Are you RGGI for this? An Analysis of the Regional Greenhouse Gas Initiative's Impact on Particulate Matter and Health

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Abstract

The Regional Greenhouse Gas Initiative (RGGI) is a cooperative effort between nine Northeastern states - Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island and Vermont. The collective goal of RGGI is reducing greenhouse gas emissions and improving air quality. This effort is supported by the Regional Greenhouse Gas Initiative, Inc. (RGGI, Inc.), a quasi-governmental non-profit organization responsible for emissions data collection and reporting, providing a platform for Carbon Dioxide (CO_2) allowance auctions and tracking trades, in addition to reviewing emissions offset project applications. Each participating state is responsible for regulation and enforcement of compliance entities within their state lines. Through summary of recent literature, this paper will delineate the connection between RGGI's carbon cap-and-trade market, carbon emissions, and Greenhouse Gas emissions (GHGs). Additionally, this paper outlines the policy question that warrants investigation - whether RGGI's binding carbon emissions constraint effects annual mean $PM_{2.5}$ concentration levels - and frames the proposed methodology that will be used to analyze this research query.

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Greenhouse Gases, Air Pollutants, and Climate Change

Many countries around the world are acting to reduce global GHG emissions and air pollutants to mitigate climate change-related health and environmental impacts. In one effort to curb GHG emissions, the Intergovernmental Panel for Climate Change (IPCC) recommended taking global measures to limit the temperature increase to 2 degrees Celsius (°C) above the pre-industrial baseline (the average temperature over the period of 1850-1900) in 1996. The IPCC subsequently altered the 1996 recommendation in October 2018 to limit the increase to 1.5 °C because new analysis concluded that severe effects attributable to human-induced global warming will be experienced by 2040 if action is not immediately taken to meet this new limit. In 2015, temperatures had already increased by 1 °C above the pre-industrial baseline, with human-induced increases primarily due to fossil fuel combustion emitting CO_2 and PM precursors (Kinney, 2018). Halting this temperature increase would require transitioning to net zero CO_2 emissions, with severe transitions required in energy, land, urban, and infrastructure sectors. The IPCC has proposed meeting this goal entirely by 2050 with an intermittent goal of reducing global CO_2 emissions by 45 percent of 2010 levels by 2030 (IPCC, 2018). This is not the first time CO_2 abatement has made the global agenda, as 195 nations adopted The Paris Agreement in 2016 with the goal of limiting the global temperature increase to 2 °C. Of these 195 nations, 174 submitted pledges to the United Nations stating the extent of their intentions to decrease global GHG emissions (Cai et al., 2018). The abatement pledges were based on the 2 °C limit and thus will need to be revised to meet the IPCC's new recommendation of 1.5 °C.

In the United States, the Clean Air Act obliges the EPA to dictate National Ambient Air Quality Standards (NAAQS) to set maximum allowable concentrations for air pollutants to limit negative public health externalities (Abt Associates, 2017). Differences in political agendas have resulted in failed bills in both the House and the Senate regarding a nationwide adoption of an emissions abatement system to combat this issue, applying pressure to states to adopt the responsibility of emissions abatement action and climate change mitigation (Knox-Hayes, 2010). President Trump's recent withdrawal from the Paris Climate Change Agreement sparked seventeen states to join the bipartisan United States Climate Alliance with the commitment to reducing greenhouse gas emissions by 26-28 percent below 2005 levels by 2025, suggesting a possible change in many states' political environment and recognizing the need for collective emissions abatement action at state and regional levels (Milne, 2017). This alliance is similar to the regional coalitions formed to meet NAAQS standards and mitigate climate change and associated effects, such as the Western Climate Initiative, the Midwestern Regional Greenhouse Gas Reduction Accord, and RGGI. RGGI is the oldest of these alliances and was created as a model for a national carbon emissions abatement program, specifically applied to fossil-fuel energy generators. Due to these attributes, this paper will analyze the $PM_{2.5}$ externalities of RGGI as a case study of a regional carbon cap-and-trade policy.

Health Externalities of Climate Change

To understand the importance of regional greenhouse gas abatement programs such as RGGI, a summary of the current science investigating the impacts of greenhouse gases and air pollutants on climate and health is necessary. GHGs are commonly defined as CO_2, nitrous oxide (NO_x), methane (CH_4), and fluorinated gases (F-gases). Air pollutants are commonly defined in the health field as particulate matter (PM), ground-level ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs) (Melamed et al., 2016). Air pollutants are also emitted through GHG emission activities, such as fossil-fuel energy generation.

The direct connection between climate change and health outcomes is becoming increasingly established in the 21st century. Epidemiological studies have concluded that increasing exposure to atmospheric GHGs, especially particle matter and ozone, has resulted in increases in cardiovascular and respiratory morbidity and mortality externalities. These adverse health effects occur because of the chemical reactions that take place during fossil fuel combustion, increasing the concentration of GHGs in the air (Kinney, 2018). $PM_{2.5}$ is deemed by the scientific community to be a robust indicator for long-term mortality, since a single exposure to high levels of $PM_{2.5}$, or prolonged exposure to lower levels of $PM_{2.5}$, increases risks of cardiovascular and respiratory diseases. Zhou et al. (2014) conducted a study of the link between air quality and mortality in China and concluded that a reduction of 1,000 tons of $PM_{2.5}$ emissions would reduce annual mortality by anywhere between 1 and 400 deaths, depending on other environmental factors and local GHG concentrations in that particular area. In the United States, Kinney's (2018) study projected that reductions in $PM_{2.5}$ concentrations could hold impacts ranging between 4,000 and 22,000 avoided deaths in 2050 and between 19,000 and 95,000 deaths in 2100. $PM_{2.5}$ is the primary GHG directly linked to health effects because it is a mixture of solid or liquid airborne particles smaller than 2.5 µm in aerodynamic diameter, making it possible for these particles to pass the human body's defenses of the nose and upper airways and land in the vulnerable tissue of the lung or be transported through the bloodstream to other organs. $PM_{2.5}$ emissions come from vehicles, energy generators, heating systems, wildfires, arid regions, and wind-blown dust. The former four emissions sources also produce SO_2, NO_x, and VOCs, which are precursor gases that can become $PM_{2.5}$ through atmospheric reactions (Kinney, 2018). The first three emissions sources aforementioned are also primary sources of CO_2 emissions; therefore, CO_2 emissions abatement actions will reduce $PM_{2.5}$ concentrations and associated negative health externalities.

