Carbon Trading & Environmental Equity: Evidence from the Regional Greenhouse Gas Initiative (2000 - 2019)

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Abstract

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The Regional Greenhouse Gas Initiative (RGGI) was the first carbon cap-and-trade policy established in the U.S. The goal of RGGI was to mitigate climate change by regulating the emission of CO_2 from fossil-fuel fired electric power plants located in the ten participating Northeast states. Given CO_2 disperses globally, any reduction in emissions regardless of geographic location is beneficial in reducing the impacts of climate change, making CO_2 an ideal pollutant for flexible market-based instruments. However, since CO_2 emissions from fossil-fuel fired power plants are accompanied with co-pollutants that cause local harm to human health, market-based solutions create the potential for co-pollutant hotspots to form. This analysis examined whether RGGI has resulted in hotspots in locations where they could disproportionately impact communities color, low-income, low-educational attainment, and linguistic isolation. Temporal trends in emission of CO_2 with respect to multiple measures of neighborhood demographics were evaluated using data from 2000 – 2019. The results of this research found that (1) neighborhoods near facilities regulated under RGGI have higher proportions of non-white residents, low educational attainment, poverty, and linguistic isolation than those further away; (2) twenty nine percent of facilities have continued to increase their emissions since the implementation of RGGI; and (3) the neighborhoods located near facilities with increasing emissions are found to have a statistically significant higher proportion of residents of color and households below the poverty line. These results raise environmental equity concerns regarding the health of communities of color and low-income located in RGGI states.

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1. INTRODUCTION

In the U.S., approximately 63% of electricity is generated by the burning of fossil fuels, namely natural gas, coal, and petroleum (EIA, 2020). Burning of these fuels emits greenhouse gases, most prominently carbon dioxide (CO_2) (Bolin & Doos, 1989). While CO_2 does not directly harm human health through exposure, its emissions alter Earth's climate by warming the atmosphere (Bolin & Doos, 1989). The impact of this warming poses a significant threat to human life through the alteration of weather patterns, an increase in ocean acidity, the loss of biodiversity, and more (Masson-Delmotte & Valerie, 2018). Furthermore, these risks are unevenly distributed as marginalized communities have heightened vulnerability to climate change (IPCC, 2014).

The burning of fossil fuels also emits co-pollutants whose shorter atmospheric lifespans mean they often deposit closer to their source of emission (Burney, 2020). These co-pollutants include substances such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), and heavy metals (Cushing et al., 2018; EIA, 2020). Exposure to these pollutants has been linked to increased risk of respiratory illnesses, cardiopulmonary diseases, and premature deaths (*Health Effects of Ozone Pollution*, 2015; Kim et al., 2015; Thompson et al., 2014). A recent study estimated that the closures of coal-fired power plants (CFPPs) in the U.S. between 2005 and 2016 saved 26,610 lives based on the reduction of air pollutants (Burney, 2020). Thus, policies that aim to reduce the emissions of greenhouse gases, namely CO_2, can have positive health outcomes due to the corresponding reduction in co-pollutants.

Within the U.S., there are several federal policies that regulate the emission of air pollutants. In 1963, the first iteration of the Clean Air Act was federally implemented (Kuklinska et al., 2015). In 1970, amendments strengthened the act by adding performance standards for emission rates and ambient standards for criteria pollutants which later expanded in 1997 to include tropospheric ozone, particulate matter of 2.5 & 10 micrometers, carbon monoxide, sulfur dioxide, and nitrogen oxides (Kuklinska et al., 2015). The Environmental Protection Agency (EPA) was also established to enforce monitoring and compliance with the standards (Kuklinska et al., 2015). Out of concern for the growing acid rain problem, the nation established its first cap-and-trade program in 1995 (Kuklinska et al., 2015). The program regulated emissions and established trading permits for SO_2 and NO_x and was particularly targeted towards CFPPs as they were the main emitters (Marcy, 2018). The adaptation of stack-gas scrubbers coupled with switches to low-sulfur coal and low-NO_x burners resulted in a significant decrease in the emission of these gases, even with relatively low trading (Dolsak, 2007; Marcy, 2018). While federal policies are in place to address air pollutants, none exist to regulate CO_2 emissions and thus mitigate climate change.

