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Effectiveness of US state policies in reducing CO_2 emissions from power plants

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President Obama's landmark initiative to reduce the CO_2 emissions of existing power plants, the nation's largest source of greenhouse gas (GHG) pollutants, depends heavily on states and their ability to devise policies that meet the goals set by the Environmental Protection Agency (EPA). Under the EPA's proposed Clean Power Plan, states will be responsible for cutting power plants' carbon pollution 30% from 2005 levels by 2030. States have already adopted several policies to reduce the electricity sector's climate impact. Some of these policies focus on reducing power plants' CO_2 emissions, and others address this outcome in a more roundabout fashion by encouraging energy efficiency and renewable energy[1]. However, it remains unclear which, if any, of these direct and indirect strategies actually mitigate plants' emissions because scholars have yet to test their effects using plant-level emission data. Here we use a newly released data source to determine whether states' policies significantly shape individual power plants' CO_2 emissions. Findings reveal that certain types of direct strategy (emission caps and GHG targets) and indirect ones (public benefit funds and electric decoupling) lower plants' emissions and thus are viable building blocks of a federal climate regime.

The EPA's state-based plan for regulating power plants' CO_2 emissions is founded on section 111(d) of the Clean Air Act, which requires the EPA to set performance standards for stationary sources of pollution, including power plants, but also directs it to work with states in developing policies to help polluters meet those standards. Given that the EPA has previously used this section to set limits on the level of nitrogen oxides and sulphur dioxide emitted by power plants, many believe that the EPA will have ample authority to establish and require states to implement the type of level-based system for regulating carbon pollution described in its Clean Power Plan[2,3]. What seems less certain is whether states have the capacity to significantly decrease power plants' carbon pollution.

Over the past two decades, states have created several policies that, in principle, could cut power plants' level of CO_2 emissions. These policies range from those such as GHG targets that were primarily motivated to combat emissions to other programs such as renewable portfolio standards that were created for other reasons but, because they try to alter how energy sources are used or managed, have implications for plants' climate-disrupting pollution[4–7]. For want of a better term, we refer to the latter programs as energy policies with climate implications. Scholars disagree, though, over whether these state initiatives are capable of reducing carbon emissions. Some argue that climate-focused policies and energy policies with climate implications can both be effective[8]. Others contend that only climate-focused policies can work[9]. Still others claim that both types are too constitutionally constrained or institutionally weak to have a significant impact[10]. Researchers have analysed the conditions under which states adopt climate-focused policies and energy policies with climate implications[11–15], their financial costs and benefits[16], their implications for the development of low-carbon energy technologies[17,18], their impact on the share of renewable energy electrification[19], and their simulated effects on future CO_2 emissions[20]. However, they have rarely assessed the effects that states' policies have had on emission outcomes. On the few occasions they have[8,21], scholars have investigated the effects of policies on the aggregate CO_2 emissions of states' electricity sectors.

Consequently, researchers stop short of examining whether states' policies reduce carbon emissions at the actual sites where electricity is produced and carbon dioxide is released—power plants. This despite other studies showing that within an industrial sector, some facilities pollute much more than others and organizational traits can affect emissions[22,23]. Studies that focus on state-level outcomes, therefore, ignore variation in power plants' emissions. They also fail to address the possibility that the observed effects of states' policies may be explained by features of plants themselves such as their size, primary fuel, pollution control equipment, dispatch systems, and whether they are publicly or privately owned[24]. In addition to these internal characteristics of plants, there may be external factors or attributes of plants' states and regions that determine the adoption of policies and thus could explain their effects. The association between emission outcomes and states' policies may be due, for example, to the fact that some policies are easier to pass in states where the coal, oil and gas industries are weak, the Democratic party exercises more control, the potential for renewable energy is high, energy efficiency is a fiscal priority, cleaner fossil fuels such as natural gas have become more affordable, and the regional demand for electricity is growing[12,25]. Until research determines the net effects of states' policies, it will be difficult for environmental officials to know which state policies produce effective and generalizable results.

