TRECH Project Research Update
Preliminary Results - October 6, 2020

I. The Context

Transportation is the largest source of greenhouse gas (GHG) emissions in the United States and in the Northeast and Mid-Atlantic regions at about 28% and 30%, respectively (EPA 2020, TCI 2010). Cars, trucks, and buses also emit tons of conventional air pollutants each year contributing to asthma, heart disease, pre-term births, and premature death among other health impacts. The largest air quality impacts occur in underserved and overburdened communities, near highways and transportation depots, and among Black people and other people of color, due to a long history of racist policies that have resulted in persistent elevated pollution exposure. Transportation systems also affect noise pollution; congestion and stress; opportunities for safe biking and walking; and access to jobs, healthcare, and education.

A group of Northeast and Mid-Atlantic states and the District of Columbia are participating in the Transportation Climate Initiative (TCI). They are expected to finalize a memorandum of understanding in Fall 2020 that aims to cut carbon dioxide (CO_2) emissions from the transportation sector. The TRECH Project team is making preliminary results available as state policymakers and stakeholders are considering how best to design a TCI climate mitigation program and achieve health gains.

II. The TRECH Project

The Transportation, Equity, Climate and Health (TRECH) Project is a multi-university research initiative conducting an independent analysis of TCI policy scenarios to address carbon pollution from the transportation sector. The project looks at changes in health outcomes from active mobility (e.g., biking and walking) and air quality using published, peer-reviewed models commonly employed in regulatory analysis. To-date, the TRECH Project team has estimated health outcomes for five illustrative TCI policy scenarios representing a range of emissions reduction caps and investment strategies.

The preliminary TRECH results below are intended to foster dialogue and help inform program design by illustrating how climate mitigation policies in the transportation sector can influence health outcomes. The actual benefits of a TCI program will depend on state policy decisions including the ambition of a CO_2 emission reduction cap, the formulas for allocating program proceeds among and within states, and the potential adoption of supporting policies.

III. Insights from Preliminary Results

1. The estimated health benefits under the five TCI climate mitigation policy scenarios are substantial and are larger than estimated TCI program proceeds, for a subset of total possible benefits.

The preliminary results show that the estimated health benefits from changes in active mobility and on-road emissions under the TCI policy scenarios include up to about 1,000 deaths avoided and nearly 5,000 childhood asthma cases avoided annually in 2032 (Table 1). The monetized value of the subset of total health benefits included here are larger than the estimated annual TCI program proceeds in 2032 under all of the TCI policy scenarios (Table 1). This analysis does not include climate-related health benefits and other potential health benefits from improving transportation systems such as those from reduced traffic congestion and noise pollution as well as improved traffic safety and access to jobs, healthcare, and education.

2. The TCI policy scenario with the largest estimated health benefits has the most ambitious emissions reduction cap and the largest share of investments dedicated to public transit and active mobility.

The TCI policy scenario that achieves the largest overall health benefits is the one with the most ambitious CO_2 emissions reduction cap (25%) and an investment portfolio focused on public transit and walking and biking infrastructure (Scenario A)(Table 1). This scenario also does the most to reduce inequalities in air pollution exposure by race/ethnicity, has the smallest difference between rural and urban benefits, and achieves the largest CO_2 emission reductions from on-road sources of the five policy scenarios examined.

Table 1: Estimated Health Benefits for Five Illustrative TCI Policy Scenarios Compared to a No-TCI Reference Scenario in 2032 (central estimates, billions of 2016$)

	Scenario A 25% CO_2 Reduction Cap	Scenario B 25% CO_2 Reduction Cap	Scenario C 25% CO_2 Reduction Cap	Scenario B 22% CO_2 Reduction Cap	Scenario B 20% CO_2 Reduction Cap
Estimated deaths avoided (biking, walking, and air quality)	1100	950	700	540	280
Estimated childhood asthma cases avoided	4700	4100	3300	2000	980
Estimated monetized benefits of eight health outcomes	$11.1	$9.6	$7.1	$5.5	$2.7
Estimated annual TCI proceeds in 2032	$8.5	$6.8	$5.4	$3.5	$1.9

3. Under all five policy scenarios, health benefits are estimated to occur in all counties across the region and are concentrated in more populated areas.

All counties in the region are estimated to receive both active mobility and air quality benefits under all five TCI policy scenarios considered here. Both the total and per capita health benefits are concentrated in more populated counties. These findings illustrate that widespread benefits are possible when proceeds are broadly distributed across the region and most of the proceeds are reinvested in transportation system improvements.

4. All five policy scenarios modestly reduce inequities in air pollution exposure between racial/ethnic groups but, even with the reductions estimated in the TCI policy scenarios, people of color would still face higher overall air pollution exposures and more emission reductions would be needed to address pre-existing inequities.

All five policy scenarios are estimated to result in some reduction in air pollution exposure inequality in the region compared to the no-TCI reference scenario in 2032, with greater relative reductions for non-Hispanic Black and Hispanic populations. However, while non-Hispanic Black and Hispanic populations, on average, are estimated to see slightly larger decreases in air pollution, they would still face higher overall air pollution exposures and more pollution reductions would be needed to address these longstanding inequities and related health outcomes.

5. Nearly a four-fold difference in the estimated health benefits exists across the five TCI policy scenarios, underscoring that there is a wide range of possible health outcomes and that actual health benefits will depend on state actions (Table 1).

About the Illustrative TCI Policy Scenarios

Under the proposed TCI cap and invest program, fuel suppliers would be required to hold allowances for the carbon content of the fuel they supply. The allowances would be auctioned off and the proceeds from those auctions would be allocated to states to reinvest. The illustrative TCI policy scenarios assume that the proceeds are evenly allocated to the participating states based on vehicle miles traveled and population. Each scenario allocates a percent of the program proceeds to 25 different transportation strategies bundled into five categories. Of the total auction proceeds, 83-92% is assumed to be reinvested in transportation improvements. The remainder is allocated to the category “indirect/other”.