As stated in Melamed et al. (2016), "it is nearly impossible to reduce emissions of one pollutant at a source without affecting the co-pollutants also emitted by the source" (pg. 88). Due to this relationship, the expectation is that air pollutant concentrations, and therefore negative human health externalities, will also be reduced from energy generators in compliance with the RGGI CO_2 emissions cap (Abt Associates, 2017). The analysis performed by Cai et al. (2018) in China supports this relationship, concluding that the implementation of a CO_2 abatement policy projected reductions in SO_2 ranging between 18 and 89 percent and reductions in NO_x between 28 and 79 percent by 2030; both SO_2 and NO_x are precursors to $PM_{2.5}$.

In light of these results, this paper will analyze the research question of wither a regional cap-and-trade program, specifically RGGI, reduces the concentration of $PM_{2.5}$. This analysis will further analyze wither a binding emissions cap constraint has a statistically significant impact on $PM_{2.5}$ concentration. This follows the hypothesis that RGGI targets CO_2 emissions from energy generators with the expectation of combating the temperature change externalities as well as reducing co-pollutant emissions and improving air quality, therefore reducing human health externalities.

In 2012, the Organization for Economic Cooperation and Development (OECD) estimated that air pollution will be the leading environmental cause of mortality around the world by 2050 (Melamed et al., 2016). This assessment is supported by a 2012 report from the World Health Organization (WHO), which names air pollution as the world's greatest environmental risk, with seven million deaths attributed to air pollution on an annual basis. This level of mortality remains relatively constant, as the WHO's 2015 report exceeded 5.6 million deaths attributed to air pollution (Xie et al., 2018). In 2014, the United Nations Environment Assembly (UNEA) recognized the connection between clean air and human health by prioritizing air quality for sustainable development (Melamed et al., 2016). In 2018, Cai et al. named climate change to be the greatest global health threat of the 21st Century. Global organizations are raising awareness of the link between air quality and human health, but awareness is not a sufficient method to combat the issue of increasing mortality due to GHG emissions decreasing air quality.

While there is great variation in the projected health benefits of carbon abatement policies, there is consensus that the health benefits of improved air quality exceed the policy implementation costs in the long-run, or beyond 2050. For example, analysis of China's working national carbon policy projected estimates of health benefits equating to 18 - 62 percent of policy implementation costs by 2030, and 300-900 percent of implementation costs by 2050 (Cai et al., 2018). The actual impacts and cost-benefit ratios will differ between regions because of the geographical distribution of carbon-intense energy generation, although the Chinese study projects benefits outweighing costs by 2050 in all Chinese regions and at the national level (Cai et al., 2018). MIT researchers produced similar conclusions for the United States, estimating that savings on health care spending could be up to 10.5 times the cost of carbon cap-and-trade policy implementation (Resutek, 2014). In 2011, the EPA produced the estimate of a 30:1 cost-benefit ratio with public health benefits exceeding the cost of meeting air quality targets, and 85 percent of the public health benefit due to reductions in the level of $PM_{2.5}$ (Abt Associates, 2017). In the context of RGGI, the cost-benefit ratio depends on each respective state's priorities, which reflect how each state chooses to apply their share of carbon allowance auction proceeds.

Background History of RGGI

RGGI is an interorganizational process involving a variety of entities with the collective goal of reducing CO_2 emissions produced by the energy sector. These entities consist of state legislatures and environmental regulatory bureaus from the nine member states and a quasi-government non-profit organization established by the RGGI Memorandum of Understanding (MOU) to manage data collection and reporting on regulated electric utility companies (Dormady, 2013). These nine member states had previously formed an alliance to mitigate the acid rain problem prevalent in the 1980s, which resulted in the creation of the Acid Rain Program, the Ozone Transport Commission, the Nitrous Oxide Budget Program, and amendments to the 1990 Clean Air Act (Huber, 2013). Each of these are multi-state air pollution control measures within the Northeastern region. The linked network for environmental action formed prior to RGGI increased trust between states and decreased start-up costs of establishing a programmatic network, which increased the attractiveness for states to join RGGI.

RGGI represents the oldest CO_2 cap-and-trade system in the United States and the first mandatory cap-and-trade program in the United States (Hibbard et al., 2018). In 2001, Governor George Pataki established the Greenhouse Gas Task Force to explore climate change policy options for the state of New York. In 2003, the Task Force released a report which recommended a statewide cap-and-trade program, spurring Governor Pataki to invite other governors from Northeastern states to collaborate on a regional cap-and-trade program for CO_2 emissions. Delaware, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine accepted Governor Pataki's invitation in 2003 and joined the RGGI collaboration as active participants, while Maryland and Pennsylvania attended meetings as observers (The Compact Clause and the Regional Greenhouse Gas Initiative, 2007). The states who joined the initiative contributed environmental and energy regulatory officials to a working group in charge of negotiating and planning RGGI (Huber, 2013). Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont signed the RGGI MOU in 2005, with Maryland, Massachusetts, and Rhode Island joining the collaboration in 2007 (Milne, 2017). The CO_2 abatement goal was set for reducing regional CO_2 emissions by 10 percent from 1990 levels by 2018, 40 percent by 2030, and 80 percent by 2050 (Stevenson, 2018). In 2011, New Jersey decided to exit the collaboration due to a change in priorities under Governor Chris Christie (Hibbard et al., 2018). The other nine states have remained RGGI members to date.

As of 2016, RGGI covered 18 percent of states within the United States, approximately 13 percent of the population living in the United States, and 7 percent of the United States' power generation and CO_2 emissions (Hibbard et al., 2018). In 2018, Virginia began looking to join the alliance, with New Jersey looking to rejoin under Governor Phil Murphy (Krutz, 2018). While RGGI covers less than one-fifth of the states in the United States at this time, this cooperative effort represents abatement efforts that are feasible due to a lack of national policy.

Carbon Policies

A carbon emissions market represents an institution with the purpose of implementing the collective goal of carbon emissions abatement and holds the associated incentive of assigning a social value to carbon emissions output to combat climate change. Market participants establish scarcity of the clean air resource by assigning a social value to emissions through the emissions allowance price. Carbon policies typically fall in one of three categories: command-and-control regulation, carbon tax, or cap-and-trade regulation. These three policy alternatives share the goal of emissions reduction, but the difference in incentive structure contributes to the degree of relative emissions abatement.

Command-and-control regulation holds little flexibility, forcing energy generators to equally share emissions reductions to comply with a reduction goal, regardless of the cost to each generator (Huber, 2013). Liu et al. (2014) found that command-and control policies create expensive implementation costs, reducing total output and increasing energy prices paid by consumers. Their study concluded that the command-and-control policy alternative lead to immediate emissions reductions, but at a higher implementation cost than alternative carbon policies.

