Evaluation of the Regional Greenhouse Gas Initiative

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Abstract

Environmental policies such as carbon taxes and cap-and-trade programs are pivotal in the global effort to mitigate climate change. This study seeks to evaluate the effectiveness of environmental policies with a focus on the Regional Greenhouse Gas Initiative (RGGI). We aim to assess its impacts on CO2 emissions, energy price, economic growth, and environmental justice. This study will utilize data from emissions tracking, auction results, investment proceeds, and census data to provide a nuanced understanding of how such policies contribute to sustainable development and climate change mitigation.

Introduction

The Regional Greenhouse Gas Initiative (RGGI) is the first mandatory cap-and-trade program in the United States targeting carbon dioxide emissions from the power sector. Implemented in 2008, RGGI encompasses a consortium of states committed to reducing greenhouse gasses through a market-driven approach. This report evaluates the effectiveness of RGGI by analyzing its impact on environmental quality, economic performance, and social equity across participating and non-participating states. The study evaluates trends in CO2 emissions, examines the fair distribution of environmental benefits and responsibilities, and studies economic changes related to the initiative applying a variety of analytical techniques, such as difference-in-differences and regression analysis. The findings contribute to a deeper understanding of regional approaches to environmental policy in the context of mitigating climate change for a more ecologically friendly world by offering important insights into the achievements and difficulties of RGGI.

Background and Literature Review

According to RGGI, Inc. (2024), the Regional Greenhouse Gas Initiative (RGGI) is a collaborative, market-based program in the United States designed to reduce greenhouse gas emissions from the power sector. Established in 2005 and fully implemented by 2008, RGGI is the first mandatory cap-and-trade system in the U.S., involving several Northeastern and Mid-Atlantic states. Under RGGI, power plants with capacities greater than 25 megawatts are required to obtain allowances for each ton of CO2 they emit. These allowances can be bought and sold in a regional market, fostering economic incentives for power plants to reduce their emissions. Allowances are sold to bidders such as power plants through quarterly CO2 auctions on an online platform. Allowances are sold at a uniform clearing price based on supply and demand (Regional Greenhouse Gas Initiative, Inc., 2024e). The revenue generated from the sale of these allowances is used by participating states to fund energy efficiency, renewable energy, and other consumer benefit programs. The initiative initially included Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont (Regional Greenhouse Gas Initiative, Inc., 2024). Over time, the coalition of participating states has experienced changes; New Jersey, for example, exited the initiative in 2011 but later rejoined in 2020 (New Jersey Department of Environmental Protection, 2023). Virginia became a member in 2020, but left the initiative at the end of 2023. (Virginia Association of Counties, 2020). State lawmakers in Virginia are currently attempting to rejoin RGGI through measures in their state budget, but are met with resistance from their governor (Chanatry, 2024). Pennsylvania has been moving towards implementation but has faced significant legislative hurdles and opposition, preventing full participation (Burtraw et al., 2023). The process of evolution presents the dynamic nature of regional efforts to combat climate change through regulatory and market-driven strategies. Figure 1 is a map of the RGGI states from the C2ES website.

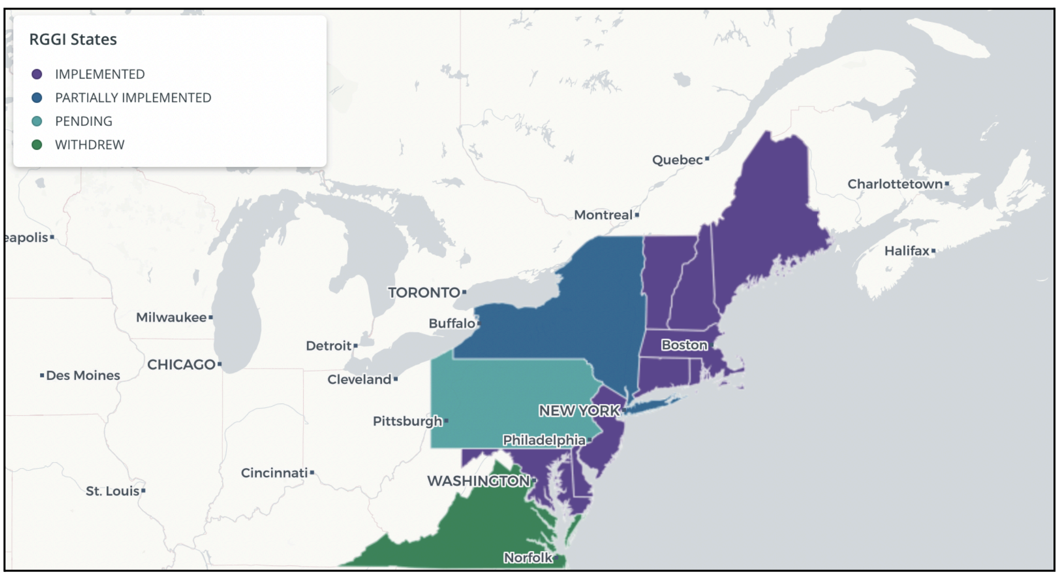

Figure 1. RGGI States Map (C2ES, 2024)

The RGGI has many benefits. By reducing pollution and emissions, the RGGI improves air quality and public health with reduced rates of asthma, premature births, and low-birth weights. Additionally, funds from the sale of CO2 allowances are directly invested in local communities, with a portion of funding going towards direct bill assistance to lower electricity prices for households and businesses. Further, investments have led to the creation of new jobs in clean energy industries (Regional Greenhouse Gas Initiative, 2024a). Additionally, participation in the RGGI may allow states to receive additional subsidies and tax credits and maximize benefits of the Inflation Reduction Act (Evergreen Action, 2023).

Moreover, previous evaluations of the RGGI and other cap-and-trade programs provide valuable insights into the effectiveness and impact of market-based approaches to reducing greenhouse gas emissions. Studies on RGGI have generally found that it has successfully reduced CO2 emissions in the power sector across participating states, with significant benefits in air quality improvement and health outcomes (Skantz, 2020). It has aligned with the program's environmental targets, illustrating a direct public health benefit of emissions reductions. Further, the economic analysis by Rich (2018) highlights how RGGI's auction revenues have been reinvested into energy efficiency projects, thereby stimulating job creation and energy savings.

However, the effectiveness of cap-and-trade mechanisms isn't uniform across different implementations, as evidenced by experiences in other regions. For example, the European Union Emissions Trading System (EU ETS) has faced challenges such as price volatility, which Clò et al. (2013) identify as undermining the predictability and stability necessary for long-term investment in cleaner technologies. The EU ETS has taken several regulatory amendments aimed at addressing these challenges, reflecting the need for adaptive governance structures in cap-and-trade programs to meet evolving environmental and economic goals. Similarly, Walch's (2018) research on California's cap-and-trade program discusses concerns about potential increases in pollution levels in disadvantaged communities because of cap-and-trade programs, emphasizing the importance of applying environmental justice concerns into account in carbon pricing programs and policy making. It implies that for programs such as RGGI to achieve the expected economic and environmental outcomes, it is necessary to ensure that reductions are implemented in a way that minimizes unanticipated negative effects on vulnerable people and fairly distributes environmental benefits. These studies collectively underscore the considerable elements required for cap-and-trade programs like RGGI to achieve intended environmental and economic outcomes.

Historically, the intersection of climate change mitigation and social equity has received limited attention within the domestic U.S. policy agenda.(Martinez, C., 2016). However, a large percentage of both low-income populations live close to power plants, making equitable reductions in power sector emissions a critical public health and environmental justice issue. Some think that carbon-trading programs are ill-suited to prevent local (i.e., at a specific particular power plant) emissions increase because these programs establish overall emissions reductions goals, and allow regulated entities to trade allowances with each other as a primary compliance mechanism (26 Ecology L.Q. 80 ,1999). Previous analysis regarding the environmental justice issue has been done for RGGI (Declet-Barreto J et al., 2022) and California's cap-and-trade program (Cushing et al.,2018). However, these studies primarily examined the conditions following the policy's implementation within the designated policy areas, neglecting to conduct comparative analyses with control groups or assess the situation prior to the policy's enactment.

Research Questions

This study paper is driven by the imperative to combat climate change through efficient policy measures, with an emphasis on the power sector as an important factor in carbon emissions. Given its groundbreaking role as the first mandated cap-and-trade program in the United States, the Regional Greenhouse Gas Initiative (RGGI) offers a compelling example in this field of study.

The purpose of this research is to evaluate the effectiveness of the Regional Greenhouse Gas Initiative (RGGI) in reducing carbon emissions in participating states relative to non-participating states, as well as the effects of these reductions on social and economic outcomes. Specifically, our research is guided by three leading questions:

1. How have CO_2 emissions trends in the power sector differed between RGGI-participating states and non-participating states?
2. Were there any observed economic changes after the implementation of RGGI and can any observed economic changes be directly attributed to RGGI?
3. Are there discernible patterns indicating an unequal distribution of environmental burdens or benefits resulting from RGGI's implementation?

These questions are crucial for evaluating the efficiency of RGGI and understanding its broader implications for environmental policy, economic health, and social equity. Through this investigation, we will provide evidence-based insights that can inform future policy decisions and strategies in the ongoing concerns against climate change.

Data

The U.S. Energy Information Administration (EIA)
EIA published time-series total energy price data from 1990 to 2023, which served as the primary dataset for the energy price analysis. This dataset allows an extensive examination of energy price trends across different classifications of states, both before and after the implementation of the RGGI.

Integrated Public Use Microdata Series（IPUMs）
IPUMS provides census and survey data from around the world integrated across time and space.The source of median income data we use is The American Community Survey. However, the ACS only allows users to download census tract data separately by city and does not provide any API, while IPUMS provides a tidy and completed integrated dataset.

Longitudinal Electric Generating Units Database (1995-2016)

A data repository of Electrical Generating Units (EGUs) in the continental United States. The data include location, capacity, generation, environmental controls, and CO2, SO2, and NOx emissions data from 1995-2016. One limitation of this dataset is that the CO2 emission data for EGUs within the RGGI state has a high missing rate.

The RGGI CO2 Allowance Tracking System (RGGI COATS)

The RGGI COATS platform tracks and facilitates each state's CO2 trading program (RGGI, 2024). Different levels of emissions data are available in the public report interface of the platform. We extracted data at the annual level. Emissions data provided in the RGGI COATS report may not include all emitting units or emissions for a specific time period due to pending data processing or resolution of technical source reporting issues. Additionally, historical data before 2008 only contains data for 10 RGGI states beginning from 2000. Furthermore, detailed breakdowns of investment of proceeds categories by state from 2014 to 2021 were also obtained from the RGGI COATS platform. Unfortunately, no data on investment of proceeds were available for the years before 2014 or after 2021.

Bureau of Labor Statistics

Seasonal-adjusted state unemployment rates were obtained from the Bureau of Labor Statistics. These data included state seasonal-adjusted unemployment rates on a monthly basis from 2006 to 2024. As employment can fluctuate throughout the year, seasonal-adjusted unemployment rates remove any seasonality effects (State of California Employment Development Department, 2024). Monthly unemployment rates for each state were aggregated by year and averaged to obtain an average yearly unemployment rate for each state.

Bureau of Economic Analysis

Further economic data were obtained from the United States Regional Economic Analysis Project, which compiles relevant state economic data from the Bureau of Economic Analysis. Yearly data on population, number of jobs, Gross Domestic Product (GDP), real GDP (in chained 2017 dollars), percent change of real GDP, and percent of national GDP total were collected for each state in the United States from 2006 to 2019.

