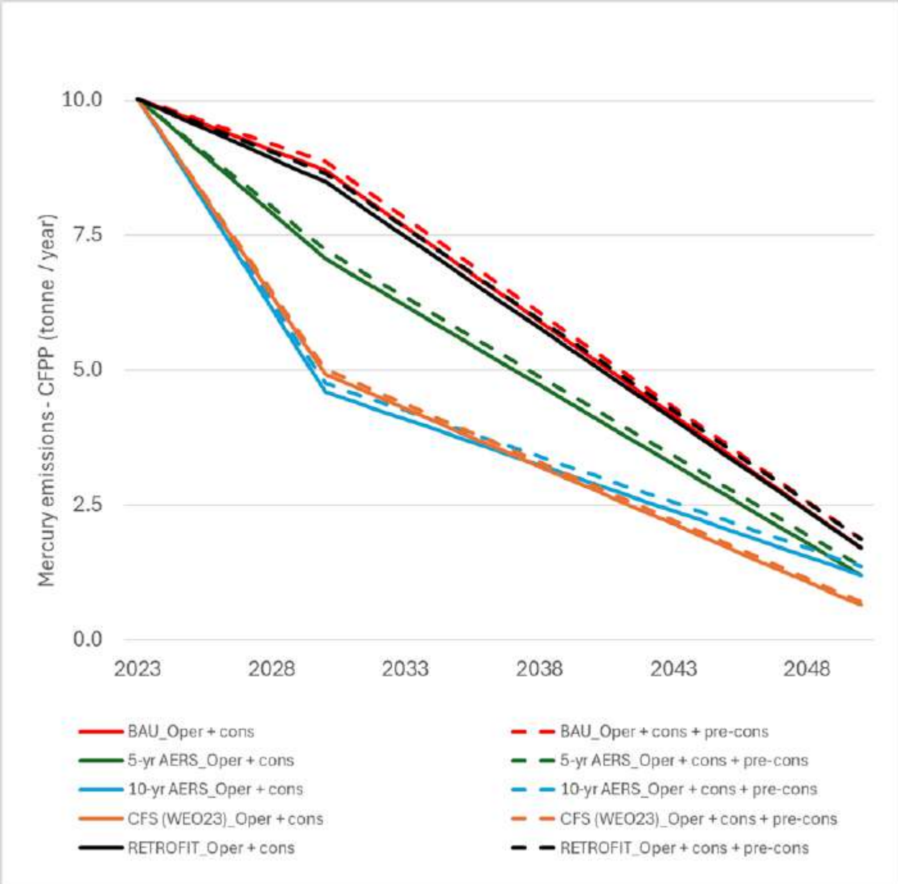

Figure 32 Estimated emissions of mercury from CFPP in South Africa

Figure 32 shows that mercury emissions will decline as coal phases down in the region. Emission reductions could be accelerated with APCD and early retirement. However, as noted in GMA report of 2018 (AMAP/UNEP 2019), South African coals are high in mercury and the chemistry is such that co-benefit reduction in APCD is minimal. As a result, South Africa contributes almost 10% of the global mercury emissions from CFPP despite having only 2.1% of the CFPP capacity. There is therefore significant indication that mercury-specific control techniques and technologies should be applied.

Unique challenges

It is clear that the aging coal fleet in South Africa should retire as soon as possible and that, for any plants that continue to operate, mercury reduction strategies should be implemented as soon as possible. However, for a country where demand exceeds capacity and funding within the energy sector is already at crisis point, there is a gap between what should be done and what is practically achievable and affordable. In meetings with generators, regulators and environmentalists in 2024, there was some evidence that their emphasis was on PM controls rather than mercury. These would likely lead to improved health outcomes and a co-benefit in mercury control.

Effective paths for future emission reduction

South Africa's power sector is unique and more problematic than any other coal fleet. The strategy for emission reduction must be pragmatic and must acknowledge that, for this large growing nation, energy security will be prioritised over environmental issues unless external forces, in this case international funding, steps in to reset the balance. In the meantime, the country must struggle on with a sub-par coal fleet until alternative reliable power is available.

6.5. Vietnam

Importance of coal to energy security

Vietnam has significant renewable energy (including hydropower) but still relies on fossil fuels for around 43% of the energy capacity. Total capacity continues to grow from 122 GW in 2022 to reach 146 GW by 2030. Whilst the proportion of renewable energy is impressive and growing, the dispatchability challenge means that coal is still currently vital to energy security. The future of the energy sector in Vietnam will be determined by the continued uptake and deployment of renewable power and the development of energy storage solutions. Coal is use is predicted to double between 2020 (67 Mt/y) and 2030 (171 Mt/y). This means that the coal fleet is very young – locking in emissions for 40 years (the design lifetime of a coal plant). Early retirement is therefore intrinsic to reducing emissions.

Relevant environmental legislation – is it working?

Vietnam aims to phase out coal by 2050 through conversion to ammonia and biomass in combustion systems and the continued development of renewable energy.

New insight from the GEF dataset

Because of the young age of the fleet and the continued build of new coal plants, even if coal use peaks by 2030, the decline in emissions will be slow. Without an early retirement strategy, the coal capacity, and therefore the emissions, could remain relatively fixed until 2050. Even if plants retire 10 years early, emissions will not begin to decline until 2040 at the earliest.

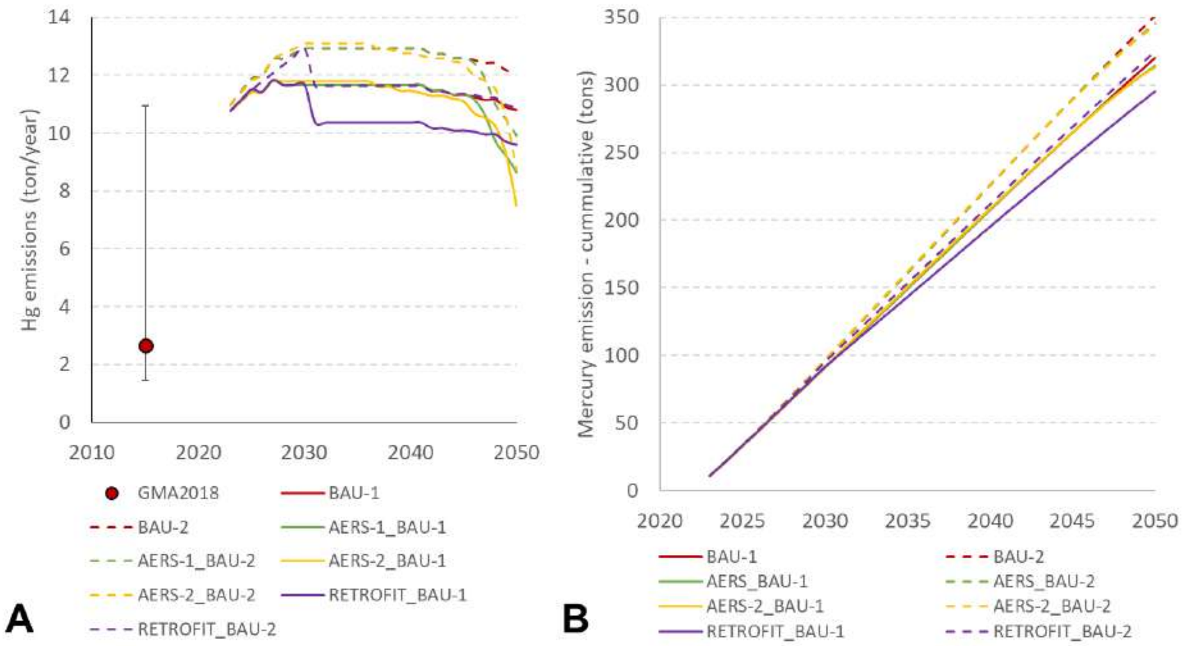

Figure 33 Estimated mercury emissions from CFPP in Vietnam

As shown in Figure 33, the installation of APCD for species such as sulfur and NOx could reduce emissions by 1-2 t/y by 2030. However, unless more mercury-specific action is taken, mercury emissions will then follow the same trajectory as the coal capacity, remaining high until 2040 at the earliest.

