Original Research Article

ISEE ENVIRONMENTAL EPIDEMIOLOGY

OPEN

Increased mortality from a two-year delay in Mercury and Air Toxics Standards (MATS) emission-reductions of filterable $PM_{2.5}$ at specific coal-fired power plants in the United States

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Background: In 2024, the US Environmental Protection Agency tightened the Mercury and Air Toxics Standards (MATS) for emissions of filterable particulate matter (fPM) from coal-fired power plants to 0.010 lb/MMBtu. In April 2025, a presidential proclamation stated that 47 specific power plant companies received a 2-year exemption from the new requirements. The proclamation provided no estimates of the resulting health impacts.

Methods: Our approach applies conventional risk-assessment calculations for mortality from inhalation of filterable $PM_{2.5}$ ($fPM_{2.5}$) emissions, for "with" versus "without" the exemption, across four steps: (1) calculate $fPM_{2.5}$ emissions, based on government databases; (2) calculate the change in ambient $PM_{2.5}$ concentrations, using the Intervention Model for Air Pollution (InMAP) source-receptor matrix (ISRM); (3) calculate mortality impacts from inhalation of $PM_{2.5}$, using the Orellano et al., 2024 concentration-response function (CRF; relative risk (RR) per 10 μg/m^3: 1.095, 95% confidence interval (CI) = 1.064, 1.127; in sensitivity analyses, we employ other CRFs); (4) aggregate results (e.g., by US state).

Results: Most (83%) of the exempted power plant facilities already have sufficient control technology installed that they operate below the new MATS limit, indicating that much of that fleet already adopted cleaner technologies. For the remaining 17% of facilities, the proclamation will increase total $fPM_{2.5}$ emissions to ~6,900 tons, from ~4,400 tons. We estimate that the additional ~2,500 tons emitted will lead to 32 (95% CI = 22, 43) deaths. The highest mortality is in St. Louis, Missouri, (population: 2.2 million) with an estimated 14 (95% CI = 10,19) deaths. The increased mortality is, for some states (e.g., Missouri, and Pennsylvania), caused by mostly in-state emissions; for other states (e.g., Illinois, Maryland, New Jersey, and Virginia), the cause is out-of-state emissions.

Discussion: Results here quantify a portion of the health impacts but leave unquantified nonmortality impacts, impacts from hazardous air pollutant (HAP) exposures, and noninhalation pathways. The reduced computational demands of the air pollution model employed here allows for more timely investigation of government actions than would traditional air dispersion modeling. Sensitivity analyses yielded mortality results that ranged from 47% lower to 169% higher than the core findings.

Conclusions: We estimate that a 2-year delay in MATS emission reductions of $fPM_{2.5}$ at the exempted coal-fired power plants will lead to 32 (95% CI = 22, 43) additional deaths.

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This paper was submitted on behalf of the Environmental Health Policy Committee of the North American Chapter of the International Society of Environmental Epidemiology.

Data and code required to replicate the core results reported in this article are available at GitHub: https://github.com/bujinb/MATS. The ISRM dataset is available at Zenodo: https://doi.org/10.5281/zenodo.2589760. Additional data, and PDF versions of the EPA reports: https://drive.google.com/drive/folders/1lx8usGk3t1KDrybdvFOGgejo208I1bih.

SDC *Supplemental digital content is available through direct URL citations in the HTML and PDF versions of this article (www.environepidem.com).*

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Environmental Epidemiology (2025) 9:e422

Received: 17 July 2025; Accepted 26 August 2025

Published online 7 October 2025

DOI: 10.1097/EE9.0000000000000422

Background

Health gains from environmental regulations occur only when standards are implemented and enforced. While rulemakings by federal agencies often receive significant attention during the regulatory process, realizing the potential benefits of these actions relies on decisions made at the implementation stage, which typically receives far less scrutiny.

In 2024, the US Environmental Protection Agency (EPA) revised the Mercury and Air Toxics Standards (MATS) for coal-fired power plants (electric generating units [EGUs]).[1] The update included a more stringent filterable particulate matter (fPM) emissions limit of 0.010 lb/MMBtu, using fPM as a surrogate for hazardous air pollutants (HAPs) such as lead, arsenic, chromium, nickel, and cadmium. The rule also required compliance to be demonstrated through continuous emissions monitoring systems (CEMS) instead of quarterly stack testing.