Methods

Environmental

To assess the environmental impact of the RGGI, it is crucial to analyze the trends in energy prices across RGGI-participating and non-participating states, as these trends provide insights into the economic pressures and incentives created by the initiative.

The methodology integrates several analytical techniques to robustly assess REGGAE's impact on energy prices. Our research categorized the dataset into four distinct groups: RGGI states, non-RGGI states, the overall US, and remaining states, which facilitates a comparative analysis of energy price impacts attributable to RGGI's operational dynamics. Non-RGGI states refer to those states that have never participated in the RGGI program and may have distinct state policies regarding emissions that are independent of the RGGI's framework; and, remaining states can include states that are considering RGGI membership, those that implement regulatory policies similar to RGGI, or even states neighboring RGGI members that might experience secondary effects like carbon leakage. An example of a remain state could be Pennsylvania, which has been involved in discussions about joining RGGI. Initially, a descriptive analysis provides a foundational understanding of general price trends within each category over the specified period. Then, a difference-in-differences analysis is employed to compare the pre- and post-RGGI implementation effects on energy prices, effectively isolating the influence of RGGI from other macroeconomic factors that could potentially affect energy prices. Furthermore, a comparative state analysis is conducted to elucidate the differences and similarities in price trends across the four defined categories.

Another environmental outcome measurement is CO2 Emissions. We first tried to reproduce results from RGGI official report about the percentage decrease rate of total CO2 emissions amount. Then we applied difference-in-differences analysis. The aim is to compare the change rate of CO2 Emissions right before and after the project implementation period (2005-2008) in and out of RGGI state to evaluate the effect attributed to RGGI. Due to the data limitation, we analyze the average emissions and total number of EGUs instead of total CO2 emissions.

Economic

To investigate how the RGGI may have influenced state economic outcomes, we analyzed changes in state unemployment rates and state GDP among states participating in the RGGI and states not participating in the RGGI. In addition, we also conducted an analysis of states' discretionary investments of auction proceeds.

Unemployment

The RGGI results in new jobs created in clean and renewable energy industries. Examples of job opportunities include contractors to improve energy efficiency measures, energy efficiency auditors, and educational staff providing information on relevant clean and renewable energy initiatives (Stuart & Hibbard, 2023). In our analysis, we investigate whether these additional jobs had an overall impact on states' unemployment rates. To conduct this analysis, we used a difference-in-differences approach. States were grouped into two categories based on RGGI participation. States were coded as a "one" if they participated in RGGI throughout all years of implementation. These states included Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. New Jersey and Virginia were excluded from this analysis since they only participated in RGGI during certain years. The other thirty-nine states that have never participated in RGGI were coded as a “zero.” Average yearly unemployment rates were determined for each grouping of states from 2006 to 2019. Average unemployment rates from the RGGI states were subtracted from the average unemployment rates from the Non-RGGI states. The difference among the rates from 2008 (one year before implementation) was subtracted from the difference among the rates from 2010 (one year after implementation) to assess the overall impact of RGGI on state unemployment rates.

Gross Domestic Product (GDP)

Further, we investigated if there was any change in state GDP after RGGI implementation. If RGGI negatively impacts GDP, states may have to decide whether to prioritize environmental or economic objectives when considering participation in RGGI. However, if RGGI positively impacts GDP by spurring new growth in clean energy industries, states may be more easily convinced to join RGGI or other similar cap-and-trade programs. To answer this question, we also used a difference-in-differences analysis, with a similar approach to methods used in our unemployment rate analysis. The same groupings of states were used and New Jersey and Virginia were once again excluded from this analysis. Total real GDP (in chained 2017 dollars) for each state was divided by the state’s population from 2006 to 2019 to obtain real GDP per capita in each state. The differences between RGGI states and non-RGGI states were calculated for each year. Additionally, the difference of GDP in 2008 (one year before implementation) was subtracted from the difference of GDP from 2010 (one year after implementation) to assess the overall impact of RGGI on state GDP. Additional similar analyses were conducted with GDP in current dollars, percent of national GDP and percent change of real GDP.

Investment of Proceeds

Finally, since each state has discretion over how to invest their allowance proceeds, we analyzed which investment categories may contribute to positive economic outcomes such as low unemployment rates and high GDP. For this analysis, we created two ordinary least squares regression models. Each model included variables for the percentage of investment in four relevant investment categories - energy efficiency, clean and renewable energy, direct bill assistance, and greenhouse gas abatement. The category of beneficial electrification started attracting investment only recently, so it was excluded from this analysis (Regional Greenhouse Gas Initiative, Inc., 2024g). Additionally, the two administrative categories were not included. The first model used the percentage of each investment category to predict next year's GDP and the second model used the percentage of each investment category to predict the next year's unemployment rate. Economic data from the following year was used for the regression models, as RGGI investments are not likely to have an immediate impact on economic outcomes. Additionally, we explored two versions of the first model, with one model including the unemployment rate as a covariate. According to Okun’s law, an increase in the unemployment rate may be associated with a decrease in productivity, and vice versa (Kenton, 2022). However, upon further analysis, this assumption did not align with our data, likely because of the high unemployment rates due to the recession. Therefore, in our results we included the model without using the unemployment rate as a covariate. It is additionally important to note there are many other factors that may affect both state unemployment rates and GDP. These will be discussed further as limitations.

Justice

Linkage different source of CO2 emissions from EGUs

In order to assess the impact of the Regional Greenhouse Gas Initiative (RGGI) on CO2 emissions from Electric Generation Units (EGUs), we employed a multi-source data integration approach. This involved the extraction, transformation, and linkage of CO2 emissions data across several datasets spanning different years and containing varied environmental and operational characteristics of the plants. We began by consolidating annual CO2 emissions data from the years 1995 to 2017. The primary data included variables such as plant identification numbers, names, prime mover, unit size, fuel type, and CO2 emissions. The RGGI status and the economic classification of the region (e.g., low income) were also appended to each record to facilitate stratified analyses. Using Python's pandas library, the dataset was reshaped from a wide format (one column per year for emissions) to a long format, where each row represents a single year's emission for a specific plant. This transformation was crucial for the subsequent temporal analysis, ensuring that each observation in our dataset represented a unique time-plant instance. Emissions data were then merged with two additional datasets. The first additional dataset provided supplementary emissions figures for the years 2000 to 2008, enabling a more comprehensive historical perspective. The second dataset included more recent data post-2018, extending our analysis window to include the latest operational outcomes.

Identification of Low income communities

To identify low-income communities using median family income data at the census tract level across the U.S., we adopted a methodology based on the latest U.S. Census data, focusing on two main poverty criterias according to Tax Code Section 45D(e). A community was classified as low-income if the poverty rate was at least 20 percent, or if the median family income did not exceed 80 percent of the statewide median, or in metropolitan areas, the greater of 80 percent of the statewide or metropolitan area median family income. Using Python’s pandas library, we segmented the income data by state and metropolitan areas, applying conditional logic to compare each tract’s median family income against the 80 percent threshold. This process resulted in a binary indicator for each census tract, marking it as a low-income community if it met any of the criteria, ensuring a systematic approach for further analysis on environmental and economic impacts.

Difference-in-Differences analysis

Our study employed a difference-in-differences (DiD) analysis to estimate the impact of the Regional Greenhouse Gas Initiative (RGGI) on CO2 emissions across different income communities. This method helps in isolating the effect of the policy by comparing the changes in outcomes over time between a treatment group (affected by RGGI) and a control group (unaffected by RGGI).We first segmented the dataset into pre-treatment (before 2005) and post-treatment (after 2008) periods to assess the temporal effects of RGGI.

Further, we distinguished between low-income and non-low-income communities using the criteria based on poverty rates and median family income thresholds.For each group—low-income and non-low-income under RGGI and non-RGGI conditions—we calculated the mean CO2 emissions both before and after the introduction of RGGI. This was done by averaging the emissions across all relevant plants within each subgroup.We computed the DiD estimator for each income status by subtracting the average change in emissions of the control group from that of the treatment group. This method allows for controlling common trends that could affect the treatment and control groups, thus isolating the impact of RGGI.

To enhance the robustness of our DiD estimates, we employed a regression model incorporating interaction terms between RGGI status, income level, and the pre- and post-treatment periods. This regression analysis helped in quantifying the differential impacts of RGGI across various groups and controlling for potential confounders.

Results and Discussion

Environmental Analysis

We examine the macro trends in average energy prices from 1990 to 2022 across various classifications of states in relation to their participation in the RGGI. The focus is on analyzing the energy price dynamics in RGGI states, non-RGGI deregulated states, remaining states, and the broader US market. We will divide the analysis into three periods, namely before the implementation of RGGI (1990-2004), during the preparation of RGGI (2005-2008), and after the implementation of RGGI (2009-2022). Figure 2 displays the overall visualization work trend.

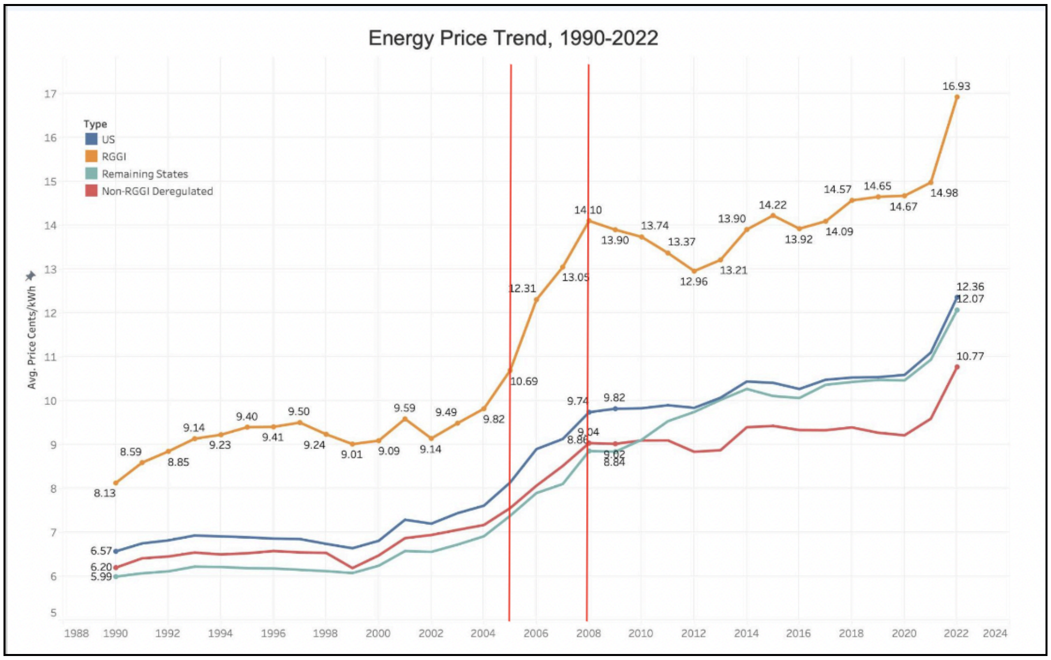

Figure 2. Average Energy Price Trend, 1990-2022. Data retrieved from EIA-861.

In the early 2000s, energy prices across the United States showed a slight upward trend, because it marked a significant period of energy transition in the United States, evidenced by the enactment of policies such as the federal Production Tax Credit (PTC) for renewables, which played a critical role in financing wind projects and promoting domestic energy sources (Stokes& Breetz, 2018). During this time, unconventional oil and gas production expanded, and the use of renewable energy sources spiked as reported by Zou et al. (2016). Together, these factors—technological advancements, shifting market dynamics, and legislative changes—have changed energy pricing. As such, renewable energy prices began to rise due to various factors such as increasing global demand, struggles in the domestic natural gas industry, and mounting pressure to address climate change.

