POLICY FORUM

ENERGY POLICY

Impacts of EPA's finalized power plant greenhouse gas standards

Emissions reductions may be met with relatively small costs

By **John Bistline[1], Aaron Bergman[2], Geoffrey Blanford[1], Maxwell Brown[3], Dallas Burtraw[2], Maya Domeshek[2], Allen Fawcett[4], Anne Hamilton[5], Gokul Iyer[4], Jesse Jenkins[6], Ben King[7], Hannah Kolus[7], Amanda Levin[8], Qian Luo[6], Kevin Rennert[2], Molly Robertson[2], Nicholas Roy[2], Ethan Russell[2], Daniel Shawhan[2], Daniel Steinberg[5], Anna van Brummen[7], Grace Van Horn[9], Aranya Venkatesh[1], John Weyant[10], Ryan Wiser[11], Alicia Zhao[4]**

The US Inflation Reduction Act (IRA) subsidizes the deployment of clean electricity, hydrogen production, and carbon capture and storage (CCS), which could enable additional actions by other federal, state, and local policy-makers to reduce emissions. Power plant rules finalized by the Environmental Protection Agency (EPA) in 2024 are one such example of complementary policies. The rules establish emissions intensity standards, not technology mandates, meaning power plant owners can choose from a range of technologies and control options provided that emissions standards are met. This flexibility makes electricity systems modeling important to understand the potential effects of these regulations. We report below a multimodel analysis of the EPA power plant rules that can provide timely information, including for other countries and states, on emissions impacts, policy design for electricity decarbonization, power sector investments and retirements, cost impacts, and load growth. We also discuss related technical, political, and legal uncertainties.

The rules for new gas and existing coal power plants are pursuant to Section 111 of the Clean Air Act, following earlier efforts to regulate greenhouse gas emissions from existing power plants like the Clean Power Plan and Affordable Clean Energy rules, which faced legal challenges or were repealed after changes in the administration (*1*). The rules require power plants to meet emissions thresholds that vary by the plants' retirement dates and operational characteristics. The emission rate limits are based on the "best system of emission reduction" (BSER), which is CCS with 90% capture for existing coal-fired plants operating past 2038 and 90% CCS for new gas-fired plants in 2032 if operating with >40% utilization (or generating at least 40% of their annual maximum capacity) [see supplementary materials (SM)]. Although the emissions limits are based on specific technological assumptions, power plants can meet or exceed these limits on their average carbon dioxide (CO_2) emissions per unit of electricity generated using a range of options, which could include CCS, cofiring with lower-emitting fuels such as natural gas at coal plants, or efficiency improvements. EPA also created additional subcategories with different thresholds, which means that not all plants are subject to CCS-based standards.

The rules intersect with other power sector trends—growing electricity use from data centers and electrified services, targets to reach net-zero emissions, political uncertainty about federal climate legislation, and grid transitions toward lower-emitting resources. Although coal use has been declining since 2011 (fig. S5), coal represented nearly half of US power sector CO_2 in 2023 despite being only 16% of generation.

Our multimodel analysis delivers timely information on:

EMISSIONS IMPACTS OF EPA'S POWER PLANT RULES: The international community and US government are assessing progress toward Paris Agreement goals (*2*) and how much work is left for other federal, state, and company actions and for other sectors after accounting for these rules. Power sector emissions also affect the timing of IRA's tax credit expirations (*3*, *4*).

POLICY DESIGN FOR ELECTRICITY DECARBONIZATION: The US electric sector is the second-highest greenhouse gas–emitting sector in the world's second-highest-emitting country (*5*). Insights about the cost-effectiveness of policy and technology strategies may be relevant for other countries and subnational jurisdictions, because committed emissions from existing power plants may jeopardize global climate targets without early retirements (*6*) and owing to the central roles of decarbonizing electricity and electrifying end uses for net-zero efforts (*7*).

POWER SECTOR INVESTMENTS AND RETIREMENTS: This information is valuable to states as they draft plans to comply with EPA's standards for existing coal plants (which are due in May 2026), technology developers and electric company planners evaluating responses, system operators considering reliability implications, and local governments understanding impacts of plant closures on jobs and tax revenue.

COST IMPACTS: Analysis on policy compliance costs and electricity prices can inform the public about potential impacts of the rules and legal challenges.

LOAD GROWTH: Utilities, policy-makers, and the public are looking to understand system implications of rapid electricity demand growth due to data centers, industrial facilities, and electrification of vehicles and other end uses (*8*) and how these effects could change with emissions regulations.

