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Carbon Standards Examined

A Comparison of At-the-Source and Beyond-the-Source Power Plant Carbon Standards

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RESOURCES FOR THE FUTURE

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Abstract

The proposed replacement rule for the US Clean Power Plan, named the Affordable Clean Energy Rule, employs a narrow "at-the-source" approach that targets heat rate improvements at individual coal plants. The emissions rebound and state-level implications of this type of policy are not well understood. We analyze the potential effects of a similar at-the-source policy scenario on national and state emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_X) in 2030 using 2014 results from the Integrated Planning Model (IPM). Compared to a no-policy scenario, we find that an at-the-source scenario that provides an average fleet wide heat rate improvement of 4 percent for coal-fired power plants could result in only a modest decrease (-2.6 percent) in national power sector CO_2 emissions, with potential increases in CO_2 emissions in eight states totaling three million additional tons of CO_2 emissions per year in those states. We decompose the CO_2 emissions changes and find evidence of a rebound effect, in which coal plants that become more efficient operate more often. The scenario also results in a modest estimated increase (2.7 percent) in national SO_2 emissions and a minor estimated reduction (-2.3 percent) in national NO_X emissions, with increases in one or both pollutants in 12 states. Estimated emissions in 2030 are substantially higher under an at-the-source scenario for CO_2 (63 percent), SO_2 (88 percent), and NO_X (56 percent) compared to a more flexible "beyond-the-source" scenario that resembles the Clean Power Plan. Our analysis suggests that a strong possibility of emissions rebound exists for at-the-source power plant standards, leading to increased CO_2 and co-pollutant emissions at multiple scales that would degrade air quality and cause adverse health effects. The results reinforce the importance of analyzing both changes in power plant utilization as well as CO_2 and co-pollutant emissions at the plant, state, regional and national scale when proposing to weaken emission standards.

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1. Introduction

The legal obligation of the United States Environmental Protection Agency (EPA) to regulate greenhouse gas emissions from existing power plants was affirmed by the Supreme Court's 2007 decision in *Massachusetts v Environmental Protection Agency* and triggered by the EPA's formal finding in 2009 that greenhouse gas emissions threaten public health and welfare (Mass v EPA 2007, EPA 2009). Consequently, as the EPA moves to repeal the Clean Power Plan (CPP), the carbon dioxide (CO_2) emissions standard for existing power plants, it is obligated to propose a replacement standard to limit greenhouse gas emissions.

The CPP, finalized in 2015, establishes state-based CO_2 emissions goals for affected fossil fuel-fired power plants and requires states to ensure that the power plants in their jurisdictions—either individually, together, or in combination with other states—achieve the state goal (EPA 2015a). The CPP incorporates flexible compliance options that allow emissions reductions to be achieved from carbon intensity reductions at individual plants—otherwise known as heat rate improvements at the source—or from the substitution of generation towards less carbon-intensive and zero-carbon energy sources. Averaging across units and trading among units within or across states is also allowed. Given this flexible structure, the CPP can be termed a "beyond-the-source" standard. At the time it was finalized, it was estimated that the CPP would decrease CO_2 emissions by 415 million tons, or 19 percent, below a business as usual base case level by 2030, or 30 percent below 2005 levels (EPA 2015b).

In response to the Trump Administration's Executive Order on Energy Independence, the EPA in 2017 released its proposed repeal of the CPP (EPA 2017). The proposed replacement

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The authors thank Habibollah Fakhraei for preparing the emissions maps and ICF for IPM modeling. This analysis used modeling scenarios and a unit-specific heat rate modeling method developed by Jennifer Macedonia in 2013 based on analysis with Jim Staudt, under contract to Bipartisan Policy Center.

rule, called the Affordable Clean Energy Rule, employs a narrow "at-the-source" regulation, commonly referred to as an "inside the fence line" regulation, which defines the legally relevant *best system of emissions reductions* as opportunities to improve heat rates at individual coal plants. Heat rate is the amount of fuel input (Btu) used to produce electricity and a lower heat rate indicates a more efficient unit; a more efficient plant burns less fuel for each kWh of electricity produced and therefore emits less CO_2 per kWh. The heat rate is strongly related to the emissions rate (kg of CO_2) per unit of electricity produced (kWh) at the facility. There is considerable heterogeneity in the heat rate of US coal plants and a substantial right-hand tail in the heat rate distribution, meaning that many coal plants could be made more efficient (Linn et al. 2014). The regulation sets standards for emissions rate improvements at facilities, but because these standards are based on estimated potential for heat rate improvements we refer to this type of at-the-source option as a heat rate improvement standard. The proposal does not does not include fuel cofiring among its described emission reduction options, although it is possible states would allow fuel switching in implementing the plan.