What this study adds

An April 2025 presidential proclamation gave 47 power plant companies a 2-year exemption from new emission requirements. Our study estimates the increase in $PM_{2.5}$-attributable mortality that will result from this proclamation. In some states, the increased mortality is caused mainly by in-state emissions; in other states, the cause is out-of-state emissions.

In April 2025, a presidential proclamation titled "Regulatory Relief for Certain Stationary Sources to Promote American Energy" exempted 159 coal-fired units at 47 power plant companies from compliance with the updated MATS standards for a 2-year period, from July 2027 to July 2029.[2] The stated rationale was that the required technology "does not exist in a commercially viable form," and that enforcing the rule could lead to plant closures significant enough to threaten national security interests.

No supporting technical or health analysis accompanied the exemption proclamation, despite longstanding evidence of the health risks associated with emissions from coal-fired power plants.[3,4] As a result, the public and relevant policymakers lack a clear understanding of the expected health consequences of this delay. This paper addresses part of that gap by providing quantitative estimates of excess mortality associated with increased inhalation of fine PM emissions during the exemption period.

Methods

As described next, our approach involves four key steps, each of which is common and standard in risk-assessment calculations: (1) obtain estimated $fPM_{2.5}$ emissions with and without the action being studied (here, the compliance extensions); (2) model the difference in attributable $PM_{2.5}$ concentrations between the two scenarios; (3) calculate the resulting difference in attributable mortality; and (4) spatially aggregate the results (e.g., by US state). These steps are applied specifically to the 47 companies granted compliance extensions, and specifically for $fPM_{2.5}$, which is the focus of MATS. Separately, as a side comparison, we collected emissions data from all US power plants; the purpose is to compare the distribution of emissions from the compliance-extension plants with those of the national power plant fleet.

Emissions

Unit-level annual heat input and $fPM_{2.5}$ emission rates were compiled using the following data sources (listed in order of priority):

1. Attachment 1 of EPA Docket No. EPA-HQ-OAR-2018-0794-6919:[5] Provided average fPM emission rates and annual-average heat input for 126 units. Of the 126 units, 123 units had data directly; for the remaining three units, the average rate from other units at the same plant was used. We calculated the fPM-to-$fPM_{2.5}$ ratio based on the ratio of reduction cost-effectiveness values. If this ratio was unavailable, we used the average ratio from units with complete data.
2. Appendix A of EPA Docket No. EPA-HQ-OAR-2018-0794:[6] Provided emission rates for two units. Annual heat inputs for these units are from the Emissions & Generation Resource Integrated Database (eGRID) (see next).
3. EPA eGRID (2018–2021) and 2017 national emissions inventory:[7,8] Provided total $PM_{2.5}$ emission rates and annual heat input data for 31 units. $fPM_{2.5}$ rates were estimated using national emissions inventory-derived emission ratio of $fPM_{2.5}$ to total $PM_{2.5}$. For annual heat input at each unit, we use the median annual value for 2018–2021.

Our calculations focus specifically on $fPM_{2.5}$. As mentioned above, we use available data (i.e., the fPM-to-$fPM_{2.5}$ ratio) to bridge between the MATS limit (0.01 lb/MMBtu, for fPM) and our analysis (i.e., $fPM_{2.5}$). We do not include condensable $PM_{2.5}$ or secondary $PM_{2.5}$ (e.g., particles formed from gaseous precursors such as NO_x), since these are not regulated under MATS and are outside the scope of this analysis. For fossil power plants, filterable PM typically represents only a small portion of total $PM_{2.5}$ emissions.[9–13]

Matched stack-height information was taken from eGRID; for units without stack-height data, an average value was assumed. Because future heat input and emissions for the compliance exemption period (2027–2029) are presently unknown, we estimated each plant's "expected" annual emissions during that 2-year period based on the datasets mentioned above.

MATS applies to coal- and oil-fired power plants. However, none of the exempted power plants are oil-fired, all are coal-fired (or, in a small number of cases, natural gas-fired; emission factors for those plants are below the MATS standard).

