Quantifying Impacts of Emission Reductions on Environmental Justice and Human Health in a Metropolitan Area

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Introduction

- Globally, ambient particulate matter (PM) pollution accounts for approximately 3.2 million premature deaths every year, and is considered one of the largest environmental health risks
- Environmental justice investigates how environmental risk factors are associated with socioeconomic status (SES; e.g. income, race, etc.)
  - Previous studies have found that lower income households are more often located in areas with higher air pollution

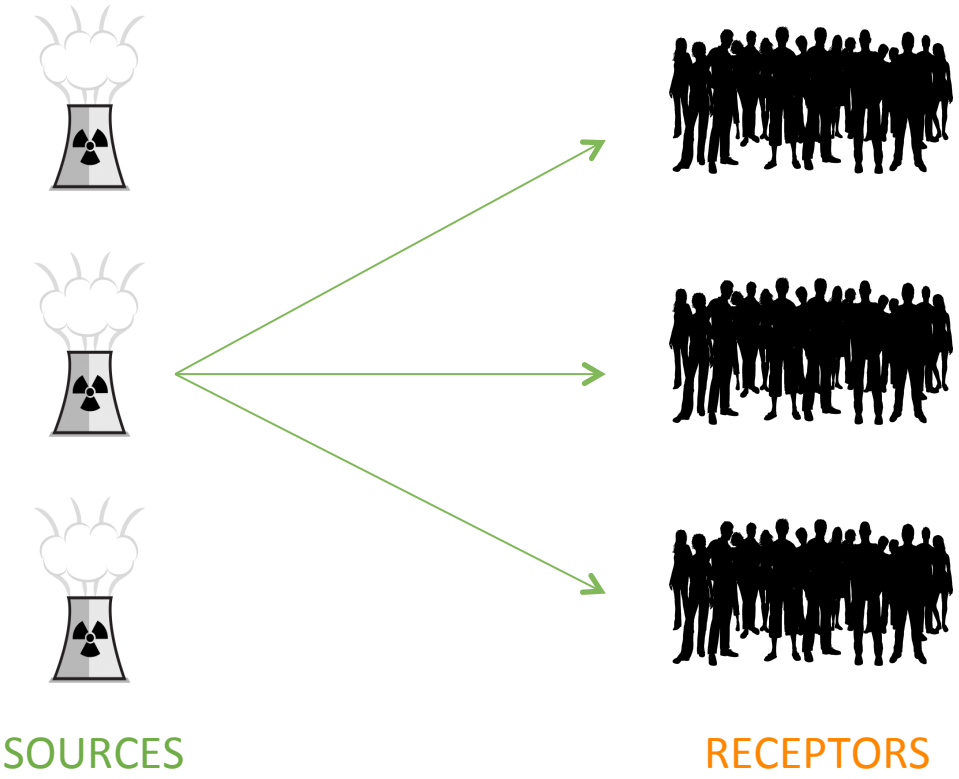
Objectives

For $PM_{2.5}$ exposure in New York City and surrounding areas:

1. Identify emission control measures to improve:
    a) human health
    b) environmental equity across income groups

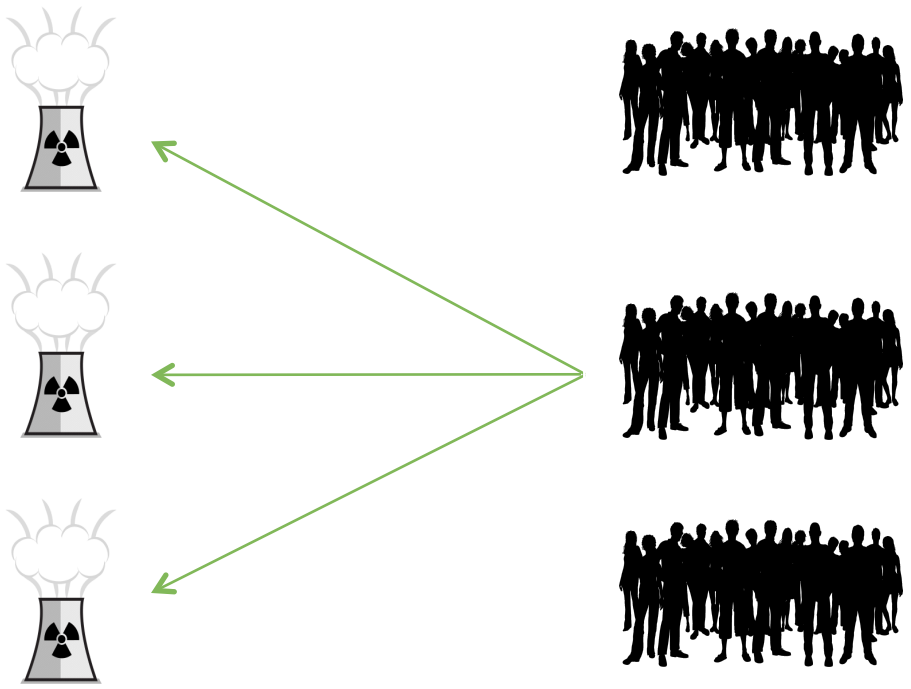
2. Contrast the sensitivities of health and equity measures to emission reductions, to better coordinate air quality management strategies

