Analyzing the Closure of Coal-Fired Power Plants in the Regional Greenhouse Gas Initiative States 2000-2015

by

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April 28, 2017

Master's Project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University.

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Abstract

The Regional Greenhouse Gas Initiative (RGGI) is a cap-and-trade program in the Northeast and Mid-Atlantic covering power sector carbon dioxide emissions. Many expect policies aimed at reducing carbon dioxide emissions, like RGGI, to cause coal-fired power plant closures as a way of complying with emissions reduction requirements, given the relatively higher carbon intensity of coal plants (as opposed to other fuel types) and the limited availability of carbon dioxide pollution control technology. This analysis qualitatively and quantitatively evaluates coal closures within the RGGI states between 2005 and 2015 to identify the extent to which RGGI caused these closures. A qualitative analysis of media reports and press releases surrounding the closures indicates that RGGI did not play a role in any of the closures; however, regression analysis suggests that RGGI did have a statistically significant impact in causing closures. The RGGI closures are compared to closures in the non-RGGI states as well as closures occurring before the policy was announced.

Executive Summary

The Regional Greenhouse Gas Initiative (RGGI) is a cap-and-trade program in the Northeast and Mid-Atlantic covering power sector emissions of carbon dioxide. The goal of the program is to curb planet-warming emissions from states within its jurisdiction by placing an overall limit (cap) on emissions and auctioning allowances that give the holder a permit to emit one ton of carbon dioxide, which can be bought and sold (traded) among covered entities. A cap-and-trade program seeks to lower societal compliance costs by prioritizing the cheapest available reductions: those firms for whom reductions are cheapest will reduce their emissions to comply while those firms for whom reduction will be more expensive can acquire allowances to comply.

A 2015 paper by Brian Murray and Peter Maniloff found that RGGI was responsible for 50% of the carbon dioxide emissions reductions experienced by the region since the program's implementation began in 2009. (The other 50% of the emissions reductions were attributable to lower natural gas prices, complementary policies, and a downturn in production resulting from the economic recession.) This analysis seeks to evaluate how those RGGI-motivated emissions reductions were achieved and whether RGGI was truly responsible for the reductions.

Under a carbon dioxide cap-and-trade program, emissions reductions will likely be realized through fuel switching away from high carbon emitting sources such as coal and oil towards low- and zero-emitting sources of electricity, like natural gas and renewables. Fuel switching can be done in three ways:

- Reduced utilization of units using more carbon-intensive fuel;
- Switching the fuel source of the generating unit; or
- Closing units using high carbon sources and opening new units fired by a less carbon-intensive source of fuel.

Due to the economic and technological constraints associated with the first two fuel switching options, the closure of high emitting units is expected to be the most prevalent option for entities looking to reduce their carbon dioxide emissions. Moreover, there is currently no economically viable pollution control technology for carbon dioxide, so changes would have to made at the input, rather than the output, stage of electrical generation.

Employing decomposition analysis, a technique that attributes changes in emissions to changes in operational factors related to the power sector, this analysis finds that fuel switching was indeed the primary factor driving carbon dioxide emissions reductions in RGGI after the announcement of RGGI.

The fuel-switching activity of interest herein is coal plant closure. Between 2006 (after the announcement of the RGGI program) and 2015, half of the coal plants that existed in the RGGI states closed. Over that same time period, only a quarter of the coal plants that existed in the rest of the United States closed. Generation from coal made up only 7% of the resource mix in the RGGI states by 2015, while it was still 40% of the resource mix in the rest of the United States in 2015. Clearly, the RGGI states were experiencing a disproportionate drop in coal utilization compared to non-RGGI states. If this switch away from coal was indeed motivated by RGGI, then that would suggest that RGGI is indeed a significant source of emissions reductions it is believed to be based on Murray and Maniloff's analysis.

A qualitative analysis of local and national news media reports, press releases, and utility website related to the closure of coal plants in the RGGI states did not reveal RGGI as a primary motivator of the closures. In fact, none of the coal plant closures in the RGGI states after the announcement of RGGI cited the RGGI program as a reason for closure.

However, a regression analysis revealed that RGGI did have a statistically significant impact in driving coal plant closures after the announcement of RGGI. The regression analysis controlled for potential confounding variables, including age of the plant (older plants are more likely to close), size of the plant (smaller plants are more likely to close), the existence of other environmental regulations on the power sector, and time.

While the failure or success of the RGGI program should not hinge on closing coal plants, it certainly provides a marker of not only the methods of compliance that can be taken with a carbon dioxide regulatory program, but also the outcomes that might occur given the pressing need to address climate change through policy.

Introduction

Finding methods for controlling greenhouse gas emissions has recently become more important than ever, due to the confluence of scientific, political, and international forces pushing climate change to the forefront of global issues. Scientists found that 2016 surpassed 2015 as the hottest year on record.[1] World leaders met in Paris at the end of 2015 for the 21st Conference of the Parties and made a historic agreement to curb global warming to 2 degrees Celsius, with attempts to limit warming to 1.5 degrees Celsius, above pre-industrial levels.[2]

As the political arena moves slowly towards consensus that greenhouse gas emissions need to be controlled through regulatory measures, designing the right type of policy to complete this daunting task has become a serious challenge. Many scholars recommend economic incentives, such as carbon taxes or cap-and-trade programs, as the best policy tool for driving greenhouse gas reductions as preferred to command-and-control regulation that is highly prescriptive for individual sources and leaves little room for cost-effectiveness across sources and technological innovation.[3] One such market-based program is the Regional Greenhouse Gas Initiative (RGGI), an interstate cap-and-trade program covering power sector carbon dioxide emissions in nine states in the Northeast and Mid-Atlantic regions of the United States: Connecticut, Delaware, Maine, Massachusetts, Maryland, New Hampshire, New York, Rhode Island, and Vermont. (New Jersey was in the program but left at the end of 2013; however, it will be included in this analysis.)

A cap-and-trade program places an overall cap on emissions to be met by a jurisdiction and creates allowances, totaling the amount of the cap, to be traded among sources covered by the program. This allows economically efficient reductions to be made; in other words, measures will be taken to reduce emissions where it is cheaper at the margin than the allowance price, while allowances will be purchased by sources for whom reducing emissions is more expensive at the margin than the allowance price. Depending on the policy, allowances are allocated directly to sources or auctioned. Trading can then take place among sources of

[1] Justin Gillis, "Earth Set a Temperature Record for the Third Straight Year," *The New York Times*, January 18, 2017.
[2] Coral Davenport, "Nations Approve Landmark Climate Accord in Paris," *The New York Times*, December 12, 2015.
[3] Joseph E. Aldy and William A. Pizer, "Issues in Designing U.S. Climate Change Policy," *Energy Journal* Volume 30, Number 3 (2009): 179.

emissions, where entities that took measures to reduce emissions can either sell their allocated allowances to other sources or forego purchase at an auction, and entities that cannot take those measures may purchase allowances from other sources or at an auction in order to cover their emissions. In the simplest terms, cap-and-trade programs make polluters pay for the pollution they cause. Therefore, finding the cheapest ways to reduce carbon dioxide emissions becomes a priority for the covered entity (in the case of RGGI, an electric power utility) under a cap-and-trade program. Covered entities have a number of options for reducing emissions to comply with a cap-and-trade regulation. They can:

- install pollution control technology to reduce emissions at the source;
- switch to a fuel source that emits less of the regulated pollutant; or
- acquire credits sufficient to cover their total emissions of the pollutant.

When examining whether a cap-and-trade program has been effective, policy analysts will look at which of these choices sources made and how that impacted emissions.

For carbon dioxide, it is widely accepted that fuel switching from coal to natural gas has propelled much of the carbon dioxide emissions reductions from the electric power sector across the country, both within and outside of the RGGI states.[4] Pollution control technology for carbon dioxide is not economically viable at this time, so fuel switching takes center stage as the best method for reducing carbon dioxide emissions. Fuel switching can take on three forms:

- utilities can switch the fuel used at that unit;
- utilities reduce utilization at a unit using a particular fuel source and replace that generation with generation from another fuel source; or
- utilities can close units and replace the old unit's generation with generation from new units that operate with a different fuel.

In particular, coal-fired power plant closures have become more common in the Unites States as utilities build new natural gas facilities.

It is important for analysts to look at what motivated coal closures in recent years: is it policy, is it changes in energy markets with prices favoring lower-emitting natural gas, is it

[4] "Today in Energy: U.S. Energy-Related Carbon Dioxide Emissions in 2015 are 12% Below Their 2005 Levels," *U.S. Energy Information Administration*, May 9, 2016.

simply plant age or is it a combination of the above? RGGI provides an excellent test case for looking at the effectiveness of one critical policy in driving coal closures. RGGI was announced around the same time that the price of natural gas dropped precipitously in the United States, meaning there are straightforward temporal and spatial groupings to compare the frequency of and motivations behind the coal closures.

Beginning with a decomposition analysis, this study will illuminate the reasons for major changes in the electric power sector within and outside of the RGGI states, as well as the United States as a whole. This will confirm what others have observed—that United States carbon dioxide emissions are declining primarily due to fuel switching from coal to natural gas—as well as provide the relative significance (or magnitude) of that trend. In addition, the decomposition will provide some context for power sector as a whole, as well as what factors are present or stronger within and outside of the RGGI states.

Then, this study will move on to seek an answer to the following question: To what extent did RGGI accelerate the closure of coal-fired power plants in covered states? I will test the hypothesis that RGGI accelerated the closure of certain coal-fired power plants after its announcement. In other words, I will seek to find whether coal-fired power plants closed at a higher rate in the RGGI states following the announcement of RGGI than in the rest of the country, where RGGI had no direct influence.

Methods

Generating units will be sorted into four spatial and temporal groupings in order to test the effect of RGGI on the closures. The four groupings are:

- RGGI units 2000-2005
- RGGI units 2006-2015
- Non-RGGI units 2000-2005
- Non-RGGI units 2006-2015

The spatial sorting accounts for the area covered by the RGGI policy. The temporal sorting accounts for the date of the RGGI announcement (December 2005). As previously mentioned, the latter half of the 2000s also saw a steep decline in the price of natural gas, so examining the time period before 2006 in both spatial groupings seeks to account for the influence of a drop in natural gas prices. The test group is, of course, the group of RGGI units 2006-2015. In statistical terms, this group of units received the “treatment” of a cap-and-trade programs regulating carbon dioxide emissions.

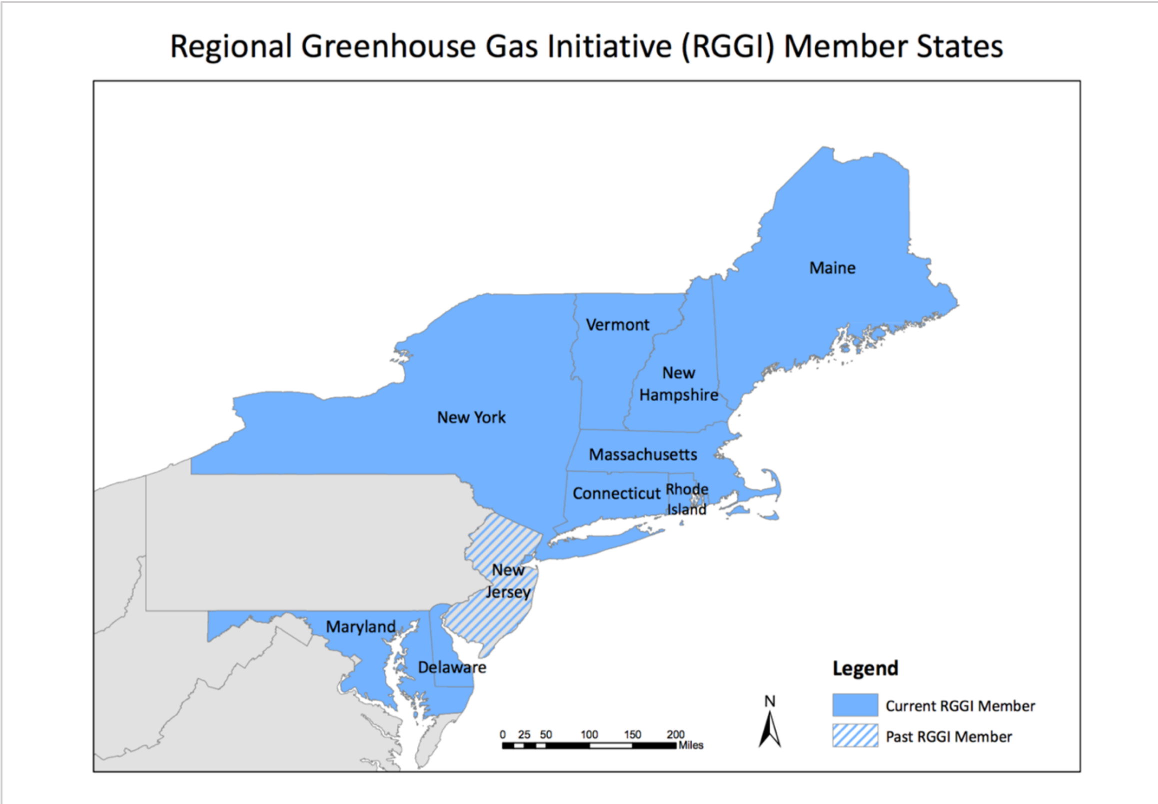
For the purposes of this study, a coal closure is defined as a plant that shut down all of its coal capacity in the corresponding time period. That could mean that the entire plant shut down or, alternatively, that all coal units shut down—with no intention of re-starting—and other gas- or oil-fired units at the plant remained operational.

This analysis will employ both qualitative and quantitative measures for examining the factors contributing to the closure of coal-fired power plants. The study begins with a decomposition analysis of emissions in order to more broadly assess the reasons for change and relative significance of each of those reasons. Then, this study employs a qualitative analysis of closures, which consists of a review of relevant local and national media reports, press releases, and utility websites pertaining to the closed plants. Motivations for the closure are pulled from these sources and categorized into economic, regulatory, and other reasons for closure. These categories will be discussed in greater detail in the Qualitative Closure Report section. The qualitative analysis sets the stage for the regression analysis. The regression analysis will more specifically illuminate what is driving these closures. (The specific methodologies for these quantitative tools are detailed in their respective sections.)

Background

Before delving into the analysis, it is important to introduce RGGI in more detail, as well as provide an overview of some of the key changes happening in the electric power sector, particularly as they pertain to coal-fired power plants and their closure.

Figure 1: Map of RGGI Member States



RGGI

In 2005, six states in the Northeast and Mid-Atlantic (Connecticut, Delaware, Maine, New Jersey, New York, and Vermont) announced their intention to form RGGI.[5] In 2007 and 2008, four additional states (Massachusetts, Rhode Island, Maryland, and New Hampshire) in the region joined RGGI.[6] These states are shown above in Figure 1. The program went into effect in 2009.[7] Since then, power sector carbon dioxide emissions in the region have dropped 42% percent. Because of this steep decline, RGGI is considered by many to be remarkably successful and a paradigm for interstate cap-and-trade implementation, though the reasons for the emissions decline and the role that the program has played has been a point of contention.

[5] In December 2005, a Memorandum of Understanding (MOU) was announced by Connecticut, Delaware, Maine, New Jersey, New York, Vermont. ("Memorandum of Understanding," *Regional Greenhouse Gas Initiative*, signed December 20, 2005, last accessed April 1, 2016.)
[6] In January 2007, Massachusetts and Rhode Island joined the MOU. In April 2007, Maryland joined. In June 2008, New Hampshire joined. ("Memorandum of Understanding," *Regional Greenhouse Gas Initiative*, signed December 20, 2005, last accessed April 1, 2016.)
[7] Regional Greenhouse Gas Initiative, "RGGI Fact Sheet," Accessed March 30, 2016.

Murray and Maniloff (2015) found through an econometric analysis of carbon dioxide emissions from the RGGI states that the program itself is responsible for about 50% of the emissions reductions in the region during the time period since its announcement.[8] They also identified several other factors that explain the additional reductions, including the recession caused by the financial crisis of 2008, the increase of natural gas availability and thus the drop in natural gas prices, and complementary state policies like Renewable Portfolio Standards.[9] The 50% figure suggests that the program itself had a significant impact on emissions. Their paper does not directly examine the role that power plant closures in the region played in emissions reductions nor whether those closures can be attributed to the implementation of the RGGI program. Murray and Maniloff's analysis thus serves as partial inspiration for this analysis.

RGGI itself is a nonprofit organization that has no enforcement ability; instead, the implementation of RGGI is done by state environmental agencies.[10] State-level caps are set under terms laid out by the MOU, and these state caps total the regional cap.[11] An annual cap on carbon dioxide emissions is set, but "true-up" (the process by which regulators check that a source has sufficient allowances to cover its emissions) occurs every three years.[12] The compliance periods and cap are outlined in Table 1 below. Auctions for emissions allowances occur quarterly.[13]

During the second compliance period, two notable events affecting the cap occurred. First, New Jersey left the program, so the cap was lowered to reflect this change. (Note: New Jersey is included as part of the RGGI states for the entirety of this analysis, however.) Second, RGGI underwent a program review that led to the cap being significantly tightened at the beginning of 2014.[14] With the decline in natural gas prices leading to a corresponding surge in natural gas utilization as well as lower energy demand, carbon dioxide emissions declined

[8] Murray and Maniloff, 588.
[9] Ibid., 583.
[10] "Regional Greenhouse Gas Initiative." *Center for Climate and Energy Solutions*.
[11] Ibid.
[12] Ibid.
[13] Ibid.
[14] Ibid.

significantly. The original cap for the second compliance period was deemed insufficient for motivating further reductions, and the cap was lowered.

Table 1: RGGI Compliance Periods[15]

Compliance Period	Cap
January 1, 2009 – December 31, 2011	188 million tons
January 1, 2012 – December 31, 2014	165 million tons (2012-2013) 91 million tons (2014) Decreasing 2.5% annually through 2020
January 1, 2015 – December 31, 2017	

Changes in the Electric Power Sector

The electric power sector has undergone many dramatic economic and regulatory changes over the last two decades. Notably, markets for electricity have undergone a restructuring of how power is delivered and sold to consumers; however, this section will not address that side of power sector. Though the restructuring of electricity markets may have influenced the generation of electric power, that will be ignored for the purposes of this analysis. Instead, this analysis will focus only on changes affecting the generation of electric power. The primary changes addressed in this section are the decline in natural gas prices and regulations affecting the generation of electric power to reduce emissions.

Because of technological advancements in hydraulic fracturing, the supply of natural gas has increased significantly in the last ten years. The amount of natural gas reserves available for harnessing because of hydraulic fracturing increased by 40% between 2006 and 2008, according to a report by the Colorado School of Mines.[16] The price of natural gas dropped 46% between 2005 and 2011 due to an increase in supply, while coal prices rose.[17] Electric power generation from natural gas doubled its share of the country's resource mix from 15% to 30% between 2005 and 2015.

In the RGGI states, generation from natural gas increased at a slightly faster rate than in the rest of the United States, increasing its share of generation by 17% to the rest of the

[15] "Regional Greenhouse Gas Initiative." *Center for Climate and Energy Solutions*.
[16] Murray and Maniloff, 583.
[17] Ibid.

country's 14% between 2005 and 2015. M.K. Kim and T. Kim (2016) examined whether the RGGI program itself caused an acceleration in the generation shift from coal to natural gas within the RGGI states. Using a synthetic controls method to model natural gas generation changes based on 38 control states, the authors compared the synthetic generation change to actual natural gas generation in RGGI.[18] They found that the real natural gas generation in RGGI exceeded what would be expected (the synthetic generation change) under conditions that existed in the rest of the United States not covered in the RGGI program.[19] This paper provides strong evidence that the switch from coal to natural gas was indeed accelerated by the RGGI program. This would seem to suggest as well that the closure of coal-fired power plants would be accelerated by RGGI as well.

In addition to economic factors, there are several federal regulations that have impacted the electric power sector and coal generation in particular. The Acid Rain Program (ARP), a cap-and-trade program for sulfur dioxide, went into effect for large power plants in 1995 and for all power plants in 2000.[20] Most affected coal units were able to remain operational and simply adjust their production by installing pollution control technology or switching to low-sulfur coal, according to analysis by EIA.[21] There were not large-scale closures of coal units associated with the Acid Rain Program.