MODELING THE EPA RULES

This analysis uses nine models of the electric sector and energy systems to understand potential impacts of EPA's finalized power plant rules. By aligning key assumptions and running harmonized scenarios, model comparisons like ours can identify common findings about impacts and quantify levels of disagreement across participating models. We also compare EPA's Regulatory Impact Analysis for the rules (*9*) with our results, thereby providing a

[1]EPRI, Palo Alto, CA, USA. [2]Resources for the Future (RFF), Washington, DC, USA. [3]Economics and Business, Colorado School of Mines, Golden, CO, USA. [4]Center for Global Sustainability, University of Maryland, College Park, MD, USA. [5]National Renewable Energy Laboratory, Golden, CO, USA. [6]Andlinger Center for Energy and Environment, Princeton University, Princeton, NJ, USA. [7]Rhodium Group, Oakland, CA, USA. [8]Natural Resources Defense Council, Washington, DC, USA. [9]Center for Applied Environmental Law and Policy, Washington, DC, USA. [10]Energy Modeling Forum, Stanford University, Stanford, CA, USA. [11]Lawrence Berkeley National Laboratory, Berkeley, CA, USA. Email: jbistline@epri.com

richer description and range of possible impacts than a single model can provide.

To evaluate effects on emissions and power sector outcomes, scenarios with EPA's standards for new and existing power plants are compared to reference scenarios without these rules (the article uses "the rules" as shorthand for EPA's finalized new and existing standards) (see SM for detailed descriptions of models and study assumptions). All scenarios include current policies as of early 2024 (table S1), including major IRA provisions, and harmonized assumptions about technology costs, fuel prices, and financing. Models include a greater range of mitigation options for coal- and gas-fired power plants than earlier studies, including CCS retrofits and cofiring with lower-emitting fuels (table S2), both to capture compliance pathways in the rules and to understand deployment of IRA-supported resources. Scenarios with and without the rules are run with higher electricity demand levels to understand how additional growth from data centers, manufacturing, and electrification may alter these outlooks. A final sensitivity analysis examines potential impacts of adding standards for existing natural gas-fired power plants, which are not included in the finalized rules.

Emissions implications

Model results suggest that the finalized rules accelerate emissions reductions in the power sector. The range of projected CO_2 emissions is 73 to 86% below 2005 levels by 2040, compared with 60 to 83% in the reference without the rules (see the first figure). The rules narrow the range of potential CO_2 emissions and hence can be viewed as backstops against higher emissions outcomes under futures with improved coal plant economics, which could occur with higher demand, slower renewables deployment from interconnection and permitting delays, or higher natural gas prices. The rules cut CO_2 by 68 to 390 metric tonnes of CO_2 (Mt-CO_2) annually in 2040 compared to current policies (fig. S4), which are greater reductions than EPA's Regulatory Impact Analysis suggests (54 Mt-CO_2).

Owing to the timelines associated with the rules, which primarily are in the 2030s (SM S2), the rules make limited contributions toward reaching the 2030 US economy-wide emissions target (*2*). Even with the rules, power sector emissions also fall short of a net-zero CO_2 goal (*2*), though the rules narrow the implementation gap (see the first figure). Technology-neutral power sector tax credits under IRA begin to expire when electricity CO_2 emissions reach 25% of 2022 levels. The rules may move this date forward, but seven of the nine models do not cross this point by 2035, and six still fail to do so by 2040.

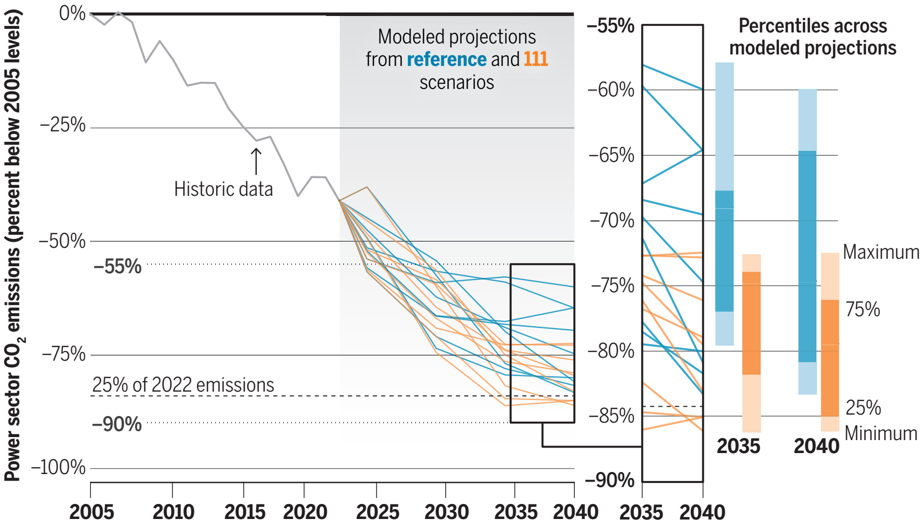
The rules also accelerate reductions of conventional air pollutants, with 88 to 98% reduction in sulfur dioxide (SO_2) by 2035 compared to 2015 (70 to 88% in the reference) and 84 to 94% in nitrogen oxides (NO_x) emissions (74 to 90% in the reference) (fig. S6). These copollutant reductions can bring near-term air quality benefits and improve public health, including in environmental justice communities (*10*), which have been disproportionately affected by pollution.

