JANA B. MILFORD

Counting the Benefits of Clean Air Regulations

By abandoning its longstanding practice of estimating the financial value of health benefits from pollution reduction, the Environmental Protection Agency is raising the question of how durable evidence-based policy will be built in the future.

Over the past 40 years, there has been a general consensus that the benefits of air-pollution regulations, achieved through research, rulemaking, and advancing technology, have greatly outweighed the costs. However, this year the Environmental Protection Agency (EPA) established a precedent to ignore long-standing estimates of health benefits. This departure is likely to harm the health of Americans as well as the environment, and it raises the question of how durable, evidence-based policy will be built in the future.

In January, EPA published revised emissions standards for stationary combustion turbines—a class of industrial power generators that are being used to power data centers. These standards were weaker than the ones the agency had proposed a year earlier. Crucially, in the revised standards—known as the final rule—EPA estimated the costs the regulation would impose on industry but did not estimate the health benefits of reducing exposure to air pollution, marking a sharp change from past practice. Instead, EPA simply listed some of the health effects associated with exposure to ozone and fine particulate matter, the two pollutants the agency most often tracks.

EPA claimed that this change is justified because "EPA's analytical practices often provided the public with a false sense of precision and more confidence regarding the monetized impacts of fine particulate matter ($PM_{2.5}$) and ozone than the underlying science could fully support...." This position reflects a break with past practices and expectations; the agency appears to be abandoning decades of its own work that aimed to reliably calculate how the benefits of air pollution regulations compare to the costs. Drawing on input from external review committees, industry representatives, the National Academies of Sciences, Engineering, and Medicine (NASEM), public health organizations, and community members across the United States, EPA has significantly advanced the practice of using cost-benefit analysis to evaluate environmental regulations. Indeed, when the agency produced the benefits estimates in its original turbine proposal, it followed methods it has been refining for a generation.

To be sure, EPA's cost-benefit analyses *are* imperfect. I have been involved in the process of benefits analysis as a scientist for more than 30 years, served on multiple NASEM committees and EPA's Science Advisory Board, and am now serving my fifth term on the Colorado Air Quality Control Commission. There are critics on all sides, including advocates who think regulations are too burdensome and many who argue that they do too

Illustration by Shonagh Rae

little to protect Americans' health. But one thing I can say confidently is that EPA has built the capacity to transparently estimate the benefits of pollution control, just as it does the costs. Likewise, EPA has established a reputation for consistently following accepted practices when estimating the dollar value of these benefits.

The omission of benefits analysis in the case of stationary combustion turbines may presage similar decisions elsewhere. The agency appears likely to overlook health consequences of air pollution as it pursues plans to roll back other regulations, including the Particulate Matter National Ambient Air Quality Standards, which address $PM_{2.5}$, or inhalable particles no larger than 2.5 micrometers in diameter, and the "good neighbor" plan meant to reduce the pollution that power plants and industrial facilities export downwind. In a recent proposal to relax control requirements for commercial sterilization facilities, EPA estimated cost savings for the industry but declined to quantify foregone health benefits of reduced exposure to ethylene oxide, a known carcinogen emitted as a byproduct of sterilization. Likewise, when EPA recently finalized weaker emissions standards for municipal waste combustors than those it had proposed in 2024, the agency failed to estimate the reduced health benefits.

By opting not to quantify the benefits of regulatory proposals, EPA is emphasizing the costs to industry of compliance without paying comparable attention to the harmful consequences of air pollution. EPA rules resulting from this sort of cost-only analysis are likely to be more permissive of pollution, leading to more exposure to toxins—with potential negative effects on the environment and on Americans' health and economic welfare. However, regulated entities are also likely to lose out on balanced assessments that could demonstrate when regulatory proposals have gone too far because benefits are outweighed by costs.