A carbon tax represents an incentive-based policy that applies a constant tax rate on burning fossil-fuels or emitting CO_2, leaving actual emissions reductions to be determined by the market. Several European countries, including Denmark, Finland, the Netherlands, Norway, Sweden Switzerland, and the United Kingdom, have a carbon tax policy. Some states within the United States, such as Washington, are considering implementing a carbon tax (He, Wang, and Wang, 2012). Typically, the uses for revenues raised by a carbon tax differ from those raised under cap-and-trade. While cap-and-trade systems give a greater percentage of revenue to environmental improvement programs, carbon taxes are more likely to be used as state general funds (Carl and Fedor, 2016).

Carbon cap-and-trade is commonly regarded as the most cost-effective method for reducing emissions due to the flexibility of market activity and abatement action, in compliance with the emissions cap constraint. The market-based mechanism of cap-and-trade reduces regulation costs and allows electricity generators greater freedom in conducting their business while abating emissions, resulting in improved production efficiency as opposed to requiring reductions across-the-board under command-and-control policy (Huber, 2013). Potomac Economics (2018) discusses how the purchase of auctioned carbon allowances lessens the competitiveness of fossil-fuels by forcing energy generators to incorporate the cost of pollution into marginal fossil fuel generation costs and planning decisions, creating incentives for energy generators to facilitate the transition to less carbon-intense electricity generation. In the long-run, this translates to altered investment decisions focused on renewable energy technology and improved air quality. The drawback to the cap-and-trade market alternative is generators with relatively lower emissions reduction costs or smaller generators are likely to bear more of the burden of the reduction activity while larger generators have increased resources and can afford to continue fossil-fuel generation while maintaining profitability (He et al., 2012). This could result in larger generators maintaining pre-policy generation levels, which implies areas surrounding larger generators may see a smaller to no reduction in air pollution levels.

Auction Distribution Method

Traditionally, cap-and-trade systems distribute emissions allowances through a grandfathering method, where historical emissions dictate how allowances are distributed, despite the increased political appeal of the auction distribution method, which forces energy generators to bid on emissions allowances in units of one metric ton, then distributes auction proceeds to a variety of sustainability projects and programs to be discussed later. Under the grandfathering method, new producers with no historical emissions would not be given allowances, so they would have to buy allowances from producers who existed before the policy was enacted (Huber, 2013). This creates a barrier to market entry, and a drawback to the cap-and-trade policy alternative if implemented under the grandfathering method. The auction method results in less political opposition from both energy generators and politicians as this method is deemed more competitive, offering producers with lower abatement costs the incentive of being able to sell their extra allowances to producers with higher abatement costs or new market entrants. Further, the auction method offers the benefit of a transparent liquid market to remedy the issue of barriers to market-entry as all generators have equal access to allowances.

According to Huber (2013), the 1970s forced separation of the energy supplier/distributor natural monopoly caused energy markets to restructure and create regional wholesale energy markets, breaking up vertically integrated utility companies and increasing the political diversity of emitting parties. State-level restructuring efforts included enabling competition and allowing consumers to choose their energy supplier. Despite the state-level changes to promote competition and lower costs, splitting up a natural monopoly results in an increase in average total costs for energy generators, which translates to increases in the average price per Megawatt hour (MWh) paid by consumers. The result is that electricity prices were likely to keep rising in the RGGI regions regardless of state participation in RGGI, but auction proceeds offered a solution to offset these increases, hence the political appeal. Auction proceeds, after covering RGGI, Inc. administrative costs, are returned to state governments based on each state's proportion of regional emissions relative to regional RGGI emissions (Hibbard et al., 2018). Participating state legislatures support the auctioning method for allowance distribution because of the ability of auction profits to offset any electricity wholesale rate increases in addition to covering RGGI administrative costs.

RGGI states agreed on the Model Rule to be adopted in each member state. The Model Rule requires a minimum of 25 percent of each state's allowances to be allocated for auction to generate revenue for public benefit purposes, with most participating states increasing that requirement for their state up to 100 percent (Huber, 2013). As seen in Figure 1, the range of percentage of auction revenue proceeds allocated for public benefit varied by state and year, with a minimum of 57 percent offered by the State of Delaware in the first control period and a maximum of 100 percent by the State of Delaware in the third control period. States who chose not to auction all allowances for public benefit did so to reserve allowances for generation sources with electrical output restricted by permit conditions, specifically if the permit restricts electrical output to under 10 percent of the annual generation capacity per emitting unit (Regional Greenhouse Gas Initiative Model…, 2008). The adoption of the Model Rule guides the states in reinvesting auction proceeds in public benefit programs and further aiding the transition to renewable energy sources.

Figure 1. Percentage of Allowances Allocated for Public Benefit by State and Control Period

	Control Period								
	2009 - 2011			***2012 - 2014***			***2015 - 2017***		
	Offered	**Sold**	***Difference***	**Offered**	**Sold**	***Difference***	**Offered**	**Sold**	***Difference***
Connecticut	96.43%	75.86%	*20.57%*	97.87%	82.58%	*15.29%*	98.03%	98.03%	*0.00%*
Delaware	57.14%	43.88%	*13.26%*	79.05%	67.63%	*11.42%*	100.00%	100.00%	*0.00%*
Maine	83.89%	66.10%	*17.79%*	83.66%	69.97%	*13.69%*	92.65%	92.65%	*0.00%*
Maryland	84.64%	66.61%	*18.03%*	94.06%	79.52%	*14.54%*	83.14%	83.14%	*0.00%*
Massachusetts	98.59%	77.55%	*21.04%*	99.40%	83.52%	*15.88%*	99.80%	99.80%	*0.00%*
New Hampshire	71.00%	55.99%	*15.01%*	79.12%	66.18%	*12.94%*	99.99%	99.99%	*0.00%*
New Jersey	89.37%	67.37%	*22.00%*	-	-	-	-	-	-
New York	94.91%	74.80%	*20.11%*	94.08%	78.94%	*15.14%*	91.21%	91.21%	*0.00%*
Rhode Island	99.96%	78.59%	*21.37%*	99.62%	85.47%	*14.15%*	99.70%	99.70%	*0.00%*
Vermont	99.67%	78.24%	*21.43%*	99.00%	83.00%	*16.00%*	99.00%	99.00%	*0.00%*
Regional Total	**89.93%**	**70.41%**	***19.52%***	**93.47%**	**78.63%**	***14.84%***	**92.38%**	**92.38%**	***0.00%***