The "without MATS" $fPM_{2.5}$ emissions employed here are unadjusted ("as-is") emission rates (Tables S1 and S2; https://links.lww.com/EE/A377). "With MATS" $fPM_{2.5}$ emissions employed here are identical to "without MATS" for plants with fPM emission rate equal to or less than 0.01 lb/MMBtu. For all remaining plants (i.e., plants with fPM emission rate greater than 0.01 lb/MMBtu), for "with MATS" simulations, we replace the actual fPM emission rate with the value 0.01 lb/MMBtu. We then calculated expected annual emissions under MATS by multiplying the adjusted fPM rate by each plant's median annual heat input (2018–2021) and applying plant-specific fPM-to-$fPM_{2.5}$ ratios. This approach ensures that while the compliance threshold is based on total fPM, our analysis focuses specifically on the $fPM_{2.5}$ fraction most relevant for health impacts.

Concentrations

Using the Intervention Model for Air Pollution (InMAP) Source-Receptor Matrix (ISRM), we estimate changes in annual-average ambient $PM_{2.5}$ concentrations resulting from modeled $fPM_{2.5}$ emission changes. The ISRM reflects a widely used reduced-complexity air quality model (InMAP) that provides, with relatively low computational demand, spatially resolved estimates of pollution concentrations and health outcomes from emissions scenarios.[14–21] The ISRM spatially covers the 48 contiguous US states, and so cannot be applied to Alaska or Hawaii. The ISRM employs a variable-resolution grid ranging from 1 km in densely populated areas to 48 km in rural/remote regions.

Reported model performance for InMAP indicates a population-weighted mean bias of—3.1 μg/m³ and a mean fractional bias (MFB) of—38% against observations, and R^2 = 0.90, MFB = –17% against WRF-Chem. Previous research indicates that InMAP meets published performance criteria but tends to underpredict $PM_{2.5}$ concentrations.[14] Consequently, results here may underestimate the true concentration and health impacts.

Mortality: Spatial Aggregation

To estimate health impacts, we used county-level population and all-cause mortality rates from the US Centers for Disease Control and Prevention (CDC) and urban area classifications from the US Census Bureau.[22–24] $PM_{2.5}$-attributable mortality was calculated using the log-linear concentration-response function (CRF) from a recent systematic review and meta-analysis by Orellano et al[25], 2024 (RR = 1.095 [95% confidence interval (CI) = 1.064, 1.127]). That study represents the most recent systematic review available. Its CRF is similar to values reported in an earlier meta-analysis by Pope et al[26], 2020 (HR = 1.09 [95% CI = 1.07, 1.11] all studies, HR = 1.08 [95% CI = 1.06, 1.11] select studies, HR = 1.08 [95% CI = 1.05, 1.11] select studies in North America).

We employ four additional CRFs as sensitivity analyses. First, Orellano et al[25] report pooled results stratified by World Health Organization (WHO) region; as a sensitivity analysis, we employ their CRF for the Region of the Americas (RR = 1.075 [95% CI = 1.055, 1.096]). The justification is that the results for the

Americas might be more applicable to exposures in the United States, though acknowledging that Orellano et al[25] reported that regional heterogeneity was not statistically significant. As two further sensitivity analyses, we use the two CRFs that were employed by the EPA in the regulatory impact analysis (RIA) for MATS: the CRF from Pope et al[26] (HR = 1.12 [95% CI = 1.08, 1.15]) and the CRF from Wu et al., 2020 (HR = 1.066 [95% CI = 1.058, 1.074]).[27–29] Wu et al[29] studied Medicare enrollees, so their CRF is for older adults (aged ≥65 years). The justification for including these two CRFs as sensitivity analyses is to compare against the regulatory approach used for MATS. As described in the MATS RIA, both studies have several important strengths.[30] For example, the Pope et al[26] cohort is representative of the US population, especially with respect to the distribution of individuals by race, ethnicity, income, and education; the Wu et al[29] cohort is 68.5 million Medicare enrollees, representing more than 20% of the US population.[28–30] Lastly, our fourth sensitivity analysis uses CRFs that Wu et al[29] report for the subgroup of people only exposed to annual-average $PM_{2.5}$ levels below 12 μg/m^3 (HR is reported as a range: 1.23 [95% CI = 1.18, 1.28] to 1.37 [95% CI = 1.34, 1.40]), which they refer to as "low exposure." The justification for this sensitivity analysis is that currently nearly everyone in the US meets that exposure level, so this subgroup result from Wu et al[29] may be more applicable than the main result.