Until now, a shared framework of cost-benefit analysis has supported fact-based regulatory debates across party lines and among stakeholders. The agency's historical commitment to refining and updating its approaches in line with scientific advances has provided assurance that cost-benefit analysis could continue to serve policymakers, industry, and the public well into the future. Explaining the steps EPA has taken to refine its benefits analyses, responding to input from a wide range of experts and stakeholders, makes clear that it will be difficult to replace this powerful tool.

The general benefits of EPA's air pollution regulations

Before looking at the history and details of EPA's use of benefits analysis, it's important to recognize that the substantial benefits resulting from the agency's regulations have been widely acknowledged. Numerous publications indicate that cutting exposure to ozone and $PM_{2.5}$ pollution saves lives and reduces the incidence and costs of treating heart attacks, strokes, cancers, Parkinson's disease, diabetes, chronic obstructive pulmonary disease, asthma, and other health problems. Reducing ozone and $PM_{2.5}$ pollution also protects crops, forests, and ecosystems and improves visibility in cities and scenic areas. Furthermore, regulations informed by EPA's cost-benefit analyses have created incentives to pioneer new equipment and pollution-reduction strategies, supporting the growth of major domestic industries.

Correspondingly, these benefits have outweighed the costs of following EPA's air pollution guidance. A 2011 report the agency prepared for Congress estimated that pollution control requirements adopted under the 1990 Clean Air Act Amendments would prevent 230,000 premature deaths over 30 years and net $2 trillion in benefits. The same study found that aggregate benefits of EPA's air pollution regulations outweighed aggregate costs by 30 to 1. Those direct health benefits are amplified throughout the economy, through lower health care costs and reduced absenteeism. Echoing EPA's findings, a 2017 Office of Management and Budget (OMB) report found that 26 regulations adopted by EPA's Office of Air and Radiation over the previous decade produced total benefits amounting to between $181 and $665 billion at a cost of between $42 and $50 billion (in 2015 dollars).

Who wants cost-benefit analysis?

Regulatory cost-benefit analysis has long had bipartisan support. It has been used to guide EPA in setting emissions control requirements that responsibly balance the costs to industry and consumers with the benefits of emissions reductions to other businesses and the public at large.

Cost-benefit analysis of federal regulations has been formally required since 1981, when President Reagan signed Executive Order (EO) 12291. That order directed federal agencies to ensure that regulatory objectives be chosen to "maximize the net benefits to society," and that proposals for major regulations be accompanied by regulatory impact analyses describing costs and benefits. These requirements were updated under EO 12866, signed by President Clinton in 1993. According to EO 12866, a federal agency considering a significant regulatory action must assess all the benefits anticipated from the action, including the "enhancement of health and safety" and "protection of the natural environment," and must quantify these benefits "to the extent feasible." EO 12866 directs that each agency "shall base its decisions on the best reasonably obtainable scientific, technical, economic, and other information concerning the need for, and consequences of, the intended regulation." Technically, this order remains in effect.

On the legislative side, Congress took bipartisan action that emphasized the value of benefits analysis in the 1990 Clean Air Act Amendments, requiring EPA to undertake the comprehensive cost-benefit analysis contained in its 2011

report. The law established a council of outside experts in economics, health, and environmental sciences to advise EPA in this process—and indeed, their input has helped refine the agency's ongoing benefits assessment practices.

Over the years, different administrations have changed their guidance on how EPA should tabulate benefits in accordance with policy preferences for more or less regulation. However, in eschewing benefits analysis altogether, the agency now appears to be going further than even advocates of deregulation have previously sought. In the past, deregulatory advocates have complained that costs are underestimated and benefits overstated, but they haven't opposed cost-benefit analysis as such. For instance, the Project 2025 report—widely viewed as a blueprint for Trump administration policy—presumes the role of cost-benefit analysis in policy design. The report calls for an executive order to direct EPA to revise guidance on several aspects of benefits analysis, including "discount rates; ... causality of health effects; [and] low-dose risk estimation (linear no-threshold analysis)." The report also asks the agency to "acknowledge the uncertainties involved in quantifying benefits." I discuss these technical points below, but for now it is enough to recognize that even advocates of deregulation have been party to the long-standing agreement in support of analyzing both costs and benefits.