Forward Sensitivity Analysis



Forward: where impacts go to …

Backward/Adjoint Sensitivity Analysis



Adjoint/backward: where influences come from

Monetized Health Impacts:
Marginal Benefits

$$\frac{\Delta\$}{\Delta\text{Emissions}} = \underbrace{\frac{\Delta\$}{\Delta\text{Mortality}}}_{\text{Economics}} \times \underbrace{\frac{\Delta\text{Mortality}}{\Delta\text{Concentrations}}}_{\text{Epidemiology}} \times \underbrace{\frac{\Delta\text{Concentrations}}{\Delta\text{Emissions}}}_{\text{Air quality modeling}}$$

Adjoint cost function

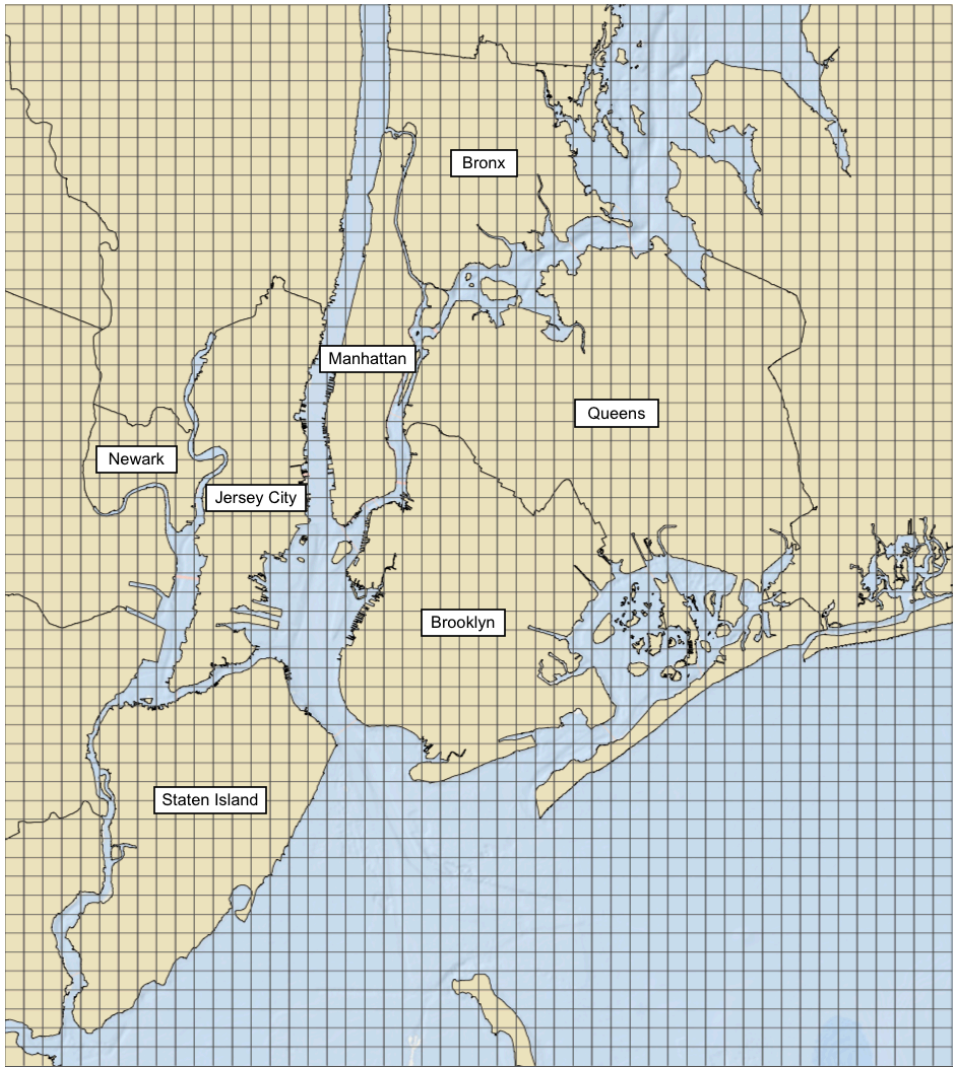
- We can use the adjoint method so long as
  - our "policy" metric can be condensed into a single number, called the **adjoint cost function**,
  - The functionality between the metric and concentrations is known.

  - Health outcomes, precipitation to a lake, average concentrations, crop damage, etc.

- Example: nationwide mortality due to long-term exposure.