Scholars have been slow to identify which state policies reduce CO_2 emissions at the level of power plants because systematic, plant-specific data on CO_2 emissions have largely been unavailable. Recently, though, the EPA began requiring power plants to submit information on their carbon pollution under its Greenhouse Gas Reporting Program (GHGRP). Using these data and other information on power plants and state/region characteristics, we conduct the first analysis of the effects of states' climate-focused policies and energy policies with climate implications. To determine how states' policies fared around the time of the recent recession, we use a lagged dependent-variable model that examines plants' emissions in the year 2010, controlling for their emissions in 2005.

Table 1 lists the policies to be tested, the states that have adopted them, and how long they have been in place (as of 2010). This list

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Table 1 | States' years of experience with climate-focused policies and energy policies with climate implications (as of 2010).

Climate-focused policies
Emission caps
1–4 years: CT, DE, FL, IL, MD, MA, MT, NJ, OR, WA
≥5 years: CA, ME, NH, NY, VT
GHG targets
1–4 years: None
≥5 years: AZ, CA, CO, CT, FL, HI, IL, ME, MA, MN, NJ, NM, NY, OR, RI, VT, VA, WA
Climate action plan
1–4 years: AR, CA, CO, FL, IA, KY, MD, MN, MT, NV, NG, NY, NC, OH, PA, SC, VT, VA, WA, WI
≥5 years: AZ, CT, IL, ME, MA, MI, NM, OR, RI
GHG registry/reporting
1–4 years: CA, FL, IA, NC, OR, WA
≥5 years: CT, DE, MD, ME, MA, NM, NY, RI, VT, WI
Energy policies with climate implications
Efficiency targets
1–4 years: CO, HI, IL, MD, MA, MI, MN, NV, NJ, NM, NC, OH, OR, PA, VT
≥5 years: CA, CT, NY, RI, TX, WA
Renewable portfolio standards
1–4 years: AZ, CO, CT, DE, IL, MD, MA, MI, MO, NH, NM, NC, OR
≥5 years: CA, HI, IA, ME, MN, MT, NV, NJ, NY, PA, RI, TX ,WA, WI
Public benefit fund
1–4 years: AZ, NE, NV, OH, TX, VA
≥5 years: CA, CT, DE, HI, IL, ME, MA, MI, MN, MT, NJ, NM, NY, OR, PA, RI, WI
Electric decoupling
1–4 years: CT, ID, MA, MN, NY, RI, VT, WI
≥5 years: CA, MD, OR

The renewable portfolio standards examined here are all binding and not voluntary.

approximates the range of measures that states have used to address power plants' carbon emissions. The first set of policies, which are explicitly climate-focused, include emission caps (carbon dioxide performance standards designed to reduce CO_2 emissions), GHG targets (goals for reducing GHG emissions to a certain level by a certain date), climate action plan (comprehensive strategies for reducing a state's CO_2 emissions), and GHG registry/reporting (systems that require plants to register and record their emissions and emissions reductions).

The next set of policies, which are energy related and have implications for the climate, include efficiency targets, renewable portfolio standards, public benefit funds, and electric decoupling. An efficiency target is a standard used to encourage more efficient generation, transmission and use of electricity and natural gas. A renewable portfolio standard requires electric utilities to deliver a certain amount of electricity from renewable or alternative energy sources. A public benefit fund provides financial assistance for energy efficiency, renewable energy, and research and development. Electric decoupling eases the pressure on utilities to sell as much energy as possible by eliminating the relationship between revenues and sales volume.

Table 1 suggests that there is considerable variation in the popularity of policies and the time since states have adopted them. For example, adopting a climate action plan is the most common policy, having been adopted by 29 states, most of which have 1–4 years of experience with it. Electric decoupling is the least common, having been adopted by only 8 states, 3 of which have used it for just 1–4 years.