With the issuance of the proposed replacement regulation, the EPA released a regulatory impact analysis (RIA) that models emissions changes on a regional level; however, at this time those changes are not reported at the state level. Few other analyses have examined the spatially explicit effects of a narrow at-the-source heat rate improvement option. We conduct an independent analysis to estimate potential national and state level CO_2 emissions in 2030 for a slightly broader at-the-source scenario that allows for cofiring to achieve emissions rate reductions, compared to a reference scenario with no power plant carbon standard, and to a flexible beyond-the-source scenario similar to the CPP. We also estimate the changes in emissions of conventional co-pollutants including sulfur dioxide (SO_2) and nitrogen oxides (NO_X), which affect local air quality and human health. This analysis builds on previous national-scale modeling of emissions impacts and potential state-level air quality and health co-benefits of a range of power plant standards (Driscoll et al. 2015, Buonocore et al. 2016).

We conduct a formal decomposition analysis of the estimated national changes in generation and emissions for the at-the-source scenario to examine the underlying drivers of the emissions changes and to estimate the contribution of a potential rebound effect. The rebound effect is a phenomenon in which facilities with high baseline emissions rates are made more efficient through investments to reduce their heat rates, and then operate more frequently and remain in operation for a longer period. Additionally, we provide decomposition results for states that are estimated to experience emissions increases under the at-the-source scenario.

2. Methods

We use the Integrated Planning Model (IPM), run by ICF International, to estimate potential changes in emissions of CO_2, SO_2 and NO_X from power plants associated with an at-the-source heat rate improvement scenario. We compare the results to a no-policy scenario with no power plant carbon standard and a beyond-the-source scenario similar to the CPP (see Driscoll et al. 2015).

2.1. Power Sector Modeling

We use emissions output for each of the three scenarios from IPM, a dynamic power sector production cost linear optimization model for North America. IPM simulates investments, changing operations and associated changes in emissions for each of 2,417 fossil-fuel fired units operating in the model domain in the conterminous US in 2014. See the Appendix for further detail. The IPM modeling for this project was initiated in 2014 and run for model years 2016 to 2030. The final CPP had not yet been published at the time this project was initiated and the most current energy demand assumptions available at that time were based on the 2013 Annual Energy Outlook.

2.2. Power Plant Scenarios

2.2.1. No-Policy Reference Scenario

The no-policy reference scenario uses the energy demand projections in the Annual Energy Outlook for 2013 as the benchmark. Current federal clean air policies are fully implemented under this scenario, including the Mercury and Air Toxics Standard and the Clean Air Interstate Rule. Moreover, state-level requirements for power sector emissions reductions and renewable energy portfolio standards that were finalized as of 2013 are implemented under this scenario.

2.2.2. Beyond-the-Source Scenario

The beyond-the-source scenario resembles the CPP as adopted by the EPA in 2015, though there are important differences. It uses emissions rate targets of 680 kg MWh^{-1} for coal and 453 kg MWh^{-1} for gas and the current generation mix to establish emissions rate performance standards and associated CO_2 emissions targets for each state. Implementation options under this scenario provide high compliance flexibility and make renewable energy and demand-side energy efficiency available for compliance. This scenario also allows the averaging and trading of emissions among all new and existing fossil units in a state and between states. It achieves an estimated 36 percent reduction in CO_2 emissions from 2005 by 2020 compared to the 32 percent reduction by 2030 under the final Clean Power Plan.

2.2.3. At-the-Source Scenario

The at-the-source scenario uses estimated potential heat rate improvements at individual coal-fired units to set unit-specific emissions rate standards. Site-to-site variation based on plant age and type exists in the potential for heat rate improvements at existing power plants and the associated cost of those improvements. To determine heat rate investment options, coal units are assigned to categories based on capacity, fuel type, steam cycle, and boiler type, and the unit with the lowest heat rate in each category sets a best-in-class heat rate standard for the category based on adjusted heat rate data from the National Electric Energy Data System (NEEDS) database v.4.10 (Staudt and Macedonia 2014). Each unit that is not best-in-class can select a heat rate investment that would close the gap between its current heat rate and the best-in-class heat rate by either 25 or 40 percent. To comply, these coal plants have the option to invest in on-site efficiency (heat rate) improvements, and co-fire up to 15 percent with natural gas or biomass so that their CO_2 emission rate is equal to the rate that would be achieved if the unit invested in the 40 percent heat rate option, with compliance by 2020. If all coal plants select the 40 percent investment option and do not change their level of output, the fleet-wide average heat rate improvement would be 5.62 percent, or 617 Btu/kWh. These fleet-wide averages are in line with other projections in the heat rate literature (Linn et al. 2014, Burtraw et al. 2011, DOE/NETL 2009, Sargent & Lundy 2009). See Appendix for more scenario specifications.