Moreover, in the period 2005-2008, prior to the formal implementation of the RGGI, energy prices in the RGGI states experienced significant fluctuations. The average rate of increase in RGGI states was 31.89%, which is relatively different from 19.65% in the general United States. The reason is that the implementation of RGGI itself involved costs related to new administrative processes, compliance measures, and the establishment of new infrastructure to support emissions trading (Ramseur, 2019). These preparatory activities likely contributed to the upward fluctuation of energy prices in RGGI states before the official start of the program.

The long-term analysis from 2008 to 2022 reveals a different pattern. During this extended period, RGGI states showed a moderated growth rate of 20.07%, suggesting that the initial shock of RGGI implementation might have been absorbed, leading to a stabilization in energy prices due to the benefits of sustained investments in energy efficiency and renewable energy projects. Even the average increase in energy in RGGI states has been lower than the overall increase in the United States (26.90%). Meanwhile, non-RGGI deregulated states displayed a lower growth rate of 19.13%, reflecting less volatility and possibly the effects of energy market deregulation without the influence of cap-and-trade mechanisms like RGGI. The average energy prices for the other three categories besides RGGI states are in less diverse ranges.

The differential impacts observed across state categories prove the significance of regional policies and market characteristics in shaping energy price dynamics. As states continue to navigate the challenges and opportunities presented by environmental and regulatory frameworks, more time-series analysis is crucial for informing policy decisions and understanding their broader economic implications.

In evaluating the CO2 emissions trends in RGGI states, we utilized longitudinal data from electric generating units (EGUs) and the RGGI CO2 Allowance Tracking System. The data showed a significant decrease in emissions from 2009 to 2015, with actual 2015 emissions of 106.6 million tons falling 21.3% below the 2009 emissions of 135.5 million tons. This trend suggests a positive impact of the RGGI on reducing emissions in participating states.

However, the data limitations, particularly the incomplete data before 2008 and lack of specific EGU emissions data, posed challenges in evaluating the full impact of the RGGI. To address this, the study compared trends both within and outside RGGI states before and after the RGGI implementation. The average CO2 emissions per EGU showed a decrease in both RGGI and non-RGGI states, but with a more pronounced reduction in RGGI states, suggesting that the program may have influenced these reductions.

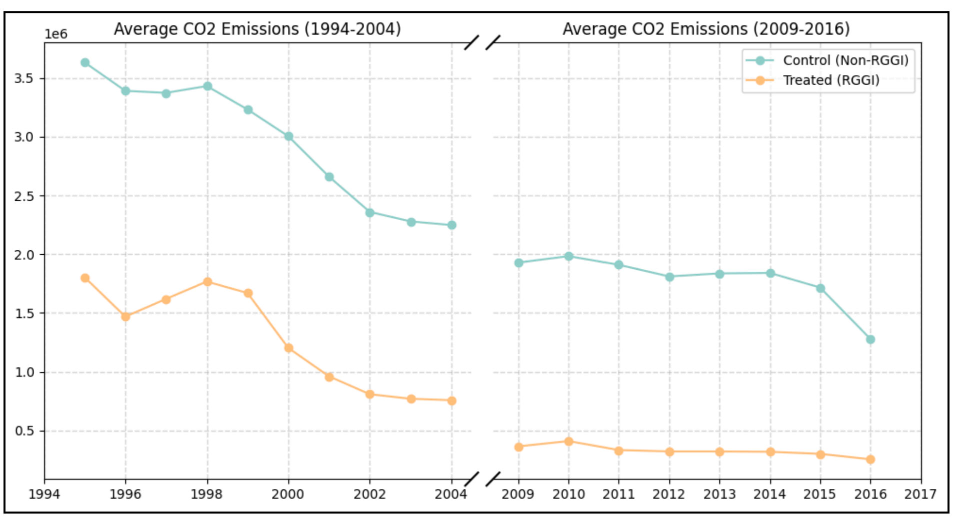

Figure 3. Average CO2 Emissions(tons) per EGU in and out of RGGI States

Despite these findings, the difference-in-differences (DiD) analysis indicated that the emissions reductions attributable directly to the RGGI were not statistically significant. This implies that while emissions in RGGI states decreased more quickly than in non-RGGI states, the RGGI program itself may not be the sole factor driving these changes. This analysis highlights the complexity of attributing environmental policy impacts directly to specific programs, especially when external factors and broader market trends could also influence emissions trends.

In conclusion, while the RGGI states have shown faster decreases in emissions compared to non-RGGI states, the direct impact of the RGGI program on these trends remains unclear, underscoring the need for more detailed data and rigorous analyses to isolate the effects of specific environmental policies.

Economic Analysis

For the following analysis, a positive difference measure indicates a more favorable economic outcome among RGGI states, while a negative difference measure indicates a more favorable economic outcome among non-RGGI states.

Unemployment Rates

First, we analyzed average unemployment rates among RGGI states in comparison to non-RGGI states. A positive difference measure indicates non-RGGI states having a higher unemployment rate than RGGI states, and a negative difference measure indicates RGGI states having a higher unemployment rate than non-RGGI states. The difference between the differences of rates in 2010 (one year after implementation) and the differences of rates in 2008 (one year before implementation) is 0.3528. This number indicates that after RGGI implementation, the unemployment rate of non-RGGI states increased 0.3528 relative to the increase in unemployment among RGGI states. This result suggests that RGGI may be associated with lower unemployment rates from the increase of clean energy jobs. However, this trend does not hold beyond 2012, as the difference measure even becomes negative in 2013 indicating that the unemployment rate among RGGI states was higher than non-RGGI states.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
RGGI														
0	4.5147	4.4017	5.3769	8.5835	8.838	8.1799	7.2784	6.6718	5.6902	5.0167	4.7472	4.1769	3.8105	3.6415
1	4.3250	4.2231	5.2537	8.0833	8.362	7.6981	7.2565	6.8148	5.7370	4.7509	4.1806	3.8880	3.4778	3.1648
Difference	0.1897	0.1786	0.1232	0.5002	0.476	0.4818	0.0219	-0.1430	-0.0469	0.2657	0.5667	0.2890	0.3327	0.4766

Figure 4
Differences of Unemployment Rates between Non-RGGI and RGGI States

Although RGGI may have resulted in initial reduced unemployment, the jobs gained in clean energy industries may have been lost in other job sectors, reducing the potential positive impact of RGGI on state unemployment rates (Murray et al., n.d.).

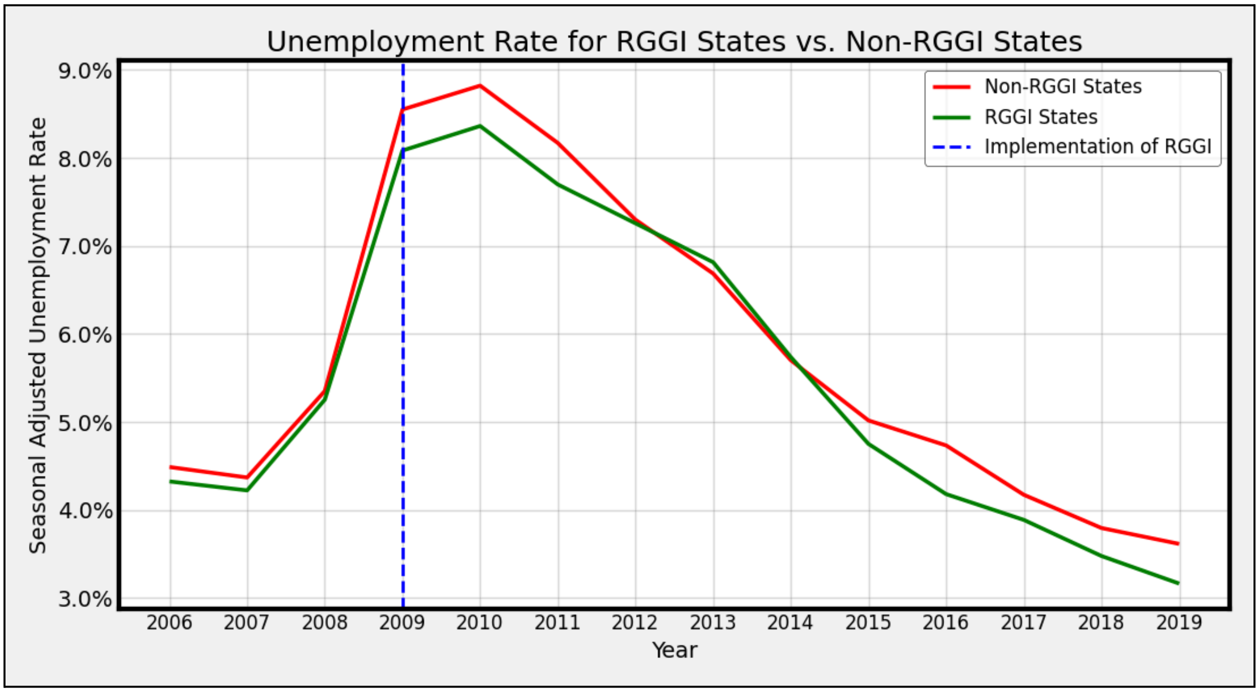

Figure 5
Unemployment Rates for RGGI vs. Non-RGGI States

Gross Domestic Product (GDP)
Next, we analyzed real GDP (in chained 2017 dollars) per capita among RGGI states in comparison to non-RGGI states. A positive difference measure indicates RGGI states having a higher real GDP per capita than non-RGGI states, and a negative difference measure indicates non-RGGI states having a higher real GDP per capita than RGGI states. The difference between the differences of GDP totals in 2010 (one year after implementation) and the differences of GDP totals in 2008 (one year before implementation) is 0.0017. This result indicates that after RGGI implementation, the GDP among RGGI states increased relative to GDP in non-RGGI states by a small amount. However, beyond 2012, the difference in GDP per capita increases returned to a similar level as pre-RGGI implementation.

RGGI	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
0	0.0484	0.0488	0.0485	0.0468	0.0473	0.0478	0.0485	0.0486	0.0494	0.0501	0.0501	0.0508	0.0517	0.0524
1	0.0562	0.0564	0.0560	0.0555	0.0565	0.0566	0.0568	0.0561	0.0569	0.0579	0.0580	0.0580	0.0587	0.0597
Difference	0.0078	0.0076	0.0075	0.0086	0.0092	0.0088	0.0083	0.0075	0.0075	0.0078	0.0079	0.0072	0.0070	0.0074

Figure 6
Differences of Real GDP Per Capita between RGGI and. Non-RGGI States

Additionally, Figure 7 shows minimal difference in the trends of real GDP per capita between RGGI states and Non-RGGI states. Although there may have been an initial small increase in GDP of RGGI states due to increased investment, job creation, and innovation, this trend eventually disappeared and returned to normal levels of GDP increase over time.

