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The Distribution of Air Quality Health Benefits from Meeting US 2030 Climate Goals

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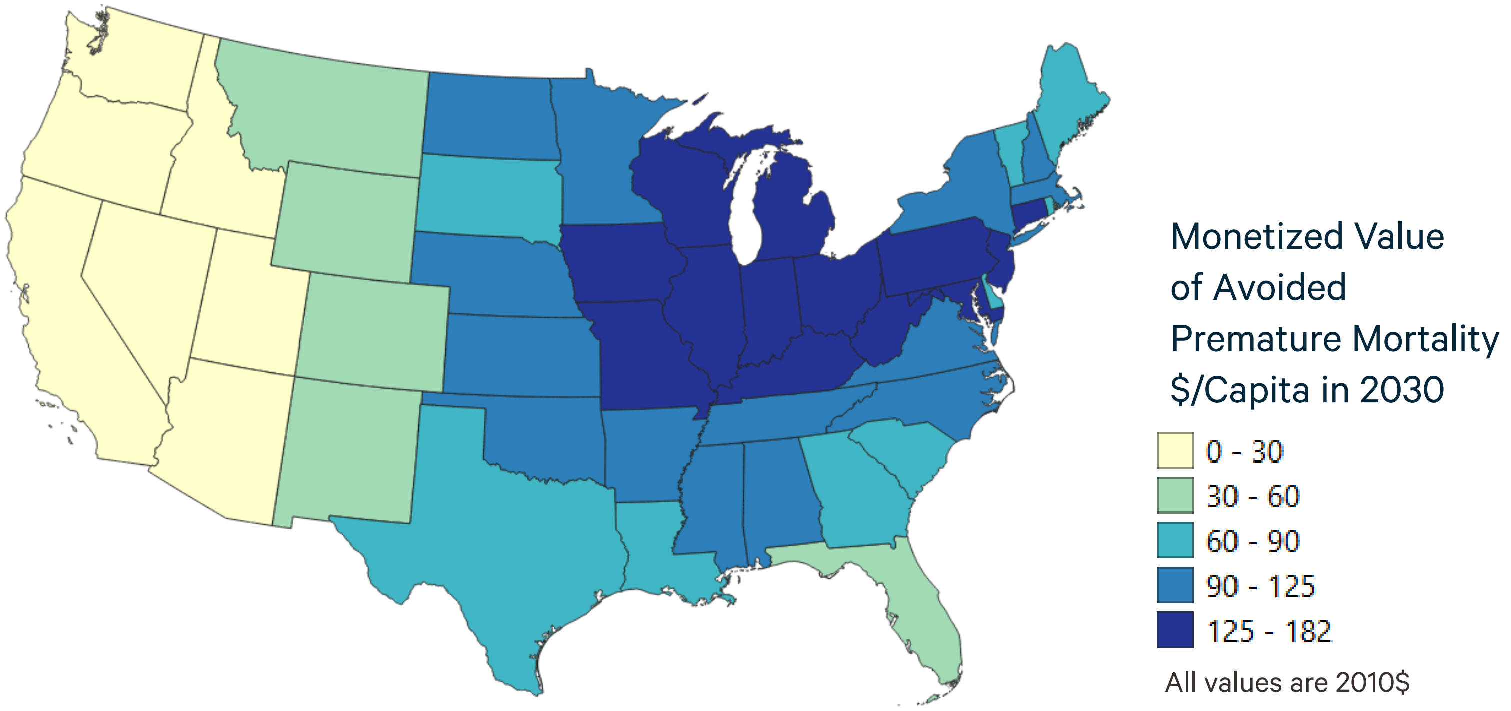
- **Respect**
- **Results**

PROJECT'S MAIN FINDING

Meeting US 2030 Climate Goals Would Yield Significant Health Benefits, and Benefits Would Be Experienced in Every State.

- This analysis quantifies the health benefits associated with reduced combustion of fossil fuels in 2030.
- We examine the distribution of health benefits across states, counties, and demographic groups.
- The monetized value of benefits in the upper Midwest is greater than $125/capita.
- This is a partial accounting of full benefits as it focuses only on avoided mortality from fine particulate matter.



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Kathy Fallon Lambert was at the Harvard T.H. Chan School of Public Health, Center for Climate Health, and the Global Environment (C-CHANGE).

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PROJECT DESCRIPTION

Assessing Health Benefits Associated with Reducing US Greenhouse Gases by 51 Percent Relative to 2005 Levels in 2030

We examine the change in annual premature deaths avoided resulting from reduced combustion of fossil fuels and associated reductions in pollutants that contribute to concentrations of fine particulate matter ($PM_{2.5}$).

Related effects from reductions in ozone, nitrogen dioxide (NO_2), and PM_{10}, and changes in other health outcomes are not included and would yield additional benefits, as would pollution reductions associated with reducing non-CO_2 greenhouse gases and greenhouse gases (GHGs) outside of the energy sector.

The policy scenario is a derivative of analysis supporting the EDF report *Recapturing US Leadership on Climate* (2021) conducted by the Rhodium Group using the National Emissions Modeling System (NEMS). The analysis examines a policy scenario that includes regulation, innovation, and cap-and-trade policies that in 2030 reduce US GHGs by 51 percent relative to 2005 and US energy-related CO_2 by 35 percent relative to 2005 levels.

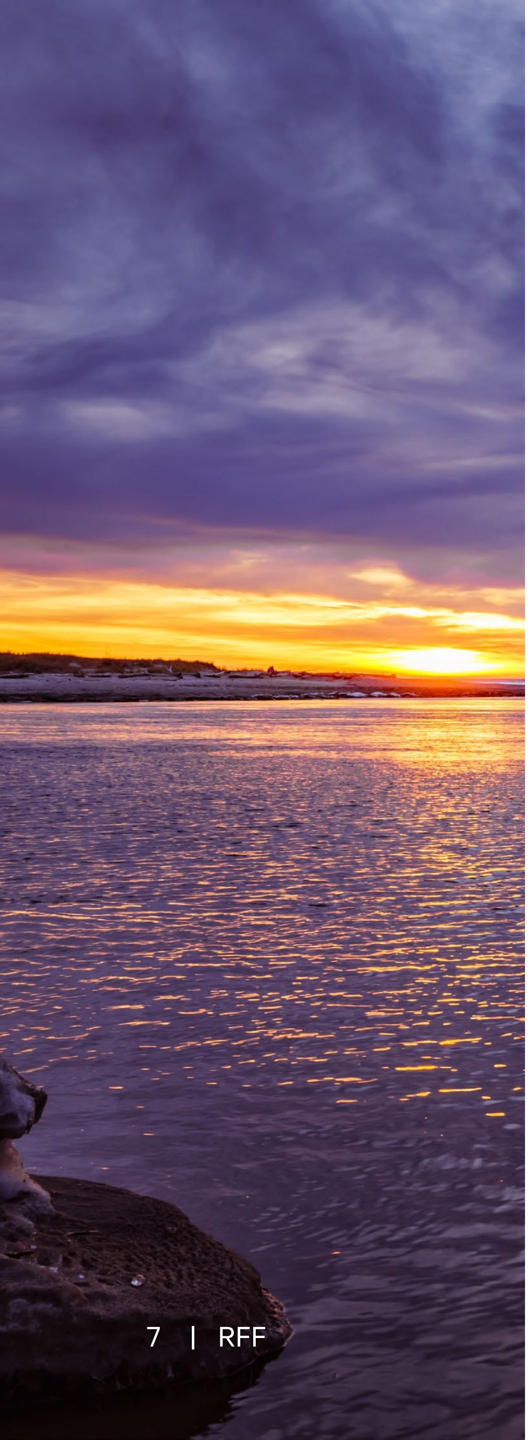
Changes in fossil fuel use and associated air quality changes were downscaled to the state and county level using datasets from the US Energy Information Administration and Environmental Protection Agency. Reduced complexity modeling of air quality changes and health impacts were conducted using EASIUR -- Estimating Air Pollution Social Impact Using Regression—built by Jinhyok Heo and colleagues. The distribution of health benefits across demographic groups was conducted using data from the US Census Bureau.

Health effects are based on Krewski et al. (2009) and valued at $8.6 million per premature mortality (2010$). The baseline mortality rate and concentration-response coefficients are general population averages and do not reflect differences that may apply importantly to specific groups. The downscaling links several models thereby compounding uncertainties, so individual county-level results may be less accurate than regional clusters. We hope further research will refine these findings. See the Methodology section for greater detail.

MAIN FINDINGS

Meeting US Climate Goals Would Yield Significant Air Quality Benefits in Every State

- The monetized value of health improvements nationally equals **$33 billion** in 2030 (2010$) and accumulate over years.
- Most health benefits result from pollution reductions in the electricity sector (mostly SO_2 and nitrous oxides, or NO_X), and secondly from transportation (mostly NO_X). Health benefits per unit CO2 reductions are largest for the industrial and transportation sectors.
- State-level reductions in premature mortality from fine particulate matter are greatest in the eastern United States and are greatest on a per capita basis in the Midwest. Reductions in premature mortality are lowest in the western United States where the electricity sector is already relatively clean.
- The distribution of health improvement is similar across income quintiles.
- The distribution of health improvement varies across racial and ethnic groups, influenced largely by their location of residence. The middle (median) US household in every racial and ethnic group realizes more than a 15 percent reduction in $PM_{2.5}$-related mortality.
- Estimates exclude expected benefits from reductions in ozone, PM_{10}, or NO_2; reductions in morbidity; and environmental improvements. They also exclude benefits from pollution reduction occurring outside of the energy sector, although such reductions play an important role in meeting 2030 targets.
- These findings provide a broad assessment of air quality benefits nationally, by state, and county. They do not inform outcomes at the community level, where some of the greatest environmental justice concerns exist. Those questions require detailed local analysis.



PROJECT ROAD MAP

- Environmental Defense Fund and Rhodium Group designed and modeled several policy scenarios that reduce US greenhouse gas emissions by 51 percent relative to 2005 levels by 2030. They modeled the energy-related CO_2 portion of those reductions using the **National Emissions Modeling System (NEMS).***
    - Results from NEMS describe changes in fuel use and CO_2 emissions by sector for nine census regions.
- Using the **State Energy Data System (SEDS)**, we downscale energy use (and CO_2 emissions) from census region to states .
- Using the **National Emissions Inventory (NEI)**, we downscale to counties.
    - Within each sector in each state, we assert a fixed historical relationship between CO_2 emissions and SO_2, NO_X, and ammonia emissions to estimate statewide SO_2, NO_X, and ammonia for each sector.
    - Within each sector for each county, we assert a fixed share of statewide SO_2, NO_X, and ammonia emissions and apply it to downscale statewide SO_2, NO_X, and ammonia to the county level.
    - Within each sector, we downscale changes in SO_2, NO_X, and ammonia emissions associated with state-level changes in energy use based on the county's historic share of each pollutant.
- Using the **EASIUR/APSCA** model, we estimate changes in premature mortality resulting from changes in secondary fine particulate matter ($PM_{2.5}$) at the county level.
- Using the **American Community Survey (ACS)**, we describe demographic characteristics of populations experiencing these changes at county level.

* See Environmental Defense Fund's NDC report. The baseline for this modeling comes from Rhodium's *Taking Stock 2019* report which is based on the AEO 2019 with updated technology costs from NREL.