In the mid-2000s, EPA implemented two additional cap-and-trade programs for sulfur dioxide and nitrogen oxides: the Clean Air Interstate Rule, which was vacated by the D.C. Circuit court, and the Cross-State Air Pollution Rule (CSAPR), which was a replacement for the Clean Air Interstate Rule in response to the court's ruling.[22] Again, most affected coal units were able to remain operational and install pollution control technology to comply with the rules.[23]

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[18] Man-Keun Kim and Taehoo Kim, "Estimating Impact of Regional Greenhouse Gas Initiative on Coal to Gas Switching Using Synthetic Control Methods," *Energy Economics* (Vol. 59): 331-332.
[19] Ibid., 333.
[20] "Acid Rain Program," *U.S. Environmental Protection Agency*.
[21] "Today in Energy: Power Plant Emissions of Sulfur Dioxide and Nitrogen Oxides Continue to Decline In 2012," *U.S. Energy Information Administration*, February 27, 2013.
[22] "Fact Sheet: Final Cross-State Air Pollution Rule Update for the 2008 NAAQS." *U.S. Environmental Protection Agency.*
[23] Ibid.

In 2011, EPA announced the Mercury and Air Toxics Standard (MATS) to reduce mercury emissions from power plants.[24] Though this regulation was litigated heavily in court, it remained mostly intact by the time it went into effect in 2015.[25] Pollution control technology does exist for mercury; however, many experts expect coal unit closures to be a prevalent compliance tool based on the timing of the rule, as it comes alongside the drop in natural gas prices (making coal relatively more expensive), industry expectation that carbon dioxide will be regulated, as well as an aging coal fleet.[26] According to EIA, about one-third of coal capacity closures in 2015 came in the month of April, which is when MATS formally came into effect.[27] This provides a strong indication that MATS will have a significant impact on coal closures.

While the aforementioned regulations do not specifically apply to carbon dioxide, they had a far-reaching impact on coal generation in the United States and merit mention in this analysis.

I searched extensively for literature pertaining to a retrospective review of fossil-fired power plant closures and failed to find literature relevant for this analysis. Most of the literature regarding closures takes a prospective view; in other words, the literature is mostly predictive of how much capacity will close given a certain economic or regulatory scenario. A review of those predictions was not relevant for this analysis.

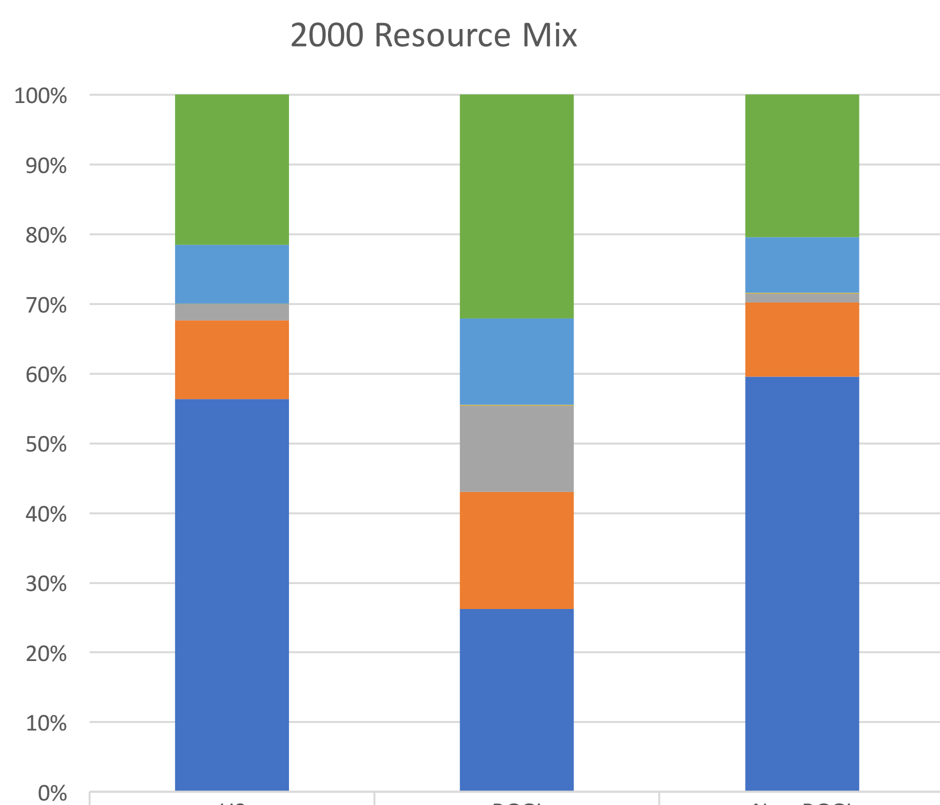
Electrical Generation in RGGI vs. Non-RGGI States

Although the RGGI and non-RGGI states are operating within similar economic and regulatory contexts (other than the presence of RGGI), they have significantly different generation portfolios. The generation portfolio (also called resource mix) describes the combination of fuels used to produce electricity. Figures 2.1-2.3 compare the resource mixes of the RGGI and non-RGGI regions, as well as the United States as a whole, in the key years in this analysis: 2000, 2005, and 2015. Figures 3.1-3.3 compare the changes within these regions and

[24] "Basic Information about Mercury and Air Toxics Standard." *U.S. Environmental Protection Agency*.
[25] Ibid.
[26] "Today in Energy: Coal Made Up More Than 80% of Retired Electricity Generating Capacity in 2015," *U.S. Energy Information Administration*, March 8, 2016.
[27] Ibid.

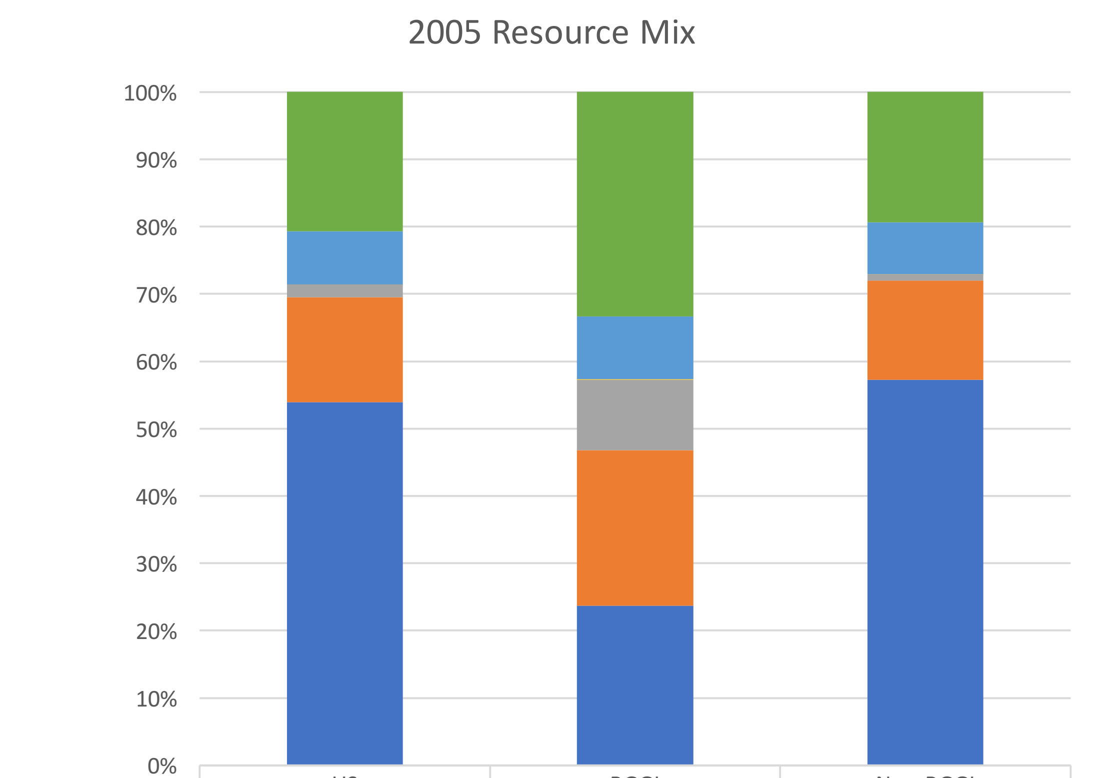
the United States as a whole across these three years. (Note: Renewable generation includes hydroelectric power, in addition to wind, solar, biofuels, and geothermal generation.)

Figure 2.1: Resource Mix Across Regions 2000



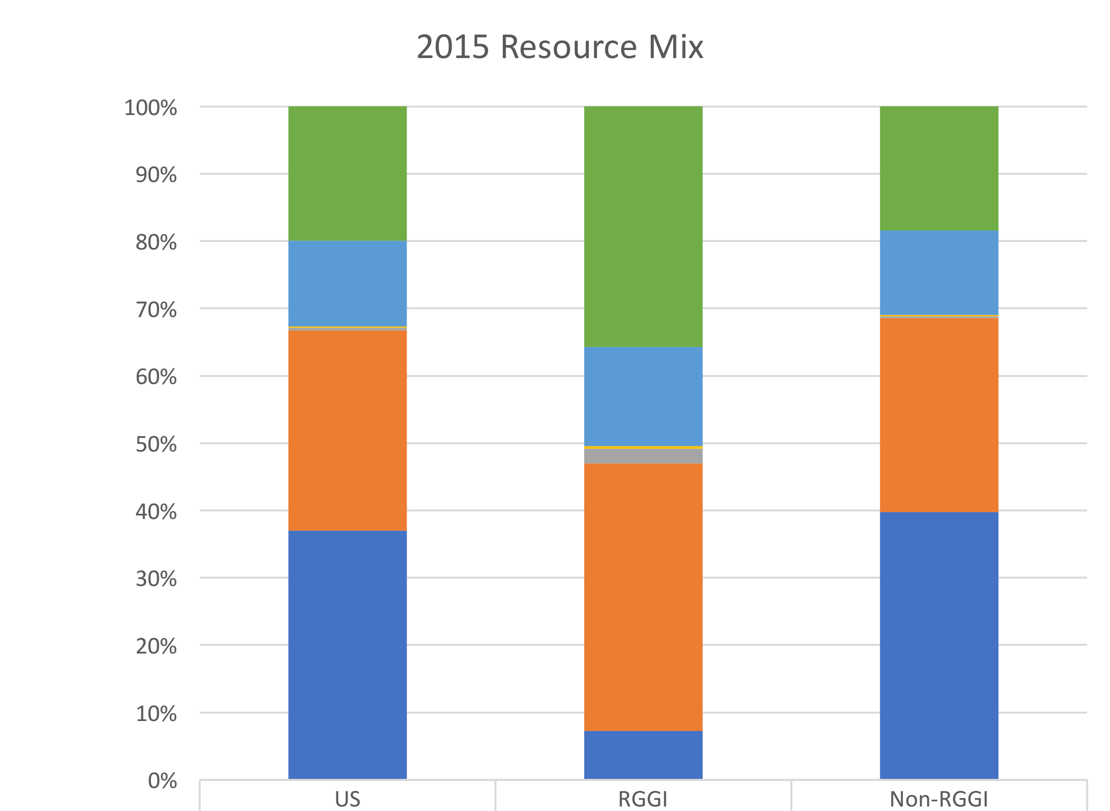
	US	RGGI	Non-RGGI
Nuclear	21.57%	32.05%	20.45%
Renewable	8.37%	12.40%	7.94%
Other Fuel	0.08%	0.10%	0.08%
Oil	2.37%	12.45%	1.29%
Gas	11.23%	16.76%	10.64%
Coal	56.38%	26.24%	59.60%

Figure 2.2: Resource Mix Across Regions 2005



	US	RGGI	Non-RGGI
Nuclear	20.69%	33.32%	19.33%
Renewable	7.88%	9.37%	7.72%
Other Fuel	0.04%	0.07%	0.04%
Oil	1.85%	10.49%	0.92%
Gas	15.60%	23.07%	14.79%
Coal	53.93%	23.68%	57.21%

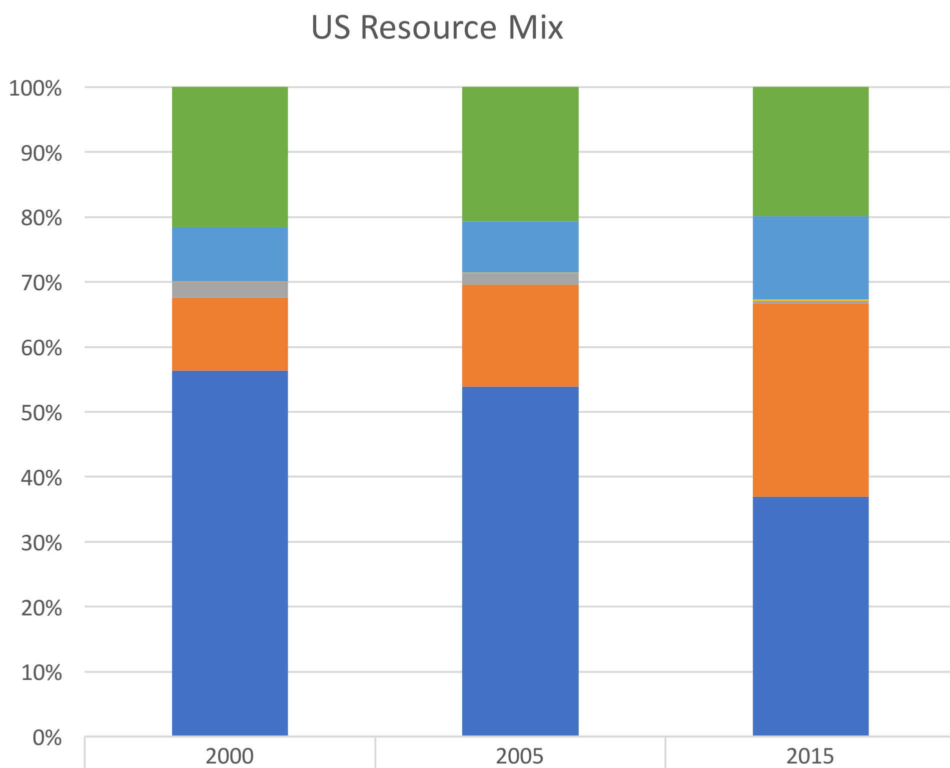
Figure 2.3: Resource Mix Across Regions 2015



	US	RGGI	Non-RGGI
Nuclear	19.92%	35.76%	18.41%
Renewable	12.77%	14.69%	12.59%
Other Fuel	0.19%	0.34%	0.17%
Oil	0.40%	2.26%	0.23%
Gas	29.75%	39.67%	28.80%
Coal	36.97%	7.27%	39.80%

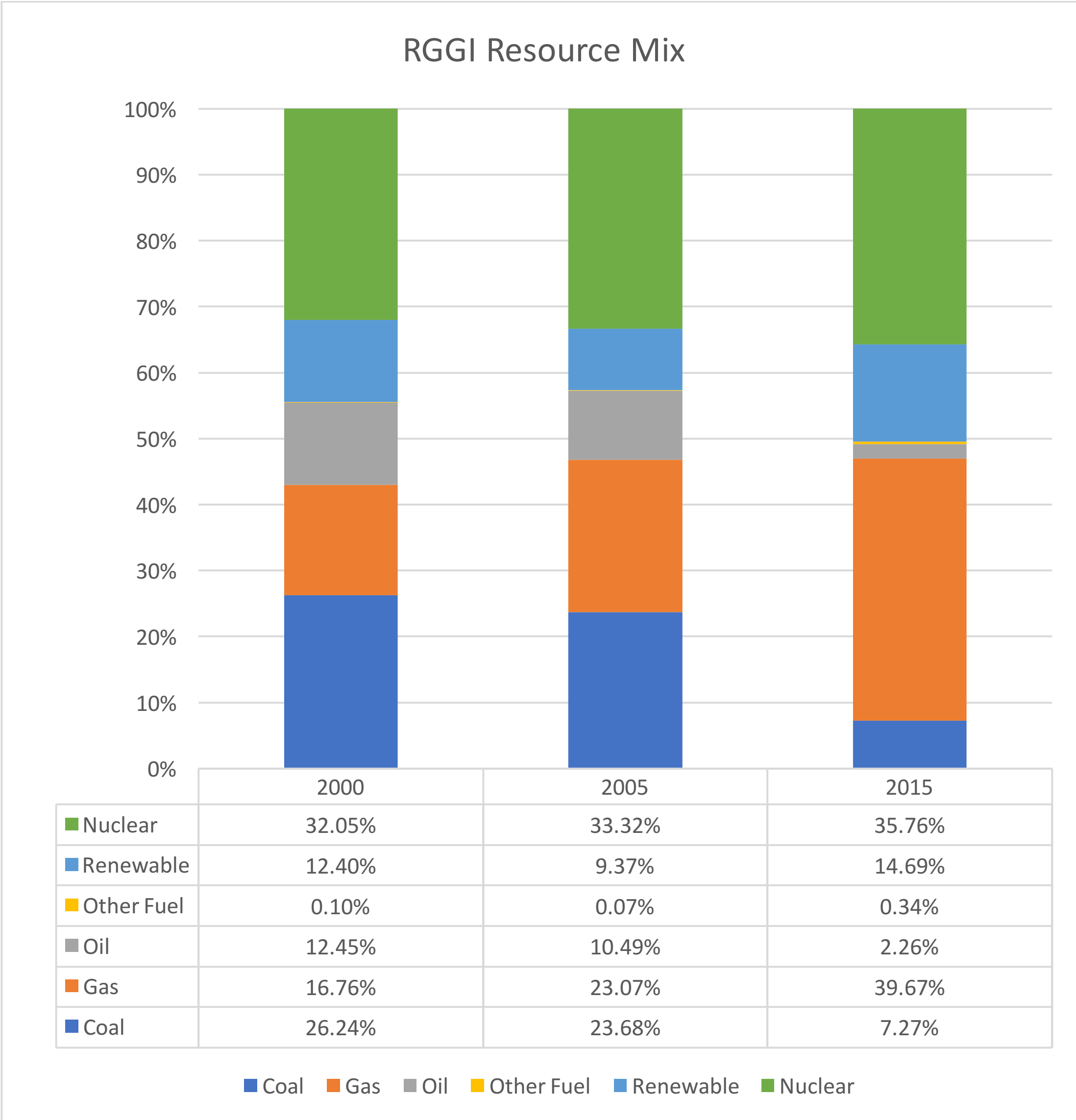
Coal Gas Oil Other Fuel Renewable Nuclear

Figure 3.1: United States Resource Mix Over Time



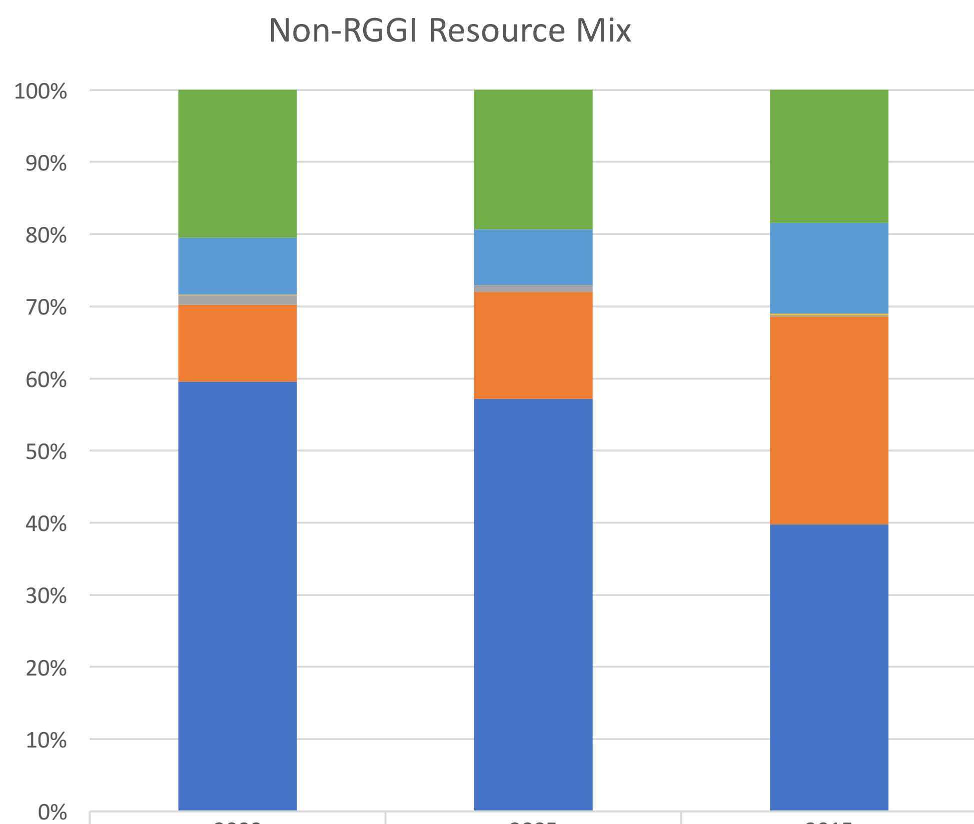
	2000	2005	2015
Nuclear	21.57%	20.69%	19.92%
Renewable	8.37%	7.88%	12.77%
Other Fuel	0.08%	0.04%	0.19%
Oil	2.37%	1.85%	0.40%
Gas	11.23%	15.60%	29.75%
Coal	56.38%	53.93%	36.97%

Figure 3.2: RGGI Resource Mix Over Time



	2000	2005	2015
Nuclear	32.05%	33.32%	35.76%
Renewable	12.40%	9.37%	14.69%
Other Fuel	0.10%	0.07%	0.34%
Oil	12.45%	10.49%	2.26%
Gas	16.76%	23.07%	39.67%
Coal	26.24%	23.68%	7.27%

Figure 3.3: Non-RGGI Resource Mix Over Time



	2000	2005	2015
Nuclear	20.45%	19.33%	18.41%
Renewable	7.94%	7.72%	12.59%
Other Fuel	0.08%	0.04%	0.17%
Oil	1.29%	0.92%	0.23%
Gas	10.64%	14.79%	28.80%
Coal	59.60%	57.21%	39.80%

Coal Gas Oil Other Fuel Renewable Nuclear

Notably, the RGGI states began with a much smaller percentage of generation from coal than the non-RGGI states, even going back to 2000. By 2005, coal made up only 24% of the RGGI states' resource mix, compared to the non-RGGI states' 57%. By 2015, coal made up only 7% of the RGGI states' resource mix, compared to the non-RGGI states' 40%. This suggests that RGGI experienced a much higher rate of coal closures than the rest of the United States.