In Table 2, we test the effects of the four climate-focused policies on power plants' CO_2 emissions in 2010, controlling for plants' characteristics, attributes of plants' states and regions, and plants' emission levels in 2005. With respect to plant characteristics, we see that plants that primarily rely on coal and are large have significantly higher emissions across all models. In contrast, plants founded at later dates consistently have lower emissions. Plants that use equipment to control the release of other pollutants have higher emissions. This may suggest that such technologies curb the emission of other harmful chemicals, but they also require more electricity to operate and thus contribute to the discharge of more carbon dioxide[26]. Independent system operators (ISOs) and regional transmission organizations (RTOs), which facilitate more efficient transfers of energy, significantly lower plants' emissions in all four models.

Turning to the other controls, we see that a state's potential for renewable energy and a change in its natural gas prices significantly shape plants' emissions in four models. Being in a region where electric output is rising (an indication of growing demand for electricity) significantly increases plants' CO_2 emissions in three models. As expected, plants' previous emission levels are strongly related to their current ones in every model. The F-statistic for the parent group dummies is significant, indicating that we can reject the hypothesis that parent companies exert a jointly insignificant effect on emissions.

Most importantly, we see that net of controls, two of the four climate-focused policies are significant determinants of plants' emissions. Specifically, in states where the arguably most direct measures—emission caps and GHG targets—have been in place for at least five years, plants' emissions are lower. Several of these states are participants in the Regional Greenhouse Gas Initiative[27]. In contrast, the two most widely implemented policies examined here—climate action plan and GHG registry/reporting—have no effect. This may be because some climate action plans are just one-off bureaucratic reports and the emissions data reported to some GHG registries are not always sufficiently publicized to mobilize local pressure on polluting plants.

In Table 3, we examine the effect of energy policies with climate implications. Net of the controls, whose effects are essentially unchanged, we see that efficiency targets and renewable portfolio standards have no effect on plants' emissions, whereas public benefit funds and electric decoupling are significant determinants. Efficiency targets may be ineffectual because, if working properly, they would decrease demand for electricity as well as cleaner renewables. Renewable portfolio standards may do little to reduce CO_2 emissions because most renewables are intermittent and therefore may still force plants to rely on more reliable, carbon-intensive fuels, especially where hydropower or storage technologies are unavailable[9]. That public benefit funds and electric decoupling reduce emissions is consistent, respectively, with the argument that levies assigned to customers' electricity bills can be used to stimulate utility investments in clean energy activities and the notion that utilities are likelier to engage in such activities when they can make more money by selling less electricity. Surprisingly, electric decoupling produces more immediate results than the two successful climate-focused policies, providing significant emission reductions in the shorter and longer term.

In general, findings reveal that certain policies devised by states to mitigate climate change have begun to reduce the emissions of the largest sources of GHGs—power plants. As more data from the EPA's annual GHGRP become available, we plan to investigate whether plants with or without the most effective policies continue to diverge in their environmental performance.

Table 2 | Lagged dependent-variable regression analysis of the effects of states' climate-focused policies on power plants' 2010 CO_2 emission levels.