To-date, the TRECH Project team has analyzed five illustrative TCI policy scenarios compared to a no-TCI policy scenario in 2032. The policy scenarios represent three carbon dioxide (CO_2) emissions reduction caps and three investment and policy mixes defined by states participating in the TCI process.

Five Illustrative TCI Policy Scenarios

	Scenario A -Diversified 25% GHG cap	Scenario B - Hybrid 20, 22, 25% GHG cap	Scenario C - MaxGHG 25% GHG cap
Electric cars, light trucks and vans	5%	30%	54%
Low & zero-emission buses and trucks	21%	23%	27%
Transit expansion and upkeep	35%	18%	-
Pedestrian and bike safety, ride sharing	16%	14%	10%
System efficiency	7%	8%	8%
Indirect/ Other	17%	8%	-

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The three investment and policy mixes for the illustrative TCI scenarios examined here represent an emphasis on public transit and active mobility (Scenario A), an emphasis on vehicle electrification and fuel-switching (Scenario C), and a blend between the two (Scenario B).

The three caps examined here represent a 20%, 22%, and 25% CO_2 emissions reduction from on-road vehicles from 2022 levels by 2032. This equates to a 1%, 3%, and 6% reduction in emissions between a no-TCI reference scenario and the TCI policy scenarios in 2032. For this research update, Scenario B was modeled with all three caps. Scenarios A and C were modeled with the 25% CO_2 emissions reduction cap. Additional scenarios will be analyzed in phase 2 of the TRECH Project. For more details, see the TCI reference and policy scenario assumptions and the TCI strategy investment tool.

A Few Caveats

- The TCI policy scenarios examined here are illustrative, not predictive, and are for the purpose of informing program design. Actual health benefits will depend on state actions.

- The scenarios assume that 83% to 92% of proceeds are reinvested in the transportation system.
- The analysis focuses on on-road emissions and does not directly incorporate potential changes in emissions from the electrical grid. A basic screening analysis was conducted of potential grid effects.
- The air quality analysis was conducted at a 12 kilometer by 12-kilometer scale, which is much smaller than a county but larger than a neighborhood. This is highly detailed for a regional analysis but is not intended for examining changes at a neighborhood scale.
- The analysis does not include climate-related health benefits and potential transportation-related health benefits that could accrue from improving safety, noise pollution, traffic congestion, and access to jobs, healthcare, and education.

IV. A Deeper Dive

Active Mobility Benefits

The TRECH Project team used the World Health Organization's Health and Economic Assessment Tool (HEAT) to estimate changes in mortality from changes in physical activity as a result of new investments in biking and walking infrastructure as well as public transit (public transit use increases walking). The analysis was conducted for the five illustrative TCI policy scenarios compared to a no-TCI reference scenario in the year 2032. The preliminary findings are summarized below.

- The estimated net deaths avoided from increased activity range from 200 to 770 under the five illustrative TCI policy scenarios in 2032. The monetized value of these health benefits span $1.8 billion to $7.4 billion (2016$)(Table 2).

- Scenario A with the 25% CO_2 emissions reduction cap has the largest estimated active mobility benefits. This scenario combines the highest total proceeds and the largest share of investments dedicated to biking and walking infrastructure and public transit of the scenarios examined here.

Table 2: Estimated Mortality Benefits from Active Mobility for Five Illustrative TCI Policy Scenarios Compared to a No-TCI Reference Scenario in 2032

	Scenario A 25% CO_2 Reduction Cap	Scenario B 25% CO_2 Reduction Cap	Scenario C 25% CO_2 Reduction Cap	Scenario B 22% CO_2 Reduction Cap	Scenario B 20% CO_2 Reduction Cap
Net deaths avoided from walking and cycling – central estimate (95% confidence interval)	770 (510, 1000)	640 (430, 840)	430 (270, 590)	390 (270, 520)	200 (130, 260)
Monetized health benefits from walking and cycling – central estimate (95% confidence interval)(billions of 2016$)	$7.4 ($3.1, $12)	$6.1 ($2.6, $9.6)	$4.1 ($1.7, $6.6)	$3.8 ($1.6, $5.9)	$1.8 ($0.8, $2.9)
Estimated TCI annual investments in biking and walking infrastructure (billions of 2016$)	$0.64	$0.51	$0.28	$0.26	$0.13