RGGI relies much more heavily on generation from nuclear and (especially at the beginning of the assessment period) oil than the non-RGGI states. Nuclear consistently makes up about one-third of RGGI's resource mix, while it makes up only one-fifth of the non-RGGI states' resource mix. In 2000, oil provided RGGI with over 12% of its generation, compared to the non-RGGI states' 1%. By 2015, however, oil had all but disappeared in both regions—making up just 2% of the RGGI states' generation and 0.2% of the non-RGGI states' generation.

As previously mentioned, all regions experienced a significant increase in generation from natural gas between 2005 and 2015: as a share of all electric power generation, natural gas increases 17% in the RGGI states and 14% in the non-RGGI states. By 2015, natural gas made up 40% of the RGGI states' resource mix and 29% of the non-RGGI states' resource mix. In RGGI, natural gas is the highest utilized fuel for electric power.

The following three tables show coal closures in capacity, plant, and unit terms. Table 2 below shows the capacity of coal closed in the two time periods for each spatial grouping. The percentages are calculated by placing the coal capacity closed between 2000-2005 and 2006-2015 and placing it over the total coal capacity and the total fossil capacity in the first year of the time period (either 2000 or 2006).

Table 2: Coal Capacity Closed Compared to All Coal and Fossil Capacity

	Coal Capacity Closed (MW)	Total Coal Capacity (MW)	Percent Closed of All Coal Capacity	Total Fossil Capacity (MW)	Percent Closed of All Fossil Capacity
2000-2005					
RGGI	130	16,535	0.79%	61,623	0.21%
Non-RGGI	3,808	340,197	1.12%	753,528	0.51%
US	3,938	356,731	1.10%	815,151	0.48%
2006-2015					
RGGI	4,262	17,799	23.95%	87,978	4.84%
Non-RGGI	42,054	347,489	12.10%	1,058,074	3.97%
US	46,316	365,288	12.68%	1,146,052	4.04%

Table 2 shows that the percentage of coal capacity closures in the first time period is actually slightly higher in the non-RGGI states than in the RGGI states, though these percentages are still quite low (about 1% or less of coal and fossil capacity). In the second time period, coal capacity closures make up a much percentage of coal and fossil capacity. The RGGI states see a higher percentage than the non-RGGI states: in the RGGI states, coal capacity closures are about one-quarter of the total coal capacity existing in 2006, compared to about 12% in the non-RGGI states. Again, this strongly suggests that the RGGI states are seeing more closures than the rest of the country.

Table 3 below shows the same information as the previous table, only at the plant level instead of capacity level.

Table 3: Coal Plants Closed Compared to All Coal and Fossil Plants

	Coal Plants Closed	Total Number of Coal Plants	Percent Closed of All Coal Plants	Total Number of Fossil Plants	Percent Closed of All Fossil Plants
2000-2005					
RGGI	2	37	5.41%	197	1.02%
Non-RGGI	11	386	2.85%	736	1.49%
US	13	423	3.07%	933	1.39%
2006-2015					
RGGI	18	39	46.15%	231	7.79%
Non-RGGI	96	407	23.59%	1,052	9.12%
US	114	446	25.56%	1,283	8.88%

Simply counting plants rather than capacity, there does not appear to be much of a difference in the rate of closures between the RGGI states and the non-RGGI states. The RGGI region actually has a slightly lower percentage of coal plants closing than the rest of the country in both time periods. When looking at the closures just as a percentage of coal plants, however, RGGI does seem to experiencing a greater percentage of closures: roughly half the coal plants existing in the region in 2006 had shut down by 2015. Though this information is relevant, plant numbers are not as strong an indicator of closure as capacity, as individual plants can vary widely in size.

Table 4 below shows similar information as Tables 2 and 3, but at the unit level. A unit is a subset of the generating plant. A plant may have just one unit or may have multiple units to produce electricity. This concept will be explained in further detail in the next section. Closures on the unit scale appear to be similar among regions and time periods, though RGGI does have a slightly lower percentage of coal units closing in both time periods as a percentage of all fossil units. This trend, coupled with the trend on the plant scale, would seem to suggest that the RGGI states did not experience as much coal generation closure as the rest of the country. However, about one-third of all coal units in the RGGI states closed between 2006-2015, suggesting that coal was more likely to close in the RGGI states. Much more detailed analysis is needed than these simple figures in order to make a conclusive statement.

Table 4: Coal Units Closed Compared to All Coal Units and Fossil Units

	Coal Units Closed	Total Number of Coal Units	Percent Closed of All Coal Units	Total Number of Fossil Units	Percent Closed of All Fossil Units
2000-2005					
RGGI	8	90	8.89%	620	1.29%
Non-RGGI	33	996	3.31%	1,988	1.65%
US	41	1,086	3.77%	2,608	1.57%
2006-2015					
RGGI	30	86	34.88%	713	4.21%
Non-RGGI	187	1,031	18.14%	3,160	5.92%
US	217	1,117	19.42%	3,873	5.60%

Data

Data for the quantitative analysis sections comes from the U.S. Environmental Protection Agency (EPA) and the U.S. Energy Information Administration (EIA). Specifically, data on fossil fuel generation and emissions comes from EPA's Clean Air Markets Division, and data on renewable and nuclear generation comes from EIA's State Energy Data System production records and queries in EIA's Electricity Data Browser.[28]

One important difference between the collection of EPA and EIA data is that EPA collects gross generation figures, while EIA collects net generation figures. Gross generation includes all electricity produced by a source, while net generation includes only electricity that is purchased and used by consumers. A discrepancy between the EPA and EIA figures can occur at the plant level due to the plant's own consumption as well as at the state level due to transmission and distribution losses. This means the fossil generation data in this analysis may be slightly higher than expected but still nonetheless representative of the production of electricity.

In addition, because many of EPA's regulatory programs for the electric power sector apply only to sources over 25 MW in capacity, this analysis includes only fossil data for sources over 25 MW. The exclusion of smaller sources from this analysis should not impact the

[28] "Electricity Data Browser," *U.S. Energy Information Administration*.; "State Energy Production Estimates 1960 Through 2014." *U.S. Energy Information Administration*.

conclusions, as the collective total of emissions from small sources is a small fraction of total emissions from the power sector from sources over 25 MW. Moreover, RGGI only applies to sources over 25 MW, so they are the sources most relevant to the analysis. The fossil fuel data includes the following source categories:

- Electric Utility;
- Cogeneration; and
- Small Power Producer.

The unit of analysis in this study is the power plant; however, the data are not grouped in that way. Power plants are made up of one or more generating units, which are generators that perform the work of transferring heat and kinetic energy into electrical energy. Units have an associated smokestack for releasing their emissions. Environmental data are often organized at the unit level, as a sensor can be easily mounted to the smokestack detect emissions from the unit. The fossil data from EPA used in this analysis are organized at the unit level, while the renewable and nuclear data from EIA are organized at the state level.

The discrepancy in the unit of analysis between the fossil and renewable/nuclear source data is due to the needs of this analysis. Fossil data were collected at the unit level in order to refine the analysis. Looking only at coal plants that had closed, and not including plants that had ceased coal generation entirely while leaving other units open, limits the sampling of data and fails to grasp the nuances of the power system, which often responds to changes at the unit level while maintaining operational plant status. So, the data for this analysis were collected at the unit level; however, units were aggregated to the plant level for research and conclusion. In other words, for the purposes of determining which coal plants were closed, the unit data were analyzed, and the qualitative section analyzes closures at the plant level. The regression section analyzes unit data, but plant status (open or closed) is set based on aggregated plant level status. The analysis ultimately makes conclusions about plants, as the units were aggregated to its plant level. Renewable and nuclear data was only used for descriptive statistics of the different spatial groupings as well as for the decomposition analysis, which aggregates data at the state level. Therefore, collection of renewable at a level below the state would have been unnecessary.

It is also important to note that this analysis analyzes emissions associated with the production of electricity rather than the consumption. Consumption of electricity might paint a very different picture of regional emissions, but as the economic and regulatory factors considered in this study are primarily related to the generation (production) of electricity, that will be the focus of the results herein.

The following tables summarize the data used in this analysis. Table 5 shows the number of observations in this analysis. Tables 6.1 and 6.2 show a state breakdown of the number of closures analyzed in this analysis. The first column shows the number of plants that closed down entirely in each time period, the second column shows the number of plants that ceased all coal generation but stayed open and switched to a different fuel in each time period, and the third column sums the other two columns for the total number of closures as defined in this analysis. A detailed list of the closures considered in this analysis can be found in the Appendix.

Table 5: Observations in this Analysis

	2000	**2005**	**2015**
Total Number of Units	2,614	3,894	4,142
Number of Coal Units	1,086	1,117	842
Number of Coal Closures (plant level)	-	20	107
Number of Coal Units Closed at Coal Plant Closures	-	41	217

Table 6.1: Coal Closures in RGGI States

RGGI Plants Closed			**RGGI Fuel Switching**			**RGGI Closures Overall**		
	2000-2005	*2006-2015*		*2000-2005*	*2006-2015*		*2000-2005*	*2006-2015*
CT		1	CT			CT		1
DE		1	DE		1	DE		2
MA		3	MA			MA		3
MD		1	MD			MD		1
NJ		2	NJ			NJ		2
NY	2	8	NY		1	NY	2	9
TOTAL	2	16	**TOTAL**	0	2	**TOTAL**	2	18

Table 6.2: Coal Closures in Non-RGGI States

Non-RGGI Plants Closed			**Non-RGGI Fuel Switching**			**Non-RGGI Closures Overall**		
	2000-2005	*2006-2015*		*2000-2005*	*2006-2015*		*2000-2005*	*2006-2015*
AL			AL		1	AL		1
CO		2	CO			CO		2
FL	1		FL			FL	1	0
GA	1	2	GA		1	GA	1	3
IL	1	6	IL			IL	1	6
IA		4	IA		2	IA		6
IN	2	3	IN			IN	2	3
KS		1	KS		1	KS		2
KY	1	4	KY		1	KY	1	5
MI	1	1	MI			MI	1	1
MN	1	4	MN		1	MN	1	5
MO		1	MO		1	MO		2
MT		1	MT			MT		1
NC		8	NC		1	NC		9
NV		1	NV			NV		1
OH		11	OH			OH		11
PA	1	11	PA			PA	1	11
SC		4	SC		2	SC		6
TN		1	TN			TN		1
UT		1	UT			UT		1
VA		5	VA	1	1	VA	1	6
WI	1	5	WI		1	WI	1	6
WV		7	WV			WV		7
TOTAL	10	83	**TOTAL**	1	13	**TOTAL**	11	96

In the RGGI states, there were 2 coal closures between 2000 and 2005 and 18 between 2006 and 2015. In the non-RGGI states, there were 11 coal closures between 2000 and 2005 and 96 between 2006 and 2015. Of the RGGI states, New York experienced the most coal closures. Four states in RGGI do not have coal generation (Maine, New Hampshire, Rhode Island, and Vermont). Of the non-RGGI states, Ohio and Pennsylvania experienced the most coal closures.

Some data points were missing from the EPA's fossil data. Table 7 below reveals how many units needed a calculated value for the particular category of data and the method used to calculate the value.

Table 7: Data Calculation Methods

Value	2000	2005	2015	Calculation Method[29]
Carbon Dioxide Emissions	438	453	502	EPA's Part 75 Methodology for calculating CO_2: $e_t = F_{Ct} \times h_t \times U_f \times W_{CO2}$ where: e is emissions (kg) F_C is a carbon-based F-factor for natural gas (29.45 CO_2 m^3/mmBtu), oil (40.21), or coal (51.54) h is heat input (mmBtu) U_f is a mass/volume constant at 1 atm and 20° C (4.1616 x 10^{-2} kg-mole/CO_2 m^3) W_{CO2} is the weight of CO_2 per kg-mole (44.0 kg)
Heat Input	6	10	9	Used default heat rate (10.9 mmBtu/MWh) and observed gross load
Generation	124	168	104	Coal units reporting steam load only: assumed 33% efficiency and converted on basis of 10 mmBtu = 1 MWh ratio Units reporting gross load and steam load: gross load value was used, steam value was ignored
Capacity	111	257	102	Conversion ratio of 1 Klb/hr = 3.28089808 MW

There were four primary numerical values associated with each unit: capacity, carbon dioxide emissions, heat input, and generation. Emissions rates and heat rates were derived from these raw values. For the entire time period, there were 42,600 individual records of data in this analysis. A total of 2,284 records (the sum of the number of calculated values listed in the table above) needed to be calculated. That is only 5.36% of the entire dataset. This means there should be no significant impact of using calculated values in the data.

[29] Carbon dioxide emissions, heat input, and generation data substitution methods developed with the assistance of staff of the U.S. Environmental Protection Agency. Capacity substitution method retrieved from: "Power Conversion Calculator," *Abraxas Energy Consulting*.

Decomposition Analysis of Emissions

The first step in this study is decomposition analysis to try to get a better empirical understanding of the various factors driving the decarbonization of electricity in the RGGI states and elsewhere over the last two decades. Decomposition analysis is a method of analyzing changes in emissions over time and attributing them to distinct operational attributes of the power system. Decomposition also provides an overview of any major changes occurring in the power sector in each of the four groupings in this study. Though decomposition cannot directly attribute emissions changes to closures, it can indicate what broad factors were causing significant changes in emissions, such as the reduction of coal as a share of generation that may be related to closures.

Methodology

Decomposition has been called a "pragmatic alternative to econometric estimation" because it allows for a much simpler examination of the weight of different factors on an outcome.[30] Through decomposition analysis, researchers can examine structural, sectoral, and production changes in emissions at the industry level.[31] These three types of change are reflected in changes in power plant attributes, such as emissions rate. For example, the emissions rate of an individual power plant could decrease due to the installation of a pollution control technology. This would be a production change in emissions. On the other hand, the emissions rate of the nation or a particular region could increase with a shift in the resource mix. That would be a structural change.

This decomposition analysis will examine changes in four power plant attributes: carbon dioxide emissions rate, heat input, generation, and heat rate. These four attributes determine the efficiency and emissions of a power plant. Emissions of a plant are a result of the equation:

[30] Adam Rose and Stephen Casler. "Input–Output Structural Decomposition Analysis: A Critical Appraisal," *Economic Systems Research* (Vol. 8, No. 1).
[31] B.W. Ang, "Decomposition Analysis for Policymaking in Energy: Which Is the Preferred Method?" *Energy Policy* (Vol. 32, No. 9): 1131.

$$e = h * m$$

where:

$$e = CO_2 emissions\ (kg)$$
$$h = heat\ input\ (mmBtu)$$
$$m = CO_2\ emissions\ rate\ (kg/mmBtu)$$

Efficiency of a plant is a result of:

$$h = g * a$$

where:

$$g = generation\ (MWh)$$
$$a = heat\ rate\ (mmBtu/MWh)$$

So, the emissions equation may be rewritten as:

$$e = g * a * m$$

Total carbon dioxide emissions is thus the indicator variable. Identifying and attributing carbon dioxide emissions changes to each of these four attributes can provide insight into the relative impacts of various regulatory, economic, and technological trends at work in the power sector that yield structural, sectoral, and production change.

One of the most important uses of decomposition analysis is attaching specific figures to changes already observed in the power system. Generation shifting is widely known as a significant contributor to carbon dioxide emissions changes, but exactly how much of the change is it responsible for and over what time period? What is the contribution of efficiency improvements at the plant? Decomposition analysis quantifies these phenomena by holding one (or more) attribute(s) constant over a given period of time and analyzing the change in another attribute and its impact on a particular indicator. There is no one equation accepted by scholars of decomposition for performing this analysis; instead, the equation depends on the indicator, the number and type of factors, and the information sought.

This analysis will use two equations that each consider only two factors at a time in order to simplify the discussion of the changes. A primary decomposition equation will break down carbon dioxide emissions into the change due to emissions rate change and the change due to heat input change. This equation will provide an indication of the output emissions efficiency of the power sector by looking at the change in emissions rate, as well as the utilization and efficiency of the technology by looking at the change in heat input.

Decomposition Equation

$$\Delta e = \left(\Delta m\ x\ h_t\right) + \left[\left(\Delta m\ x\ \Delta h\right)\left(\frac{-\Delta m\ x\ h_t}{\left(\Delta m\ x\ h_t\right) + \left(\Delta h\ x\ m_t\right)}\right)\right] +$$

$$\left(\Delta h\ x\ m_t\right) + \left[\left(\Delta m\ x\ \Delta h\right)\left(\frac{-\Delta h\ x\ m_t}{\left(\Delta m\ x\ h_t\right) + \left(\Delta h\ x\ m_t\right)}\right)\right]$$

where:

$$e = emissions\ (kg)$$

$$m = emissions\ rate\ (kg/mmBtu)$$

$$h = heat\ input\ (mmBtu)$$

$$\Delta x\ \left(any\ variable\right) = x_t - \ x_0$$

A secondary "subdecomposition" equation will break down heat input into the change due to generation change and the change due to heat rate change. Heat input is the amount of energy needed to produce useful output of work. Heat input could perhaps more easily be understood by explaining heat rate, which is the energy needed to produce 1 megawatt-hour of electricity. Heat input is determined both by the utilization of the plant (if there is more output, in megawatt-hours, then there will be more heat input needed) and the efficiency of the power generation technology (if the plant can produce the same amount of electrical output, 1 megawatt-hour, using less energy, the plant is more efficient). Thus, heat input needs to be further separated into its utilization and efficiency components to reveal the primary drivers of the heat input change that affects overall carbon dioxide emissions.

Subdecomposition Equation

$$\Delta h = (\Delta g \; x \; a_t) + \left[(\Delta g \; x \; \Delta a)\left(\frac{-\Delta g \; x \; a_t}{(\Delta g \; x \; a_t) + (\Delta a \; x \; g_t)}\right)\right] +$$
$$(\Delta a \; x \; g_t) + \left[(\Delta g \; x \; \Delta a)\left(\frac{-\Delta a \; x \; g_t}{(\Delta g \; x \; a_t) + (\Delta a \; x \; g_t)}\right)\right]$$

where:

$$h = heat\ input\ (mmBtu)$$
$$g = generation\ (MWh)$$
$$a = heat\ rate\ (mmBtu/MWh)$$
$$\Delta x\ (any\ variable) = x_t - x_0$$

These equations were applied to aggregate power sector data for each of the four groupings in this study. The data in each group was then further evaluated by resource type (all generation, fossil, coal, natural gas, and oil). This was necessary given the significant shifts in the resource mix across the United States during this time period.

Results

The results of the decomposition analysis are graphed and discussed in the following sub-sections. Data for the entire United States in the two time periods were included as well in order to provide a frame of reference for the two regional groupings.

The decomposition results bar charts indicate how emissions would have changed had only one factor changed. For example, in the U.S. Decomposition 2000-2005 chart, for fossil generation, one interprets the results in this way: carbon dioxide emissions would have increased by about 150 million tons if the heat input was the only power plant attribute that changed, and carbon dioxide emissions would have decreased by about 50 million tons if the emissions rate was the only power plant attribute that changed. Alternatively, one can interpret this to see that the net impact of these two changes was an emissions increase of about 100 million tons, which is caused primarily by the increase in heat input, as that is the only factor (as opposed to emissions rate) that led to a net increase in emissions.