When the model is run, the scenario achieves a 4 percent increase in the fleet-wide average heat rate for coal-fired power plants. Several studies found reasonable efficiency investments could decrease heat rates by as much as 4 percent (Linn et al. 2014, Burtraw et al. 2011, DOE/NETL 2009, Sargent & Lundy 2009, MIT 2009, SFA 2009). By 2030, the estimated national average CO_2 emissions rate for coal-fired power plants decreases modestly under this scenario compared to the reference case to 907 kg MWh^{-1}.

2.3. Decomposition Analysis

To analyze estimated changes in facility utilization and associated emissions, we use a logarithmic mean decomposition index (LMDI) approach, based on Ang (2015).[1] This analysis allows us to estimate the extent to which three main factors contribute to the change in emissions under the at-the-source scenario compared to the no-policy reference scenario: activity, structure, and

[1] We implement Model 1 in Table 1 of Ang (2015). We substitute CO_2 emissions for energy consumption (E) and electricity generation for industrial output (Q). This method follows from that used in Palmer et al. (2018) to decompose modeled emissions changes under a carbon tax.

intensity. The activity factor can be interpreted as emissions changes due to changes in total electricity generation; the structure factor as emissions changes due to shifts in generation sources; and the intensity factor as emissions changes due to changes in emissions intensity within fuel types.

The emissions intensity of fuel types (the intensity factor) is the factor that is targeted by a heat rate improvement standard, and it can differ across scenarios when policies cause various fossil fuel plants to improve their efficiency. Under a heat rate improvement standard, the intensity factor contributes to reductions in emissions if the standard successfully reduces the emissions intensity of coal plants.

The rebound effect is embodied in changes in the generation mix (the structure factor), which changes across scenarios when policies affect the relative competitiveness of generation sources. This factor is equal to the rebound effect under a heat rate improvement standard because the regulation improves the efficiency of coal plants and thus causes substitution towards coal away from other, lower-emitting generation sources. Our estimate of the rebound effect is likely conservative because the IPM model holds total demand constant. If demand were allowed to change, the rebound effect would include both the structure factor and the activity factor. This is because the increased efficiency of coal may lower the cost of electricity and thus increase total electricity demand, as would be expected to occur in organized wholesale power markets. However, under constant demand, the activity factor in our analysis is not directly associated with the rebound effect. Although electricity demand is held constant, total electricity generation (the activity factor) can still differ across model scenarios for several reasons: policies may cause changes in trade flows between the US and Canada, or changes in state or regional generation within the US. These changes may affect the total amount of electricity transferred between regions, thus affecting total losses and therefore total generation.

3. Results

3.1. National and State Level Changes in CO_2 Emissions

At the national scale, we find that compared to a no-policy reference scenario, an at-the-source scenario could lead to modest reductions in CO_2 emissions. In 2030, national CO_2 emissions in 2030 are estimated to be 65 million short tons, or 2.6 percent, lower under the at-the-source scenario compared to the no-policy reference scenario (see Table 1). Estimated emissions are 920 million short tons, or 63 percent, higher than the beyond-the-source scenario.

Table 1. Estimated Total and Change in National CO_2 Emissions from Power Sector in 2030 under an At-the-Source Scenario

	Emissions	
	(Million short tons)	(Percent)
At-the-source scenario	2,386	
Change from no-policy reference scenario	-64.7	-2.6%
Change from beyond-the-source scenario	920.2	63%

Most states likewise show modest estimated reductions in emissions in 2030 under the at-the-source scenario compared to the no-policy reference scenario (see Figure 1). Unintuitively, the at-the-source scenario could lead to increased CO_2 emissions at many facilities, and even an increase in total CO_2 emissions in some states. Indeed, eight states—Arizona, Florida, Idaho, Mississippi, New Jersey, Nevada, Oregon and Washington—show an increase in estimated CO_2 emissions, ranging from two thousand to 1.5 million tons (Figure 1). When comparing the at-the-source scenario to the more flexible beyond-the-source scenario, all states except two (Vermont and Delaware) have higher emissions under the at-the-source scenario in 2030 (see Figure 2).