Source: RGGI, Inc. Distribution of Control Period CO2 Allowances

After administrative costs, states distribute auction revenues to energy efficiency improvement, direct electric bill assistance, clean technology research and development, renewable investment, greenhouse gas reduction, education, outreach, and job training programs (Hibbard et al., 2018). Stutt (2016) found that auction proceeds allowed RGGI states to increase their budgets for electricity efficiency programs by $1.3 billion, going from a collective regional $575 million in 2008 to $1.9 billion in 2015. Hibbard et al. (2018) summarized that RGGI states collectively put the majority (54 percent) of auction proceeds towards energy efficiency improvements (e.g. lighting improvements, insulation additions, appliance upgrades) followed by direct bill assistance (13 percent). An example of individual priorities is the range between the New England region allocating 72 percent of proceeds for energy efficiency updates and PJM states allocating only 33 percent for energy efficiency programs and focusing more on direct utility bill assistance (40 percent). Remaining auction revenues are distributed to clean technology research and development, program administration, renewable investment, GHG programs, education, outreach, and job training. Occasionally, individual goals result in states' use of proceeds for items outside of environmental and energy programs, such as New York and New Hampshire repurposing proceeds towards their state budget deficits instead of the intended energy efficiency and environmental and health public interest investments (Huber, 2013). Despite these constraints, the cooperative effort has been recognized as a successful abatement effort.

Emissions Cap

The RGGI Board of Directors sets the aggregate emissions cap, with state caps determined by their individual percentage of emissions relative to the region. As seen in Figure 2, from 2009 to 2013, each state's annual base CO_2 emissions budget remained constant, as the regional cap remained constant (Regional Greenhouse Gas Initiative Memorandum of Understanding, 2005). Between 2009 and 2013, 690 million allowances were circulated, but only 550 million tons were applied towards compliance obligations, leaving 140 million allowances banked at the beginning of 2014 (Potomac Economics, 2018). This surplus suggests an oversupplied market, with 108 million tons of surplus allowances remaining at the end of 2017. From 2009 to 2013 Potomac Economic (2018) found that the regional non-binding cap remained constant, before becoming a binding constraint in 2014. At the end of 2013, a 45 percent reduction in carbon allowances from 165 million tons to 91 million tons was set for January 1, 2014, followed by a 2.5 percent per year reduction in the number of allowances added to circulation from 2015 to 2020 to achieve a collective target level of 78.2 million tons of emissions by 2020. Since the 2012 program revision, the amount of surplus allowances is deducted from newly circulated allowances at the start of the three-year control period after the surplus is accrued. With the adjustment, the surplus is projected to be depleted by 2025. Looking beyond 2020, the 2030 cap is currently set to 54.7 million tons, representing a 30 percent decrease from the 2020 cap and one-third of power plant CO_2 emissions in 2000 (Hibbard et al., 2018). Figure 3 summarizes the adjusted state emissions caps and percentages relative to the regional emissions cap for each of the three completed control periods with dates as follows: January 1, 2009 to December 31, 2011, January 1, 2012 to December 31, 2014, and January 1, 2015 to December 31, 2017. The declining emissions cap increases the incentive for entities to reduce CO_2 emissions on an annual basis in addition to investing in low-carbon electricity generation technology and strategy in the long-run.

Figure 2. Regional Emissions Cap By Year

	Year											
	2009	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***
Regional Emission Cap (millions of metric tons)	188.00	188.00	188.00	165.00	165.00	91.00	88.73	86.51	84.34	82.24	80.18	78.18

Note: Regional cap reduced in from 188 to 165 million tons in 2012 to account for New Jersey's exit from the program

Source: Potomac Economics (2018) and Hibbard et al. (2018)

Figure 3. Adjusted Emissions Cap By State and Control Period

	Control Period					
	2009 - 2011		***2012 - 2014***		***2015 - 2017***	
	Cap (metric tons)	**%**	**Cap (metric tons)**	**%**	**Cap (metric tons)**	**%**
Connecticut	32,085,108	5.69%	26,749,998	6.47%	12,549,950	6.47%
Delaware	22,679,361	4.02%	18,808,658	4.55%	8,681,726	4.48%
Maine	17,846,706	3.16%	14,879,487	3.60%	6,983,303	3.60%
Maryland	112,511,949	19.94%	93,505,549	22.63%	43,447,515	22.41%
Massachusetts	79,980,612	14.18%	66,482,919	16.09%	30,910,772	15.94%
New Hampshire	25,861,380	4.58%	21,561,629	5.22%	10,119,391	5.22%
New Jersey*	68,678,190	12.17%	-	-	-	-
New York	192,932,415	34.19%	160,655,192	38.88%	75,108,088	38.74%
Rhode Island	7,977,717	1.41%	7,471,331	1.81%	4,700,646	2.42%
Vermont	3,677,490	0.65%	3,046,065	0.74%	1,400,463	0.72%
Regional Emission Cap	**564,230,928**	**100.00%**	**413,160,828**	**100.00%**	**193,901,854**	**100.00%**

*Regional cap reduced in 2012 to account for New Jersey's exit from the program

Source: RGGI, Inc. Distribution of Control Period CO2 Allowances

Summary of RGGI's Cap-and-Trade System

Appendix A summaries RGGI participant roles**.** Appendix B summarizes the inputs, outputs, and outcomes of RGGI's carbon cap-and-trade system through logic model visualization. The public/non-profit partnership encourages the transition away from fossil-fuel generation, with the goal of executing emissions abatement action and facilitation. The carbon cap-and-trade component assigns and controls the social value of emissions and ensures that energy generators with capabilities exceeding 25 MWh comply with regional and state emissions targets. Short-run outcomes are aimed at reducing the competitiveness of fossil-fuel generation and consumption while simultaneously increasing consumption for energy efficiency improvements, disposable income for low-income consumers through direct bill assistance, and investment in renewable technology, energy generation, and sustainability. These short-run outcomes support the transition towards net zero carbon and GHG emissions and therefore air quality improvements, associated health benefits of averted morbidity and mortality of pollution-related cardiovascular and respiratory conditions, and health care cost savings. The cap-and-trade system also supports job creation and economic growth through increased consumption and investment. In the long-run, this translates to attempting to limit global climate change to 1.5°C above the pre-industrial baseline and lessen the effects of carbon and GHG emissions. This system remains limited by the lack of federal policy and the Compact Clause restrictions resulting in leakage.