Unique challenges

Vietnam has a relatively high input from renewable energy and plans more but until energy storage and dispatchability issues are resolved, the necessary baseload power for energy security will continue to come from coal. Even if the country cuts back on new coal build plants, the rate of addition of new units over the past few years means that the current fleet is significant and is young. Emissions from the sector are locked in for decades, even if 10-year early retirement requirements are introduced.

Effective paths for future emission reduction

As with China, the age of the coal fleet in Vietnam is the major challenge. The current plants may well operate for 40 years and, even with emission control technologies for the major pollutants, the emissions from the sector will be significant for decades. Closing the coal plants will only be possible if an alternative source of reliable and affordable power is developed. Since the coal fleet is largely new and state-of-the-art, there is the option for Vietnamese plants to consider advanced pollution control technologies such as those applied in China. This would be expensive but, if the coal plants run for the predicted 30-40 years, the return on investment is achievable (although early retirement would affect this). Another option is switching of the current coal plants to fire biomass or ammonia.

6.6. The Philippines

Importance of coal to energy security

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 to 2030. And, as for the other regions with many plants which are still new, the major challenge is accelerating emission reduction from a coal fleet which has, theoretically, 40 years of operation left.

Relevant environmental legislation – is it working?

Under the Paris NDC, the Philippines aims to reduce emissions from the coal sector by 70% by 2030, relative to the BAU scenario.

New insight from the GEF dataset

Figure 34 shows mercury emissions from the Philippines coal fleet.

Emissions from the fleet could start to decline after 2030, with reductions from both retrofitting and early retirement being similarly effective.

Unique challenges

The Philippines has relaunched its nuclear program which could accelerate the move away from coal. However, electricity prices in the Philippines are already the highest in all southeast Asia and nuclear power is not cheap. Any change to the energy sector will affect fuel prices and few of any of these changes will reduce energy costs in the short term. This could lead to a significant issue with energy security and affordability in the country.

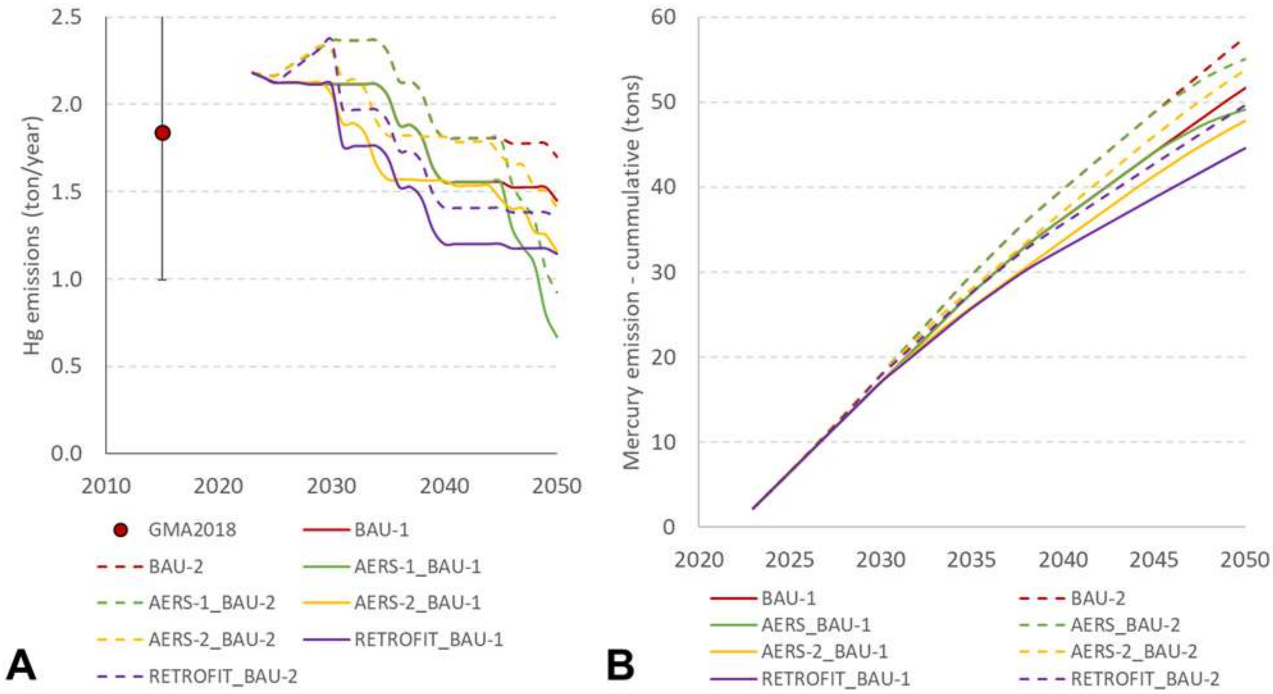

Figure 34 Mercury emissions from CFPP in the Philippines

Effective paths for future emission reduction

The Philippines faces similar emission reduction challenges to China, Indonesia and Vietnam and could therefore follow their lead in terms of policy and change within the sector. However, the challenge may be greater for the Philippines due to the risk of escalating the cost of power in the region beyond what is already well above average.

6.7. Pakistan and Bangladesh

These two countries have been included because of future plans to significantly increase the installed capacity of the CFPP fleets.

As of January 2024, the Global Energy Monitor's Global Coal Plant Tracker database indicates that Pakistan has a total coal-fired power plant capacity of 7.6 GW consisting of 20 operating units. An additional 0.7 GW capacity (3 units) is listed to be under construction, along with an estimated 4.0 GW (8 units) that have been announced, permitted, or pre-permitted (pre-construction).

The share of power generation from coal was 24% in FY21 and is expected to increase to 31% by FY 25 due to plants committed to be built but will then decrease to 20.1% by FY30. Since all operating CFPPs are recorded to be less than- or equal to 9 years and considering the remaining lifetime of the operating CFPP fleet and plants under construction (with a 40-year life expectancy), the country's CFPP capacity is expected to remain at 8.4 GW until 2050 unless they are retired early. If all expected projects eventuate, a CFPP capacity of 12.4 GW could be reached which will persist beyond 2050.

According to the Global Energy Monitor's Global Coal Plant Tracker database (updated July 2023), Bangladesh currently has a total coal-fired power plant capacity of 2.9 GW which consists of 7 operating units. An additional 5.8 GW (9 units) is listed to be under construction, along with an estimated 6.0 GW of projects (7 units) that are either under announced, permitted, or pre-permitted status (pre-construction). This suggests that the country's CFPP capacity is expected to double if all plants under construction are commissioned and increase five-fold if all projects under pre-construction also continue. A calculated 91% of all existing CFPP units are younger or equal to 10 years in operation, from which 57% of the operating units have a capacity more than or equal to 300 MW. This suggests that most of the country's existing CFPP fleet is already expected to operate for the next three decades at least, considering a default CFPP life expectancy of around 40 years.

Although these two countries make a relatively minor global contribution to CFPP-related emissions, a significant proposed expansion of CFPP capacity is indicated for them. There are some major issues in renewable energy generation for these countries, e.g., challenges with Pakistan's hydropower generation, so it is possible that CFPP projects under a pre-construction stage will proceed to construction. As a result, these plants could potentially operate for another 40+ years, past 2060. If renewables development does accelerate however, this increase in CFPP capacity may represent a stranded asset risk.

7. Conclusions and possible solutions

In the whirlwind of recent global events, a global consensus is essential to accelerate our efforts in reducing our reliance on fossil fuels. Equitable and sustainable energy shifts are needed for both climate action and to reduce the unnecessary health burden associated with atmospheric emissions.

Although projections suggest a peak in coal-fired power production by 2030-2035, backed by data on the planned retirements of existing and new plants, emissions from this sector are likely to peak sooner due to the replacement of aging fleets with modern plants equipped with efficient multi-pollutant control technologies. This is a welcome development but must be supported by accelerated climate action and similar developments in the industrial boiler sector.