To align with the respective study populations, for the two Orellano et al[25] CRFs and the Pope et al[28] CRF, we used population and mortality rates for individuals aged ≥18 years; for the Wu et al[29] CRFs, we restricted to individuals aged ≥65 years. In the results section, we aggregate mortality by urban area and state, distinguishing between deaths caused by in-state versus out-of-state emissions.

Results

Our input datasets generally reflect 159 units across 68 power plants in 23 states, associated with the 47 companies that were granted MATS compliance extensions in the Proclamation. One power plant (two combustion units) in Healy, Alaska, was excluded from our analyses because the ISRM is limited to the contiguous 48 US states; thus, results below are for 157 units at 67 power plants (46 companies) in 22 states.

Among the 157 units, 83% (131 units) already operate below the new MATS limit of 0.01 lb/MMBtu for fPM, indicating that a substantial portion of the exempt fleet has already adopted cleaner technologies. Health impact analyses below reflect the difference in emissions between "with" versus "without" MATS requirements; that emission difference is nonzero at the remaining 17% of units (26 units; 16 power plants).

Figure 1A displays the 67 power plant locations, with icon sizes proportional to each plant's total $fPM_{2.5}$ emissions under two scenarios: with and without MATS implementation. During the 2-year exemption period, total $fPM_{2.5}$ emissions from the 67 power plants are ~13,400 tons without MATS, ~10,900 tons with MATS (difference: ~2,500 tons). (Among just the 16 power plants with nonzero emission difference, total emissions are 6,900 tons without MATS and 4,400 tons with MATS.) Figure 1B illustrates the resulting increase in ambient $PM_{2.5}$ concentrations attributable to the additional $fPM_{2.5}$ emissions from the exemption (i.e., the Proclamation). Figure 1C shows the spatial distribution of attributable mortality, highlighting areas with the greatest health burden.

In total, the proclamation (i.e., converting from "with MATS" to "without MATS" for 2 years) results in 32 (95% CI = 22, 43) additional deaths. The highest absolute mortality is projected in St. Louis, Missouri, (population: 2.2 million), with an estimated 14 (95% CI = 10, 19) excess deaths. Figure 1 reveals that the mortality burdens can be spatially concentrated, as in St. Louis, or spatially more dispersed, as in Texas.

Our core result (32 additional deaths, attributable to 2,500 tons of $PM_{2.5}$ emitted) indicates an impact of 0.013 deaths per ton emitted. That result is broadly consistent with literature results on damages-per-ton for electricity generation. For example, Fann et al[31] reported, for $PM_{2.5}$ emissions from electricity generation (see their Figure 3), $130,000 in damages per ton, using a value of statistical life of $8.9 million; those values indicate ~0.015 deaths per ton emitted (a value within ~15% of our result). Conditions investigated are different here than in the prior paper; nevertheless, the consistency in damages-per-ton values increases confidence that the results here are realistic and are consistent with expected values.

Figure 2 shows the emissions and aggregated mortality by state, for in-state and out-of-state emissions. In total, six US States (Figure 2) experience >1 death in that state, attributable to the increased $PM_{2.5}$ burden. Several states, such as Illinois, Maryland, New Jersey, and Virginia experience no change in emissions, but do experience mortality impacts (i.e., from changes in out-of-state emissions). For other states, such as Missouri and Pennsylvania, most of the mortality impacts are attributable to changes in in-state emissions.

Results above employ the CRF from Orellano et al[25] Sensitivity analyses employing alternative CRFs (Table; Figures S1–S4; https://links.lww.com/EE/A377) indicate mortality estimates of 26 (95% CI = 19, 33; Orellano-Americas), 42 (95% CI = 27, 50; Pope), 17 (95% CI = 15, 19; Wu-overall), and 56 (95% CI = 45, 67) to 86 (95% CI = 80, 92) (Wu-low exposure). Compared to the core results above (32 [95% CI = 22, 43] deaths), results from sensitivity analyses CRFs are 19% lower (Orellano-Americas), 31% higher (Pope), 47% lower (Wu-overall), and 75–169% higher (Wu-low exposure). Thus, employing the CRFs used in the EPA's RIA for MATS (Pope; Wu-overall) would increase our core mortality estimates by 31% (Pope) or decrease them by 47% (Wu-overall). Stated differently, our core results are between the two CRF values (Pope; Wu-overall) from the EPA RIA. Across all sensitivity analyses, results ranged from ~1.9 times lower (Wu-overall) to ~2.7 times higher (Wu-low exposure) than the core results.