POLICY SCENARIO

Reducing US GHGs Emissions to 51 Percent below 2005 Levels in 2030

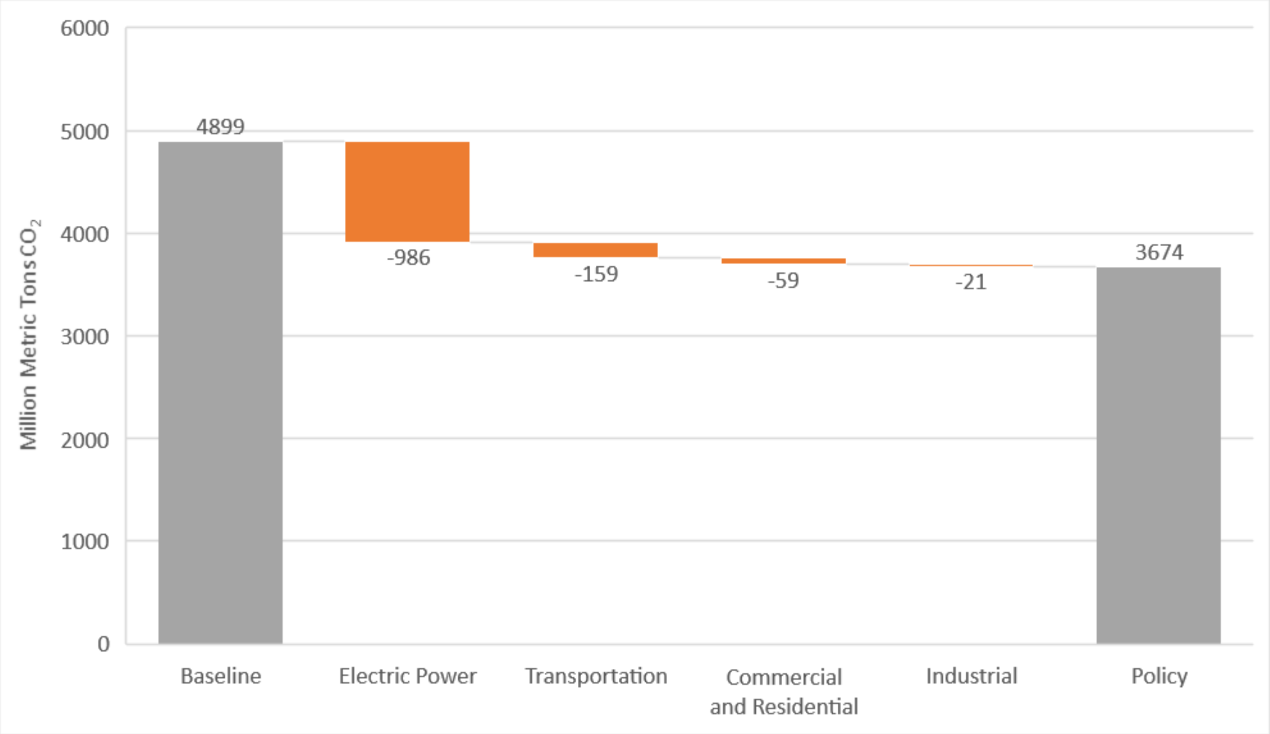
The policy scenario we examine combines cap-and-trade, regulations, and innovation policies to reduce total US GHG emissions 51 percent below 2005 levels in 2030 and energy-related CO_2 by 35 percent below 2005 levels in 2030.*

- **Cap-and-trade:** A federal economy-wide program beginning in 2022 with full auction, banking, and no revenue recycling guarantees emissions targets are achieved.
- **Regulation**:
  - In the electricity sector, regulation achieves a 70 percent emission reduction by 2030 compared to 2005 for new and existing sources.
  - In the transportation sector, regulatory policies include reinstated Obama-era light-duty vehicle standards; 20 percent ZEV sales by 2030 in CA+17 states and 2035 elsewhere; and 15 percent and 30 percent ZEV purchasing requirements in 2025 and 2030, respectively, for Class 4-8 trucks.
  - In the industrial sector, regulation requires a 25 percent reduction in GHG emissions in 2030 relative to baseline (excluding oil and gas as well as construction).
  - In the building sector, the National Energy Efficiency Resource Standard ramps up to 2 percent annual energy savings for electricity and 1 percent for natural gas by 2025.
- **Innovation:** Technology investments lower costs for renewables, energy storage and electric vehicles (EVs).

* This project analyzes the health benefits associated with CO_2 reduction from energy use only. While the full 51 percent GHG reduction in the EDF/Rhodium scenario occurs partially as a result of regulations affecting emissions from agriculture, landfills, oil and gas, and HFCs, we here describe only the policies that affect energy-related CO_2.

POLICY SCENARIO

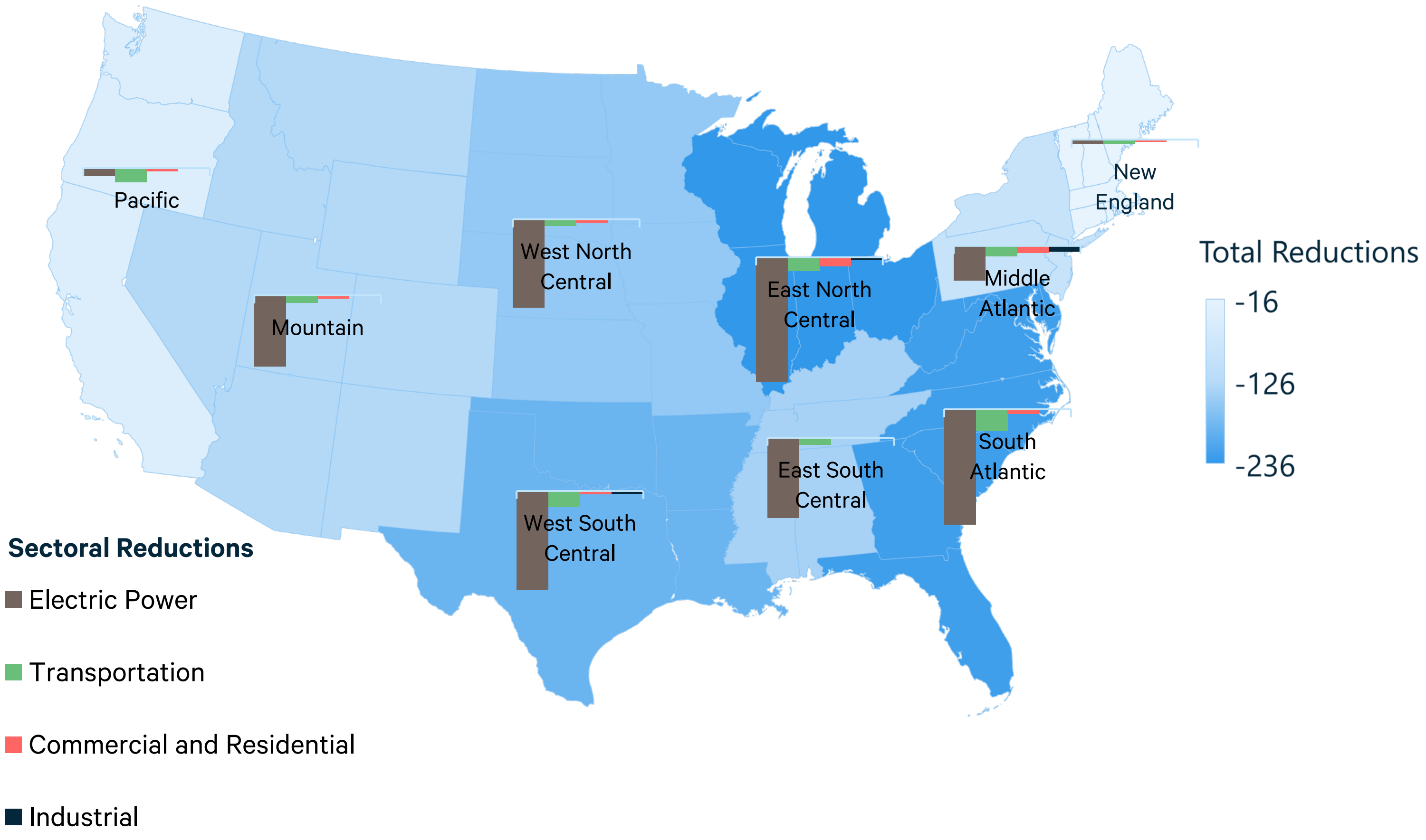
Economy-Wide CO_2 Emissions Reductions from Business as Usual in 2030



- Measured from 2030 business-as-usual baseline (rather than 2005 levels) the policy portfolio leads to CO_2 reductions of 1.225 billion tons (25 percent).
- The policy yields the greatest emissions reductions in the electricity sector.
- Light-duty vehicle efficiency standards and ZEV standards for light, medium, and heavy-duty vehicles reduce emissions and increase EV sales, but by 2030 those EV sales are not enough to substantially reduce emissions in the transportation sector.

POLICY SCENARIO

CO_2 Emissions Reductions from Baseline in 2030 (Million Metric Tons)