	1	2	3	4
Plant characteristics				
Coal fuel (1 = yes)	0.294*	0.307*	0.302*	0.319*
	(0.141)	(0.152)	(0.152)	(0.151)
Size	0.003**	0.003**	0.003**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)
Year founded	−0.012***	−0.013***	−0.013***	−0.012***
	(0.003)	(0.003)	(0.003)	(0.003)
Equipment to control other pollutants	0.290*	0.289*	0.292*	0.283*
	(0.148)	(0.147)	(0.148)	(0.143)
ISO/RTO (1 = yes)	−0.283*	−0.337**	−0.334**	−0.340**
	(0.144)	(0.142)	(0.143)	(0.141)
Public utility (1 = yes)	−0.075	−0.097	−0.133	−0.105
	(0.393)	(0.396)	(0.388)	(0.384)
State/region attributes				
Coal industry influence	−69.308	−66.912	−72.134	−74.784
	(44.326)	(44.764)	(45.113)	(44.195)
Oil and gas industry influence	141.240	138.143	147.521	140.683
	(117.992)	(117.041)	(118.640)	(116.661)
Democratic control (1 = yes)	−0.163	−0.207	−0.193	−0.120
	(0.193)	(0.186)	(0.188)	(0.193)
Percentage of spending on efficiency	−38.195	−68.985	−46.356	−80.167
	(60.629)	(57.959)	(63.197)	(58.386)
Renewable energy potential	−0.008**	−0.007*	−0.006*	−0.009**
	(0.003)	(0.003)	(0.003)	(0.003)
Change in natural gas prices	0.163*	0.175*	0.213*	0.191*
	(0.076)	(0.086)	(0.094)	(0.094)
Change in regional electric output	4.809*	4.011*	2.546	3.952*
	(2.350)	(2.192)	(2.839)	(2.008)
Number of other tested policies	−0.012	0.043	−0.095	−0.165
	(0.092)	(0.132)	(0.096)	(0.087)
Previous pollution				
Logged emission level in 2005	0.824***	0.820***	0.824***	0.818***
	(0.041)	(0.041)	(0.041)	(0.041)
Policies				
Emission caps (1–4 years)	−0.178			
	(0.242)			
Emission caps (≥5 years)	−0.511*			
	(0.233)			
GHG targets (1–4 years)		—		
GHG targets (≥5 years)		−0.286**		
		(0.107)		
Climate action plan (1–4 years)			−0.023	
			(0.219)	
Climate action plan (≥5 years)			−0.151	
			(0.300)	
GHG registry/reporting (1–4 years)				−0.097
				(0.267)
GHG registry/reporting (≥5 years)				0.337
				(0.256)
Constant	−22.529	−23.351	−24.038	−22.942
R^2	0.776	0.774	0.772	0.772
N	1129	1129	1129	1129
Number of groups	846	846	846	846
F-statistic of joint significance for group effects	1.88	1.87	1.87	1.86
p value for F-statistic	0	0	0	0

Regression coefficients are unstandardized. Standard errors are in parentheses, p = * ≤ 0.05; ** ≤ 0.01; *** ≤ 0.001 (two-tailed tests). Models include group dummies for parent companies.

Table 3 | Lagged dependent-variable regression analysis of the effects of states' energy policies with climate implications on power plants' 2010 CO_2 emission levels.