S20). Coal capacity is replaced by a portfolio that varies by model: Retirements are offset by dispatchable capacity that can adjust output to meet demand (fig. S9), which is largely new gas-fired units with some energy storage (e.g., batteries), CCS, and retained nuclear capacity. Gas capacity increases relative to reference levels for many models, even with new source standards, though magnitudes are small in comparison with solar and wind additions (fig. S10).

Although the standards are based on the application of CCS, the analysis finds limited CCS deployment by 2035 for new gas or existing coal (fig. S10). The IRA's

Cross-model comparison of US power sector emissions reductions

Ranges on the right show values in 2035 and 2040 under current policies only ("reference") and with Environmental Protection Agency rules ("111"). Inflation Reduction Act tax credits begin to expire in 2032 or after power sector carbon dioxide (CO_2) reaches 25% of 2022 levels, whichever is later. See supplementary materials.



Effects on power sector capacity and generation

The rules could have the largest impacts on reducing installed coal capacity (fig. S10) and generation (see the second figure), which historically have been the largest source of power sector CO_2 and conventional air pollutants. Coal capacity declined steadily over the past 15 years (fig. S7), which reflects economic pressures in many markets and retirement announcements linked to company emissions targets. Models indicate that the rules could accelerate coal retirements relative to historical levels and reference trends (fig. S10), albeit with differences across models in this extent. Compared to EPA's Regulatory Impact Analysis, models in this analysis have fewer coal retirements in the reference scenario by 2040 and lower CCS-equipped coal with the rules (fig.

credits of up to \$85/t-CO_2 improve the economics of CCS, but most coal capacity retires instead of retrofitting with CCS. CCS-equipped generation is a small part of total generation by 2040 (0.7 to 3.0%; see the second figure) and similar to the reference (fig. S8), suggesting that projects are driven more by IRA incentives and state policy than by EPA rules. These scenarios illustrate the possibility that compliance with the rules could be achieved without incremental CCS.

The rules are more likely to reduce coal than to curb new gas capacity, because new gas-fired units operating at less than 40% annual utilization do not face stringent emissions standards under the rules (fig. S8). Although new gas dominates capacity changes (fig. S9), existing natural gas combined cycle (NGCC) plants—which are not regulated under the finalized rules—are the

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largest substitute for displaced coal generation, in addition to increased renewables, existing nuclear, and CCS. NGCC plants are the most common gas-fired generation resources in the US and use both gas and steam turbines to improve efficiency. The rules increase the utilization of existing NGCC and decrease generation from units covered by regulations such as new gas-fired capacity (fig. S11). These offsetting effects of different parts of the rules lead to slight increases in gas generation shares for most models under the rules. However, models generally suggest smaller roles for gas in both the reference and 111 scenarios (see the second figure) compared with its generation share of 42% in 2023 (14 to 31% in the reference and 15 to 31% with the rules in 2035). Similarly, average capacity factors of gas-fired capacity are expected to decline relative to today (fig. S12), and this declining utilization means that many new gas plants opt to run with reduced capacity factors rather than to install CCS. These gas increases are approximately offset by coal generation decreases, which makes changes to overall fossil generation shares under the rules relatively small (fig. S13).