Area of Study

- 1km grid focused on New York City and surrounding area
- Focused on $PM_{2.5}$ concentrations
- CMAQ 5.0 and its adjoint
- July 1st – 14th, 2008
- Income data was taken from the U.S. Census: 12-month household income, divided into 16 income bins

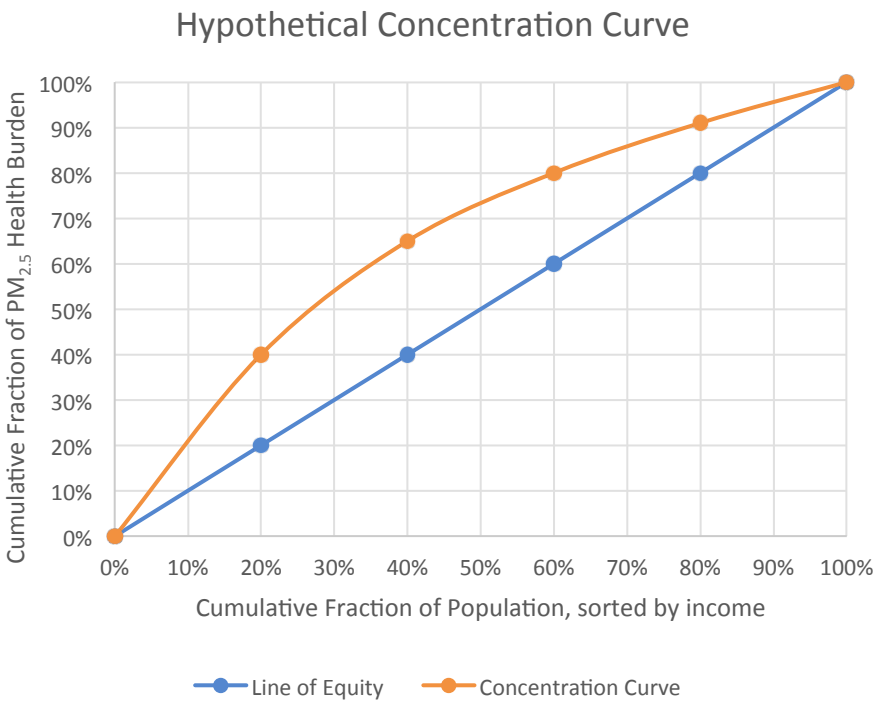


Health Benefits vs. Health Inequity

- Health Benefits: Monetized domain-wide reduction in mortality per ton of emissions (primary $PM_{2.5}$)
  - Chronic exposure mortality
  - Local baseline mortality

- Health Inequity: Change in domain-wide inequity metric (or its monetized form) due to one tonne reduction in emissions
  - Disparity in share of $PM_{2.5}$ mortality risk
  - Results only shown for primary PM emissions