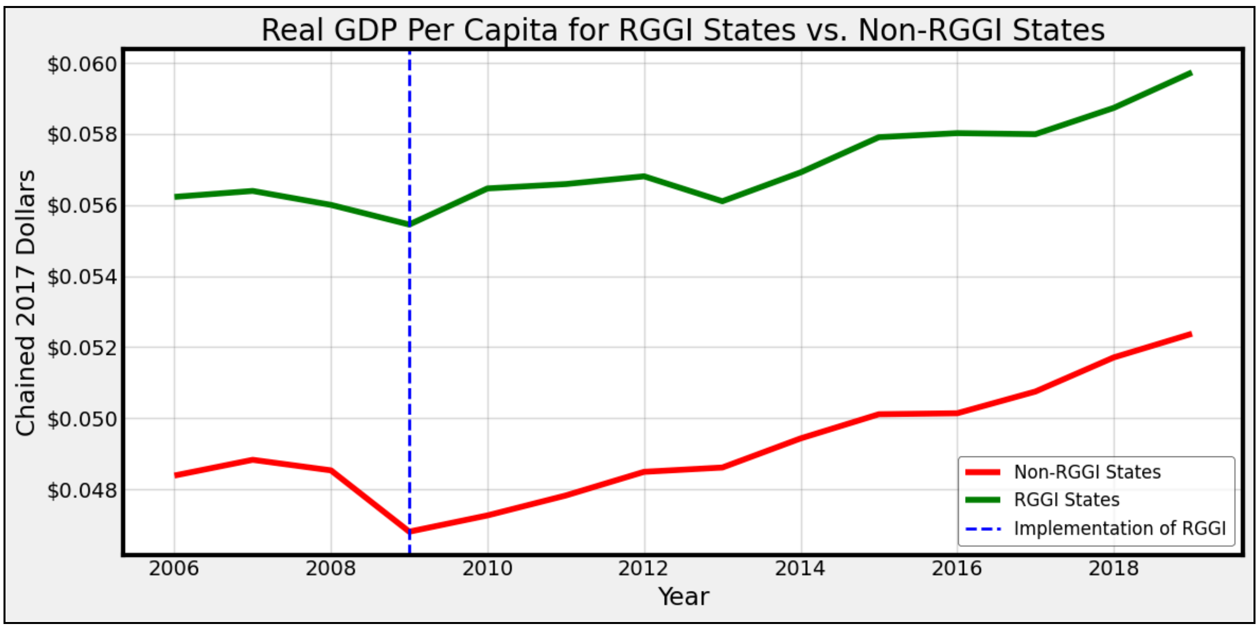

Figure 7
Real GDP Per Capita for RGGI vs. Non-RGGI States

Further, Figure 8 compares the percent of national GDP within the RGGI states and the percent of national GDP within the non-RGGI states. These percentages do not sum to one due to the exclusion of New Jersey and Virginia from this analysis. Percent of national GDP among RGGI states increased in 2009 and 2010, but decreased in 2011. Information in this figure aligns with our previous results of an initial association of RGGI with positive economic outcomes, that eventually reverts back to its initial trends. Similar results occurred when analyzing GDP in current dollars and percent change of real GDP in chained 2017 dollars.

RGGI	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
0	77.0641	77.1817	77.1521	76.3760	76.3037	76.6447	76.6303	76.9010	77.0700	76.9685	76.8648	77.1562	77.2247	77.1541
1	15.6643	15.5891	15.4562	16.0814	16.1887	15.9701	16.0573	15.8576	15.8579	15.9812	16.1278	15.9609	15.9028	15.9736

Figure 8
Percent of National GDP for Non-RGGI vs. RGGI States

Investment of Proceeds

Each state has discretion over how to invest their proceeds earned from allowances sold. Figure 9 provides a breakdown of each state's investments. Investment categories vary considerably by state. For example, Vermont invests almost all of its proceeds on energy efficiency projects, while New Hampshire focuses mostly on direct bill assistance and New Jersey on greenhouse gas abatement. Further detail on each investment category is available in table 3 in the appendix.

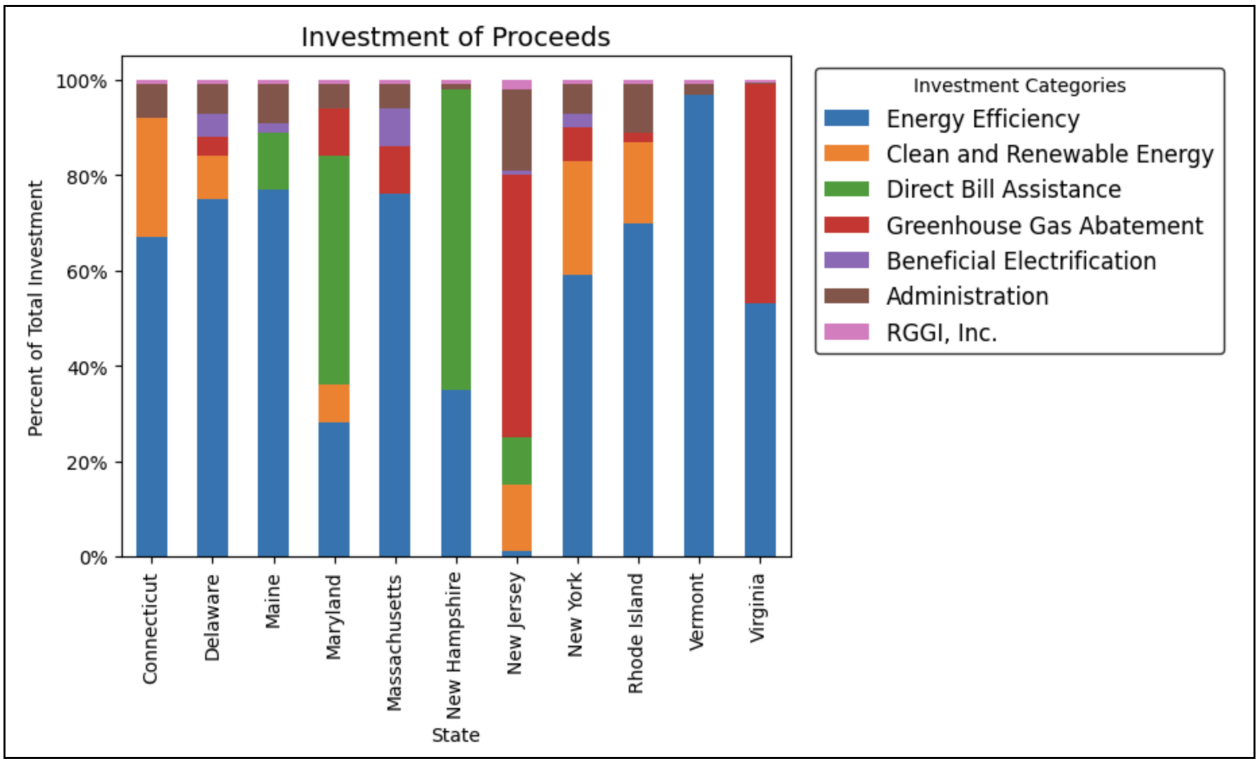

Figure 9
Investment of Proceeds by State

In our first regression model we used the percentage of state investment in four different categories to predict state GDP. Regression results from the first model are found in Figure 10. All coefficients of investment categories are positive, indicating an increase in the percentage of investment in each category is associated with an increase in GDP. In addition, many of the variables included in this model have relatively low p-values, with greenhouse gas abatement and clean and renewable energy statistically significant at the 0.05 significance level. In summary, these results suggest that an increase in investment in any category is associated with an increase in state GDP. The largest positive coefficient was attributed to greenhouse gas abatement, indicating that investments in research and development may pay off in the future and result in an increase in total state GDP. Clean and renewable energy investments also had a large positive coefficient suggesting programs such as solar panels and deploying new non-carbon emitting energy technologies may also lead towards increased productivity.

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	-2.795e+06	1.53e+06	-1.822	0.076	-5.9e+06	3.06e+05
Greenhouse_Gas_Abatement	5.28e+06	1.76e+06	2.996	0.005	1.72e+06	8.84e+06
Clean_Renewable_Energy	4.528e+06	1.78e+06	2.546	0.015	9.34e+05	8.12e+06
Direct_Bill_Assistance	2.903e+06	1.57e+06	1.844	0.073	-2.79e+05	6.09e+06
Energy_Efficiency	2.988e+06	1.63e+06	1.836	0.074	-3.01e+05	6.28e+06

Figure 10
Model 1 Regression Results

Regression results from the second model are found in Figure 11. All coefficients of investment categories are negative, indicating a decrease in the unemployment rate with an increase in the percentage of investment in each category. Direct bill assistance is found to be significant at the 0.05 significance level, while greenhouse gas abatement and energy efficiency are statistically significant at the 0.1 level. According to the coefficients, this model attributes the largest decrease in unemployment rate to an increased investment in greenhouse gas abatement. Direct bill assistance is also found to have a large predicted impact on the unemployment rate. Overall, it appears that investing a high percentage of proceeds in greenhouse gas abatement may lead to more optimal economic outcomes.

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	10.2720	3.564	2.882	0.006	3.068	17.476
Greenhouse_Gas_Abatement	-7.5808	4.095	-1.851	0.072	-15.857	0.695
Clean_Renewable_Energy	-4.9839	4.133	-1.206	0.235	-13.337	3.369
Direct_Bill_Assistance	-7.5312	3.659	-2.058	0.046	-14.926	-0.137
Energy_Efficiency	-6.8803	3.781	-1.820	0.076	-14.522	0.761

Figure 11
Model 2 Regression Results

Justice Analysis

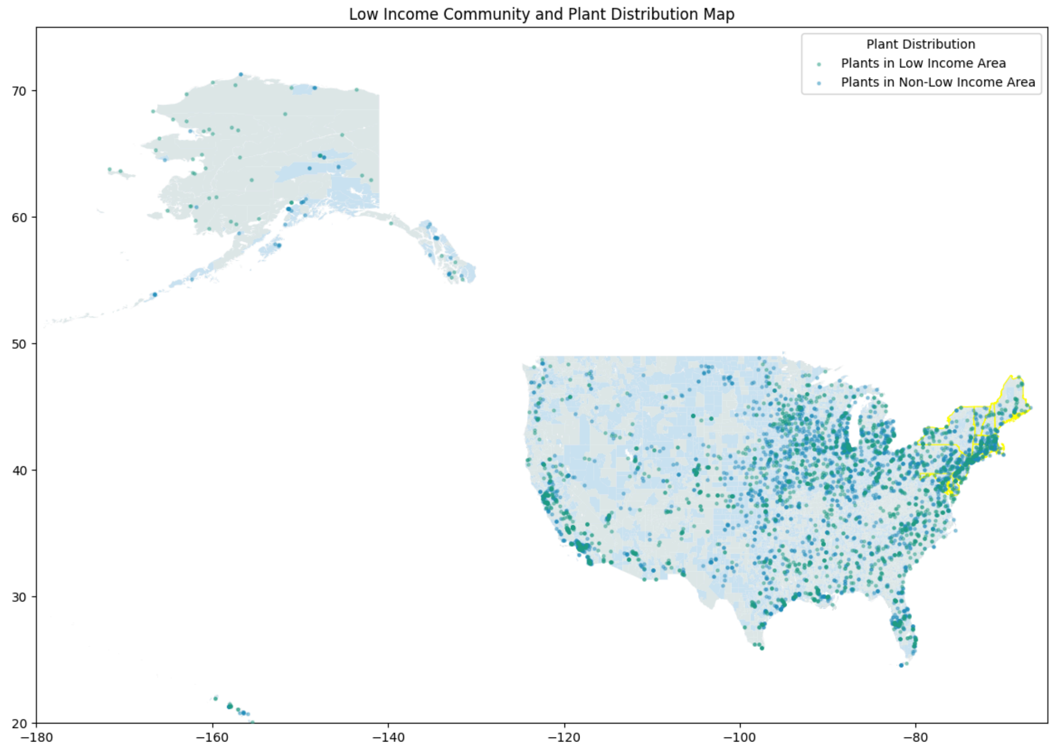

Figure 12. Low Income Communities and Plant Map

"Environmental justice" means the just treatment and meaningful involvement of all people in agency decision-making and other Federal activities that affect human health and the environment. Previous analyses indicate that the RGGI might be effective in reducing overall carbon emissions. However, the impact of this reduction on carbon emissions across individual regions remains unclear. Consequently, we assess environmental justice at three distinct levels to better understand the regional disparities in emission changes under the RGGI program.