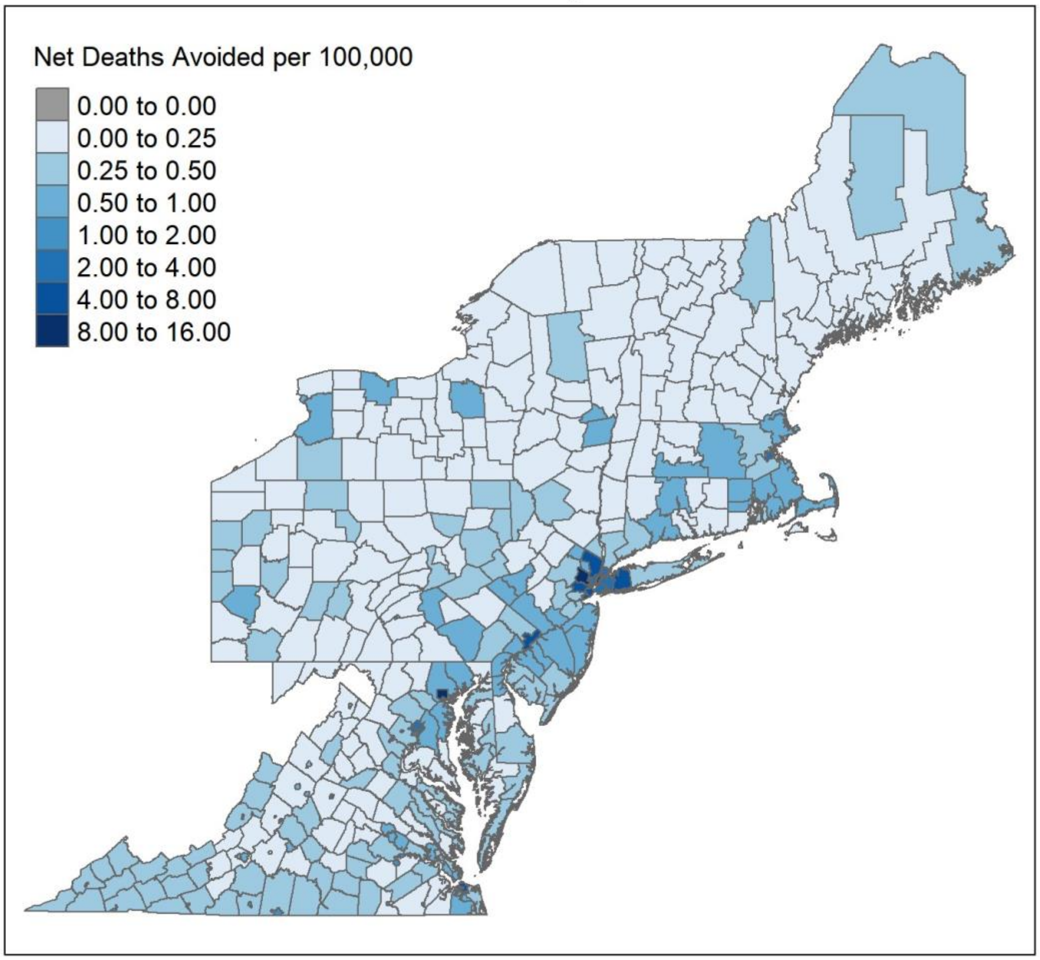
Table credit: M. Raifman, P. Kinney. Based on Raifman et al. In review.

- All counties in the region receive some active mobility benefits in all scenarios and the benefits are concentrated in more populated counties. This is due to the cost-effectiveness of investment in areas with large populations and high population density. The spatial pattern of benefits per 100,000 people for a mid-range scenario illustrates the pattern of "per capita" benefits, which is similar across the full set of scenarios (Figure 1; see technical appendix for additional scenarios).

- The mortality-related health benefits associated with investments in walking and biking infrastructure and public transit are larger than the health benefits from air quality improvements for a given scenario, underscoring the benefit of providing more opportunities for physical activity.

- The equity of the distribution of physical activity benefits by race/ethnicity, income, and education was not analyzed here but is an important policy consideration and a focus of future research.

Figure 1: Estimated Net Deaths Avoided per 100,000 People from Walking and Biking for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032



Map credit: M. Raifman, P. Kinney. Based on Raifman et al. In review.

<u>Air Quality Benefits</u>
The TRECH Project team used changes in vehicle miles traveled from Cambridge Systematics to estimate changes in on-road emissions, air quality, air pollution exposure, and health outcomes for the five illustrative TCI policy scenarios compared to a no-TCI reference scenario in 2032 (see the technical appendix for more details). Using the CMAQ model, estimates were generated for changes in fine particulate matter ($PM_{2.5}$), ozone, and nitrogen dioxide (NO_2) for each 12 km by 12 km grid cell across

the TCI region. The preliminary results below reflect changes in on-road emissions from light-duty autos, light-, medium-, and heavy-duty trucks, and buses. *Air Quality*

- Annual on-road emissions in the TCI region under the five TCI policy scenarios compared to a no-TCI reference scenario in 2032 are estimated to decrease by:

    - 2% to 6% for volatile organic compounds (VOCs)
    - 2% to 9% for nitrogen oxides (NO_X)
    - 2% to 7% for sulfur dioxide (SO_2)
    - 2% to 7% for ammonia (NH_3)
    - 2% to 7% for directly emitted particulate matter

- For the five TCI policy scenarios, all 12 km by 12 km grid cells are estimated to receive some air quality benefits compared to a no-TCI reference scenario. Specifically, population-weighted air pollution concentrations at the grid-cell level are estimated to change by:

    - -0.1 to -0.5% for $PM_{2.5}$
    - +0.2 to -0.34% for ozone
    - -0.7 to -7% for NO_2