	1	2	3	4
Plant characteristics				
Coal fuel (1 = yes)	0.297*	0.294*	0.296*	0.271*
	(0.149)	(0.145)	(0.140)	(0.128)
Size	0.003**	0.003**	0.003**	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
Year founded	−0.012***	−0.012***	−0.013***	−0.011***
	(0.003)	(0.003)	(0.003)	(0.003)
Equipment to control other pollutants	0.329*	0.314*	0.330*	0.367*
	(0.148)	(0.148)	(0.148)	(0.150)
ISO/RTO (1 = yes)	−0.236	−0.268*	−0.192	−0.175
	(0.149)	(0.128)	(0.158)	(0.156)
Public utility (1 = yes)	−0.165	−0.124	−0.142	−0.024
	(0.386)	(0.387)	(0.385)	(0.392)
State/region attributes				
Coal industry influence	−73.488	−75.689	−84.395	−81.787
	(44.857)	(44.711)	(45.943)	(44.238)
Oil and gas industry influence	84.633	121.065	106.467	128.666
	(126.925)	(125.919)	(123.318)	(123.693)
Democratic control (1 = yes)	−0.213	−0.254	−0.285	0.081
	(0.190)	(0.208)	(0.214)	(0.250)
Percentage of spending on efficiency	−62.311	−77.174	−73.160	−10.640
	(58.916)	(57.950)	(56.198)	(64.924)
Renewable energy potential	−0.006*	−0.007*	−0.008*	−0.009**
	(0.003)	(0.003)	(0.003)	(0.003)
Change in natural gas prices	0.172*	0.197*	0.251**	0.182*
	(0.087)	(0.087)	(0.089)	(0.088)
Change in regional electric output	4.602*	5.134	3.757	6.201*
	(2.249)	(2.575)	(2.215)	(2.610)
Number of other tested policies	−0.156	−0.113	0.045	−0.093
	(0.107)	(0.088)	(0.104)	(0.067)
Previous pollution				
Logged emission level in 2005	0.821***	0.826***	0.831***	0.821***
	(0.041)	(0.041)	(0.041)	(0.041)
Policies				
Efficiency targets (1–4 years)	0.187			
	(0.184)			
Efficiency targets (≥5 years)	−0.029			
	(0.272)			
Renewable portfolio (1–4 years)		0.179		
		(0.218)		
Renewable portfolio (≥5 years)		0.018		
		(0.251)		
Public benefit fund (1–4 years)			−0.367	
			(0.238)	
Public benefit fund (≥5 years)			−0.447*	
			(0.224)	
Electric decoupling (1–4 years)				−0.528*
				(0.245)
Electric decoupling (≥5 years)				−0.913**
				(0.351)
Constant	−21.989	−23.119	−23.601	−19.963
R^2	0.774	0.773	0.771	0.774
N	1129	1129	1129	1129
Number of groups	846	846	846	846
F-statistic of joint significance for group effects	1.87	1.88	1.88	1.86
p value for F-statistic	0	0	0	0

Regression coefficients are unstandardized. Standard errors are in parentheses, $p = {}^{*} \leq 0.05$; $^{**} \leq 0.01$; $^{***} \leq 0.001$ (two-tailed tests). Models include group dummies for parent companies.

Of course, ours is not the final word on the efficacy of particular policies. Some of those we found to be ineffective as of 2010 might eventually become significant determinants. For instance, the first compliance period for several renewable portfolio standard policies had not occurred by 2010. Conversely, earlier adopted policies may have reduced emissions in the years leading up to the base year of 2005.

In addition, our study does not examine the optimal way to design individual policies. More research is needed on whether certain variations on a policy—for example, whether renewable portfolio standards allow the trading of renewable energy credits and/or have aggressive, binding targets[12]—make a difference in power plants' environmental performance. Likewise, more studies are needed to determine the most effective policy combinations[28] and the mechanisms through which policies affect emissions. For instance, energy efficiency targets may reduce emissions when bundled with electric decoupling. With respect to mechanisms, renewable portfolio standards may reduce emissions by moving electricity production away from fossil-fuel plants, or, by raising the cost of electricity.

We also recognize the importance of overall carbon outputs; increased efficiency at the plant level could be negated if the total number of power plants or amount of electrical output increases in the future. Our study does not address potential problems involving 'carbon leakage' or interactions with other climate-related policies such as fuel economy standards[29]. Finally, although our models control for state-level changes in natural gas prices and plants' dispatch systems (ISO/RTOs), the effects of lower gas prices may be more complex than our models capture. Other studies estimate that between 2005 and 2010, the US electricity sector's CO_2 emissions dropped by 6% and its carbon intensity fell by 2.5% (ref. 25), suggesting that much of the decline in emission levels was due to electricity mix switching. Future studies, therefore, will need to tease out the direct effects of fuel switching on plants' emissions from the indirect ways that states' policies facilitate the shift to natural gas.

These limitations notwithstanding, our findings offer encouraging news about the efficacy of states' policies. The fact that some have decreased individual power plants' emissions after controlling for several other possible determinants highlights their potential as regulatory tools and suggests that states are capable of achieving the emission goals set by the federal government.