A just energy transition pathway for many emerging economies is needed, including the early retirement of coal-fired plants. However, many countries cannot deploy this strategy too quickly without risking energy security. Hence evaluation of the best available technologies and best environmental practices (BAT/BEP) for such coal-reliant countries was a high priority for this project. In some cases, coal may have a continuing but reduced role in electricity production as the deployment of renewables increases. However, this reduced role requires coal-fired plants to operate differently (less often or with lower quantities of coal and with rapid requirements for performance shifts) than they have historically which may present technical challenges. There is also evidence that some countries are operating coal capacity for captive use with dedicated power plants being operated and utilised by industry for mineral processing. For example, almost 25% of the operating coal capacity in Indonesia is for captive use (Parapat and Hasan 2023). In some cases, these coal plants face more lenient emission control requirements that coal utility plants and therefore release proportionally greater emissions, often in more densely populated areas.

The examination of global perspectives and country-specific profiles, coupled with their stated policies and commitments toward emission reduction in the coal sector, reveals a complex landscape. Each nation faces unique and multifaceted challenges, combined with the regional, social and economic context, which significantly influences its capacity for a just energy transition.

Global uncertainties regarding energy security and equity, coupled with delays in renewable energy infrastructure to secure baseline electricity provision, create challenges towards a rapid just energy transition in some regions of the world, resulting in a continued reliance on coal as a primary energy resource. This presents challenges to signatory countries to the Paris Agreement who are required to accelerate the transition away from coal.

This project contributes to the consolidation of knowledge on global coal-fired power plant development and emissions mitigation plans, concentrating on focus countries that remain highly dependent on coal.

This work built on the extensive knowledge compiled from a comprehensive inventory of technical reports, energy databases, government energy statistics, and scientific literature. These resources contain various case studies and emissions inventories related to the coal sectors of different countries. Eight countries which continue to rely on coal-fired power infrastructure to meet their energy demands and foster economic growth were initially identified: China, India, Indonesia, Vietnam, Philippines, Thailand, Malaysia, and South Africa. In subsequent work it was established that both Pakistan and Bangladesh also have future plans to commission new coal-fired plant in future years and warrant more attention than Thailand and Malaysia.

The project activities successfully established baseline data for estimating future carbon, mercury, and POPs emissions from coal-fired power generation. Extensive engagement with stakeholders has strengthened shared knowledge of energy sector developments, shaping realistic projections for coal capacity, greenhouse gas, and mercury emissions in these countries. Project learnings suggest a need for emissions control technologies resulting in a co-benefit for mercury emissions reduction, rather than specific mercury control. Ongoing stakeholder involvement is clarifying the understanding of country-specific challenges and progress toward emissions improvements and a just energy transition in the coal sector.

7.1. Primary strategies for emission reduction

Within the spectrum of approaches to reducing emissions from the coal sector, two primary strategies stand out: coal phase-out through early retirement; and investment in air pollution control for both existing and new coal-fired power projects.

7.1.1. Coal Phase-Out Strategy:

The implementation of a coal phase-out strategy offers several advantages:

- it addresses and minimises the risks associated with stranded assets for new coal projects;
- it addresses operational challenges arising from the rapid integration of renewable energy;
- it directly reduces emissions at the source, resulting in immediate improvements in air quality.

However, challenges persist. Emerging economies often require international support and financing mechanisms to execute such transitions effectively. Additionally, the strategy's short-term implications on energy security must be acknowledged and managed. Moreover, global pricing dynamics for fossil fuels and international investment patterns play crucial roles in promoting this transition.

The main considerations here are:

- Avoiding stranded asset risks for new projects and increased challenges with the operation of the plants as renewables are/will be introduced at an accelerated pace. This affects the affordability of power for both utilities and consumers.
- Acknowledging the short-term implications and challenges on energy security resulting from early retirement. Until alternative dispatchable baseload power is available, such as through improvements in energy storage, countries will not accept potential societal risk from closing their existing baseload power supply. In many regions, coal is the only baseload supplier as the only other dispatchable baseload power option – gas, diesel, nuclear or hydro - are limited or lacking completely.
- The benefit of directly reducing emissions from the source having immediate effects on the outlook of improved air quality in each country. This has a long term and significant financial benefit with respect to reducing health costs and lost workdays.

- Emerging economies will be reliant on international support to make this happen through financing mechanisms – there is a need to ensure that these funds are spent in an optimal way.
- Global pricing markets for fossil fuels as one of the key drivers to promote this change, along with restrictions on international investment in new coal projects. It is critical to acknowledge that the withdrawal of international funding for new coal projects will not necessarily result in coal projects being cancelled – rather there is a risk that private funding will be used to build cheaper, and likely more polluting, plants to meet the power demand.

Rather than simply being told not to use coal - countries must be offered practical and affordable alternatives to coal that will ensure power for their growing economies.

7.1.2. Improved Air Pollution Control Strategy:

Enhancing air pollution control presents its own set of opportunities and challenges. Many pollution control systems provide co-benefit effects, reducing several pollutants simultaneously. These retrofitted flue gas treatment systems allow sources to align with goals outlined in various UN Conventions, whilst benefiting public and ecological health. Nevertheless, substantial financial investments and timely implementation are essential to realize significant emission reductions within the next two decades. These financial commitments may coincide with increased investments in renewable energy, necessitating upgrades in infrastructure such as battery storage and transmission systems. Additionally, the operation of these technologies, most of which require power to operate, may reduce the efficiency of coal-fired plants and pose constraints on their operational flexibility amidst increasing penetration of renewables.

The main challenges for this strategy are:

- Strategic selection and deployment of technologies to comply with potentially competing UN Conventions and public/ecological health requirements whilst maximising co-benefit reduction of multiple pollutants. Technology selection is complex and must balance affordability against efficacy.
- There are large financial costs to approve and install the APCD infrastructure required to significantly reduce emissions such as mercury in the next two decades. Many emerging regions are required to install multiple or complex control systems to reduce several pollutant species simultaneously. And whilst systems to achieve this have proven successful in regions such as Europe and North America, they do not necessarily "cut and paste" into regions which fire different coals in different plant configurations and with additional regional challenges (such as limited water availability, and lack of regional expertise).
- The cost of the control systems are significant and add to both the capital and running costs of the modified plant. Running cost increases largely result from reduction in plant output and for the purchase of consumables such as sorbents or filter maintenance. They also add to the challenge for early closure as they often extend the time needed to achieve the return on investment for the entire plant.
- Financial costs are also affected by the need for increased investment in renewable energy (including battery storage & transmission upgrades).

There are costs associated with running emission control technologies, including reducing the efficiency of the plant in conjunction with the marked constraint on flexible coal plant operation due to renewables penetration. Plants which flex to low load (at or below 60% of normal fuel use; or operate cycling, by turning off and on as required to meet demand) often shut off pollution control systems such as FGD as they do so to reduce the risk of damage from temperature and moisture changes.

7.1.3. Competing aims and challenges

Coal phase out and the installation of APCD will both accelerate emission reduction across coal fleets. However, these approaches are somewhat conflicting - why should countries invest in expensive APCD if the plant is to retire early?

Addressing emissions from the coal sector demands a nuanced approach that considers both global imperatives and country-specific challenges. Strategies such as coal phase-out have a realistic long-term outlook, whereas enhanced air pollution control offers pathways towards emissions reduction in the shorter term for countries which do not have sufficient energy security to consider an accelerated transition from fossil fuels. Both strategies require careful planning, international cooperation, and substantial investments to navigate the complexities of the energy transition effectively. As nations grapple with these challenges, concerted efforts are essential to achieve sustainable and just outcomes for both the environment and society.

For nations with growing populations and economies, changes to the energy sector must be strategic and pragmatic. Coal-phase out plans must consider the potential for stranded assets and for loss of investment in APCD. To avoid negative economic impact and to reassure nations that policy decisions are appropriately considered, strategies for a coal fleet should include both early retirement and APCD options but these should be determined on a coordinated plant-by-plant basis, whilst still considering the electricity generating fleet, and its ability to meet energy demands, as a whole.

