Housing, Lead Paint, and Electrification in New York City

Prepared in Partnership with WE ACT for Environmental Justice

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EXECUTIVE SUMMARY

This report, a collaborative effort between the Yale School of Public Health's Climate Justice, Law, and Public Health Clinic and WE ACT for Environmental Justice (WE ACT), examines the intersection of climate change, electrification, lead exposure, and health equity in New York City (NYC).

Due to NYC's old housing stock (half of all the city's buildings were constructed before 1950), residents who have not experienced a recent renovation can be subject to the compounding disadvantages of energy inefficiency and health hazards like lead and mold.[1] These issues disproportionately affect low-income and minoritized families, highlighting a critical intersection of housing, environmental justice, and health equity. This report focuses on leveraging the clean energy transition and accompanying movement towards all-electric and energy-efficient buildings to advance equitable health outcomes in NYC. By remediating lead hazards prior to electrification upgrades, we can reduce toxic exposures; and by eliminating indoor fossil fuel combustion through electrification, we can improve indoor air quality and overall respiratory health.

Our analysis aims to first identify areas that would benefit most from integrated electrification and lead initiatives, and second to highlight policy levers that can support these efforts. We utilize publicly available environmental and public health data to map different risk factors for lead and indoor air pollutant exposure at the ZIP code level. By standardizing and layering these maps, we then pinpoint specific ZIP codes where lead remediation and electric or energy-efficient upgrades would be most useful. We also review the policy landscape on lead and electrification to highlight programs that WE ACT could capitalize on to target interventions toward the selected ZIP codes. As examples, we highlight Medicaid 1115 waivers and the Weatherization Assistance Program as ways to prioritize apartments with lead contamination on easy-to-access surfaces like windows.

Building electrification provides an invaluable opportunity to simultaneously reduce climate-warming emissions, improve indoor air quality, decrease energy bills, and remove toxic home hazards. However, if electrification incentives and programs are not implemented with an environmental justice lens, we risk leaving communities that could benefit most from these improvements behind. Through this report, we hope to provide insight into where electrification and lead remediation could yield the greatest public health gains in NYC and achieve a more equitable, sustainable, and healthy future.

INTRODUCTION

This report, conducted in partnership with WE ACT for Environmental Justice (WE ACT), examines the relationships between climate change, electrification, lead exposure, and health equity. We map known lead, energy efficiency, and health indicators in New York City (NYC), analyze the associations between these indicators, and identify areas that would particularly benefit from place-based policy interventions towards health-maximizing energy efficiency and.

Climate Change, Electrification, and Weatherization

Electrification broadly refers to the process of replacing fossil fuel-based systems with electrical ones.[5] Examples include converting oil-burning furnaces to heat pumps, or transitioning gas ranges to electric stoves. Fossil fuels are the primary source of energy across the globe and are responsible for around three quarters of all anthropogenic carbon emissions,[6] making electrification a key solution to climate change and its health hazards. Although fossil fuel-derived electricity production does emit greenhouse gas emissions, NYC has pledged to reach 100% renewable energy by 2040, making electric appliances significantly more climate-friendly than fossil fuel-based ones over the long-term.[7]

Electrification often goes hand-in-hand with weatherization and energy efficiency, both of which can reduce electricity demand and its associated carbon emissions. Weatherization, which refers to home improvements like insulation that protect against outside temperatures and precipitation, is often the first step in electrification upgrades – as of 2022, 24% of U.S. electrification incentives required weatherization prior to electrification, and 50% encouraged it.[8] Energy efficiency can occur through both weatherization, which reduces the amount of energy required to heat and cool homes, and also through electrification, which can replace old appliances with new and efficient ones. In fact, transitioning old technologies to energy-efficient electric home systems may reduce greenhouse gas emissions so much that this transition alone could offset projected emissions increases from climate change-induced electricity demand.[9]

NYC's dense population and seasonally cold climate (and consequent heating demands) make building decarbonization vital to achieve climate change mitigation goals. This is especially true of residential areas, as NYC's housing sector is

accountable for 52.9 million metric tons of CO_2 each year.[10] In the winter, buildings account for 75% of NYC's energy consumption[10] as demand for space heating surges, which is typically provided by oil or gas boilers.[11] Studies have shown that substituting gas heating systems for electric heat pumps can reduce peak energy demand from 21,500 MW to 5800 MW by avoiding the inefficiencies and heat losses of fossil fuel-based systems.[10]

Electrification & Health

In addition to building electrification's environmental benefits, transitioning away from fossil fuels can improve public health. Gas-burning appliances like boilers and stoves emit harmful pollutants including benzene, carbon monoxide, and nitrogen oxides, which can accumulate indoors without proper ventilation.[12–14] Both boilers and stoves have also been shown to leak methane, sometimes continuously, even when they are not in use.[15,16] Gas stoves in particular have been linked to a 42% increase in childhood asthma risk, with the World Health Organization, U.S. Environmental Protection Agency, and American Medical Association high-lighting connections between gas stoves, indoor nitrogen dioxide, and respiratory harms.[17–20]

Fossil fuel-based appliances also contribute to outdoor air pollution, with over 10% of total U.S. greenhouse gas emissions attributable to natural gas combustion in buildings.[21] The outdoor particulate matter (PM2.5) generated by fossil fuel appliances in U.S. buildings is estimated to cause around 6,000 premature deaths per year, in addition to thousands of nonfatal asthma attacks, heart attacks, and other pollution-induced illnesses.[22]

Last, electrification upgrades can improve health outcomes through increased energy efficiency and hazard remediation. Pre-electrification building envelope improvements like air sealing can help reduce moisture infiltration, limit mold growth, and prevent pest invasion, thereby reducing common respiratory triggers.[23] Additionally, major home renovations often require prior remediation of hazards like lead and asbestos, creating compounding benefits of improved air quality and toxics remediation when implemented.[24]

By converting to all-electric household appliances, NYC can dramatically reduce both indoor and outdoor air pollution, and improve health outcomes for all. While the City has already taken strides to reduce fossil fuel combustion in buildings by setting ambitious greenhouse gas reduction goals for buildings in Local Law 97, and phasing out fossil fuel combustion in new construction through Local Law 154, these policies are less likely to benefit low-income communities and communities of color, who often cannot afford new and efficient housing.[25,26] As such, targeted electrification programs are necessary to ensure an equitable distribution of benefits from the transition away from fossil fuels.

Lead Paint & Health

Lead is an extremely toxic heavy metal that poses a major environmental and health hazard; despite awareness of its toxicity, it remains in homes and buildings to this day, with half of all Americans estimated to have been exposed to adverse levels as children.[27] Lead's numerous health effects negatively impact nearly every system in the body, leading to adverse health outcomes such as hypertension, anemia, and cognitive decline.[28] It is of particular danger to children, given that children absorb higher levels of lead through age-specific respiratory and metabolic processes,[29] are more likely to ingest paint chips due to hand-to-mouth behaviors common in young life stages,[30] and are still undergoing substantial neurological development.[31] There are several potential routes of exposure to lead, with two of the most common being lead paint and lead dust, as lead paint was used in many homes before 1978.[28] The EPA estimates that 87% of homes built before 1940 contain some amount of lead paint,[32] and there was a lead paint violation for 58 out of every 1,000 NYC buildings between June 2020-March 2023.[33] In 2004, NYC passed Local Law 1, which requires landlords to identify and fix lead paint hazards in buildings.[34] Despite this law and variety of ensuing local laws which expanded on and augmented lead remediation practices, 133,372 lead paint violations were issued in NYC between 2018 and March 2023.[33]

Nationally and locally, there are vast inequities in exposure to lead. Communities of color, low-income, and urban residents are at far greater risk of lead exposure and its related health outcomes[35] due to a variety of factors such as residential racial segregation,[36] occupational exposures, and age of housing stock.[35] Black children have higher blood lead levels than white children nationally, as do those with lower incomes and education levels.[37] Additionally, those who rent instead of own their homes have fewer options to investigate and remediate lead in apartments and buildings, and may face retaliation against complaints submitted;[38] this is especially important, given that 30% of renter-occupied units were found to contain lead-paint based hazards, as compared to 23% of owner-occupied units.[39]

Current U.S. EPA standards for lead include 400 ppm for lead in play area soils, 15 µg/L for public drinking water, and 0.15 µg/m3 in the ambient air.[40] However, there is no 'safe' blood lead level35 or levels of lead exposure[41] – the U.S. CDC notes that even low levels of child blood lead levels can cause neurological defects that impact long-term academic achievement and intelligence.[42] In July 2023, the EPA proposed revisions to the Hazard Standards and Clearance Levels for Lead in Paint, Dust and Soil by the EPA that would lower hazard standards for lead dust to anything above zero.[43] While this is promising, lead hazards must be found and identified in order to comply with these regulations and before they can be fixed.[38] One way to identify and remove lead hazards could be through the process of home hazard remediation prior to home energy efficiency or electrification retrofits, and the process of considering them concurrently, as examined in this report, provides great potential for both health improvements and cost savings.

Lead, Electrification, and Equity

Structural racism embodied in historic policies and current inequitable processes create racially segregated neighborhoods with disparate health outcomes that persist to this day in NYC.[44] A prominent example of a practice that has historically contributed to geographic inequality is "redlining", which refers to maps created by the federal housing agency Home Owners Loan Corporation (HOLC) in the 1930s.[45] These maps ranked the financial risk of investing in neighborhoods based on racial composition, rating predominantly African American areas as "D," or undesirable. Map ratings discouraged mortgage lending and investment in redlined communities, resulting in reduced environmental health, economic opportunity, and housing quality for African Americans.[46] Studies have shown that even today, street-level air pollution is worse in historically redlined NYC neighborhoods than in historically white neighborhoods.[47]

In addition to legacies from redlining, gentrification – the process where lower-income residents are displaced by wealthier people moving into their neighborhoods – has also increased racial segregation in NYC, while City policies around affordable housing have helped maintain it.[48,49] All of these racialized

processes have created place-based inequalities that influence health disparities today, including access to good-quality housing.

Regarding housing quality, indoor air pollution is worse in residences with old, inefficient, and unmaintained appliances, as well as in smaller homes where pollutants are more prone to accumulate at higher concentrations.[15] Older poor-quality homes are also more likely to have sources of lead exposure like lead pipes or lead paint.[31] Compounded on home exposure are disparate environmental threats due to the disproportionate siting of polluting power plants, waste treatment sites, and bus depots in parts of NYC where minoritized communities have historically lived.[50] The health of those residing in these neighborhoods is not only affected by housing and environmental exposures, but also through upstream structural limitations to accessing the skills and knowledge needed for higher income potential.[51] An example of economic disenfranchisement exists in the systemic closure of essential facilities like hospitals within redlined areas.[51] This strategic disinvestment limits access to healthcare services while simultaneously restricting employment opportunities, reducing the economic capacity of the area and personal socioeconomic mobility.[52]

Unhealthy housing is an environmental justice issue that we can address through equitable electrification and lead remediation. In 2022, the Inflation Reduction Act was signed into law, which allocates $8.8 billion in rebates towards home electrification and home energy efficiency projects.[53] As a result, various federal, state, and local governments have instituted programs and policies that aim to actualize these improvements. However, programs such as the Weatherization Assistance Program (WAP) do not serve homes burdened by severe conditions that deem them unsafe or ineffective to weatherize such as moisture, electrical issues, and environmental contaminants like lead.[54] Therefore, in order for programs to bring about meaningful improvements to housing quality, there must be a structural recognition of the need to pre-weatherize homes (prepare them for the weatherization process) through leveraging existing programs to extend funding and workforce to these efforts. To understand the mechanisms by which low-income and minority households face adverse health outcomes from lead exposure and pollution-intensive energy sources, we investigated the correlation between factors associated with lead, electrification, and health, as well as identified the geospatial areas which face the heaviest burdens. Our findings begin to delineate the spatial distribution of these relationships and provide insights to inform lead remediation and building retrofit priorities.

METHODS

Overview

Broadly, our methods involved:

1. Selecting target variables (eg. demographics, housing age, building energy efficiency) for analysis
2. Standardizing all variables and summing them to create aggregate maps highlighting NYC ZIP codes that could most benefit from targeted intervention programs
3. Creating a policy database and extracting programs that could be best leveraged to support electrification and lead remediation

Spatial Scale

A major component of our analysis is spatial representation of lead exposure, health indicators, and socioeconomic variables across NYC to identify areas best suited for electrification intervention. We chose to use ZIP code and ZIP code tabulation area (which map onto each other exactly in NYC) as our primary unit of analysis because many data points we were interested in, such as elementary school test scores, were only available at the ZIP code level.[55] ZIP codes were not our first unit of choice due to the well-known issue of their being designed for mail delivery rather than population data analysis.[56] We considered cross-walking ZIP code variables to census tracts but ultimately decided against this due to both time constraints and accuracy concerns – crosswalking from ZIP codes to census tracts in highly populated areas like NYC can yield inaccuracies because ZIP codes will cut across multiple census tracts (e.g., one NYC ZIP code incorporates segments from 46 different census tracts).[57]

Quantitative Analysis

We ran linear regressions on different combinations of variables (eg. eviction rates and lead paint violations) to look for correlations and identify the most relevant variables to include in our final analysis. For the variable of elementary school test

scores, we used a nonlinear model (generalized additive model) to assess the association.

Use of Z-Scores

To standardize and layer the different variables into one cohesive map, we created z-scores for each factor. Z-scores for every variable were calculated by ZIP code using the formula , where x refers to a specific value, is the mean, and is the standard deviation. This takes away scale by calculating how many standard deviations away from the mean any particular value is.[58] We reversed the directionality for indicators that would result in higher risk for lead exposure and energy inefficiency to map onto the 'high' and 'low' levels for other variables (for example, we multiplied median income z-scores by -1 so that low incomes would add correctly onto high asthma rates). All z-scores were summed for aggregate maps to highlight ZIP codes that might yield the greatest benefit from targeted electrification and lead remediation.