Methods

We constructed a data set that includes indicators of US fossil-fuel electric power generation facilities' CO_2 emissions in 2010 (NAICS code 221112) as well as other relevant factors. Although our sample ($N = 1,129$) contains about a third of all power plants in the United States in 2010 ($N = 3,406$), this is largely because the GHGRP data on emissions primarily include plants that met the EPA's criterion of a 'major source' polluter (emits 25,000 metric tons or more CO_2 equivalent in a year) and were required to submit emissions reports ($N = 1,426$). Of these plants, 297 were excluded from our analysis because information on their internal characteristics (for example, type of ownership) and/or 2005 emissions were unavailable. Importantly, the 1,129 plants examined here, by themselves, account for 90.1% of all carbon dioxide emitted by the electricity sector.

Our measure of emission level (total pounds of emitted carbon dioxide in 2010) is transformed using a logarithmic function to account for the skewed distribution of emissions across plants. Our indicators of states' climate-focused policies and energy policies with climate implications come from the Pew Center on Global Climate Change and the Database of State Incentives for Renewables and Efficiency. As the amount of experience a state has with a policy may affect its success, we tested the effects of each of these policies using a set of dichotomous variables—one indicating whether a particular state policy had been implemented for five years or more as of 2010 (1 = yes) and another indicating whether a policy had been in place for 1 to 4 years (1 = yes). (We coded states that adopted a policy in 2010 as having one year of experience, adoption in 2009 as having 2 years of experience and so forth.) The comparison group consisted of plants whose states had never adopted the policy as of 2010 (0 = never).

Using data collected by the US Energy Information Administration (EIA), we also tested the effects of plants' characteristics, namely whether coal is their primary fuel (1 = yes), their size (nameplate capacity), the year they were founded, whether they use equipment to control other pollutants (nitrogen oxides; 1 = yes), whether they fall into a balancing authority area governed by an ISO or are part of a RTO that facilitates more efficient power flows and transactions (1 = yes), and whether they are a public utility (1 = yes). With respect to pollution control equipment, we examined devices for pollutants other than nitrous oxide but found that they had no effect on CO_2 emissions. Also, we did not control for a plant's electrical output because it was highly correlated with other predictors in our models (size and previous pollution) and our purpose here is to analyse levels rather than rates of emission. Using data from the US Statistical Abstracts, the US Department of Energy's National Renewable Energy Laboratory, the American Council for an Energy-Efficient Economy, and the US EIA, we assessed the effects of the following attributes of a plant's state and region: coal industry influence (coal employment per 1,000 residents), oil and gas industry influence (oil and gas workers per 1,000 residents), Democratic control (1 = Democratic governor and Democratic majority in both legislatures), percentage of state expenditures on energy efficiency, technical potential for renewable energy, change in natural gas prices between 2005 and 2010, change in a census region's net electric output between 2005 and 2010 (a proxy for increases in electricity demand that might drive up emissions) and the number of other tested policies (that is, the total of climate-focused and climate-implication policies in a state without the specific policy being examined).

To analyse changes in plants' emissions over time, we used lagged values of (logged) emission levels for 2005, which were derived by aggregating data on the emissions of multiple generators for that year (compiled by the US EIA) up to the plant level. We report findings here using a lagged dependent-variable model[30]. The effects of states' policies generated by this model are essentially the same as those produced by a change score specification (Supplementary Note and Tables). We also used a single cross-section of 2010 data rather than continuous panels because the GHGRP data were available only for 2010 at the time this study was conducted and several of our predictors were measured only in that year.

In conducting ordinary least-squares regression analyses of the determinants of power plants' CO_2 emissions, we effectively control for the average differences across parent companies in any observable or unobservable predictors by including dummies for each parent company in our models. In doing so, we also account for the fact that there is not the same number of plants in each company. Finally, we conducted robustness checks, the results of which indicated that our standard error estimators were not biased by heteroskedasticity.

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Author contributions

D.G. conceived of the study, performed data analysis, and wrote the text. K.B. and K.R. conducted data collection and helped to write and edit the manuscript.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to D.G.

Competing financial interests

The authors declare no competing financial interests.