In response to the lack of federal regulation on CO_2 emissions, restrictions have been adapted at the state level. In 2009, ten states in the U.S. Northeast (Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine) enacted the nation's first carbon cap-and-trade program, building on the lessons of the federal SO_2 and NO_x programs (RGGI Inc., 2020). The states collectively agreed to combat climate change by regulating CO_2 emissions in the region with a carbon cap-and-trade mechanism (RGGI Inc., 2005). Known as the Regional Greenhouse Gas Initiative (RGGI),

RGGI regulates emissions of CO_2 from fossil-fuel fired power plants within the participating state's electricity sectors (RGGI Inc., 2020).

Under RGGI, emitters with a generation capacity of 25 megawatts or more are required to hold allowances equal to their CO_2 emissions over a three-year control period (RGGI Inc., 2020). The majority of allowances are distributed through quarterly auctions although allowances may also be traded in secondary markets (Potomac Economics, 2020). The total number of available allowances in the market is fixed, acting as a "cap" on emissions (RGGI Inc. 2020). In 2014 the cap was set at 91.0 million tons and has continued to reduce by 2.5% each year (Potomac Economics, 2020). The program was designed to provide emitters with flexibility in how they respond to the regulation and determine if it is more cost-effective to abate their emissions or pay to emit. Since 2019, RGGI has held 46 auctions, selling approximately 1.025 billion CO_2 allowances and generating a revenue of $3.36 billion (Potomac Economics, 2020).

However, the flexibility of RGGI makes the region vulnerable to unequal reductions in the emissions of CO_2 and corresponding toxic co-pollutants (Farber 2012). While RGGI as a whole has resulted in a decrease in region-wide CO_2 emissions, localized co-pollutant hotspots, areas with high pollutant concentrations, may be forming if individual emitters find it cheaper to purchase more emissions permits and increase their emissions of both CO_2 and co-pollutants rather than abate their emissions (Acadia Center, 2019; Farber, 2012). In this research, a hotspot was defined as a neighborhood that experienced an increase in emissions following the implementation of RGGI due to the neighborhood's proximity to one or multiple regulated facilities.

Given multiple studies have found evidence that indicate race and class are significant determinants of proximity to an environmental hazard, it is plausible that communities located within hotspots are of low socioeconomic status (Farber 2012; Mohai and Bryant 1992). As a result, there is concern that RGGI may place communities of color, low educational attainment, poverty, and linguistic isolation, at higher risk of experiencing negative health consequences by being continuously exposed to air pollution.

A study examining the nation's second carbon cap-and-trade program in California identified the occurrence of pollution hotspots (Cushing et al., 2018). It established that neighborhoods located in these hotspots were disproportionately composed of residents of low socioeconomic status (Cushing et al., 2018). Based on data from 2011 to 2015, their results found that (1) a disproportionate amount of regulated emitters in the cap-and-trade program were located in economically disadvantaged neighborhoods with a statistically higher proportion of residents of color; (2) the quantity of greenhouse gases emitted by facilities correlated positively over time with the quantity of emitted co-pollutants and; (3) pollution hotspots occurred and they occurred in neighborhoods with higher proportions of people of color, lower incomes, lower levels of educational attainment, and higher linguistic isolation as compared to neighborhoods that did not experience an increase in pollution (Cushing et al., 2018).

Given the results of Cushing et al. and RGGI's status as a prominent climate change policy intervention, it is important to assess if a similar exacerbation of environmental inequities is occulting in participating RGGI states. This study aims to replicate the analysis of Cushing et al. as closely as possible given data constraints, to assess if increases in CO_2 and thus co-pollutant emissions regulated by RGGI occur in neighborhoods of low socioeconomic status.