Effectiveness – Abatement

RGGI states have achieved relative emissions abatement through the implementation of cooperative effort of carbon abatement legislation. When comparing across the United States, the forty non-member states (California was excluded due to the presence of their statewide carbon cap-and-trade system) saw a 14 percent reduction in CO_2 emissions since RGGI implementation in 2009 due to market factors of increases in the regional electricity price and decreases in the natural gas price, while RGGI states experienced a 30 percent reduction in CO_2 emissions over the same period (Stutt, 2016). The cost of allowances increases the price of electricity, with electricity generators passing this cost along to consumers in price per MWh. This price increase alters consumer behavior for an aggregate reduction in electricity demand, therefore abating emissions. Stevenson (2018) found that electricity demand within RGGI states decreased by 18 percent since 2009, while his sample of non-member states of Illinois, Pennsylvania, Ohio, Oregon, and Texas saw a mere 4 percent decrease over the same period (Stevenson, 2018). This market-based program drives innovation and technological advancement in the pursuit of profit, resulting in an estimated decrease in coal generation by 71 percent, decrease in oil of 58 percent, and increase in natural gas - which emits 44 percent less carbon emissions compared to coal - plus increases in renewable energy sources since the 2009 implementation (Stutt, 2016). Abt Associates (2017) estimate approximately 30 percent of the total decline in CO_2 emissions since the 2009 implementation was due to fuel switching from oil and coal to natural gas and renewables, with the remainder of the change due to weather (25 percent), increased renewable generation capacity (21 percent), reduced electricity demand (12 percent), and the economic recession (4 percent). Both electricity demand and carbon emissions project a negative trend since RGGI implementation in 2009, supporting the success of RGGI in meeting its objectives.

Abt Associates (2017) concluded that $PM_{2.5}$ precursors of NO_x and SO_2 emissions have also displayed annual reductions since RGGI implementation. The greatest NO_x abatement occurred in 2009, 2013, and 2014, with a minimum reduction of about 9,000 metric tons of NO_x in the RGGI region for each of those years and a total reduction of 43,000 metric tons over the period of 2009 to 2014. Approximately 73 percent of RGGI-induced NO_x abatement is attributed to the transition away from coal generation, where adjacent states of Pennsylvania and New Jersey saw a 26 percent reduction in NO_x over the same period. SO_2 emissions displayed a similar negative trend, with the greatest reduction of approximately 76,000 metric tons in the RGGI region occurring in 2009 and a total reduction of 109,000 metric tons from 2009 to 2014. Coal generation was also cited as the primary reason behind the RGGI regional SO_2 reductions. This supports the earlier connection between CO_2 abatement policy and reductions in GHG co-pollutants.

Effectiveness - Health Effects

All Northeastern states, RGGI or adjacent, displayed positive externalities in terms of health benefits that can be credited to RGGI implementation. The states with the highest estimated benefits include Delaware, Maryland, New Jersey, New York, and Pennsylvania (Abt Associates, 2017). The largest published improvement in air quality and health benefits occurred in 2009 at the beginning of RGGI implementation when cost incentives were altered, and energy generators began substituting in favor of less carbon-intense power sources and investing in energy efficiency. Public health benefit estimates are created by multiplying the incidence of a health condition under different levels of air pollution by the cost of that condition or the Value of a Statistical Life (VSL). Some of the health conditions resulting from exposure to $PM_{2.5}$ emissions include premature death, heart attack, stroke, asthma attacks, and other cardiovascular and respiratory conditions.

Banks, Marshall, and Schoengold (2015) concluded that by 2012, reductions in emissions due to RGGI enforcement resulted in an 88.5 percent reduction in overall air quality-related health impacts relative to pre-RGGI 2005 levels. Specifically, this study found that within member states, between 2005 (pre-implementation) and 2012 (post-implementation) air quality-related mortality decreased 88.6 percent (1,585 deaths to 180 deaths), acute and chronic cases of bronchitis decreased 88.3 percent (3,165 to 370 cases), heart attacks decreased 88.4 percent (2,715 to 315 attacks), asthma incidents decreased 88.4 percent (26,510 to 3,070 incidents), and hospital admissions decreased 88.4 percent (1,255 to 145 admissions). Quantified, this translates to an 88.3 percent reduction in air quality-related health costs from $12.3 billion to $1.4 billion. It should be noted that the risk of health effects increases for individuals living in a zip code containing a fossil-fuel energy generator, and thus the benefits will be disproportional relative to where an individual resides. Liu, Lessner, and Carpenter (2012) conducted a study of 1993-2008 hospital discharge data in New York State, and found a statistically significant increases in hospitalization rates for asthma (11 percent), acute respiratory infection (ARI) (15 percent), and chronic obstructive pulmonary disease (COPD) (17 percent) for individuals over the age of 10 living in a zip code that contained a fossil-fuel energy generator relative to those living in a zip code without a fossil-fuel energy generator.

The positive health externalities of RGGI did not stop in 2012. Abt Associates (2017) summarized the conservative and optimistic health benefits of RGGI over the longer period of 2009 to 2014, where the conservative estimate discounts point-estimates of non-member state benefits of averted health incidents by 50 percent and the optimistic estimate retains non-member state health benefit point-estimates at 100 percent. RGGI-related benefit estimates consisted of 300 - 830 avoided premature adult deaths, 35 - 390 avoided non-fatal heart attacks, 420 - 510 averted new cases of acute bronchitis, 8,200 – 9,900 avoided asthma exacerbations, and 13,000 – 16,000 averted cases of respiratory symptoms. This translates to averting between 180 – 220 hospital admissions, 200 – 230 emergency room visits, and 39,000 – 47,000 lost work days in the aggregate RGGI and adjacent Northeastern states of Pennsylvania, Virginia, and West Virginia, plus the District of Columbia. The value of the health benefits will only increase over time, as most of the associated health conditions result from prolonged exposure to air pollution and thus require time to reflect air quality improvements.

Abt Associates (2017) used the VSL to monetize public health benefits because it represents the price individuals are willing to pay for a reduction in the risk of a health condition, producing increasing public benefits in the long-run. The median monetized RGGI public health benefit in 2009 is estimated at $2.9 billion in 2015 dollars, followed by $95 million - $250 million in public health benefits for the period of 2010 to 2014. The value of health benefits varies between states and even counties due to demographic differences, environmental factors, and weather conditions. This value ranges between $10,000 and $100 million depending on the county over the period of 2009 – 2014. Using a 3 percent discount rate, the total value of monetized health benefits ranges from a conservative estimate of $2.4 billion within RGGI states plus $1.3 billion in the adjacent states of Pennsylvania, Virginia, and West Virginia, plus the District of Columbia, for a total conservative benefit estimate of $3.7 billion to an optimistic estimate of $5.4 billion within RGGI states plus $2.9 billion in the adjacent states for a total optimistic benefit estimate of $8.3 billion. The VSL method yields positive health benefit estimates across both RGGI-member and adjacent states.