It is important to keep in mind while looking at these charts that the vertical axis indicates a **net** change in emissions, not overall emissions.

Decomposition 2000-2005

Carbon dioxide emissions from the power sector increased 4.2% in the United States between 2000-2005. According to the results of the decomposition analysis, shown in Figures 4.1-4.3 below, this was primarily due to a change in heat input. If only the emissions rate had changed, carbon dioxide emissions would have decreased, indicating that increases in heat input are responsible for the entire increase in emissions. Furthermore, the increases in heat input of individual fossil fuels account for the changes at the aggregate fossil level, particularly heat input increases at coal and natural gas units. Oil units actually experienced a drop in heat input.

In the RGGI states, carbon dioxide emissions increased 5%, slightly more than the United States' increase, between 2000-2005. This was also primarily due to an increase in heat input. If only the emissions rate of the power sector had decreased during this time, carbon dioxide emissions would have decreased. However, as for the United States as a whole, the increase in heat input canceled out the emissions benefits of the emissions rate improvement in the RGGI states.

Carbon dioxide emissions in the non-RGGI states increased 4.1% between 2000-2005. Again, this was due to increases in heat input, which also canceled out emissions benefits from emissions rate improvements.

Power sector carbon dioxide emissions change trends appear very similar in both the RGGI and non-RGGI states between 2000-2005: increases in heat input, rather than increases in emissions rate, appear to be causing carbon dioxide emissions increases across all groupings.

The emissions rate is also improving in all regions, though not enough to counteract the effects of the heat input increases. This suggests that changes in the power sector were uniform across regions prior to the RGGI period, and that divergences in the trends between the regions in later time periods may in fact be due to the effect of RGGI. However, before it can conclusively be said that the regions experienced similar trends, the results of the subdecomposition (which further breaks down heat input) must be evaluated.

Figure 4.1: United States Decomposition 2000-2005

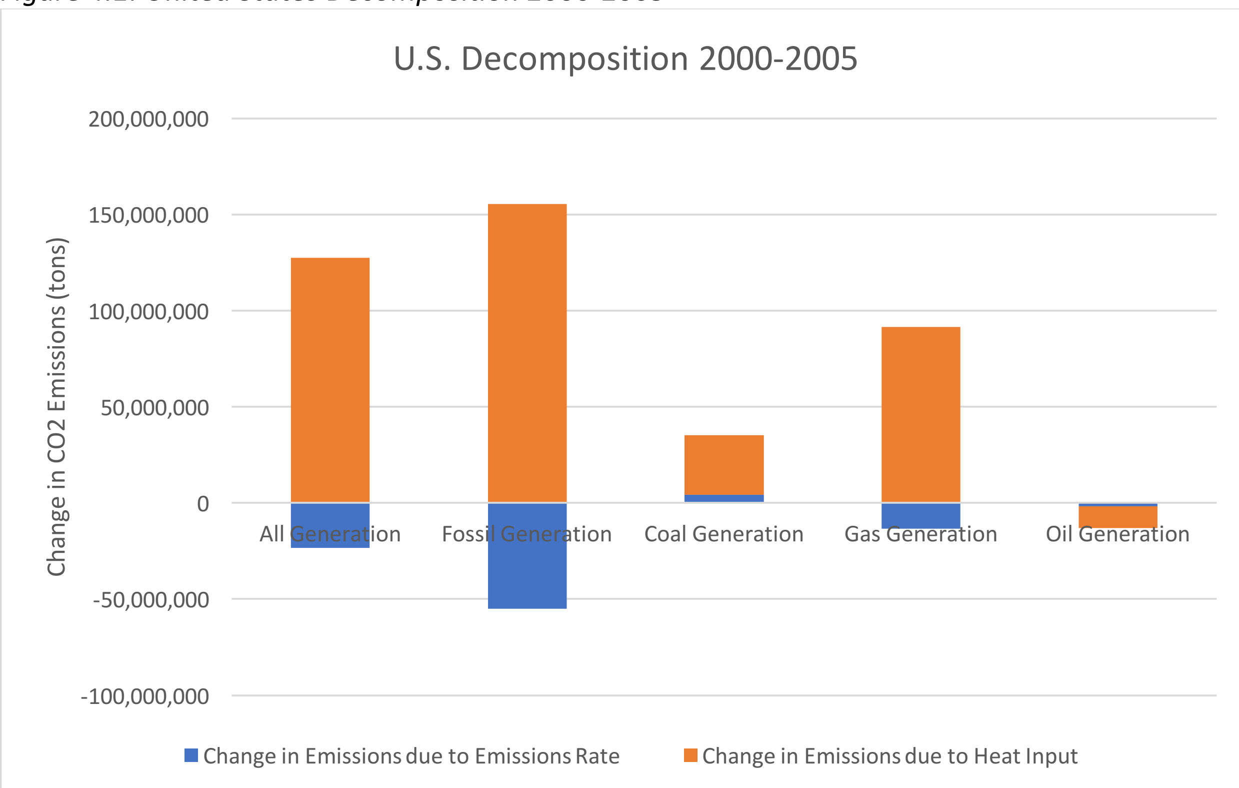


Figure 4.2: RGGI Decomposition 2000-2005

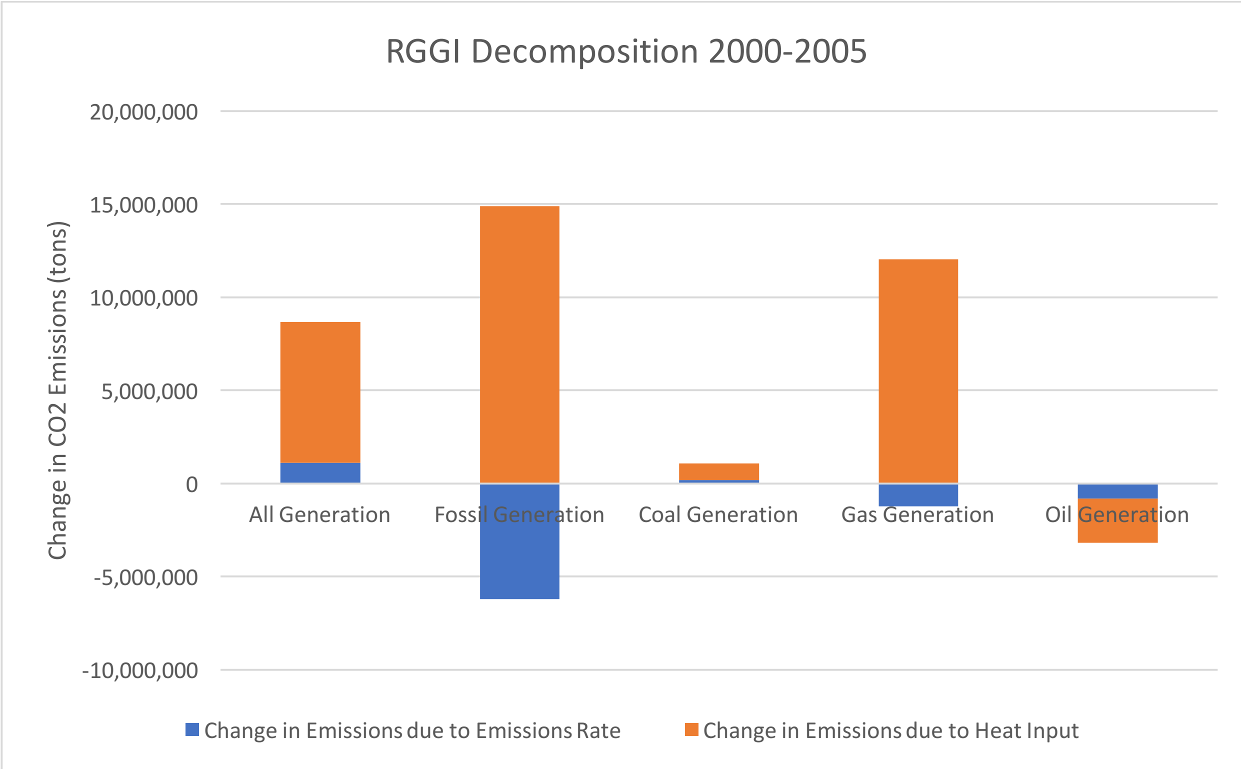
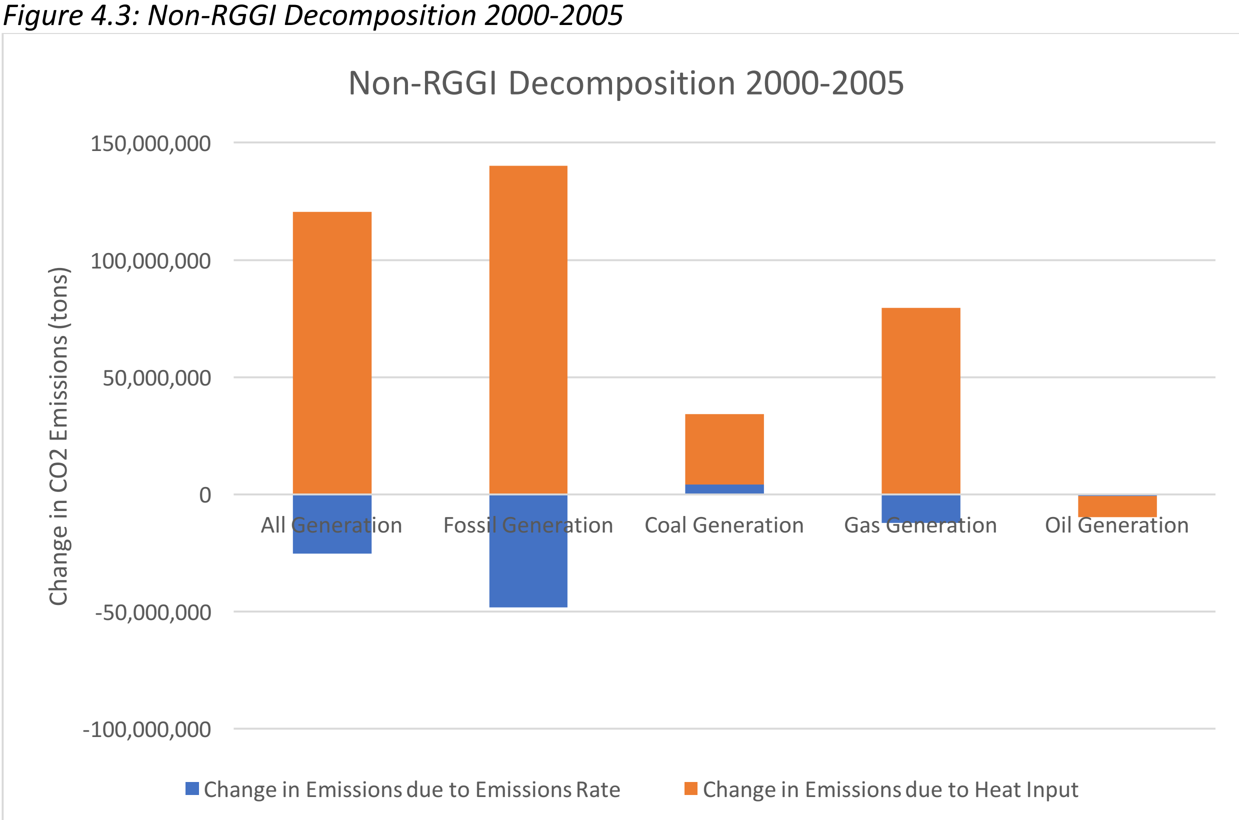


Figure 4.3: Non-RGGI Decomposition 2000-2005



Subdecomposition 2000-2005

The results of the subdecomposition for 2000-2005 are shown in Figures 5.1-5.3 below. The U.S. subdecomposition shows that the overall change in heat input is primarily due to changes in generation among different fuel sources. Significant improvements in heat rate were made at coal and natural gas units (which indicates an overall increase in efficiency of power plants), but the increases in generation at both coal and natural gas units counteract the emissions benefits of these efficiency improvements and lead to a net increase in emissions.

The subdecomposition for the RGGI states from 2000-2005 shows that the increase in heat input is almost entirely due to generation increases. However, the increases in heat input are occurring almost entirely at natural gas units, while heat input remains relatively flat or decreases slightly at coal units and oil units, respectively. In fact, natural gas generation increased by 50% in the RGGI states between 2000-2005, while coal generation decreased by 40% and oil generation decreased by about 8%. As a share of total generation, natural gas increased 6%, while the share of coal and oil generation each decreased by about 2% (see Figure 3.2). The subdecomposition reveals that shifting from coal (and oil) generation to natural gas generation was already well underway in the RGGI states prior to the announcement of the RGGI program. In addition, the average coal heat rate in the RGGI states increased slightly (meaning coal units became slightly less efficient), and this contributed to an increase in heat input and thus emissions. This is a departure from the trend in the rest of the United States, as coal heat rates in the non-RGGI states decreased slightly (meaning coal units became slightly more efficient).

The subdecomposition for the non-RGGI states from 2000-2005 also shows that heat input increases are entirely due to increases in generation. The heat rate improved and would have led to a net decrease in heat input, which did not occur. Like the RGGI states, the non-RGGI states experienced a 50% increase in generation from natural gas, but that only accounted for a 4% increase in its share of generation (Figure 3.3). Unlike the RGGI states, however, coal generation did increase in this time period (though by a modest 3%). This suggests that the non-RGGI states were simply adding new generation from natural gas, rather than shifting historic generation away from coal.

The 2000-2005 subdecomposition reveals a key regional divergence: the RGGI states were already shifting generation away from coal towards natural gas prior to the announcement of the RGGI program. This strong generation shifting suggests significant decrease in utilization of coal-fired power plants. In the context of this study's focus on the relationship between RGGI and coal-fired power plant closures, this may prove to be of significance: were the closures in the RGGI states indeed accelerated by the announcement and implementation of RGGI, or were they following a pattern that had already started prior to RGGI?

Figure 5.1: United States Subdecomposition 2000-2005

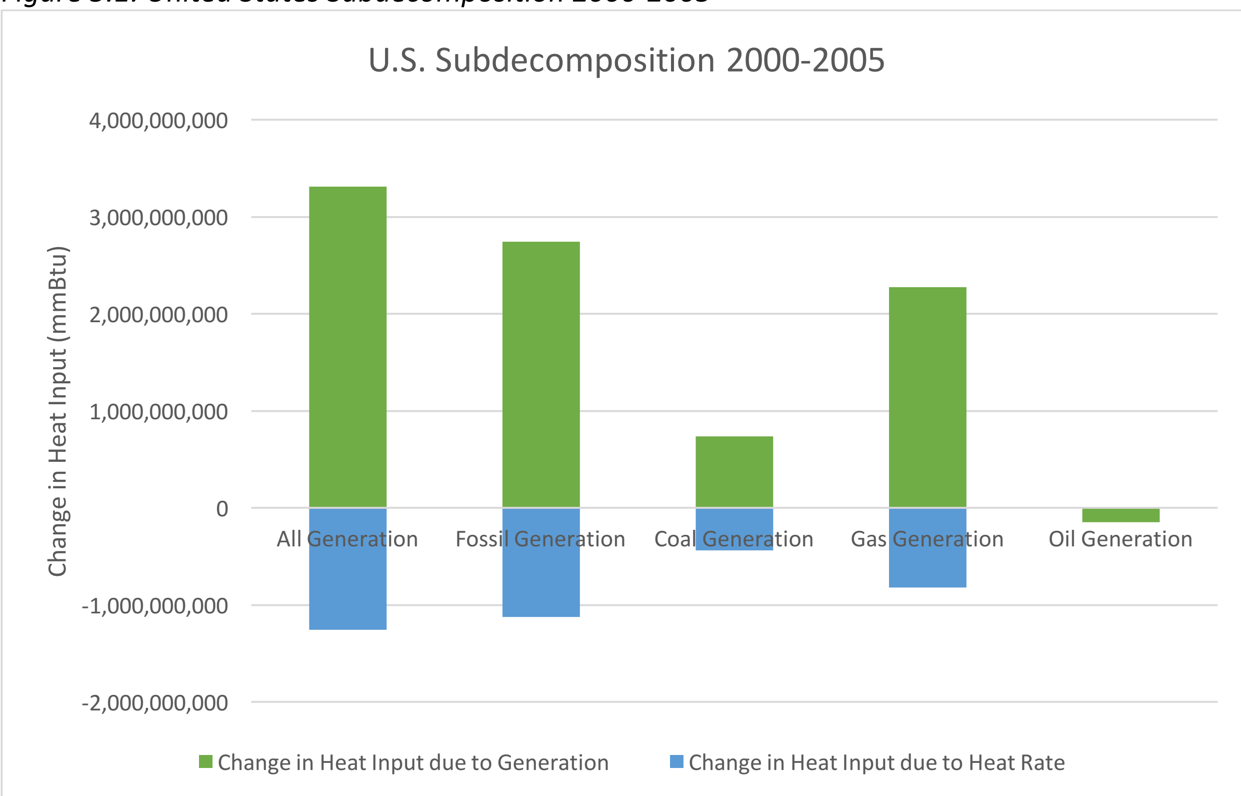


Figure 5.2: RGGI Subdecomposition 2000-2005

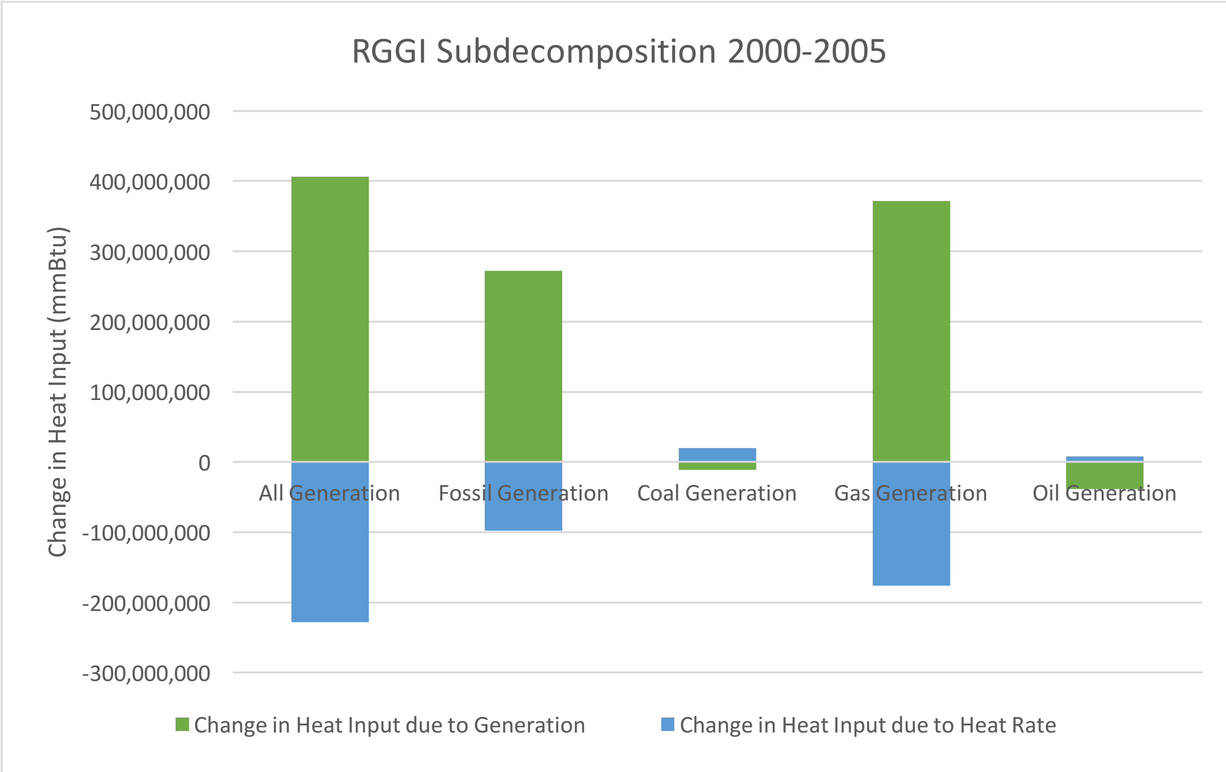
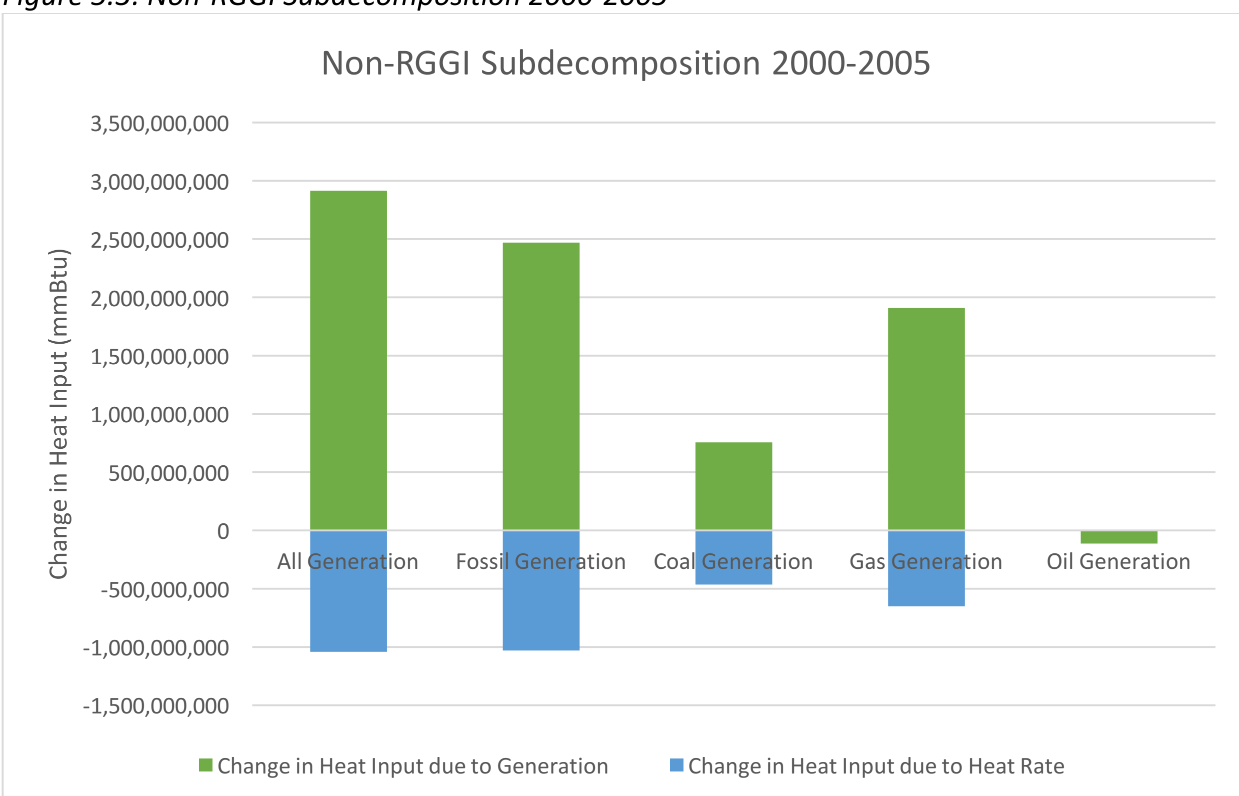