7.2. Timeline, evolution and lessons learned from the project

Refinement and evolution of the project

Based on the considerations for future strategies discussed above, the selection criteria for future GEF projects/ programs included projections of a large reliance on coal-fired power in some regions in coming decades due to recent installations, or operation of ageing plants longer than their design lifetimes. The largest future emissions from the coal sector are predicted to come from China and India. Together with other identified focus countries, more than 90% of the share of global coal-fired power plant capacity is largely predicted to come from Asia. On that basis, several engagement activities were carried out to disseminate initial country-specific emissions forecasts, such as:

- Mercury Group of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 2023;
- International Centre for Sustainable Carbon (ICSC) meetings on coal power generation in Indonesia;

- an event in Delhi in June 2024 which included a workshop specifically targeted at future Indian developments in the coal sector, and a more general presentation on all the focus countries;
- presentations to online workshops in South Africa, Vietnam and Pakistan;
- a presentation to the Minamata Convention Effectiveness Evaluation Expert Group.

The insights gained from these engagement activities helped the project team identify key components among the focus countries, which is crucial for future projects aimed at achieving significant emissions mitigation in the coal sector. In the process, a series of country-specific reports was drafted (included as appendices to this summarising report), encompassing essential details such as:

- country profiles regarding coal-fired energy production,
- commitments to various UN Conventions,
- mercury emissions forecasts from the CFPP sector under different scenarios, and
- the potential for emissions mitigation through ongoing and planned energy development plans and policies.

In parallel, the project identified challenges in energy security and equity across the globe, which emerged from recent global events over the past four years, including decisions by some developed and developing countries to increase their reliance on fossil fuels. Related uncertainty regarding future emissions was further assessed and factored in the overall assessment and emission projections.

Project activities provided insights into the challenges inherent in future emissions estimations. Focus countries, mainly in Asia with developing economies, heavy coal reliance, and substantial mercury emissions, have been compiled for in-depth exploration to identify relevant stakeholders. Stakeholder engagement has benefited by links with the Global Mercury Partnership on Mercury from Coal Combustion and included a project inception workshop, project steering committee meetings, discussions with technical expert groups, and presentations of country profiles during international conferences, workshops, and implementing agency meetings. In 2023/24 as the project moved towards to completion, these activities were enhanced by participation in Minamata COP5 (Oct-Nov 2023), the International Conference on Mercury as a Global Pollutant (July 2024), and a UNEP Mercury from Coal Combustion Partnership Meeting in hybrid format in New Delhi in June 2024. In addition participation in the Minamata Convention Effectiveness Evaluation Expert Group (a 2 day UNEP Workshop on emissions and releases from industrial sectors in Cape Town in June 2024), and a UNEP SSFA on "Mercury emissions from Annex D sources: emission quantification and control and support for the Minamata Convention" which involved workshops for South Africa, Vietnam, and Pakistan (all focus countries for the current project) also helped refine understanding of focus country strategies, policies and challenges. In the latter two cases, these activities were directly attributable to the current GEF project but the learnings and engagement were very beneficial. A special in-person workshop with Indian stakeholders was also held in conjunction with the coal partnership meeting. This meeting had attendees from the Central Pollution Control Board, Uttar Pradesh Pollution Control Board, National Environmental Engineering Research Institute, The Energy and Resources Institute, Toxic Links, EPIC Asia, Shakti Sustainable Energy, Indian Institute of Technology Delhi, UNEP-India, UNEP Kazakhstan, Center for Study of Science, Technology and Policy, Federation of Indian Chambers of Commerce & Industry, RTI International, GIZ, Tata Power, Prayas Energy Group, and EPRI (USA) who contributed very useful discussion on Indian energy and power futures.

In this project valuable insights have been gathered into the current status of the eight focus countries' short-term energy development plans, their commitments towards various UN Conventions on climate action, and their efforts to control emissions from the coal sector. This knowledge was acquired through an extensive literature review and meticulous data sourcing. Furthermore, a specialized coal-fired power plant database containing various scenarios was created. It can be customized based on each country's capabilities to transition away from coal or enhance their emissions control technologies. The tool is being adapted to form a dashboard included in a webpage on the UNEP website (https://www.unep.org/globalmercurypartnership/Emissions-reduction-scenarios-from-coal-sector).

The project database serves as a powerful legacy tool to support decision-making processes and advise on appropriate strategies for emissions reduction in the coal sector for each focus country.

Refinement of national and regional focus

The estimates of predicted future mercury and POPs emissions from the coal sector are highly dependent on party's future energy strategies of the parties to the relevant UN conventions, most importantly including how quickly they will replace coal as a source of electricity and process heat with alternate sources. The predictions are also subject to significant uncertainties related to the lack of plant specific data on coal mercury content, installed air pollution control devices and their efficiency in removing mercury, changing capacity factors as renewables replace coal, and the early closure of plants which still have the potential to operate until or beyond their design lifetime. In the latter case, early closure in developing countries depends on sufficient enabling finance which is currently uncertain. For all these reasons, having countries endorse reduction potentials and scenarios is problematic.

Options for emissions reduction strategies in the coal sector have been evaluated for the focus countries. It is clear that these strategies will be of necessity complex and require holistic considerations of sometimes conflicting options. For example, in many focus countries there is no appetite for specific mercury reduction technologies or more stringent regulated emission limits. The emphasis tends to be on reducing the so-called priority pollutants emitted by coal combustion, namely fine particles and their precursors, oxides of nitrogen (NOx) and sulfur (SOx). Emissions of these pollutants lead to formation in the atmosphere of both primary and secondary fine particles which have demonstrable impacts on human health. Hence improved control technologies for these pollutants are being prioritised and these also have a co-benefit on mercury reduction. However, these measures have the potential unwelcome impact of reducing the overall efficiency of the power plants and thus increasing GHGs emissions as a function of electricity produced. It is essential to recognize that ongoing developments and improvements are being made by Parties to the Paris Agreement in their climate action commitments, and how these affect other pollutant reduction targets requires careful evaluation.

Given that the focus countries are primarily located in Southeast Asia, attention has been directed towards identifying at least three countries where high-impact projects can be developed. The largest emissions of mercury from the coal sector are estimated to come from India and China. Together emissions from these countries are estimated to contribute 50-60% of the mercury from coal fired power stations, and 70-80% of emissions from industrial boilers. In future years these proportions are predicted to increase even as total emissions decrease. Hence the largest reductions in emissions are dependent on what pathway these countries follow.

In China recent developments (see Section 4) reported previously and more extensively at ICMGP 2024, reveal that closure of older power stations and retrofit of improved air pollution control devices (APCDs) have already resulted in large reductions. China also has well developed plans for Clean Air Actions and GHGs reductions and it is unlikely that they would commit to additional projects specifically for mercury reduction.

In India our workshops in Delhi in June 2024 revealed that their focus is over-whelming in reducing the traditional pollutants emitted by power stations (fine particles, NOx, SOx) and there is no appetite for specific measures to control mercury. The reason for this is that the traditional pollutants from coal combustion make a large contribution to population exposure to fine particles with resultant impacts on population mortality and morbidity (see Section 4). Again, committing to mercury specific projects in the absence of other considerations (such as energy security and GHG emissions) appears unlikely.

Drawing valuable experiences and successful achievements from US State funded projects in Indonesia, the project team gained valuable lessons and methodologies for identifying projects that have the potential to make a substantial impact on emissions mitigation. Vietnam has expressed interest in similar studies in their rapidly growing industrial coal sector and have already applied for funding under the SIP scheme to better understand their current emissions. There is also potential in Pakistan which has announced plans to significantly expand their coal-fired fleet. By applying the knowledge and insights gained in Indonesia, similar projects can be implemented in these countries to contribute effectively towards reducing emissions and promoting sustainable practices in their coal sectors. This approach will foster collaboration and mutual learning among the focus countries and facilitate the adoption of best practices across the region.