Effectiveness – Economic Benefits

Actual direct costs of RGGI have been found to be lower than pre-RGGI implementation cost estimates, with benefit estimates increasing over time. RGGI implementation costs were lower than originally projected due to increased capacity for wind and natural gas electricity generation without significant capacity or capital spending investments (Stutt, 2016). The economic value added through the program is commonly measured as investments made using auction proceeds. As of December 2017, 38 auctions raised a cumulative $2.7 billion in allowance proceeds (Hibbard et al., 2018). In the example of the State of Maryland, each auction generates between $12 million to $15 million for the Maryland treasury, which is applied to investments in energy transitions to cleaner sources and assistance programs for utility ratepayer relief (Krutz, 2018). Comparatively, Xie et al. (2018) project that global economic costs associated with air pollution will reach 1 percent of global GDP by 2060. Applying this ratio to a state government, and assuming general fund revenues for fiscal year 2019 of $18.08 billion for the Maryland general fund budget, this would translate to annual air pollution costs of $1.8 million for the State of Maryland (Franchot, Kopp, and Brinkley, 2018). The auction proceed revenue promotes economic growth by recirculating dollars around the economy. How states choose to spend their portion affects general consumption behavior of consumers. If used for offsetting electricity price increases for low-income consumers, energy efficiency subsidies to reduce electricity bills, or job creation to assess and perform energy efficiency improvements, consumers will have more disposable income. An increase in disposable income increases consumption of goods and services. RGGI implementation in 2009 struck first order changes in economic activity, with multiplier effects extending into the future.

RGGI implementation is positively associated with economic growth, job creation, and positive net economic benefit. Stutt (2016) found that since implementation in 2009, RGGI states' economies have grown by 24.5 percent, compared to 21.3 percent growth in states with no carbon pricing or emissions regulation. Electricity prices in RGGI-member states have decreased by 3.4 percent since implementation in 2009, compared to the 7.2 percent price increase found in the rest of the country. The difference in price increases implies consumers in member states saved more on their electricity bill, allowing them to spend the money on other goods and services, increasing economic activity. Additionally, Abt Associates (2017) estimated job creation between 2009 and 2014 at 30,000 job-years, where one job-year equals one full-time position for a year. More jobs also imply an increase in disposable income, and therefore eventually economic growth. The benefits of RGGI-related economic growth are not confined to consumers who made energy efficiency investments, instead applying to all consumers in the RGGI region. Since 2009, cumulative net economic value added for member states totaled $4.7 billion in 2018 dollars (Hibbard et al., 2018). RGGI has proved carbon cap-and-trade policy not only helps the environment, but also adds value to the economy in the form of economic growth and job creation.

It should be noted that RGGI was developed with the understanding that low-income consumers are disproportionally affected by carbon cap-and-trade implementation costs seen through electricity price increases per MWh and by health impacts. Electricity generators pass the short-term costs of the required allowances and the long-term costs of transitioning towards a completely renewable energy portfolio on to the consumer by increasing the price of electricity per megawatt hour, subject to the consumers' aggregate price elasticity of demand. Auction proceeds are combined with federal dollars from the United States Department of Health and Human Services for the federal Low-Income Home Energy Assistance Program (LIHEAP) to reduce social welfare losses and help low-income consumers who see a greater direct increase in utility costs relative to their income (Stevenson, 2018). Similarly, these direct price increases are offset by the benefits of energy efficiency improvements and programs, ratepayer assistance for low-income consumers, education and job training opportunities, and increased state general funds offered on both a regional and local scale (Abt Associates, 2017). This development is the result of low-income consumers being disproportionally affected in terms of income and associated health impacts. Richardson et al. (2012) find a strong and consistent positive correlation between income and health outcomes, likely due to lower-income consumers having less disposable income to spend on health insurance and out-of-pocket medical costs, plus increased risk of occupational injury and illness. Since low-income populations may be more susceptible to increased direct utility costs and negative health impacts, a portion of public benefit auction proceeds are typically allocated to programs that reduce this disparity. The percentage of auction proceeds invested in public benefit programs depends on the requirements specified by legislators (Potomac Economics, 2018).

Methodology

This analysis focuses on actual changes in annual-averaged daily $PM_{2.5}$ concentration and NAAQS violation counts at the Zip Code Tabulated Area-level (ZCTA), for nine member RGGI member states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont) compared to four non-member states (New Jersey, Pennsylvania, Virginia, and West Virginia) plus the District of Columbia. ZCTAs represent the U.S. Census Bureau's approximation of zip code boundaries defined by U.S. Postal Service routes for standardized comparison over time.

This analysis will flow through three stages: 1) run a fixed effects OLS regression of RGGI and non-RGGI factors on monthly observation points of annual-averaged daily $PM_{2.5}$ concentration at the ZCTA-level, with standard errors clustered by AQS monitor, 2) perform Oaxaca decomposition on the OLS regression in the first stage to isolate the magnitude of RGGI participation on the change in $PM_{2.5}$ concentration, and 3) run a Poisson regression of RGGI and non-RGGI factors on the number of times per year the daily $PM_{2.5}$ concentration exceeds the 24-hour NAAQS maximum of 35 $\mu g/m^3$ for primary and secondary $PM_{2.5}$ concentration using monthly observation points at the ZCTA-level. The third stage is included as part of sensitivity analysis, to determine if there was a reduction in NAAQS violations as a result of RGGI policy implementation.

Data

Daily AQS monitor station $PM_{2.5}$ concentration data was downloaded from the EPA's Air Market Program, which contains raw data by local air quality monitor. Daily observations of local conditions (code 88101) will be converted into annual-average concentrations, as well as used to create the count of number of days per year the $PM_{2.5}$ concentration exceeded the $PM_{2.5}$ 24-hour NAAQS. It should be noted that only monitors with at least one year's worth of data pre- and post-2014 policy change will be included, with the exception of data from the state of Maine due to limited data availability. Energy generator location data was also found through the EPA's Air Market Program Data. The Geographical Information

System (GIS) software *QGIS* will be used to calculate the distance between the air quality monitors, the closest energy generator, and the closest weather monitor using the nearest neighbor distance matrix method.

Population density per square mile will be computed as ZCTA population divided by ZCTA land area in square miles. Annual intercensal population estimates for the years 2011 – 2017 were pulled from the American Community Survey (ACS) 5-year estimates. Annual population estimates for 2010 came from 2010 Census data. 2010 annual estimates will also be applied to 2009 observation points due to the lack of ZCTA-level data available existing prior to 2010. Land area in square miles is based on current information in the TIGER database, calculated for use with the 2010 census. This is recorded once every ten years when the full census is conducted by the U.S. Census Bureau, Census of Population and Housing.