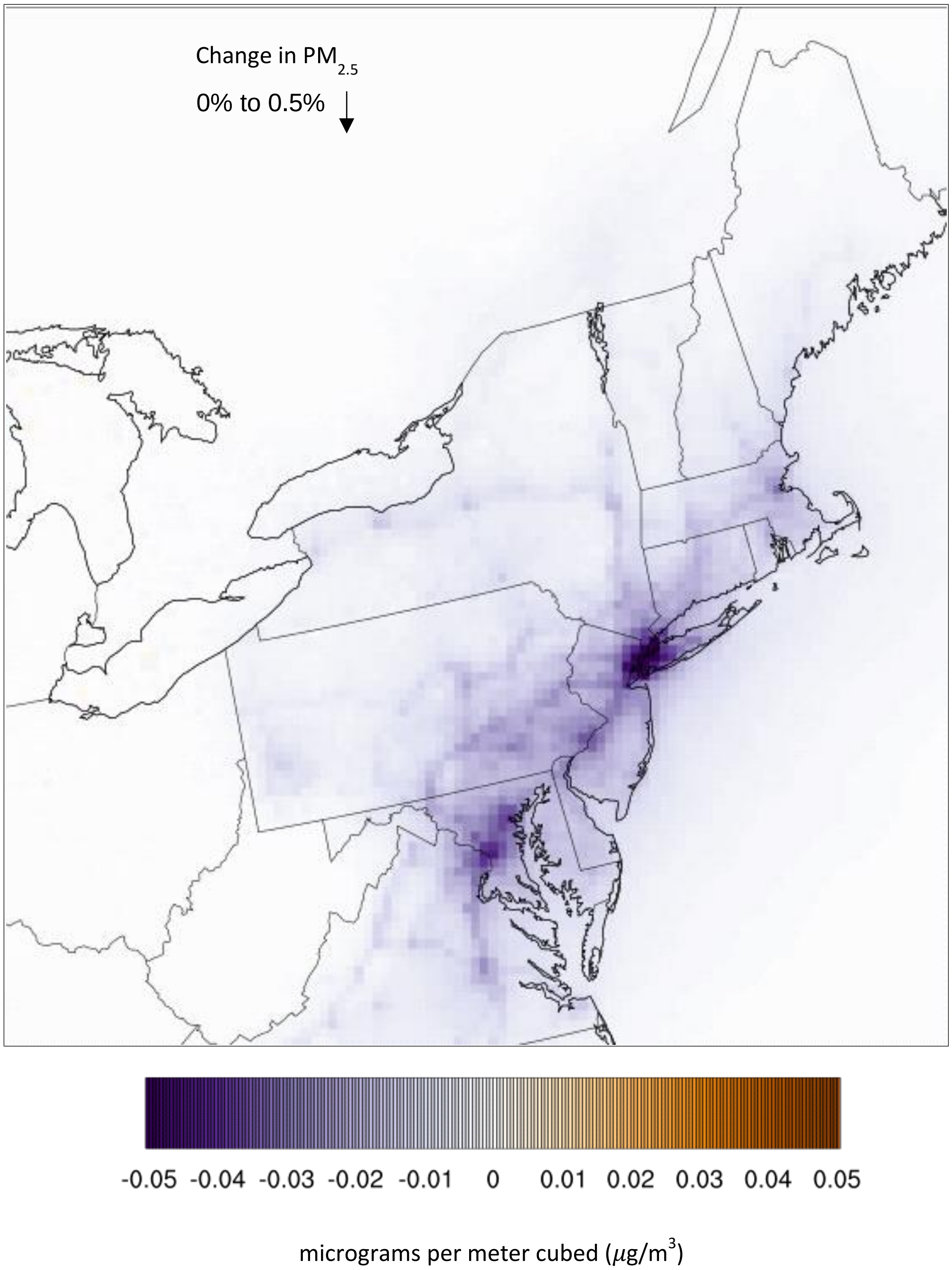
- Areas of modest increases in ozone concentrations that are associated with decreases in NO_x emissions from on-road sources were identified in some urban areas of the New York-New Jersey metropolitan statistical area. This seemingly counter-intuitive but well-understood impact occurs when reductions in NO_X emissions can increase ozone formation where there are high levels of VOCs. The health benefits of the $PM_{2.5}$ reductions outweigh the impacts of the ozone increases in these locations, resulting in net positive benefits.

- As shown in a mid-range policy scenario, the largest $PM_{2.5}$ reductions are projected to occur in cities and along interstate highways (Figure 2a). Ozone reductions are more widespread with the greatest reductions occurring across the Mid-Atlantic states of Delaware, Maryland, New Jersey, and Pennsylvania (Figure 2b). NO_2 improvements are most pronounced in Pennsylvania (Figure 2c).

- Scenario B with the 25% CO_2 reduction cap results in the largest estimated decrease in regional $PM_{2.5}$ concentrations. This scenario decreases vehicle miles traveled by 6% in non-electric light-duty autos and trucks, 7% in non-electric medium-duty trucks and gas/diesel heavy-duty trucks, and 42% in non-electric buses. This scenario also had the largest decrease (7%) in primary particulate matter emissions that contribute strongly to $PM_{2.5}$ concentrations.