Variable Justification

We reviewed existing environmental justice (EJ) indexes to understand which factors are generally considered in EJ analysis, which variables are missing from current EJ resources, and the current data landscape. EJ indexes reviewed included:

- EJScreen (U.S. Environmental Protection Agency)[59]
- Climate & Economic Justice Screening Tool (CEJEST) (The White House)[60]
- Low-Income Energy Affordability Data Tool (U.S. Department of Energy)[61]
- Disadvantaged Communities Criteria (New York State Climate Justice Working Group)[62]

Through our review, we made the following observations:

- **There are no measures of lead exposure beyond building age as a proxy for lead paint.** Given that 80% of all NYC housing units are in buildings constructed before 1974, and over half of all units are in buildings built before 1947, most of the city is at risk of lead paint by the building age metric.[63] We chose to incorporate child blood lead levels in our analysis as an additional measure of lead exposure that might avoid the biasing effects of recent lead remediation in old buildings.

- **Race is underrepresented in EJ indexes, despite racialization being a crucial factor in disproportionate environmental exposures**.[64] Only two of the four EJ indexes incorporate race, and only the New York State Disadvantaged Communities Criteria includes a racial breakdown beyond simply "people of color." To provide more insight into the specific racial dynamics of inequitable environmental exposures in New York City (NYC), we run multiple analyses by each ethnoracial group.

- While multiple EJ indexes incorporate health burdens like asthma and heart disease, **none of the existing indexes look at cognitive outcomes.** Because lead exposure is linked to poorer cognitive (and academic) performance,[65–67] we decided to investigate elementary school test scores as a possible symptom of lead exposure, in addition to more typically studied health outcomes.

To investigate the combined impacts of lead exposure, energy inefficiency, and fossil fuel combustion in NYC, we chose the following variables for analysis:

- **Sociodemographic Indicators:** Race/Ethnicity and Education Level

- **Measures of Lead Exposure:** Recent Lead Paint Violations, Child Blood Lead Levels, and Housing Age

- **Housing Health:** Energy Efficiency Ratings, Housing Maintenance Code Violations, and Air Quality

- **Economic Indicators:** Displacement Risk, Eviction Risk, Median Income, and Rent Burden

- **Health and Cognitive Indicators:** Cardiovascular Disease, Asthma, Birth Outcomes, and Elementary School Test Scores

By examining these variables, we hope to understand associations between these indicators and identify areas that might particularly benefit from policy interventions related to lead and electrification.

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Race & Ethnicity*	2021 US American Community Survey (5-Year Estimates): Table B03002 – Hispanic or Latino Origin by Race[68]	Calculated proportion of people of color by dividing number of non-Hispanic white residents by total residents per ZIP code, subtracting from one, and multiplying by 100.	Racial and ethnic disparities in child blood lead levels, household energy efficiency, and asthma outcomes persist to present day.[37,69–71] Incorporating racial demographics into this study is vital to understanding the populations most impacted by lead exposure and energy inefficiency.
Education Level	2021 US American Community Survey (5-Year Estimates): Table S1501 – Educational Attainment[72]	Calculated proportion of each level of education (less than high school, Associate's, Bachelor's, graduate degree) by dividing number of residents at each level by total residents.	Educational attainment is a well-known factor in overall income level, with all educational levels above Associate's degree earning above the U.S. median wage.[73] Because of its impacts on opportunities and wealth, as well as its role as a social determinant of health,[74] educational attainment could impact both exposure and adaptation to lead and air quality hazards.
Recent Lead Paint Violations*	NYC Open Data: Recent Lead Paint Violations[75]	Filtered by those which occurred in 2022, then summed the total count for each ZIP code	This is an incomplete measure of lead, given these were violations issued to rental units by the Department of Housing Preservation and Development, which have been determined to violate local housing codes or laws, which required multiple steps of lead testing and inspection before documentation. However, it does provide insight into areas with high lead presence without relying on lead poisoning data.

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Child Blood Lead Levels*	NYC Environment and Health Data Portal[76]	Data was crosswalked to ZIP code and census tract level from an NTA spatial scale	This is an incomplete measure of lead, given that there is bias in testing rates across the city. However, it does provide important insight into the demographic (children) most affected by lead poisoning and exposure in NYC.
Housing Age	Primary Land Use Tax Lot Output (PLUTO) – City of New York[77]	Data was compiled to a ZIP code spatial scale from individual lots.	This represents the indicator of lead contamination by the federal government, with any pre-1978 building being suspected of having lead paint unless total lead remediations were performed. This data also can act as a proxy for energy inefficiency with older homes tending to have less insulation, older appliances, etc.
Energy Efficiency Ratings*	NYC Department of Buildings Sustainability Compliance Map[78] (This data comes from the NYC Department of Finance, the US EPA's Portfolio Manager, and grading metric based on Local Law 95 of 2019)	Data was compiled to a ZIP code spatial scale from individual buildings.	This represents an indicator of energy efficiency in homes. This data might be biased given that it includes all buildings and not merely residential homes, but it remains a very good indicator of energy efficiency in NYC.

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Housing Maintenance Code Violations	NYC Open Data: Department of Housing Preservation and Development (HPD)[79]	All housing violations with descriptions including keywords related to weatherization (e.g., mold, lead, lead-based paint, lead paint leak, water damage, damp, dampness, electric, wiring, outlet, insulation, broken or defective window, broken or defective roof, broken window, defective window, defective roof, broken roof) were kept and the rest of the violations were cleared. Variables were created for the following violation categories: mold, water leak, energy inefficiency, electrical issue, and lead. An additional variable was created for all violations within this subset designated 'Class C', meaning immediately hazardous.	Housing maintenance code violations may be a valuable proxy for housing health. An understanding of the spatial distribution of various violations may help determine where weatherization efforts should be targeted.
Air Quality	EJSCREEN tool from the U.S. Environmental Protection Agency (EPA)[124]	Data was collected in the whole country by census tract and then subset to New York City. Data was crosswalked to the ZIP code from the census tract.	This represents the ambient annual average PM2.5 and ozone pollution exposure in New York City. An understanding of this could help target areas that are already exposed to ambient air pollution and address the indoor lead exposure in the targeted neighborhood first.

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Displacement Risk (external index)	Equitable Development Data Explorer (NYC Department of City Planning)[80]	Data was compiled from several different sources by this site before download, before it was crosswalked to the ZIP code level from an NTA spatial scale	This index compiles data points on various factors related to displacement risk, including % of rental housing, % of rent stabilized housing, % of population below 2x the poverty rate, and more. It was included both to examine the correlation with blood lead levels, as well as highlight those communities which are more at risk of overall displacement due to these intersecting factors.
Eviction Risk*	NYC Open Data: Evictions[81]	Sorted for only evictions which were carried out in 2022, then counted the number of evictions per ZIP code in this year	As noted below, eviction risk is not usually included in existing environmental justice indexes. We included it here to both examine the correlation with blood lead levels, as well as highlight communities most impacted by the stress and health harms of losing their homes.
Median Income*	2021 US American Community Survey (5-Year Estimates): Table S1903 – Median Income in the Past 12 Months[82]	Median income by ZIP code was already provided in the ACS table; converted "250,000+" to "250000" for z-score calculations.	In addition to being a fundamental determinant of health, income disparities are associated with differential lead exposure, energy efficiency access, and asthma outcomes.[83–86]

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Rent Burden	Equitable Development Data Explorer: NYC Displacement Risk Map, Rent Burden[80]	Compiled the number of 'Severely Rent Burden' households, defined as those spending 50% or more of their income on rent, then crosswalked to the ZIP code level from an NTA spatial scale as part of the 'Displacement Index' dataset	We wanted to examine whether there was any significant association between not only income, but also areas with high areas of rent burden, both in highlighting communities facing stressors related to rent burden as well as its impact on potential displacement.
Cardiovascular Disease	Health Data NY: Medicaid Chronic Conditions, Inpatient Admissions and Emergency Room Visits by ZIP Code: Beginning 2012;[87] Medicaid Beneficiaries, Inpatient Admissions and Emergency Room Visits by ZIP Code: Beginning 2012[88]	All variables were cleared except for 'ZIP Code' and 'Major Diagnostic Category'. Data was filtered to include only NYC ZIP codes and only the rows displaying Diseases And Disorders Of The Cardiovascular System. This dataset was normalized using a Total Medicaid Beneficiaries dataset from the same source.	Air pollution exposure is a notable risk factor for cardiovascular disease.[89] Identifying areas most burdened by cardiovascular conditions may inform the areas in which to direct interventions that improve air quality, such as electrification. This variable was analyzed within the Medicaid population because it was the only identifiable cardiovascular condition dataset at the ZIP code level. Additionally, some of our policy recommendations are most relevant to medicaid beneficiaries.
Asthma Hospitalization Rate*	New York State Asthma Dashboard: Sub-County Data (Revised October 2023) – Sheet AD21[90]	Filtered the dataset for only NYC ZIP codes.	Draftiness in urban areas, indoor air pollution, and mold can contribute to poor respiratory health.[91,92] We include asthma outcomes in our analysis as an indicator for targeting indoor air quality interventions like electrification retrofits.

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Birth Outcomes	New York State County/ZIP Code Perinatal Data Profile - 2018-2020[93]	Created NYC-specific spreadsheet manually by copying data from all relevant counties.	We included ZIP code rates for low birth weight and premature births in our initial analysis due to the association between maternal lead exposure and poor birth outcomes including premature birth, miscarriage, low birth weight, and physical defects.[94]
Elementary School Test Scores*	NYC OpenData 2013-2018 School Math Test Results[95]	Reverse-geocoded school addresses to latitude/longitude using crosswalk dataset created by The City reporting;[96] subset out third and fourth grades for 2013 and 2018; removed rows for students with disabilities due to concerns regarding data skewing (for example, schools specializing in disability could skew the ZIP code average – we believe there are advantages and disadvantages to keeping these students in the dataset, and this is an easily reversible step); averaged all test scores by school ZIP code.	We incorporate elementary school test scores into our analysis as a potential outcome of lead exposure. Child lead exposure is associated with poor academic achievement, including on math and reading standardized tests, and we include elementary school math tests as one of the only publicly available measures of potential lead-impacted academic capability.[97,98]

VARIABLE NAME	DATA SOURCE	DATA CLEANING TRANSFORMATION	RELEVANCE
Heating Fuel Type No. 4 and No. 6	NYC Open Data: NYC Clean Heat Dataset (Historical)	Counted the occurrences of No. 4 and No. 6 fuel types per ZIP code.	The NYC Clean Heat program works to improve air quality and lower energy costs through phasing out No. 4 and No. 6 heating oils and reducing financial barriers to cleaner fuels. We included the areas that have been identified by the NYC Clean Heat program to have heavy oil fuel types to gain a spatial understanding of where retrofits may be most needed.

*Variables we included in our final analysis.

NOTABLE OBSERVATIONS

Before selecting the variables used in our final map, we mapped each variable to New York City ZIP codes and ran regressions on associations of interest (see Appendix A). Below, we highlight associations we found particularly interesting, including some that influenced our final decision:

Figure 1. Housing Age versus Building Energy Efficiency:

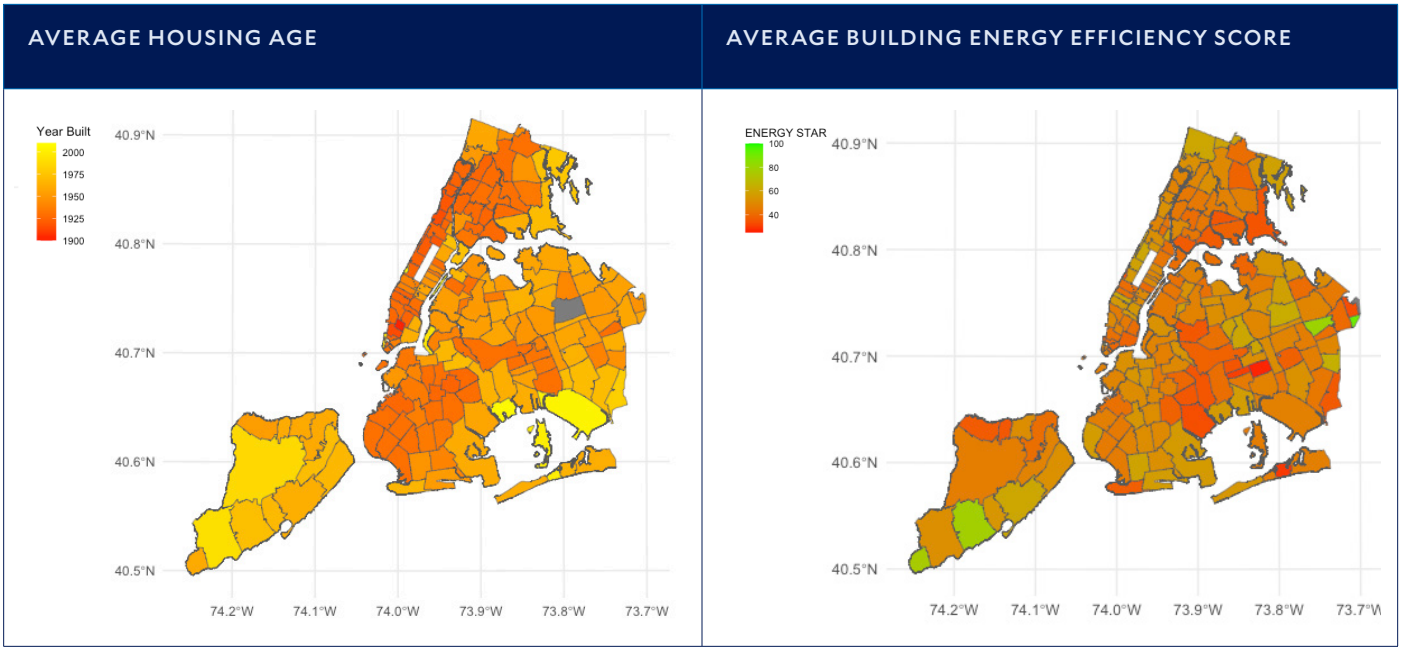


Fig. 1 shows maps of the spatial distribution of housing age and the average Energy Star Scores for energy efficiency in all buildings in NYC on a scale of 0 to 100. We utilized these datasets as an indicator for areas where energy efficiency and electrification measures could offer the greatest benefits, as areas with lower building scores could be targeted for energy efficiency improvements. Of note, New Hyde Park in Queens has the least energy-efficient buildings in the city. While we do not see many substantive trends in energy efficiency in this representation, it does appear that areas with slightly lower energy efficiency (East Harlem and parts of the Bronx) correspond with areas that have higher proportions of Black

and Hispanic residents. Interestingly (and perhaps unsurprisingly), the Upper West Side – a neighborhood that is one of the whitest and most highly educated NYC neighborhoods – has some of the oldest housing stock in Manhattan but also some of the best scores for energy efficiency. This suggests that the Upper West Side may have more newly renovated buildings, and as such, we cannot consider housing age alone as an indicator of lead exposure or energy inefficiency. This is important to consider given the fact that eligibility for many federal protections for lead exposure are based on housing age.