We separately compared distributions of emission factors and heat rates for exempted versus for nonexempted facilities. These comparisons reveal that $fPM_{2.5}$ emission factors tend to be higher for the exempted facilities than for nonexempted facilities (Fig. S5; https://links.lww.com/EE/A377). Since filterable $PM_{2.5}$ is typically a small portion of total $PM_{2.5}$ emissions (i.e., total $PM_{2.5}$ emissions: filterable plus condensable), we conducted the same comparison for total $PM_{2.5}$ emission factors. The result is similar (i.e., within the distribution, emission factors tend to be higher for exempted than for nonexempted facilities; Fig. S6; https://links.lww.com/EE/A377). Lastly, we compared heat rates (annual total MMBtu); results indicate that within the distribution, heat rates tend to be higher for the exempted than the nonexempted facilities (Fig. S7; https://links.lww.com/EE/A377).

Discussion

This analysis provides estimates of the health impacts anticipated to occur as a result of the two-year exemption provided to 46 of the listed 47 power plant companies in meeting the 2024 MATS requirements. (We do not investigate impacts for the one power plant company in Alaska.) The additional 32 excess deaths that are estimated to occur because of the 2-year delay are expected to primarily occur in populated areas near and downwind of the exempted facilities. In some cases, units with comparatively high emissions were located in sparsely populated regions of the United States (e.g., Colstrip Power Plant in Montana), which resulted in fewer estimated excess deaths compared with units closer to more densely populated regions (e.g., Labadie Power Plant near St. Louis, Missouri). In total, St. Louis County experienced approximately 12,400 deaths in 2020; thus, 14 additional deaths over a 2-year

Figure 1. A, Emissions of $fPM_{2.5}$ from 67 power plants operated by 46 companies, shown with and without MATS implementation. "With MATS" (gray color) refers to estimated 2 years of emissions without the compliance-extension; "without MATS" (red color) is the reverse (i.e., 2-year estimated emissions with the compliance-extension in place). The with/without MATS difference appears as the size difference between the gray circles versus red circles; for locations with no difference between with/without MATS, the icon displays only gray, no red. B, Increased $PM_{2.5}$ concentrations (µg/m³) for shifting from "with MATS" (i.e., without the compliance-extension) to "without MATS" (i.e., with the compliance-extension). For locations with no emission difference between with/without MATS (i.e., only gray-colored circles in [A]), those locations would not contribute to concentrations or health impacts studied in this paper. C, Increased $PM_{2.5}$-attributable mortality, resulting from the 2-year shift from "with MATS" to "without MATS." City labels highlight the five urban areas and clusters with the highest absolute mortality.