Figure 1. Change in Estimated CO_2 Emissions in 2030 for an At-the-Source Scenario Compared to a No-Policy Reference Scenario

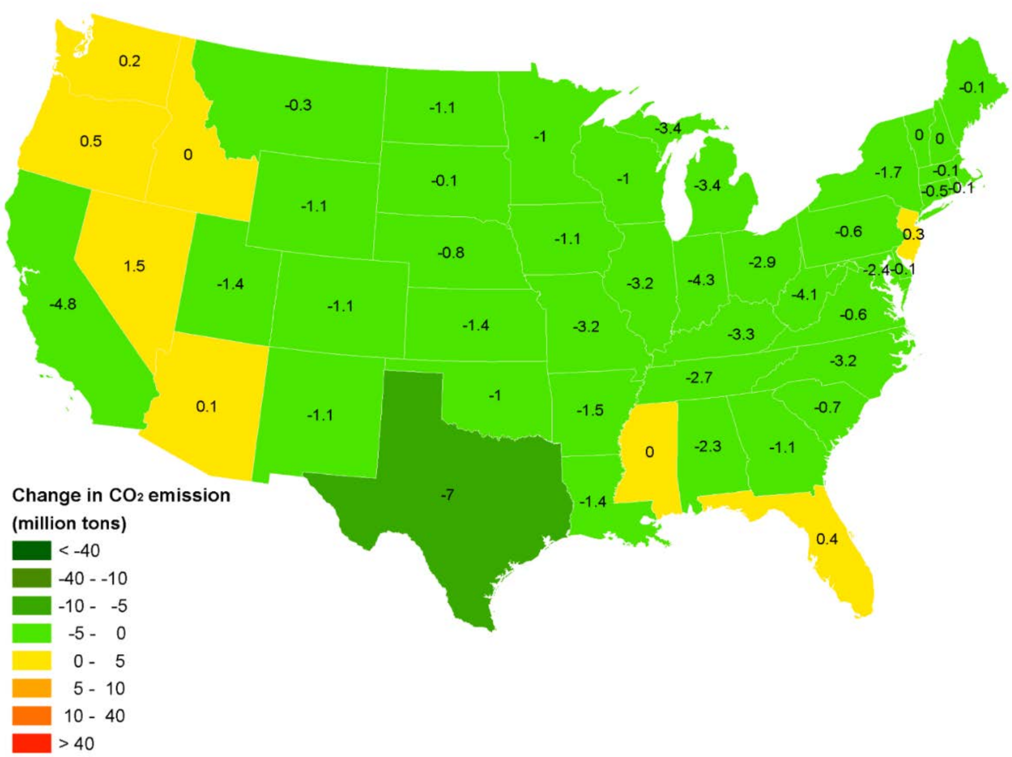
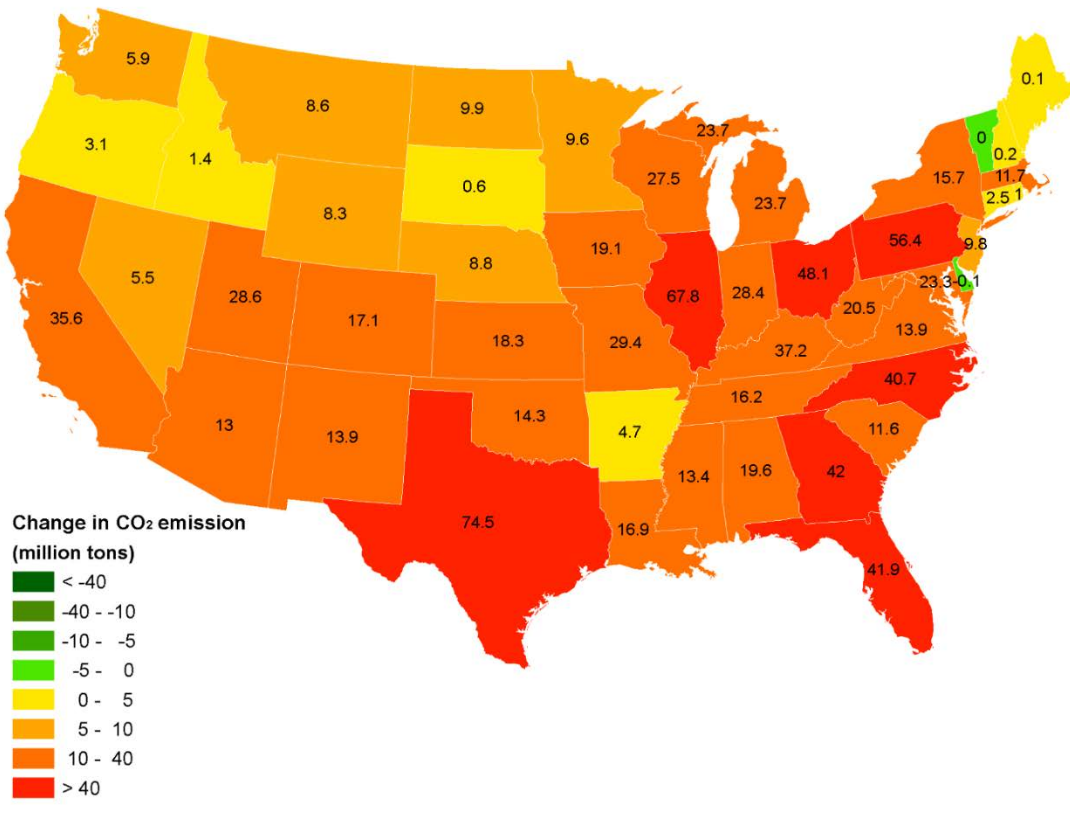