2. METHODS

Temporal trends in emission of CO_2 with respect to multiple measures of neighborhood demographics were evaluated using data from 2000 – 2019, which includes 10 years before and after the implementation of RGGI. The analysis sought to determine if increases in CO_2 and thus co-pollutant emissions regulated by RGGI occur in neighborhoods of low socioeconomic status. The research aimed to answer the following questions:

(1) What are the demographic characteristics of census block groups surrounding facilities that are currently regulated under RGGI? Based on the findings of Cushing et al., it was hypothesized as follows:

> Hypothesis 1: *Block groups located near a regulated facility as compared to block groups not located near a regulated facility would contain higher proportions of black residents, residents of color, residents with less than a high school degree, residents with less than a college degree, households below the poverty line, and linguistically isolated households as well as relatively lower median household incomes.*

(2) Have individual emitters continued to increase their CO_2 emissions following the implementation of RGGI and thus create co-pollutant hotspots?

(3) If so, what are the demographic characteristics of block groups located in these hotspots? Based on the findings of Cushing et al., it was hypothesized as follows:

> Hypothesis 2*: Block groups in hotspots as compared to block groups also near regulated facilities but not in hotspots would contain higher proportions of black residents, residents of color, residents with less than a high school degree, residents with less than a college degree, households below the poverty line, and linguistically isolated households as well as relatively lower median household incomes.*

2.1 UNIT OF ANALYSIS

Census block groups are the unit of analysis in this study. The block group boundaries defined by the 2000 U.S. Census were downloaded from Social Explorer (https://geodata.socialexplorer.com/dataset/aaa11095-764a-42a2-93bf-90e974b63579). Block groups are generally contiguous geographic areas that contain between 600 and 3,000 people and can vary in size depending on population density (U.S. Census Bureau, n.d.). A total of 30,262 block groups from all the participatory RGGI states were included in this study.

A buffer of 1 mile and 2.5 miles was established around the perimeter of each block group to identify which block groups were located near a facility. The chosen buffer distances of 1 and 2.5 miles were used to replicate the methods of Cushing et al. These distances also reflect the short-lived nature of many co-pollutants in the atmosphere and the likelihood that they will deposit near their emissions source.

2.2 EMISSIONS DATA

Each emitter under RGGI is required to collect, record, quality-assure, and report their own CO_2 emissions (RGGI Inc., 2020). The emissions data is recorded in the U.S. EPA's Clean Air Markets Division database, in accordance with federal rule, and then transferred to the RGGI CO_2 Budget Trading Program (COATS) where it is made publicly available. Historic emissions from the years 2000 to 2008, prior to the implementation of RGGI were downloaded from RGGI COATS (https://www.rggi.org/allowance-tracking/emissions). Emissions reported after the implementation of RGGI were available from years 2009 to 2019 and downloaded from the EPA Air Markets Program (https://ampd.epa.gov/ampd/). Both datasets contain the same variables including annual CO_2 emissions from regulated facilities and details of the facilities' geographic locations.

The two datasets reported emissions at the individual stack level for each facility. Since facilities often operate multiple stacks at a single site, this study conducted a spatial comparison in R and confirmed that all stacks belonging to a facility were located at the same latitude and longitude. Emissions were then summed across all stacks sited at an individual facility to represent the total emissions from the facility.

During the study period, 19 facilities underwent a name change for reasons such as a change in operating status or a change in ownership. It was confirmed that emissions from these facilities were properly merged into a single dataset to ensure consistent temporal reporting of emissions over the study period.

To minimize compounding factors not necessarily related to the onset of RGGI and thus simplify the analysis, 31 facilities were excluded because they were not in operation during the entire study period. Secondly, New Jersey opted to leave RGGI in 2011 leaving an incomplete dataset of emissions from the state. Thus New Jersey was excluded from the analysis (39 facilities). In total, 148 facilities were included in the analysis.