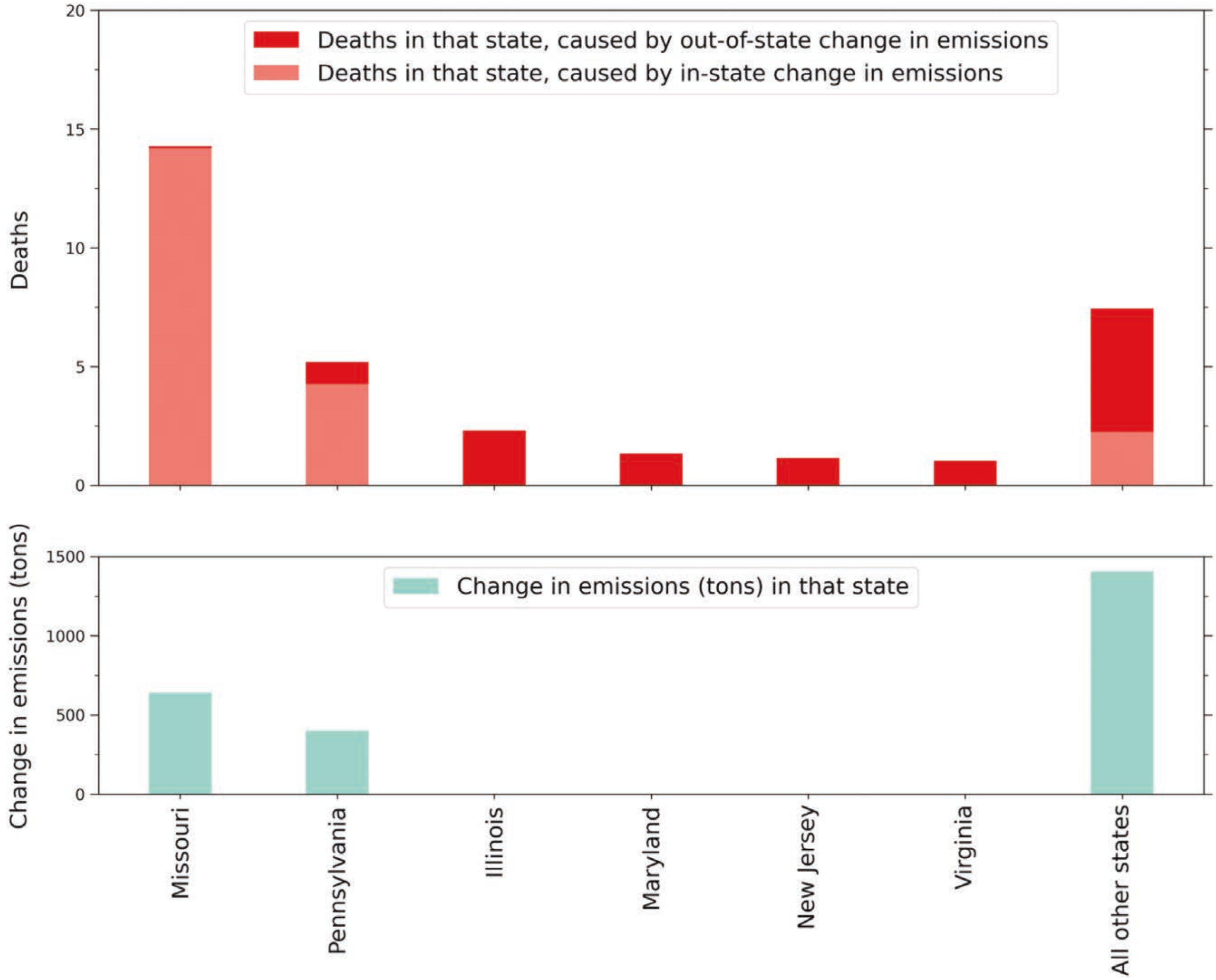

Figure 2. State-level changes without versus with the 2-year MATS compliance extension: $PM_{2.5}$-attributable deaths (upper; red) and $PM_{2.5}$ emissions (lower; green). Mortality values distinguish between contributions from out-of-state (dark red) and in-state (light red) emissions. For example, Missouri shows an emissions increase of 650 tons and a resulting impact of 14 deaths (nearly all from in-state emissions), while Pennsylvania shows an emissions increase of 400 tons and 5 resulting deaths (about 4 from in-state emissions, about 1 from out-of-state emissions). The national totals are 2.5 thousand tons filterable $PM_{2.5}$ emitted and 32 (95% CI = 22, 43) deaths.

Table

Concentration-response functions (CRFs) used in core results or sensitivity analyses and the resulting mortality estimates

CRF - citation	Method	Overall result or subgroup	CRF per 10 μg/m³ (95% CI)	Reference population	Core result or sensitivity analysis	Used in EPA's RIA?	Estimated mortality (95% CI)
Orellano et al[25], 2024 – overall	Meta-analysis	Overall (global pooled estimate)	RR = 1.095 (1.064, 1.127)	Adults (18+)	Core	No	32 (22, 43)
Orellano et al[25], 2024 –Americas	Meta-analysis	Subgroup (Regional pooled estimate: Region of the Americas)	RR = 1.075 (1.055, 1.096)	Adults (18+)	Sensitivity	No	26 (19, 33)
Pope et al[28], 2019[a]	Cohort study	Subgroup (USA; individuals with full covariate information)	HR = 1.12 (1.08, 1.15)	Adults (18+)	Sensitivity	Yes	42 (27, 50)
Wu et al[29], 2020 – overall[b]	Cohort study	Overall (USA)	HR = 1.066 (1.058, 1.074)	Older adults (65+)	Sensitivity	Yes	17 (15, 19)
Wu et al[29], 2020 – low exposure[c]	Cohort study	Subgroup (USA; people only exposed to $PM_{2.5}$ levels <12 μg/m³)	HR = 1.23 (1.18, 1.28) to 1.37 (1.34, 1.40)	Older adults (65+)	Sensitivity	No	56 (45, 67) to 86 (80, 92)

[a]Pope et al. report findings for the full cohort (1.6 million people) and for a subgroup for which full covariate information (i.e., including BMI and smoking status) was available (0.6 million people). The two CRFs for all-cause mortality were nearly identical (1.13 vs. 1.12 per 10 μg/m³; see Table 2 in Pope et al., 2019). We selected the CRF employed in the EPA RIA, which is the subgroup value.