By opting not to quantify the benefits of regulatory proposals, EPA is emphasizing the costs to industry of compliance without paying comparable attention to the harmful consequences of air pollution.

Regulatory cost-benefit analysis: an evolving science

How has EPA been quantifying benefits? It's worth exploring this in some detail to appreciate how, over its decades-long effort to follow its mandate, the agency has developed scientifically grounded models for estimating the societal benefits of regulation while accounting for uncertainties.

EPA has historically broken down regulatory-benefits analysis into three steps. First, to what extent will proposed regulations reduce emissions of, and corresponding exposure to, air pollution? Second, how many deaths or illnesses are expected to be avoided by lowering this exposure? And third, what is the value, in monetary terms, of the reduced risks?

Estimating reductions in pollutant exposure. When EPA undertakes regulatory analysis, it uses state-of-the-science air-quality models to estimate the degree to which proposed regulations will reduce exposure to ozone and particulate matter. These models track emissions and chemical transformation of numerous pollutants that are precursors to the formation of $PM_{2.5}$ and ozone. For benefits analyses, EPA first runs the model with baseline emissions and then conducts simulations with reduced emissions from the sources (e.g., power plants or cement kilns) that would be affected by the proposed rule. The modeled changes in $PM_{2.5}$ or ozone concentrations represent the expected reductions in air pollution exposure. EPA's models have been refined over some 30 years to incorporate the latest science on atmospheric dynamics and chemistry and to keep pace with changing emissions trends. The models have also been rigorously evaluated to show they can reasonably reproduce ozone and $PM_{2.5}$ concentrations observed at hundreds of air quality monitors across the country and thus are reliable tools for regulatory analyses.

One unavoidable source of uncertainty when predicting exposure levels is incomplete knowledge of future emissions and emissions sources to which proposed rules will apply. For example, EPA cannot know with certainty how many new stationary combustion turbines will be installed in the next decade, nor where they will be deployed. When considering certain types of sources, such as power plants, EPA has made projections using formal models. Locations of new sources have typically been assumed to match those of existing sources in the same sector. For cost-benefit calculations, the impact of uncertainty about future sources is somewhat mitigated by the fact that the same assumptions about source numbers, size, and utilization would be applied on both sides of the cost-benefit ledger.

Not all regulations are modeled in the same way. For example, when evaluating multistate limits for power plants, EPA has performed full-scale simulations to determine how a new rule will likely affect pollutant concentrations across the country, using detailed, rule-specific emissions inventories input to a full chemistry and transport model. However, where proposed regulations are expected to have smaller emissions impacts, EPA has used a more streamlined approach, multiplying the tons of emissions the regulations are expected to avoid by an average health "benefit per ton" (BPT) value. EPA has produced BPT estimates for 21 different sectors of stationary sources, ranging from residential woodstoves to cement kilns. The agency used the BPT method to estimate the benefits of

nitrogen oxide emissions reductions in its 2024 proposal to regulate stationary combustion turbines. Under this approach, EPA draws on previously developed maps showing the extent to which exposure would affect the per-unit change in emissions from the sources in a given sector, based on the historical distribution of those emissions.

The BPT approach has been targeted by deregulation advocates, who argue that it is imprecise—a complaint highlighted in the recent rule change. But the method is a valuable shortcut for EPA and is widely used by state agencies, researchers, and others.

Estimating reductions in health risks. Let's turn to EPA's second regulatory-benefits question: How many deaths or illnesses can we expect to avoid by decreasing exposure to the airborne toxins the agency regulates?