2.3 DEMOGRAPHIC DATA

Demographic information for each block group was obtained from the 2000 U.S. Decennial Census. Census variables of interest were accessed and downloaded from Social Explorer (https://www.socialexplorer.com/explore-maps) The demographic categories assessed include race, educational attainment, poverty status, and linguistic isolation. These variables were selected to replicate the methods of Cushing et al. and are also common indicators used to define communities of low socioeconomic status (Jones & Shen, 2014). Race variables included the percent of individuals who identified as black and the percentage of individuals who identified as a person of color (individuals who did not self-identify as white). Educational attainment variables included the percentage of individuals above the age of 24 who earned less than a high school degree and the percentage of individuals above the age of 24 who earned less than a college degree. The poverty variables considered were the percent of households that fell below the federally defined poverty line for the year 1999 and median household incomes. The linguistic isolation variable measured the percent of households in which no one above the age of 13 identified as speaking English very well. Missing data from the Census accounted for 0.44% or race variables, 0.7% of poverty variables, 0.91% median income variables, and 0.91% of linguistic isolation variables.

2.4 ANALYSIS

Dataset construction and statistical analyses were conducted in R (R Foundation; https://www.r-project.org). Emissions data from each regulated facility were averaged for two different time periods to represent a pre- and post- RGGI period. The pre-RGGI period included average emissions from 2000 to 2006. The post-RGGI period included average emissions from 2011 to 2019. Years 2007 to 2010 were removed from the averaging periods to negate potential impacts the 2008 recession had on energy demand (Slini et al., 2015). If a block group was located near multiple facilities, the emissions of all nearby facilities were summed to indicate the total emissions experienced. To answer research question 2, the difference in emissions experienced by a block group between the two averaged periods was used identify if any block groups experienced an increase in emissions following the implementation of RGGI and were thus located in a hotspot.

A series of Mann-Whitney-Wilcoxon (MWW) tests were used to test for differences in medians of block group demographics to answer research questions 1 and 3. This type of statistical test was used because demographic variables were not normally distributed (de Winter & Dodou, 2010). To answer research question 1, MWW tests were used to check for a difference of medians for each demographic variable between block groups located within 1 mile of a facility and block groups beyond 1 mile of a facility. The analysis was repeated at the 2.5-mile radius.

To answer research question 3, MWW tests were used to check for a difference of medians between block groups that were located within 1 mile of a facility and experienced an increase in CO_2 emissions from 2011 – 2019 to 2000 – 2006 as compared to block groups that were located within 1 mile of a facility but did not experience an increase the emissions over the same period. The analysis was repeated at the 2.5-mile radius.

3. RESULTS

3.1 FACILITIES REGULATED UNDER RGGI ARE DISPROPORTIONATELY LOCATED IN BLOCK GROUPS OF LOW SOCIOECONOMIC STATUS

In response to research question (1), 'What are the demographic characteristics of block groups surrounding facilities that are currently regulated under RGGI?'; facilities regulated under RGGI are disproportionately located in block groups with higher non-white populations, lower educational attainment, lower income, and higher linguistic isolation (Table 1). The difference in medians for all variables assessed is statistically significant at the 0.05 alpha level. The same trend is seen at the 2.5-mile buffer distance (Table 2). These results support hypothesis 1.

Table 1. Characteristics of U.S Census block groups within 1 mile of a facility regulated by the Regional Greenhouse Gas Initiative.

Characteristics	Within 1 mile of a facility (n = 1,269 BGs; n = 1,702,743 people)[1]	Beyond 1 mile of a facility (n = 28,993 BGs, n = 37,276,317 people)[1]	p-Value[2]
Median (IQR) percent black	3.21 (0.89 - 12.84)	2.10 (0.56 - 12.94)	<0.001
Median (IQR) percent people of color	17.92 (5.21 - 48.25)	9.65 (3.51 - 38.20)	<0.001
Median (IQR) percent less than highschool education[3]	19.78 (10.80 - 33.07)	15.72 (8.69 - 25.90)	<0.001
Median (IQR) percent less than college education[4]	79.54 (63.33 - 88.65)	77.09 (62.08 - 86.85)	<0.001
Median (IQR) household income ($)	39,617.5 (28,234.25 -55,192.5)	46,103 (33,750 -62,778)	<0.001
Median (IQR) percent households below poverty line	11.44 (5.46 - 24.54)	7.55 (3.29 - 16.12)	<0.001
Median (IQR) percent households linguistically isolated[5]	3.67 (0.00 - 11.84)	1.76 (0.00 - 5.91)	<0.001

[1] Based on geographic census block groups. Block group demographics were obtained from the U.S. 2000 Decennial Census.