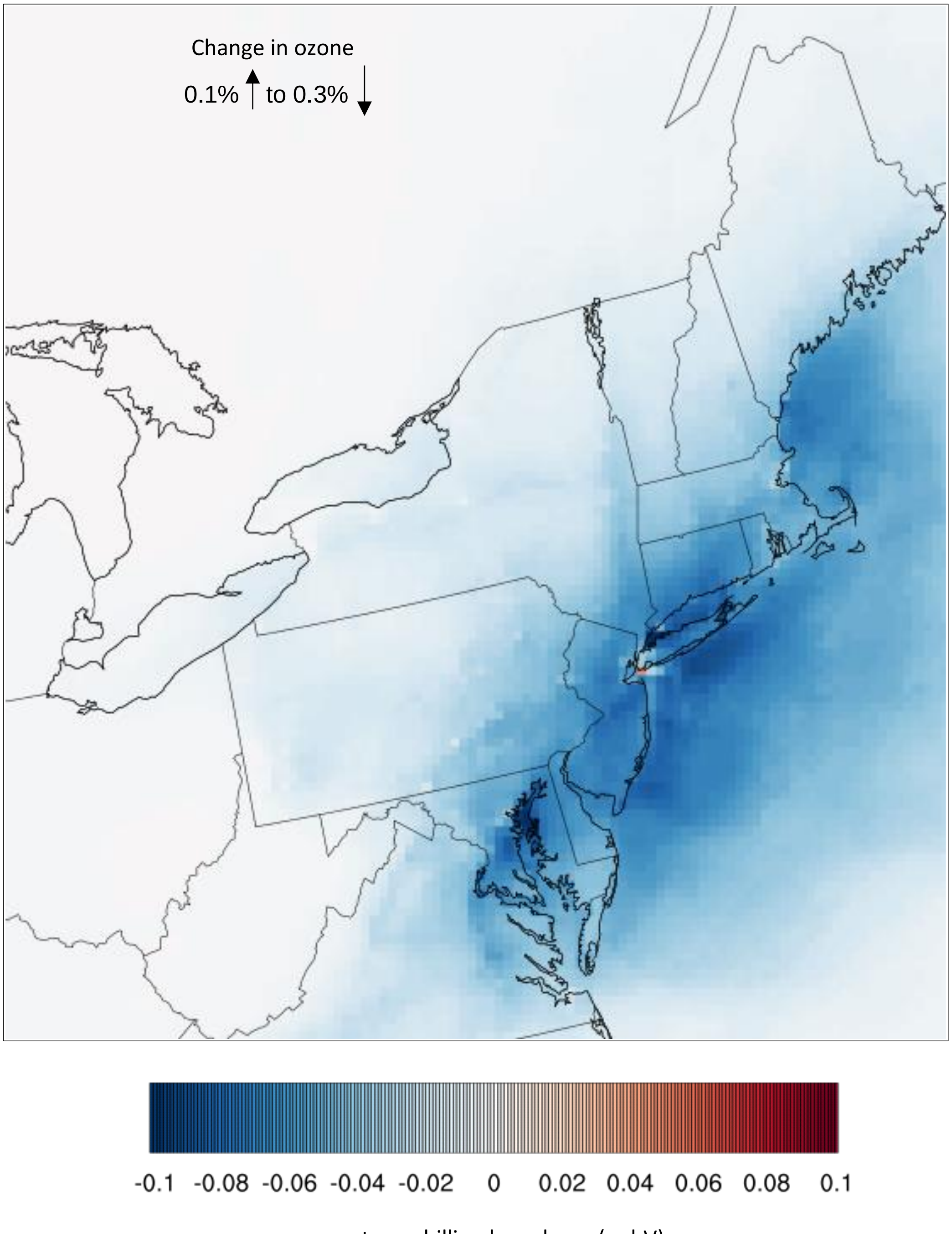
- Scenario A with the 25% CO_2 reduction cap also achieves the largest estimated decrease in regional ozone and NO_2 concentrations. This scenario achieves the largest reduction in vehicle miles traveled by non-electric buses (67%) and gas/diesel heavy duty trucks (11%).

Figure 2a: Estimated Changes in $PM_{2.5}$ Concentrations for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032



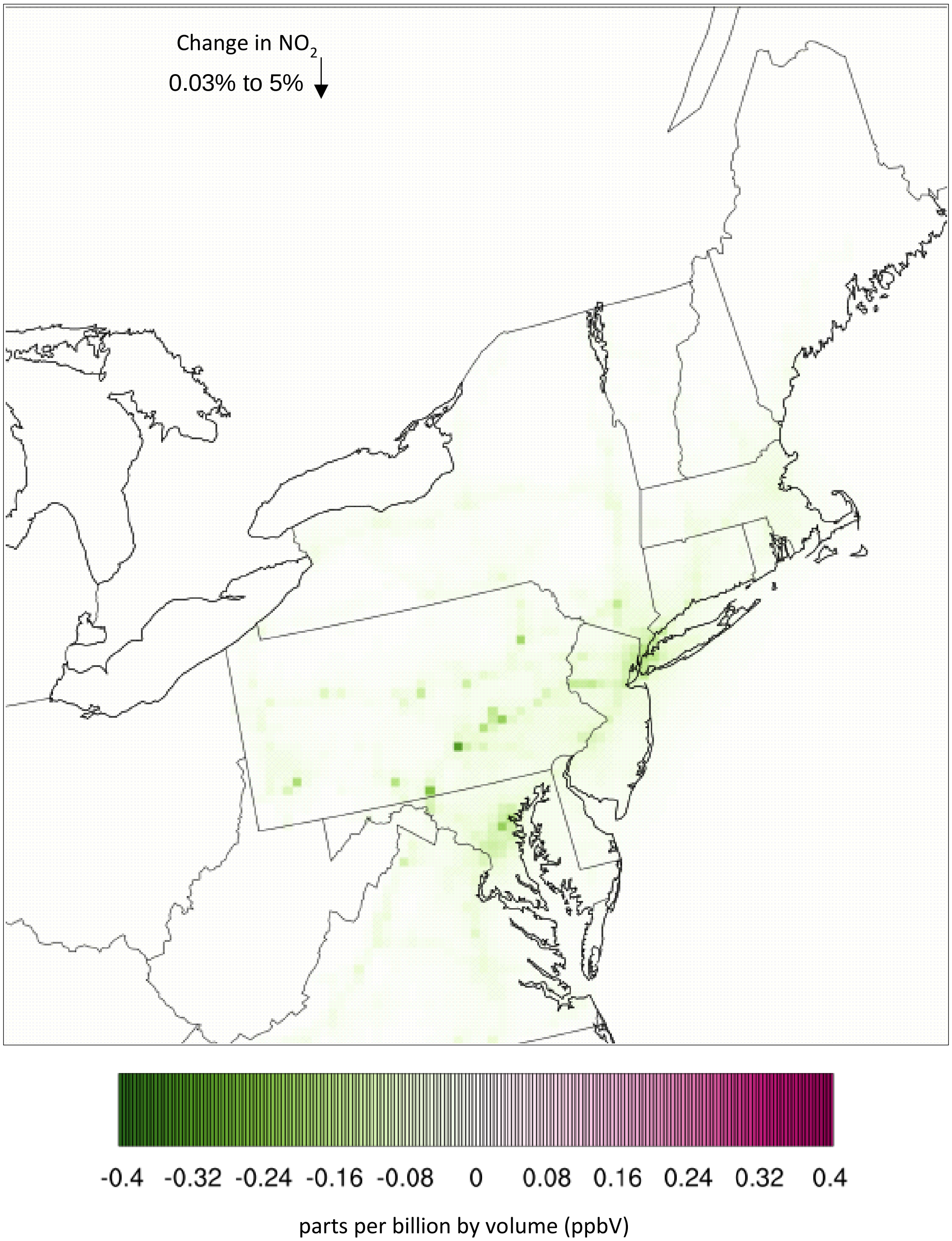
Map credit: C. Arter, S. Arunachalam. Based on Arunachalam et al. In prep.