Finally, our list of focus countries includes South Africa. In this case the future electricity supply stands in contrast to the Asian countries where recent construction of new plants has resulted in a relatively young fleet overall. In South Africa there are no plans for new plant and an ageing fleet. Hence there are possible opportunities to explore detailed studies to identify high emitting and possibly inefficient plants. Our recent meetings with Eskom, other industry and regulators revealed no plans for specific mercury emission limits, but rather a focus on the traditional pollutants.

The project has focused on estimating both country-specific and global potential reductions in CO_2 and mercury emissions from the coal-fired power plant sector. These estimates have been supported by various scenarios, considering business-as-usual, early retirement of coal power plant units, potential improvements to the existing coal fleet through the implementation of multi-pollutant control devices, and changes to the capacity factor (a measure of how often a plant is running at maximum power) of coal fired plants. As renewables replace coal generation it is expected that capacity factors will reduce. Although estimating emissions and forecasts for persistent organic pollutants (POPs) on a country-by-country basis is challenging due to limited information, the project acknowledges the co-benefits of multi-pollutant control technologies in reducing POPs emissions, and has made some estimates of the benefits of applying these technologies.

Global estimates of current and future POPs emissions from the coal sector have also been made, but it is likely that these are subject to large uncertainties. In addition, profiling the development and future plans of the coal-fired industrial boiler sector on a country-specific level has also posed challenges due to limited information for some of the focus countries. Nevertheless, the project has thoroughly reviewed this limitation in our project activities. Where available, technical reports and scientific literature on this topic for the focus countries have been included in the country specific reports (gathered in the appendices to this summarising report) to provide a comprehensive perspective.

2.2 In summary

Identification of the focus countries included in this project has been a first step in determining selection criteria for future projects. Our workshops in Delhi and other engagement activities recently have clarified countries priorities in control of GHGs and air pollutants. The two major pathways to reduce emissions of mercury and POPs from the coal sector are transitioning away from coal to other energy sources preferably renewables, and retrofitting existing power stations with improved air pollution control devices (APCDs). The energy transition can be achieved by the early closure of power stations or reductions in how often they operate at full capacity. These changes require large amounts of financing in developing countries. Current levels of funding (Powering Past Coal Alliance (PPCA); Accelerating Coal Transition Program (ACT; Climate Investment Funds); Energy Transition Mechanism (ETM; Asian Development Bank) Just Energy Transition Partnership (JETP; World Bank) are problematic to achieve a rapid transition in countries still highly dependent on coal. A potential technical-economic project on how this transition may be achieved could assist in making clear this challenge. What is clear is that the exit from coal has the highest potential to make major reductions in mercury. The other pathway, retrofitting of existing plants, also has challenges. Our discussions with stakeholders in India, South Africa, Vietnam and elsewhere revealed that their highest priority is on reducing population exposure to fine particles; there is effectively no appetite for specific mercury control technologies or more stringent mercury emission targets. Instead controls on the major power station pollutants (fine particles, and their atmospheric precursors, oxides of nitrogen (NOx) and sulfur (SOx) would have a co-benefit for mercury reduction. A downside to this approach is that retrofit of APCDs usually reduces efficiency in power stations and will thus increase GHG emissions.

Finally, it is important to emphasize the largest reductions in mercury emissions from the coal sector are dominated by what actions are taken in China and India. It is clear that China's Clean Air Action from 2013 has already resulted in major reductions in mercury emissions not just from the coal sector but more broadly. In the case of the coal sector a program of plant closure, retrofit and other measures is well established, and hence they are probably unlikely to be candidates for future GEF projects.

Some level of identification and selection has already occurred through past and ongoing activities, primarily focused on India, Indonesia, Vietnam, and the Philippines. Drawing on the results and outcomes of US State funded projects in Indonesia and India, similar projects to comprehensively assess the coal fleets in Vietnam and South Africa are possible to identify high emitting plants (candidates for early closure or retrofit) and management options as plants begin to accommodate the entrance of more renewables into the grid. Discussions have been held with these countries on possible projects and Vietnam has already sought SIP funding to improve its understanding of the country's emission inventory. Pakistan and Bangladesh have also indicated plans to increase electricity from coal-fired power stations, but security reasons may be challenging in those cases. As part of the selection criteria process, the project team can provide some guidance on additional elements that can be added to the existing BAT/BEP guidance. This will involve identifying treatment and management options that are most feasible and effective for each focus country's unique circumstances.

8. Future program/project recommendations – the way ahead

Future initiatives aimed at promoting policy guidance in emissions reduction, must focus on several key areas.

Financing Mechanisms for Coal Phase-Out

Existing mechanisms such as the Joint European Transition Programme (JETP), Emissions Trading Mechanisms (ETM), and initiatives led by institutions like the World Bank play vital roles in determining energy sector developments. However, their impacts warrant scrutiny, and improvements are necessary. In the past, international funding agencies would provide loans or grants to developing countries for them to build new power plants, on the guarantee that they would meet minimum performance criteria in terms of high efficiency and low emissions. However, within the last 10 years, virtually all these funds have been withdrawn and most if not all large international banks, with green credentials, will no longer fund coal plants or even any retrofits which could be argued to extend the life of a coal plant. This approach aims to stop all new coal build and thus remove coal from the energy mix. However, this is not what is happening in practice. Rather countries such as Indonesia have recently sought funding for new coal plants from other regions such as China, often buying the cheapest option. This has resulted in many of the new plants in Indonesia being below current standards with respect to efficiency and emission control. The withdrawal of funding has therefore achieved the opposite to what was intended – rather than fewer coal plants in Indonesia, there are now more plants, many of which are emitting more emissions because they are low cost and of potentially lower quality.

Another example of how a financial mechanism may not achieve the best results is also from Indonesia. JETP funding has been announced for early retirement of the Cirebon coal plant. This plant was identified in the USDOS study carried out by the ICSC as the most polluting plant in the Indonesia coal fleet due to the fact that it runs at high capacity, has no control systems installed for SO_2, NOx or mercury and has several decades left to run before its scheduled retirement. The JETP project aims to encourage Cirebon to retire 10-15 years early by funding the building of new renewable energy and storage capacity to offset Cirebon's output. However, this now means that Cirebon, the most polluting plant, may avoid installing APCD for emission reduction, since it is on a retirement path. This locks in emissions from this plant for 10-15 more years. Further, since Indonesia is a growing economy, it is likely that it will still need baseload power in 10-15 years and if Cirebon continues to provide cheap dispatchable baseload power (which it will do as it is likely to remain cheaper with respect to other coal plants since it is not covering APCD costs), it is quite feasible for the country to argue that keeping Cirebon running is vital to the national grid. Finally, the JETP funding for the potential retirement of Cirebon is a loan, not a grant. The Indonesian government is hesitant to accept this offer since it simply adds to the country's already significant national debt[38].

[38] https://www.sustainable-carbon.org/report/prospects-for-mercury-emission-reduction-project-finance-in-indonesia/

It is therefore imperative to evaluate the effectiveness of financial mechanisms when facilitating coal phase-out and explore avenues for enhancement, possibly by increasing accessibility to funding (grants rather than loans) or streamlining application processes.

Improved Emission Standards/Norms:

Challenges persist in the adoption of stringent emission norms due to the time taken for policy formulation and implementation. Europe and North America began to introduce emission limits for PM in the mid-20th century and then emission limits for SO_2, NOx and mercury were introduced and tightened slowly over the following decades. Countries such as those in emerging Asia are now being expected to adopt standards of similar stringency to those in western regions over a significantly shorter period of time. This accelerated uptake of emission control is expected in nations which have little or no experience in these control technologies, no national experts or suppliers of equipment and little or no help with strategic implementation. A further, and often significant, factor to be considered is that the majority of APCD systems have been developed to work with coals used in western economies, on plants designed for western economies, and in regions which have ready access to important commodities, not least water, which may be significantly less available in emerging regions.

In many of these countries, affordable power is already limited. Adding APCD requirements pushes up the costs of electricity production and in some cases, such as FGD or mercury sorbent addition, may create new waste streams which may incur additional disposal costs.