Data on carbon emissions allowance allocations and quarterly auction proceeds were found in publicly available reports created and published by RGGI, Inc. Specifically, data will be pulled from *RGGI Distribution of Control Period* CO_2 *Allowance* and *State Proceeds by Auction* reports. Quarterly auction proceeds will be divided by 3 to obtain equivalent monthly auction proceed amounts.

A quantity weighted, monthly-average secondary market transfer price will be calculated using the price and quantity of each transaction recorded in the CO_2 Allowance Tracking System (COATS) tracking system for the period of 2009 – 2017.

Data from weather monitors, including hourly readings of air temperature, humidity, precipitation, and windspeed were collected from Local Climatological Data made available through the National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA). The hourly readings will be translated into monthly averages, with the exception of precipitation, which will be summed for each month of the analysis period. GIS nearest neighbor analysis will be used again to associate the closest weather monitor with each air quality monitor.

Figure 4. Descriptive Statistics

Variable	*Obs*	*Mean*	*Std.Dev.*	*Min*	*Max*
Log(Annual Mean PM2.5 Concentration)	17,359	2.17	0.24	0.94	3.08
Annual Mean PM2.5 Concentration	17,359	9.02	2.02	2.56	21.80
Annual Count Daily PM Violations	17,647	0.07	0.26	0.00	1.00
RGGI Membership	17,659	0.51	0.50	0.00	1.00
2014 Policy Change	17,659	0.44	0.50	0.00	1.00
Policy Change Interaction Term	17,659	0.21	0.41	0.00	1.00
Distance to Energy Generator	17,659	15138.12	16950.21	704.00	83717.23
Population Density	17,659	6576.54	13074.34	0.00	99496.53
Secondary Market Allowance Transfer Price	17,659	3.53	1.50	1.68	8.17
Air Temperature	16,794	53.31	16.10	5.11	86.48
Relative Humidity	17,423	70.60	7.36	41.00	97.00
Precipitation	17,637	7.95	5.86	0.00	116.13
Windspeed	16,892	7.72	3.52	1.17	24.04

Contribution to Previous Literature

Paoella et al. (2019) found coarse-resolution grids, such as county-level estimation, to underpredict exposure to pollutants. Their study concluded using finer-resolution grids, such as zip codes, increased average pollutant concentration estimates by 27 percent. Similarly, Hernandez et al. (2018) found the use of Air Quality System (AQS) monitoring stations data to provide less biased, more certain estimates of the true ambient air pollutant concentration where air quality monitors were present. Contrary to the previous county-level RGGI literature, this analysis will apply OLS and Poisson regression to estimate coefficients of RGGI and non-RGGI factors on the real annual change in $PM_{2.5}$ concentration data at the ZCTA-level using AQS monitor station data from the EPA's Outdoor Air Quality Datamart.

Further, this paper aims to extend the evaluation period of previous literature to cover the third control period of RGGI, to include the years 2015 through 2017. The extension through 2017 will allow for generalized difference-in-difference regression analysis to determine the effect of the carbon emissions cap becoming a binding constraint when the regional cap was reduced by 45 percent effective January 1, 2014. This occurred after a 2012 program review of the effectiveness of the first control period covering the years of 2009 – 2011 found that the emissions cap - the allowance supply - was significantly greater than demand for energy production. Despite improvements in $PM_{2.5}$ concentration and associated health benefits through 2012, the RGGI board determined that program effectiveness could be increased. The analysis in this paper will compare the effectiveness of improving air quality and reducing $PM_{2.5}$ concentration before and after the 2014 policy change.

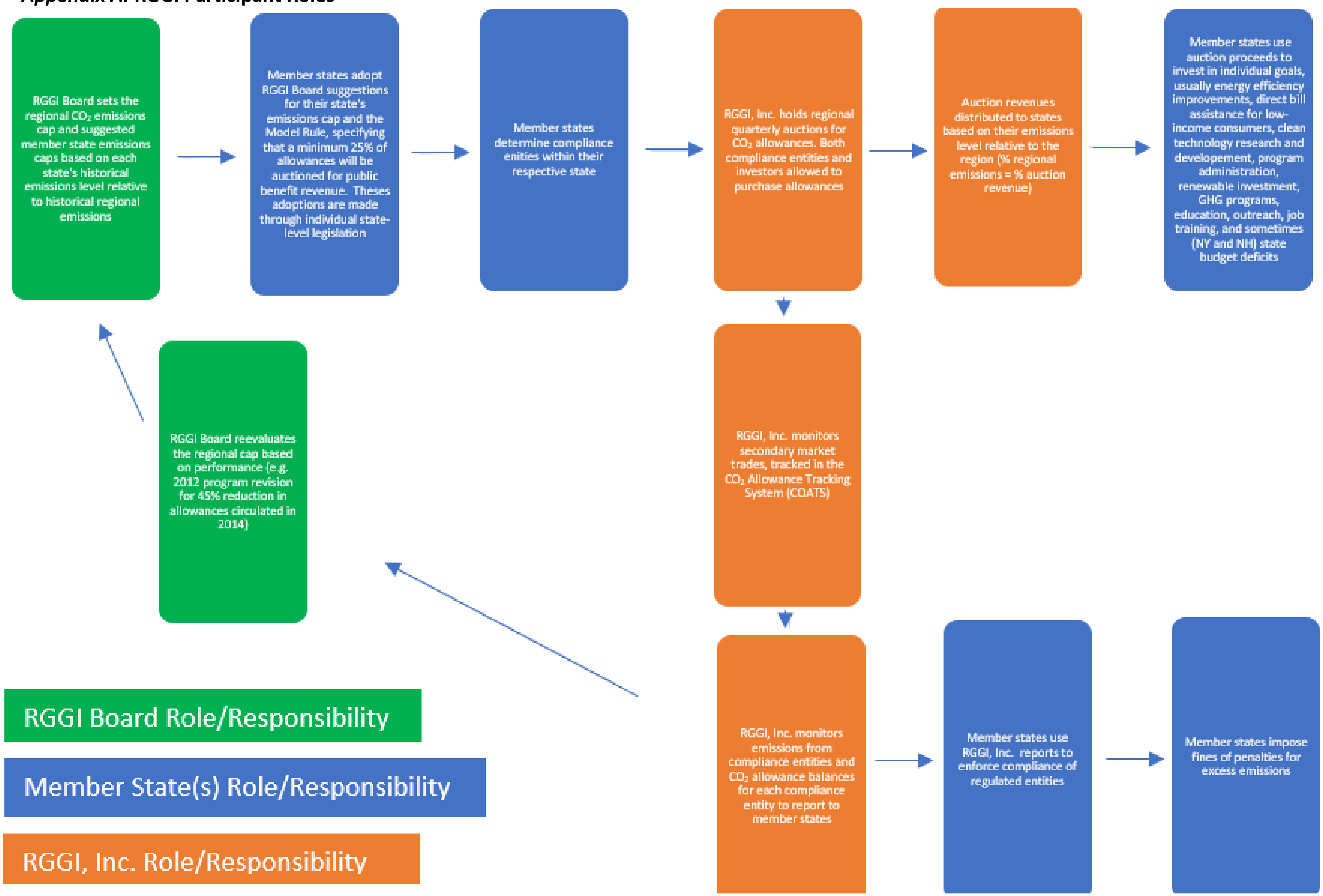
Additionally, this research will utilize Oaxaca decomposition to separate the effect of RGGI participation on the change in Particulate Matter concentration compared to regional changes in air quality. Since air quality benefits cannot be isolated within the boundaries of member states, neighboring states will experience some air quality improvement and associated health benefit regardless of their participation in the carbon cap-and-trade program. The Oaxaca decomposition will attempt to isolate the change in $PM_{2.5}$ that can be explained by RGGI policy participation and the change in $PM_{2.5}$ which remains unexplained or due to factors unaccounted for in this analysis. This tool will provide insight about the percentage of the change in $PM_{2.5}$ which is attributable to RGGI policy and suggest an expectation for the air quality improvement that could result from an expansion of this regional cap-and-trade program.