Figure 2b: Estimated Changes in Ozone Concentrations for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032



Map credit: C. Arter, S. Arunachalam. Based on Arunachalam et al. In prep.

Figure 2c: Estimated Changes in NO_2 Concentrations for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032



Map credit: C. Arter, S. Arunachalam. Based on Arunachalam et al. In prep.

Air Pollution and Equity

The TRECH Project team assessed changes in air pollution exposure for different population groups to understand how implementation of the TCI scenarios would impact persistent disparities in air pollution exposure and related health outcomes across different race/ethnicity, income, and education groups.

- Using air quality results from the mid-range Scenario B with a 25% CO_2 reduction cap as an example, this investment strategy is estimated to yield a 0.24% decrease in total population-weighted exposure to $PM_{2.5}$ across the region in comparison to no-TCI reference scenario in 2032 (Table 3). The average percent decrease across groups is higher for Hispanic and Non-Hispanic Black populations, with an average 0.3% decrease, compared to a 0.2% decrease for Non-Hispanic White populations. Similarly, Scenarios A and C with a 25% CO_2 reduction cap also result in greater relative $PM_{2.5}$ concentration decreases for the Hispanic and Non-Hispanic Black populations than the non-Hispanic White population.

Table 3: Estimated Population-weighted Exposure to $PM_{2.5}$, NO_2, and Ozone for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032

	$PM_{2.5}$ (µg/m$_3$) in 2032			NO_2 (ppb) in 2032			Ozone (ppb) in 2032		
	No-TCI Reference Scenario	TCI Scenario B 25% CO_2 Reduction Cap	% Decrease	No-TCI Reference Scenario	TCI Scenario B 25% CO_2 Reduction Cap	% Decrease	No-TCI Reference Scenario	TCI Scenario B 25% CO_2 Reduction Cap	% Decrease
Total population	7.94	7.92	0.24	4.48	4.43	1.14	36.34	36.30	0.11
Non-Hispanic White population	7.36	7.34	0.21	3.64	3.60	1.14	36.12	36.08	0.10
Non-Hispanic Black population	9.39	9.37	0.29	6.51	6.44	1.14	37.27	37.23	0.12
Hispanic population	9.90	9.87	0.31	7.42	7.34	1.13	36.75	36.70	0.13
Other populations	9.32	9.29	0.29	6.43	6.35	1.14	36.69	36.64	0.12

Table credit: L. Buckley, J. Levy.

- Using the Atkinson Index, an inequality measure that characterizes between-group inequality across the distribution, Scenario A and Scenario B with a 25% CO_2 reduction cap result in similar decreases in inequality between racial/ethnic groups, with a lesser reduction for Scenario C, which also had lower total health benefits.

- The modeled population-weighted average exposures to the pollutants displayed in Table 2 illustrate that while Hispanic and non-Hispanic Black populations, on average, are estimated to see slightly larger decreases in pollution, these communities would still face higher overall exposures to $PM_{2.5}$, NO_2, and ozone in 2032, even with the reductions estimated under the illustrative TCI policy scenarios.

- Therefore, while the TCI scenarios are estimated to result in some equity benefits compared to a no-TCI reference scenario in 2032, more pollution reductions would be needed to address longstanding inequities and related health outcomes.

Air Quality Health Outcomes

The TRECH Project team estimated changes in eight health outcomes from changes in $PM_{2.5}$, NO_2, and ozone due to on-road emissions for the five TCI policy scenarios compared a no-TCI reference scenario in 2032. The resulting county-level estimates are based on estimates from a customized version of the U.S. Environmental Protection Agency's BenMAP tool (see the technical appendix for modeling details). The estimated health benefits include outcomes for both adults and children. The preliminary findings are summarized below.

- The TRECH Project analysis shows that on-road emissions in the TCI region contributed to an estimated 10,000 premature deaths from air pollution in the TCI region in 2016. The largest number of estimated premature deaths occurred in New York (2,930), Pennsylvania (1,760), and New Jersey (1,640)(Figure 3). $PM_{2.5}$ pollution accounted for one-half of the estimated deaths, ozone accounted for 20%, and NO_2 accounted for 30% regionwide in 2016.