These capacity changes may have implications for resource adequacy and reliability. Although regional analysis is needed to evaluate such impacts in detail (*11*), the analysis suggests that retiring coal is largely replaced by dispatchable capacity, which means that the direction and magnitude of reliability metrics depend on the relative outage rates of existing coal vis-à-vis natural gas, location of retirements and additions, timing of replacement capacity, and the ability of energy storage and renewables to contribute to system reliability. In addition, the rules contain features to aid reliability during periods of system stress, including options for units to respond to declared system emergencies and to stay online for documented reliability needs, the extension of compliance timelines due to implementation delays, and additional compliance flexibilities.

These comparisons highlight a few potential unintended consequences of the rules' design. The models project that the rules may cause reductions in generation from covered units (i.e., existing coal and new gas) and increases from uncovered units (i.e., existing gas and renewables). Despite this rebound from existing gas, the overall effect of the rules is to lower CO_2 emissions (fig. S5). The increase in generation from existing gas is larger for many models than EPA's modeling (fig. S9), which partially reflects more coal retirements in EPA's reference case. Some have raised concerns about whether the 40% capacity factor threshold for new gas could lead to more installed capacity that reaches this limit. The analysis shows that new NGCC additions increase under the rules (fig. S8), though this increase is also caused by retiring coal units from the existing source standards.

Cost impacts

Model results indicate that the rules may be met with relatively small costs, even before accounting for climate, public health, and other societal benefits. Bulk power system costs increase 0.5 to 3.7% with the rules through 2050 relative to the reference owing primarily to higher investment costs for gas capacity that replaces retiring coal, though there is cross-model variation in the composition of power system expenditures (fig. S14). Wholesale electricity price changes are similarly low with the rules and decrease over time to less than 2.2% above reference levels in 2040 across all models (see the second figure). Note that even if aggregate national costs are low, regional impacts could be larger.

These low system costs mean that abatement costs of these rules are much lower than many recent estimates of the social cost of CO_2, cost of controls for other EPA rules, and BSER costs (fig. S15). Average abatement costs range from \$6 to \$44/t-CO_2. These low abatement costs reflect flexibilities in the rules and coal retirements being among the lowest-cost mitigation opportunities owing to their ease of substitution (independent of the EPA rules), which aligns with the broader decarbonization literature (*7*). The consistency of this result is notable given the differences in compliance pathways across models.

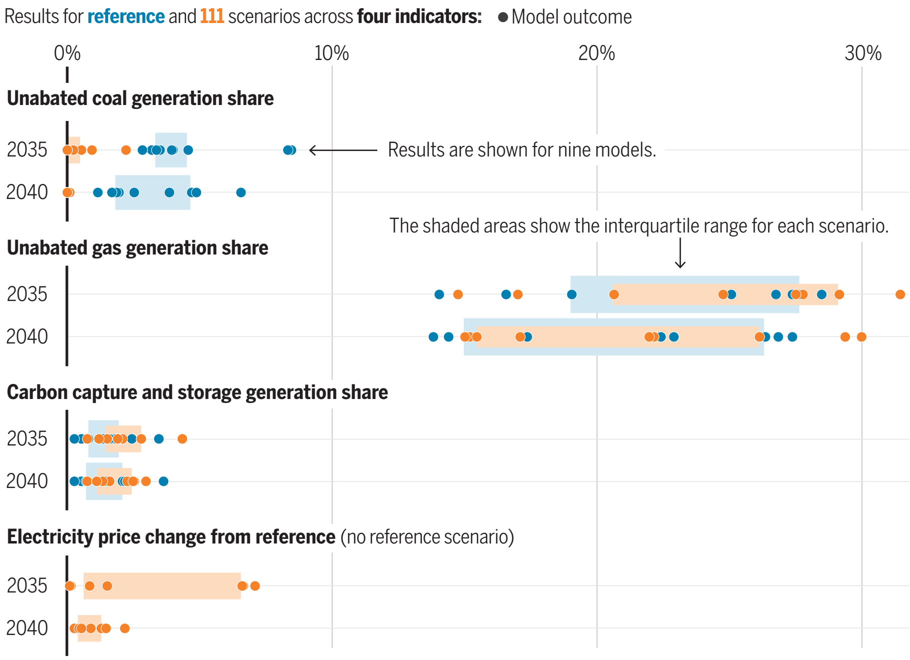
Load growth impacts

Policy-makers and planners expect future electricity demand growth to exceed recent historical levels, though there is uncertainty about contributions from data centers (in part from artificial intelligence applications), domestic manufacturing, IRA-subsidized electrolytic hydrogen production, and end-use electrification (*8*). These trends are reflected in the earlier scenarios, which have 1.3 to 2.3% annual growth rates in total electricity demand through 2035 (compared with an average 0.2% rate in the 2010s), but we also analyze scenarios with even higher load growth rates (1.8 to 2.8%) to understand implications for 111 compliance and emissions.