Attending to industry critiques, EPA's practice has been to restrict benefits tabulations to categories of health endpoints that the agency has found to be causally or likely causally connected to air pollution. Corresponding endpoints in recent benefits assessments for $PM_{2.5}$ exposure include nonaccidental mortality, certain cancers, and certain cardiovascular, respiratory, and nervous system effects. With respect to ozone exposure, the list has included respiratory mortality and other respiratory effects including asthma onset and symptoms.

As EPA has acknowledged, strong evidence of causality is a high bar, and as a result, the agency's assessments may underestimate health benefits. Associations of reproductive and metabolic effects with ozone and $PM_{2.5}$ exposures are among the categories of effects that have been excluded to date because EPA found the evidence to be "suggestive" but not yet sufficient to conclude that the observed relationships are causal or likely causal. EPA's decision to draw the line at health outcomes likely causally connected to pollution exposure appears to be a compromise—public health groups have called for endpoints with suggestive evidence to be included in benefit tabulations, while deregulatory advocates have urged for a stricter standard.

Notwithstanding the restrictive criteria for inclusion, EPA's process for selecting health endpoints has real strengths. In particular, that process has relied heavily on the Integrated Science Assessments (ISAs) EPA scientists conduct in reviewing national air quality standards. ISAs are rigorous reports that are extensively reviewed by outside experts to analyze and synthesize hundreds of peer-reviewed studies that are themselves individually vetted for quality and relevance prior to consideration.

ISAs have been crucial to EPA's causality determinations. They apply a "weight-of-evidence" approach that integrates evidence across studies and scientific disciplines. A pollutant is considered a cause of a specified health effect only if multiple and consistent high-quality studies have ruled out chance and minimized potential for confounding and other biases. In cases where primary evidence comes from epidemiologic studies, mechanistic understanding that supports the biological plausibility of a causal relationship is also important. A committee of the National Academies recently endorsed this weight-of-evidence approach.

Once EPA has identified which health effects are causally connected to pollution, the next step is risk estimation: quantifying the extent to which the likelihood of experiencing a health effect increases with a given increase in pollutant exposure. EPA derives risk estimates from the strongest studies reviewed in the most recent ISAs—or from newer studies judged to be even stronger. These studies use a combination of different exposure estimation methods to avoid bias and provide higher resolution. The agency has also prioritized studies with large sample sizes and broad representation of the US population, as well as studies of health effects associated with air pollution exposure close to current levels, since these are most relevant to new regulations. Appropriately, EPA's benefits analyses have presented results using risk estimates derived from multiple studies or statistical models in order to characterize uncertainty. EPA analyses also show how the statistical errors in risk estimates that are reported in the original health studies would affect benefits results.

Regulations informed by EPA's cost-benefit analyses have created incentives to pioneer new equipment and pollution-reduction strategies, supporting the growth of major domestic industries.

What all this boils down to is a scrupulous process for quantifying benefits—precisely what EPA now claims it cannot do. Consider the benefits analysis that accompanied the agency's now-weakened 2024 proposal to update standards for stationary combustion turbines. Among the health effects of long-term $PM_{2.5}$ exposure EPA considered was premature mortality, which has been a significant contributor to benefits calculations for many air pollution control regulations. In the benefits analysis, EPA took its mortality-risk estimates for $PM_{2.5}$ from two

large epidemiology studies assessing the effects of long-term exposure. The first study analyzed publicly available data from National Health Interview Surveys, covering a representative cohort of 1.6 million US adults. The second study analyzed data from 68.5 million Medicare enrollees representing adults over 65 years of age. Both studies used state-of-the-art methods to estimate the subjects' exposures to $PM_{2.5}$ and included rigorous steps to adjust for or rule out a wide array of potential confounding factors. The two studies produced different risk estimates, both consistent with a large body of prior work, so EPA presented separate low- and high-benefits results as a measure of uncertainty in the 2024 turbines proposal.