Figure 2. Number of Race and Lead Violations by ZIP Code, 2017-2022

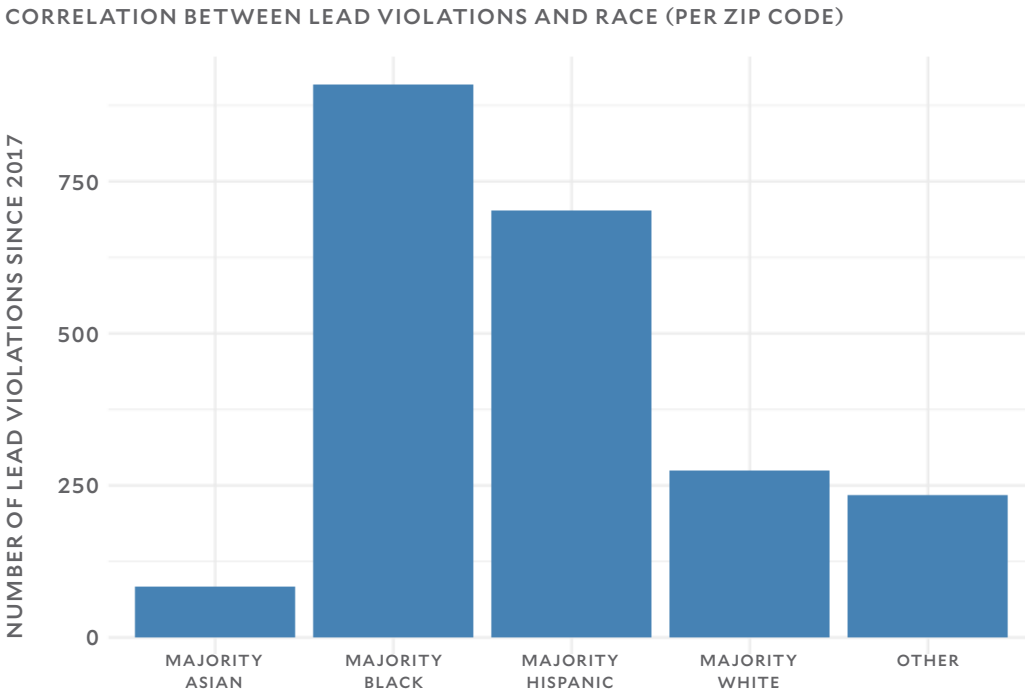
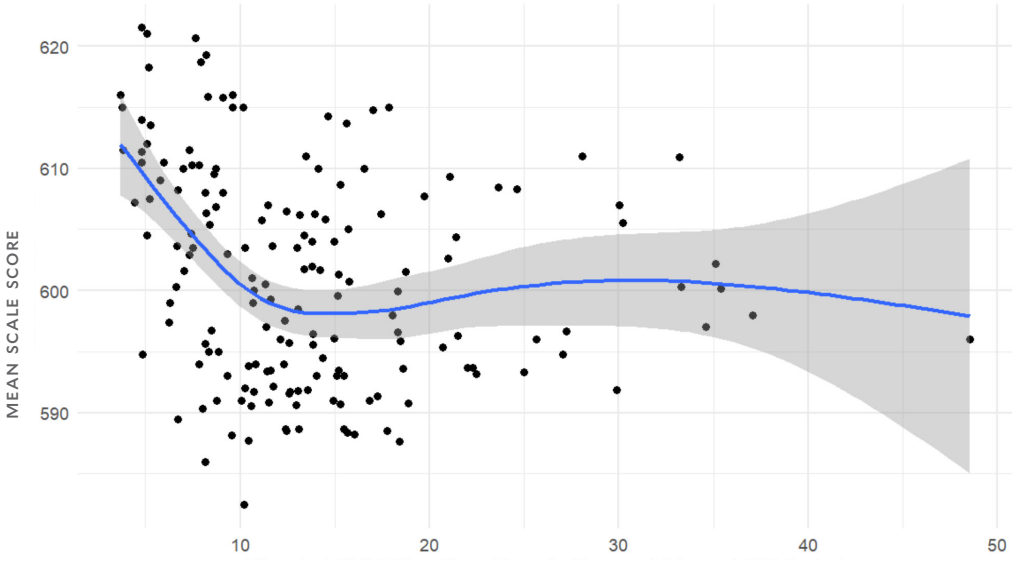


Figure. 2 shows that ZIP codes with majority Black or Hispanic populations experienced the highest numbers of recent lead violations, and that ZIP codes with a majority Asian population experienced the lowest. This figure highlights the limitations of combining all races into one "people of color" variable the way indexes like the EJSCREEN do. Ethnoracial groups experience discrimination and differential exposures in different ways – given this figure, it appears that majority Asian ZIP codes are not threatened by lead the same way as other areas, and therefore may not benefit from inclusion in our analysis.

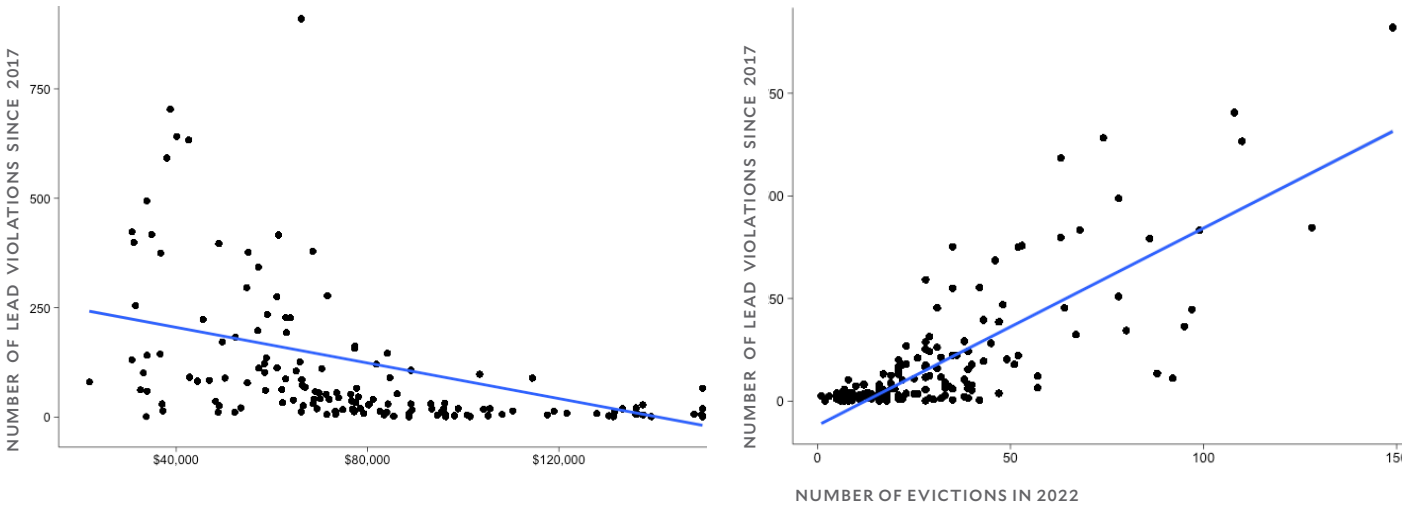
Figure 3. Association Between Lead Exposure and Elementary School Math Test Scores:



* GAM model adjusting for median household income (R square: 0.508, p value:0.00114)

Figure. 3 shows relationships between child blood lead levels and mean math test scores using linear regression, polynomial regression, and generalized additive models (GAM). We calculated Akaike information criterion (AIC) values for the linear regression (AIC = 1105.605), polynomial regression (AIC = 1103.892), and GAM (AIC = 1088.684) models. Given that the model with the lowest AIC is typically considered the "best" model, and an AIC difference of 10 or more suggests a substantial difference in model quality, we selected the GAM model based on it having the lowest AIC value. This indicates an inverse relationship between blood lead levels and children's cognitive abilities indicated by test scores, which is consistent with findings from existing literature.[99] The GAM model results show nonlinear correlations between lead and achievement ranging around 0.5, controlling for income; all of these associations are statistically significant at $p < 0.05$. The relationship appears to be negative at lower levels of lead exposure but remains relatively stable at higher levels.

Figure 4. Correlations Between Lead Violations and Economic Indicators



For each $1,000 increase in median household income, the number of lead violations decreases by 20.3. (R square: 0.1877, p value: < 2.2e-16)

For every additional eviction in a ZIP code in NYC, the number of lead violations increases by 4.8. (R square: 0.615, p value: < 2.2e-16)

Figure. 4 shows correlations between economic indicators and lead violations at the ZIP code level. We observe significant associations between lead violations and both median income and evictions rates (p<0.01), consistent with literature connecting low income to higher lead exposure and unsafe living conditions with increased eviction rates.[85] Interestingly, the correlation between eviction rates and lead violations is much stronger compared to the one between income and lead (R2 of 0.62 compared to 0.19), indicating that eviction rates may be a better measure of lead vulnerability than low income.

SELECTION OF FINAL INDICATORS

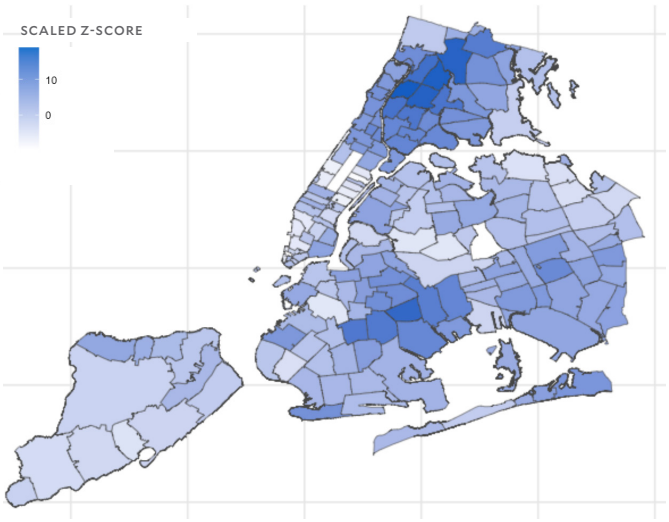
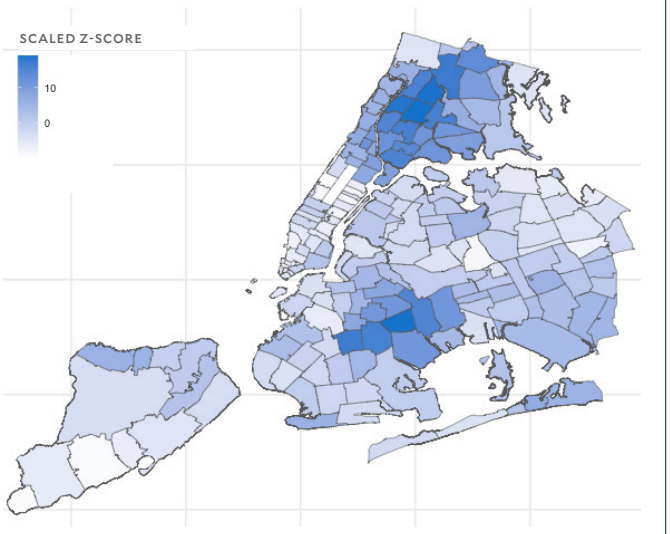
We create two maps for the purposes of this project. The first shows the z-scores of all the variables we looked at combined, and the second shows z-scores of only select variables of highest interest. The variables we included in the select map are:

VARIABLE	JUSTIFICATION FOR FINAL INCLUSION
Percent of Population Identifying as Non-Hispanic Black Percent of Population Identifying as Hispanic	We chose to include only Hispanic and non-Hispanic Black ethnoracial groups in our index since ZIP codes with high proportions of Black and Hispanic folks experienced by far the highest numbers of documented lead violations compared to other ethnoracial groups. Additionally, we chose to add their z-scores together (as opposed to averaging them) for the final maps because Hispanic and non-Hispanic Black residents tend to concentrate in separate areas of NYC (Appendix A) – Hispanic folks are most concentrated in Harlem and the Bronx while non-Hispanic Black residents tend to live in parts of Brooklyn and Queens. Although adding the z-scores weights race higher than the other variables, it avoids the diluting effect of averaging very low and very high numbers from the two groups. It is important to note that including any ethnoracial or linguistic group in this analysis is NOT due to underlying biological mechanisms, but that these groups are disproportionately put at risk due to systemic racism as described above.

VARIABLE	JUSTIFICATION FOR FINAL INCLUSION
Recent Lead Paint Violations	We include recent lead paint violations as a lead exposure indicator instead of housing age because of the issue we noted in Figure 1, where housing age may not be the best indicator for housing factors we typically associate with old buildings, given that most NYC buildings are very old but only those living in wealthier areas will live in better-quality renovated homes. We believe that using recent lead paint violations may provide a more accurate indicator of where lead issues actually exist in NYC, and also adds value to our index given that most other indices only consider building age.
Child Blood Lead Levels	We chose this variable as a direct indicator of lead exposure, and one that is not typically shown in existing environmental justice indexes.
Energy Efficiency Ratings	While we note the limitations inherent to NYC's energy efficiency ratings, we still believe that they provide useful and unique (few other cities have this type of data) insight into areas that could best benefit from weatherization, energy efficiency, and electrification programs, and are particularly relevant to our specific project.