Figure 2. Change in Estimated State CO_2 Emissions in 2030 for an At-the-Source Scenario Compared to a Beyond-the-Source Scenario



3.2. Decomposition of Results and the Rebound Effect

Under the at-the-source scenario that would reduce emissions per unit of generation at coal facilities by 4 percent, our modeling analysis estimates a total reduction in national power sector CO_2 emissions of only 2.6 percent in 2030 compared to the no-policy reference scenario. This modest change is due in part to the emissions rebound effect, with coal generation estimated to be 1.1 percent higher in 2030 relative to the no-policy reference case (see Table 2).

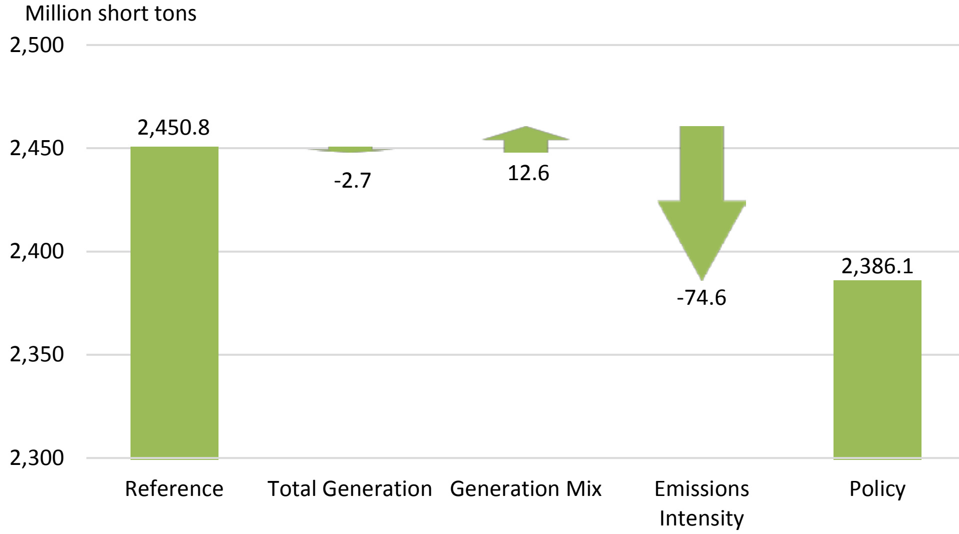
Table 2. Estimated National Electricity Generation by Source in 2030

Source	No-Policy Reference Scenario (GWh)	At-the-Source Scenario (GWh)	Change (GWh)	Change (%)	Change in Emissions Intensity (%)
Biomass	40,836	40,816	-20	0.0%	0.0%
Coal	1,808,040	1,827,261	19,221	1.1%	-3.9%
Combined Cycle	1,147,564	1,125,019	-22,545	-2.0%	0.1%
Combustion Turbine	79,233	78,565	-667	-0.8%	0.7%
Nuclear	805,940	805,940	0	0.0%	-
Oil/Gas	3,909	3,202	-708	-18.1%	1.6%
Other	52,330	52,290	-40	-0.1%	0.1%
Renewable	635,953	635,602	-351	-0.1%	-
Total	**4,573,805**	**4,568,695**	**-5,110**	**-0.1%**	**-2.5%**

