IDS 701 Project

Effectiveness of RGGI on Generation Emission

Difference-in-Difference Analysis

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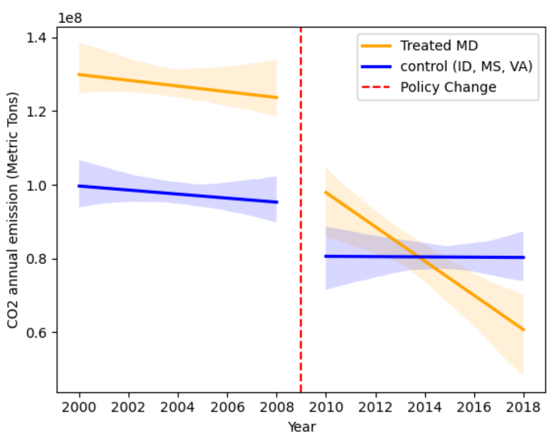
Executive Summary

The urgency to address climate change has led to innovative policy interventions across the globe. In the United States, the Regional Greenhouse Gas Initiative (RGGI) stands as a prime example of a collaborative, state-led effort to reduce carbon emissions. This report evaluates the RGGI's effectiveness by analyzing the differences in CO2 generation emissions between states participating in the RGGI and those not participating as of 2019.

Our causal analysis hinged on a Difference-in-Differences (DiD) model with fixed effects, which capitalized on the natural experiment provided by the varying adoption times of RGGI across states. Using data on generation emissions, energy production sources, and electricity retail prices, we controlled for confounding variables like energy production profiles and weather dynamics. Our model controlled for state and time-fixed effects, thereby adjusting for potential unobserved heterogeneity and time-varying factors that might influence emissions.



The analysis yielded a statistically significant negative coefficient for the interaction term between RGGI treatment and the post-treatment period, indicating that RGGI implementation is associated with a reduction in CO2 generation emissions. Specifically, the implementation of RGGI is associated with a 24.2% reduction in CO2 emissions on average, compared to states not participating in RGGI over the same study period. This key finding substantiates the efficacy of the RGGI program in lowering emissions among participating states. While this general result is compelling, it is important to note that our Difference-in-Differences analysis focusing on one treated state with multiple control states did not yield conclusive results. However, when examining all treated states as a group, the regression outcomes were significant and indicative of RGGI's effectiveness. The different coal, natural gas and oil mix was also found to be a significant determinant of emissions levels, emphasizing the link between the energy source and CO2 output. Importantly, the analysis also revealed that higher Cooling Degree Days (CDD), which reflect increased temperatures requiring more air conditioning, are associated with increased emissions. This underscores the challenge of rising temperatures and their impact on energy consumption and emissions, reinforcing the need for comprehensive strategies that address both emissions trading and energy efficiency under varying climatic conditions.

The report's conclusions offer crucial insights into the policy's success and underscore the potential of cap-and-trade programs to mitigate climate change impacts. By demonstrating RGGI's positive environmental outcomes, this study lends support to the continued use and potential expansion of market-based regulatory approaches to environmental challenges.

Our findings are intended to inform policymakers, stakeholders, and the public about the benefits of cooperative regional efforts like RGGI and their vital role in the broader context of sustainable energy policy and climate change mitigation.

Introduction

As the United States confronts the challenges posed by its reliance on non-renewable energy sources, significant hurdles remain in achieving its environmental and climate goals. This project centers on evaluating the effectiveness of regional policies designed to reduce generation emissions. In particular, it focuses on the Regional Greenhouse Gas Initiative (RGGI), a collaborative effort among several U.S. states to cap and reduce carbon dioxide emissions from the power sector through a market-based emissions trading scheme. This analysis compares the generation emission trends of the original states that joined RGGI in 2009 with those of states that had not joined the initiative by 2019, aiming to assess the impact of RGGI in mitigating power generation emissions within participating states.

Question and Motivation

The causal question we aim to answer is: How has the RGGI impacted the reduction of generation emissions in participating states compared to non-participating states? This question arises from several key findings in our exploratory analysis.