VARIABLE	JUSTIFICATION FOR FINAL INCLUSION
Eviction Risk	Eviction risk, another variable not typically included in existing environmental justice indexes, is a measure of economic stability that is highly correlated with lead paint violations in NYC (Fig. 4). We include it in our analysis to highlight both those communities most impacted by the stress and health harms of losing their homes, and because of a possible relationship between evictions and lead remediation (or lack thereof): when faced with stringent lead abatement policies, some landlords may evict tenants rather than remediate lead.[100] Inspections of unsafe housing conditions in NYCHA buildings have been associated with an increase in evictions, which is consistent with the relationship we observed in Figure 4.[101]
Median Income	We included income in our analysis as a measure of resident ability to remediate lead hazards or move into safer housing (association observed in Figure 4), and also ability to renovate homes with energy efficiency and electrification upgrades.

MAPPING

INITIAL MAP OF ALL VARIABLES	FINAL MAP OF SELECT VARIABLES
	

In creating the final map, we first created z-scores for all variables; several variable scores, notably blood lead level data, were then crosswalked from census tract into ZIP code spatial scale. In order to achieve a comparable scale, with a high z-score indicating a greater risk factor, variables such as educational data and energy efficiency scores were multiplied by -1. The scores were then scaled, using the R "scale" function, and finally summed together to create the maps above. The first includes a visualization of all variables included in this report, while the second is only the variables selected for final analysis based on the criteria noted above; while they are largely similar, there are minor differences, including slightly higher values throughout South Brooklyn in addition to those in the Bronx. See Table 1 of ZIP codes with the highest z-scores, which can be used to identify future geographic priority areas for policy and advocacy interventions. Of the ten highest ZIP codes, seven are in the Bronx (10457, 10458, 10453, 10467, 10456, 10460, and 10468) and three are in South Brooklyn (11212, 11226, and 11203). We thus propose that equitable policy interventions focus on areas such as those identified here which face multiple, overlapping health risk factors such as environmental exposures, adverse outcomes, displacement, and impacts of systemic racism.

TABLE 1. SELECT ZIP CODES BY Z-SCORES

ZIP CODE	PERCENT BLACK POPULATION	PERCENT HISPANIC POPULATION	LEAD VIOLATIONS	EVICTIONS	CHILD BLOOD LEAD LEVELS	MEDIAN INCOME	ASTHMA	ELEMENTARY MATH TEST SCORES	ENERGY EFFICIENCY	TOTAL Z-SCORE
10457	0.98	2.57	3.71	1.62	2.28	1.55	4.00	1.45	0.81	18.98
11212	3.66	-0.59	2.47	4.42	0.70	1.77	2.74	1.39	2.36	18.92
10458	0.06	3.03	4.53	3.56	1.19	1.53	3.69	1.66	-0.49	18.77
10453	0.59	2.83	2.42	1.84	3.15	1.65	3.36	1.54	0.84	18.22
10467	0.87	1.73	4.01	3.65	-0.03	1.42	4.02	1.12	-0.12	16.67
11226	3.07	-0.73	6.06	5.32	0.77	0.72	0.89	0.61	-0.26	16.45
10456	1.43	2.09	2.29	1.62	-0.32	1.76	4.63	0.80	1.40	15.70
10460	0.69	2.67	1.23	2.27	1.03	1.75	3.69	1.75	0.62	15.69
11203	4.26	-1.27	2.41	3.17	2.21	0.86	1.32	0.75	1.91	15.63
10468	-0.07	3.50	4.07	2.10	0.04	1.49	2.95	1.24	0.07	15.39

LIMITATIONS

Spatial and Temporal Scales

As previously noted, ZIP codes were not our first choice for scale, given their primary use in mail delivery rather than population analysis. In fact, for some variables where we had access to high-quality data at both census tract and ZIP code level, our analysis generated insignificant results at a ZIP code level, despite observing significant trends at a census tract level. However, in order to maintain the breadth of data types in our index without resorting to crosswalking, we chose to maintain our analysis at the ZIP code level.

Additionally, many of our datasets were only available over specific timeframes, forcing us to layer data from different years over one another in our maps. As such, one of the limiting assumptions in our analysis is that lead exposure, energy efficiency, and demographic patterns in NYC have remained constant over time, and can therefore be compared across years.

Datasets

While many of the datasets we used have limitations in some form, we pull out a few of note:

- **Energy Efficiency:** This data was limited by issues with data reporting (buildings can receive low scores for administrative reasons that may not reflect true efficiency), and aggregation of commercial and residential buildings, as the data provided did not allow for separation of the two. We still chose to include this variable in our analysis given the importance of understanding relationships between energy efficiency and lead exposure, but acknowledge that any conclusions drawn must take into account these limitations.

- **Student Test Scores:** While we observed a relationship between test scores and lead exposure that could reflect lead's neurotoxic effects on children (even controlling for income), we cannot establish a causal relationship due to many other factors that can impact academic performance and may also be correlated

with lead. We also recognize that standardized tests are not the optimum measure of academic success; they are simply the only measure available to us in quantitative form.

- **Blood Lead Levels:** Areas where child testing is low may not accurately reflect levels of lead poisoning present in a community.

- **Lead Violations:** Mapped lead violations were only issued in rental units where lead was both inspected and identified. Given the relative invisibility of lead hazards[38], the number of lead violations may therefore not capture the prevalence of lead that is currently unknown, unreported, or uninspected.

Z-Scores

Our use of z-scores to create our final maps resulted in all variables being weighted equally, with the exception of the ethnoracial group, which was weighted twice – once for Hispanic residents and once for non-Hispanic Black residents. This choice is inherently limited, given that some measures are undoubtedly more important than others regarding lead and housing quality harms.

POLICY LANDSCAPE OVERVIEW, OVERLAPS, AND FUNDING MECHANISMS

There are numerous state and federal laws and regulations supporting lead remediation and electrification separately, but little explicit overlap in connecting these two initiatives, despite their complementary goals and processes. However, connecting this work could serve to decrease a wide variety of adverse health outcomes, improve the spread of lead testing, and increase electrification in a more cost-effective manner. There are several areas in which synergies exist, including workforce development and training, as well identifying and prioritizing housing components for both lead and electrification processes. In lead abatement and mediation, there is necessarily a set of regulations and certifications required for those doing this work; most notably, contractors working in pre-1978 must be Lead Renovation, Repair, and Painting (RRP) certified by the EPA. However, the federal Weatherization Assistance Program (WAP), which aims to lower costs and support homeowners with electrification work, does not currently require those doing electrification work to be RRP certified.[102] Given the overlap between pre-1978 buildings and targets for electrification, workforce training and funding could be provided to ensure those working on electrification projects are able to identify and remediate lead, which could also expand the number of companies and individuals available to conduct electrification work in pre-1978 buildings.[103] State and Federal policies could also promote and increase the consideration of lead hazards, such as replacement of old windows, when identifying target areas or buildings for electrification.[103] The lead paint and dust levels of windows is the highest among all other building components;[104] these could be remediated or replaced during common electrification procedures such as the installation of window heat pumps, 30,000 of which are planned to be installed in NYC public housing.[105]

Prioritizing potential lead-contaminated buildings for electrification would also provide economic benefits for homeowners and the city more broadly. One study estimated a modeled lead remediation intervention would generate between $1.09-1.39 per $1 invested,[103] and electrification provides a myriad of savings through initiatives such as pipe insulation, air sealing, and energy-efficiency improvements.[106] The incorporation of health benefits and subsequent cost savings into investment calculations, especially for communities experiencing disproportionate environmental exposures, can help promote a more equitable identification of electrification priorities, putting first those who would benefit sthe most from these interventions and processes.[104]

Another powerful area for potential collaboration is in the development and implementation of Medicaid 1115 waivers, which are designed to allow states to allocate Medicaid funding to various innovation proposals aimed at improving health more broadly for those enrolled in Medicaid.[107] New York State is currently in the process of a Medicaid 1115 waiver approval process, based on a proposed submitted by a 'Medicaid Redesign Team', which is looking at reducing health disparities made worse by the COVID pandemic.[108] This includes an allocation of $325 million to create Health Equity Regional Organizations (HEROs), made up of a variety of local stakeholders, which would engage with local health departments for the central mission of "Building a more resilient, flexible, and integrated delivery system that reduces racial disparities, promotes health equity, and supports the delivery of social care".[109] While the HEROs would not distribute any funds, they would serve as sites of coordination and research for local health priorities; it could thus be an interesting place within which to situate this work and future interventions, depending on the details of programmatic roll-out. Additionally, there are several examples of other states using Medicaid 1115 waiver funds for both climate-specific devices, such as Oregon, whose waiver is used to provide air conditioners in hot months.[110] Notably, Rhode Island's 1115 Waiver leverages 1115 funding for 'Health Equity Zones', a program similar to HEROs which has, among other outcomes, resulted in a "Reduction in childhood lead poisoning by 44 percent".[111] This funding and implementation technique shows promise for combining the processes of weatherization and lead remediation, as well as providing concrete mechanisms for prioritization of areas such as those outlined above through a lens of health equity.

Deployment and evaluation of equitable policies, especially around climate mitigation, is increasingly supported through federal laws, regulations, and grants. For example, the Justice40 initiative, created by the Biden-Harris administration, states that 40% of federal investments must go towards disadvantaged communities',[112] including the funding provided to a number of state, local, and federal programs.[113,114] However, as noted above, the tool used to define disadvantaged communities for a number of agencies, CEJEST,[115] does not include race in its calculations. A recent study demonstrates that this omission would not decrease racial and ethnic disparities in air pollution,[116] despite the overarching goals of Justice40. While further research is needed to identify the ways in which this would apply to other environmental exposures such as lead, previous studies have identified explicit correlations between race and blood lead levels in children,[117] which was supported in our city-level analysis as well. Excluding race in policy design and analysis ignores the ongoing impacts of systemic racism on communities of color;[118] racial and ethnic demographics and disparities must be therefore considered in all decisions around resource allocation, lead testing, and prioritizing housing areas for electrification assistance.

FUNDING MECHANISMS

FUNDING NAME	AGENCY IN CHARGE	APPLICABLE TIME PERIOD	DESCRIPTION
Weatherization Assistance Program	DOE	Ongoing; contact local providers for more information	This grant looks to lower costs for eligible homeowners, renters, and rental property owners through electrification of buildings, homes, or apartments. Along with the electrification work, services also include "mitigation of energy-related health and safety issues", including lead remediation. As discussed above, this program could incorporate lead remediation by placing higher prioritization on common lead hazards, including windows in pre-1978 units.
Medicaid 1115 Waivers	CMS	Ongoing; CMS approval pending	Medicaid 1115 waivers can be powerful tools for funding and implementing strategies to work towards lead remediation and electrification. States such as Rhode Island have used Medicaid 1115 waivers to provide funding for projects related to increased lead testing (RI 1115 Waiver), and a recent Oregon waiver aims to, among other projects, distribute devices such as air conditioners which enable safe living conditions in response to increased climate change[119]. Medicaid can thus be an innovative mechanism for policy development and funding, especially given the variation between states which can inform new ideas and direction.

FUNDING NAME	AGENCY IN CHARGE	APPLICABLE TIME PERIOD	DESCRIPTION
Lead Hazard Reduction and Healthy Homes Program	HUD	Ongoing	This program provides grants for the remediation of lead in buildings to be overseen by the NYC Department of Housing Preservation and Development. Federally, the Department of Housing and Urban Development, in which this program is housed, is working to address the intersection with climate initiatives including electrification and facilitate connections between Lead Hazard Reduction and WAP grantees[120]. They are also working towards the sharing of income eligibility information between lead and electrification project approval processes.
Empower	NYSERDA		This program offers low and moderate income single-family households financial incentives and aid for energy efficient improvements such as insulation, air-sealing, health & safety items, and replacement of inefficient refrigerator appliances. This program recognizes the need to address residential energy inefficiency before contractors are able to introduce larger-scale electrification mechanisms such as heating system upgrades. Lead abatement falls under the health & safety core priority for improvements.

FUNDING NAME	AGENCY IN CHARGE	APPLICABLE TIME PERIOD	DESCRIPTION
Climate Friendly Homes Fund	HCR	Ongoing	The Climate Friendly Homes Fund (CFHF), administered by The Community Preservation Corporation, provides financing for existing, 5-50-unit buildings in New York State with a focus on replacing older and less energy-efficient systems with all-electric, high-performance heating, cooling, and hot water heating systems.
LIHEAP	HHS	Ongoing	LIHEAP funds, while primarily allocated for home energy bills, can also extend to support weatherization assistance. This includes renovations aimed at addressing lead paint hazards. Another mechanism for lead abatement is the opportunity to identify lead during energy audits on a residence.
NYS Clean Heat	NYSERDA		The New York State Clean Heat Program encourages the adoption of efficient electric heating and cooling systems, such as heat pumps, in an effort to reduce emissions. Its relationship with pre-weatherization lies in ensuring buildings are structurally sound and free of issues like leaks before installing these systems. This preparatory phase enhances the effectiveness and safety of the clean heating technologies promoted by the program, aligning with New York's broader energy efficiency and environmental goals.

CONCLUSION

This report outlines the interconnectedness of lead remediation and electrification processes, provides visual and analytic support for prioritization of certain geographic areas, and suggests potential policy mechanisms which could be used to connect these domains. We have noted particularly several ZIP codes in the Bronx and Brooklyn which could be placed as higher priority in both lead and electrification work, due to the prevalence of factors which are highly correlated with high blood lead levels. Many current screening tools for disadvantaged and high-risk communities frequently leave out race and ethnicity in similar analysis; we hope that in including it, we can further demonstrate the need to consider racial demographics to more precisely prioritize electrification and lead remediation in target areas, especially in high-population, diverse neighborhoods as is common throughout NYC. The work of switching to clean energy should be done with equity at the forefront, ensuring some mitigation of adverse health and economic impacts on those who have been and are being subject to ongoing systemic marginalization and discrimination. While many policies exist, their synergies are an underexplored area, especially given the recent influx of environmental funding and federal consideration of equity and justice. The combining of lead remediation and electrification specifically could be achieved in a variety of ways, such as expanding requirements or technical considerations in programs like the Weatherization Assistance Program, leveraging federal funding mechanisms through existing state channels like Medicaid 1115 waivers, or programmatically streamlining eligibility for synergistic programs such as is being considered at the Department of Housing and Urban Development. It will likely involve many small changes, and future evaluation and accountability are necessary to ensure these programs are being implemented effectively and are successful in reducing adverse health outcomes overall, while reducing health disparities based on factors such as race, ethnicity, income, and education level through prioritizing these communities for funding and intervention.