[2] Two-tailed Mann-Whitney-Wilcoxon tests.

[3] Percent of residents older than 24 years without a high school education.

[4] Percent of residents older than 24 years without a college education.

[5] Percent of population living in households where no one above age 13 speaks English very well.

BG, census block group; IQR, interquartile range.

Table 2. Characteristics of U.S Census block groups within 2.5 miles of a facility regulated by the Regional Greenhouse Gas Initiative.

Characteristics	Within 2.5 miles of a facility (n = 5,110 BGs; n = 6,501,851 people)[1]	Beyond 2.5 miles of a facility (n = 25,152 BGs, n = 32,477,209 people)[1]	p-Value[2]
Median (IQR) percent black	3.97 (1.06 - 20.17)	1.87 (0.52 - 11.39)	<0.001
Median (IQR) percent people of color	22.46 (6.86 - 59.16)	8.37 (3.23 - 32.78)	<0.001
Median (IQR) percent less than highschool education[3]	20.49 (10.20 - 35.49)	15.23 (8.57 - 24.58)	<0.001
Median (IQR) percent less than college education[4]	79.66 (62.45 - 89.24)	76.72 (62.09 - 86.46)	<0.001
Median (IQR) household income ($)	40,750 (27,679 -59,474)	46,722.5 (34,700.75 -63,204)	<0.001
Median (IQR) percent households below poverty line	11.88 (5.09 - 25.62)	7.03 (3.12 - 14.93)	<0.001
Median (IQR) percent households linguistically isolated[5]	4.18 (0.95 - 13.00)	1.53 (0.00 - 5.11)	<0.001

[1] Based on geographic census block groups. Block group demographics were obtained from the U.S. 2000 Decennial Census.

[2] Two-tailed Mann-Whitney-Wilcoxon tests.

[3] Percent of residents older than 24 years without a high school education.

[4] Percent of residents older than 24 years without a college education.

[5] Percent of population living in households where no one above age 13 speaks English very well.

BG, census block group; IQR, interquartile range.

3.2 Pollution hotspots have formed

In response to research question (2), ‘Have individual emitters continued to increase their CO_2 emissions following the implementation of RGGI and thus create co-pollutant hotspots?’; the temporal analysis found that 29% of facilities had higher average CO_2 emissions after the implementation of RGGI (2011 – 2019) as compared to before the implementation (2000 – 2006) (Fig 1). Of block groups located within 1 mile and 2.5 miles of a facility, 35% and 41% experienced an increase in emissions, respectively. Thus, pollution hotspots have occurred in these block groups. A third party review calculated that total CO_2 emissions from RGGI power plants fell by 47% from 2008 – 2019 (Acadia Center, 2019). While RGGI has reduced CO_2

emissions as a whole, localized areas are bearing the burden of increased CO_2 and co-pollutant emissions.