Firstly, we observed a discernible shift towards cleaner energy sources in the U.S. energy mix, driven by environmental concerns, technological advancements, and the evolving price dynamics of fuel resources. RGGI's focus on reducing greenhouse gas emissions aligns with this broader trend, prompting us to evaluate its specific contribution to emissions reduction compared to other drivers.

Furthermore, the inverse relationship between the increase in renewable energy generation and the decrease in greenhouse gas emissions, particularly within the power generation sector, presents a crucial opportunity for climate change mitigation. Understanding whether this trend is primarily driven by the organic integration of renewable energy sources or by policy interventions like RGGI is imperative for informing future policy decisions.

Lastly, public sentiment overwhelmingly supports the development and adoption of renewable energy sources, indicating strong backing for policies that promote emissions reduction and sustainable energy practices. Consequently, assessing the effectiveness of public policies such as RGGI in reducing emissions is essential for aligning policy measures with public preferences and achieving meaningful progress towards a cleaner, more sustainable energy future.

In summary, evaluating the impact of RGGI on generation emissions in participating states relative to non-participating states is crucial for understanding the efficacy of regional emissions reduction initiatives and guiding future policy decisions related to climate change mitigation and renewable energy adoption.

Method

1. Statistical and Econometric Analysis

Our empirical strategy to evaluate the effectiveness of the RGGI on generation CO_2 emissions was a Difference-in-Differences (DiD) approach within a fixed-effects framework. The model was specified to understand the differential impact of the RGGI policy on emissions across states, leveraging variation in RGGI participation over time.

In 2009, there were significant national energy policy changes in the United States that could potentially impact any state-level analysis of emissions or energy usage. One of the most prominent legislative efforts was the American Clean Energy and Security Act of 2009, also known as the Waxman-Markey Bill. Although it ultimately failed to become law, it did stimulate discussion and could have influenced energy policies at various levels. Additionally, in 2009, the U.S. Environmental Protection Agency (EPA) formally declared that greenhouse gases (GHGs) threatened public health and the environment, leading to the EPA's increased regulation of emissions under the Clean Air Act. This action marked a significant shift towards national efforts to control GHG emissions and would have influenced emissions independent of RGGI's efforts.

These events underscore the importance of using a Difference-in-Differences (DiD) approach rather than a simple pre-post analysis. A pre-post analysis in this context might falsely attribute changes in emissions to RGGI if it coincided with these broader federal actions. In contrast, the DiD approach can help isolate the effect of RGGI by comparing changes between participating and non-participating states, assuming that national policies affected all states similarly, thus providing a more accurate measure of RGGI's true impact.

2. Control for Confounding Variables

In our analysis, we meticulously incorporated several control variables to isolate the effect of the Regional Greenhouse Gas Initiative (RGGI) on emissions from other factors that could also influence these outcomes. This approach ensures that our findings more accurately reflect the impact of RGGI, independent of external influences.

a. Control for Energy Mixture:

To account for fluctuations in energy demand, we included the ratio of coal, natural gas, crude oil usage as a key control variable. This measure represents the proportion of energy generated from coal, natural gas and crude oil relative to total energy production within each state. By controlling for this factor, we aimed to adjust for differences in the energy mix that could affect emissions levels. For instance, shifts towards natural gas from coal, which emits less CO_2 per unit of energy produced, could lower emissions irrespective of RGGI policies. Thus, including this variable helps ensure that any observed changes in emissions are not merely due to shifts in the types of energy sources used but are associated with RGGI implementation.

b. Accounting for Weather Variations:

The seasonal cyclic pattern of energy usage, as revealed in our exploratory questions, highlights the significant influence of weather conditions on energy consumption and emissions. For instance, colder winters can spike heating demands, potentially increasing emissions, while warmer seasons might yield the opposite effect. Recognizing this, we integrated historical climate data, specifically Heating Degree Days (HDD) and Cooling Degree Days (CDD), into our analysis. These data offer standardized metrics for seasonal temperature fluctuations, enabling us to control for weather-induced variations in energy usage. By incorporating HDD and CDD as control variables, we mitigate the impact of weather on emissions, ensuring that any observed reductions attributed to RGGI are accurately assessed independent of seasonal climate effects. This meticulous approach bolsters the reliability and precision of our analysis, facilitating a more nuanced understanding of RGGI's efficacy in reducing greenhouse gas emissions across participating states.