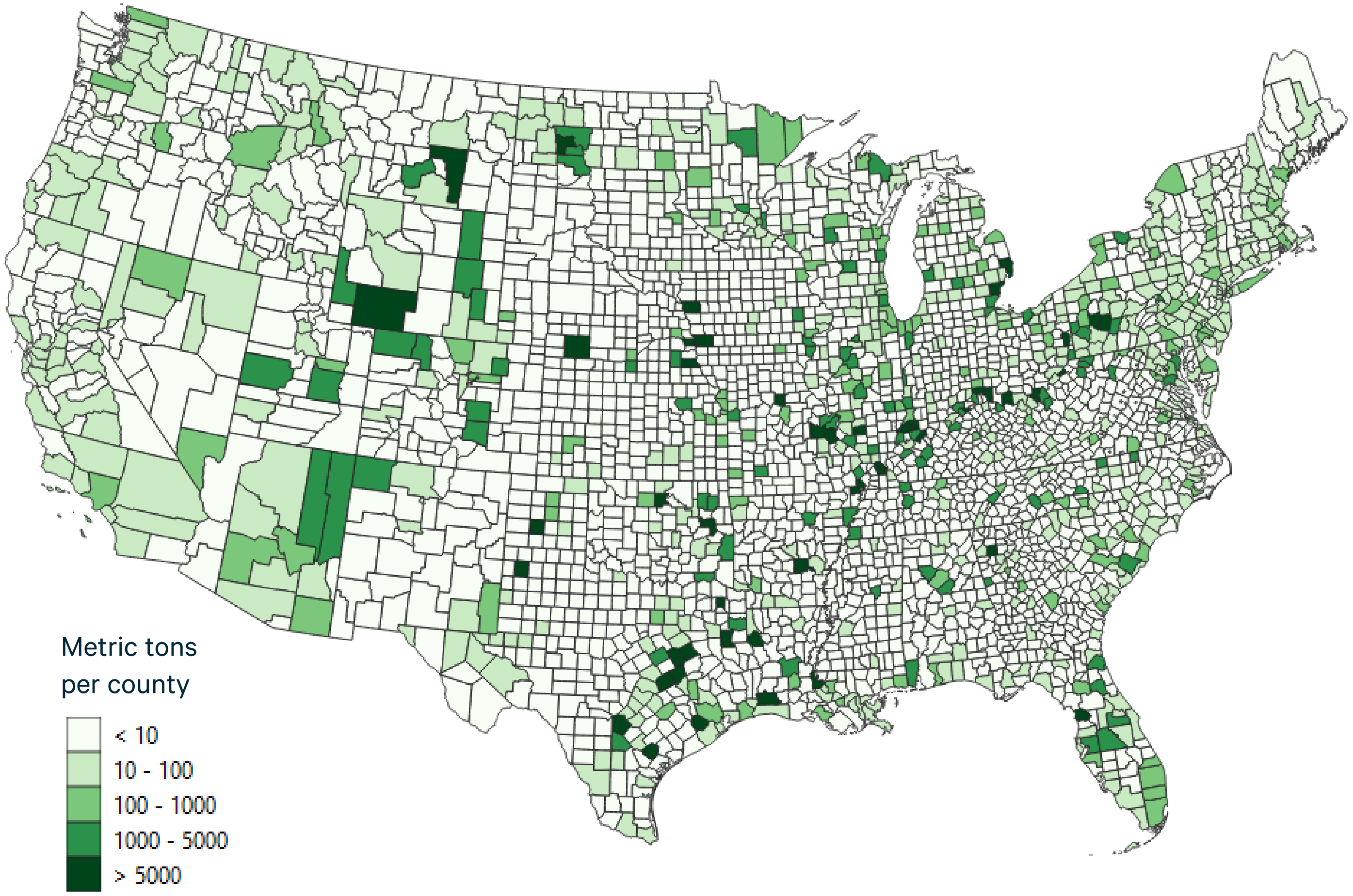


- CO_2 reductions occur across the United States and are especially concentrated in the upper Midwest and South Atlantic regions.
- The electricity sector is the largest source of emissions reductions in all regions, and the regions with the dirtiest electricity sectors see the largest reductions.
- The New England and Pacific regions, which already have the cleanest electricity sectors, see the lowest drop in emissions.

Distribution of Pollution Reductions from Meeting US Climate Goals

POLLUTION REDUCTIONS

Sulfur Dioxide (SO_2) Emission Decreases in 2030



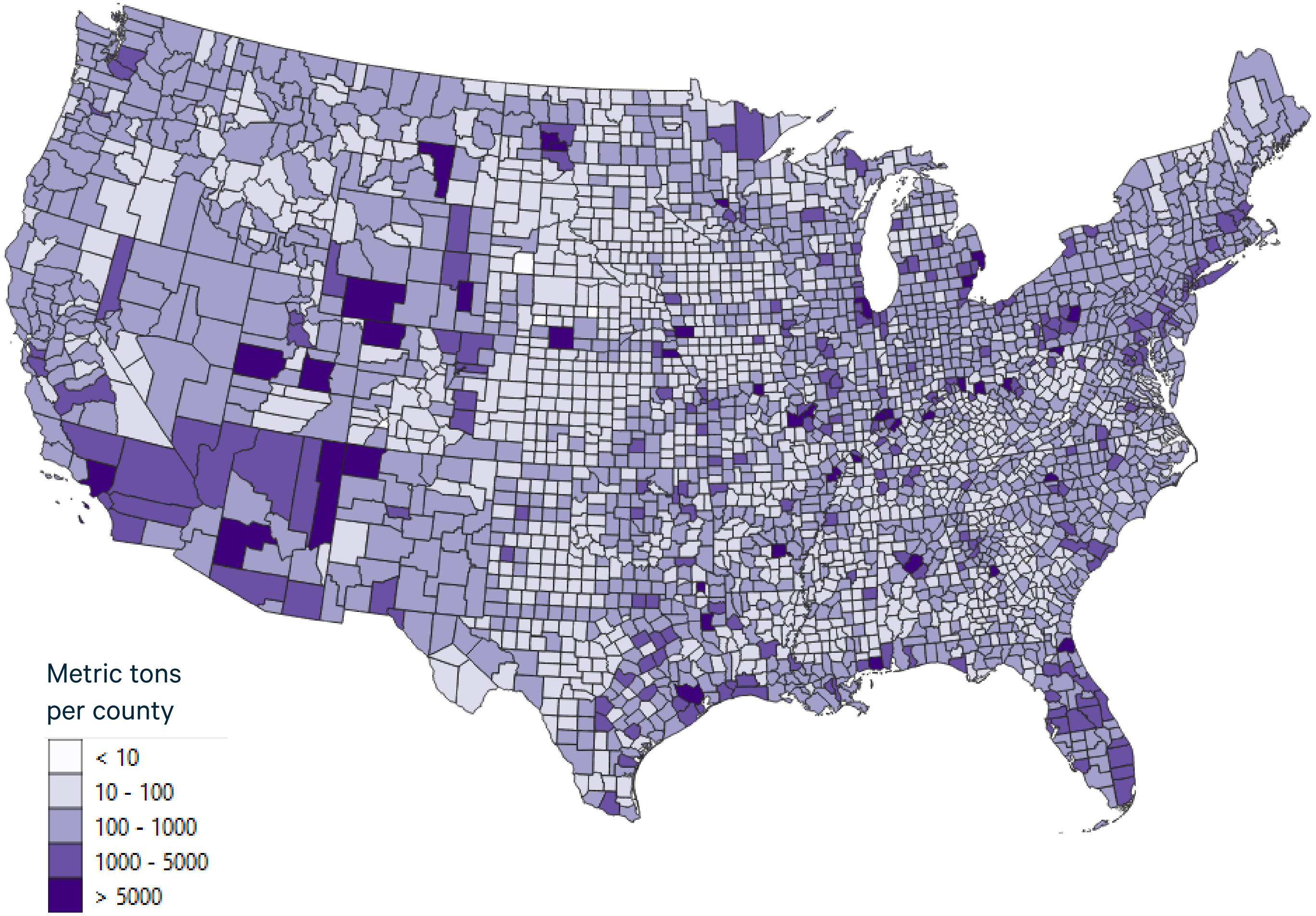
- SO_2 emissions contribute to the formation of fine particulates ($PM_{2.5}$ sulfates) which constitute the greatest air quality-related threat to public health.

- SO_2 is also a noxious gas, and deposition of sulfur contributes to acidification of the environment. These effects are not included here.

- The major sources of SO_2 are combustion of coal and oil in electricity generation and industry, and use of diesel in transportation.

POLLUTION REDUCTIONS

Nitrogen Oxides (NO_X) Emission Decreases in 2030

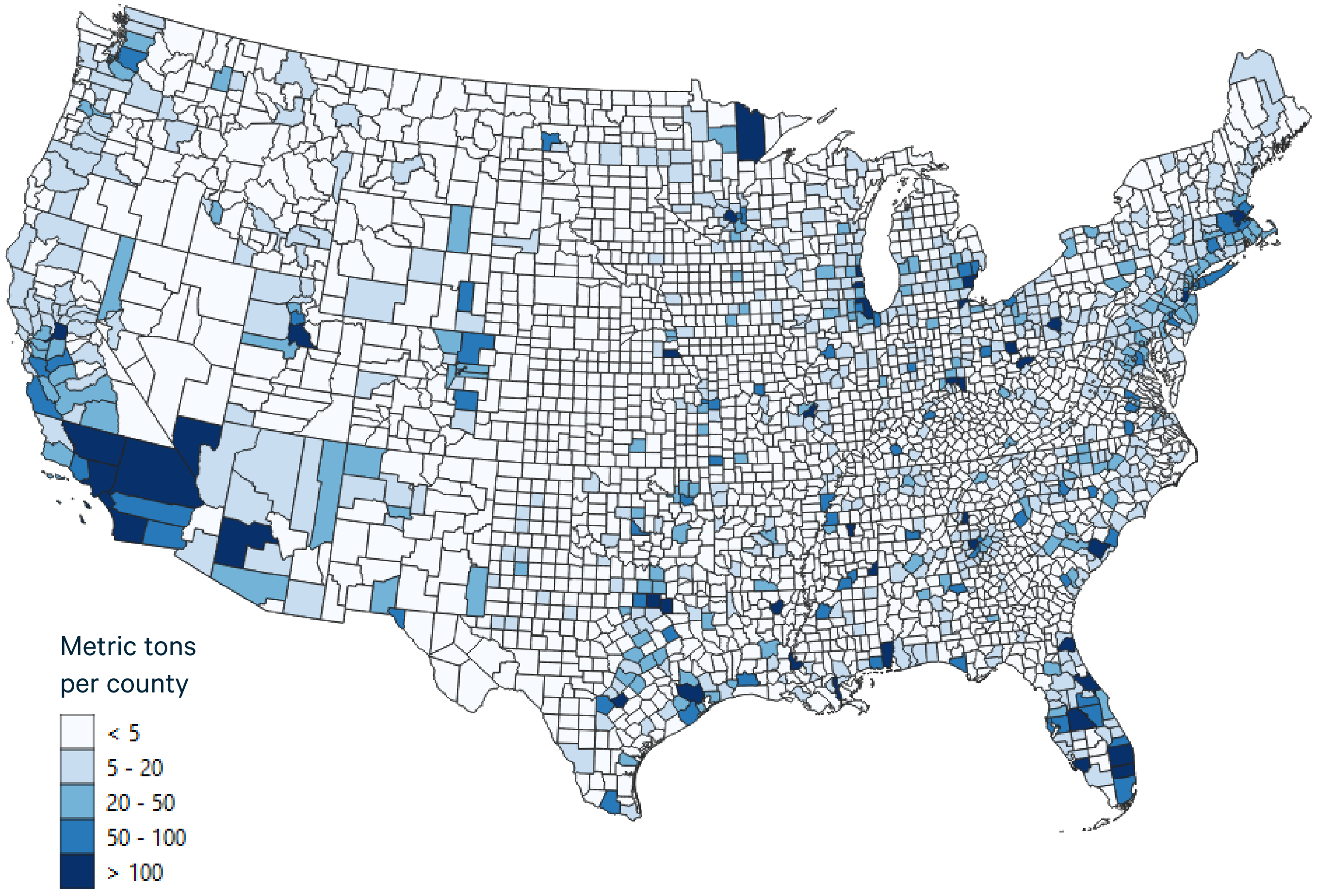


- NO_X emissions contribute to the formation of fine particulates ($PM_{2.5}$ nitrates).
- NO_X contributes to the formation of ground-level ozone, and deposition of nitrogen contributes to acidification of the environment. These effects are not included here.
- The major sources of NO_X are combustion of coal, fossil gas, and oil in electricity generation and industry, and fuel use in transportation, especially in trucks and older vehicles.