Lastly, this analysis will apply Poisson regression to determine the effect of RGGI and non-RGGI factors on annual counts of daily NAAQS violations. Similar to the OLS regression, the Poisson regression will estimate the difference-in-difference coefficient to determine the effect of the carbon emissions cap becoming a binding constraint, with respect to annual counts of daily NAAQS violations. This research represents the first exploration of changes in NAAQS violations due to carbon cap-and-trade policy participation, to the best of the author's knowledge. This regression will estimate the difference in human health externality risk between RGGI member and non-member states, as well as estimation of the change in health risk externalities before and after the 2014 policy change.

Summary

Fossil-fuel energy generation produces both carbon emissions and GHG co-pollutants. Carbon and GHG pollutants contribute to the global temperature increase and externalities resulting from the temperature change. Exposure to GHGs, especially $PM_{2.5}$, results in increased risk of cardiovascular and respiratory morbidity and mortality health externalities. RGGI represents a sustainable market-driven policy implemented to directly reduce CO_2 ambient concentration - and indirectly GHG concentrations - with the goal of achieving net zero carbon emissions levels by 2050, therefore improving air quality and reducing negative health externalities. Theoretically, this is accomplished by applying a social value to CO_2 emissions in the form of carbon allowance auctions to encourage substitution away from fossil-fuel generation and towards development of renewable energy generation while stimulating an increase in consumption of energy efficiency projects and services through investment of auction proceeds. This paper will extend the evaluation period of the RGGI program to estimate the impacts on air quality, specifically $PM_{2.5}$, through 2017.

Appendix A. **RGGI Participant Roles**



***Appendix B.* RGGI CO_2 Cap-and-Trade Abatement Program Logic Model**

Inputs

- Public and non-profit partnership
- Carbon cap-and-trade program

Outputs

Activities

- Transition away from coal and towards renewable energy generation
- Limit emissions to improve air quality
- Model Rule – allocate a minimum of 25% of allowances for public benefit revenues
- pools allowances for regional quarterly allowance auctions

- Increase the price of carbon emission
- Control the social value of carbon emissions using the Cost Containment Reserve (CCR) and Emissions Containment Reserve (ECR)
- Generate revenue from auction proceeds for investments in energy efficiency and renewable sources

Participation

- Energy generators with capabilities exceeding 25 MWh must demonstrate emissions reductions, allowance trades, or offset projects to meet target emissions levels
- Regional and State emissions caps set by the RGGI Board and individually adopted by member states
- Conferences are held annually to build and continue relationships between market participants and set expectations for and between involved parties
- Less political opposition than a carbon tax or command-and-control policy due to revenue generate and efficiency of policy
- Reduced regulation costs of a market-based system

Outcomes

Short

- Lessen the competitiveness of fossil-fuel electricity generation
- Assign a social value to carbon emissions, reflected in the price of carbon allowances.
- Carbon abatement
- Reduced electric demand
- Stimulate an increase in consumption for energy efficiency improvements
- Increase disposable income for low-income consumers through direct bill assistance
- Stimulate investment
- Monetize the public health benefits using the Value of a Statistical Life (VSL) for member states and adjacent states

Medium

- Transition towards net zero carbon and GHG emissions
- Improve air quality, especially PM2.5 and GHG precursors (SO2, NOx, and VOCs)
- Economic growth through increased consumption and investment
- Job creation

Long

- Limit global climate change to 1.5°C above the pre-industrial baseline
- Lessen the incidence of mortality from cardiovascular and respiratory diseases
- Lessen the health care costs associated with poor air quality
- Lessen the effects of continual GHG and air pollutant emissions: heat extremes in most inhabited regions, heavy precipitation in some regions while drought and wildfire risks increase in other regions, sea level rise, coastal erosion, loss of ecosystems, increased food and water scarcity

External Factors

- Compact Clause restricts agreements between states without congressional consent, resulting in leakage (non-regulated power imported from non-member states to member states)
- Lack of federal policy

***Appendix C.* Acronym List**

ACS - American Community Survey

AQS - Air Quality System

ARI - Acute Respiratory Infection

BenMAP – Benefits Mapping and Analysis Program

CH_4 – Methane

CO - Carbon Monoxide

CO_2 - Carbon Dioxide

COATS – CO_2 Allowance Tracking System

COBRA - CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool

COPD - Chronic Obstructive Pulmonary Disease

EPA – Environmental Protection Agency

F-gases – Fluorinated Gases

GHGs – Greenhouse Gases

GIS – Geographical Information System

IPCC - Intergovernmental Panel for Climate Change

MOU - Memorandum of Understanding

MWh - Megawatt hour

NAAQS - National Ambient Air Quality Standards

NO_2 - Nitrogen Dioxide

NOAA - National Oceanic and Atmospheric Administration

NO_x - Nitrous Oxide

O_3 - Ground-Level Ozone

OECD - Organization for Economic Cooperation and Development

PM – Particulate Matter

$PM_{2.5}$ - Particle $Matter_{2.5}$

RGGI – Regional Greenhouse Gas Initiative

RGGI, Inc. - Regional Greenhouse Gas Initiative, Inc.

SO_2 - Sulfur dioxide

UNEA - United Nations Environment Assembly

VOCs - volatile organic compounds

VSL - Value of a Statistical Life

WHO - World Health Organization

ZCTA - Zip Code Tabulation Area

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