Estimating Environmental Inequity from $PM_{2.5}$

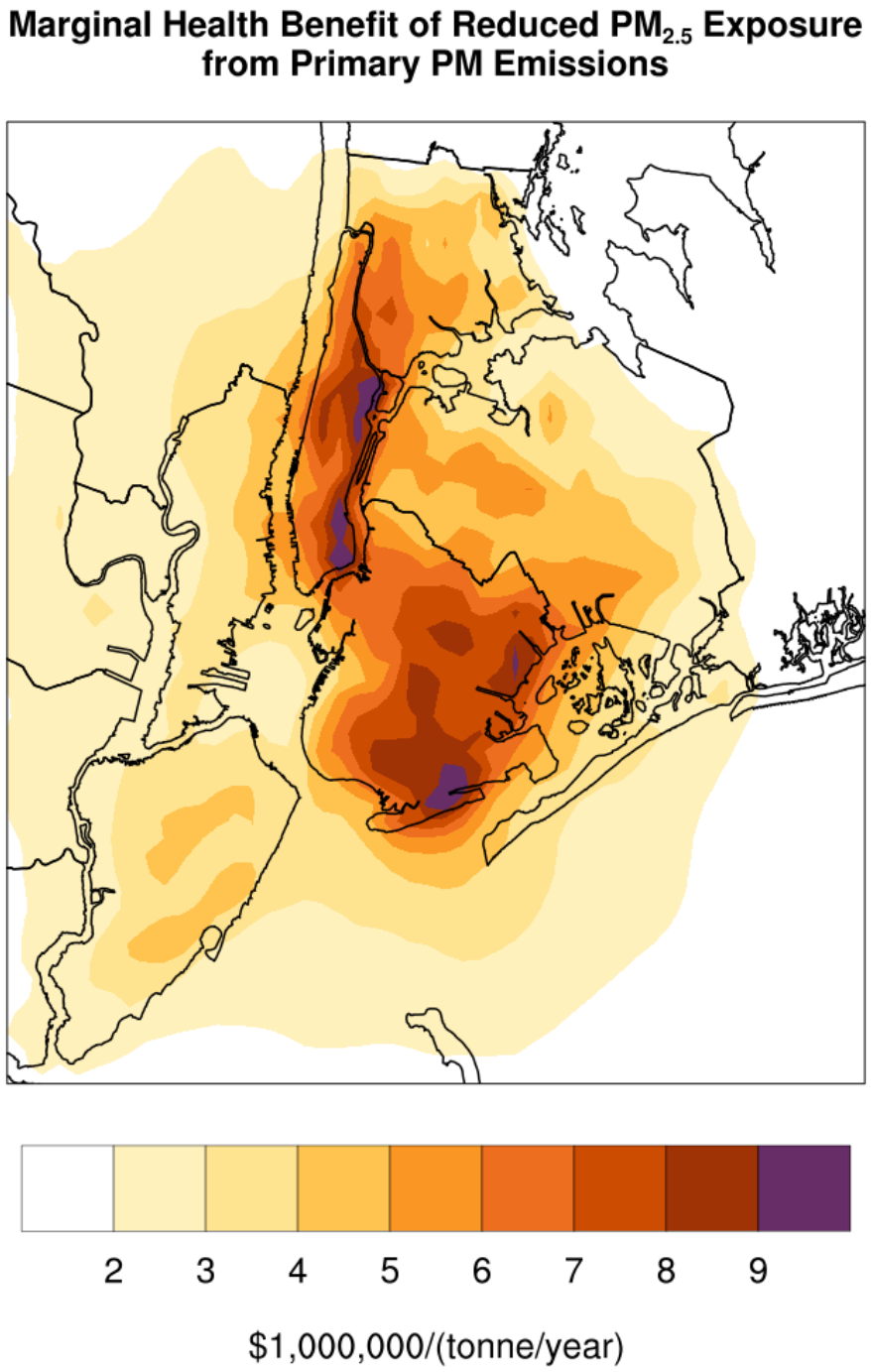


- **Concentration Curve** plots the fraction of $PM_{2.5}$ health burden earned by the cumulative fraction of the population, sorted by income
- **Concentration Index** is double the area between the Concentration Curve and the Line of Equity
  - Index ranges from 0 – 1
  - 0 – Indicates equity
  - 1 – Indicates inequity

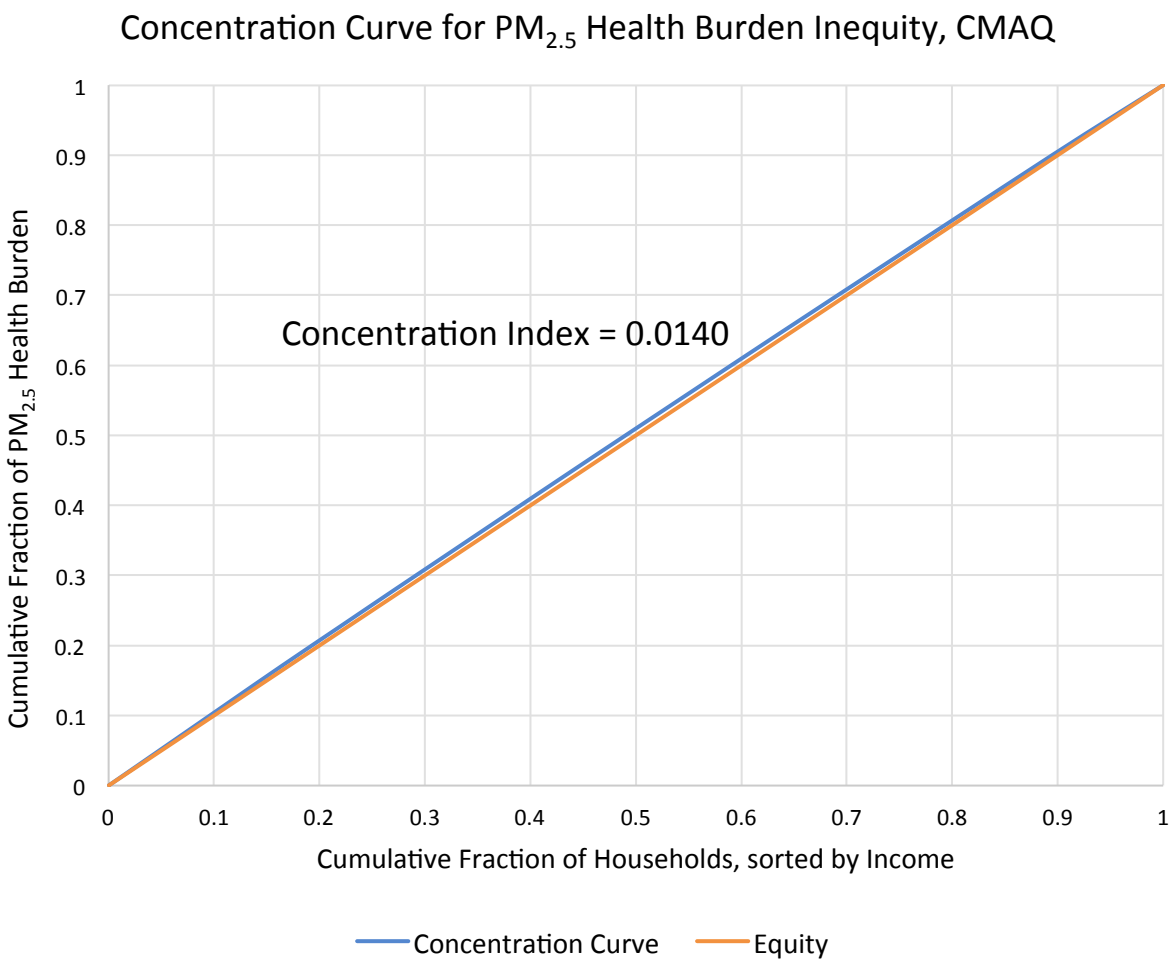
Results

Marginal Benefits of Reduced Mortality

- Annual health benefits experienced across the region
- For a reduction of primary PM emissions by 1 tonne/year at that location
- Highly sensitive to population