POLLUTION REDUCTIONS

Ammonia (NH_3) Emission Decreases in 2030*

** Excluding industrial NH_3*

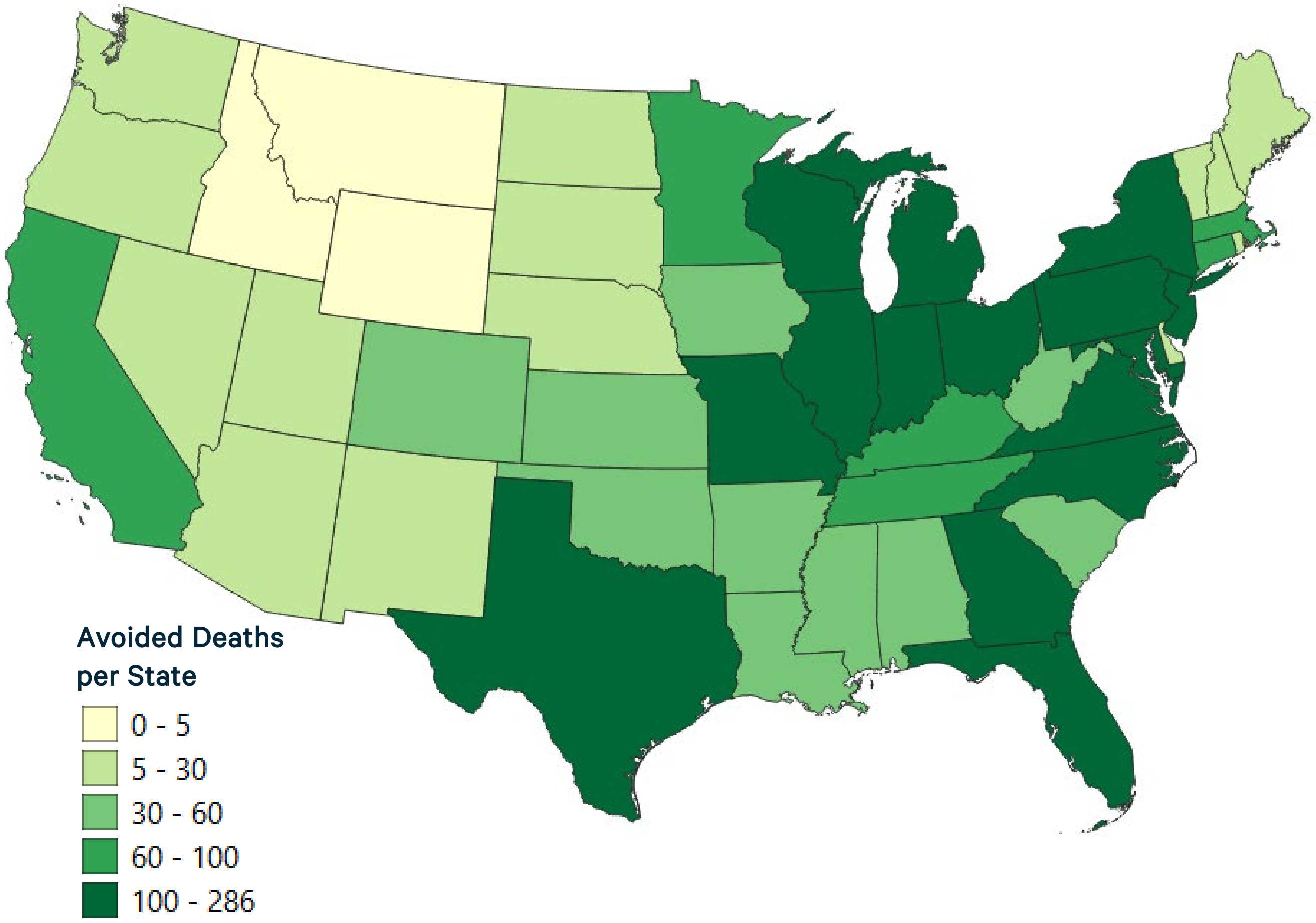


- NH_3 emissions combine with SO_2 and NO_X to form ammonium sulfates and ammonium nitrates ($PM_{2.5}$).
- NH_3 also contributes to acidification of the environment, can be directly toxic to plants, and contribute to nitrogen accumulation in the environment.
- The major sources of NH_3 are livestock waste and fertilizer applications, which are included in the industrial category. These sources are omitted from this study because they are not tracked by the NEMS model.
- Other sources of NH_3 include industry and vehicles.

Avoided Premature Mortality Impacts

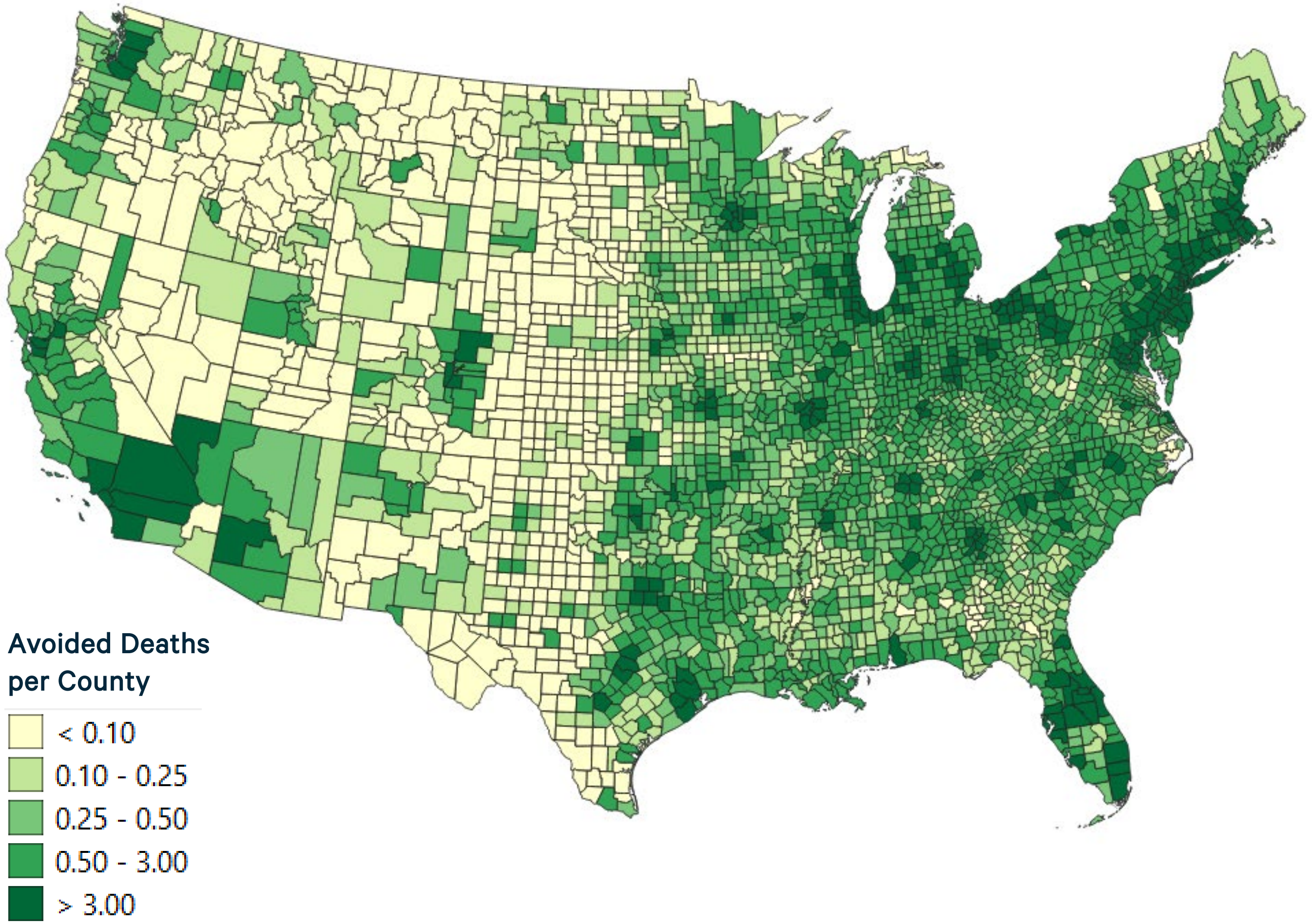
MORTALITY IMPACTS

Number of Premature Deaths Avoided in 2030 by State



- Reductions in $PM_{2.5}$ result in 3,794 premature deaths avoided in 2030.
- The greatest reductions in premature mortality are observed in the upper Midwest, New York, Texas, North Carolina, Georgia, and Florida.
- The benefits of reductions in other pollutants including ozone, NO_2, and PM_{10} are not included.

Number of Premature Deaths Avoided in 2030 by County



- Health benefits are most evident in population centers in the eastern United States.
- The larger the population of a county, the greater the health benefits that accrue to that county.
- Due to downscaling, county-level results may be more accurate in a regional cluster.

Number of Premature Deaths Avoided in 2030

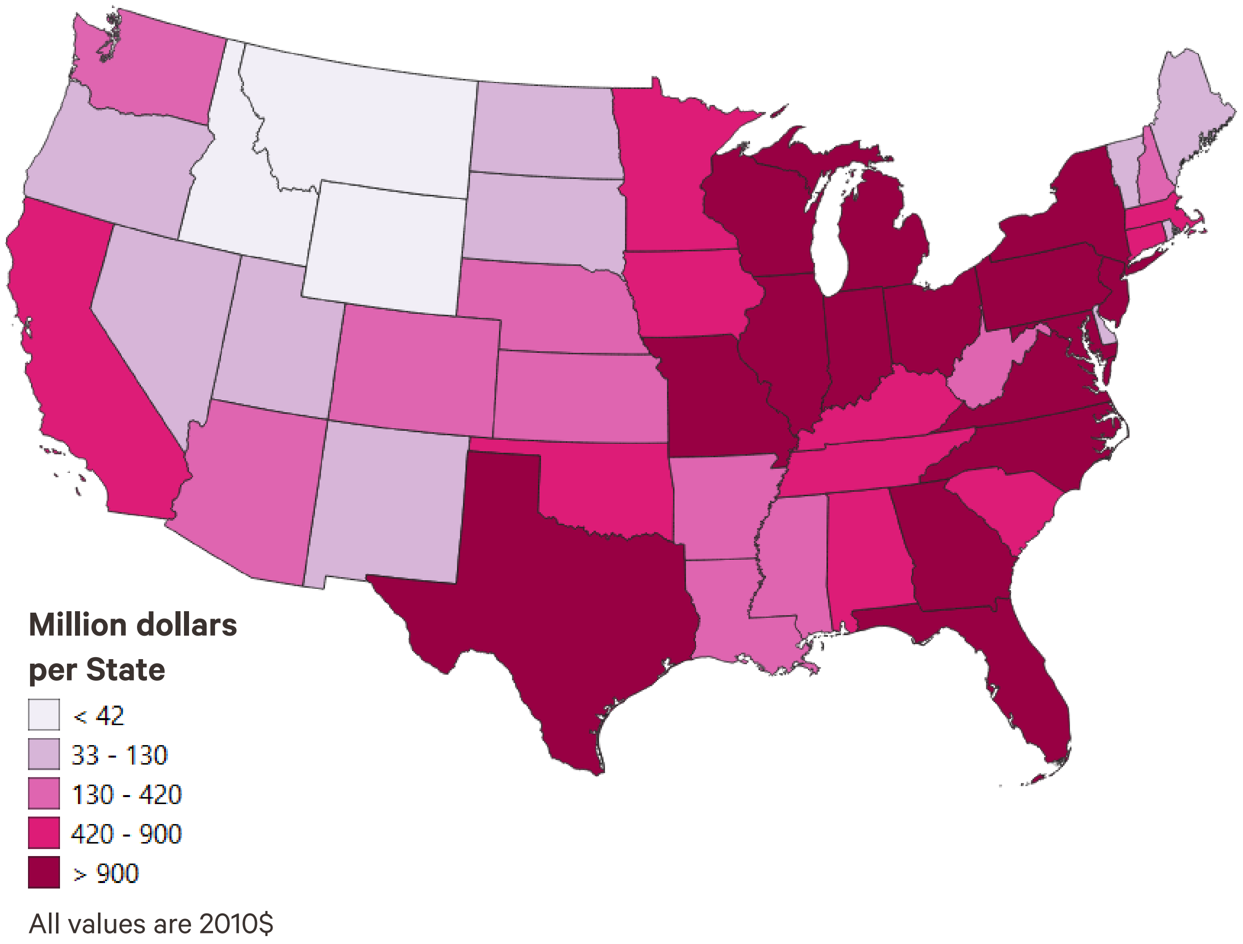
- Pollution reduction in the electricity sector accounts for most of the health improvement.
- The greatest health benefits per ton of CO_2 reduced are associated with reductions in the industrial sector.
- Only health benefits of reductions in fine particulates are included. Total benefits would be greater.