State level: Carbon leakage in the state next to RGGI State

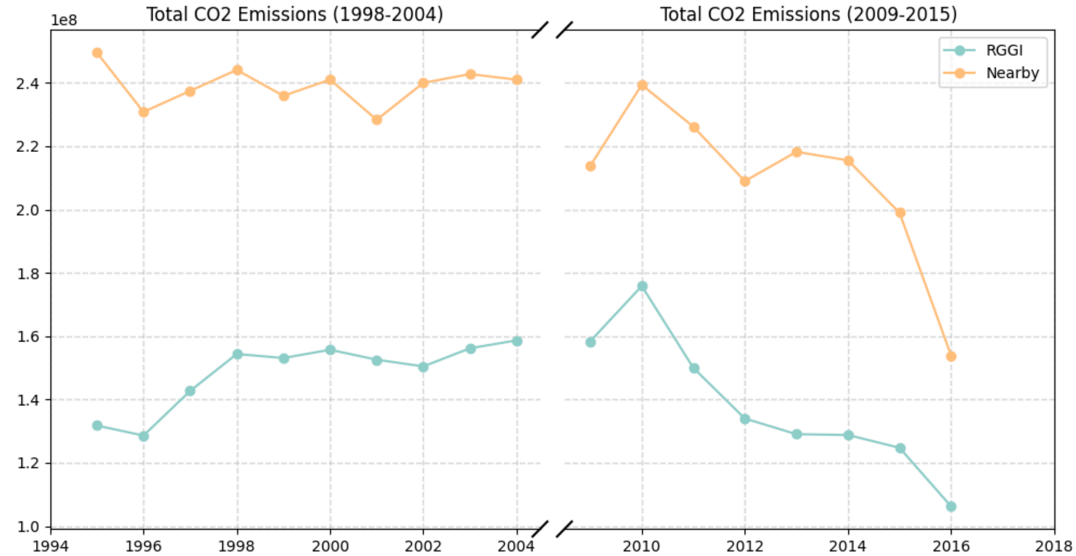

Figure 13. The Total CO2 emissions trend in RGGI States and nearby States.

The analysis at the state level highlights concerns about carbon leakage due to the Regional Greenhouse Gas Initiative (RGGI). Carbon leakage refers to the phenomenon where reductions in emissions in one area lead to increases in another, typically as a result of shifting energy production to regions with less stringent environmental regulations. This study compares carbon emission trends from 2009 to 2015 between RGGI states and nearby states that have not implemented similar environmental policies.

Our findings reveal a significant disparity in emissions reductions: RGGI states achieved a 21.34% reduction in carbon emissions, while nearby states such as Pennsylvania, Virginia, and West Virginia saw a much smaller decrease of 6.91%. The aggregate reduction across all these states was 9.98%. The modest reduction in the nearby non-RGGI states raises concerns about the potential for carbon leakage, suggesting that while RGGI states have effectively lowered their emissions, some of the emission sources may have shifted to neighboring states with less rigorous environmental controls. This underscores the necessity for a more coordinated regional approach to carbon regulation to mitigate the effects of carbon leakage.

Census tract level: CO2 commissions in low-income communities

At the tract level, our study focused on the disparities in carbon emissions between low-income communities and more affluent areas within and outside the RGGI states. If reducing emissions is more expensive in low-income areas compared to other places, businesses will likely cut emissions where it's cheaper. This could lead to higher emissions in low-income communities as companies look to save money.

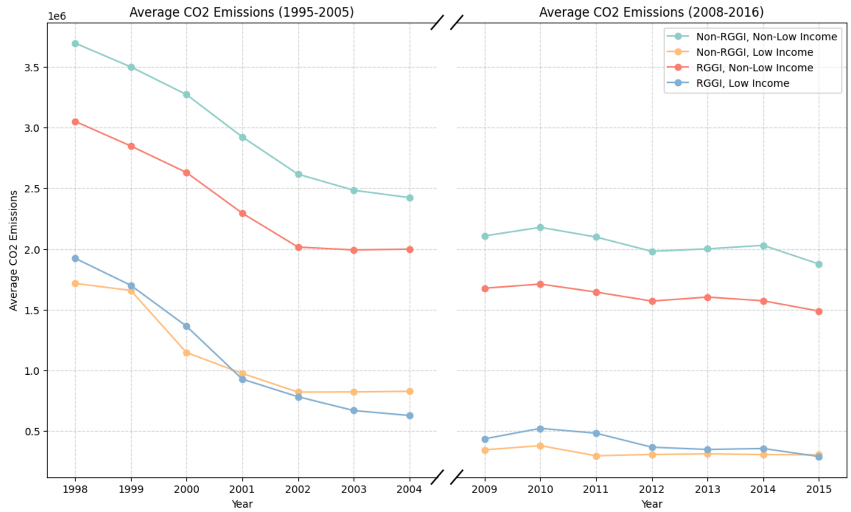

Figure 14. The Average CO2 emissions trend in 4 groups(RGGI-low income, RGGI - non low income, non RGGI - low income, and non RGGI - non low income).

According to the data, RGGI states demonstrated a notable reduction in emissions across both community types when compared to non-RGGI states. Specifically, the emission reductions in low-income communities within RGGI states were more pronounced than those in non-RGGI states, indicating a targeted effect of the environmental policies on these vulnerable populations.

rggi	Low_Income	Pre-Treatment Mean Emissions	Post-Treatment Mean Emissions	Change in Emissions	DiD Between Income Groups	Diff DiD RGGI 1 vs RGGI 0
0	0	2.910472e+06	2.038595e+06	-871877.399924	NaN	NaN
	1	2.334942e+06	1.610195e+06	-724747.055469	147130.344455	NaN
1	0	1.050366e+06	3.228510e+05	-727515.501519	NaN	NaN
	1	9.440914e+05	3.969837e+05	-547107.709702	180407.791818	33277.447362

Table 1. Emissions Change Analysis Summary

However, despite the overall positive trend in emission reductions in RGGI states, the differential in emission reductions between low-income and higher-income tracts within these states suggests a persistent environmental justice issue. The analysis shows that while emissions decreased across the board, the rate of decrease was less in low-income communities compared to their more affluent counterparts. This observation raises concerns about the equity of emissions reductions and suggests that low-income areas might not be benefiting equally from environmental policies aimed at reducing carbon emissions.

	coef	std err	t	P>|t|	[0.025	0.975]
const	2.673e+06	4.79e+04	55.831	0.000	2.58e+06	2.77e+06
rggi	-1.73e+06	1.13e+05	-15.366	0.000	-1.95e+06	-1.51e+06
Low_Income	-5.257e+05	7.41e+04	-7.095	0.000	-6.71e+05	-3.8e+05
Post	-6.342e+05	7.21e+04	-8.796	0.000	-7.75e+05	-4.93e+05
post_treatment	1.398e+04	1.45e+05	0.096	0.923	-2.71e+05	2.99e+05
rggi_low_income	3.937e+05	1.93e+05	2.043	0.041	1.6e+04	7.71e+05
post_low_income	9.729e+04	1.12e+05	0.871	0.384	-1.22e+05	3.16e+05
post_treatment_low_income	1.088e+05	2.63e+05	0.415	0.678	-4.06e+05	6.23e+05

Table 2. DiD Regression Model Summary

Moreover, the statistical analysis conducted using a difference-in-differences approach highlighted that the reductions in emissions in low-income tracts did not significantly outpace those in non-low-income tracts, which complicates the narrative of environmental justice. Although RGGI states have made strides in reducing emissions, the data suggests that these reductions may not be sufficiently addressing the disproportionate environmental burdens faced by low-income communities. This finding underscores the need for more refined strategies that ensure equitable environmental benefits across all socioeconomic groups within RGGI states.

EGU level: Change of Fuel type

At the Electric Generating Unit (EGU) level, our study observes a significant shift in fuel type usage across both RGGI and non-RGGI states, particularly with a marked transition from coal to natural gas. This trend is accentuated in low-income areas within RGGI states, where the data demonstrates an even stronger decrease in coal usage coupled with an increase in natural gas and biomass. Specifically, in RGGI states, coal usage decreased by 1,329 units in low-income areas, while natural gas increased by 816 units and biomass by 126 units.

The transition to cleaner energy sources like natural gas and biomass, particularly in low-income communities, indicates a positive shift towards reducing environmental disparities. This shift not only represents a reduction in carbon emissions but also aligns with environmental justice objectives by making cleaner energy technologies more accessible in economically disadvantaged areas. The graphical analysis reflects these changes distinctly, showing a robust decline in the use of oil and coal, which are typically higher in carbon emissions compared to natural gas.

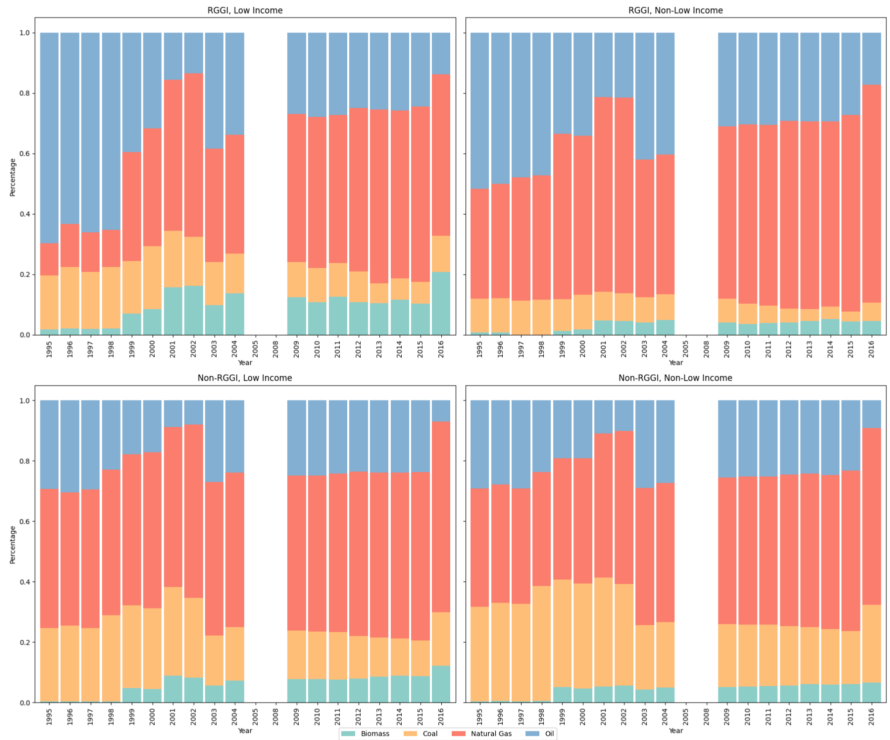

Figure 15. Total net generation by fuel type in EGUs in RGGI site (Up) and out of RGGI (Down) in low income communities (Left) and non low income communities (Right). Percent of total net generation by fuel type is indicated in left y-axis

Limitations

The analysis of CO2 emissions in RGGI states presents several limitations that could impact the validity of the conclusions. A major concern is the lack of complete data prior to 2008 and specific emissions data for electric generating units, which challenges the accuracy of baseline emissions assessments. Additionally, the analysis may not sufficiently account for external variables such as economic fluctuations, energy price changes, technological advancements, or other regional environmental policies that could independently influence emissions trends. The Difference-in-Difference (DiD) analysis indicated that the emission reductions were not statistically significant, suggesting that the observed changes might not be directly attributable to the RGGI program. Moreover, the comparative analysis might suffer from a lack of matching between RGGI and non-RGGI states on key economic and industrial characteristics, potentially leading to biased results. Also, the results are limited in their generalizability to other regions with different regulatory and economic contexts. Lastly, the relatively short timeframe post-RGGI implementation examined may not fully capture the long-term impacts of the initiative, as environmental benefits often take several years to materialize fully. More comprehensive data collection and robust statistical techniques in future research could provide a clearer picture of the RGGI's effectiveness.