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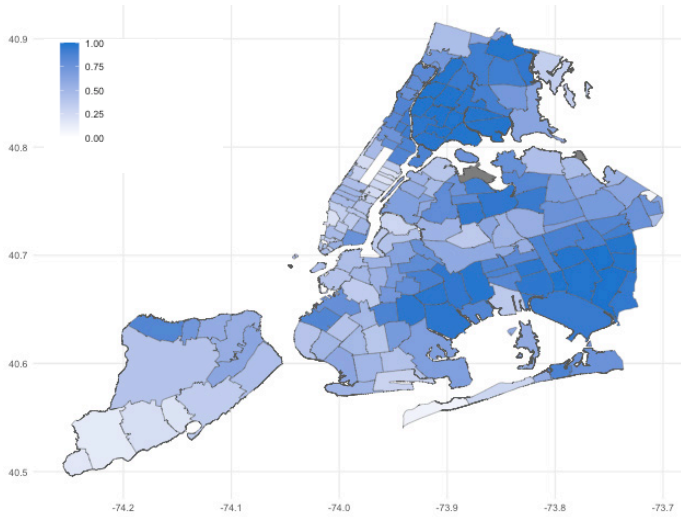
APPENDIX A - INDIVIDUAL VARIABLE MAPS

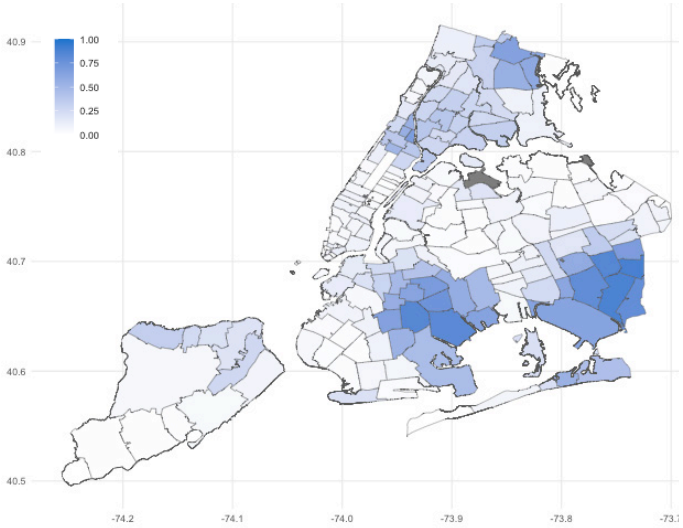
Due to disparate exposure patterns, Black children have higher blood lead levels nationally than do white children, and in 2019, the majority of children with elevated blood lead levels were Black, Asian, or Latino.[121] These maps show the areas of high concentration of people of color (POC) in NYC, broken out by different racial and ethnic groups.

PERCENT OF POPULATION IDENTIFYING AS PEOPLE OF COLOR

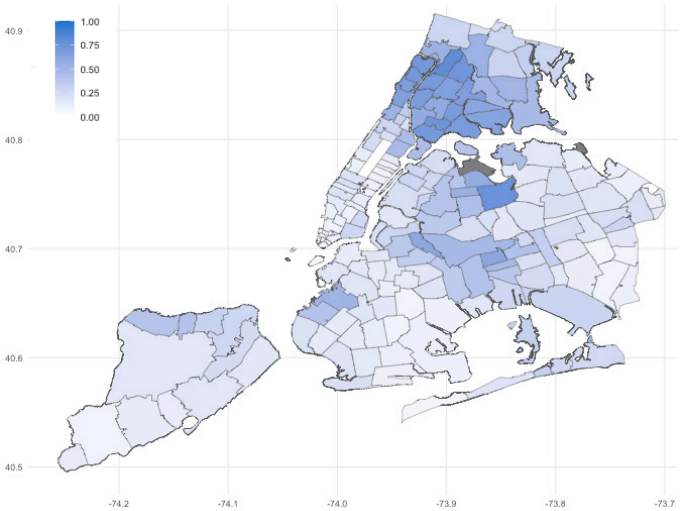


Race/Ethnicity

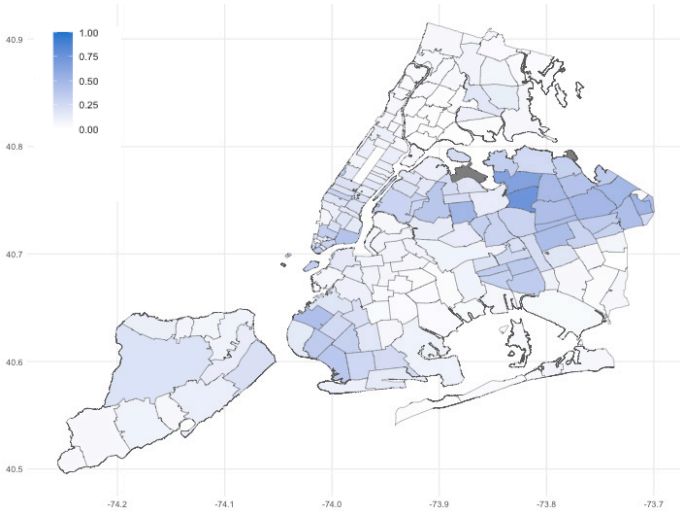
PERCENT OF POPULATION IDENTIFYING AS NON-HISPANIC BLACK



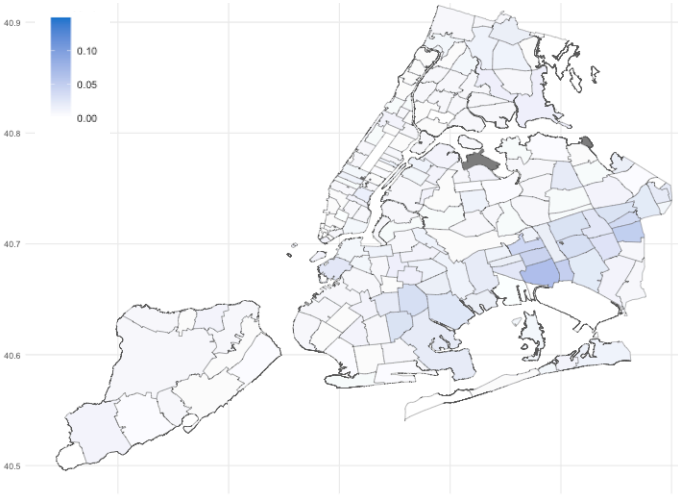
PERCENT OF POPULATION IDENTIFYING AS HISPANIC



PERCENT OF POPULATION IDENTIFYING AS ASIAN

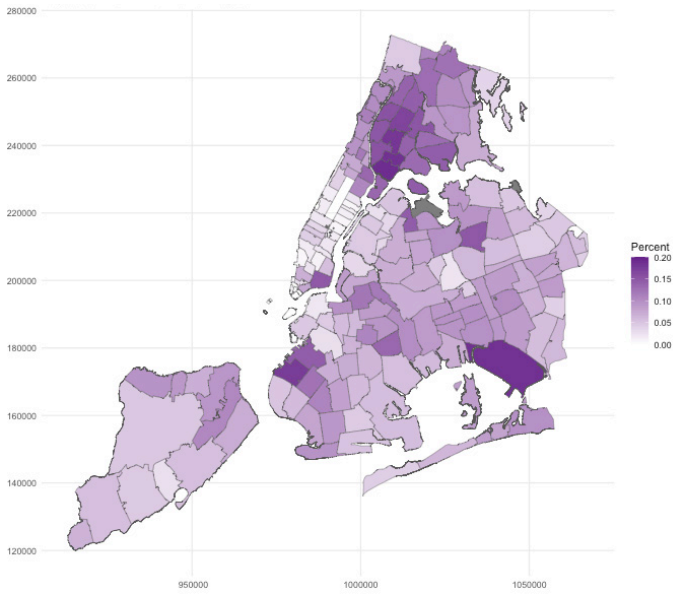


PERCENT OF POPULATION IDENTIFYING AS A DIFFERENT RACE, OTHER THAN WHITE

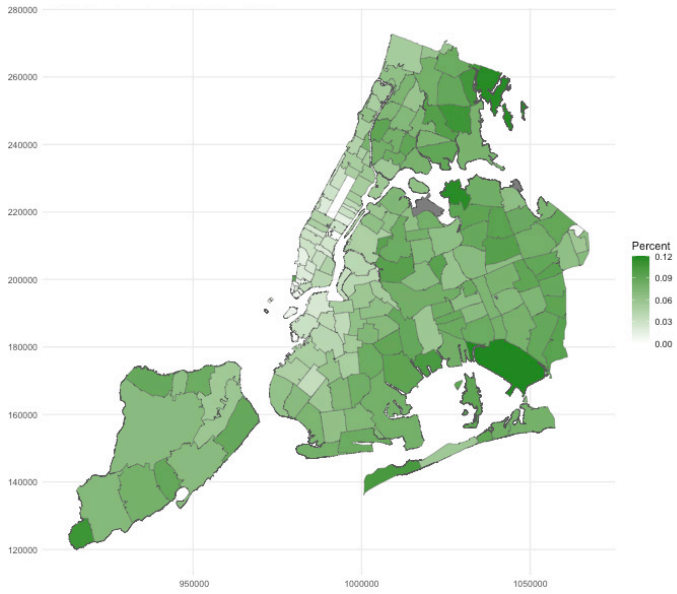


Education Levels

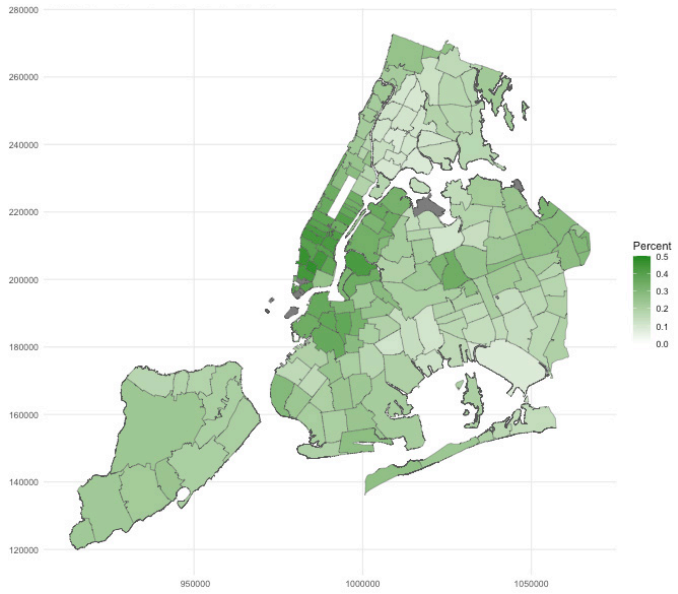
PERCENT OF POPULATION AGE 25+ WITH NO HIGH SCHOOL DEGREE



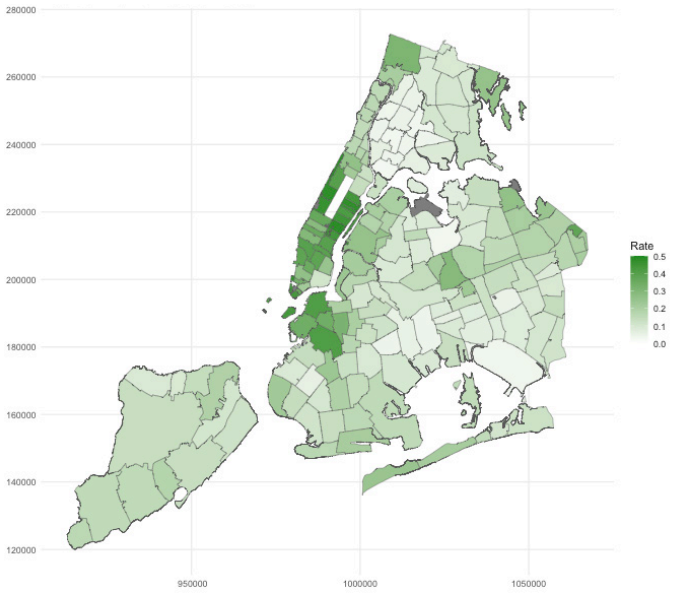
PERCENT OF POPULATION AGE 25+ WITH AN ASSOCIATES DEGREE



PERCENT OF POPULATION AGE 25+ WITH A BACHELOR'S DEGREE



PERCENT OF POPULATION AGE 25+ WITH A GRADUATE DEGREE

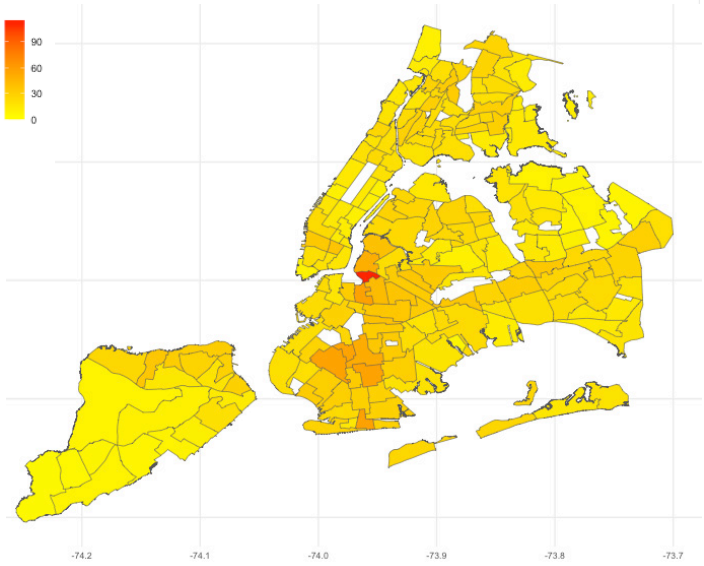


Measures of Lead Exposure

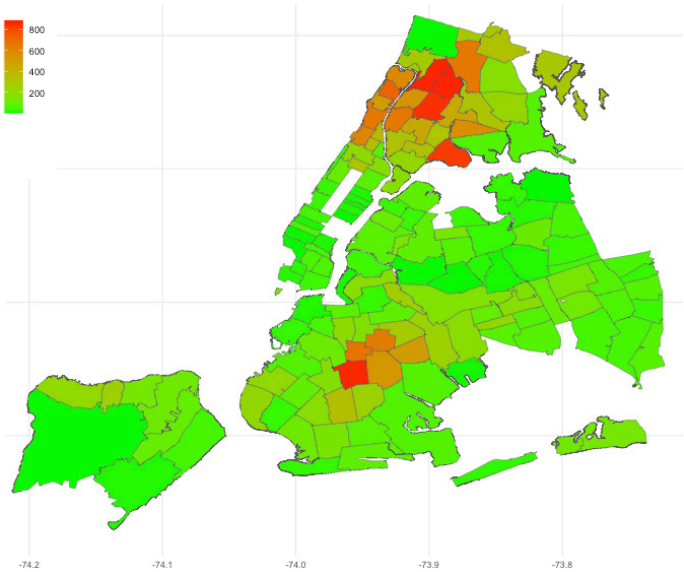
In considering lead exposure, we looked at the following metrics to obtain a holistic understanding of both potential lead presence and measured exposure:

- **Child Blood Lead Levels:** Specifically refers to children under age six.
- **Lead Violations:** These occurred in rental units in 2022, where an inspection determined there was a violation of the New York City Housing Maintenance Code (HMC) or the New York State Multiple Dwelling Law (MDL).[75] We did not adjust for the number of buildings or apartment units.
- **Number of Children Tested:** Widespread testing is essential to understand the severity of the issue and identify exactly where lead is causing the most harm.
- **Building Age:** Building age is a known risk factor for lead exposure,[122] due to its prevalence of lead paint before 1978. We looked at building age to determine whether inequitable lead exposure could still be an issue despite decade-old New York City laws requiring landlords to remediate lead paint hazards in apartments with young children.[123]

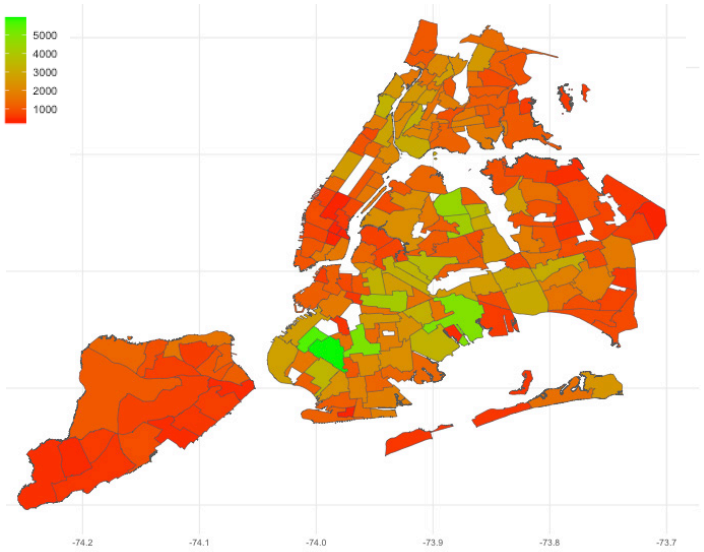
ELEVATED BLOOD LEAD LEVELS IN CHILDREN UNDER AGE 6, PER 1,000 CHILDREN TESTED



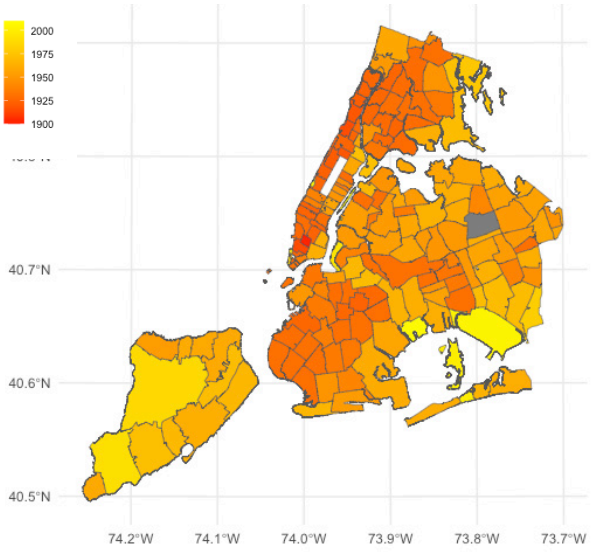
LEAD PAINT VIOLATIONS PER 100,000 PEOPLE



AVERAGE NUMBER OF CHILDREN TESTED PER YEAR



AVERAGE BUILDING AGE



Housing and Air Quality

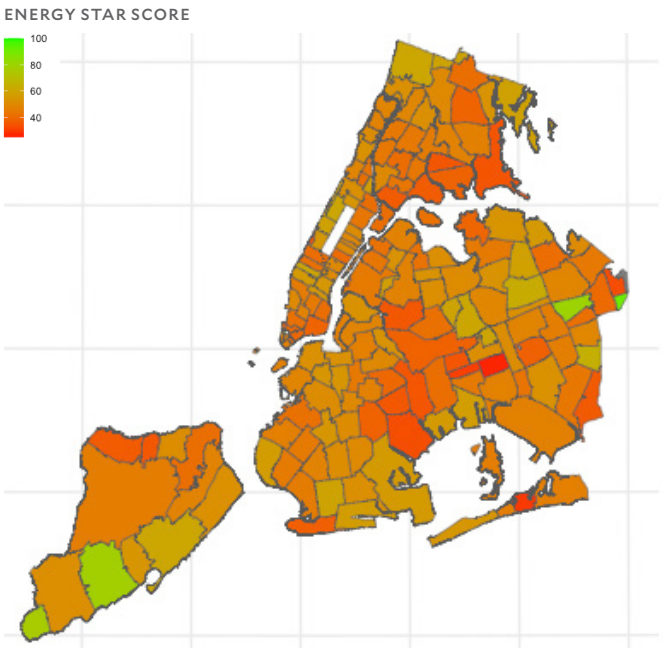
Housing factors assessed included energy efficiency ratings and housing violations for issues like mold and pests to examine housing quality, electrification, and lead exposure from multiple angles:

- **Energy Efficiency:** New York City law requires building owners to participate in a benchmarking program that rates all buildings on energy and water efficiency based on U.S. Environmental Protection Agency standards.[24] We use these energy efficiency scores as one indicator for areas where energy efficiency and electrification measures could offer the greatest improvements.

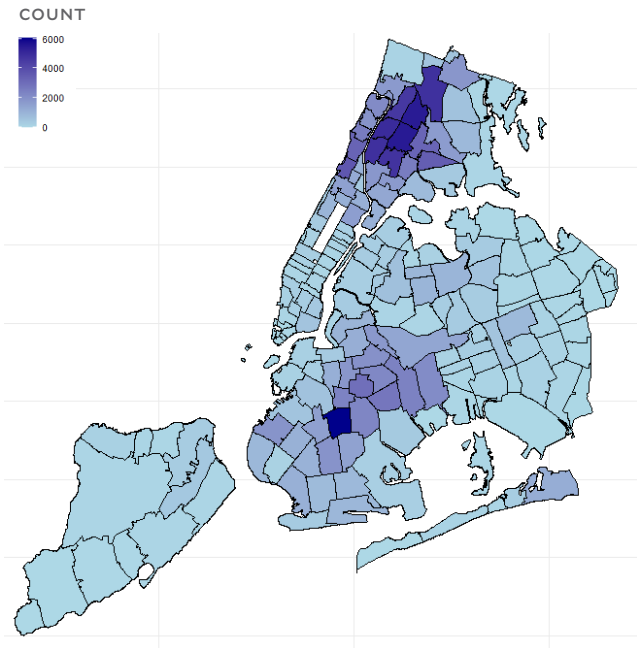
- **Housing Violations:** We mapped 2012-2023 housing maintenance code violations by ZIP code from a NYC Department of Housing Preservation and Development (HPD) dataset organized by mold, lead, water leaks, electrical issues, and energy inefficiency, where each category is determined by the presence of key words: “mold”, “lead/lead-based paint”, “leak/water damage/dampness”, “electric/wiring/outlet”, and “insulation/broken or defective window/broken or defective roof”, respectively. Class C violations specifically refer to severe violations for all issues related to energy efficiency, water leaks, electrical issues, lead and mold.

- **Outdoor Air Quality:** Targeting areas with higher levels of air pollutants for electrification would ensure that we drive the indoor air quality benefits of electric appliances to populations most exposed to air pollution. We map the average annual PM2.5 concentrations across the city.

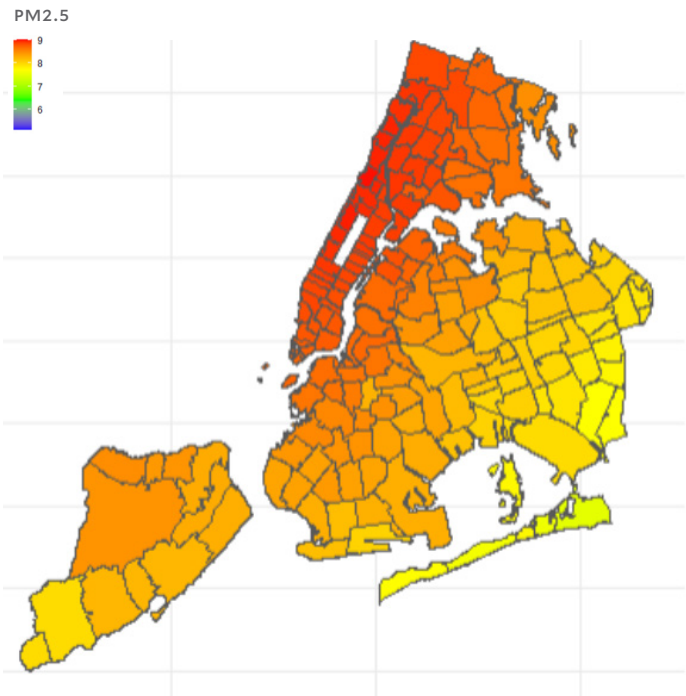
AVERAGE ENERGY-EFFICIENCY BUILDING SCORES



CLASS C VIOLATIONS



PM2.5 CONCENTRATIONS (ΜG/M³)

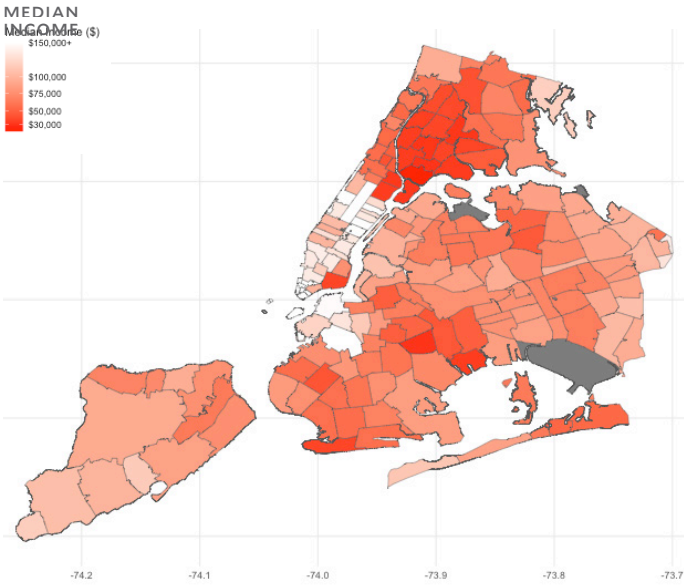


Economic Indicators

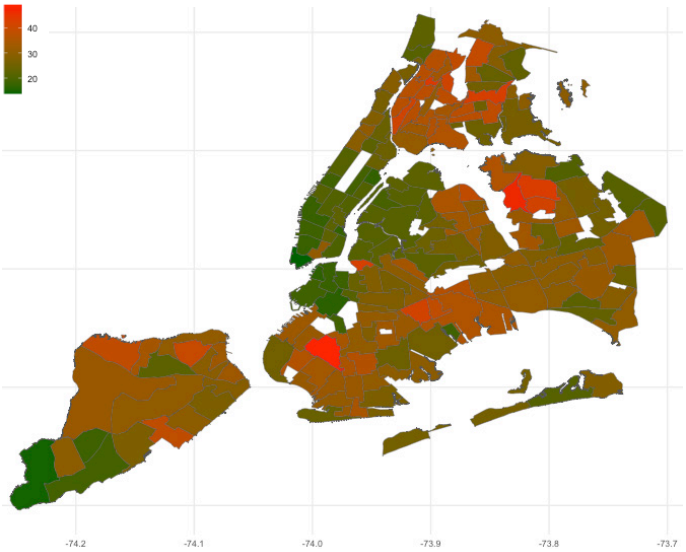
We included measures of economic wealth and stability as indicators of the resources available to residents to address energy inefficiency and home lead hazards:

- **Median Income:** One of the primary measures of financial status used in research.
- **Rent Burden:** Proportion of income spent on rent.
- **Displacement Risk:** An external index that incorporates multiple factors including number of rental units, amount of rent-stabilized housing, and proportion of people living below twice the poverty line.
- **Eviction Rate:** When faced with stringent lead abatement policies, some landlords may evict tenants rather than remediate lead, and unsafe housing conditions in NYCHA buildings are associated with an increase in evictions.[100,101] We include eviction rate as a measure of both economic stability and potential for excess lead exposure.