3. Sensitivity Analysis

We explored variations in our model's outcomes by applying different analytical approaches. Specifically, we incorporated a different method to calculate fuel ratios, and electricity prices as confounding variables to examine their impact on our findings. Despite these adjustments, the significance of the interaction term, which represents the effect of being treated post-policy implementation, remained consistent. For a detailed account of these variations and their implications, please refer to Appendix 3.

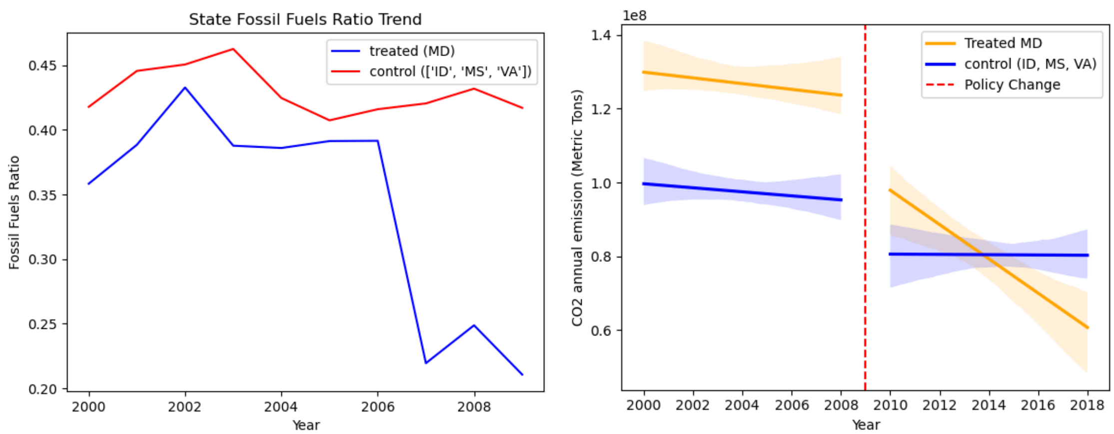
Result

1. Difference-in-Difference (DiD) on State Level

To discern the impact of the fuel mixture used in production on generation emissions between RGGI participant and non-participant states, we meticulously analyzed production data to calculate their fuel usage ratios and natural gas usage ratio. Our goal was to identify pairs of states with comparable fuel usage ratios or gas ratios, or with similar trends before RGGI's implementation in 2009.

In examining state fossil fuel ratios, Maryland (MD) was designated as the treated state, with Idaho (ID), Mississippi (MS), and Virginia (VA) serving as controls. These states exhibited similar trends from the year 2000 onward, marked by fluctuations but generally showing a downward trajectory. (Plot 1 left) This similarity suggests that before the implementation of the Regional Greenhouse Gas Initiative (RGGI), these states were likely influenced by comparable energy market dynamics or similar environmental policies, providing a consistent baseline from which to evaluate the impact of RGGI.

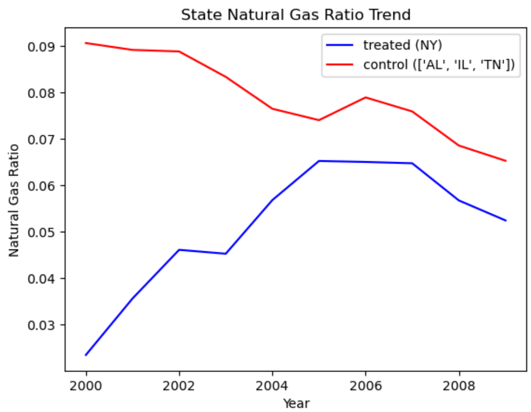
The DiD analysis, as shown in the graphs, reveals a significant post-policy decrease in Maryland's CO_2 emissions compared to a slight increase or stabilization in the emissions trends of the control states. (Plot 1 right) This marked divergence post-RGGI implementation underscores the initiative's impact and highlights its potential effectiveness in reducing emissions. Given the parallel trends in fossil fuel usage ratios before the policy change, the observed reduction in Maryland's emissions post-RGGI can be cautiously attributed to the effects of the initiative, suggesting that RGGI could serve as an effective regulatory mechanism for managing and potentially reducing state-level emissions under similar initial conditions.