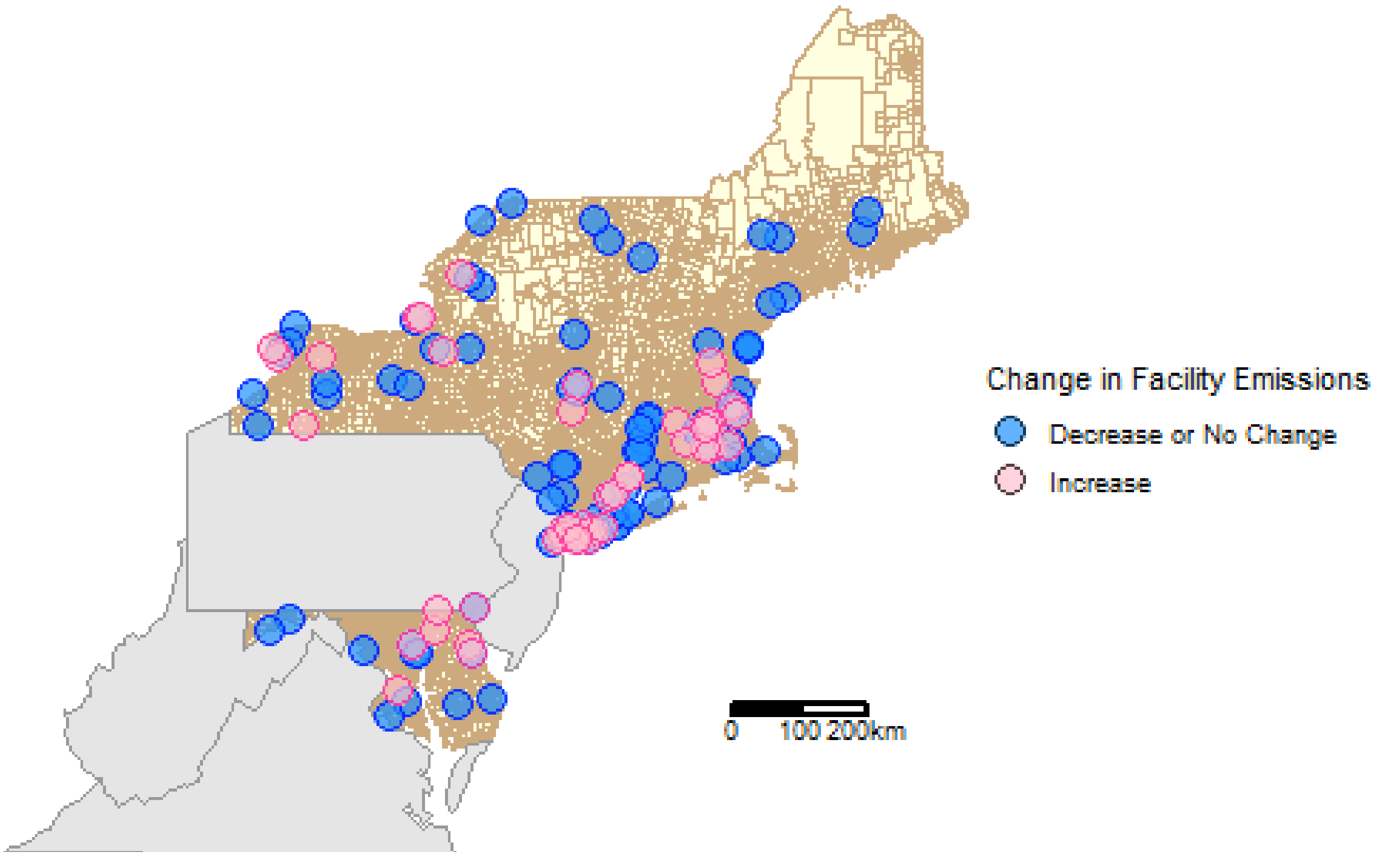

Figure 1. Geographic location of facilities regulated under RGGI.. Pink dots (n = 43) represent the location of facilities that increased their annual emissions during 2011 – 2019 in comparison to 2000 – 2006. Blue dots (n = 105) represent a facility that did not experience an increase in emissions over the same period. The map background represents the outlines of block groups as established by the 2000 U.S. Decennial Census.