Current State of Environmental Equity



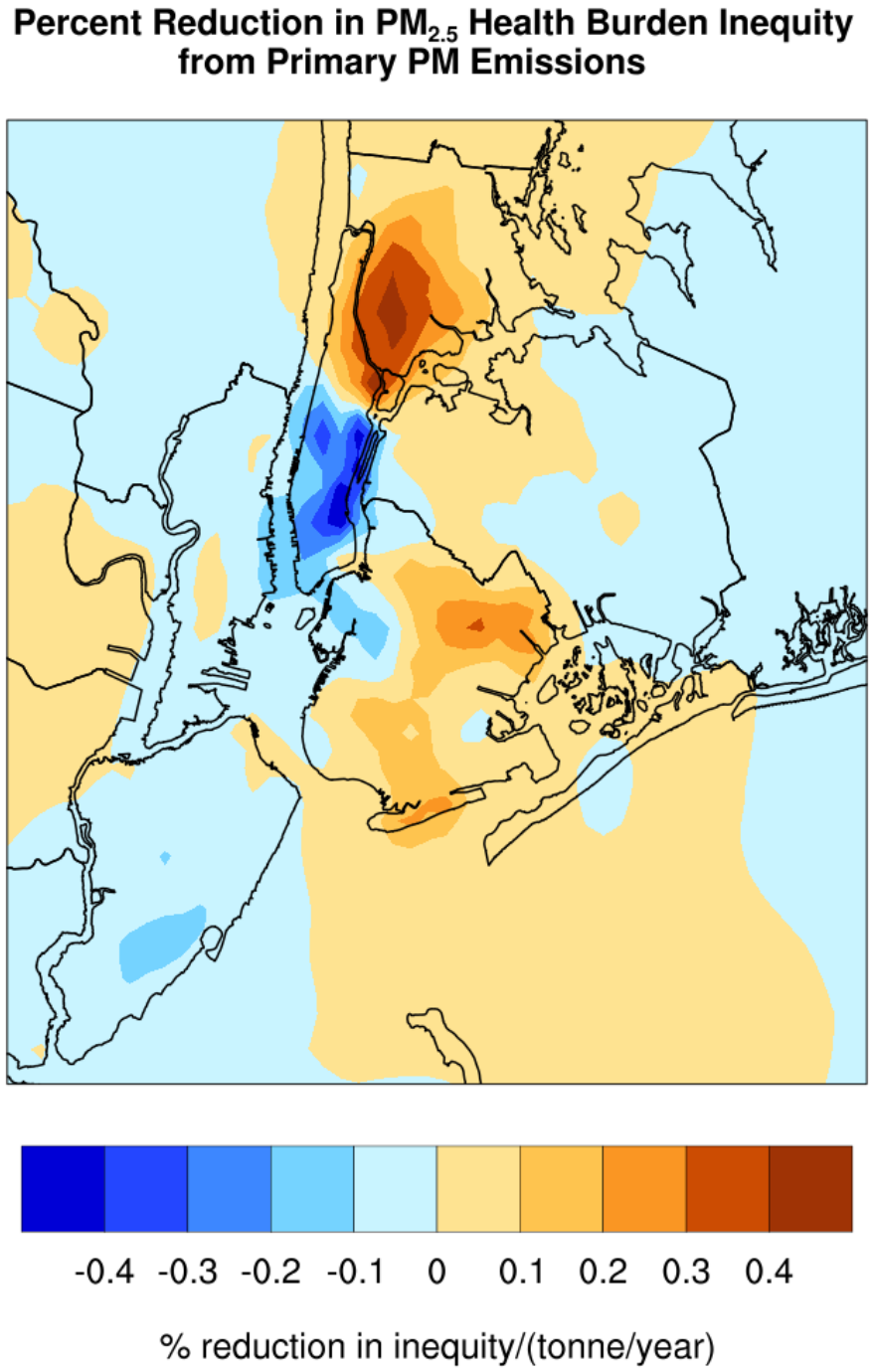
Concentration Index:
CMAQ = 0.0140
LUR = 0.0122 – 0.0152

Typical values:
Los Angeles = 0.020 – 0.031
(Su et al., 2009)

Detroit = 0.010 – 0.067
(Martenies et al., 2017)