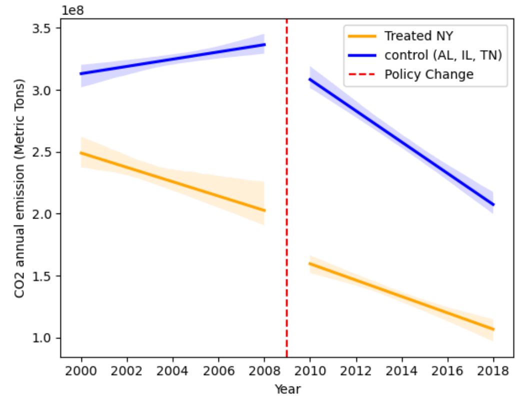


Plot 1 (left): Fossil Fuel Ratio for MD (treated) and ID, MS, VA (controlled)
Plot 1 (right): DiD - Generation Emission Before and After the Policy

In analyzing the natural gas ratio trends, New York (NY) was selected as the treated state, with Alabama (AL), Illinois (IL), and Tennessee (TN) serving as control states. The trend data beginning from 2005 shows alignment between the states with a noticeable uptick before a gradual decline, suggesting a shared influence or policy aimed at reducing natural gas usage. (Plot 2 left) Despite this common trend, the nuances in the trajectories warrant attention, especially when considering the implementation impact of regulatory policies like RGGI.

The DiD analysis concerning generation emissions provides an intriguing perspective. (Plot 2 right) After the implementation of RGGI, there is no discernible change in the trend of New York's emissions, which continue without significant slope alteration. Conversely, the control group exhibits a pronounced shift from an upward to a downward trend in emissions. This unexpected pattern in the control states, which did not participate in RGGI, suggests a more pronounced reduction in emissions compared to New York, where RGGI was expected to drive emission decreases. This analysis indicates that factors other than RGGI may be influencing emissions trends in the control states, leading to a conclusion that RGGI's direct effectiveness in reducing generation emissions in New York during this period remains inconclusive on an individual level.





Plot 2 (left): Natural Gas Ratio for NY (treated) and AL, IL, TN (controlled)
Plot 2 (right): DiD - Generation Emission Before and After the Policy

2. Difference-in-Differences (DiD) model with fixed effect comparing all states

This analysis sought to investigate the impact of the RGGI on reducing CO_2 generation emissions across all states. Utilizing a panel dataset within a fixed-effects framework, we employed a Difference-in-Differences (DiD) approach. The dependent variable in our regression was the natural logarithm of CO_2 emissions, providing a clear measure of changes in emission levels. We analyzed data from the eight years preceding and following the implementation of the RGGI policy in 2009, enabling a comprehensive assessment of its long-term effects.

PanelOLS Estimation Summary

Dep. Variable:	CO2_log	**R-squared:**	0.1736
Estimator:	PanelOLS	**R-squared (Between):**	0.0383
No. Observations:	752	**R-squared (Within):**	0.2529
Date:	Mon, Apr 29 2024	**R-squared (Overall):**	0.0384
Time:	20:06:33	**Log-likelihood**	435.43
Cov. Estimator:	Clustered		
		F-statistic:	23.941
Entities:	47	**P-value**	0.0000
Avg Obs:	16.000	**Distribution:**	F(6,684)
Min Obs:	16.000		
Max Obs:	16.000	**F-statistic (robust):**	6.7941
		P-value	0.0000
Time periods:	16	**Distribution:**	F(6,684)
Avg Obs:	47.000		
Min Obs:	47.000		
Max Obs:	47.000		