Additionally, there are notable limitations for the economic analysis of RGGI. Many different factors and policies influence a state's unemployment rate and GDP. Some of those factors include the breakdown of industries present in each state, labor force participation, investment, consumer spending, and political stability (McGee, 1985). Additionally, the 2008 recession and the COVID-19 pandemic may have greatly impacted our data, especially in regards to unemployment rates. To mitigate the impact of the COVID-19 pandemic, data were only analyzed up until 2019. To mitigate the impact of the recession, we used the difference-in-differences approach. However, this approach is only valid if the recession affected RGGI and non-RGGI states in a similar manner. It is entirely possible that RGGI states were not impacted as negatively by the recession, which is why they had relatively more positive economic outcomes around the first few years after RGGI implementation. To summarize, there are many covariates that are not included in our analysis that may have a large impact on economic outcomes such as unemployment rate and GDP. A further in-depth analysis is needed to specifically analyze the unique economic policies and conditions of each state to discern whether or not RGGI had an impact on state economic outcomes.

Lastly, the specific focus on RGGI states may not account for the broader national or global context. Factors unique to the RGGI states or the specific time frame studied may limit the generalizability of our findings to other regions or future periods.

Ethical Considerations

At the time of writing the report, we found that historical data of CO2 emissions is no longer publicly available. There are concerns about whether we have the right to use the data or there would be further action needed. Also, analyzing the RGGI from a justice perspective ensures that policies do not disproportionately harm vulnerable communities. In addition to achieving positive environmental and economic outcomes, it is imperative that the RGGI provides equitable outcomes to all populations. It is important to handle topics such as the differential impacts on various demographics, particularly low-income communities, with sensitivity and thoughtfulness, recognizing the broader implications of energy policies on social and environmental justice. Moreover, any future projections and recommendations included in our analysis should be based on robust data and a clear understanding of potential outcomes. It is ethically important to consider both the short-term and long-term consequences of any recommendations, particularly their impact on vulnerable populations, to ensure that policy interventions contribute to sustainable and just outcomes for all community members.

Conclusion

In conclusion, our analysis demonstrated that energy prices in RGGI states experienced significant fluctuations in the three years prior to implementation of RGGI, but stabilized once RGGI was implemented. RGGI involves additional costs such as new administrative processes, compliance measures, and new emissions trading infrastructure, which may lead to higher energy prices. However, sustained investment in energy efficiency and renewable energy projects may have led to stabilization of prices. In addition, emissions in RGGI states decreased more quickly than emissions in non-RGGI states, but as the results are not statistically significant, the RGGI program itself may not be the sole factor driving these changes.

To summarize the conclusions of our economic analysis, the RGGI may have a small positive impact on economic outcomes such as lower state unemployment rates and higher state GDP. This may be attributed to job creation and growth in clean energy and energy efficiency industries. However, this trend does not continue long term, and is no longer noticeable three to four years after RGGI implementation. Further in-depth economic analysis is needed to determine whether the RGGI was the cause of these changes, as many other factors can affect state unemployment rates and state GDP. Additionally, dedicating a higher percentage of investment proceeds to greenhouse gas abatement may result in more positive economic outcomes.

With regards to our analysis on environmental justice, we observe distinct patterns of emission reductions and fuel type changes, particularly in low-income areas. Key findings indicate that there is potential for carbon leakage as emissions may be displaced to neighboring states with less stringent environmental policies. Furthermore, the study reveals that environmental injustice remains more pronounced within RGGI states despite these states' efforts to shift towards more sustainable fuels in economically disadvantaged areas. This shift includes a notable move from coal to cleaner energy sources like natural gas and biomass in low-income communities, reflecting a positive trend towards reducing the environmental burden on these vulnerable populations. The long-term analysis of energy prices suggests a normalization of costs in RGGI states, indicating that initial regulatory expenses associated with carbon pricing have been balanced over time, demonstrating the economic feasibility of environmental regulations designed to transition towards sustainable energy use.

However, the evidence does not conclusively show whether the RGGI program has had a direct positive or negative impact on the severity of environmental injustice observed. This underscores the need for ongoing evaluation and adjustment of the policies to ensure that they not only contribute to overall emission reductions but also advance environmental justice by equitably distributing environmental benefits and burdens.

Author Contribution Statements

All authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. Yanyu wrote the background literature analysis and carried out the leading questions. Junyi and Yanyu worked out the environmental effects section. Junyi performed the justice analysis and Madison created the report structure, handled the economic analysis, and provided additional contributions to the background literature analysis.

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Appendix

Figure 1. RGGI States Map

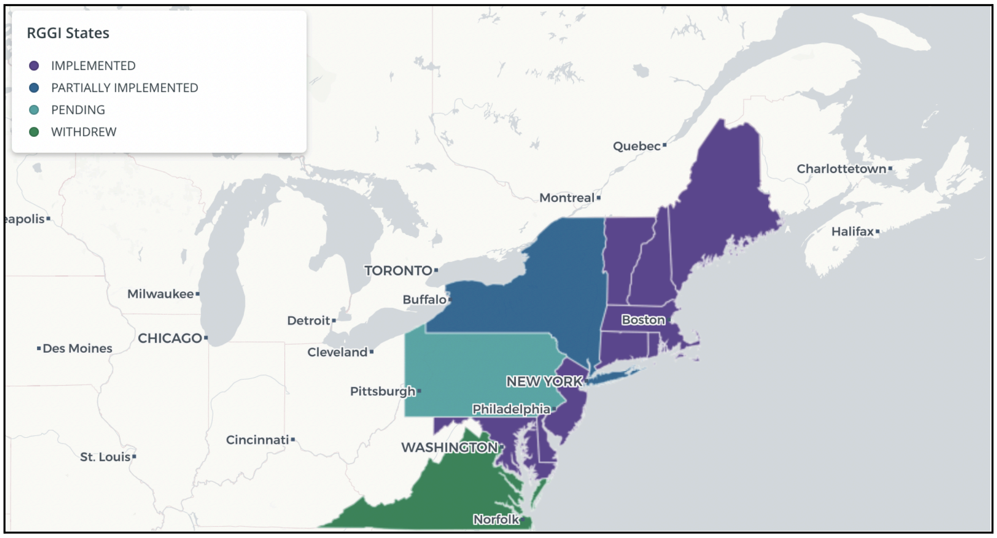

Figure 2. Average Energy Price Trend, 1990-2022

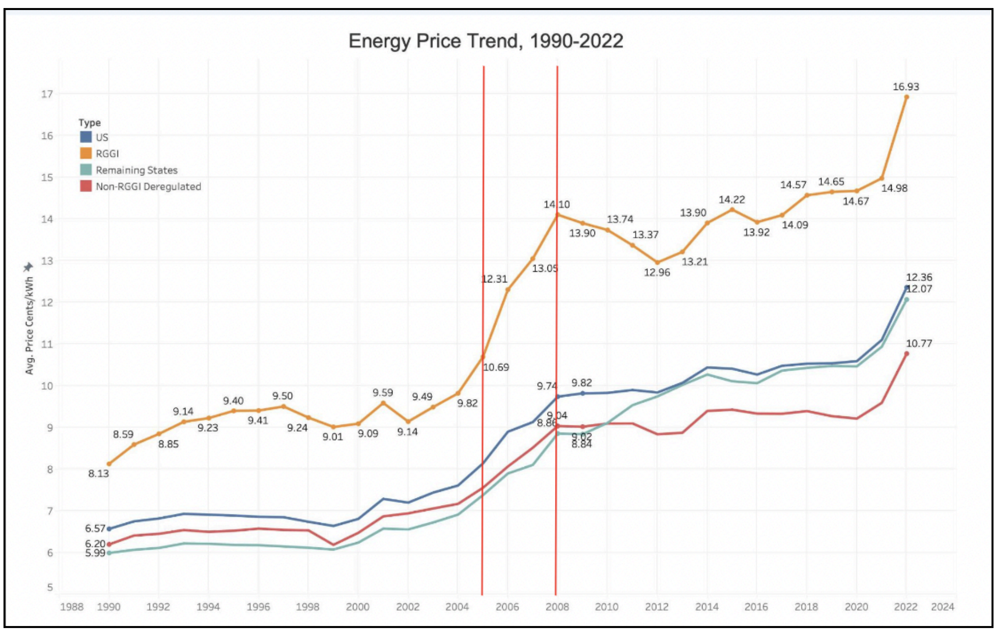

Figure 3. Average CO2 Emissions(tons) per EGU in and out of RGGI States

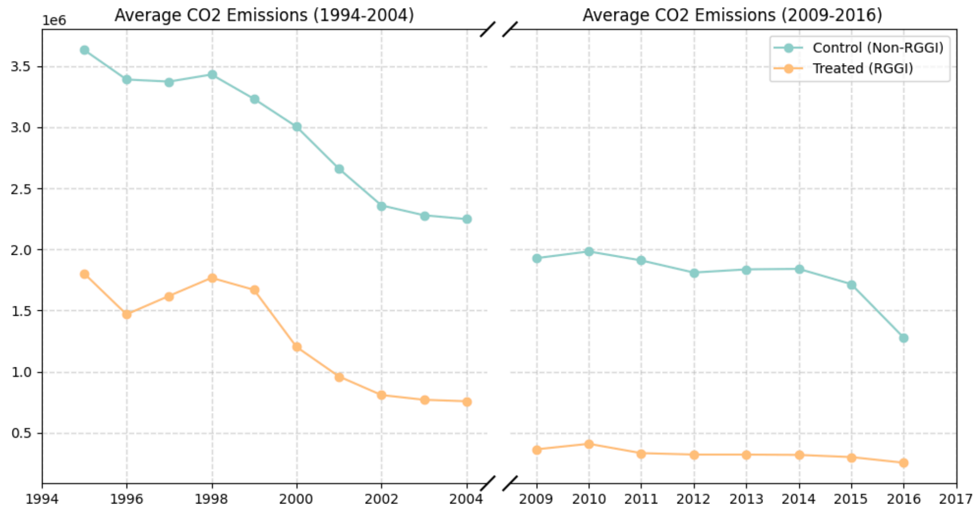

Figure 4: Differences of Unemployment Rates between Non-RGGI and RGGI States

Year RGGI	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
0	4.5147	4.4017	5.3769	8.5835	8.838	8.1799	7.2784	6.6718	5.6902	5.0167	4.7472	4.1769	3.8105	3.6415
1	4.3250	4.2231	5.2537	8.0833	8.362	7.6981	7.2565	6.8148	5.7370	4.7509	4.1806	3.8880	3.4778	3.1648
Difference	0.1897	0.1786	0.1232	0.5002	0.476	0.4818	0.0219	-0.1430	-0.0469	0.2657	0.5667	0.2890	0.3327	0.4766