Figure 3: Estimated Air Pollution-related Deaths from On-road Emissions in the TCI Region, 2016

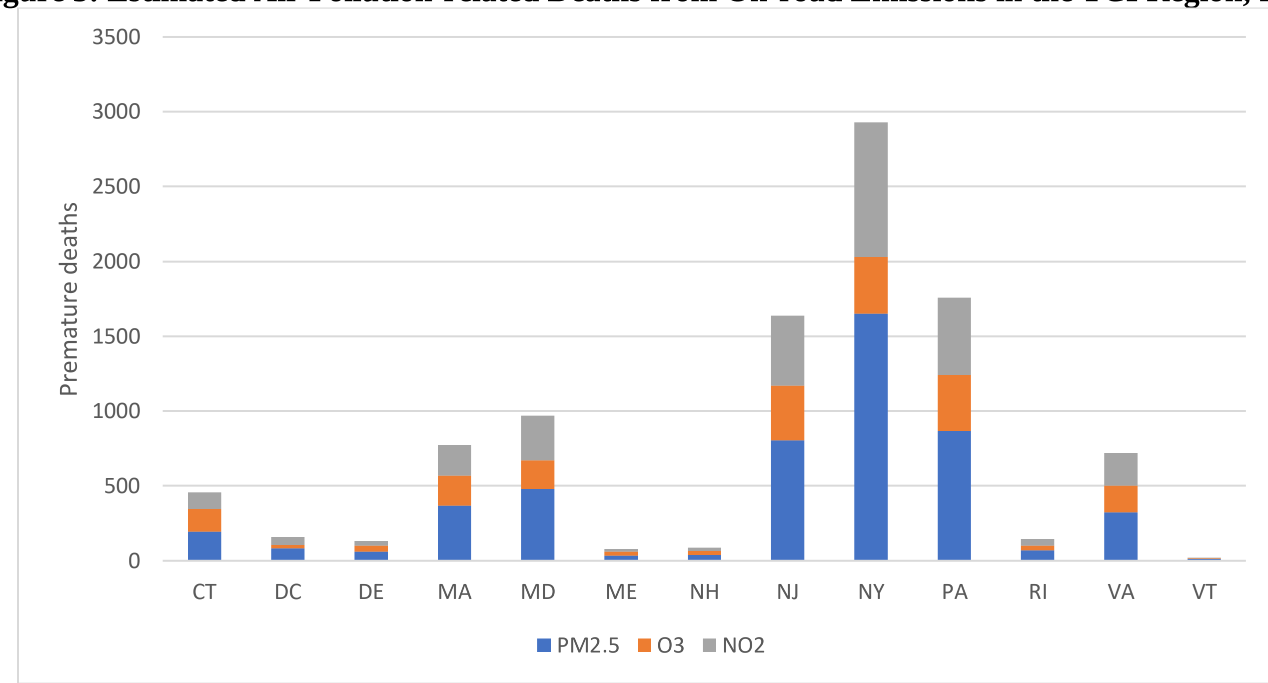


Figure credit: C. Arter, S. Arunachalam.

- The five illustrative TCI policy scenarios are estimated to avoid 80 to 330 premature deaths regionwide from changes in on-road emissions compared to a no-TCI reference scenario in 2032 (Table 4). This represents a 2% to 8% reduction from estimated deaths from air-pollution related deaths from on-road vehicle emissions in the TCI region in 2032. The estimated reduction in cases of childhood asthma range from 980 to 4700 regionwide for the TCI policy scenarios (see technical appendix for state-level results).

- Scenario A with the 25% CO_2 reduction cap has the largest air quality-related health benefits from changes in on-road emissions, followed closely by Scenario B with the 25% CO_2 reduction cap. These scenarios have considerably lower investments in electric vehicles and fuel-switching than Scenario C, suggesting that mode switching from vehicles to active mobility and public transit can drive high air quality benefits in addition to physical activity benefits.

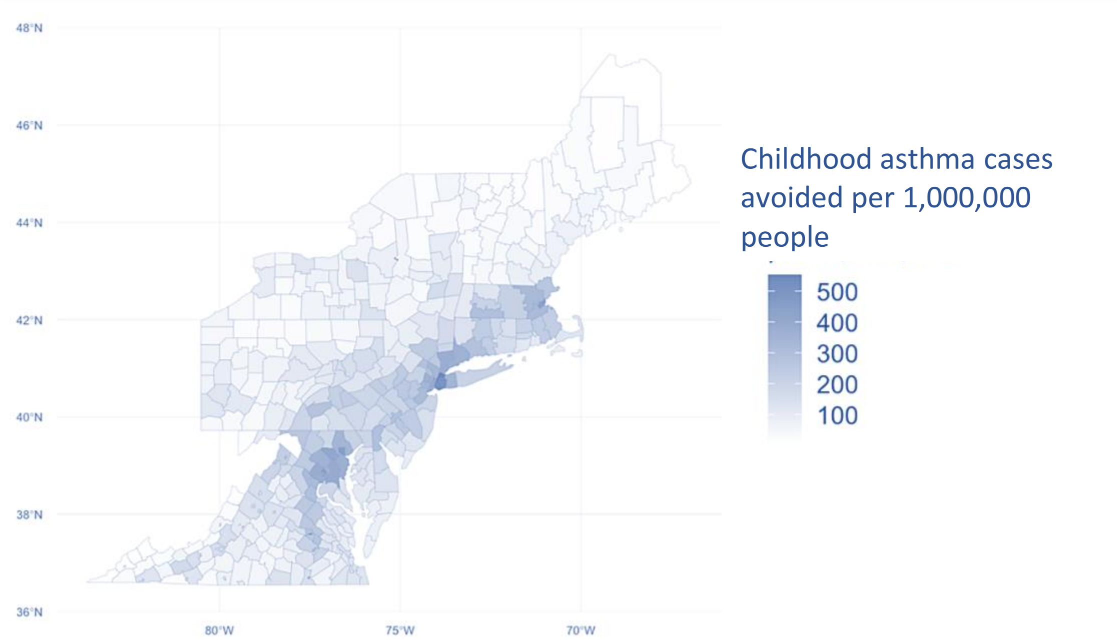
- Under all TCI policy scenarios, all counties are projected to see health benefits from air quality improvements and the largest benefits are concentrated in more populated areas. Figures 4 and 5 show per capita results for a mid-range scenario, Scenario B with a 25% CO_2 reduction cap. The spatial patterns are similar under other scenarios (see technical appendix for additional scenarios).