3.3 BLOCK GROUP DEMOGRAPHICS IN HOTSPOTS VARY BASED ON DISTANCE FROM A FACILITY

In response to research question (3), 'What are the demographic characteristics of block groups located in hotspots?'; the demographic characteristics of block groups located in hotspots vary based on distance from a facility. For all block groups located within 1 mile of a facility (n = 1264), block groups that experienced an increase in emissions, as compared to those that did not, had statistically significant differences in medians at the 0.05 alpha level in the hypothesized direction for the proportion of black residents, residents of color, and households below the poverty line, partially supporting hypothesis 2 (Table 3). While the proportion of residents with less than a college degree was statistically significant, the difference was not in the hypothesized direction. The differences for all other variables were not statistically significant (Table 3).

Table 3. Characteristics of U.S Census block groups that experienced an increase in average aggregate emissions from regulated facilities within 1 mile after (2011-2019) as compared to before (2000–2006) implementation of RGGI.

Characteristics	CO2 emissions increased (n = 439 BGs; n = 641,390 people)[1]	CO2 emisisons did not increase (n = 825 BGs, n = 1,054,299 people)[1]	p-Value[2]
Median (IQR) percent black	4.12 (1.32 - 10.44)	2.73 (0.73 - 14.50)	0.011
Median (IQR) percent people of color	25.74 (7.67 - 45.73)	14.06 (4.43 - 50.92)	<0.001
Median (IQR) percent less than highschool education[3]	20.25 (11.03 - 32.91)	19.47 (10.71 - 33.10)	0.734
Median (IQR) percent less than college education[4]	77.74 (57.59 - 86.80)	80.35 (65.59 - 89.62)	<0.001
Median (IQR) household income ($)	40,215 (29,352.5 -54,762)	39,389 (27,853.25 -55,661)	0.733
Median (IQR) percent households below poverty line	13.22 (6.57 -24.33)	10.36 (5.01 -24.70)	0.04
Median (IQR) percent households linguistically isolated[5]	5.03 (0.26 -12.02)	3.25 (0.00 -11.69)	0.11

[1] Based on geographic census block groups. Block group dempgraphics were obtained from the U.S. 2000 Decennial Census.

[2] Two-tailed Mann-Whitney-Wilcoxon tests.

[3] Percent of residents older than 24 years without a high school education.

[4] Percent of residents older than 24 years without a college education.

[5] Percent of population living in households where no one above age 13 speaks English very well.

BG, census block group; IQR, interquartile range.

For all block groups located within 2.5 miles of a facility (n = 5,103), block groups that experienced an increase in cumulative emissions, as compared to those that did not, had statistically significant differences in medians at the 0.05 alpha level in the hypothesized direction for the proportion of residents of color, households below the poverty line, and linguistically isolated households, partially supporting hypothesis 2 (Table 4). While the proportion of black residents and residents without a college degree were also statistically significant, the differences were not in the hypothesized direction. The differences for all other variables were not statistically significant (Table 4). At both the 1-mile and 2.5-mile radii, the proportion of residents of color and households below the poverty line were found to have statistically significant differences in medians indicating that these groups are more likely to be located near hotspots and have greater exposure to co-pollutants.

Table 4. Characteristics of U.S Census block groups that experienced an increase in average aggregate emissions from regulated facilities within 2.5 miles after (2011-2019) as compared to before (2000–2006) implementation of RGGI.

Characteristics	CO2 emissions increased (n = 2,098 BGs; n = 2,643,260 people)[1]	CO2 emisisons did not increase (n = 3,005 BGs, n = 3,849.558 people)[1]	p-Value[2]
Median (IQR) percent black	3.83 (1.20 - 15.06)	4.26 (1.00 - 25.00)	0.031
Median (IQR) percent people of color	24.41 (9.15 - 55.04)	20.79 (5.84 - 61.81)	0.003
Median (IQR) percent less than highschool education[3]	20.13 (10.05 - 36.21)	20.90 (10.28 - 35.23)	0.781
Median (IQR) percent less than college education[4]	78.16 (57.98 - 88.05)	80.68 (65.22 - 89.93)	<0.001
Median (IQR) household income ($)	41,607 (28,155 -60,054)	40,261 (27,424.75 -59,235.25)	0.265
Median (IQR) percent households below poverty line	12.50 (5.48 - 26.53)	11.29 (4.90 - 24.92)	0.021
Median (IQR) percent households linguistically isolated[5]	5.08 (1.23 - 15.46)	3.76 (0.78 - 11.72)	<0.001

[1] Based on geographic census block groups. Block group dempgraphics were obtained from the U.S. 2000 Decennial Census.