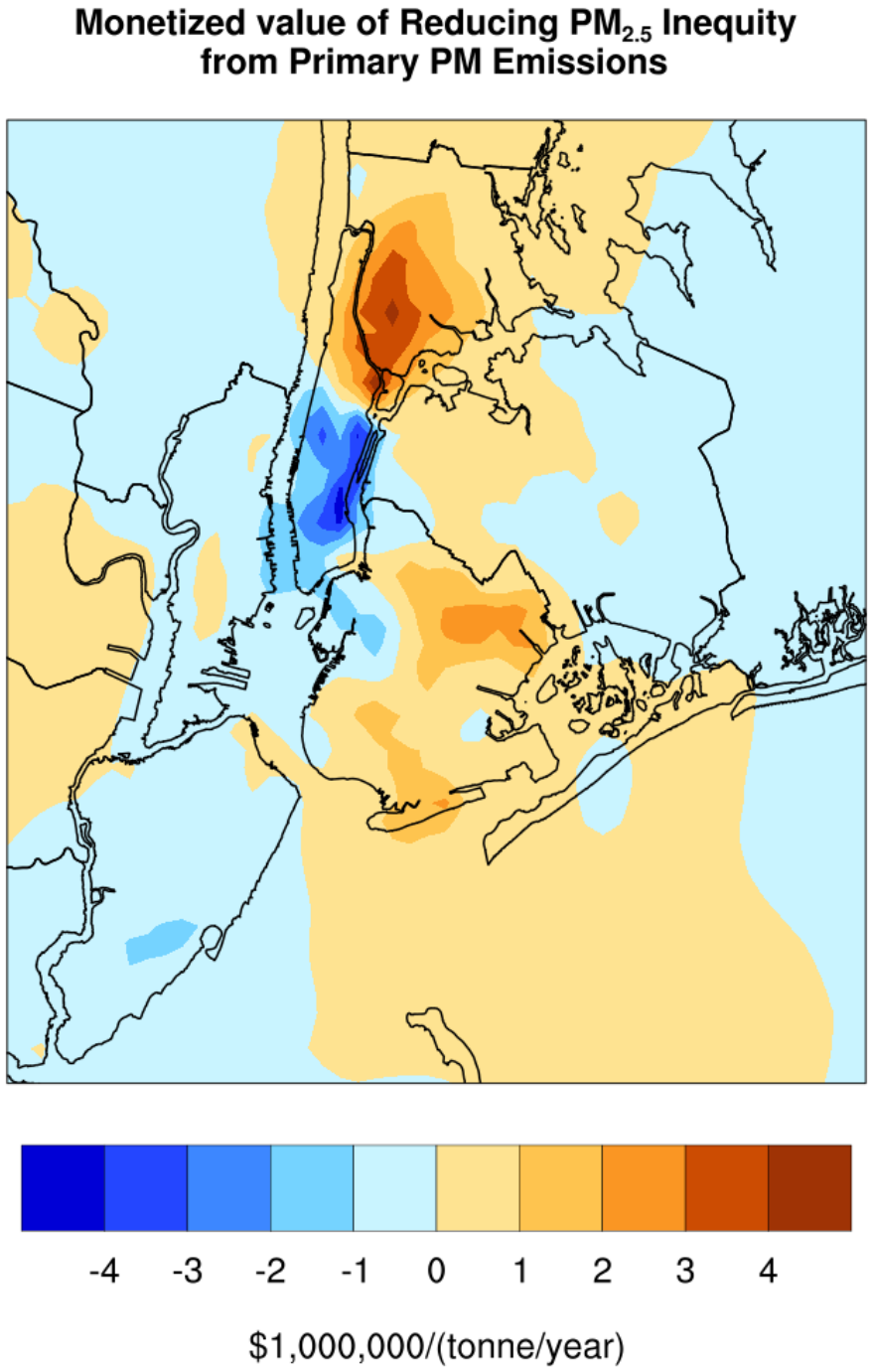
Sensitivity of Health Burden Inequity

- Positive sensitivity = a reduction in emissions reduces inequity
  - Biggest positive sensitivities occur in areas with a high proportion of low-income people
- Negative sensitivity = a reduction in emissions aggravates inequity
  - Biggest negative sensitivities occur in areas with a high proportion of high-income people