Figure 5.3: Non-RGGI Subdecomposition 2000-2005



Decomposition 2005-2015

There was a 17.9% decrease in power sector carbon dioxide emissions in the United States between 2005-2015. The decomposition analysis, shown in Figures 6.1-6.3 below, indicates that decreases in the emissions rate of all generation of the power sector was responsible for the entire emissions drop, as emissions would have increased had only heat input changed. This change in the emissions rate is likely due to the shifting from coal towards natural gas, as natural gas is a less carbon intensive fuel than coal. The share of generation from coal dropped 17% during this time period, while the share of generation from natural gas increased 13% (Figure 3.1). Increases in renewable generation may also have played a role in the drop in the emissions rate from all generation, as renewables increased their share of generation 5% during this time period (Figure 3.1). At the fossil generation level, changes in both emissions rate and heat input contributed to the decrease in emissions. This discrepancy between the all generation and fossil generation patterns, as well as the increases in heat input for all generation, will be explored further in the subdecomposition.

Carbon dioxide emissions in the RGGI states decreased by 42% between 2005-2015. Like the United States as a whole, this drop is due entirely to the decrease in emissions rate among all generation. Again, at the fossil generation level, changes in both emissions rate and heat input contributed to the decrease in emissions.

Carbon dioxide emissions in the non-RGGI states decreased 16% in this time period, also due entirely to the drop in the emissions rate due to fuel switching. At the fossil generation level, the same pattern holds in the non-RGGI states as in the RGGI states and the United States as a whole. Notably, the average carbon dioxide emissions rate for coal units in the non-RGGI States actually increased slightly over this time period.

Based on the decomposition analysis for this time, the RGGI states appear to be experiencing a stronger improvement in emissions rate than the rest of the United States, again primarily due to fuel switching. The carbon dioxide emissions reductions in the RGGI states in this period were nearly three times larger in percentage terms than in the non-RGGI states. Because both regions were seeing a drop in natural gas prices and thus an increase in natural gas use in generation, RGGI appears to be the only difference leading to a more significant drop in emissions between the two regions. The subdecomposition will shed more light on the generation shift.

Figure 6.1: United States Decomposition 2005-2015

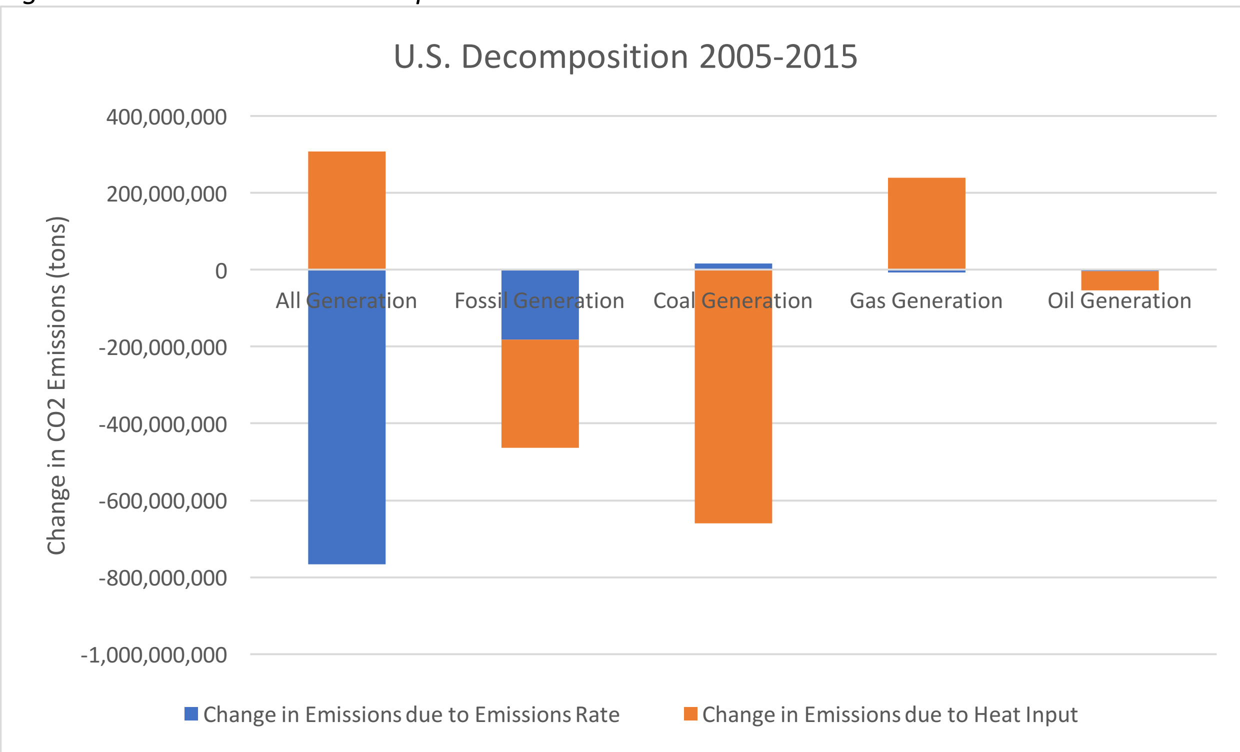


Figure 6.2: RGGI Decomposition 2005-2015

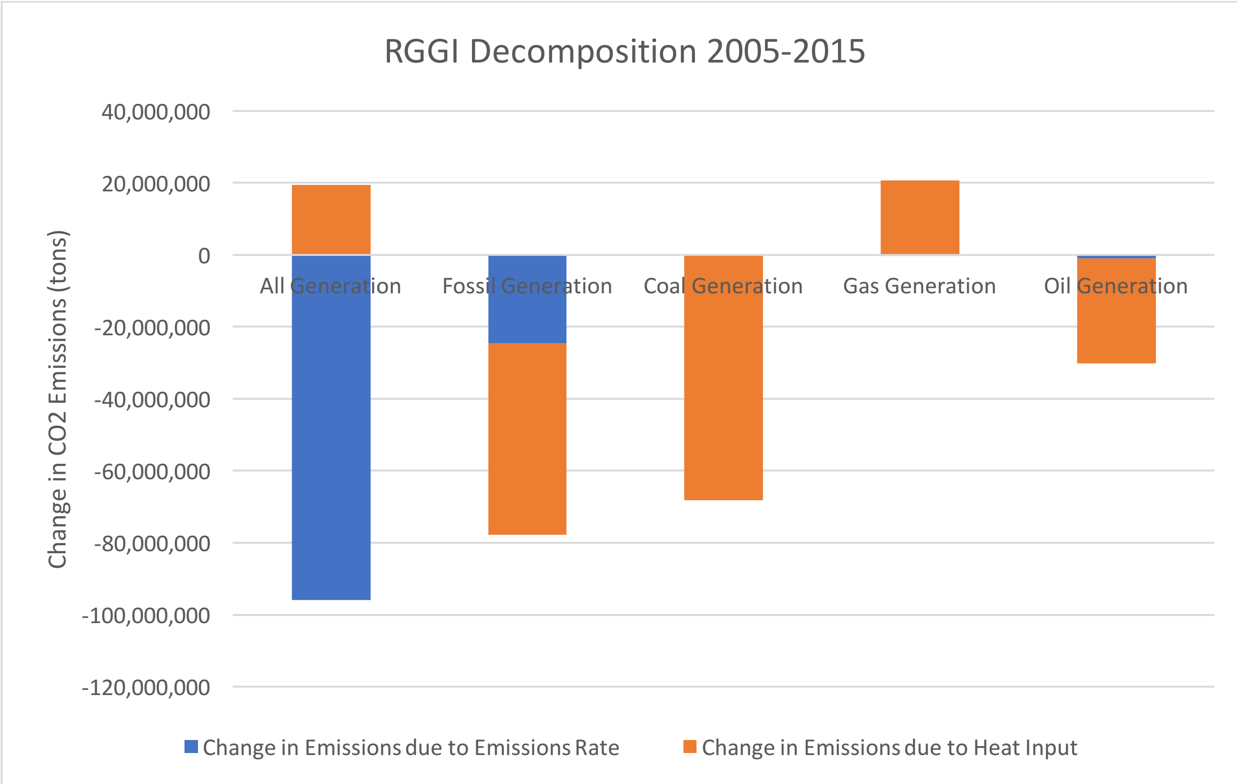
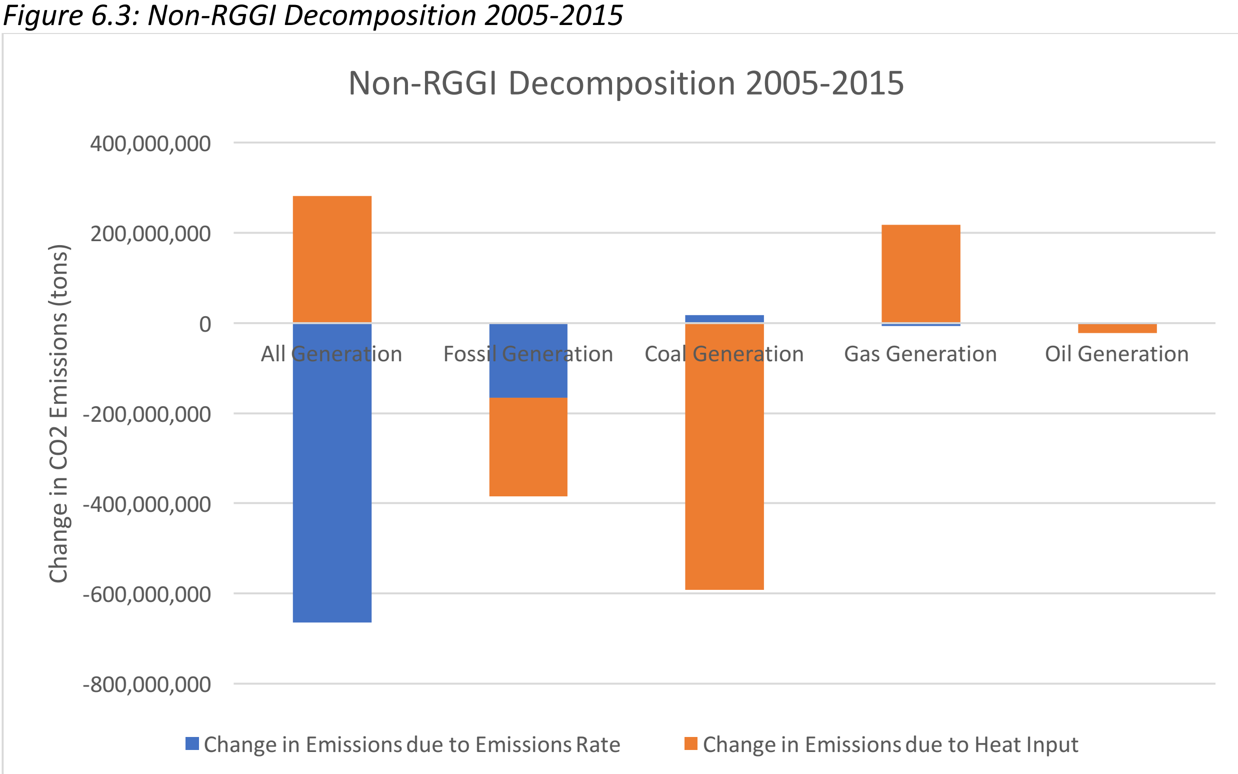


Figure 6.3: Non-RGGI Decomposition 2005-2015



Subdecomposition 2005-2015

The results for the subdecomposition 2005-2015 are shown in Figures 7.1-7.3 below. Overall, there was an increase in heat input for each regional grouping. This increase is primarily due to the change in heat rate associated with all sources of generation, and heat rates appear to increase (become less efficient over time). The increase is heat rates is likely due to assumptions made about the heat input of renewable and nuclear generation. These zero-emitting sources of generation do not have "heat input" in the true sense of the definition, in that they do not convert fossil fuels to power. However, most sources of data (including EIA and EPA) calculate a total heat input figure based on an assumed heat rate of 10 mmBtu/MWh (the typical efficiency of a coal unit) for renewable and nuclear generation in order to represent generation shifts through heat input. Because renewable generation experienced such a significant uptick over this time period (in all regions), the heat rate of the power sector appears to have gotten less efficient, and heat input appears to have increased dramatically, when in reality it was probably decreasing. The figures for fossil generation thus paint a more accurate picture of what was happening with heat input, generation, and heat rate, so this discussion will focus on the fossil generation column rather than the all generation column of each bar chart.

At the aggregate fossil level, the subdecomposition for the United States between 2005-2015 shows that the change in heat rate caused the greatest change in heat input. Though an improvement in heat rate of all fossil units caused most of the change, the generation shift away from coal and oil towards natural gas actually explains the heat rate change as well. Natural gas units, particularly combined cycle units, tend to be more efficient than coal units (produce more electricity per unit of heat input), and switching to plants running natural gas would decrease the overall heat rate of the fossil-fired power system.

Like the pre-RGGI subdecomposition, the post-RGGI subdecomposition for the RGGI states indicates that the change in heat input for fossil generation is contributing the most to the decreases in heat input. Nearly 70% of the decrease in heat input in the RGGI states is due to the change in generation from fossil sources, which declined 22%. This would suggest that a shift in generation away from fossil sources entirely, towards renewables, is playing a large role in the change in emissions from the RGGI states. Generation shifting towards natural gas also led to significant improvements in the heat rate of the RGGI states' fossil generation, which further decreased heat input and emissions. This shift also affects the overall emissions rate, again because natural gas is a less carbon-intensive fuel than coal (and oil).

The non-RGGI subdecomposition from 2005-2015 shows that, overall, an improvement in heat rate contributed the most to the decrease in heat input for fossil generation. Like the United States and RGGI, this is due to shifts in generation at the individual fuel level because natural gas generation has a lower heat rate than coal and oil generation. Natural gas generation increased proportionately much more in the non-RGGI states than in the RGGI states (99% versus 55% respectively between 2005-2015), though the non-RGGI region started from a lower base generation share from natural gas. Coal generation declined 29% over this time, and oil generation declined 75%. The shift in generation away from fossil sources appears to play less of a role in the non-RGGI states than in the RGGI states, as generation from fossil sources only declined 3% over this time period.

Both the RGGI and non-RGGI regions are experiencing vast shifts away from coal and oil towards natural gas and renewables. Coal generation in the RGGI region has declined nearly two and a half times more than in the non-RGGI region. In the context of coal-fired power plant closures, this would seem to suggest that RGGI would experience more coal-fired power plant closures than the non-RGGI region, but the decomposition analysis cannot definitively demonstrate that.