[b]In Wu et al., 2020, the HR is reported as a range, "1.06 (95% CI = 1.05, 1.08) to 1.08 (95% CI = 1.07, 1.09)," with five specific HR values (each with 95% CI) given in their Supplementary Material, Table S3. Here, we select the CRF employed in the EPA RIA, which is the Cox value.

[c]In Wu et al., 2020, the HR is reported as "1.23 (95% CI = 1.18, 1.28) to 1.37 (95% CI = 1.34, 1.40)" for "low exposure," which they define as the portion of the cohort "that were always exposed to $PM_{2.5}$ levels lower than 12 μg/m³." The EPA RIA did not select a CRF from this subgroup, so we employ the range as given by Wu et al.

period represent approximately 0.06% of total deaths. While small in absolute terms compared with total annual mortality, these estimates are meaningful within the framework of air quality health impact analysis, which routinely evaluate incremental health benefits or risks from emission changes at similar magnitudes. Moreover, such localized impacts may be concentrated among vulnerable populations living near these power plants, emphasizing that even relatively modest changes in emissions can have noteworthy public health implications.

An additional consideration is the potential nonlinear shape of the CRF for long-term $PM_{2.5}$ exposure. Studies such as Burnett et al[32] using integrated exposure–response and global exposure mortality models have demonstrated steeper relative risks at lower concentrations and a flattening at higher concentrations. The updated systematic review (Orellano et al[25]), which we use as our primary CRF, reflects pooled evidence across cohorts spanning a wide range of exposures and thus implicitly incorporates these nonlinear effects.[25] This supports our use of the overall effect estimate (RR = 1.095 per 10 μg/m^3) rather than the slightly lower Americas-specific estimate (RR = 1.075), where heterogeneity was not statistically significant. In addition, Wu et al[29] reported a substantially higher risk among individuals who had always lived in areas with annual-average $PM_{2.5}$ levels <12 μg/m^3 (see Table), a concentration range particularly relevant for present-day US conditions. Together with evidence from Burnett et al[32] on nonlinearity, this supports the application of the overall effect estimate from Orellano et al[25] while acknowledging that risks may be greater in lower-concentration settings.[33]

The health estimates in this study vary slightly from the previous Regulatory Impact Analysis (RIA) that accompanied the 2024 MATS rule. This is largely due to differences in how baseline emissions are calculated in EPA's RIAs to avoid "double-counting" both costs and health benefits across multiple rules that affect an emission source.[1] However, some of the rules and regulations that were accounted for in the baseline RIA have either been put on hold by legal challenge or have been repealed by the current administration. Analyses here do not employ a regulatory baseline based on assumptions about what may happen in the future. Instead, average emissions at the unit level, as they currently operate, were compared with the new $fPM_{2.5}$ emission requirements to determine the estimated health impacts of the proclaimed exemptions.

The mortality estimates in this study, based on changes in $fPM_{2.5}$ emissions, do not include health risks from the HAPs that are the primary target of the MATS rule. While the $PM_{2.5}$ CRF applied in this study reflects any chronic or acute health effects that are encompassed within long-term all-cause mortality (including outcomes related to respiratory disease and lung cancer), it does not isolate factors such as specific causes-of-death, the impacts attributable to individual chemical species, or risks to specific subpopulations. Health impact estimates presented here are population-level and assume a causal relationship between exposure and outcome, consistent with standard practice in air pollution epidemiology. These health risks to individuals will occur even in locations with lower population densities (e.g., for Colstrip: residents in Montana). Our analysis also does not directly address the new mercury emission limits for lignite coal facilities or the new start-up requirements. Exemptions from these requirements are also expected to result in adverse health impacts but are not quantified here.