Effects at the Sector Level	Deaths Avoided	
	Total	Per million tons of CO_2 Reduced
Electric Power	2,645	2.7
Transportation	753	4.7
Commercial and Residential	265	4.5
Industrial	131	6.2
TOTAL	3,794	3.1

Monetized Health Benefits

MONETIZED HEALTH BENEFITS

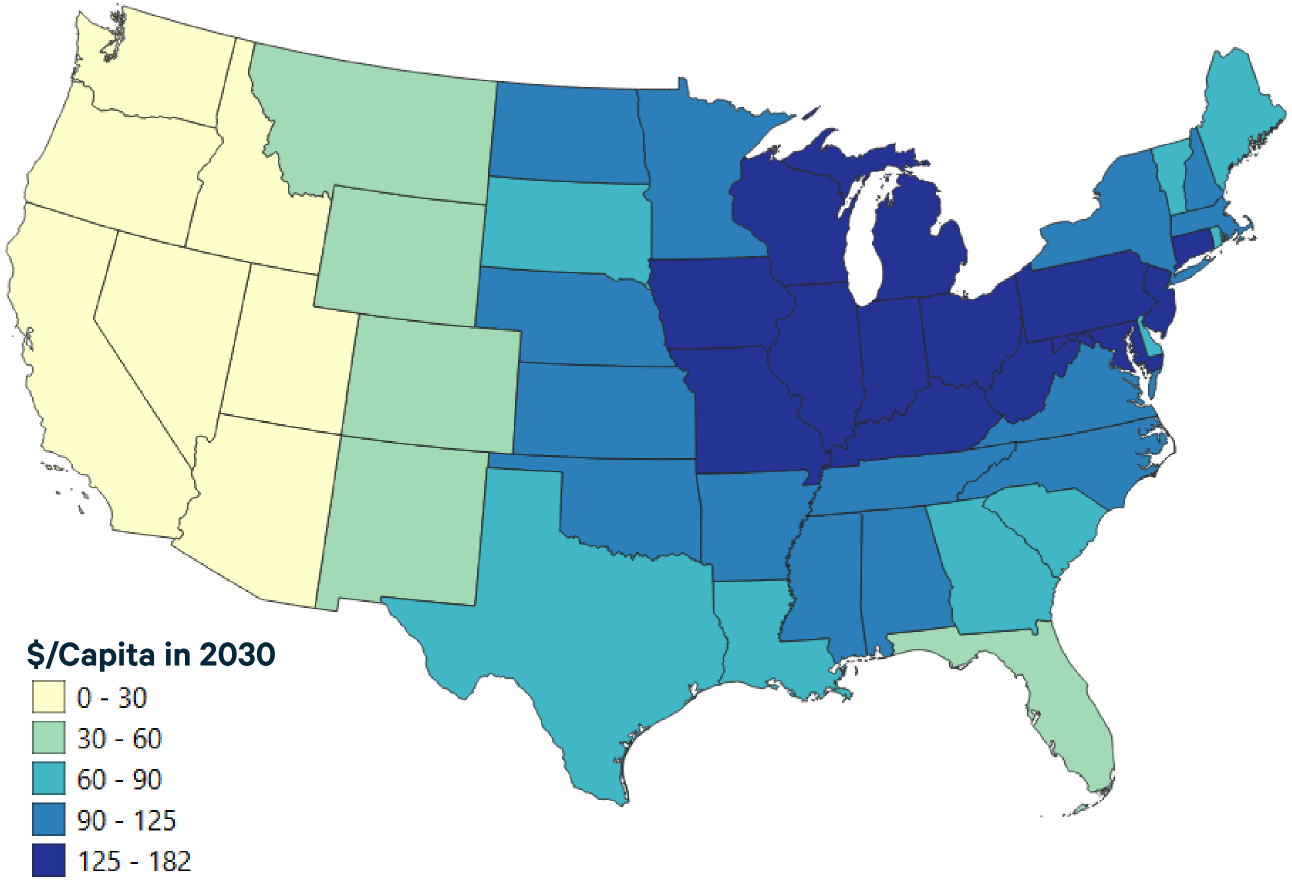
Monetized Value of Health Benefits from $PM_{2.5}$ Reductions in 2030 ($/State)



- Monetized value of health benefits mirrors the distribution of changes in premature mortality.
- The greatest reductions in premature mortality are observed in the upper Midwest, New York, the Mid-Atlantic, Texas, North Carolina, Georgia, and Florida.

MONETIZED HEALTH BENEFITS

Monetized Value of Health Benefits from $PM_{2.5}$ Reductions in 2030 ($ Per Capita)

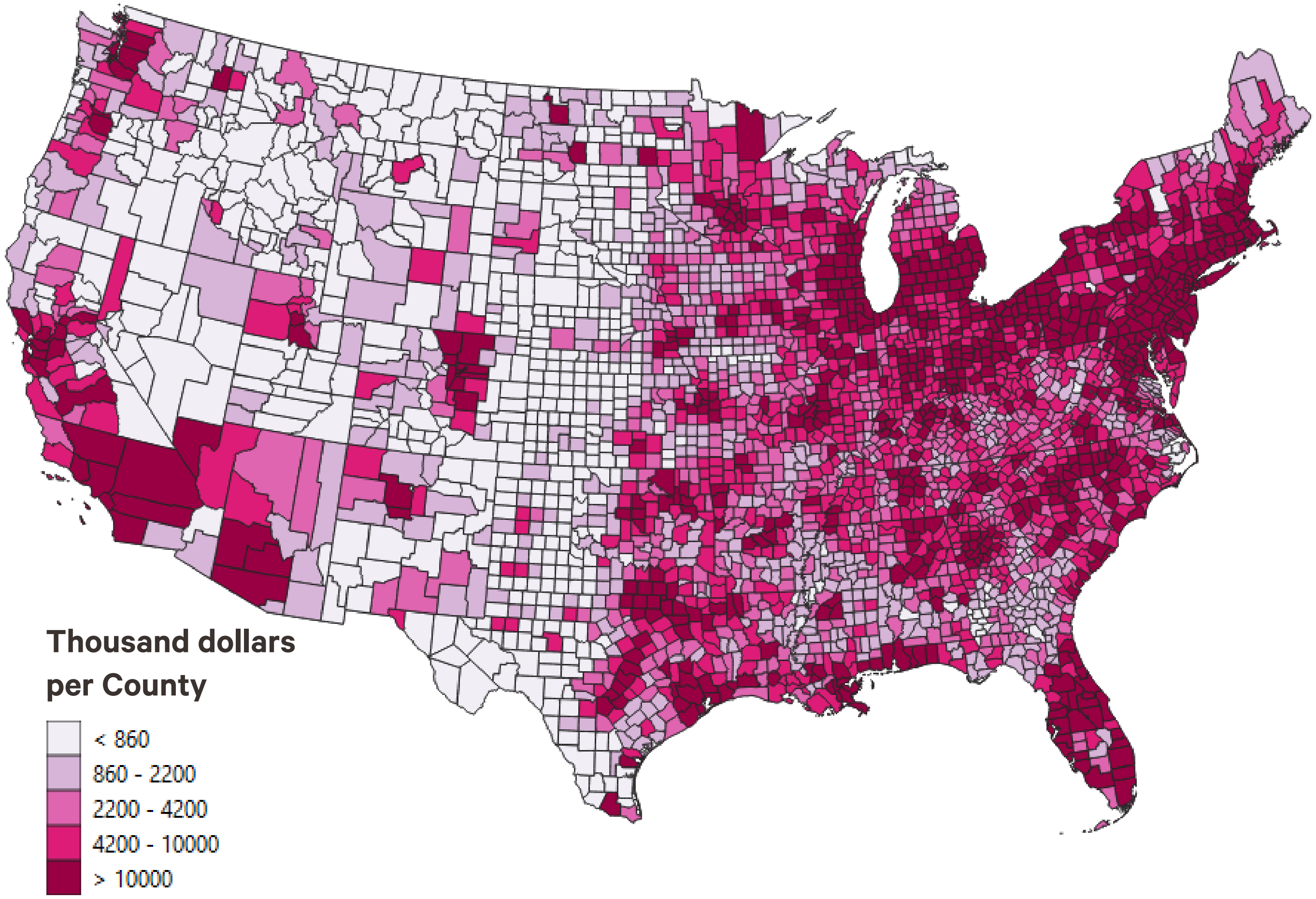


All values are 2010$

- Monetized value of health benefits are greater than $125 per capita in the upper Midwest.
- Only health benefits of reductions in fine particulates are included. Total benefits would be greater.

MONETIZED HEALTH BENEFITS

Monetized Value of Health Benefits from $PM_{2.5}$ Reductions in 2030 ($/County)

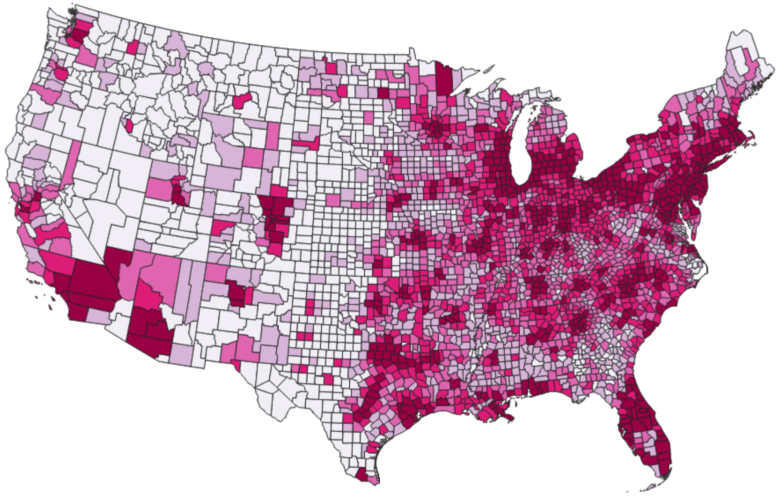


All values are 2010$

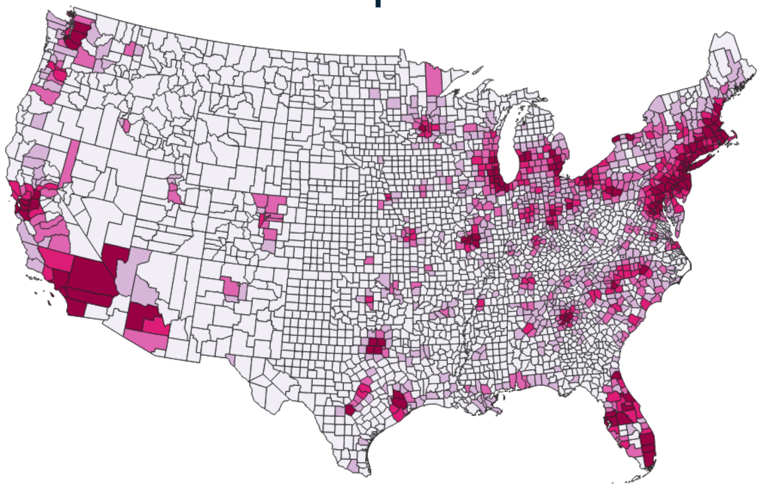
- Values mirror the distribution of health outcomes shown previously and are most evident in population centers.
- The larger the population of a county, the greater the health benefits that accrue to that county.
- Due to downscaling, county-level results may be more accurate in a regional cluster.