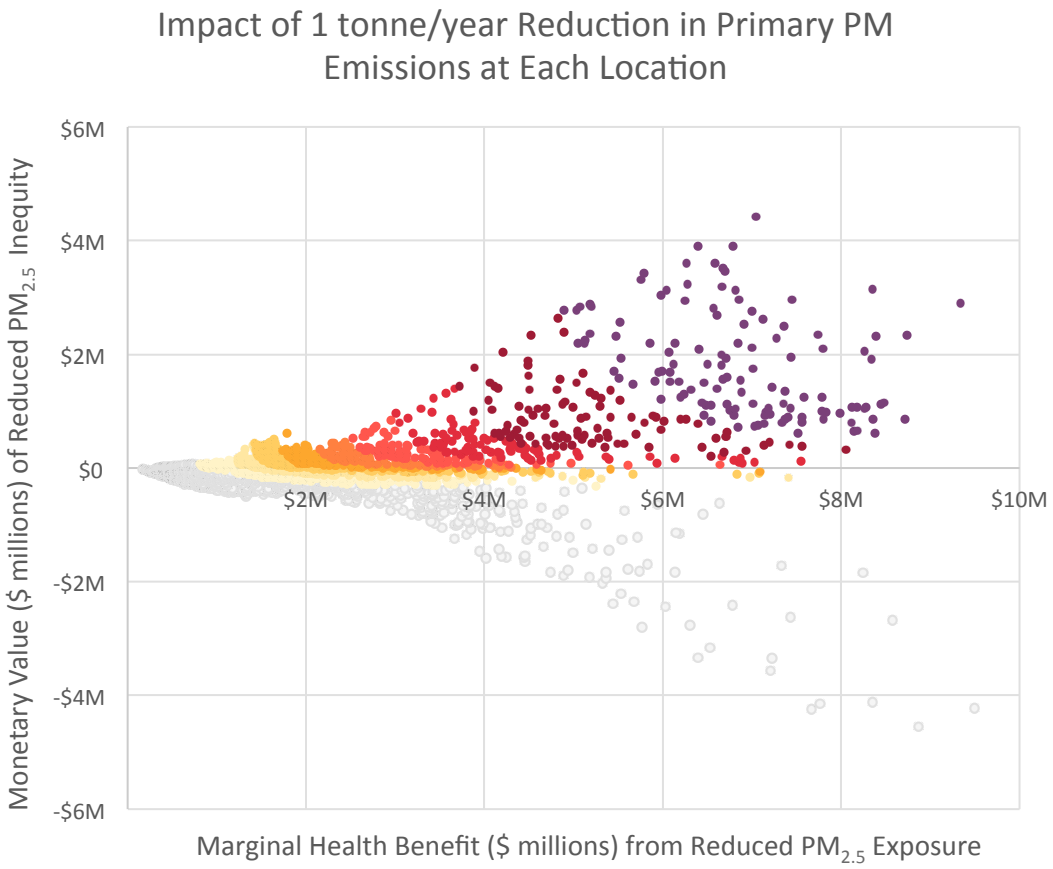


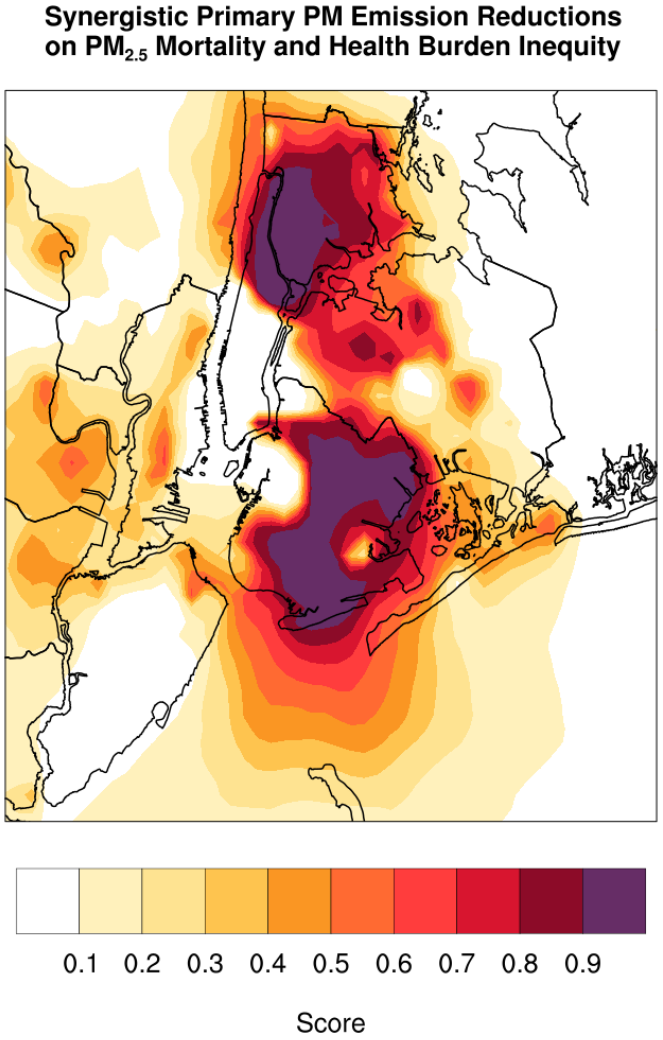
Monetized Health Burden Inequity

- Represents the amount of money that would need to be added to the system to create an equivalent reduction in inequity
- Equivalent to reducing 1 tonne/year of Primary PM at that location.