Figure 5: Unemployment Rates for RGGI vs. Non-RGGI States

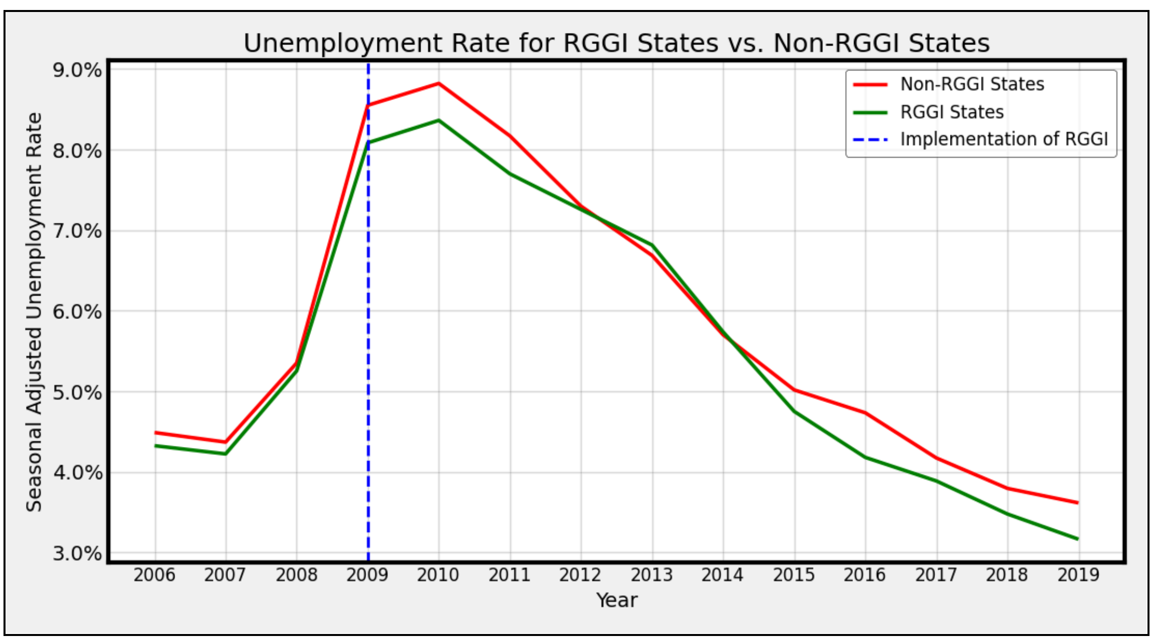

Figure 6: Differences of Real GDP Per Capita between RGGI and. Non-RGGI States

RGGI	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
0	0.0484	0.0488	0.0485	0.0468	0.0473	0.0478	0.0485	0.0486	0.0494	0.0501	0.0501	0.0508	0.0517	0.0524
1	0.0562	0.0564	0.0560	0.0555	0.0565	0.0566	0.0568	0.0561	0.0569	0.0579	0.0580	0.0580	0.0587	0.0597
Difference	0.0078	0.0076	0.0075	0.0086	0.0092	0.0088	0.0083	0.0075	0.0075	0.0078	0.0079	0.0072	0.0070	0.0074

Figure 7: Real GDP Per Capita for RGGI vs. Non-RGGI States

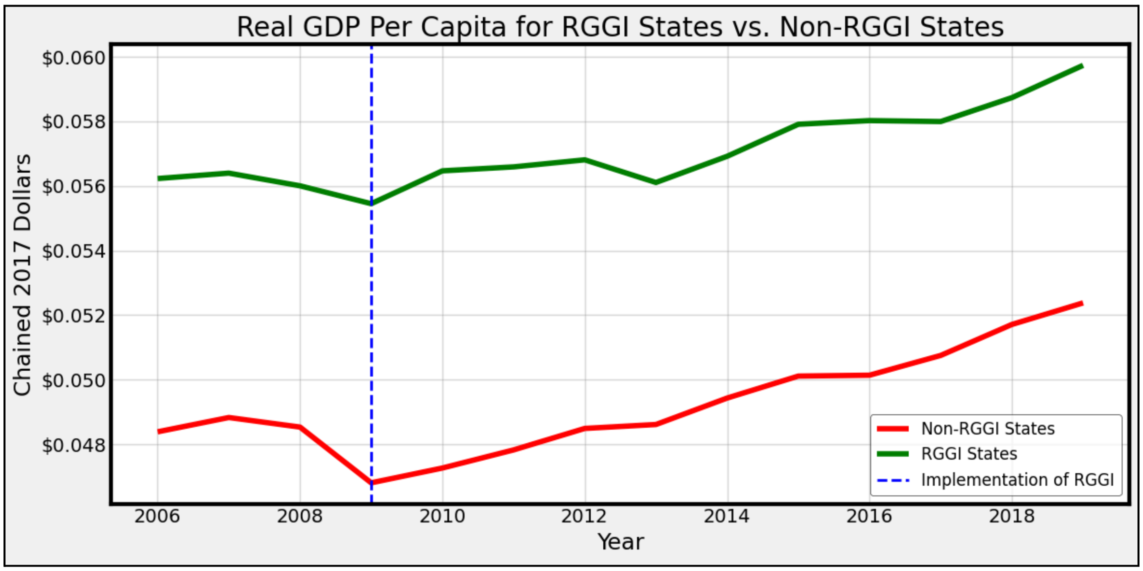

Figure 8: Percent of National GDP for Non-RGGI vs. RGGI States

RGGI	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
0	77.0641	77.1817	77.1521	76.3760	76.3037	76.6447	76.6303	76.9010	77.0700	76.9685	76.8648	77.1562	77.2247	77.1541
1	15.6643	15.5891	15.4562	16.0814	16.1887	15.9701	16.0573	15.8576	15.8579	15.9812	16.1278	15.9609	15.9028	15.9736

Figure 9: Investment of Proceeds by State

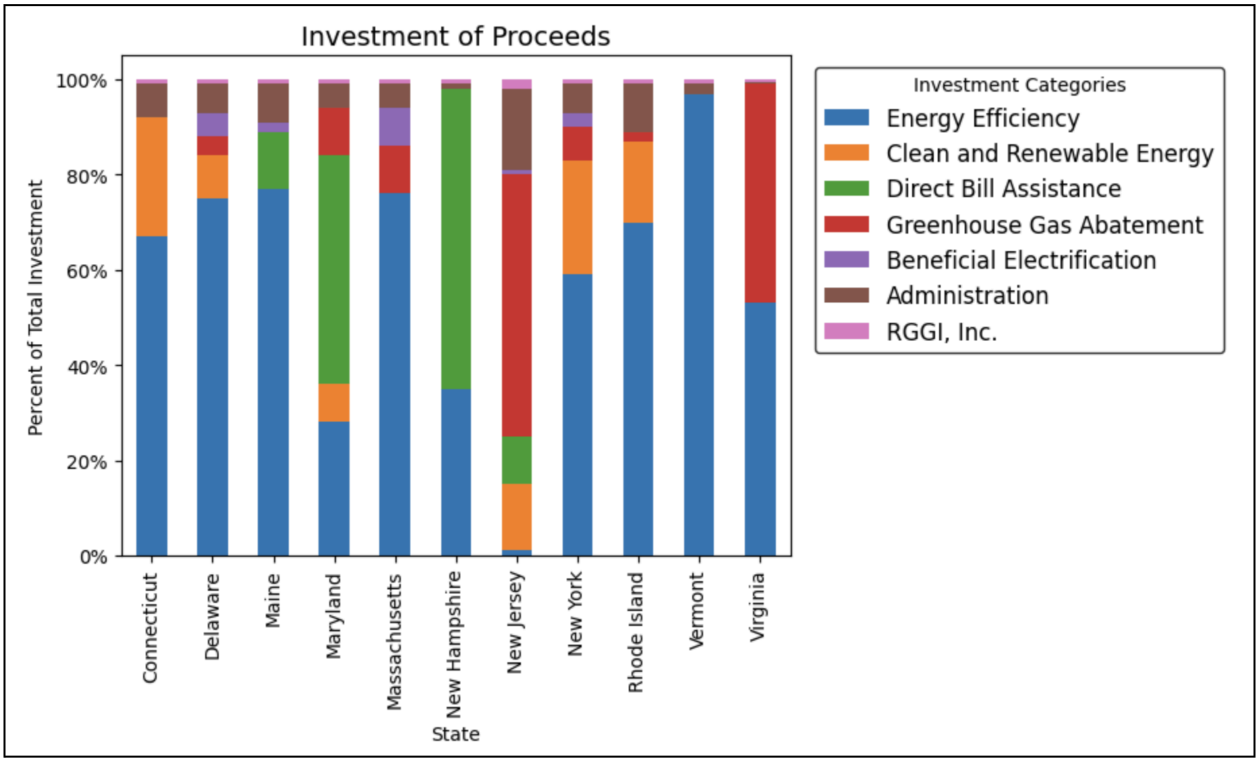

Figure 10 Regression Model 1

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	-2.795e+06	1.53e+06	-1.822	0.076	-5.9e+06	3.06e+05
Greenhouse_Gas_Abatement	5.28e+06	1.76e+06	2.996	0.005	1.72e+06	8.84e+06
Clean_Renewable_Energy	4.528e+06	1.78e+06	2.546	0.015	9.34e+05	8.12e+06
Direct_Bill_Assistance	2.903e+06	1.57e+06	1.844	0.073	-2.79e+05	6.09e+06
Energy_Efficiency	2.988e+06	1.63e+06	1.836	0.074	-3.01e+05	6.28e+06

Figure 11 Regression Model 2

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	10.2720	3.564	2.882	0.006	3.068	17.476
Greenhouse_Gas_Abatement	-7.5808	4.095	-1.851	0.072	-15.857	0.695
Clean_Renewable_Energy	-4.9839	4.133	-1.206	0.235	-13.337	3.369
Direct_Bill_Assistance	-7.5312	3.659	-2.058	0.046	-14.926	-0.137
Energy_Efficiency	-6.8803	3.781	-1.820	0.076	-14.522	0.761

Figure 12. Low Income Communities and Plant Map

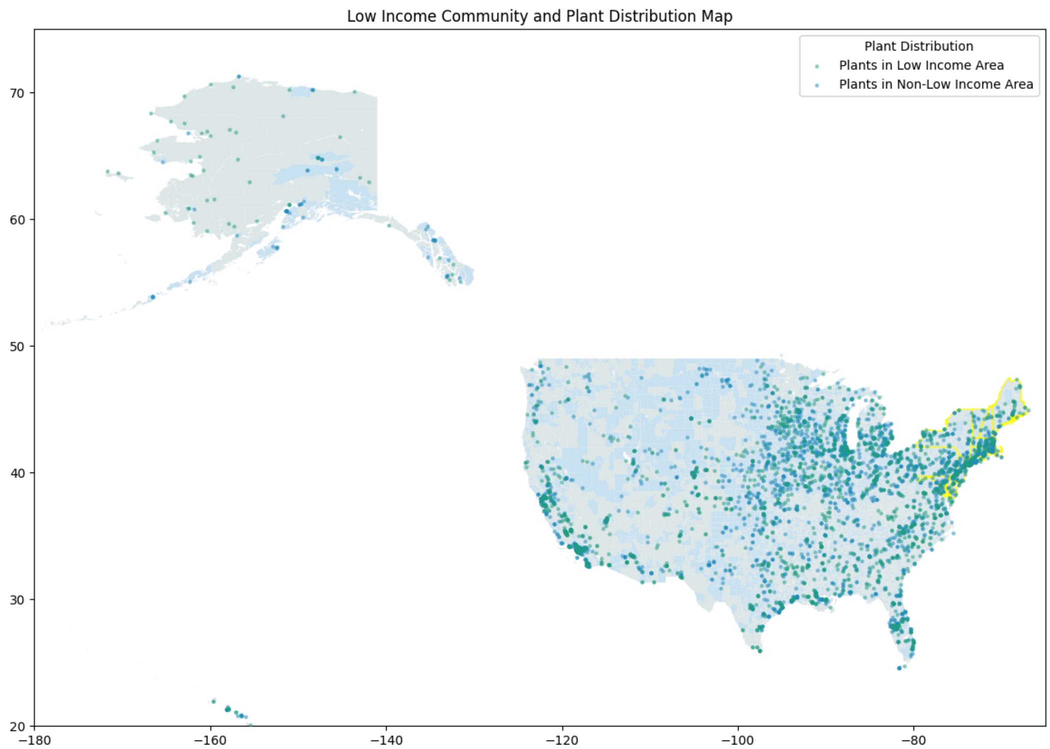

Figure 13. The Total CO2 emissions trend in RGGI States and nearby States.