Figure 7.1: United States Subdecomposition 2005-2015

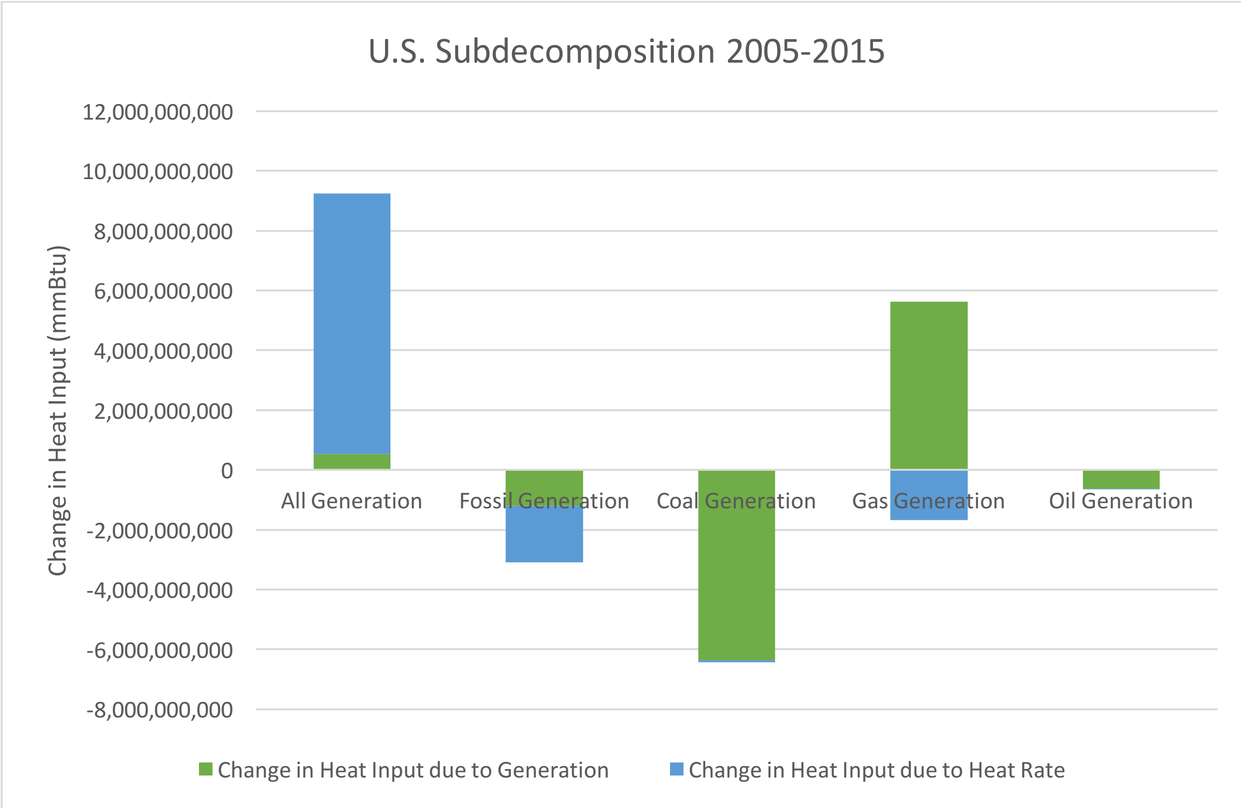


Figure 7.2: RGGI Subdecomposition 2005-2015

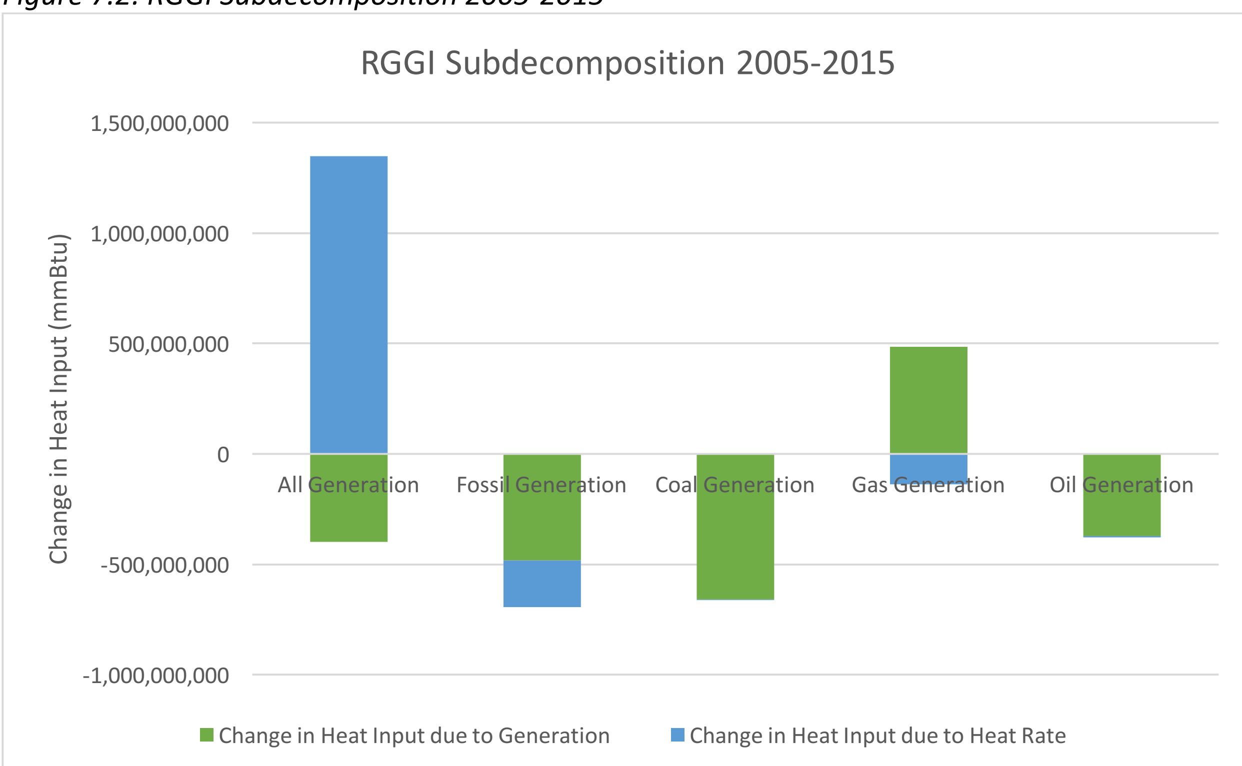
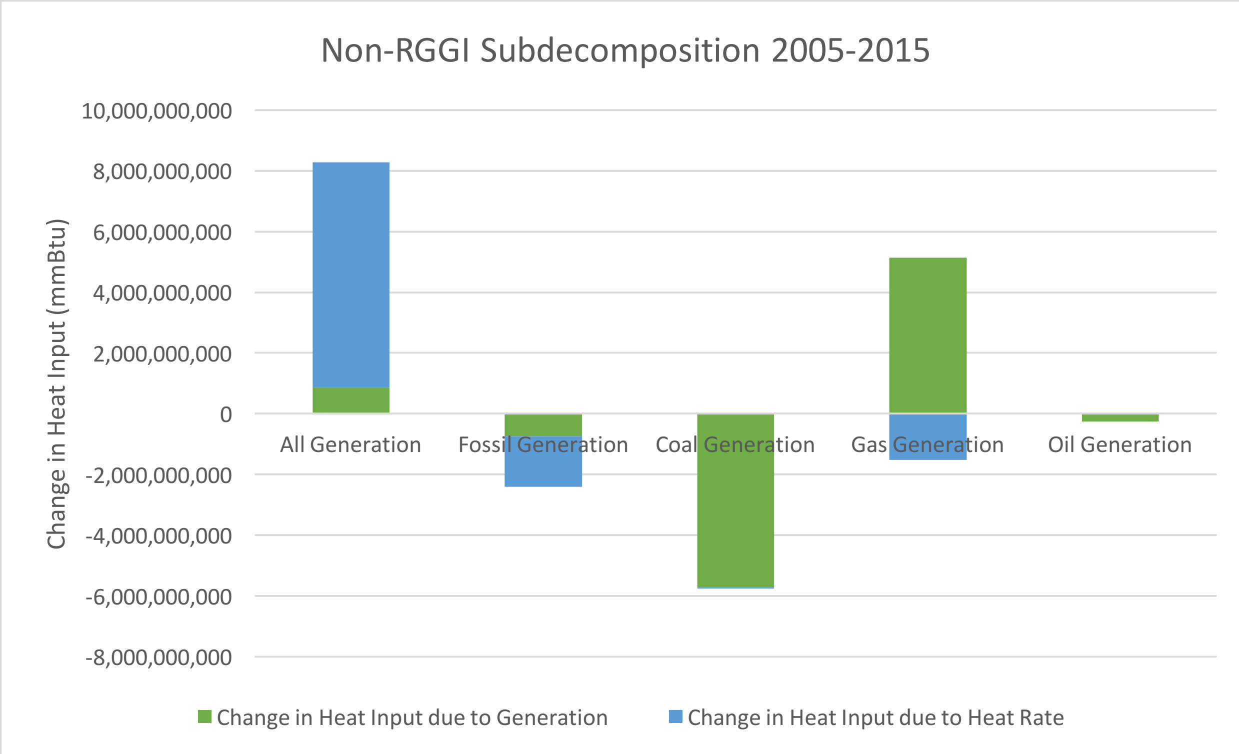


Figure 7.3: Non-RGGI Subdecomposition 2005-2015



Key Conclusions from the Decomposition

Heat input change, driven by shifts in generation from coal and oil to natural gas and renewables, is indeed driving carbon dioxide emissions changes in both the RGGI and non-RGGI regions, according to the results of this decomposition analysis. In RGGI, the effect of generation changes across fuel sources has a proportionally larger impact on emissions than in non-RGGI states. The RGGI states also experienced a steeper decline in coal-fired generation between 2005-2015 than the non-RGGI states, which would, if viewed in isolation, seem to suggest that RGGI is accelerating the closure of coal-fired power plants.

The decomposition analysis did reveal, however, that the shift away from coal and oil towards natural gas in the RGGI states was well underway prior to the announcement of RGGI in 2005. Between 2000-2005, the non-RGGI states saw an increase in coal generation, thus making this fact about the RGGI states all the more noteworthy. Between 2006-2015, the RGGI states continued to shift away from coal and oil towards natural gas and renewables, and the non-RGGI states began to shift away from coal and oil towards natural gas.

Decomposition analysis cannot attribute causation to any particular policy or economic driver; however, it strongly suggests that fuel switching, and power plant closures by extension, is playing a significant role in emissions changes. The next sections will focus attributing causation to specific policy or economic drivers through both qualitative and quantitative mechanisms.

Qualitative Closure Report

The decomposition analysis established that fuel switching is playing the most significant role in reducing carbon dioxide emissions both within and outside of the RGGI states. Coal-fired power plant closures are certainly part of the drop in generation from coal that the decomposition illuminates. But can the closures within the RGGI states be attributed to RGGI itself? And how do the reasons for closures within the RGGI states compare to those outside of the RGGI states? The first step in analyzing the motivations for closure of coal-fired power plants is a qualitative review of the reports on those closures. Assessing the primary motivations based on these reports is not only an important step in understanding the narrative surrounding the closures, but it can also provide important information to guide a regression analysis of the closures.

Methodology

The qualitative analysis relies on many different types of sources, including local and national news reports, press releases by utilities, and litigation as a result of enforcement action related to the closure of the plants. Reasons given by representatives of the utility itself were specifically targeted. I will note that it was more difficult to find information for plants closed prior to 2006, but each of the four groupings had data so no grouping needed to be completely excluded from the analysis.

There were a variety of reasons given ranging from economic to regulatory motivations, and these were “coded” into different categories. The possible reasons for closure were sorted into the following categories:

- Economic
    - Low natural gas prices
    - Higher coal prices
    - Fuel delivery costs
    - Capacity market concerns
    - Loss of major customer in service area
    - Decreased electricity demand
    - Low electricity prices
    - Profit concerns
    - Balanced generation portfolio
- Regulatory
    - Compliance costs
    - Compliance timeline
    - Federal standards (unspecified)
    - Cross-State Air Pollution Rule (CSAPR)
    - Mercury and Air Toxics Standard (MATS)
    - National Ambient Air Quality Standard (NAAQS) for Ozone
    - State law/measures
    - Other regulations (unspecified at what level of governance)
    - Reduce carbon dioxide
    - Regulatory enforcement action
    - Environmental outcomes
- Other
    - Age of facility
    - Continued reliability
    - Efficiency

It quickly became apparent over the course of this analysis that plants are often closed for multiple reasons rather than one specific reason. Therefore, instead of trying to identify one "primary" motivation as the direct cause of a closure, all explanations given in the coverage of the closure were noted. This means that one plant may have many reasons for closure—perhaps both economic and regulatory reasons. After evaluating the relevant sources, the plants were grouped into their respective temporal and regional groupings and examined for patterns based on these groupings.

Results

This discussion will focus on key conclusions related to the qualitative review of closures. Please see the Appendix for a full list of the closures considered in this analysis, as well as information on the age, capacity, emissions rate, and reasons cited for closure for each closure.

The most important conclusion I drew from this qualitative review is that carbon dioxide reduction is rarely stated as a motivation for closing a coal plant. Only one post-RGGI announcement closure in the RGGI states references cutting carbon dioxide as a goal of the closure (Salem Harbor in Massachusetts).[32] However, RGGI itself is never specifically referenced in the context of this closure. In fact, none of the closures in the RGGI region specifically refer to RGGI as a reason motivating the closure.

In the non-RGGI states, this pattern holds: reducing carbon dioxide is rarely mentioned as a motivation for closing a plant. Only four plants (Arapahoe and Cameo in Colorado, Bremo in Virginia, and Cane Run in Kentucky) contain references to cutting carbon dioxide in reports of their closure. These closures all happen in the second time period of this analysis. Notably, the two Colorado closures come after the announcement of a state law requiring utilities to make plans to reduce greenhouse gas emissions.[33] Neither Virginia nor Kentucky have laws in place requiring reduction of carbon dioxide.

Of all the regulations named as motivations for closure, MATS is the most commonly-cited driver of coal closures. This is particularly true in the non-RGGI states in the second time

[32] "Dominion to Shut Mass. Salem Harbor Coal/Oil Plant," *Reuters*, November 18, 2010.
[33] Andy Vuong, "Xcel Stacks Up Renewables," *Denver Post*, November 15, 2007.

period. MATS is only cited for closure in the RGGI states once post-RGGI announcement (R. Paul Smith in Maryland).[34] It is cited 19 times for plants in the non-RGGI states.

Overall, compliance costs, age, and federal standards are the most common reasons for closure. They are cited for 34, 25, and 23 closures, respectively. Federal standards are not as frequently referenced for closures in the non-RGGI states between 2000-2005 as opposed to 2006-2015, but compliance costs are cited.

Economic motivations for closure become much more common in the second time period for both regions, but particularly in the non-RGGI states, where they are referenced in 19 closures. General profit motivations (often discussed as either increased operating costs or decreased profit margins) are not referenced by RGGI closures. Only 8 closures in the non-RGGI states specifically reference low natural gas prices; however, this does not mean they do not factor into the decision somehow. General "economics" hints at fluctuations in prices as a motivation.

In the RGGI states between 2000 and 2005, only two closures occurred (AES Hickling and AES Jennison). Both were small, older plants in New York. These were mostly pertaining to the financial solvency and regulatory violations of the parent company at the time.

In the non-RGGI states between 2000 and 2005, there was indeed a paucity of information. I was unable to find information on 4 of the 11 closures there. Those for which there was information often reference age and efficiency of the plant, as well as compliance costs for environmental regulations.

In the RGGI states between 2006 and 2015, there were 18 closures. New York had the most closures of the RGGI states (9). Utilities stated more often that these closures were environmentally motivated. Federal standards and compliance costs, as well as general environmental outcomes, are cited most commonly. Age also plays a role in these closures.

In the non-RGGI states after 2005, there were 96 closures. Pennsylvania and Ohio had the most closures (both had 11) followed closely by North Carolina (9). Three of the major utilities in these areas, AEP, FirstEnergy, and Progress Energy Carolinas announced a significant number of coal closures at once, all of which were environmentally-motivated. AEP stated it

[34] Timothy B. Wheeler, "Maryland Power Plant Closing to Avoid Pollution Rules," *Baltimore Sun*, January 26, 2012.

would close 7 plants due to compliance costs with EPA regulations.[35] FirstEnergy stated it would close 6 coal plants due to MATS.[36] In 2009, Progress Energy Carolinas announced that it would reduce and eventually eliminate generation from un-scrubbed coal-fired power plants, which led to 4 of the closures in this analysis.[37]

The qualitative closure analysis demonstrates that both economic and regulatory factors are driving coal-fired power plant closures. Regulatory motivations are more often cited than economic motivations, but carbon dioxide reduction measures are rarely referenced. This is particularly surprising for the RGGI state closures post-RGGI announcement. The qualitative closure report therefore suggests that RGGI was not clearly determinant in driving coal-fired power plant closures. With greater context for the circumstances surrounding these closures, the quantitative analysis can proceed.

Regression Analysis of Closures

The decomposition analysis showed that reductions in coal generation are driving emissions changes, but, as previously mentioned, decomposition cannot attribute causality to a particular policy or economic factor. The qualitative analysis of closures illuminated certain economic and regulatory factors that played a crucial role in the closure of coal-fired power plants. None of the closures in the RGGI states specifically attributed the closures to RGGI; however, it still could be underlying decision-making even if it does not permeate the narrative. Regression analysis will be used in order to examine whether there is a causal link between RGGI and coal closures.

Methodology

National data on coal unit operation were examined for the regression analysis on determinants of coal unit closure. Panel data representing all existing coal units for the years

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[35] "AEP Shares Plan for Compliance With Proposed EPA Regulations," Press Release, *American Electric Power*," June 9, 2011.
[36] "FirstEnergy, Citing Impact of Environmental Regulations, Will Retire Six Coal-Fired Power Plants," Press Release, FirstEnergy Corp., January 26, 2012.
[37] "Progress Energy Carolinas Plans to Retire Remaining Unscrubbed Coal Plants in N.C.," Press Release, *Progress Energy Carolinas*, December 1, 2009.

2000 and 2005 were analyzed. The data are at the unit level. Only coal-fired units were included in the analysis.

The dependent variable in this analysis is unit status. For the data representing 2000, units that were operating in 2000 and remained open in 2005 were coded as 0, while units that were operating in 2000 but closed by 2005 were coded as 1. For the data representing 2005, units that were operating in 2005 and remained open in 2015 were coded as 0, while units that were operating in 2005 but closed by 2015 were coded as 1. As status is a binary variable, I used a probit regression analysis.

The primary explanatory variable is presence in the RGGI region. Units in the RGGI states post-RGGI announcement in 2005 were coded as 1, while units in the non-RGGI states and units in the RGGI states pre-2005 were coded as 0.

The qualitative analysis revealed that there may be a couple of significant confounding variables in this analysis: age and capacity. Utilities frequently cited the age of a plant as being a factor in its closure—specifically, that the plant is older. Utilities also occasionally cited the size of the plant as being a factor in its closure: smaller plants were more likely to be closed. These two variables thus needed to be added as control variables in the regression. Age for each observation was set as the age of the unit in the beginning of the time period (so age in 2000 for the 2000 data and age in 2005 for the 2005 data). As seen in Table 8 below, among all regional and temporal groupings, closed units do tend to be older and smaller than those that remain open.

Table 8: Comparison of Average Values of Age and Capacity for Coal Units Across Region, Time Period, and Status

	RGGI			**Non-RGGI**			**US**		
2000									
	Closed	*Open*	*All*	*Closed*	*Open*	*All*	*Closed*	*Open*	*All*
Age (years)	51.3	37.2	38.4	38.8	27.0	28.2	48.9	34.2	34.7
Capacity (MW)	16.3	206.7	189.4	136.1	273.1	260.9	103.6	342.3	333.8
2005									
	Closed	*Open*	*All*	*Closed*	*Open*	*All*	*Closed*	*Open*	*All*
Age (years)	43.8	37.0	39.4	47.0	34.4	36.9	40.1	34.5	37.1
Capacity (MW)	115.3	260.2	211.9	172.0	378.2	337.4	155.1	370.7	327.9

Moreover, all units in the RGGI region tend to be older and smaller compared to the rest of the United States, both before and after the treatment period. Differences in age and capacity among the treatment (RGGI post-2005) and control (non-RGGI and RGGI pre-2005) groups were tested for statistical significance. Using a t-test with unequal variance, treatment units did show a statistically significant difference in age and capacity from control units. Units in RGGI were more likely to be older and have a smaller capacity, as shown in Tables 9.1 and 9.2 below.

Table 9.1: t-test Results for Differences in Age Among Treatment and Control Groups

Group	Obs.	Mean	Std. Err.	Std. Dev.	95% Conf. Interval	
Non-RGGI	2117	35.775	0.282	12.971	35.222	36.328
RGGI	86	39.379	1.653	15.326	36.086	42.658
p-value = 0.0346						

Table 9.2: t-test Results for Differences in Capacity Among Treatment and Control Groups

Group	Obs.	Mean	Std. Err.	Std. Dev.	95% Conf. Interval	
Non-RGGI	2095	335.584	6.155	281.739	323.513	347.655
RGGI	84	211.894	19.698	180.539	172.715	251.073
p-value = 0.0000						

Two of the three aforementioned regulatory factors (ARP, MATS) are not controlled for, as they apply nationwide to all units. In addition, significant economic factors (low natural gas prices, relatively higher coal prices) are not controlled for in this analysis, as they also apply nationwide.

However, one regulatory factor, CSAPR, did not apply nationwide and is thus controlled for in the regression. CSAPR applies only to select states in the East, South, and Midwest. CSAPR does apply to three of the ten RGGI states (Maryland, New Jersey, and New York). Therefore, it could be having an additional impact within the RGGI states as well as an impact outside of the RGGI states. The regression is run both with and without a binary variable representing CSAPR applicability in order to observe any effect it may have had in addition to RGGI, age, and capacity.

There still may be differences among states that confound the data. I include a fixed effects regression analysis as well in order to control for these variations. Forty-three states have coal-fired generation, but only 28 states had coal closures. Of those states that had coal closures, 6 are RGGI states and 22 are non-RGGI states.

A dummy variable for time period was also employed in two of the regression models. This variable was binary: 0 for an observation in the first panel data year (2000) and 1 for an observation in the second panel data year (2005). This variable was added in order to control for the second time period being longer than the second, as units would be more likely to close anyway, given the longer time period.

Results

Table 10: Regression Results

	No CSAPR, No Fixed Effects 1	No CSAPR, Fixed Effects 2	CSAPR, No Fixed Effects 3	No CSAPR, Time Dummy 4	CSAPR, Time Dummy 5
RGGI	0.687** (0.156)	1.302** (0.287)	0.422** (0.158)	0.278 (0.160)	0.341* (0.164)
Age	0.037** (0.004)	0.036** (0.004)	0.033** (0.004)	0.034** (0.004)	0.033** (0.004)
Capacity	-0.001** (0.000)	-0.002** (0.000)	-0.002** (0.000)	-0.002** (0.000)	-0.002** (0.000)
CSAPR			0.985** (0.089)		0.283 (0.168)
Time period				1.088** (0.097)	0.823** (0.184)
constant	-2.321** (0.196)	-1.534** (0.279)	-2.687** (0.199)	-2.804** (0.203)	-2.779** (0.202)
State Fixed Effects?	No	Yes	No	No	No
Time Period dummy?	No	No	No	Yes	Yes

Note: Standard errors are in parentheses. The model in Column 1 does not include CSAPR or state fixed effects. The model in Column 2 does not include CSAPR but includes state fixed effects. The model in Column 3 includes CSAPR but does not include state fixed effects. The model in Column 4 does not include CSAPR or state fixed effects but adds in a dummy variable for the second time period. The model in Column 5 includes CSAPR and a dummy variable for the second time period but does not include state fixed effects.
*Significant at 0.05 level.
**Significant at 0.01 level.