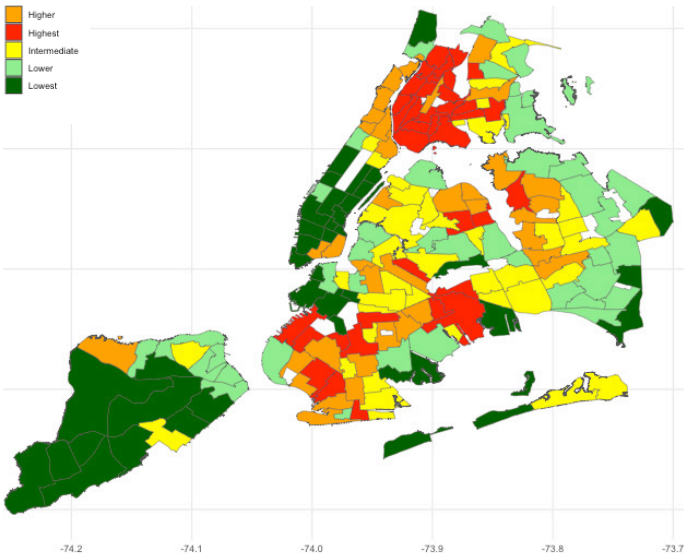
MEDIAN INCOME BY ZIP CODE



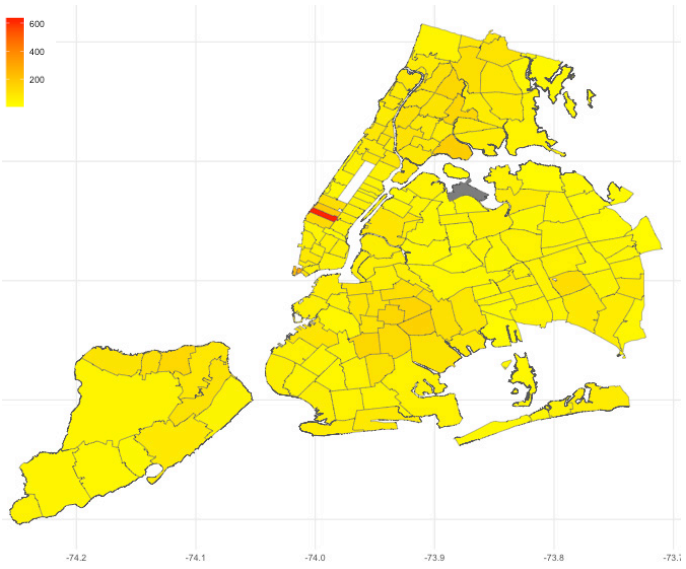
RENT BURDEN BY ZIP CODE



DISPLACEMENT RISK BY ZIP CODE



NUMBER OF EVICTIONS PER 100,000 PEOPLE

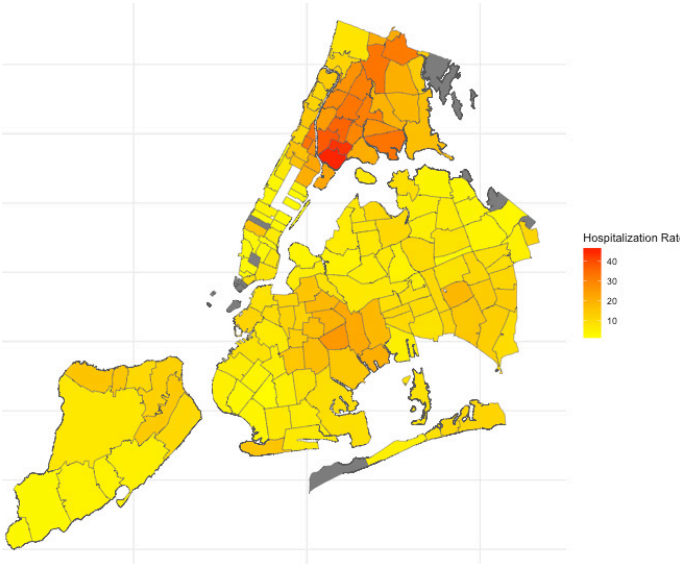


Health and Cognitive Outcomes

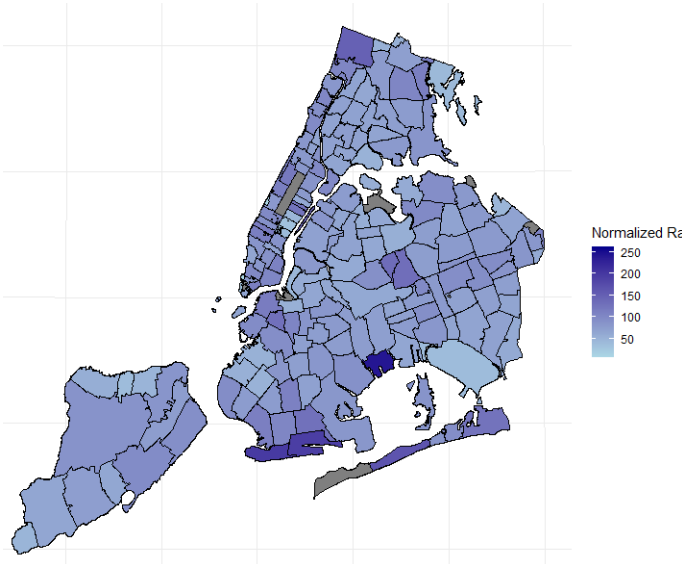
We examined health and cognitive outcomes relevant to electrification and lead exposure:

- **Asthma Hospitalizations:** Health harms related to air pollution like asthma and cardiovascular health could be improved by replacing fossil fuel-combusting home appliances with electric ones.[89,124]
- **Cardiovascular Disease:** Due to a lack of available data for cardiovascular health outcomes, we were only able to map cardiovascular disease among Medicaid beneficiaries. As such, the population shown in our map is limited to only those on Medicaid.
- **Birth Outcomes:** We mapped rates of low birth weight and premature births as an indicator of lead poisoning, given that both are associated with prenatal lead exposure.[66,125,126]
- **Elementary School Test Scores:** Poor academic performance is associated with childhood lead exposure, so we averaged school-reported test scores by NYC ZIP code.65 We focused on elementary school math scores since NYC schoolchildren are more likely to attend an elementary school near where they live, so school ZIP codes might more accurately correspond to child home ZIP codes.[127]

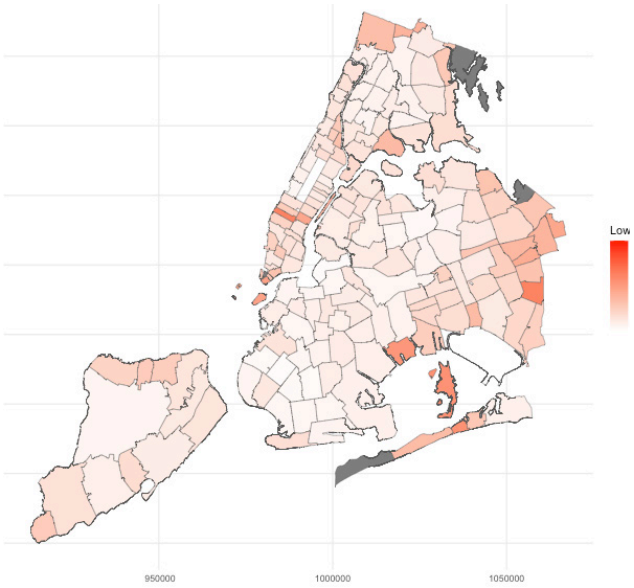
ASTHMA HOSPITALIZATIONS PER 10,000 PEOPLE BY ZIP CODE



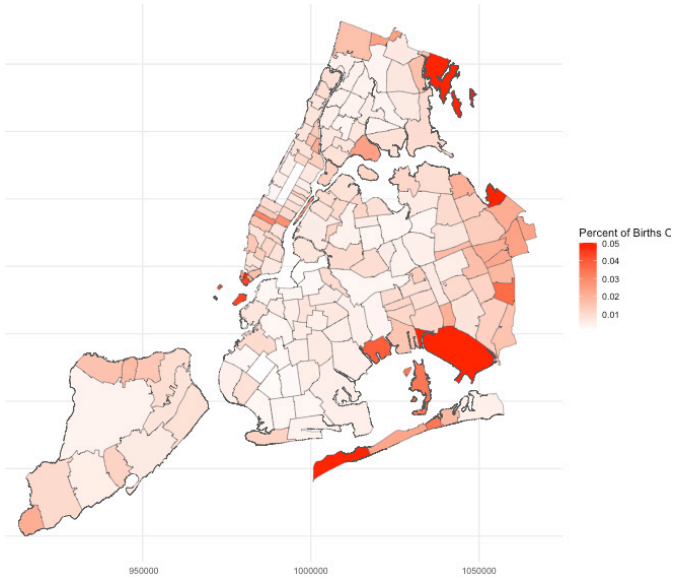
CARDIOVASCULAR DISEASE IN MEDICAID POPULATION BY ZIP CODE



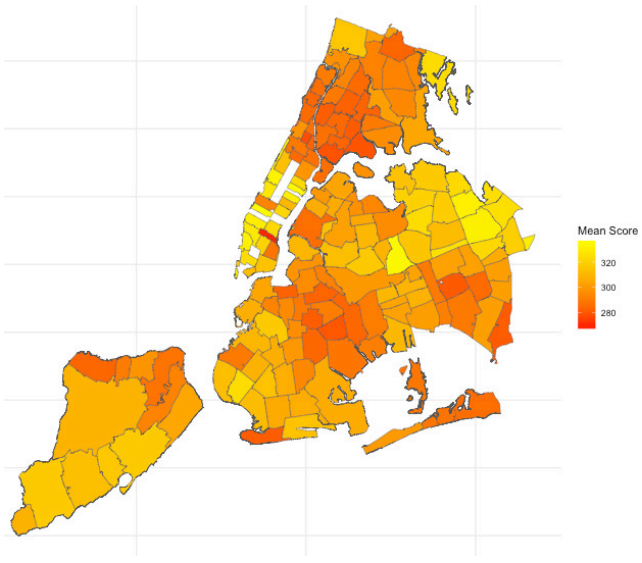
RATE OF LOW BIRTH WEIGHT BY ZIP CODE (2017-2019)



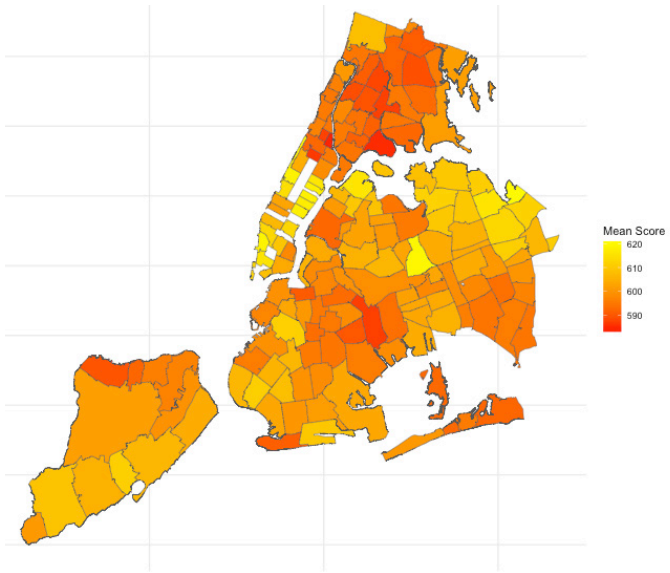
RATE OF PREMATURE BIRTH RATES BY ZIP CODE (2017-2019)



AVERAGE THIRD GRADE MEAN TEST SCORES FOR MATH (2013)



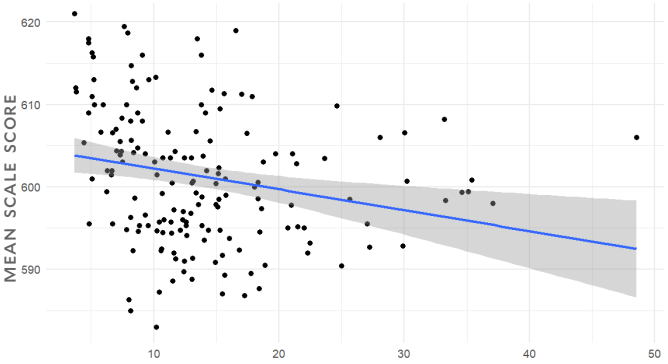
AVERAGE THIRD GRADE MEAN TEST SCORES FOR MATH (2018)



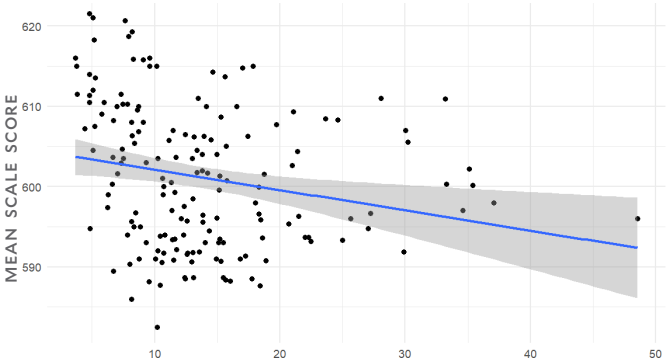
APPENDIX B – CORRELATIONS

We ran a series of linear regressions and other models to analyze variables of interest and help inform our final decisions regarding which variables to include in our pared down map.

ASSOCIATION BETWEEN LEAD EXPOSURE AND THIRD GRADE MEAN MATH SCORES (2018): LINEAR REGRESSION ADJUSTED FOR INCOME (COEFFICIENT: -1.020E-01, R SQUARE: 0.47, P VALUE: 0.111).



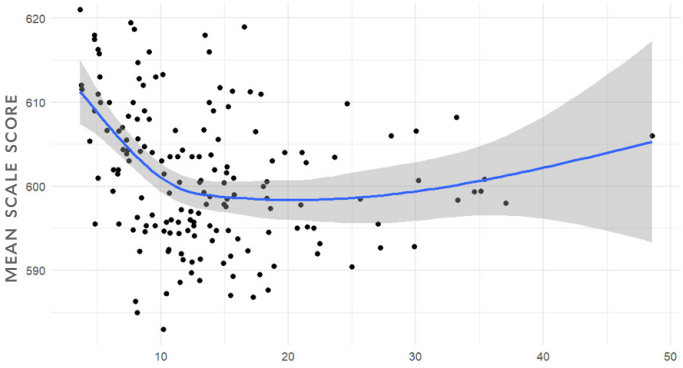
ASSOCIATION BETWEEN LEAD EXPOSURE AND FOURTH GRADE MEAN MATH SCORES (2018), ADJUSTED FOR INCOME (COEFFICIENT: -9.785E-02, R SQUARE: 0.431, P VALUE: 0.165).