3.2.1. National Emissions Effects

The decomposition shows the extent to which the rebound effect offsets emissions reductions under the at-the-source scenario. Based on the model output, total national emissions under the at-the-source scenario are estimated to decrease by 64.7 million short tons compared to the no-policy reference scenario in 2030 (Figure 3). Our decomposition analysis finds that reductions in total electricity generation drive emissions down by 2.7 million tons. Reductions in emissions intensity within fuel types are estimated to reduce emissions by 74.6 million tons, due to the lower emissions intensity of coal generation. However, the rebound effect associated with greater utilization of coals plants is estimated to increase emissions by 12.6 million tons, partially offsetting the reductions from the other two factors and resulting in smaller estimated total reductions.

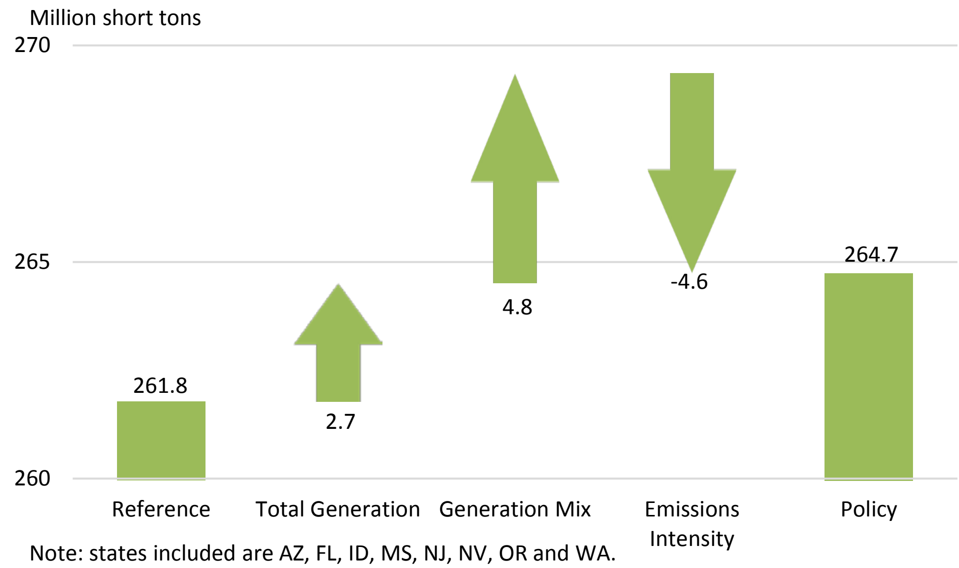
Figure 3. Decomposition of National CO_2 Emissions Change in 2030 under an At-the-Source Scenario Compared to a No-Policy Reference Scenario



3.2.2. State Emissions Effects

For the eight states projected to experience higher CO_2 emissions in 2030 under the narrow at-the-source scenario compared to the no-policy reference scenario in 2030 (Figure 1), decomposition reveals that emissions intensity improvements drive down emissions by 4.6 million tons, but these reductions are more than offset by the generation mix shifts which drive up emissions by 4.8 million tons (Figure 4). This rebound effect is caused almost entirely by shifts towards increased coal generation. For the eight states, annual CO_2 emissions are expected to increase a total of 3.0 million short tons.