The results for the first regression analysis model (Column 1) show that, holding age and capacity constant, coal units in the RGGI states post-RGGI announcement (those that receive treatment) were more likely to close than other units. This difference was statistically significant at the 0.01 level. Age and capacity also have statistical significance at the 0.01 level, and the results do align with expectations that older, smaller units are more likely to close in general.

The results for the second regression model (Column 2), which includes fixed effects to control for state-level factors that are unobservable (e.g., certain state-specific policies or state economic conditions), show that, holding age and capacity constant and controlling for state fixed effects, coal units in the RGGI states post-RGGI announcement (those that receive treatment) were more likely to close than other units. The difference was statistically significant at the 0.01 level. Again, age and capacity have statistical significance at the 0.01 level, which aligns with expectations that older, smaller units are more likely to close in general. It should be noted that some of the states had statistical significance as well.

The third regression model (Column 3) includes CSAPR as an additional control. As previously mentioned CSAPR did not apply uniformly across the United States, so a binary variable was added to indicate CSAPR applicability in order to control for its effects. However, one issue with including CSAPR is that it was finalized in 2011, which is more than halfway through the second temporal grouping used in this analysis. The results will nonetheless be reported here, though further refinement of the methods of the study are needed in order to allow for a robust consideration of CSAPR given the temporal grouping problems. The results in Column 3 indicate that coal units in RGGI were more likely to close, holding constant age, capacity, and applicability of CSAPR. The difference was statistically significant at the 0.01 level. Age, capacity, and CSAPR also have statistical significance at the 0.01 level in causing coal unit closure.

The fourth and fifth regression models (Columns 4 and 5) include a dummy variable for time, due to the different lengths of each time period in this analysis. The results in Column 4 suggest that coal units in RGGI were more likely to close, holding age, capacity, and time period constant; however, this value was not statistically significant, while age and capacity were statistically significant. The regression model in Column 5 adds CSAPR to the model used in Column 4. The results in Column 5 suggest that coal units in RGGI were more likely to close, holding age, capacity, CSAPR, and time period constant. This result was statistically significant at the 0.05 level. Age and capacity also have statistical significance at the 0.01 level in causing unit closure; however, CSAPR does not have a statistically significant impact.

Overall, the regression analysis suggests that RGGI is correlated with closure of coal-fired units in the RGGI states when other relevant factors are controlled. In particular, Models 3 and 5 provide the strongest evidence of this correlation, given the statistical significance of the RGGI coefficient with the inclusion of CSAPR and the time period dummy variable. Further analysis should examine other variables besides RGGI status, age, capacity, and CSAPR that affect coal unit closures across states, given the existence of statistically significant state level fixed effects.

Conclusion

The Regional Greenhouse Gas Initiative (RGGI) has been cited as a successful model of a cap-and-trade program for carbon dioxide. The region's power sector carbon dioxide emissions have dropped much more substantially than the rest of the United States. The decomposition analysis in this study has shown that those reductions are largely due to fuel switching from coal to natural gas, rather than significant improvements in efficiency or emissions rates at generating stations.

Fuel switching can be done in a number of ways: by reducing utilization of coal units and increasing utilization of natural gas units, by replacing the use of coal at the unit with natural gas, or by closing coal units and opening gas units. Coal plant closures are thus expected to accompany any policy that regulates carbon dioxide. The closure of coal plants is a very politically-charged issue, given the influence of the coal industry in politics and the loss of jobs expected. The conclusions of this analysis, while specific to the RGGI program, may provide some insight into the true impact of carbon dioxide cap-and-trade programs on the closure of coal-fired power plants or, at least, one example of how to evaluate coal closures in the context of a carbon dioxide cap-and-trade program.

A qualitative analysis of the reports on coal-fired power plant closures did not clearly indicate that RGGI was playing a significant role in closures post-RGGI. Environmental regulations and their expected compliance costs, particularly for the Mercury and Air Toxics Standard, were frequently cited as reasons for closure. However, the economics of natural gas also factored into the narrative of decision-making surrounding coal closures.

The results of the regression analysis provide strong evidence that RGGI was in fact determinant in closing coal units, even when controlling for age, capacity, and state. CSAPR may be having an impact that outweighs RGGI, but more research is needed in order to make that conclusion definitively. Older and smaller coal units are more likely to close, but RGGI may be causing closures independent of those factors.

While the failure or success of the RGGI program should not hinge on closing coal plants, it certainly provides a marker of not only the methods of compliance that can be taken with a carbon dioxide regulatory program, but also the outcomes that might occur given the pressing need to address climate change through policy.

Future analysis should perhaps consider a finer temporal separation in the time periods, accounting for the implementation effect as well as the exact date that the particular state came under (or left) the RGGI program, as that was more generalized in this analysis. In addition, an expansion of the analysis to include all fossil fuel-fired power plant closures may be warranted.

Appendix

Table 11: Coal Closures Considered in this Analysis by Region and Time Period

State	Generating Station Name	Year Opened	Year Closed	Age at Closure	Capacity (MW)	CO_2 Emissions Rate (kg/mmBtu)	Reason(s) for Closure
RGGI 2000-2005 (2 closures)							
NY	AES Hickling	1948	2000	52	70	95.35	Regulatory settlement for CAA violations
NY	AES Jennison	1945	2000	55	60	94.54	Regulatory settlement for CAA violations
RGGI 2005-2015 (18 closures)							
NY	AES Greenidge	1950	2011	61	345	93.08	Regulatory settlement for CAA violations
NY	AES Westover	1943	2011	68	357	93.14	Regulatory settlement for CAA violations
CT	AES Thames	1990	2012	22	469	94.38	Fuel costs, transportation costs, compliance costs
NY	Black River	1991	2014	23	183	94.38	Environmental objectives by Army, runs on wood now
NY	Danskammer	1959	2013	54	400	92.72	Hurricane Sandy damages, EPA/DEC made them switch to gas to reopen
NJ	Deepwater	1954	2015	61	90	93.08	Federal standards for criteria air pollutants
DE	Edge Moor	1954	2010	56	285	92.85	Environmental objectives by new owner, switch to gas
NJ	Howard M Down	1969	2012	43	25	94.38	Regulatory settlement for CAA violations, switch to gas
NY	Lovett	1966	2008	42	420	92.28	State lawsuit on pollution control
MA	Mount Tom	1960	2014	54	158	93.08	Natural gas demand driving down coal demand
NY	Niagara	1991	2015*	24	59	99.43	Environmental objectives by state, switch to wood
DE	NRG Energy Center Dover	1985	2013	28	56	94.38	Environmental objectives by new owner, switch to gas
MD	R Paul Smith	1947	2012	65	128	93.08	MATS, other regulations, compliance costs, aging plant
NY	Russell (Rochester 7)	1948	2008	60	277	93.08	State litigation, environmental regulations
NY	SA Carlson	1950	2015*	65	70	93.08	No information
MA	Salem Harbor	1951	2014	63	345	93.08	Environmental regulations aimed to curb climate change, ozone rule, old plant
MA	Somerset	1959	2011	52	305	91.30	No information
NY	Syracuse Energy	1992	2013	21	290	94.38	Losing major customer
Non-RGGI 2000-2005 (11 closures)							
GA	Arkwright	1943	2002	59	104	93.08	Economics-IRP process, reduce criteria air pollutants

IN	Dean H Mitchell	1959	2002	43	315	93.08	Age, cost of compliance, declining demand
FL	FJ Gannon	1957	2004	47	1278	93.08	No information
IL	Grand Tower Energy Center	1951	2005*	54	388	93.08	No information
MI	Marysville	1930	2009	79	549	80.90	No information
MN	Minnesota Valley	1954	2009	55	60	93.01	No information
IN	Noblesville	1950	2003	53	302	93.16	Increase capacity, reduce emissions, switch to gas
KY	Pineville	1951	2001	50	37	93.08	Compliance costs
WI	Port Washington	1935	2005	70	100	93.08	Increase capacity, switch to gas
VA	Possum Point	1955	2005*	50	371	93.08	Switch to gas
PA	Warren	1948	2002	54	305	93.08	No information
Non-RGGI 2005-2015 (96 closures)							
WV	Albright	1952	2012	60	339	93.08	MATS compliance costs
WI	Alma	1947	2014	67	1030	93.26	Compliance costs
VA	Altavista	1992	2015*	23	180	93.08	Reduce emissions, switch to wood
CO	Arapahoe	1951	2013	62	169	93.08	State law, federal law preparation for cutting carbon dioxide
PA	Armstrong	1958	2012	54	400	93.08	MATS, other regulations, compliance costs, aging plant
OH	Ashtabula	1958	2012	54	266	92.75	MATS, other regulations, compliance costs, aging plant
OH	Bay Shore	1959	2012	53	605	93.08	MATS, other regulations, compliance costs, aging plant
OH	Beckjord	1952	2014	62	1100	93.08	Environmental regulations
WI	Blount Street	1949	2011	62	28	93.07	Switch to gas
MO	Blue Valley	1965	2015	50	55	92.56	Environmental objectives
VA	Bremo	1950	2014	64	268	93.08	Environmental objectives, cheaper to run gas
NC	Buck	1941	2013	72	433	93.08	Switch to gas
CO	Cameo	1960	2013	53	54	93.08	State law, federal law preparation for cutting carbon dioxide
SC	Canadys Stream	1962	2013	51	482	93.08	MATS, other regulations, environmental objectives
KY	Cane Run	1962	2015	53	689	93.08	Federal regulations, aging plant, switch to gas
NC	Cape Fear	1956	2012	56	351	93.05	Duke Energy shutting down all non-scrubbed coal units, aging plant, reduce emissions
UT	Carbon	1954	2015	61	199	93.08	MATS, aging plant
MO	Chamois	1960	2013	53	53	93.06	Compliance costs, fuel delivery costs, low demand growth, low gas prices
VA	Chesapeake Energy Center	1953	2014	61	696	93.08	Compliance costs

KY	Coleman	1969	2014	45	527	93.08	Loss of major service territory customer
IL	Crawford	1958	2012	54	600	93.08	Compliance costs
PA	Cromby	1954	2011	57	162	93.08	Decreased demand, gas prices, increased operating costs, aging plant
NC	Dan River	1949	2012	63	335	93.08	Coal ash waste problem
SC	Dolphus Grainger	1966	2015	49	192	93.08	Compliance costs, aging plant
IA	Dubuque	1941	2011	70	94	93.08	Switch to gas
OH	Eastlake	1953	2012	59	1510	93.08	MATS, other regulations, compliance costs, aging plant
PA	Eddystone	1959	2011	52	693	93.08	Decreased demand, gas prices, increased operating costs, aging plant
PA	Elrama	1952	2012	60	535	93.08	High price of coal, lower demand, aging plant
IA	Fair Station	1967	2013	46	50	93.08	Compliance costs, aging plant
IL	Fisk	1959	2012	53	360	93.08	Compliance costs
IN	Frank E Ratts	1970	2015	45	288	93.08	Compliance costs
AL	Gadsden	1949	2015	66	402	93.08	Switch to gas, federal standards
VA	Glen Lyn	1944	2015	71	380	93.08	Compliance costs
KY	Green River	1954	2015	61	197	93.08	Federal regulations, aging plant, switch to gas
SC	HB Robinson	1960	2012	52	193	93.06	Duke Energy shutting down all non-scrubbed coal units, aging plant, reduce emissions
NC	HF Lee	1951	2013	62	444	93.04	Duke Energy shutting down all non-scrubbed coal units
OH	Hamilton Municipal Power Plant	1964	2015	51	76	93.42	No information
MI	Harbor Beach	1968	2015	47	110	93.07	MATS compliance costs
GA	Harllee Branch	1965	2015	50	1750	93.08	MATS compliance costs
PA	Hatfield's Ferry	1969	2013	44	1847	93.06	MATS compliance costs, low demand
KY	Henderson	1968	2008	40	28	93.07	Rising costs, environmental regulations
MN	High Bridge	1942	2006	64	1300	93.08	Environmental objectives, switch to gas
PA	Hunlock Creek	1959	2015	56	50	97.35	Switch to gas ("way to go in PA"), efficiency, federal standards
IL	Hutsonville	1953	2012	59	169	93.08	CSAPR
GA	Jack McDonough	1963	2012	49	570	93.00	Environmental objectives, switch to gas
MT	JE Corette	1968	2015	47	139	93.08	MATS compliance costs
SC	Jeffries	1970	2015	45	342	93.08	Compliance costs, aging plant
TN	John Sevier	1955	2013	58	840	93.08	Aging plant, enforcement action
WV	Kammer	1958	2015	57	690	93.08	Compliance costs
WV	Kanawha River	1953	2015	62	484	93.08	Compliance costs

NC	LV Sutton	1954	2014	60	673	93.04	Duke Energy shutting down all non-scrubbed coal units
OH	Lake Shore	1962	2012	50	230	93.08	MATS compliance costs, aging plant
IL	Lakeside	1961	2009	48	74	93.08	Compliance costs, aging plant
MN	Laskin Energy Center	1953	2015	62	120	93.08	Compliance costs, aging plant
WI	Manitowoc	1957	2015*	58	110	93.58	No information
PA	Martins Creek	1954	2007	53	300	93.07	State regulatory settlement
IL	Meredosia	1948	2012	64	662	93.08	CSAPR
IA	Milton L Kapp	1967	2015	48	121	93.08	Switch to gas, reduce emissions
PA	Mitchell	1963	2013	50	309	93.08	MATS compliance costs, low demand
NV	Mohave	1970	2006	36	1660	93.03	Regulatory settlement
OH	Muskingum River	1953	2015	62	1630	93.08	Compliance costs
WV	North Branch	1992	2012	20	274	93.08	Closed in agreement with state to build cleaner gas plant elsewhere
MN	Northeast	1971	2012	41	32	93.08	Switch to gas, federal regulations, cheaper to operate
NC	NC Renewable Power - Elizabethtown	1985	2015*	30	52	93.52	No information
NC	NC Renewable Power - Lumberton	1985	2015*	30	104	93.05	No information
OH	OH Hutchings	1948	2013	65	414	93.43	MATS compliance costs
IA	Pella	1963	2011	48	85	93.08	Compliance costs, aging plant, small plant
WV	Phil Sporn	1950	2015	65	1180	93.08	Compliance costs
OH	Picway	1955	2013	58	115	93.08	Compliance costs
PA	Piney Creek	1992	2013	21	40	94.38	Energy prices too low, compliance costs high
PA	Portland	1958	2014	56	437	93.08	Regulatory settlement, switch to oil
VA	Potomac River	1949	2012	63	510	93.08	Low gas prices, high compliance costs expected
KS	Quindaro	1965	2015	50	220	92.75	Regulatory settlement
OH	RE Burger	1950	2011	61	1216	93.07	Federal regulations
OH	Richard Gorsuch	1951	2012	61	817	93.08	Regulatory settlement
NC	Riverbend	1952	2013	61	553	93.08	Federal regulations
MN	Riverside	1949	2009	60	445	93.08	Switch to gas, reduce emissions
KS	Riverton	1949	2015	66	98	92.48	MATS, other regulations, switch to gas
WV	Rivesville	1944	2012	68	149	93.08	MATS compliance costs
MN	Silver Lake	1969	2015	46	60	92.52	Regulations, anticipated enforcement action, economics
IA	Sixth Street	1940	2008	68	419	87.74	Flooding

VA	Southampton	1992	2013	21	186	93.08	Switch to wood, reduce emissions
IN	State Line	1955	2012	57	582	93.08	Anticipated enforcement action, reduce emissions
WI	Stoneman	1949	2008	59	70	92.23	Switch to wood, environmental objectives
IA	Sutherland	1955	2015	60	424	93.07	Switch to gas, reduce emissions
IN	Tanners Creek	1951	2013	62	1183	93.08	Limited demand growth
PA	Titus	1951	2015	64	270	93.08	MATS compliance costs
KY	Tyrone	1953	2015	62	80	93.08	Federal regulations, aging plant, switch to gas
SC	Urquhart	1955	2012	57	110	93.08	Switch to gas, compliance costs, aging plant, small plant
WI	Valley (WEPCO)	1968	2015	47	792	93.08	Switch to gas, lower natural gas prices, reduce emissions
IL	Vermilion	1955	2011	56	189	92.83	Aging plant, small plant, fuel delivery costs, low demand growth, low power prices, regulatory uncertainty
NC	WH Weatherspoon	1949	2012	63	195	93.06	Duke Energy shutting down all non-scrubbed coal units
SC	WS Lee	1951	2014	63	430	93.08	Environmental objectives
WV	Willow Island	1949	2012	63	274	93.08	MATS compliance costs
GA	Yates	1950	2013	63	1407	93.08	MATS compliance costs

Note:

- Year Opened: year oldest continuously operating coal unit opened at the facility
- Year Closed: year coal generation ended at the facility
    - *Exact year of closure could not be determined; however, the facility was definitely closed within the time period in which it is grouped. The year closed is indicated as the final year of the analysis, which was used to calculate the age of the plant as well.
- Capacity: coal capacity only (does not include other fuel capacity if plant runs on multiple fuels), this is the amount of capacity that closed
- Emissions Rate: calculated for first year of time period in which is closed (either 2000 or 2005)

References

"Acid Rain Program," *U.S. Environmental Protection Agency*, https://www.epa.gov/airmarkets/acid-rain-program, last accessed February 26, 2017.

"AEP Shares Plan for Compliance With Proposed EPA Regulations." Press Release. *American Electric Power*." June 9, 2011. http://www.aep.com/newsroom/newsreleases/?id=1697.

"AEP to Retire Entire Tanners Creek Plant in Indiana." Press Release. *American Electric Power*. September 17, 2013. https://www.aep.com/newSroom/newSreleaSeS/Default.aspx?id=1834.

Aldy, Joseph E. and William A. Pizer. "Issues in Designing U.S. Climate Change Policy." *Energy Journal* Volume 30, Number 3 (2009): 179-209.

"American Municipal Power Clean Air Act Settlement." *U.S. Environmental Protection Agency*. May 18, 2010. https://www.epa.gov/enforcement/american-municipal-power-clean-air-act-settlement. Last accessed February 25, 2017.

Ang, B.W. "Decomposition Analysis for Policymaking in Energy: Which Is the Preferred Method?" *Energy Policy* (Vol. 32, No. 9): 1131-1139.

Augustein, Seth. "Pa. Power Plant Stops Burning Coal, But Fires Up Diesel, Irking Local N.J. Officials." *NJ.com*. July 22, 2014. http://www.nj.com/warren/index.ssf/2014/07/pa_power_plant_stops_burning_coal_but_fires_up_diesel_irking_local_nj_officials.html.

"Austin to Close Northeast Power Plant." *Post-Bulletin*. December 22, 2014. http://www.postbulletin.com/news/local/austin-to-close-northeast-power-plant/article_99012b06-3554-50fe-9a1d-b7126d8d3f8c.html.

Barlas, Thomas. "Vineland Municipal Electric Utility Breaks Ground for Natural Gas Turbine." *New Jersey Press of Atlantic City*. March 24, 2011. http://www.pressofatlanticcity.com/news/press/cumberland/vineland-municipal-electric-utility-breaks-ground-for-natural-gas-turbine/article_a86e940a-567b-11e0-8eb4-001cc4c002e0.html.

"Basic Information about Mercury and Air Toxics Standard." *U.S. Environmental Protection Agency*. https://www.epa.gov/mats/basic-information-about-mercury-and-air-toxics-standards. Last accessed February 25, 2017.

Bennish, Steve. "DP&L Power Plant to Close." *Dayton Daily News*. May 9, 2013. http://www.mydaytondailynews.com/news/power-plant-close/FChHShH0Ionj0cNjym4IUN/.

"Big Rivers Gets Extra Year to Install Pollution Controls." *Coal Age*. March 16, 2015. http://www.coalage.com/news/latest/4313-big-rivers-gets-extra-year-to-install-pollution-controls.html#.WLIrp7xExXi.

Brown, Clint. "Pella to Retire Coal Fired Power Plant, Accepts New Electric Agreement." *The Pella Chronicle*. June 17, 2011. http://www.pellachronicle.com/news/local_news/pella-to-retire-coal-fired-power-plant-accepts-new-electric/article_663976f7-d3f8-5ae2-81e2-c7e900cf083a.html.

Bustillo, Miguel. "Edison to Shut Down Polluting Coal Plant." *Los Angeles Times*. December 30, 2005. http://articles.latimes.com/2005/dec/30/local/me-mohave30.

Bruggers, James. "Sixty Years of Coal Burning Ends at LG&E Plant." *Courier-Journal*. July 6, 2015. http://www.courier-journal.com/story/tech/science/environment/2015/07/06/lge-ku-energy-dedicates-new-natural-gas-power-plant-cane-run-property/29762011/.

"Buck Steam Station." *Duke Energy*. https://www.duke-energy.com/our-company/about-us/power-plants/buck-steam-station. Last accessed February 25, 2017.