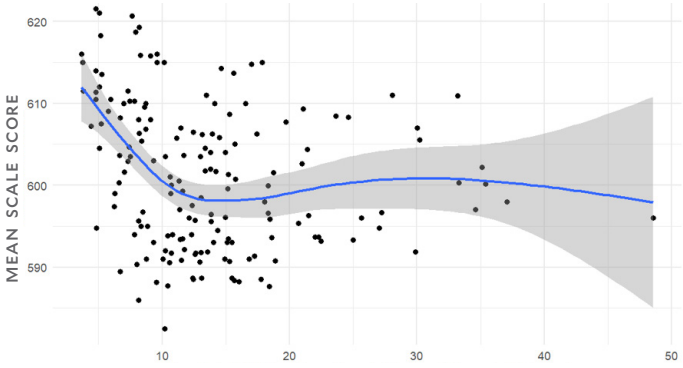
Initially, we used linear regression to assess the relationship between child blood levels and mean scale scores for 3rd and 4th grade in 2018. But the correlation was not strong and was not significant when adjusting for median household income. We further explored the data using nonlinear models.

Lead, Health, and Educational Outcomes:

GAM MODEL ADJUSTING FOR INCOME (R SQUARE: 0.537, P VALUE: 0.00411).



GAM MODEL ADJUSTING FOR INCOME (R SQUARE: 0.508, P VALUE: 0.00114).

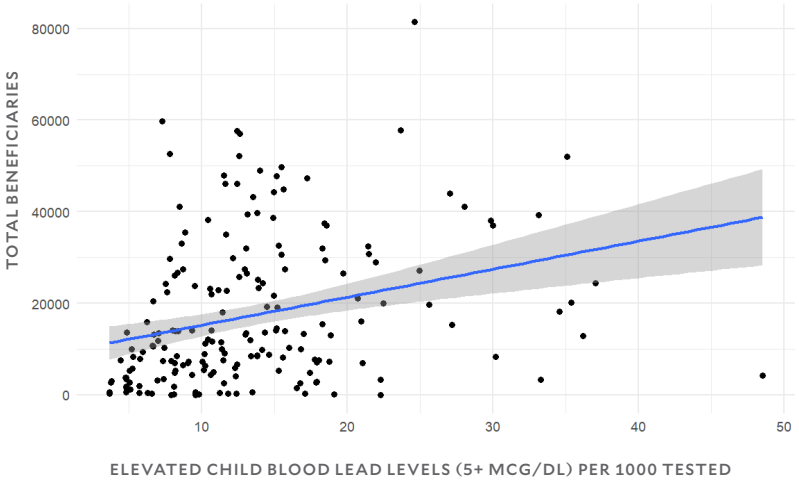


Lead, Health, and Educational Outcomes:

We examined the relationships including linear regression, polynomial regression and generalized additive models (GAM). We calculated AIC for linear regression, polynomial regression and GAM respectively. Given that the model with the lowest AIC is typically considered the "best" model and a difference of 10 or more suggests a significant difference in quality, we chose the GAM model. This indicates a nonlinear relationship between child blood lead levels and mean math test scores, which are consistent with findings from existing literature.[99] The results present nonlinear correlations between lead and achievement, controlling for income; these correlations range around 0.5. All of these associations are significant at a level less than 0.05. The relationship could be negative at lower levels of lead exposure and remain relatively stable at higher levels. In addition, there might be residual confounding variables like parental education. Controlling for median family income may not fully remove this potential confounding effect. If parental education is a confounder, the true relationship between lead and test scores would be weaker than we reported. Furthermore, our exposure data is from 2011 to 2019 so there is a limitation of temporality, thus we cannot establish a causal relationship between these two variables.

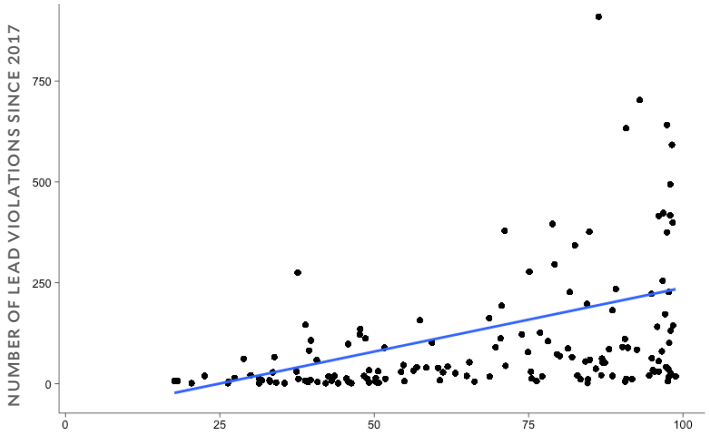
LINEAR REGRESSION ADJUSTED FOR INCOME (COEFFICIENT: 220.74, P VALUE: <2E-16 *).**

ASSOCIATION BETWEEN LEAD EXPOSURE AND CARDIOVASCULAR DISEASES AND DISORDERS



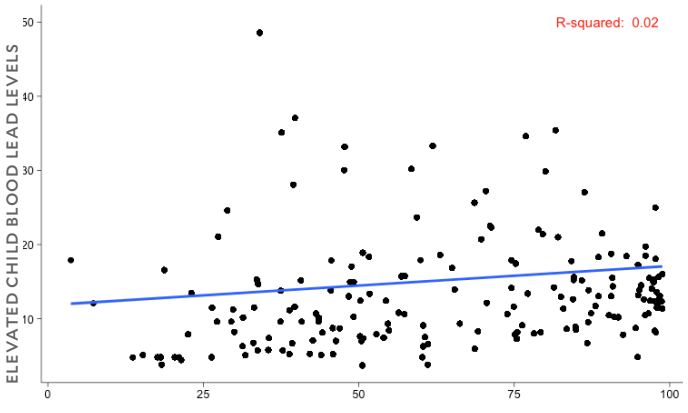
Lead exposure has been identified to have a significant adverse association with cardiovascular outcomes in our Medicaid study population. For each increase in the rate of elevated blood lead levels, the total beneficiaries from cardiovascular diseases and disorders increase by 220.74. However, our findings are limited in generalizability beyond Medicaid groups due to constraints on data collection. Many prior studies across broader populations have similarly demonstrated negative associations of lead exposure with clinical cardiovascular outcomes such as coronary heart disease, stroke mortality, and peripheral arterial disease. Further report analysis should aim to clarify the cardiovascular effects of lead in more diverse socioeconomic strata.

CORRELATION BETWEEN LEAD VIOLATIONS AND RACIAL DEMOGRAPHICS (BY ZIP CODE)



For each 1% increase in POC population of a ZIP code in NYC, the rate of elevated child blood lead levels goes up by 0.05.

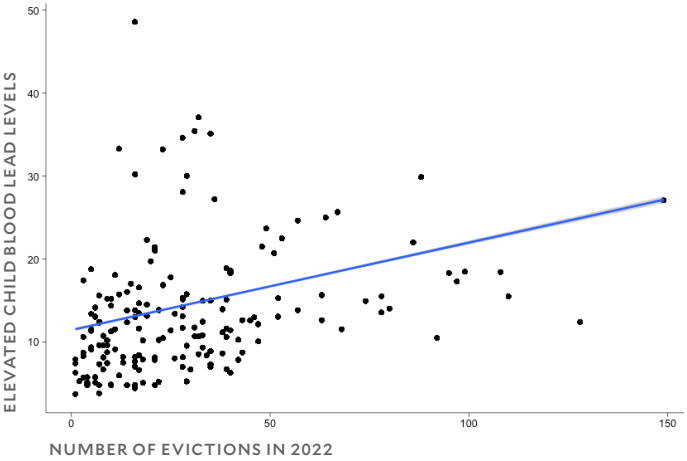
CORRELATION BETWEEN ELEVATED CHILD BLOOD LEAD LEVELS AND PERCENT OF POPULATION IDENTIFYING AS POC



For each 1% increase in the POC population of a ZIP code in NYC, the number of recent lead violations in the ZIP code goes up by 3.17.

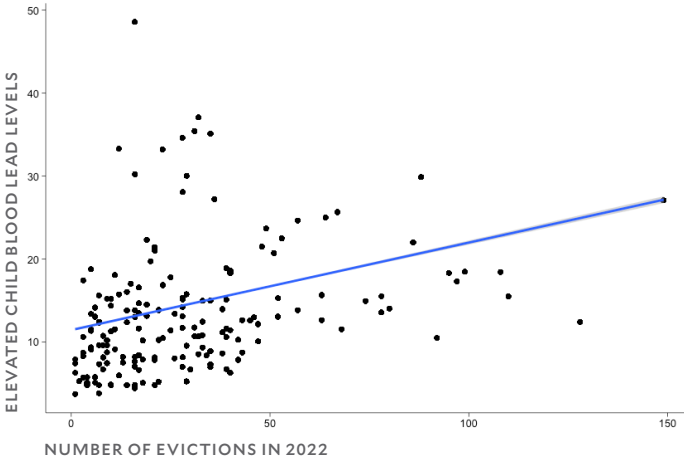
Lead, Housing, and Wealth:

CORRELATION BETWEEN ELEVATED CHILD BLOOD LEAD LEVELS AND EVICTIONS (BY ZIP CODE)



For every additional eviction in a ZIP code in NYC, the rate of elevated blood lead levels increases by 0.11.

CORRELATION BETWEEN LEAD VIOLATIONS AND EVICTIONS (BY ZIP CODE)

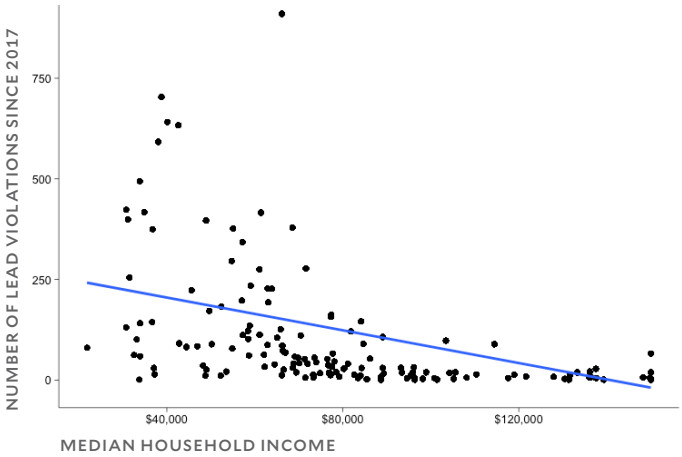


For every additional eviction in a ZIP code in NYC, the number of lead violations increases by 4.8.

CORRELATION BETWEEN ELEVATED CHILD BLOOD LEAD LEVELS AND MEDIAN INCOME (BY ZIP CODE)

For each $1,000 increase in median income, the rate of elevated blood lead levels decreases by 0.7.

CORRELATION BETWEEN LEAD VIOLATIONS AND MEDIAN INCOME (BY ZIP CODE)



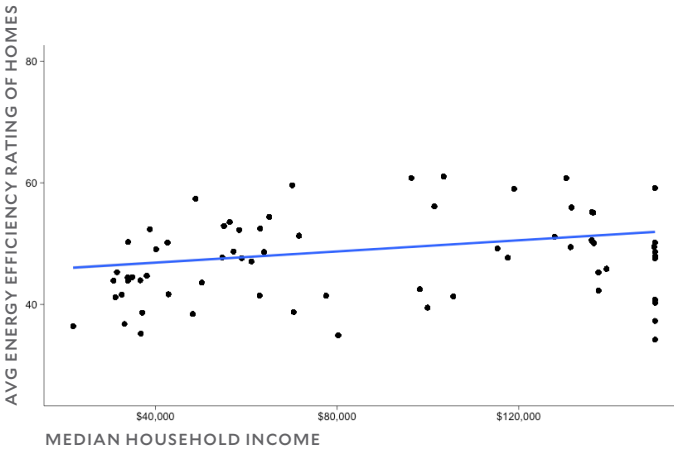
For each $1,000 increase in median household income, the number of lead violations decreases by 20.3.

CORRELATION BETWEEN ELEVATED BLOOD LEAD LEVELS AND HOUSING AGE (BY CENSUS TRACT)

Coefficient is -0.079, for every year newer homes are on the median in a census tract, there is a decrease in the rate of elevated child lead levels.

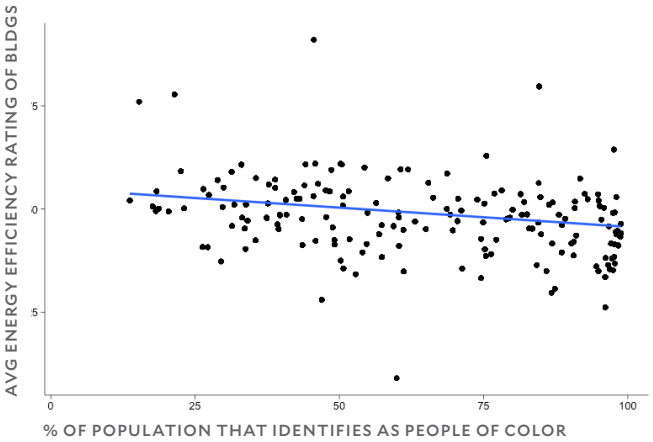
Energy Efficiency:

CORRELATION BETWEEN ENERGY EFFICIENCY AND MEDIAN INCOME (BY ZIP CODE)



For each $1,000 increase in median household income, the average energy efficiency rating of buildings goes up by 0.49.

CORRELATION BETWEEN ENERGY EFFICIENCY AND PERCENT OF THE POPULATION IDENTIFYING AS A PERSON OF COLOR (BY W CODE)



For every 1% increase in the POC population of a ZIP code in NYC, the average energy efficiency rating of buildings goes down by 0.7.