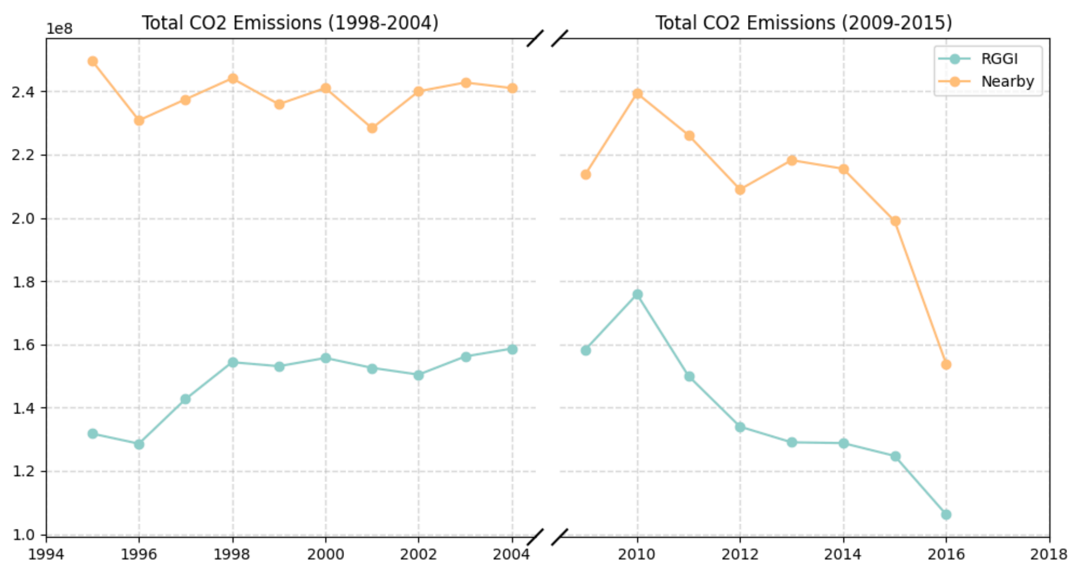

Figure 14. The Average CO2 emissions trend in 4 groups. (RGGI-low income, RGGI - non low income, non RGGI - low income, and non RGGI - non low income)

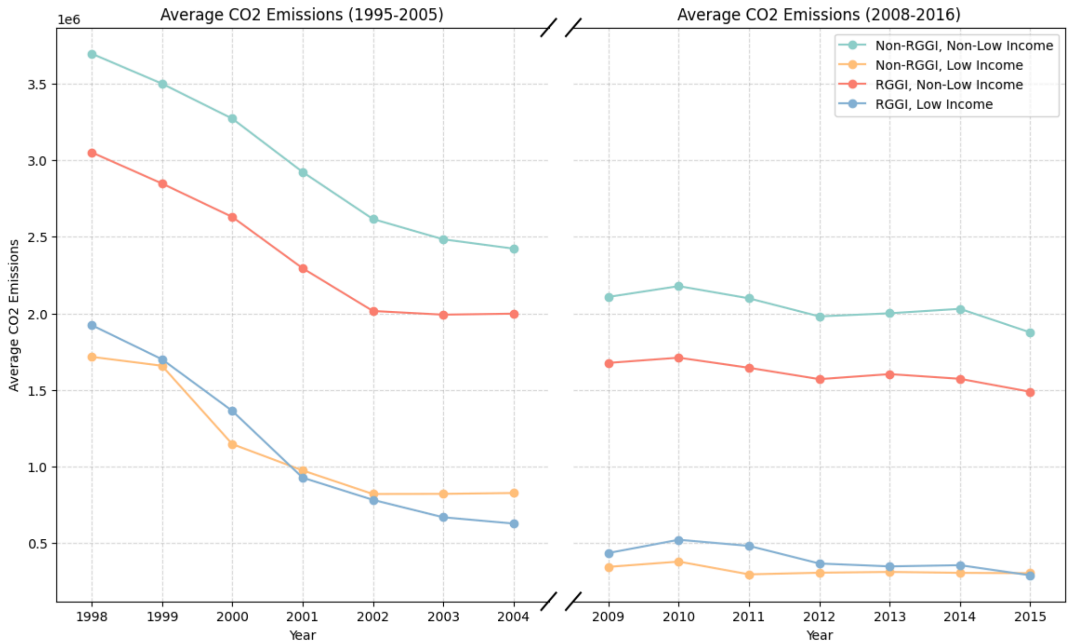

Figure 15. Total net generation by fuel type in EGUs in RGGI site (Up) and out of RGGI (Down) in low income communities (Left) and non low income communities (Right). Percent of total net generation by fuel type is indicated in left y-axis

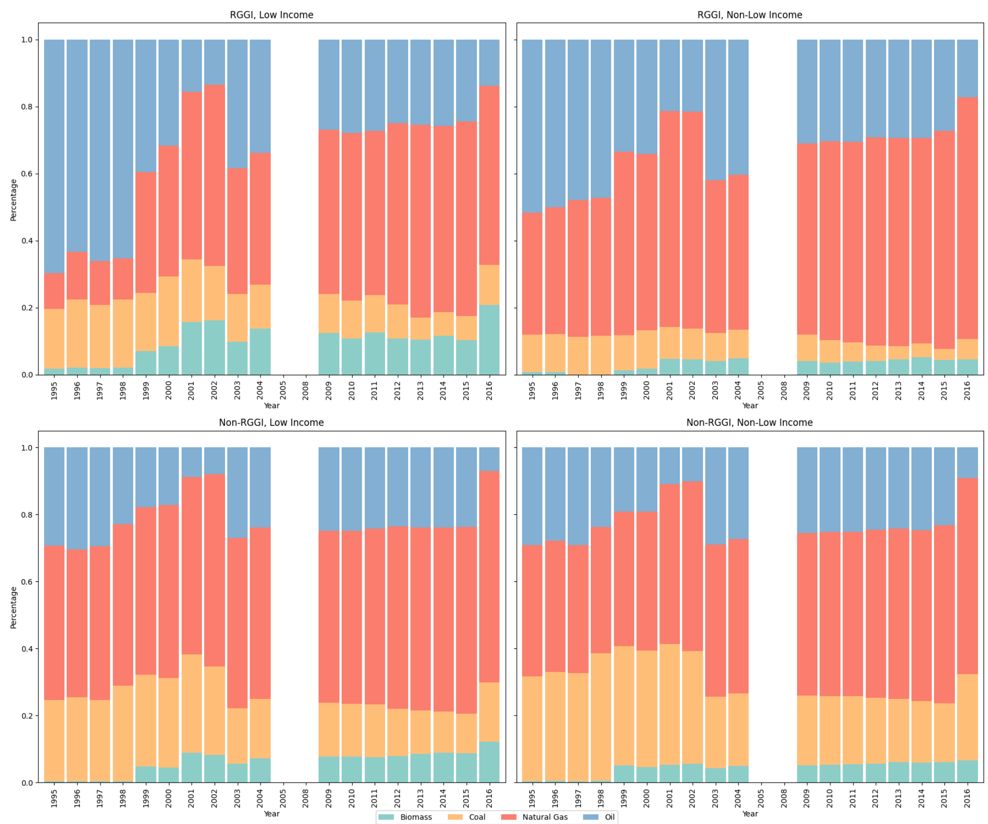

Table 1. Emissions Change Analysis Summary

rggi	Low_Income	Pre-Treatment Mean Emissions	Post-Treatment Mean Emissions	Change in Emissions	DiD Between Income Groups	Diff DiD RGGI 1 vs RGGI 0
0	0	2.910472e+06	2.038595e+06	-871877.399924	NaN	NaN
	1	2.334942e+06	1.610195e+06	-724747.055469	147130.344455	NaN
1	0	1.050366e+06	3.228510e+05	-727515.501519	NaN	NaN
	1	9.440914e+05	3.969837e+05	-547107.709702	180407.791818	33277.447362

Table 2. Did Regression Model Summary

	coef	std err	t	P>|t|	[0.025	0.975]
const	2.673e+06	4.79e+04	55.831	0.000	2.58e+06	2.77e+06
rggi	-1.73e+06	1.13e+05	-15.366	0.000	-1.95e+06	-1.51e+06
Low_Income	-5.257e+05	7.41e+04	-7.095	0.000	-6.71e+05	-3.8e+05
Post	-6.342e+05	7.21e+04	-8.796	0.000	-7.75e+05	-4.93e+05
post_treatment	1.398e+04	1.45e+05	0.096	0.923	-2.71e+05	2.99e+05
rggi_low_income	3.937e+05	1.93e+05	2.043	0.041	1.6e+04	7.71e+05
post_low_income	9.729e+04	1.12e+05	0.871	0.384	-1.22e+05	3.16e+05
post_treatment_low_income	1.088e+05	2.63e+05	0.415	0.678	-4.06e+05	6.23e+05

Table 3. Investment of Proceeds Categories (Regional Greenhouse Gas Initiative, 2024g)

Investment Category	Description
Administration	Administrative overhead expenses associated with all RGGI-funded programs, including outsourced and in-house overhead expenses
Beneficial Electrification	Programs designed to reduce fossil fuel consumption by implementing or facilitating fuel-switching to replace direct fossil fuel use with electric power. Examples include incentives for electric vehicles and home appliances, and installation of electric vehicle infrastructure.
Clean and Renewable Energy	Programs directed at accelerating the deployment of renewable or other non-carbon emitting energy technologies. Examples include incentives for residential solar panels, financing of commercial renewable energy projects through green banking, and research and development of new energy technologies.
Direct Bill Assistance	Programs providing energy bill payment assistance, including direct bill assistance to low-income ratepayers.
Energy Efficiency	Programs designed to improve energy efficiency by reducing overall energy use without degrading functionality. This includes programs directed at assisting low-income families and small businesses. Examples include home energy audit programs, home and building weatherization, energy efficient appliance or industrial equipment rebate programs, compact fluorescent light bulb programs, and energy efficiency workforce training programs.

Greenhouse Gas Abatement	Programs promoting the research and development of advanced energy technologies, the reduction of vehicle miles traveled, the reduction of emissions in the power generation sector, tree-planting projects designed to increase carbon sequestration, other initiatives to reduce greenhouse gasses, and climate adaptation and community preparedness initiatives. Some projects can support multiple functions, such as natural area restoration that also serves flood mitigation planning purposes.
RGGI, Inc	Funds provided to RGGI, Inc. to support and implement state CO2 Budget Trading programs.