Cassell, Barry. "Missouri Town to End Coal Use at Two Power Plants." *Electric Light & Power*. July 23, 2014. http://www.elp.com/articles/2014/07/missouri-town-to-end-coal-use-at-two-power-plants.html.

Cassell, Barry. "Two AES Eastern Plants Headed for Bankruptcy Sale." *GenerationHub*. March 5, 2012. http://generationhub.com/2012/03/05/two-aes-eastern-coal-plants-headed-for-bankruptcy.

"Central Electric Power Cooperative to Cease Operation of Chamois Power Plant." Press Release. *Central Electric Power Cooperative*. http://www.cepc.net/content/central-electric-power-cooperative-cease-operation-chamois-power-plant. Last accessed February 25, 2017.

"Cinergy/PSI Dedicates Modernized Noblesville Power Plant." Press Release. *Cinergy*. June 19, 2003. http://www.businesswire.com/news/home/20030619005360/en/CinergyPSI-Dedicates-Modernized-Noblesville-Power-Plant.

Crane, Tracy. "Dynegy Will Close Power Plant Near Oakwood." *The News-Gazette*. December 28, 2010. http://www.news-gazette.com/news/business/2010-12-28/dynegy-will-close-power-plant-near-oakwood.html.

Davenport, Coral. "Nations Approve Landmark Climate Accord in Paris." *The New York Times*. December 12, 2015. https://www.nytimes.com/2015/12/13/world/europe/climate-change-accord-paris.html.

"Dominion to Shut Mass. Salem Harbor Coal/Oil Plant." *Reuters*. November 18, 2010. http://www.reuters.com/article/utilities-dominion-salem-idUSN1811822820101118.

"Dominion Virginia Power Offers to Close Coal-Fired Station in Accord Over Proposed Gas-Fired Power Station; Closing Would Help Regional Air Quality." Press Release. *Dominion Virginia Power*. December 2, 2010. http://www.prnewswire.com/news-releases/dominion-virginia-power-offers-to-close-coal-fired-station-in-accord-over-proposed-gas-fired-power-station-closing-would-help-regional-air-quality-111197529.html.

"Edge Moor Energy Center." *Calpine*. http://www.calpine.com/edge-moor-energy-center. Last access February 25, 2017.

"Electricity Data Browser." *U.S. Energy Information Administration*. http://www.eia.gov/electricity/data/browser/.

"Exelon To Retire 933 MW of Capacity In 2011." *Power Engineering*. December 2, 2009. http://www.power-eng.com/articles/2009/12/exelon-to-retire-933-mw-of-capacity-in-2011.html.

"Fact Sheet: Final Cross-State Air Pollution Rule Update for the 2008 NAAQS." *U.S. Environmental Protection Agency.* https://www3.epa.gov/airmarkets/CSAPRU/FINAL_FinalCSAPRUR_Factsheet.pdf. Last accessed February 25, 2017.

"Federal Environmental Mandates Force Elimination of Coal at Alabama Power's Plant Gadsden." *The Gadsden Times*. March 10, 2015. http://www.gadsdentimes.com/news/20150310/federal-environmental-mandates-force-elimination-of-coal-at-alabama-powers-plant-gadsden.

Ferro, John. "Danskammer: An Old Plant Breeds New Controversies." *Poughkeepsie Journal*. November 22, 2014. http://www.poughkeepsiejournal.com/story/tech/science/environment/2014/11/22/danskammer-riverkeeper-hudon-environment/19419773/.

"FirstEnergy, Citing Impact of Environmental Regulations, Will Retire Six Coal-Fired Power Plants." Press Release. FirstEnergy Corp. January 26, 2012. http://www.prnewswire.com/news-releases/firstenergy-citing-impact-of-environmental-regulations-will-retire-six-coal-fired-power-plants-138115263.html.

"FirstEnergy Completes Demolition of R.E. Burger Power Station." Press Release. *FirstEnergy Corp*. July 29, 2016. https://www.firstenergycorp.com/content/fecorp/newsroom/news_releases/firstenergy-completes-demolition-of-r-e--burger-power-station.html.

Foderaro, Lisa W. “State Closes Coal-Fired Plant That Failed to Limit Emissions.” *The New York Times*. May 11, 2007. http://www.nytimes.com/2007/05/11/nyregion/11plant.html?_r=1.

Ford, George C. “Alliant Plans Power Plant Fuel Change.” *The Gazette*. June 27, 2015. http://www.thegazette.com/subject/news/business/alliant-plans-power-plant-fuel-change-20150627.

Funk, John. “FirstEnergy to Close More Coal-Fired Power Plants.” *The Plain Dealer*. July 9, 2013. http://www.cleveland.com/business/index.ssf/2013/07/firstenergy_to_close_more_coal.html.

“Georgia Power Completes Plant McDonough-Atkinson Conversion to Natural Gas.” Press Release. *Georgia Power*. October 29, 2012. http://www.prnewswire.com/news-releases/georgia-power-completes-plant-mcdonough-atkinson-conversion-to-natural-gas-176265521.html.

“Georgia Power Proposes Retirement of Older Power Plants.” Press Release. *Southern Company*. https://southerncompany.mediaroom.com/index.php?s=&item=1446. Last accessed February 25, 2017.

Gibson, Lisa. “Two Wisconsin Power Plants Convert to Biomass.” *Biomass Magazine*. October 27, 2010. http://biomassmagazine.com/articles/5090/two-wisconsin-power-plants-convert-to-biomass.

Gillis, Justin. “Earth Set a Temperature Record for the Third Straight Year.” *The New York Times*. January 18, 2017. https://www.nytimes.com/2017/01/18/science/earth-highest-temperature-record.html?_r=0.

Hawthorne, Michael. “Aging Indiana Power Plant to Shut Down, Cutting Chicago-area Air Pollution.” *Chicago Tribune*. May 5, 2011. http://www.chicagotribune.com/business/ct-met-coal-plant-shutdown-20110505-story.html.

Hessling, Kate. “DTE to Close Harbor Beach Power Plant.” *Huron Daily Tribune*. July 11, 2012. http://www.michigansthumb.com/news/article/DTE-to-close-Harbor-Beach-Power-Plant-7288405.php.

Hopey, Don. “Off Switch Hit for Power Plants.” *Pittsburgh Post-Gazette*. March 1, 2012. http://www.post-gazette.com/local/region/2012/03/01/Off-switch-hit-for-power-plants/stories/201203010466.

“Hutsonville Power Plant to Close Down.” *Robinson Daily News*. October 5, 2011. http://www.robdailynews.com/main.asp?SectionID=2&SubSectionID=2&ArticleID=9174.

Israel, Brett. “Coal's Slipping Grip: Death of a Georgia Coal Plant.” *Environmental Health News*. July 2, 2013. http://www.environmentalhealthnews.org/ehs/news/2013/georgia-coal.

Jarosz, Joe. “Coal Plant Powers Down.” *Muscatine Journal*. November 14, 2013. http://muscatinejournal.com/news/local/coal-plant-powers-down/article_2c179996-c8d9-50c1-b8b1-eae6f69bc2d1.html.

Johnson, Tricia. “Bremo Bluff Power Conversion Complete.” *Fluvanna Review*. May 6, 2014. http://www.fluvannareview.com/index.php?option=com_content&id=5702:bremo-bluff-power-conversion-complete&Itemid=152.

Kennedy, Wally. “Empire District Electric Co. Building Combined-Cycle Power Plant at Riverton.” *The Joplin Globe*. September 10, 2015. http://www.joplinglobe.com/news/local_news/empire-district-electric-co-building-combined-cycle-power-plant-at/article_e68fa138-013c-5713-951d-abc979d9daf5.html.

Kim, Man-Keun and Taehoo Kim. “Estimating Impact of Regional Greenhouse Gas Initiative on Coal to Gas Switching Using Synthetic Control Methods.” *Energy Economics* (Vol. 59): 328-335.

Kimmerer, Tom. “Old Coal Plants Never Die.” *PlanetExperts*. November 25, 2014. http://www.planetexperts.com/old-coal-plants-never-die/.

Knauss, Tim. “Solvay Cogeneration Plant to Close, Lay Off 24.” *Syracuse.com*. June 18, 2013. http://www.syracuse.com/news/index.ssf/2013/06/solvay_cogeneration_plant_to_c.html.

Koepp, Paul. “BPU Agrees to Shut Down KCK Coal Plant.” *Kansas City Business Journal*. June 21, 2013. http://www.bizjournals.com/kansascity/news/2013/06/21/bpu-agrees-to-shut-down-kck-coal-plant.html.

Kotrba, Ron. “Niagara Falls for Wood Power.” *Biomass Magazine*. http://biomassmagazine.com/articles/1400/niagra-falls-for-wood-power. Last accessed February 25, 2017.

“Laskin Energy Center Conversion to Natural Gas Advances EnergyForward.” Press Release. *Minnesota Power*. July 2, 2015. http://www.mnpower.com/Content/Documents/Company/PressReleases/2015/20150702_NewsRelease.pdf.

Lutey, Tom. “PPL: J.E. Corette Power Plant Will Close for Good in August.” *Billings Gazette*. February 10, 2015. http://billingsgazette.com/news/local/ppl-j-e-corette-power-plant-will-close-for-good/article_468ca4e2-7dfd-5824-a235-e024deec2638.html.

“Memorandum of Understanding.” *Regional Greenhouse Gas Initiative*. http://www.rggi.org/docs/mou_12_20_05.pdf. Last accessed April 1, 2016.

Miller, Michael. “New Jersey's Coal-Fired Power Plants Come Clean Ahead of Pollution Crackdown.” *New Jersey Press of Atlantic City*. July 8, 2010. http://www.pressofatlanticcity.com/news/press/new_jersey/new-jersey-s-coal-fired-power-plants-come-clean-ahead/article_b0b1782f-28f2-5eaa-bf21-74f0b5b1817a.html.

Morrell, Alan. “Highly Visible Site in Greece Will Soon Be Gone.” *Democrat & Chronicle*. March 25, 2014. http://www.democratandchronicle.com/story/news/2014/02/24/highly-visible-site-greece-soon-will-gone/5666325/.

Murray, Brian C. and Peter T. Maniloff. “Why Have Greenhouse Emissions in RGGI States Declined? An Econometric Attribution to Economic, Energy Market, and Policy Factors.” *Energy Economics* (Vol. 51): 581-589.

“New York PSD Settlements: AES and NRG Cases.” *National Association of Clean Air Agencies*. January 27, 2005. http://www.4cleanair.org/NewYorkPSDSettlements.pdf.

“NIPSCO Announces Shutdown of Dean H. Mitchell Generating Station.” Press Release. NiSource, Inc. December 5, 2001. http://www.prnewswire.com/news-releases/nipsco-announces-shutdown-of-dean-h-mitchell-generating-station-74499587.html.

O’Donoghue, Amy Joi. “End of an Era: Mercury Rule Shutters Utah's Oldest Power Plant.” *Deseret News*. April 14, 2015. http://www.deseretnews.com/article/865626442/End-of-an-era-Mercury-rule-shutters-Utahs-oldest-power-plant.html?pg=all.

Pearson, Amy. “Dairyland to Shutter Three Alma Coal Units.” *LaCrosse Tribune*. December 7, 2011. http://lacrossetribune.com/news/dairyland-to-shutter-three-alma-coal-units/article_4fc77d4a-2096-11e1-8cb7-0019bb2963f4.html.

Peltier, Robert. “High Bridge Combined Cycle Project St. Paul, Minnesota.” *POWER*. September 15, 2008. http://www.powermag.com/high-bridge-combined-cycle-project-st-paul-minnesota/.

Petrillo, Matt. “UGI’s Hunlock Creek Energy Center Now Operating on Natural Gas.” *ABC WNEP 16*. December 2, 2015. http://wnep.com/2015/12/02/ugis-hunlock-creek-energy-center-now-operating-on-natural-gas/.

Plaisance, Mike. “Holyoke Meeting Set on Reuse of Closed Mount Tom Power Station Site and Cleaning Soil of Contaminants.” *MassLive*. December 2, 2014. http://www.masslive.com/news/index.ssf/2014/12/holyoke_meeting_set_on_cleanin.html.

“Plans to Demolish the Sixth Street Power Plant Remain, But Progress is Slow.” *The Gazette*. June 13, 2013. http://www.thegazette.com/2013/06/13/plans-to-demolish-the-6th-street-power-plant-remain-but-progress-is-slow.

"Port Washington Generating Station." *WeEnergies*. December 2012. https://www.we-energies.com/home/pwgs.pdf.

"Power Conversion Calculator," *Abraxas Energy Consulting*. http://www.abraxasenergy.com/energy-resources/toolbox/conversion-calculators/power/. Last accessed February 26, 2017.

"Power Plants: Lakeside Power Station (Retired)." *City Water Light & Power*. http://www.cwlp.com/electric/generation/powerplants.html. Last accessed February 25, 2017.

"PPL Retires Two Coal-Fired Units at Martins Creek Power Plant." Press Release. *PPL*. September 17, 2007. http://pplweb.mediaroom.com/index.php?s=12270&item=20329.

"Progress Energy Carolinas Plans to Retire Remaining Unscrubbed Coal Plants in N.C." Press Release. *Progress Energy Carolinas*. December 1, 2009. http://www.prnewswire.com/news-releases/progress-energy-carolinas-plans-to-retire-remaining-unscrubbed-coal-plants-in-nc-78229887.html.

"Ratts Generating Station." *Hoosier Energy*. https://www.hepn.com/ratts.asp. Last accessed February 25, 2017.

"ReEnergy Black River." *ReEnergy Holdings, LLC*. http://www.reenergyholdings.com/our-facilities/energy-generation-facilities/owned-and-operated-by-reenergy/reenergy-black-river/. Last accessed February 25, 2017.

"Regional Greenhouse Gas Initiative." *Center for Climate and Energy Solutions*. https://www.c2es.org/us-states-regions/regional-climate-initiatives/rggi. Last accessed February 25, 2017.

"Repowered NRG Energy Center Dover Unveiled." Press Release. *State of Delaware*. July 26, 2013. http://www.dnrec.delaware.gov/News/Pages/Repowered-NRG-Energy-Center-Dover-Unveiled.aspx.

"RGGI Fact Sheet." *Regional Greenhouse Gas Initiative*. https://www.rggi.org/docs/Documents/RGGI_Fact_Sheet.pdf. Last accessed March 30, 2016.

"Riverbend Steam Station." *Duke Energy*. https://www.duke-energy.com/our-company/about-us/power-plants/riverbend-steam-station. Last accessed February 25, 2017.

Rose, Adam and Stephen Casler. "Input–Output Structural Decomposition Analysis: A Critical Appraisal." *Economic Systems Research* (Vol. 8, No. 1): 33-62.

"RPU Votes to Retire Silver Lake Power Plant." *Post-Bulletin*. August 7, 2012. http://www.postbulletin.com/news/local/rpu-votes-to-retire-silver-lake-power-plant/article_d68a1928-1e3f-51dd-bc66-0c430ced0ee6.html.

"SCE&G Announces Plans to Close Part of its Coal-Fired Plant System." *The Collectonian*. http://thecolletonian.com/sceg-announces-plans-to-close-part-of-its-coal-fired-plant-system/. Last accessed February 25, 2017.

"SCE&G Retires Canadys Station Power Plant as Part of Strategy to Meet More Stringent Environmental Regulations." Press Release. *SCE&G*. November 13, 2013. https://www.sceg.com/about-us/newsroom/2013/11/13/sce-g-retires-canadys-station-power-plant-as-part-of-strategy-to-meet-more-stringent-environmental-regulations.

Schutzman, Nina. "Danskammer Set to Return to Financially-Strapped School District." *Poughkeepsie Journal*. November 23, 2014. http://www.poughkeepsiejournal.com/story/news/local/2014/11/23/return-danskammer-marlboro-district/19463265/.

Sheler, Jeff. "Fly Ash Dump in Chesapeake Has History of Leaks." *The Virginian-Pilot*. August 19, 2014. http://pilotonline.com/news/government/local/fly-ash-dump-in-chesapeake-has-history-of-leaks/article_6aa955e0-cc19-5feb-b157-5947ecac664d.html.

"Southampton Power Station." *Dominion*. https://www.dom.com/about-us/making-energy/renewables/biomass/southampton-power-station. Last accessed February 25, 2017.

Stahl, Lesley. "The Spill at Dan River." *CBS 60 Minutes*. June 14, 2015. http://www.cbsnews.com/news/duke-energy-on-coal-ash-waste-at-dan-river-2/.

"State Energy Production Estimates 1960 Through 2014." *U.S. Energy Information Administration*. Downloaded January 18, 2016.

Stinnett, Chuck. "Henderson Power Plant to Close." *Evansville Courier & Press*. August 27, 2008. http://archive.courierpress.com/news/local/henderson-power-plant-to-close-ep-448211833-327001361.html.

Sullivan, Patricia. "GenOn Power Plant in Alexandria is Set to Close." *The Washington Post*. September 29, 2012. https://www.washingtonpost.com/local/genon-power-plant-in-alexandria-is-set-to-close/2012/09/29/daa355ea-08d7-11e2-858a-5311df86ab04_story.html?utm_term=.2c47e2d1bde3.

"Today in Energy: Coal Made Up More Than 80% of Retired Electricity Generating Capacity in 2015." *U.S. Energy Information Administration*. March 8, 2016. http://www.eia.gov/todayinenergy/detail.php?id=25272.

"Today in Energy: Power Plant Emissions of Sulfur Dioxide and Nitrogen Oxides Continue to Decline In 2012." *U.S. Energy Information Administration*. February 27, 2013. http://www.eia.gov/todayinenergy/detail.php?id=10151.

"Today in Energy: U.S. Energy-Related Carbon Dioxide Emissions in 2015 are 12% Below Their 2005 Levels." *U.S. Energy Information Administration*. May 9, 2016. https://www.eia.gov/todayinenergy/detail.php?id=26152.

"Three Coal-Fired Power Plants to Be Replaced By Natural Gas." *Power Engineering*. September 15, 2011. http://www.power-eng.com/articles/2011/09/three-coal-fired-power-plants-to-be-replaced-by-natural-gas.html.

"TVA May Shutter Aging Coal-Fired Plants." *Times Free-Press*. August 24, 2009. http://www.timesfreepress.com/news/news/story/2009/aug/24/tva-may-shutter-aging-coal-fired-plants/231934/.

"Valley Power Plant Conversion." *We Energies*. https://www.we-energies.com/home/projects/vapp.htm. Last accessed February 25, 2017.

Vuong, Andy. "Xcel Stacks Up Renewables." *Denver Post*. November 15, 2007. http://www.denverpost.com/2007/11/15/xcel-stacks-up-renewables/.

"W.S. Lee Steam Station." *Duke Energy*. https://www.duke-energy.com/our-company/about-us/power-plants/w-s-lee-steam-station/. Last accessed February 25, 2017.

Ward Jr., Ken. "3 W.Va. Plants Latest to Close Under Utility Restructuring." *Charleston Gazette-Mail*. February 8, 2012. http://www.wvgazettemail.com/News/201202080125.

Weinberger, Evan. "AES Thames To Liquidate After Asset Sale Collapses." *Law360*. January 24, 2012. https://www.law360.com/articles/302630/aes-thames-to-liquidate-after-asset-sale-collapses.

Wheeler, Timothy B. "Maryland Power Plant Closing to Avoid Pollution Rules." *Baltimore Sun*. January 26, 2012. http://www.baltimoresun.com/features/green/bs-gr-coal-plant-closure-20120126-story.html.

Wernau, Julie. "Midwest Generation to Close 2 Chicago Coal Plants Early." *Chicago Tribune*. May 2, 2012. http://articles.chicagotribune.com/2012-05-02/news/chi-midwest-generation-to-close-2-chicago-coal-plants-20120502_1_fisk-and-crawford-coal-plants-environmental-groups.

Williams, David O. "Xcel Files Plan to Cut 900 Megawatts of Coal-Fired Electrical Power." *The Colorado Independent*. August 13, 2010. http://www.coloradoindependent.com/59669/xcel-files-plan-to-cut-900-megawatts-of-coal-fired-electrical-power.

Wilshire, Ron. “Piney Creek Power Plant Purchased at Auction.” *Explore Clarion*. March 4, 2014. http://www.exploreclarion.com/2014/03/04/piney-creek-power-plant-purchased-at-auction/.

Wise, Warren L. “Old Santee Cooper Coal-Fired Plant Will Soon Be History.” *The Post and Courier*. April 19, 2015. http://www.postandcourier.com/business/old-santee-cooper-coal-fired-plant-will-soon-be-history/article_bcd45dd0-4c78-5d37-baaa-32e51303ae51.html.