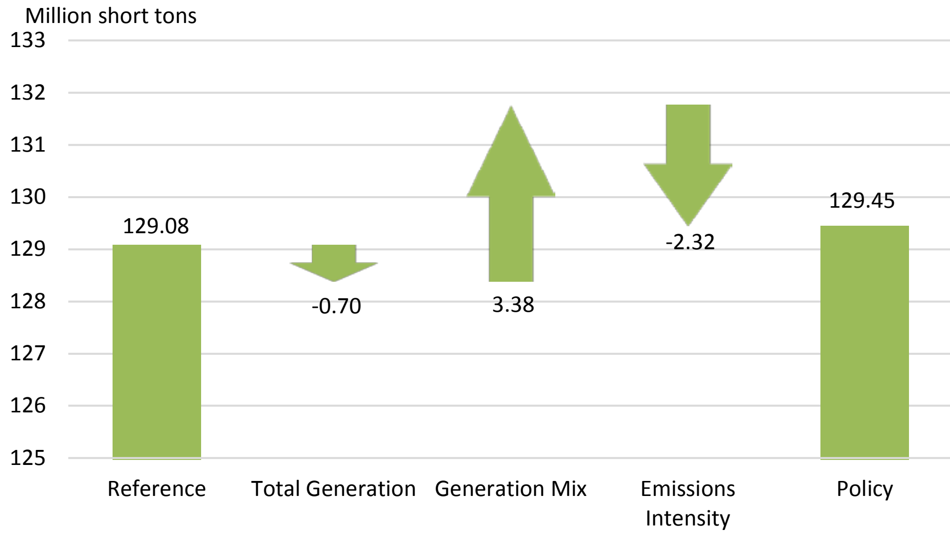
Figure 4. Decomposition of CO_2 Emissions Changes in 2030 under an At-the-Source Scenario Compared to a No-Policy Reference Scenario in States with Emissions Increases



Note: states included are AZ, FL, ID, MS, NJ, NV, OR and WA.

Florida shows the largest estimated rebound effect, resulting in a modest estimated increase in CO_2 emissions of 0.4 million tons in 2030 compared to the no-policy reference scenario (Figure 5). While reductions in total generation are estimated to drive down emissions by 0.7 million tons and improved emissions intensity drives down emissions by 2.3 million tons, these factors are countered by a generation mix shift towards coal. The rebound effect, driven almost entirely by shifts toward coal, drives up emissions by 3.4 million tons. While its emissions intensity declines, coal generation grows from supplying 20.3 percent of Florida's electricity generation to 22.5 percent.

Figure 5. Decomposition of CO_2 Emissions Change in Florida in 2030 under At-the-Source Scenario Compared to a No-Policy Reference Scenario



At the national level and in many states, the shift towards coal generation and the coal rebound effect drive the upward pressure on emissions. However, some states experience other types of generation shifts that drive up expected emissions. For example, in some states that exhibit total emissions increases—particularly Arizona, New Jersey, Oregon and Washington—our analysis shows that increases are driven primarily by shifts towards combined cycle natural gas generation rather than shifts towards coal. In particular, all coal plants in Oregon and Washington are retired in the at-the-source scenario, so the emissions increases are driven entirely by generation shifts towards natural gas. This phenomenon could occur for several reasons that are specific to state and regional electricity markets. This pattern exposes another set of unintended consequences of an at-the-source scenario that can diminish overall emissions outcomes.

3.3. Changes in Conventional Air Pollutants

We see an increase of 2.7 percent in national SO_2 emissions in 2030 for the at-the-source scenario relative to the no-policy reference scenario, due to emissions increases in six states: Connecticut, Florida, Indiana, Nevada, South Carolina and South Dakota (Driscoll et al. 2015). A 2.3 percent decrease in NO_x emissions occurs nationally for the at-the-source scenario relative to the no-policy reference scenario, with eight states showing increases: Florida, Georgia, Idaho, New Jersey, Nevada, Oregon, Pennsylvania and Washington.

Compared to the beyond-the-source scenario, we estimate that total national SO_2 emissions could be 88 percent higher and NO_X emissions could be 56 percent higher in 2030.

4. Discussion

Our analysis of sharply contrasting scenarios for a power plant carbon standard illustrates the potential for a rebound effect to occur under a narrow at-the-source policy scenario that could greatly increase emissions relative to a more flexible beyond-the-source alternative. Previous studies have found evidence that a rebound effect is associated with heat rate improvements at high-emissions rate facilities, and changes in the operation of these facilities diminishes the reduction in emissions that would otherwise occur (Linn et al. 2013). Moreover, because these facilities have lower operating costs after the heat rate improvements are made, they are likely to delay their ultimate retirement and may remain in service longer into the future (Burtraw et al. 2011).

The rebound effect under an at-the-source scenario, in addition to diminishing total emissions reductions at a national level, could also lead to emissions increases in some states compared to a reference scenario and emissions increases in almost all states relative to a beyond-the-source scenario. This result could have important implications for the twenty states that have adopted greenhouse gas emissions targets (C2ES 2018), as it could make meeting state emissions goals costlier.