Synergistic Emission Reductions on Equity and Health





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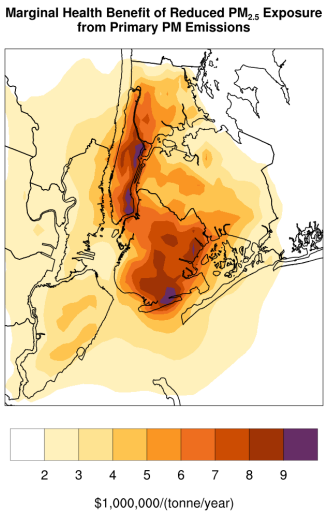
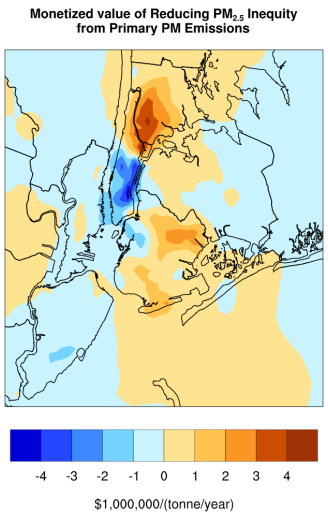
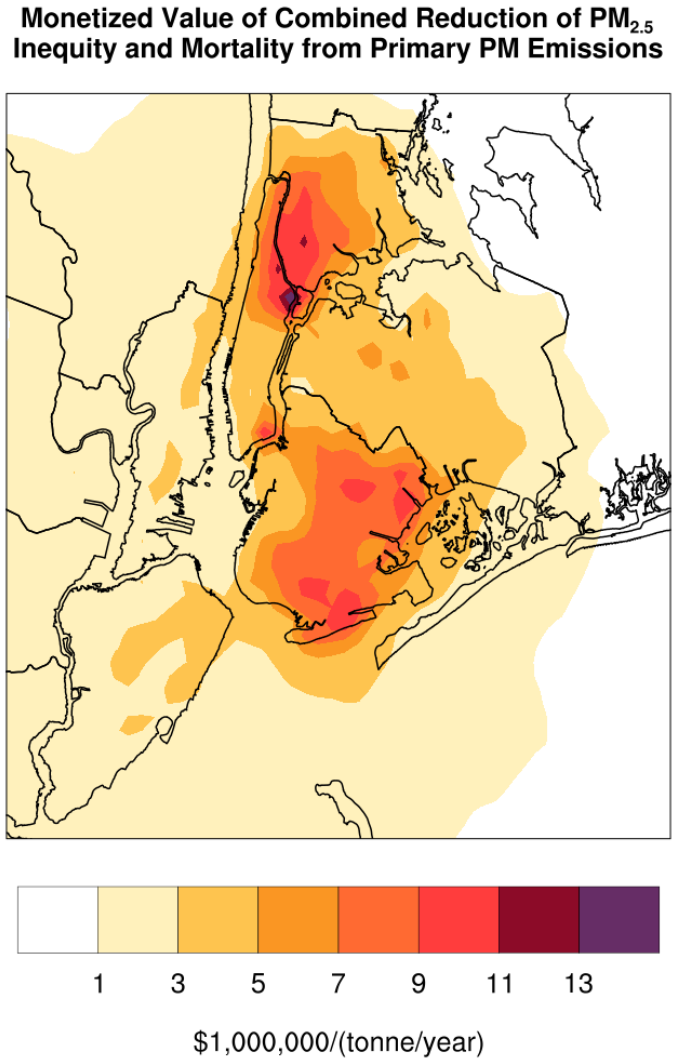
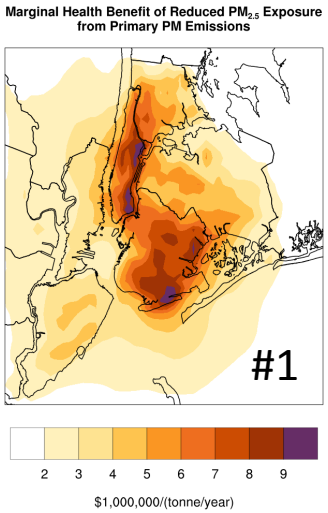
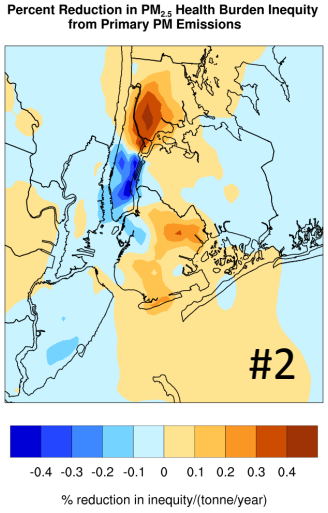


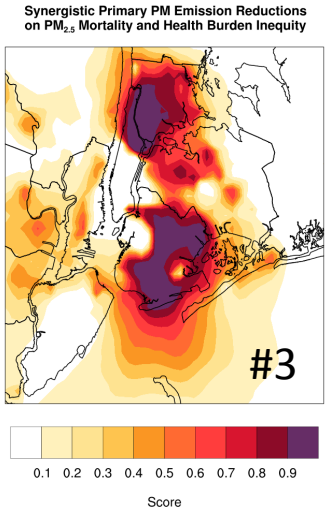


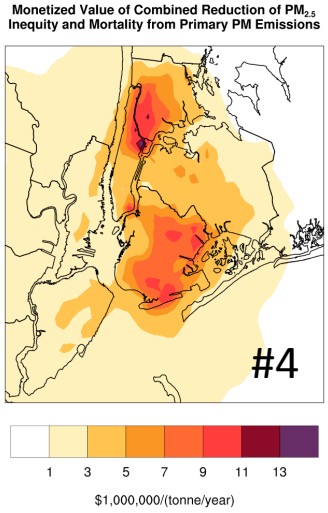


Emission Reduction Case Study









Scenario	Health Benefits ($ billion USD)	Equity Benefits ($ billion USD)	Equity Benefits (% Reduction in Inequity)
#1: Prioritize Health	$ 4.01	$ 0.15	13.9 %
#2: Prioritize Equity	$ 3.48	$ 1.02	95.1 %
#3: Percentile Scores	$ 3.65	$ 0.98	91.4 %
#4: Combined Monetization	$ 3.71	$ 0.95	88.3 %

Conclusion

- Considering synergistic emission reductions can lead to substantial benefits for both health and equity
    - This can provide policy-relevant information to better coordinate air quality policies that target various endpoints

Adjoint vs. Reduced Form Models

- Development of an adjoint model is difficult
  - It's now done
- Adjoint simulations are computationally expensive
  - Quite affordable for medium size domains
  - May necessitate episodic simulation
- Preparing high resolution inputs is a demanding task
  - Also true for reduced form models

- Adjoint is as accurate as the underlying model
- All the results in a single run

Acknowledgements

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