Table 4: Estimated Air Quality-related Health Benefits for Five Illustrative TCI Policy Scenarios Compared to a No-TCI Reference Scenario in 2032

	Scenario A 25% CO_2 Reduction Cap	Scenario B 25% CO_2 Reduction Cap	Scenario C 25% CO_2 Reduction Cap	Scenario B 22% CO_2 Reduction Cap	Scenario B 20% CO_2 Reduction Cap
Childhood asthma cases avoided – central estimate (95% confidence interval)	4700 (1900, 7200)	4100 (1600, 6400)	3300 (1300, 5200)	2000 (770, 3100)	980 (380, 1500)
Premature deaths avoided – central estimate (95% confidence interval)	330 (220, 470)	310 (220, 430)	270 (190, 360)	150 (110, 210)	80 (54, 110)
Respiratory hospitalizations avoided – central estimate (95% confidence interval)	37 (22, 51)	33 (22, 44)	27 (19, 6)	16 (11, 21)	8 (5, 11)
Total estimated monetized air quality benefits – central estimate (95% confidence intervals) (billions 2016$)	$3.7 ($2.2 , $4.8)	$3.4 ($2.2, $4.8)	$2.9 ($2.0, $4.0)	$1.7 ($1.2 , $2.4)	$0.8 ($0.6, $1.2)

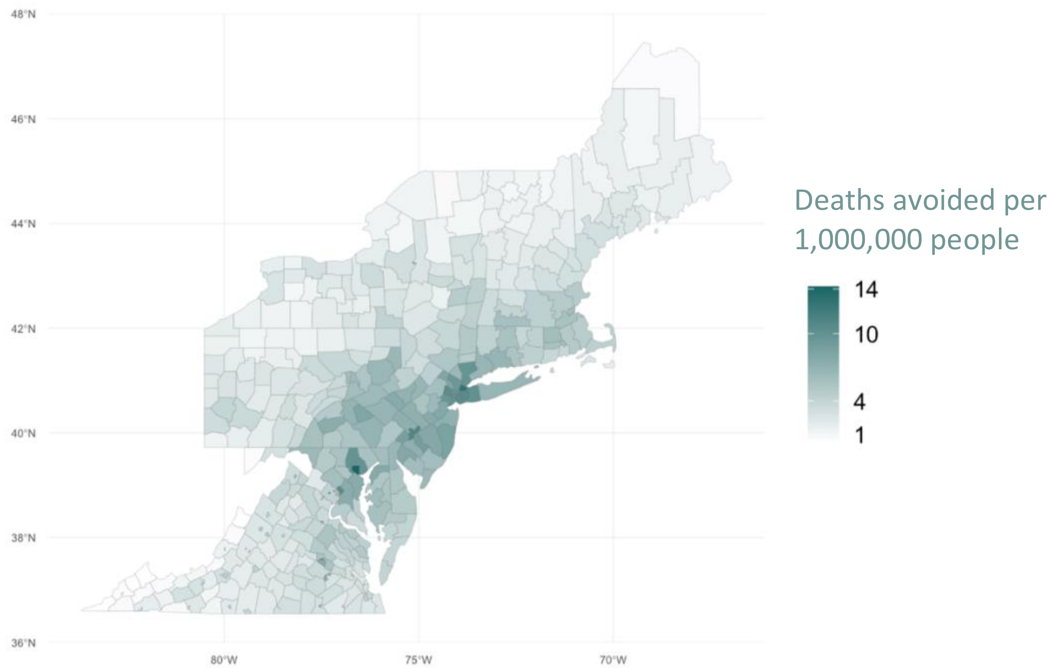
The total estimated monetized health benefits included additional benefits associated with avoided heart attacks, low-birth weight, pre-term birth, and autism in children. *Table credit: J. Buonocore, F. Perera, A. Berberian.*

Figure 4: Estimated Asthma Cases Avoided (Ages 0-18) per Million People for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032



Map credit: J. Buonocore, F. Perera, A. Berberian

Figure 5: Estimated Deaths Avoided per Million People for Scenario B with a 25% CO_2 Reduction Cap Compared to a No-TCI Reference Scenario in 2032



Map credit: J. Buonocore.

- The preliminary TRECH Project results focus on changes in on-road emissions. The potential exists for the adoption of electric vehicles in the TCI policy scenarios to increase emissions from the electrical grid. While analyzing emissions "bounce back" was beyond the scope of this study, screening calculations were conducted to estimate the potential for adverse health effects. Results for Scenario B with a 25% CO_2 reduction cap suggest that the average annual health impact of estimated emissions increases from the electrical grid across the full eastern U.S. is roughly an order of magnitude less than the health benefits for that scenario, though year-to-year differences may vary. Additional analysis is underway to estimate the combined air quality effects of transportation and electricity sector emissions changes and to project where impacts are likely to occur.

- The estimated mortality benefits associated with decreases in $PM_{2.5}$ and ozone from changes in on-road emissions for the five illustrative TCI policy scenarios range from 12 to 27 deaths avoided for every million tons of CO_2 emissions reduced in 2032. Other studies of the $PM_{2.5}$ and ozone benefits from national power sector policies have estimated 3 to 7 premature deaths avoided per million metric tons of CO_2 abated (Driscoll et al. 2015). The relative effectiveness of on-road emissions reductions in delivering health benefits underscores the value of prioritizing pollution reduction from the transportation sector.

TRECH Project Technical Appendix

About the TRECH Project

The Transportation, Equity, Climate and Health (TRECH) Project is a multi-university research initiative conducting independent analyses of the potential health benefits of transportation climate mitigation policies, including TCI cap and invest scenarios. The TRECH Project team includes:

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