Although somewhat specific to certain APCD systems, is the creation of new hazardous waste streams. For instance, replacing emissions reduced in flue gas with releases from air pollution control waste products could offset environmental gains – specifically, careful evaluation of seawater flue gas desulfurization is crucial, considering potential mercury release into seawater and its impact on coastal ecosystems. This is now the focus of a new USDOS project being carried out by EPRI. The concern raised over the potential new source of mercury emissions to local seawater and fishing regions is now also being built into the effectiveness evaluation work of the Minamata Convention and into future considerations of cross-sectoral movement of mercury. Full chain-of-custody for mercury is vital to ensure that reduction in mercury release in one form does not lead to increased mercury release in another.

The environmental effects of PM, SO_2 and NOx have been recognised for decades and so the control technologies are readily available and commonly over 90% effective. For mercury the concern is somewhat newer and the challenge more plant specific. There is no single best option for mercury control. During the USDOS study in Indonesia and India it was clear that many plants are not yet ready to build mercury into their compliance strategies, not least because they have only recently been made aware of the concern and do not yet have a reliable means to determine the importance of the issue in their own plants. Mercury emissions are highly variable – some plants may capture almost all emissions relatively easily through co-benefit effects whilst others may face having to install expensive mercury-specific control technologies to reduce emissions. However, in order to determine the situation for each plant there must be a significant investigation into the behaviour of mercury through the plant. This requires expensive measurements which can only be made using expensive methods operated by experts. Most plants in these emerging regions cannot easily determine whether mercury control is an important issue for their plant and will be unwilling to assume that expensive controls are required until told otherwise. Mercury emissions will therefore not be addressed for years unless they are incorporated within multipollutant control strategies.

Recognizing emissions as a global issue underscores the importance of implementing norms that address cumulative emissions rather than focusing solely on localized "hotspots" near coal plants. India has faced significant challenges in recent years in forcing power plants to meet emission norms (Sloss *et al.* 2023). Tightened emission limits were introduced in 2015 and yet, almost 10 years later, fewer than 10% of the fleet are in compliance[39]. Plants continue to derogate against the new standards by arguing on affordability of the APCD systems required. Although there is a reported acceleration of APCD installation across the fleet, demonstrated by the number of tenders and contracts in process, there is now a potential bottle-neck of availability of equipment, materials and experts which could slow down installation even further. And as the legislative timeline continues to drift off track, plants are now arguing that APCD is no longer financially viable due to the threat of enforced early plant retirement.

The Indian government is more than aware of the importance of reducing emissions from the coal fleet and now, in addition to the new norms, has required that all large plants co-fire biomass. At the same time, most plants are now required to flex their output to help the uptake of renewable energy onto the grid. Most plants in India must be available to flex to 50% load when required – significantly lower than any other fleet in the world. Combine this with biomass co-firing, APCD installation, and potential early closure and it is understandable that utility operators in India are hesitant to make any significant investment into their coal plants, even, in some cases, for general maintenance. As a result, the fleet efficiency and performance are declining and emissions are rising[39].

Industrial Sector

There is a pressing need to increase focus on emissions reduction within the industry sector, given its high demand for minerals essential for renewable energy production. Captive Coal-Fired Power Plants (CFPPs) within industries tend to have higher emissions than utility plants since they tend to be smaller (less efficient) and generally face emission limits which are significantly more lenient. Ironically, as pressure mounts for the closure of large coal plants under fossil fuel phase-out goals, the reliance on captive plants increases. The same is true for the increase of renewable energy on the grid – the demand for fast, dispatchable power to replace electricity loss when weather conditions do not support renewable energy production increases the importance and profitability of captive plants. Even in countries such as the UK, as coal is removed from the grid, captive plants become profitable as back-up energy sources and this is even leading to an increase in small industrial engines, often gas or even diesel powered, to provide emergency dispatch. These smaller captive power sources are significantly more polluting than large coal-fired plants.

One of the most important considerations for industrial coal units is that, in addition to generally being more polluting than larger utility plants, they are often sited in industrial areas in or near to the population, thus creating local pollution hotspots. Ideally, industrial processes should move away from incorporating captive coal units to using alternative energy sources or to working directly from the grid. However, unless this grid power actually comes from renewable sources, the extra capacity required to meet the now increased demand from the grid will simply increase the reliance on baseload coal.

Gender Considerations in Project Development and Policy Guidance

Integrating gender considerations into future projects and policy guidance is paramount. A separate report detailing gender-specific impacts and considerations should be referred to ensure inclusivity

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[39] https://www.sustainable-carbon.org/report/accelerating-emission-control-at-coal-fired-power-plants-in-india/

and equity in decision-making processes. Gender-sensitive approaches can enhance the effectiveness and sustainability of emissions reduction initiatives by addressing the diverse needs and perspectives of all stakeholders.

9. Follow on initiative proposal

This current project has demonstrated that, despite the potential peak of coal use in the next 5 years, emissions from the coal sector will continue for decades. This is particularly true for countries such as China, Indonesia and Vietnam whose coal fleets are young and have decades of planned operation ahead. Accelerating coal fleet closure is part of the Paris commitment for many countries and is vital to the aims of the convention.

An additional concern for all future emission projections, including those produced by the IEA, is that they are based on a small number of emission factors. For CO_2, there is commonly one emission factor used across a whole national coal fleet. In the IEA's guidance on methodologies for estimating CO_2 emission factors for national coal fleets, the document acknowledges "*the available data for the year Y only include the breakdown of electricity generated by fuel, but not the fuel input to the plant. The assumption is that there was no change in the efficiency of the plants and in the energy content of the input products compared to the year Y-1*". This means that coal plants are assumed to run continually at the same efficiency, regardless of how they are used. These assumptions do not hold true for coal plants in high-dependent coal regions such as India due to operational challenges relating to flexing and cycling to facilitate increased renewable capacity on the grid.

Most existing coal utility plants were designed to operate at baseload and achieve their highest efficiencies when doing so. However, when coal plants age, or when they are operated in flexing and cycling modes (dispatching power to balance supply and demand on national grids which are obliged to prioritize input from variable renewable energy sources) the average plant efficiency can decrease significantly, as shown in Figure 35.

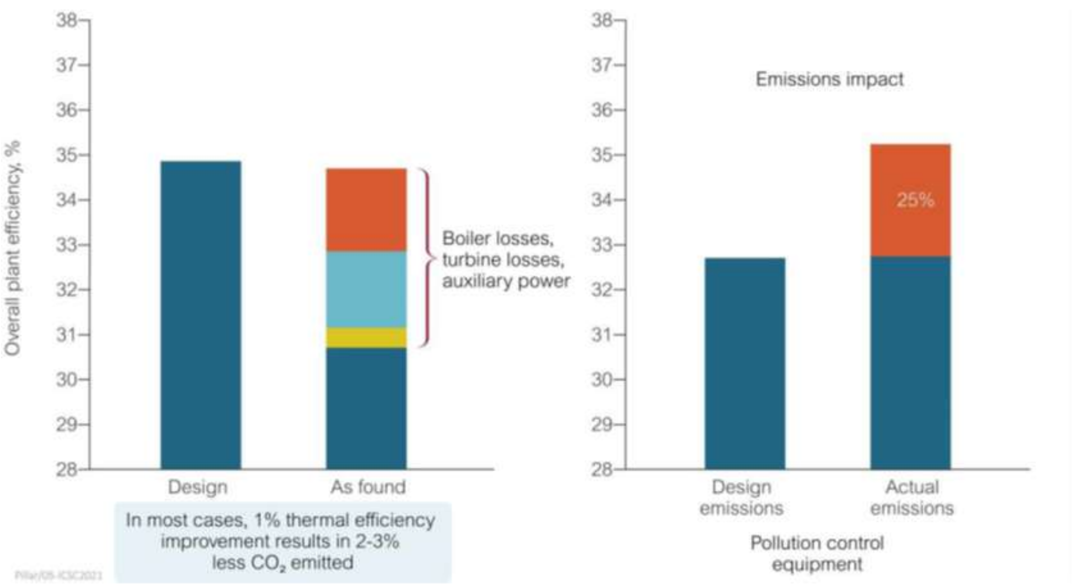

Figure 35 Potential increases in emissions due to changes in plant performance

Whilst these data are somewhat assumptive, any plant which is not operating as designed will result in increased emissions, potentially significantly so. As the existing coal fleet in countries such as India continues to operate, the emission intensity of these units is likely to increase for several reasons:

- plants in India are already required to flex to 50% load or lower to maintain grid capacity as the proportion of renewable energy increases – flexing plants face significantly more operation and maintenance issues and lower average efficiency
- plants are required to cycle more frequently – cycling plants face significantly more operation and maintenance issues and lower average efficiency
- plants are requested to start co-firing biomass with coal. Whilst the replacement of coal with biomass will reduce the new CO_2 emissions from the plant, the reduction in plant efficiency due to the lower efficiency of biomass combustion will likely also reduce the overall efficiency of the coal being combusted in the same boiler, thus potentially increasing the CO_2 emissions from the coal being fired
- plants are required to install APCD such as flue gas desulphurization (FGD) to reduce emissions of SO_2. FGD systems may require several % of the plant output to run, reducing plant output and increasing the CO2/kWh

Future emissions from coal are therefore likely underestimated in terms of many tonnes of mercury and many mega tonnes of CO_2.

Improving coal plant performance is a win-win approach – more power is produced from less coal, facilitating the reduction of all pollutants whilst ensuring the existing coal fleets perform efficiently during their remaining operational years acting as the necessary bridge to cleaner energy solutions.

In addition to the potential to reduce emissions through plant performance improvement, there is also the potential to operate coal fleets strategically to reduce total sectoral emissions. This can include strategies such as prioritized retirement of less efficient units first, or through coordination of dispatch orders to maximize the production of power from plants most prepared to provide clean power when it is needed (minimizing coal starts).

Proposed project summary

The proposed follow-up project aims to address the operation of coal fleets with the aim of strategic management to accelerate emission reduction. The project will not require the installation of control technologies but rather will address the operation of the existing fleet. The project would work with target regions to promote best practice in coal use in utility fleets as they transition towards retirement. The initiative would:

- Highlight the vulnerability of current coal assets to producing excess emissions (above current estimates)
- Educate stakeholders on operating practices to mitigate and minimize vulnerability to producing excess emissions
- Provide training and capacity for best practice in clean coal operation (full balance of plant)
- Provide free models and tools for plant operators to provide guidance on optimal operation, especially during flexing and cycling operation
- Enable plant-by-plant analyses of performance to prioritize early closure of the dirtiest plants
- Provide guidance to utility companies and government utilities on how to create a dispatch priority system to ensure maximization of total fleet operation on a real-time basis
- Provide guidance on plant closure and repurposing
- Provide Just Energy Transition guidance for affected staff and communities

Expected outcomes

The aim of the project is to work with governments and utilities to strategize coal plant use on the glide path to complete closure of the existing coal fleet.

The proposed project will demonstrate performance and efficiency improvements at real plants, quantifying the expected reduction in emissions over the remaining plant lifetime.

Back-of-the-envelope calculations suggest that improving the efficiency of a 500 MWe coal utility plant in SE Asia could reduce the potential emissions of CO_2 by 100,000 t/y saving $125,000 in fuel costs. For a country such as Vietnam with a 30 GW coal fleet, this would mean a reduction of 3 Mt/y CO_2 and a fleet fuel saving of $3-4 million. If this fleet runs for 10 years to retirement, efficiency improvements could lead to a reduction in total CO_2 emissions of 30 Mt. In addition, emissions of SO_2, NOx, PM and $PM_{2.5}$ particulates would also be reduced in terms of thousands of t/y, even without the retrofitting of flue gas emission controls. For mercury, the emission reduction could be at least 4 kg/y per 500 MWe plant, 240 kg/y for a 30 GW coal fleet and a total of over 2 t mercury avoided if the fleet continues to operate for 10 years.

These are conservative estimates – the real value will be greater for countries such as India where the potential to increase plant performance is higher.

The project would follow a pre-determined path through fleet evaluation and analysis in order to strategically coordinate plant upgrade, retrofitting, repurposing and/or closure. Each coal unit within each fleet would follow a planned strategy to reduce emissions as effectively as possible through a planned path to closure. This would involve:

- Dataset analyses and ranking of national coal fleets to identify plants of concern and prioritize action, such as early retirement.
- Application of integrated energy-economic-environmental models to comprehensively assess environmental and economic outcomes of integrated climate, air pollution and mercury policies. These models can estimate the health benefits of an integrated approach, through a reduction in population exposure to fine particulate pollution.
- Fleet analysis and guidance on real-time strategies to coordinate dispatch of power across the fleet.
- Guidance on Just Energy Transition considerations such as plant retirement strategies, including repurposing of plants to alternative energy sources, and reemployment of staff. This would include promotion of coal plant "hybridization" – the movement of conventional coal plants through various emission reduction strategies (co-firing, energy storage and hybrid operation) to maintain grid output on the path to repurposing or closure. Provide focus on gender and minority considerations as part of this process.
- Support for implementing of obligations under the Minamata Convention, the Paris Convention, and other international treaties in terms of effective policy and application of relevant BAT/BEP

This initiative, tentatively entitled "Glide Path" has been developed into a full project proposal for GEF funding.

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10. References

AMAP/UNEP (2019). Technical Background Report for the Global Mercury Assessment 2018., viii + 426 pp including E-Annexespp. https://web.unep.org/globalmercurypartnership/global-mercury-assessment-2018

Ban, J., Cheng, J., Zhang, C., Lu, K., Zhou, Z., Liu, Z., Chen, Y., Wang, C., Cai, W., Gong, P., Luo, Y., Tong, D., Hu, J., Guo, X., Hao, J., Li, T., 2024. China's carbon-neutral policies will reduce short-term PM(2.5)-associated excess incidence of cardiovascular diseases. One Earth 7, 497-505.

Chatterjee, D., McDuffie, E. E., Smith, S. J., Bindle, L., van Donkelaar, A., Hammer, M. S., Venkataraman, C., Brauer, M., Martin, R. V., 2023. Source Contributions to Fine Particulate Matter and Attributable Mortality in India and the Surrounding Region. Environmental Science & Technology 57, 10263-10275.

Cheng, J., Tong, D., Liu, Y., Geng, G., Davis, S. J., He, K., Zhang, Q., 2023. A synergistic approach to air pollution control and carbon neutrality in China can avoid millions of premature deaths annually by 2060. One Earth 6, 978-989.

China State Council 2013. Action Plan on Prevention and Control of Air Pollution, China State Council, Beijing, China. Accessed 28th October, at

CNPC Economics & Technology Research Institute (CNPC ETRI) (2018). China Energy Outlook 2050, IEEJ, 58pp. https://eneken.ieej.or.jp/data/8192.pdf

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., Pope, C. A., III, Shin, H., Straif, K., Shaddick, G., Thomas, M., van Dingenen, R., van Donkelaar, A., Vos, T., Murray, C. J. L., Forouzanfar, M. H., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. The Lancet 389, 1907-1918.

Feng, X., Fu, X., Zhang, H., Wang, X., Jia, L., Zhang, L., Lin, C. J., Huang, J. H., Liu, K., Wang, S., 2024. Combating air pollution significantly reduced air mercury concentrations in China. Natl Sci Rev 11, nwae264.

Fisher, S., Bellinger, D. C., Cropper, M. L., Kumar, P., Binagwaho, A., Koudenoukpo, J. B., Park, Y., Taghian, G., Landrigan, P. J., 2021. Air pollution and development in Africa: impacts on health, the economy, and human capital. Lancet Planet Health 5, e681-e688.

Geng, G., Liu, Y., Liu, Y., Liu, S., Cheng, J., Yan, L., Wu, N., Hu, H., Tong, D., Zheng, B., Yin, Z., He, K., Zhang, Q., 2024. Efficacy of China’s clean air actions to tackle PM2.5 pollution between 2013 and 2020. Nature Geoscience 17, 987-994.