Monetized Value of Health Benefits from $PM_{2.5}$ Reductions by Sector in 2030 ($/County)

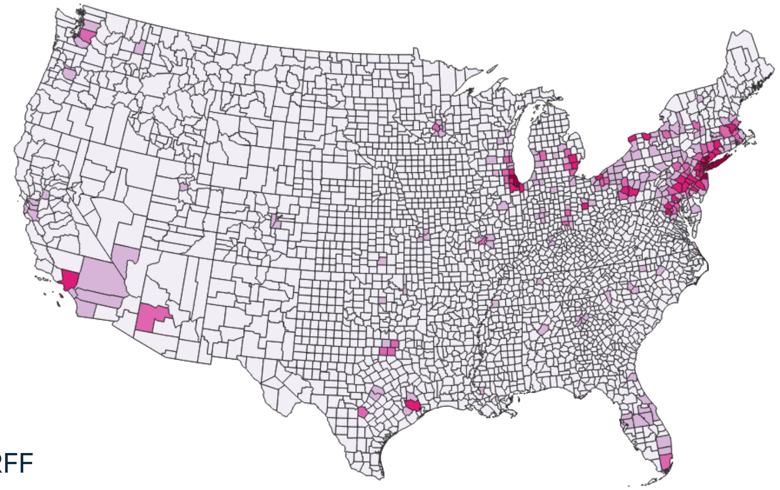
Electric



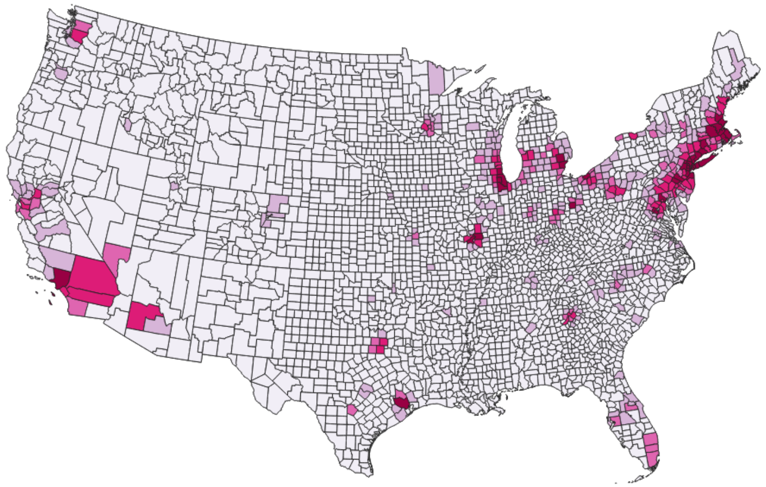
Transportation



Industrial



Commercial & Residential



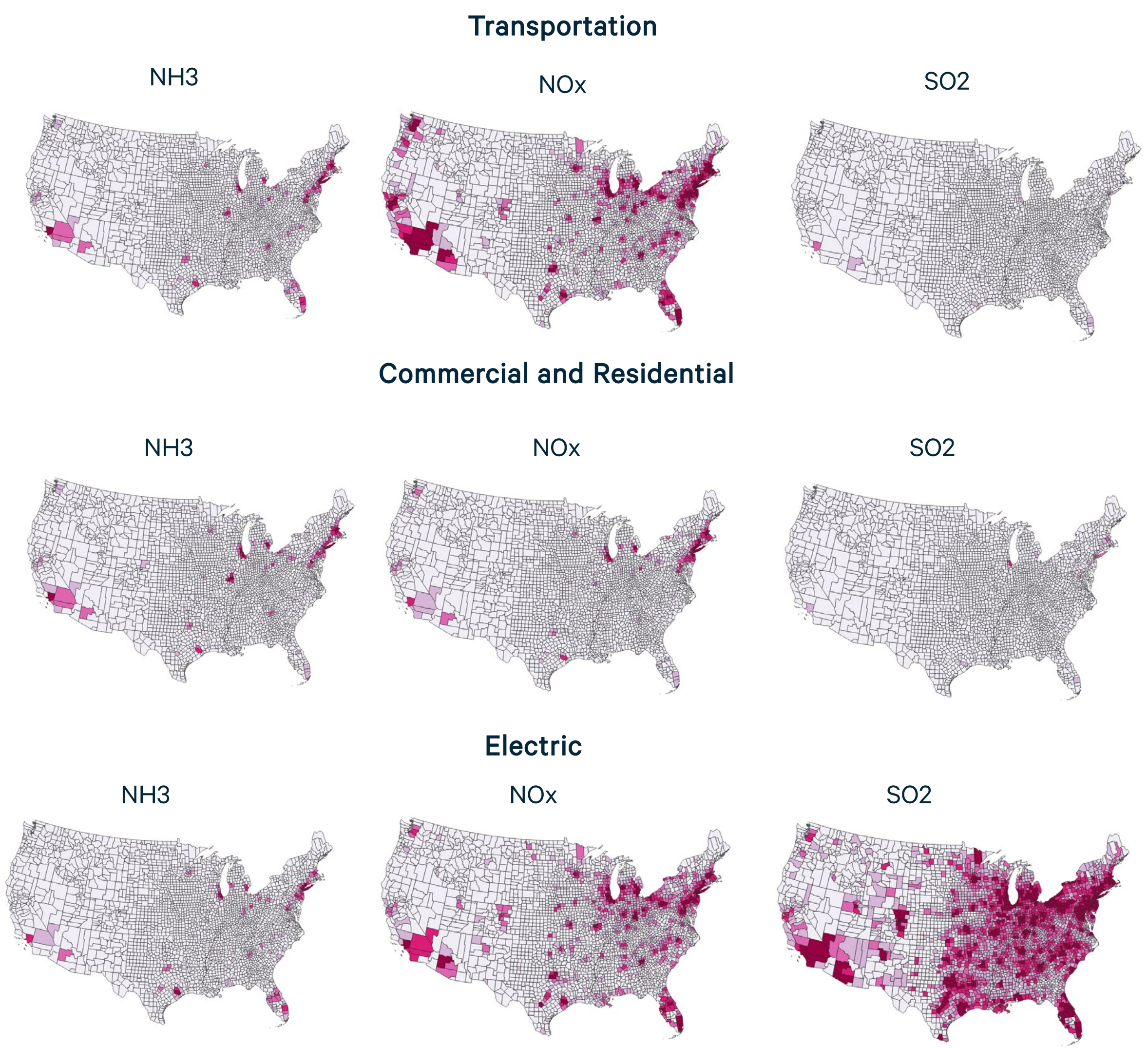
- The greatest health improvements are associated with emissions changes in the electricity sector.

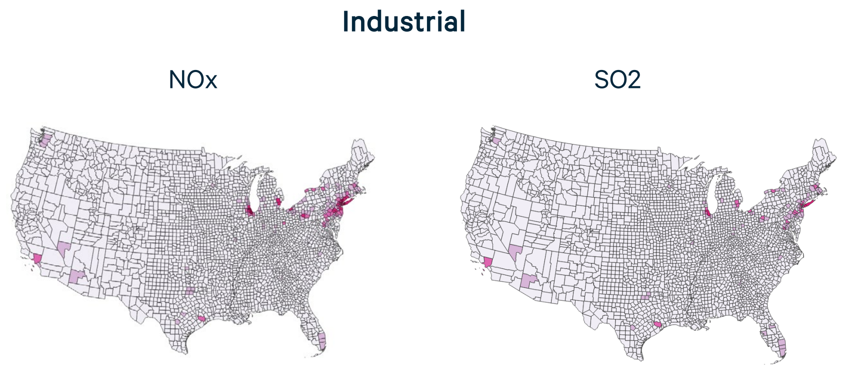
Thousand dollars per County

- < 860
- 860 - 2200
- 2200 - 4200
- 4200 - 10000
- > 10000

All values are 2010$

Monetized Value of Health Benefits from $PM_{2.5}$ Reductions by Sector and Pollutant in 2030 ($/County)





Thousand dollars per County

- < 860
- 860 - 2200
- 2200 - 4200
- 4200 - 10000
- > 10000

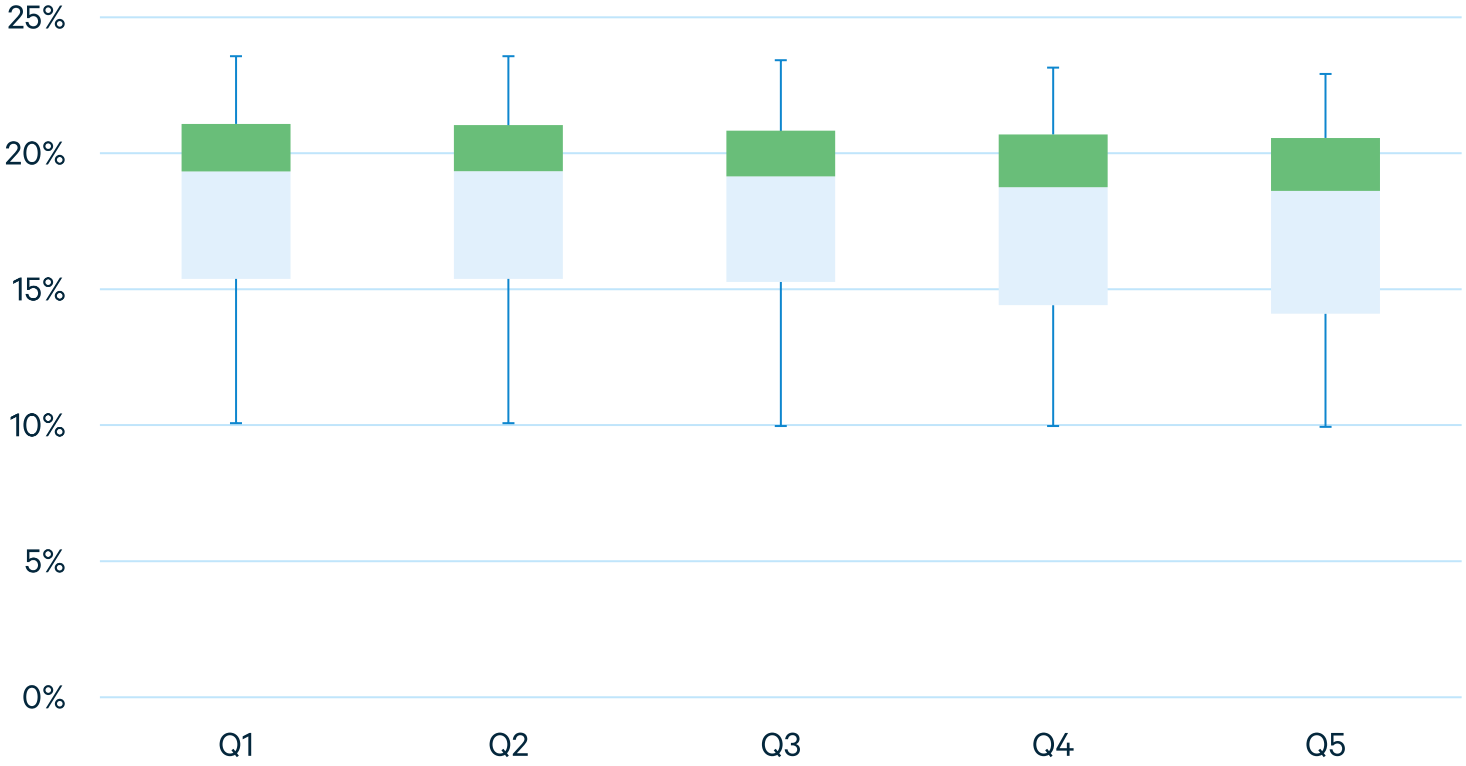
All values are 2010$

- The greatest health improvements are associated with SO_2 and NO_X changes in the electricity sector and NO_X changes in transportation.
- The greatest health benefits per ton of CO_2 are associated with reductions in industry.