[2] Two-tailed Mann-Whitney-Wilcoxon tests.

[3] Percent of residents older than 24 years without a high school education.

[4] Percent of residents older than 24 years without a college education.

[5] Percent of population living in households where no one above age 13 speaks English very well.

BG, census block group; IQR, interquartile range.

4. DISCUSSION

The results of this research indicates that (1) census blocks near facilities regulated under RGGI have higher proportions of non-white residents, low educational attainment, poverty rates, and linguistic isolation than those further away (statistically significant at the 0.05 level); (2) localized pollution hotspots have formed as 29% of facilities have continued to increase their emissions despite an annual lowering of the emissions cap; and (3) while the demographic characteristics of block groups located in these hotspots are variable, at both the 1-mile and 2.5-mile radius from a facility, block groups are found to have a higher proportion of residents of color and households below the poverty line (statistically significant at the 0.05 level). Given a high correlation exists between CO_2 emissions and emissions of local air pollutants, these results raise serious environmental equity concerns regarding the health of communities of color and low-income located in RGGI states (Cushing et al., 2018; Dedoussi et al., 2019). While these results are not as comprehensively indicative of neighborhood disparities as compared to the results of Cushing et al., which found neighborhoods in hotspots more likely to have higher proportions of residents of color, higher rates of poverty, lower educational attainment, and higher linguistic isolation, the findings for RGGI still warrant concern and call for policy solutions.

One such solution could be to create geographic grading zones, where emitters located in certain areas based on demographics are allotted a stricter limit on the amount of emissions permits they may purchase (Farber 2012). A second solution is to impose a ceiling on individual emitters. Under current RGGI operating procedures, a single emitter is not limited in the amount of greenhouse gas emissions they can emit, only the total pool of permits is set (Farber 2012). However, these proposed solutions have only been theorized to work as they have never been implemented in a real-world setting.

An important adaptation RGGI could implement is a collaborative management practice that enables clearer steps for public comment and more frequent periods of review. Given the finding that at the 2.5-mile radius, neighborhoods are more likely to be composed of linguistically isolated households, it would also be important for RGGI to provide informative materials in multiple languages to increase accessibility and ease of public engagement. By incorporating more community voices into review periods, a more effective remediation plan is likely to be found.

When compared to other climate mitigation options such as a carbon tax, the same risk for pollution hotspots and social inequities exists. By being the nation's first carbon cap-and-trade mechanism and direct effort to slow climate change, RGGI has the unique opportunity to address these injustices and provide an improved model for other states or the federal government as they look to adapting their own climate mitigation policies.

Amidst the current political backdrop, where coronavirus has highlighted more than ever the social disparities that exist in the U.S.'s healthcare system and the Black Lives Matter protests have forced the nation to bear witness to the racially unjust treatment of African Americans by the police, it is vital more than ever that climate change is not just mitigated but done so in a manner that does not add to the burdens faced by those of color, minority status, or low income.

In summary, this analysis reflects local CO_2 emissions and social equity patterns for the first 10 years of RGGI. One limitation to this analysis is the lack of measurement of co-pollutants directly from the regulated facilities. Thus, this analysis had to rely on the assumption that CO_2 emissions were positively correlated with co-pollutant emissions. While this correlation is well established, knowing the exact ratio that CO_2 and certain co-pollutants are emitted at could provide more informative insights into the health consequences experienced by residents located in pollution hotspots. Future studies could utilize modelled co-pollutant emissions from the U.S. EPA's Co-Benefits Risk Assessment which can provide neighborhood level estimates of particulate matter concentrations (Perera et al., 2020).

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