These studies, and many others, demonstrate that pollution-control benefits can be estimated in quantitative terms. We also know from well-designed research that reducing exposure to pollutants can reduce health effects, even where baseline exposure was already relatively low. This speaks to another concern raised by deregulation advocates. For instance, as mentioned earlier, Project 2025 seeks new guidance concerning "low-dose risk estimation."

A pollutant is considered a cause of a specified health effect only if multiple and consistent high-quality studies have ruled out chance and minimized potential for confounding and other biases.

This refers to disputes over whether there are concentration thresholds below which pollutants such as $PM_{2.5}$ and ozone don't cause significant health effects. EPA has at times taken this view. Under some past administrations, EPA conducted analyses governed by the assumption that there would be no benefits to reducing $PM_{2.5}$ exposure below a threshold of 10 $\mu g/m^3$, or micrograms per cubic meter—a level just above the current national standard of 9 $\mu g/m^3$. However, recent studies covering very large cohorts of adults in the United States, Europe, and Canada have found consistent positive associations between $PM_{2.5}$ exposure and premature mortality even at lower concentrations, with no apparent threshold. Accordingly, EPA did not include a threshold in the analyses it conducted during the Biden administration, and instead assumed that benefits would accrue from reducing exposure to $PM_{2.5}$ at any level.

Placing a dollar value on health benefits. EPA's final concern in the context of benefits assessment is the monetary value of reducing medical conditions or risks of premature death from air pollution. For medical conditions, this value has typically been equated to the cost of treatment; for example, the value of preventing a case of pulmonary disease is estimated as the cost of treating the condition. EPA has relied on studies that estimate actual treatment costs, as opposed to charges billed to insurance companies or patients, to avoid overstating the cost reductions that would arise from reducing pollution. That said, there is consensus that the cost of a disease is greater than just the cost of treatment. For this reason, EPA's standard approach has also accounted for lost work and school days. Yet even this method doesn't account for total cost, because it overlooks the pain and suffering associated with disease.

When quantifying the cost of premature mortality for regulatory analyses, EPA and other federal agencies have traditionally used something called the "value of a statistical life" (VSL), estimated from labor studies of extra pay workers require to take a riskier job. In recent rulemakings, EPA has used a VSL of $12 million. Some economists suggest that the value of statistical life-years lost due to emissions exposure would theoretically be a better metric. However, that is a developing approach which requires further research to estimate how to account for differences in the value of extra years across different life stages from childhood to old age. Using VSL has the advantage of its broad acceptance by economists and consistency with long-standing practice since the 1990s.

Another contested issue in benefits valuation is the common practice of discounting. Economists apply discount rates to reflect the assumption that society values near-term costs and benefits more than long-term impacts. This is arguably true even of health effects, as people might rationally prefer deferred risk of illness, in part because treatment prospects could improve in the future. Societal discount rates for regulatory benefits are approximated by the rate of return on long-term US government debt, supporting the use of actual discount rates in the range of 1.5–3% per year.

During the Biden administration, OMB directed federal agencies to use a standard real discount rate of 2%, based on the 30-year average of inflation-adjusted interest rates for 10-year US Treasury securities. Under some administrations, EPA has reported costs and benefits for air quality regulations using both 3% and 7% discount rates, but the higher rate represents private costs of capital and is inappropriate for discounting reduced health risks and other public benefits. Use of a higher discount rate tends to

underestimate benefits of pollution reductions in comparison to costs, as there is often a substantial lag between exposure and health outcomes. In contrast, costs begin to accrue as soon as a regulation takes effect.

EPA could easily do more to promote transparency around the estimates it uses. For example, the agency can mitigate disputes about monetization and discount rates by directly reporting the number of illnesses or deaths it expects to avoid through a regulation, including when those benefits are expected to materialize. Putting a dollar value on regulatory benefits is a value-laden project which can obscure the significance of the underlying risks being averted, and recognizing it as such can help the agency facilitate openness. Avoided illnesses and deaths can be reported in both full and streamlined analyses, with BPT numbers supplemented by incidents per ton estimates for specific health outcomes.