Distribution of Health Benefits across Demographic Groups

DEMOGRAPHIC DISTRIBUTION

Percent Reduction in Premature Deaths by Income Quintile in 2030

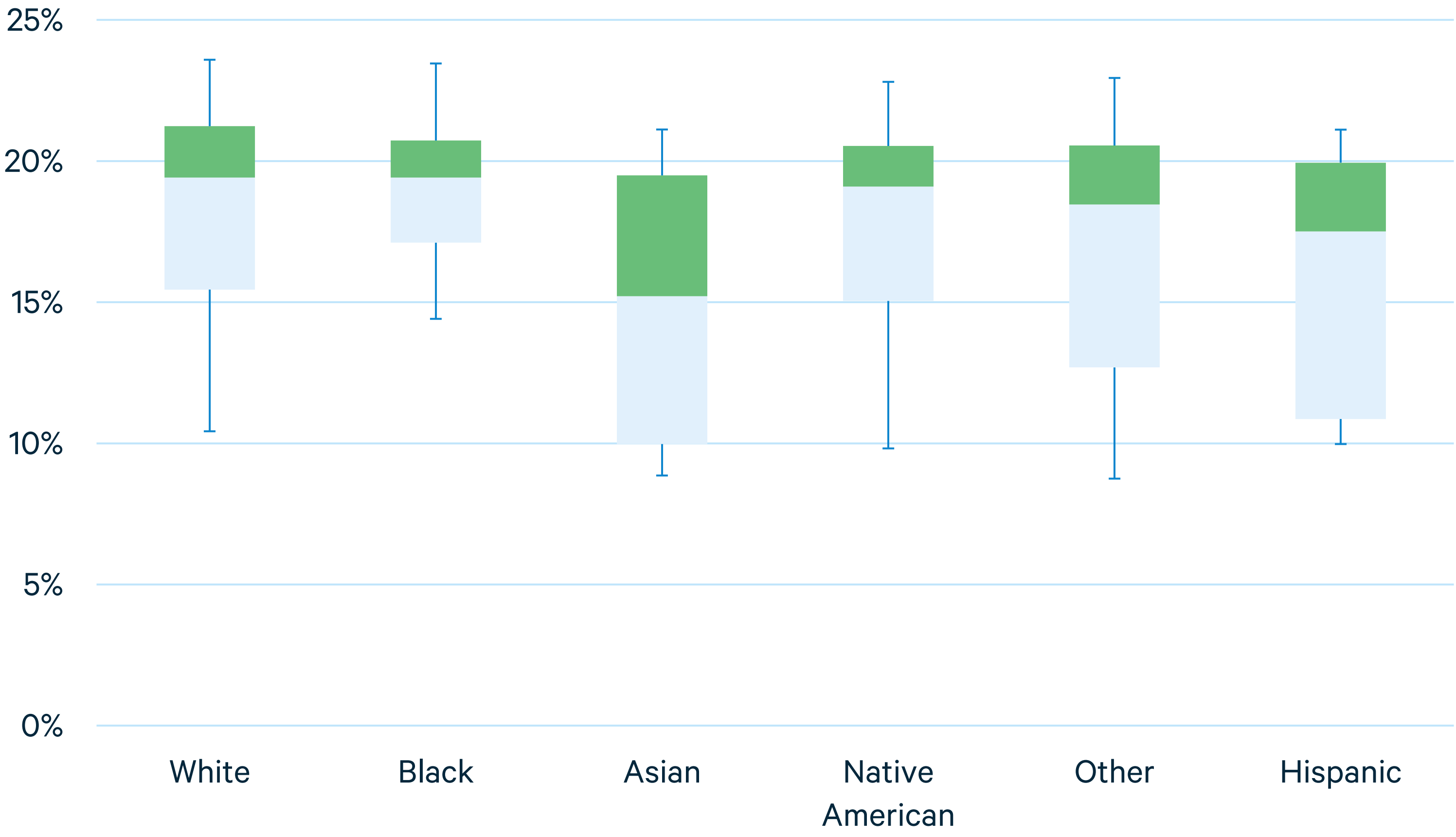


- Reduction in $PM_{2.5}$-related mortality is roughly uniform across income quintiles.

The figure displays the distribution of impacts across households in each group. Boxes describe inter-quartile range around the median. Whiskers describe range to 10th and 90th percentile.

DEMOGRAPHIC DISTRIBUTION

Percent Reduction in Premature Deaths by Racial/Ethnic Group in 2030



- The middle (median) of all racial and ethnic groups realize greater than 15 percent reduction in $PM_{2.5}$-related mortality.
- Asian and Hispanic populations are relatively concentrated in the West and Southwest, where air quality improvements are more modest.

The figure displays the distribution of impacts across households in each group. Boxes describe inter-quartile range around the median. Whiskers describe range to 10th and 90th percentile.

Methodology

METHODOLOGY

Models and Datasets Used to Estimate Air Quality Benefits of US Climate Goals

Annual Energy Outlook 2019
with projections to 2050

National Energy Modeling System (NEMS)

Environmental Science & Technology

Estimating Air Pollution Social Impact Using Regression (EASIUR)

eia *Independent Statistics & Analysis* U.S. Energy Information Administration
U.S. STATES
State Profiles and Energy Estimates

State Energy Data System (SEDS)

United States® Census Bureau

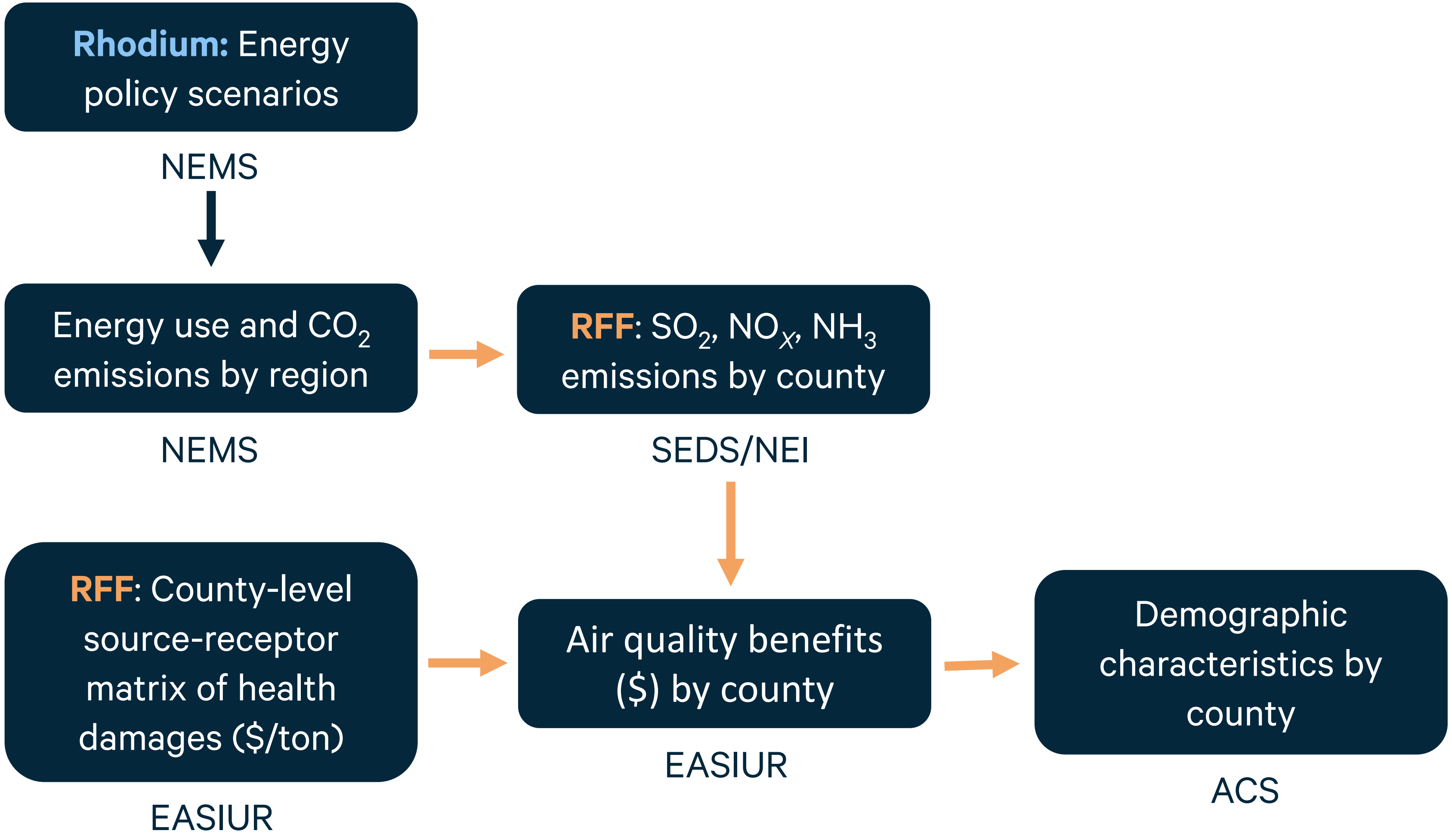
American Community Survey (ACS)

EPA United States Environmental Protection Agency

National Emissions Inventory (NEI)

METHODOLOGY

Using Economy-Wide NEMS Modeling to Assess Air-Health Benefits



METHODOLOGY

Downscaling Methodology Overview

- Downscale census division fuel consumption by sector from NEMS to state level fuel consumption by sector using SEDS historical (2018) fuel consumption by sector. This assumes a fixed distribution of fuel use between states in a census division over time.