The 95% CIs reported here reflect uncertainty in the individual CRFs but do not capture uncertainty in the estimated changes in population exposure. Exposure modeling introduces additional uncertainty, including from emission inventories, atmospheric transport, and population weighting. For example, as stated above, InMAP has a reported MFB of −38% against observations, indicating that concentration predictions given here may be underestimates. While our analysis does not propagate these uncertainties quantitatively, they are expected to contribute to overall uncertainty in the mortality estimates and should be considered when interpreting the results.

Additional health impacts from the exemptions, which are unquantified here, include nonmortality (i.e., morbidity) outcomes from inhalation of $PM_{2.5}$ (e.g., nonfatal asthma attacks, heart attacks, lung cancer, and bronchitis; restricted activity days; nonfatal exacerbation of heart and lung disease; and increased hospital admissions and emergency room visits)—see for example a recent review by Forastiere et al[34]—and outcomes from noninhalation pathways (e.g., via consumption of food, such as fish from rivers and lakes downwind of power plants).

The difficulty in quantifying the adverse health impacts of HAPs (i.e., as distinct from the $PM_{2.5}$ impacts quantified here) is accounted for in Section 112 of the Clean Air Act, which focuses on reducing HAP emissions from major sources. These requirements are technology-based and reflect clear guidance from Congress to establish standards that achieve a maximum degree of reduction that is at least as stringent as the average control achieved in practice by the best-performing sources in the category or subcategory.[35] This approach has built-in technological and economic feasibility considerations by requiring emission limitations that have already been widely achieved in practice, rather than those that are merely theoretically achievable. The Clean Air Act also requires that these standards be reviewed at least every 8 years, and revised as needed, to ensure they reflect any developments in practices, processes, and control technologies. These requirements were not in the original 1970 Clean Air Act but were included in the 1990 amendments due to Congress's dissatisfaction with delays in addressing HAP emissions under the risk-based approach promulgated in 1970.[36]

A small number of exempted facilities for which monitoring data were available, 12 units, did not meet the revised standard and would likely need to invest in new control technologies that are widely used across the industry to meet the revised fPM standard. This outcome is the intent of Section 112 of the Clean Air Act, to ensure that major sources of HAPs keep up with the processes and control technologies already in place within the same source category.

A similar number of exempted sources, 13 units, already have the needed pollution control technology to meet the revised fPM standards but had average emissions above the 0.010 lb/MMBtu limit. For these facilities, meeting the standard presumably will not require new control technology equipment but rather will require proper operation and maintenance of already installed control technologies, such as electrostatic precipitators, to consistently remain in compliance with the new rule. These units are evidence that owning the proper equipment is not, by itself, universally sufficient for meeting the emission limit; presumably, proper operation and maintenance is also required (See comments below; CEMS can help shed light on and potentially partially address this compliance issue.).

For the 83% of facilities already meeting the revised MATS fPM limit, our analysis assumes no change in emissions. However, the exemption could create incentives for reduced operation or maintenance of control technologies, potentially increasing the emissions. Thus, the exemption's true impacts to emissions and health may be greater than results reported here.

The revised MATS rule requires all units to convert to CEMS to demonstrate compliance with the emissions standard, instead of using quarterly stack tests (or the much less commonly used continuous parameter monitoring approach). A major benefit of this requirement is that it provides needed information to operators and regulators to help ensure that emission-control technologies are properly maintained throughout the year, not just in preparation for scheduled stack tests. The exemption weakens this safeguard.

Based on EPA cost estimates, a 2-year exemption for facilities from CEMS requirements, as well as improved operations and maintenance investments, does not represent a meaningful cost savings for these companies.[1] For example, EPA estimates the marginal cost of converting from quarterly stack testing to CEMS is ~$12,000 per year for each unit.[5] EPA estimates operations and maintenance cost for units with average emissions above the revised $fPM_{2.5}$ limit is ~$60,000 per year. We are unaware of evidence that the revised MATS rule is truly onerous or unachievable for a given facility; however, if that were the case, then a detailed analysis and more narrowly tailored exemption could be considered for that facility, rather than broad-based and uninvestigated exemptions from congressionally- and regulatorily-required HAP emissions reductions.

Conflicts of interest statement

The authors declare that they have no conflicts of interest with regard to the content of this report.

Acknowledgements

We thank EPA staff and former staff for technical assistance with EPA datasets, and we thank the editor and reviewers for their helpful comments and feedback.

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