Parameter Estimates

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
coal_ratio	0.8117	0.2959	2.7435	0.0062	0.2308	1.3927
natural_gas_ratio	0.5693	0.2196	2.5929	0.0097	0.1382	1.0005
crude_oil_ratio	0.9490	0.3118	3.0437	0.0024	0.3368	1.5611
cdd	0.0017	0.0004	4.0158	0.0001	0.0009	0.0026
hdd	-0.0002	0.0003	-0.6520	0.5146	-0.0008	0.0004
treated:post	-0.2766	0.0880	-3.1416	0.0018	-0.4494	-0.1037

F-test for Poolability: 864.66
P-value: 0.0000
Distribution: F(61,684)

Included effects: Entity, Time

Table 1. Panel Ordinary Least Squares (PanelOLS) regression model summary

The results of the PanelOLS model illustrated in Table 1 with entity and time fixed effects suggest that the type of fuel used for energy (coal, natural gas, and oil) is significantly associated with the level of CO_2 emissions, with coal having the largest impact, followed by oil, and then natural gas. Additionally, higher temperatures, requiring more cooling, are associated with increased emissions. Most importantly, the significant negative coefficient for the interaction term indicates that RGGI implementation is associated with a reduction in emissions, which is a key finding for policymakers considering the effectiveness of cap-and-trade systems like RGGI. Specifically, the analysis estimates a 24.16% [6] reduction in emissions, highlighting that RGGI not only significantly decreases emissions but does so to a substantial degree, making it a compelling option for reducing greenhouse gas in participating states. The lack of significance in the Heating Degree Dates (HDD) coefficient implies that colder temperatures and the need for heating do not have a discernible impact on emissions within this model. The robustness of the fixed effects was confirmed by a large F-test for poolability (864.66 with a p-value < 0.0001), demonstrating that the use of fixed effects to control for unobserved heterogeneity was warranted. Overall, these results provide strong support for the effectiveness of the RGGI program in reducing CO_2 generation emissions.

Conclusion

The empirical findings from our Difference-in-Differences analysis using the PanelOLS framework provide compelling evidence on the determinants of CO_2 emissions and the effectiveness of policy interventions. Specifically, the type of fuel used for energy generation—coal, natural gas, and oil—significantly impacts the level of emissions, with coal showing the largest effect, followed by oil and natural gas. This underscores the critical environmental cost of relying on coal for energy production and highlights the need for policies that either reduce its use or make its use cleaner. Moreover, the model indicates that higher temperatures, which increase cooling demands, are associated with higher emissions. This relationship captures the environmental challenge posed by climate change, where increased temperatures could lead to a vicious cycle of higher energy use and further emissions. Critically, our study shows a significant negative effect on emissions. Quantitatively, this translates into an estimated 24.16% reduction in emissions due to the implementation of RGGI. This substantial decrease not only confirms the effectiveness of RGGI but also highlights its potential as a model for other regions and countries aiming to curb greenhouse gas emissions through cap-and-trade systems.

Given the evidence that RGGI has helped reduce emissions, expanding the initiative to include additional states could potentially amplify the environmental benefits. RGGI could potentially achieve greater emissions reductions and serve as a model for other states and regions considering similar market-based approaches to tackle climate change. The implementation of these adjustments should be monitored and evaluated continuously to measure effectiveness and ensure the policy remains aligned with evolving environmental goals and economic contexts.

Appendix

Appendix 1: Project GitHub repository

https://github.com/MIDS-at-Duke/uds-2024-flamingo

Appendix 2: Data

Generation Emission Data [1]: The generation emission data was obtained from the Energy Information Administration (EIA) website, a reputable source for comprehensive energy statistics and environmental impact assessments. The emission data includes the type of producer, energy source, and their respective emissions of CO2, SO2, and NOx at the state level from 1990 to 2022. Specifically, we focused on CO2 emissions as the primary measure of environmental impact due to its significant role in contributing to global climate change. Emissions data is aggregated annually by state, facilitating our analysis of time trends and the distinction between treated states (those participating in RGGI) and control states (those not participating).