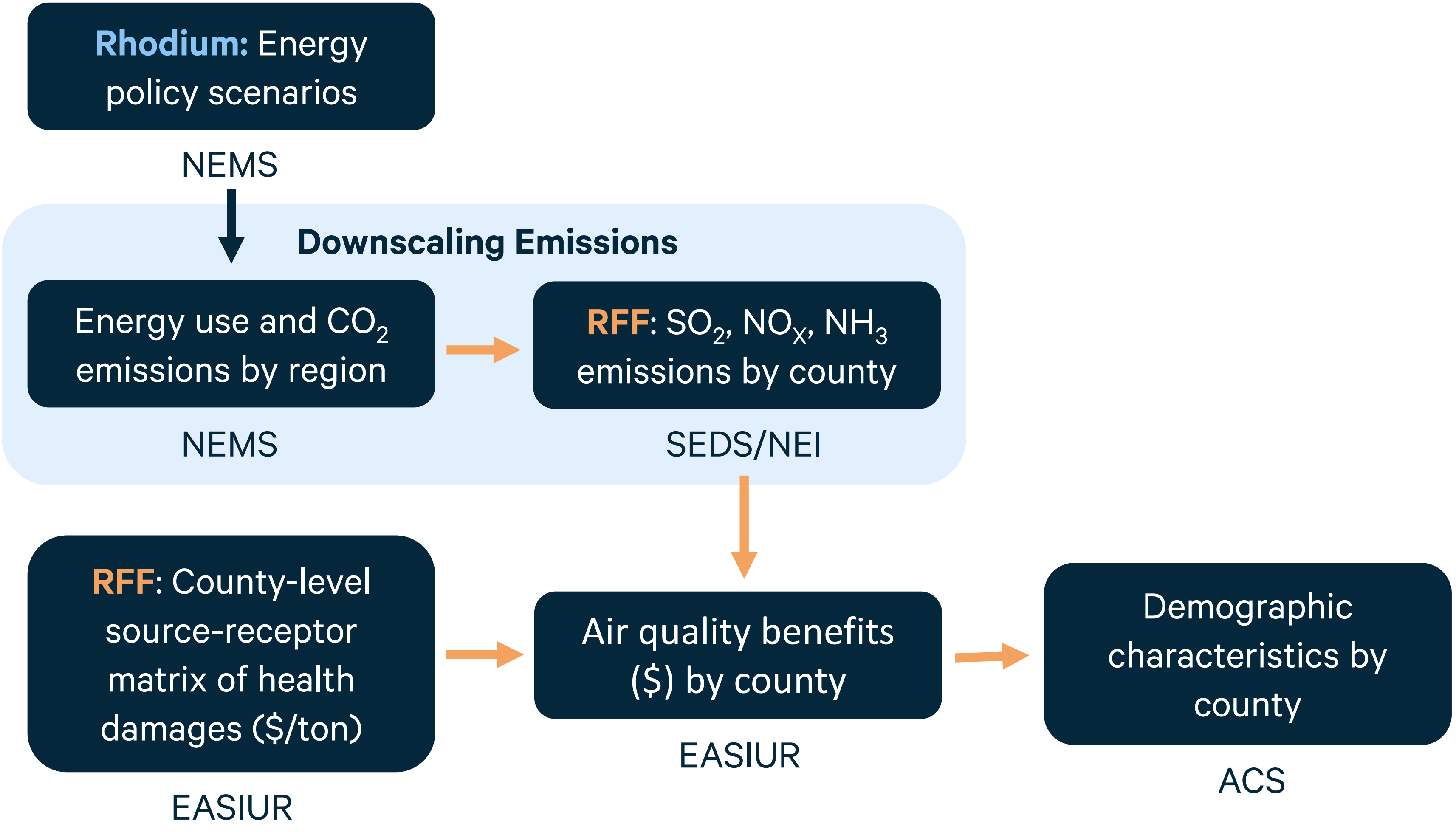
- Determine state-level CO_2 emissions by sector using NEMS-based ratios of CO_2 to fuel consumption and SEDS fuel consumption.

- Determine state-level conventional air pollutants using the ratio of historical CO_2 to historical conventional air pollution from NEI. This assumes a fixed ratio of conventional air pollution to CO_2 over time.

- Determine county-level conventional air pollutants using ratio of sectoral county level to state level criteria air pollutants from NEI. This assumes a fixed ratio of conventional air pollution between county sectors within a state over time.

METHODOLOGY

Using Economy-Wide NEMS Modeling to Assess Air-Health Benefits



METHODOLOGY

Using Economy-Wide NEMS Modeling to Assess Air-Health Benefits

Energy use and CO_2 emissions by region

Projected energy use and CO2 emissions by sector, fuel, and nine census divisions

SEDS historical energy use by sector, fuel, state

Projected energy use and CO2 emissions by sector, fuel, state

NEI historical air pollution by sector, state

Projected air pollution by pollutant, sector, state

NEI historical air pollution by sector, county

Projected air pollution by pollutant, sector, county

Historical stack height per power plant from CEMS

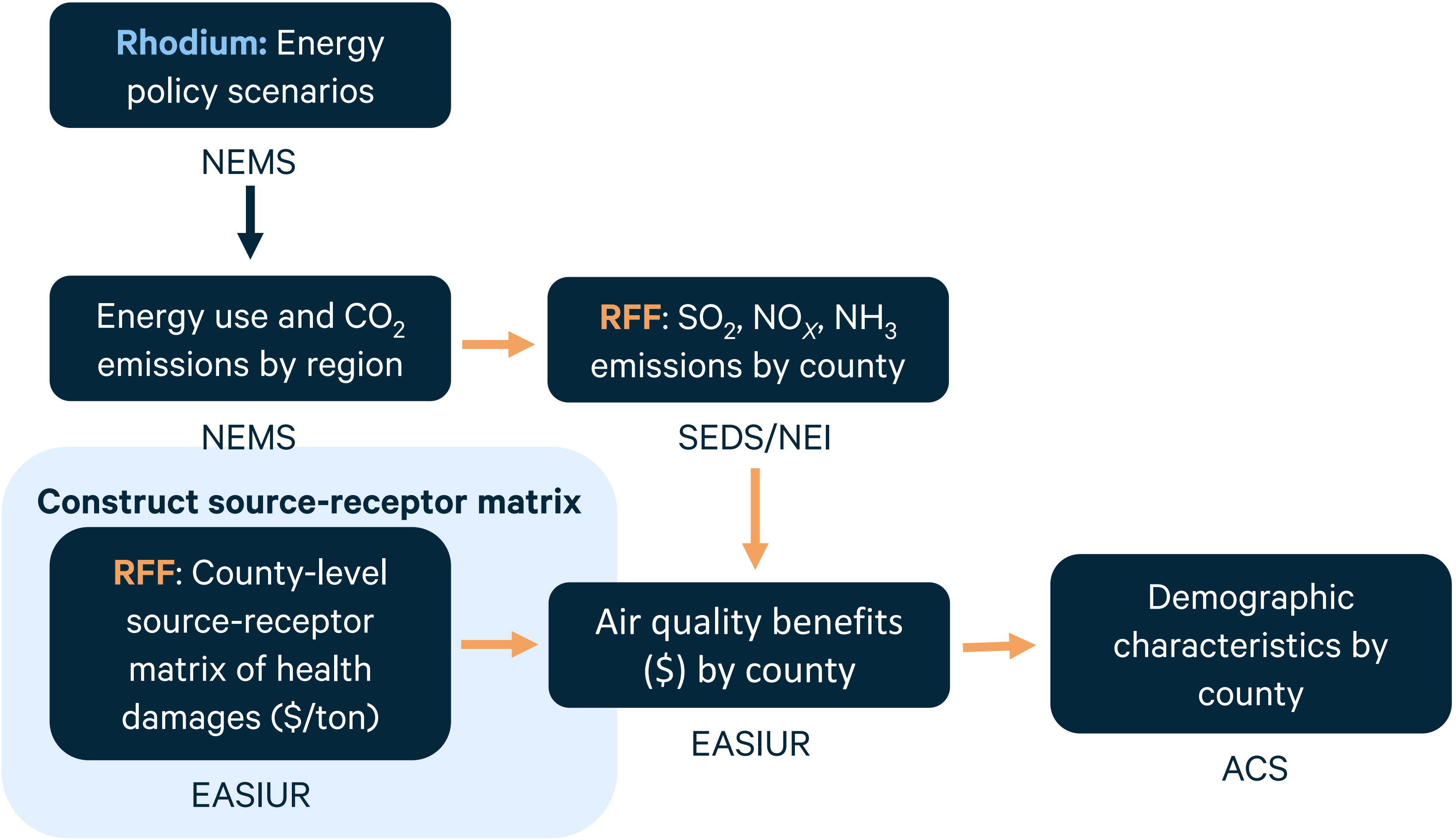
Downscaled emissions by county by sector by pollutant (SO_2, NO_X,NH_3) by elevation using NEI, SEDS, and CEMS

RFF: SO_2, NO_X, NH_3 emissions by county

We downscaled regional emissions to the county level to estimate co-pollutant emissions by sector. The health model estimates damages for pollution dispersed from three elevation bins. Residential and commercial, industrial, and transportation emissions were assigned to EASIUR's ground-level elevation bin. To downscale emissions per pollutant for the electricity sector, we used regression analysis on EIA860 reported generator characteristics and associated environmental equipment to infer stack heights associated with various uses of fuel. County electricity sector generator emissions were proportionately assigned to EASIUR elevation bins.

METHODOLOGY

Using Economy-Wide NEMS Modeling to Assess Air-Health Benefits



METHODOLOGY

Construct Source-Receptor Matrix to Estimate the Benefit of Air Quality Changes

36km by 36km EASIUR/APSCA source-receptor matrix gives health damages ($/ton) by receptor location based on pollution changes at source location

Aggregate to county level

Aggregate to county-level source-receptor matrix by pollutant and elevation

RFF: County-level source-receptor matrix of health damages ($/ton)

EASIUR used 2005 air quality modeling to estimate premature mortality associated with direct and secondary $PM_{2.5}$ at the 36km by 36 km grid scale. We derive county-to-county source-receptor matrices and apply them to 2030 emissions changes and population to estimate the changes in health outcomes and monetized benefits associated with reduction in $PM_{2.5}$ at the national, state, county and per capita level. EASIUR uses Krewski et al. (2009) for the concentration-response coefficients and $8.6 million as the value of a statistical life (2010$).

Heo, J., Adams, P. J., Gao, H. O. 2017. Public Health Costs Accounting of Inorganic $PM_{2.5}$ Pollution in Metropolitan Areas of the United States Using a Risk-Based Source-Receptor Model, *Environment International* 106: 119-126.
Heo, J., Adams, P.J., Gao, H.O. 2016. Public Health Costs of Primary $PM_{2.5}$ and Inorganic $PM_{2.5}$ Precursor Emissions in the United States, *Environmental Science & Technology* 50: 6061-6070.
Krewski, D., Jerrett, M., Burnett, R.T., Ma, R., Hughes, E., Shi, Y., Turner, M.C. et al. 2009. Extended Follow-up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. Boston, MA: Health Effects Institute,

METHODOLOGY

Uncertainty: Downscaling

- The shares of fuel use across states might not remain constant over time.
- The relationship between CO_2 and local air pollutants might not remain constant over time.
- The relationship between counties in a state for a given pollutant and sector might not remain the same over time.
- Sector-specific emissions source elevations may obscure outliers.
- Regression model analysis for the electricity sector brings additional uncertainty.

METHODOLOGY

Uncertainty: Other

- Industrial ammonia is excluded because the NEMS model does not track agricultural emissions. Consequently, we do not model potential benefits associated with industrial sector ammonia reductions outside agriculture.

- The EASIUR source-receptor matrix is estimated based on a single year (2005) of data. As a reduced complexity model, it does not represent nonlinear chemical processes, or meteorological variation, which is increasingly important over time with climate change.

- There is inherent uncertainty in the underlying concentration-response function (Krewski et al. 2009) and economic valuation of changes in health status that are used in the model.

- Future population estimation is a linear projection of county-level population and demographic characteristics in 2005.

- EASIUR does not account for organic particulate matter that is created secondarily from certain volatile organic compounds (VOCs), which is an important issue in places like southern California.