IEA (2021a). Net Zero by 2050. Paris, International Energy Agency, 224pp. https://www.iea.org/reports/net-zero-by-2050

IEA (2021b). World Energy Outlook 2021. Paris, International Energy Agency, 386pp. https://www.iea.org/reports/world-energy-outlook-2021

IEA (2023). World Energy Outlook 2023, 355pp. https://www.iea.org/reports/world-energy-outlook-2023

https://iea.blob.core.windows.net/assets/86ede39e-4436-42d7-ba2a-edf61467e070/WorldEnergyOutlook2023.pdf

India State-Level Disease Burden Initiative Air Pollution, C., 2021. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. Lancet Planet Health 5, e25-e38.

Jones, K. C., 2021. Persistent Organic Pollutants (POPs) and Related Chemicals in the Global Environment: Some Personal Reflections. Environmental Science & Technology 55, 9400-9412.

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V., McTeer, M. A., Murray, C. J. L., Ndahimananjara, J. D., Perera, F., Potočnik, J., Preker, A. S., Ramesh, J., Rockström, J., Salinas, C., Samson, L. D., Sandilya, K., Sly, P. D., Smith, K. R., Steiner, A., Stewart, R. B., Suk, W. A., van Schayck, O. C. P., Yadama, G. N., Yumkella, K., Zhong, M., 2018. The Lancet Commission on pollution and health. The Lancet 391, 462-512.

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., Pozzer, A., 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525, 367-371.

Lemieux, P. M. 1998. Polychlorinated Dioxins and Furans: Sources, Emissions, Formation and Control. UNEP Regional Awareness Raising Workshop on POPs,. Puerto Iguazu, Argentina.

Liu, K., Wang, S., Wu, Q., Wang, L., Ma, Q., Zhang, L., Li, G., Tian, H., Duan, L., Hao, J., 2018. A Highly Resolved Mercury Emission Inventory of Chinese Coal-Fired Power Plants. Environmental Science & Technology.

Liu, K., Wu, Q., Wang, L., Wang, S., Liu, T., Ding, D., Tang, Y., Li, G., Tian, H., Duan, L., Wang, X., Fu, X., Feng, X., Hao, J., 2019. Measure-Specific Effectiveness of Air Pollution Control on China's Atmospheric Mercury Concentration and Deposition during 2013–2017. Environmental Science & Technology 53, 8938-8946.

Liu, K., Wu, Q., Wang, S., Ouyang, D., Li, Z., Ding, D., Li, G., Tang, Y., Xiang, L., Han, D., Wen, M., Liu, T., Duan, L., Tian, H., Hao, J., 2021. Highly Resolved Inventory of Mercury Release to Water from Anthropogenic Sources in China. Environmental Science & Technology 55, 13860-13868.

Liu, L., Wen, Z., Liu, S., Zhang, X., Liu, X., 2024. Decline in atmospheric nitrogen deposition in China between 2010 and 2020. Nature Geoscience 17, 733-736.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E., 2020. Environmental and Health Impacts of Air Pollution: A Review. Frontiers Public Health 8.

McDuffie, E., Martin, R., Yin, H., Brauer, M. (2021a). Global Burden of Disease from Major Air Pollution Sources (GBD MAPS): A Global Approach, 1-46pp.

McDuffie, E. E., Martin, R. V., Spadaro, J. V., Burnett, R., Smith, S. J., O'Rourke, P., Hammer, M. S., van Donkelaar, A., Bindle, L., Shah, V., Jaegle, L., Luo, G., Yu, F., Adeniran, J. A., Lin, J., Brauer, M., 2021b. Source sector and fuel contributions to ambient PM(2.5) and attributable mortality across multiple spatial scales. Nat Commun 12, 3594.

Ordonez, J. A., Vandyck, T., Keramidas, K., Garaffa, R., Weitzel, M., 2024. Just Energy Transition Partnerships and the future of coal. Nature Climate Change 14, 1026-1029.

Pan, Y., Liu, X., Zhou, Z., Guo, Y., Feng, Z., Wang, S., Wu, Q., Ouyang, D., Xie, Y., Wu, K., Xu, S., Guo, C., Welsch, E., Huang, C., Li, J., 2024. Carbon neutrality and clean air acts can enable China to meet the Minamata Convention goals with substantial cost savings. One Earth 7, 483-496.

Parapat, J., Hasan, K. (2023). Emerging captive coal power: Dark clouds on Indonesia's clean energy horizon, Center for Research on Energy and Clean Air, 24pp. https://energyandcleanair.org/wp/wp-content/uploads/2023/10/CREA_GEM-Indonesia-Captive-Briefing_EN_09.2023.pdf

Qin, Y., Zhou, M., Hao, Y., Huang, X., Tong, D., Huang, L., Zhang, C., Cheng, J., Gu, W., Wang, L., He, X., Zhou, D., Chen, Q., Ding, A., Zhu, T., 2024. Amplified positive effects on air quality, health, and renewable energy under China's carbon neutral target. Nature Geoscience 17, 411-418.

Sino German Energy Transition Project (2021). China Energy Transition Status Report 2021, Commissioned by the German Federal Ministry for Economic Affairs and Energy, 28pp. https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2021/China_Energy_Transition_Status_Report_2021.pdf

Sloss, L., Kanchan, S. K., Jozewick, W. (2023). Accelerating emission reductions at coal-fired power plants in India, International Centre for Sustainable Carbon, 68pp. https://www.sustainable-carbon.org/report/accelerating-emission-control-at-coal-fired-power-plants-in-india/

Sloss, l., Smith, I. M. (2001). Organic compounds from coal utilisation, IEA Coal Research, 60pp.

Taghizadeh-Hesary, F., Taghizadeh-Hesary, F., 2020. The Impacts of Air Pollution on Health and Economy in Southeast Asia. Energies 13.

UNEP (2013). Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs under Article 5 of the Stockholm Convention, UN Environment, 445pp. http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-TOOLKIT-TOOLK-PCDD-PCDF-2012.En.pdf

UNEP (2019a). Guidance on best available techniques and best environmental practices. Minamata Convention on Mercury. Geneva, Switzerland, Secretariat of the Minamata Convention on Mercury, 193pp. http://mercuryconvention.org/Portals/11/documents/publications/BAT_BEP_E_interractif.pdf

UNEP (2019b). Stockholm Convention on Persistant organic pollutants, pp.

UNEP (2023). Emissions Gap Report 2023 – Temperatures hit new highs, yet world fails to cut emissions (again). Nairobi, United Nations Environment Program, 108pp. https://doi.org/10.59117/20.500.11822/43922

Van Remmen, T., 1998. Evaluation of the available air pollution control technologies for achievement of the MACT requirements in the newly implemented new source performance standards (NSPS) and emission guidelines (EG) for hospital and medical/infectious waste incinerators. Waste Management 18, 393-402.

World Energy Council (2024). WORLD ENERGY TRILEMMA 2024: EVOLVING WITH RESILIENCE AND JUSTICE, pp. https://trilemma.worldenergy.org/reports/main/2023/World%20Energy%20Trilemma%20Index%202024.pdf

Yin, P., Brauer, M., Cohen, A. J., Wang, H., Li, J., Burnett, R. T., Stanaway, J. D., Causey, K., Larson, S., Godwin, W., Frostad, J., Marks, A., Wang, L., Zhou, M., Murray, C. J. L., 2020. The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990-2017: an analysis for the Global Burden of Disease Study 2017. Lancet Planet Health 4, e386-e398.

Zheng, B., Tong, D., Li, M., Liu, F., Hong, C., Geng, G., Li, H., Li, X., Peng, L., Qi, J., Yan, L., Zhang, Y., Zhao, H., Zheng, Y., He, K., Zhang, Q., 2018. Trends in China's anthropogenic emissions since 2010 as the consequence of clean air actions. Atmos. Chem. Phys. 18, 14095-14111.

Zivin, J. G., Neidell, M., 2012. The Impact of Pollution on Worker Productivity. Am Econ Rev 102, 3652-3673.