Emissions and generation responses to higher electricity demand vary over time

Summary of key indicators across models

Results are shown for current policies only ("reference") and with Environmental Protection Agency rules ("111"). From the top, indicators are generation share from coal without carbon capture and storage (CCS), generation share from natural gas without CCS, CCS-equipped generation share, and wholesale electricity price changes relative to the reference scenario. See supplementary materials.



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and by model (fig. S17). New gas-fired resources are generally more responsive to new electricity demand in the near term, but the CO_2 intensity of power generation declines over time and is less than the current grid mix for nearly all models and scenarios, especially with the rules. Overall, zero-emitting resources make up 55 to 83% of increased generation by 2040 under the rules compared with 36 to 81% by 2035. Incremental CO_2 reductions from the rules are similar under reference and higher-demand assumptions (2 to 16 percentage points versus 3 to 16, respectively, in 2040). CO_2 impacts from load growth are generally lower with the rules than without them, though some models show little impact whereas others show large declines for cases where coal generation increases with higher demand in the reference scenario, which is mitigated by the rules. This finding reinforces the role of these rules as a potential risk reduction tool to prevent emissions rebounds if load growth or other factors increase the competitiveness of coal generation. Note that emissions could be even lower with company procurement goals, greater flexibility of end-use loads, and displaced production outside of the US for manufacturing, which are not included here.

EFFECTS OF FUTURE POLICIES

Although the finalized rules do not cover existing natural gas–fired combustion turbines, EPA could, in the future, undertake rulemakings to address carbon emissions and other pollutants from the existing gas fleet (*1*). To understand how these regulations could alter power sector emissions and other outcomes, we conduct an additional scenario that adopts similar timelines and subcategories for existing gas units as the finalized new source standards for gas. The largest modeled impact of extending standards to existing gas units is to increase generation from new NGCC with and without CCS, whereas generation is lower for existing NGCC (fig. S19). However, these changes are relatively small compared to other system changes, which means that incremental CO_2 reductions from the modeled existing gas standards are lower than impacts of the finalized rules (fig. S18). One driver of the more limited emissions response is that a substantial share of existing gas plants opt to operate at capacity factors of 40% or lower rather than retrofitting with CCS or other measures to more substantially reduce their emissions rates, given that gas utilization already declines before accounting for the rules (fig. S12).

Future policy uncertainty at federal and state levels also may affect the rules. Many state policies and company targets look to reduce emissions to net-zero levels by mid-century across the economy. Because rapid declines in coal consumption are features of such pathways (*7*), these actions could lower the impacts of the rules, though many states that currently have net-zero policies and stringent clean electricity standards are not ones with large shares of existing coal capacity.

ADDITIONAL UNCERTAINTIES

In addition to unknowns about load growth and future policies, several uncertainties could alter EPA's power plant rules. US presidential and congressional elections and the change in administration may influence whether the EPA power plant regulations remain in place, are revised, or are augmented. There are also unknowns about how congressional elections may shape IRA's tax credits and further legislative climate policy, which may affect technology deployment and compliance under the rules.

There have already been court challenges to the rules, and although motions to stay the rules have thus far been denied, all parties agreed to an expedited briefing on the merits before the US Court of Appeals for the District of Columbia Circuit that was held on 6 December 2024. As litigation of these rules continues, there is still potential for the courts to stay the rules or to require them to be rewritten in response to legal challenges.

Ultimately, states have flexibility in developing their state plans to comply with existing source standards for coal plants. States can implement trading, averaging, and several types of flexibility and invoke the remaining useful life and other factors (RULOF) to apply less stringent standards of performance. State plans currently are due to EPA in May 2026.

Uncertainties around the siting, permitting, and interconnection of power sector resources raise questions about the rate of future change (*12*). The pace of scaling and associated infrastructure buildouts are especially pressing for wind and solar, which are the technologies with the highest deployment rates across all models in our analysis (fig. S10). These issues are also uncertain for emerging technologies such as CCS and hydrogen, which are expected to play key roles in reaching economy-wide net-zero emissions (*13*, *14*) but require supporting energy economies for potential transport and storage. States can include a mechanism that allows extensions up to 1 year for unanticipated delays beyond the owner or operator's control, such as permitting or supply chain challenges. ■

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SUPPLEMENTARY MATERIALS

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