An important consideration when evaluating the potential for and magnitude of a rebound effect is the set of assumptions in the reference case. A limitation of this study is that it develops analysis based on the electricity industry as it was configured in 2014. The industry has been undergoing substantial change, including retirement of many fossil units. Coal generation declined from 40 percent of total power generation in 2013 to 31 percent of total generation in 2017, and overall fossil fuels supplied 62 percent of total generation in 2017 compared to 67 percent in 2013 (EIA 2018). Nonetheless, it is not clear whether these changes would lead to a decrease or increase in the rebound effect and other unintended consequences of a heat rate improvement standard.

In addition, when we developed this analysis, the form of the proposed CPP replacement had not yet been published. Our estimate of the rebound effect may be conservative because we include cofiring as a compliance option, while the proposed Affordable Clean Energy Rule has a narrower set of options focused only on heat rate improvement. While this clearly creates uncertainties in characterizing the implications of the proposed replacement policy, the qualitative insights from our model regarding the potential for emissions rebound to occur are robust and highly relevant, and our analytical approach could be used to analyze the future policy options.

Therefore, the changes in emissions under these scenarios are not meant to represent precise predictions of the future. Rather the contrasting results between a narrow at-the-source scenario relative to a no-policy reference and a flexible beyond-the-source scenario demonstrate the vast relative differences in potential generation and associated emissions. The results also show the potential for a rebound effect under an at-the-source approach to substantially diminish the emissions benefits from a more flexible alternative.

The outcomes of an actual heat rate improvement standard could be impacted by the EPA's New Source Review (NSR) program for new and significantly modified emitting facilities, which would likely include many of the facilities making investments to improve their heat rates. NSR would require the investment in modern controls for conventional pollutants at these facilities and would require offsets for pollution increases in areas that are in nonattainment of the National Ambient Air Quality Standards. Linn et al. (2014) find suggestive evidence that NSR and other environmental regulations may have affected the decision to make investments to improve heat rates at coal facilities historically and could reduce the rebound effect and provide greater emissions reductions than we estimate would occur. However, electric generating units have a lookback period against which emissions changes can be compared that covers any 24-month period in the preceding 5 years (Shanks 2017). In recent years the utilization of coal-fired plants has been falling almost uniformly, creating headroom to potentially avoid the NSR constraint. Further, the EPA is currently pursuing NSR reform and NSR requirements may be relaxed, which would reduce the likelihood that NSR could play a role in diminishing the rebound effect (EPA 2018). Our findings thus have implications not only for the potential replacement of the CPP but for other greenhouse gas federal regulatory measures as well.

Understanding the impact of a heat rate improvement standard on co-pollutant emissions is also critical because these pollutants have consequences for local air quality and public health. In previous research, we linked our modeled emissions results with air quality and epidemiological models to quantify these effects in 2020 (Driscoll et al. 2015). We found that an at-the-source scenario could lead to modest increases in average annual $PM_{2.5}$. We estimated that the scenario would result in a net of 10 additional premature deaths per year based on an estimated decrease of approximately 124 premature deaths in some states and an additional 134 premature deaths in others, reflecting the heterogeneity of emissions and air quality changes. A slight increase in heart attacks and modest reduction in hospitalizations is also estimated to occur under this scenario (Driscoll et al. 2015). Additionally, many states have anticipated that enforcement of the CPP would lead to reductions in conventional pollutants and help with attainment of air quality goals. Increases in these pollutants have significant consequences for public health and local economies.

5. Conclusions

Our analysis finds that an at-the-source scenario may generate only minor national reductions in CO_2 emissions compared to a no-policy reference scenario, and substantial increases in CO_2 emissions compared to a beyond-the-source scenario. The results demonstrate the potential for a rebound effect under an at-the-source scenario to result in increased CO_2 emissions in some regions, states, and plants compared to a no-policy reference scenario. We also find that emissions of co-pollutants SO_2 and NO_X could increase in many states compared to a no-policy reference case.

The impacts of a heat rate improvement standard on CO_2 emissions have implications for states, many of which have carbon emission reduction targets. Our analysis estimates that eight states—five of which have CO_2 reduction targets in place—could experience higher emissions compared to having no power plant carbon standard. Further, nearly all states could have higher emissions compared to a CPP-like policy. These outcomes would make meeting state emissions goals harder and costlier.

Our novel analysis provides information on the potential impacts of an at-the-source standard on national and state-level emissions of CO_2 and conventional pollutants, indicating that outcomes under a narrow type of at-the-source standard focused largely on plant-level heat rate improvements could undermine the intent of the standard.

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