Energy Production Source Data [2]: The energy production source data was obtained from the State Energy Data System (SEDS) on the EIA website. The SED is the source of the EIA comprehensive state energy statistics. The dataset contains energy production data for all states from 1960 to 2021 across various energy sources and production types. It provides annual measurements in physical units and energy content, including coal, natural gas, crude oil and total primary energy for production. The dataset equips us to execute a Difference-in-Differences (DiD) analysis by identifying states with similar pre-RGGI fuel use profiles, ensuring a fair comparison. It helps isolate RGGI's impact on generation emissions by controlling for initial fuel consumption patterns across treated and control states.

Weather Data [3]: The detailed historical weather records, including temperature, precipitation, and more was provided by National Centers for Environmental Information (NCEI).

Electricity Retail Price Data [4]: The dataset, sourced from the EIA, comprises annual data on the average retail price of electricity for all states from 2001 to 2023. This data serves as a key confounder in our analysis, allowing us to account for and mitigate the impact of electricity pricing on energy production and emissions trends within our study period.

Participants of RGGI in 2009 [5]: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont. For our analysis, the 'treated' group comprises these 9 states, while the 'control' group is selected from the remaining states not participating in RGGI at least by 2019.

All State[5]: New Jersey was excluded due to its initial withdrawal from the RGGI in 2012 and subsequent rejoining in 2020, which could confound the results. Additionally, Alaska and Hawaii were omitted from the all states study due to the unavailability of comprehensive weather data.

Appendix 3: Sensitivity Analysis with Different Confounders

Regression summary table using fuels ratio and electricity price as confounding variables:

PanelOLS Estimation Summary

Dep. Variable:	CO2_log	**R-squared:**	0.1047
Estimator:	PanelOLS	**R-squared (Between):**	0.0211
No. Observations:	800	**R-squared (Within):**	0.1875
Date:	Thu, Apr 25 2024	**R-squared (Overall):**	0.0211
Time:	13:36:43	**Log-likelihood**	344.25
Cov. Estimator:	Clustered		
		F-statistic:	28.546
Entities:	50	**P-value**	0.0000
Avg Obs:	16.000	**Distribution:**	F(3,732)
Min Obs:	16.000		
Max Obs:	16.000	**F-statistic (robust):**	4.9703
		P-value	0.0020
Time periods:	16	**Distribution:**	F(3,732)
Avg Obs:	50.000		
Min Obs:	50.000		
Max Obs:	50.000		

Parameter Estimates

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
Fuels_ratio	0.5220	0.2513	2.0774	0.0381	0.0287	1.0152
e_price	0.0008	0.0053	0.1416	0.8875	-0.0097	0.0112
treated:post	-0.2565	0.0875	-2.9300	0.0035	-0.4284	-0.0846

Reference

1. Generation Emission by state annually:
   https://www.eia.gov/electricity/data/state/emission_annual.xlsx
2. Energy Production source by state annually:
   https://www.eia.gov/state/seds/sep_prod/xls/Prod_dataset.xlsx
3. Weather data by state:
   https://www.ncei.noaa.gov/pub/data/cirs/climdiv/
4. Average Electricity Retail Price Data by state annually:
   https://www.eia.gov/electricity/data/browser/#/topic/7?agg=1,0&geo=fvvvvvvvvvvvo&endsec=g&freq=A&start=2001&end=2023&ctype=linechart&ltype=pin&rtype=s&maptype=0&rse=0&pin=
5. Wikipedia - Regional Greenhouse Gas Initiative:
   https://en.wikipedia.org/wiki/Regional_Greenhouse_Gas_Initiative

6. How do I interpret a regression model when some variables are log transformed?: https://stats.oarc.ucla.edu/other/mult-pkg/faq/general/faqhow-do-i-interpret-a-regression-model-when-some-variables-are-log-transformed/