Advancing benefits analysis

When EPA claimed in its final rule for updated turbine standards that it shouldn't quantify regulatory benefits due to uncertainties in health risk estimates, monetary valuation of premature mortality, discount rates, and source locations used in deriving BPT estimates, it relied on a flawed rationale. Some of these uncertainties have been largely resolved in the scientific literature, and uncertainties that aren't resolved can be readily reported, as done in the past. Reporting avoided illnesses and deaths along with monetized benefits can aid in communicating benefits more transparently. EPA is obligated to use the best available science, which requires characterizing uncertainty without covering up what is confidently understood. To the extent there are legitimate questions about benefits estimates, these should motivate continued research and methodological advance—not a disavowal of benefits assessment altogether.

Indeed, policymakers, stakeholders, and the public need more information on the benefits of air quality regulations, not less. Although EPA is required by EO 12866 to consider the "protection of the natural environment," it has generally not quantified benefits of emissions reductions for ecosystems or visual air quality except in limited cases when rules were adopted specifically to address endpoints such as acid rain or regional haze. When Congress has requested comprehensive analyses of Clean Air Act benefits, EPA has shown that ecosystem and visibility benefits are substantial. There would be much to gain from consistently quantifying ecosystem and aesthetic benefits of pollution control.

Then too, EPA should quantify risk reductions for additional air pollutants and health endpoints and develop methods to account more completely for the value of avoiding illness and death, including the value of reduced pain and suffering. Up to now, EPA has focused on quantifying health benefits of reducing ozone and $PM_{2.5}$. For other pollutants, such as nitrogen dioxide, the agency has described evidence for health effects but hasn't taken the additional steps of quantifying risk reductions or monetary valuation. The data needed to estimate benefits of reductions in exposure to nitrogen dioxide and some carcinogenic pollutants are becoming available and should be developed to help guide future rulemaking.

Policymakers and the public also need more information about whether regulations are advancing equity by easing the persistent disproportionate burdens that air pollution imposes on certain communities. Distributive effects have often been overlooked or obscured when regulators have aggregated costs and benefits on a national basis. In the past, EPA has published internal guidance encouraging the presentation of benefits disaggregated by race, ethnicity, income, and other relevant demographic or socioeconomic factors. As an example of an effort to follow that guidance, in a 2024 regulatory impact analysis for revised air quality standards, EPA assessed how alternative standards might affect disparities in $PM_{2.5}$ exposure across demographic and socioeconomic categories as well as corresponding differences in rates of premature mortality across racial and ethnic groups. The agency noted the need for more research on additional social and demographic factors and risk disparities for health endpoints aside from mortality. Indeed, environmental justice is a vital agenda item that researchers, EPA, and state regulatory entities should pursue.

Unquestionably, then, EPA benefits assessments have not been complete. But the existing gaps should inspire improvement of the process, not suspension. In fact, not only is improvement possible—it was, until recently, the norm. EPA's history shows a good-faith effort to quantify many benefits of air pollution regulations, using methods and making assumptions that reflect decades of review and refinement. Over the years, through sustained collaboration, EPA has received input from bipartisan elected officials, scientists, economists, and stakeholders, and used it to improve its benefits analyses and how it communicates the results, assumptions, and uncertainties. There is no sound basis for discontinuing those efforts. Failing to account for benefits alongside the costs of air pollution regulations would grossly distort the picture conveyed to policymakers, regulated parties, and the public. EPA should hew to its mission and legal obligations by continuing its benefits analysis work, to the advantage of all Americans.

Jana B. Milford *is professor emerita in the Department of Mechanical Engineering and the Environmental Engineering Program at the University of Colorado Boulder and a member of the Colorado Air Quality Control Commission. She previously served on the Board on Environmental Studies and Toxicology of the National Academies of Sciences, Engineering, and Medicine and the Science Advisory Board of the US Environmental Protection Agency.*