Quantifying Co-benefits of CO_2 Emission Reductions in Canada and the United States: An Adjoint Sensitivity Analysis

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Outline

- Introduction
- Methodology
- Results
- Discussion

Introduction

- Co-benefits due to reduced emissions of criteria pollutants (or their precursors)
  - Air pollution impact on human health (PM, O_3, and NO_2)
    - Not considering the climate feedback on air quality
- CO_2 reduction co-benefit or coincident health air pollution damage: dependent on the policy measure
  - Sectoral
  - Spatial
- Co-benefits due to reduced chronic exposure mortality
  - Reduced NO_X emissions → reduced O_3/NO_2 health impacts (presented before)
  - Reduced primary (e.g., EC, OC) and precursor (SO_2, NH_3, NO_x) emissions → reduced $PM_{2.5}$, health impacts

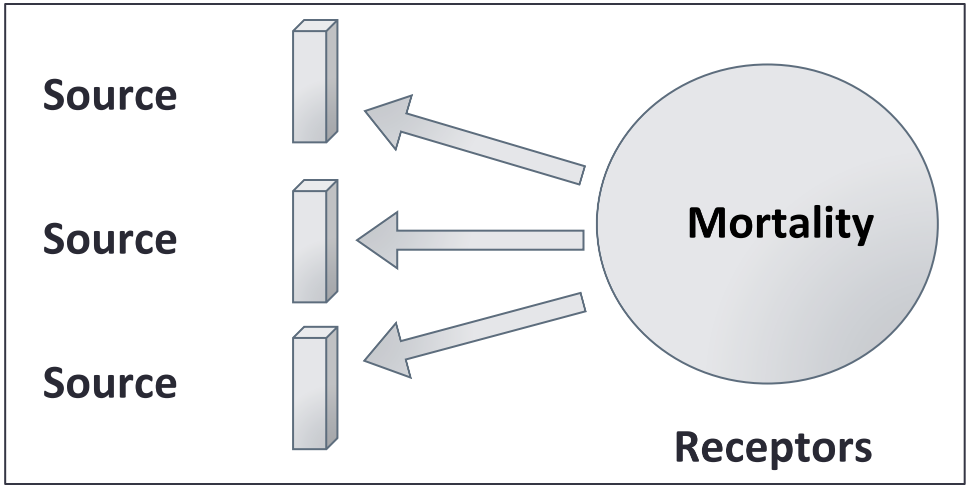
Methodology

$$\underbrace{\frac{\partial J}{\partial E_{CO_2}}}_{\text{Co-benefit}} = \underbrace{\frac{\partial J_i}{E_i}}_{\text{Marginal Benefit}} \times \underbrace{\frac{E_i}{E_{CO_2}}}_{\text{Emission Ratio}}$$

- Adjoint-based marginal benefits (MBs or benefit-per-ton) based on Pappin et al. (2013)

- Concentration response functions (CRFs):
  - Canada
    - PM, O3, NO2 from Crouse et al. (2015)
    - Nonlinear CRF for PM and NO_2; Pappin et al. (2016)
  - U.S.
    - O3 from Bell et al. (2004)
    - PM based on Krewski et al. (2009)

Marginal Benefit Estimation: Adjoint model



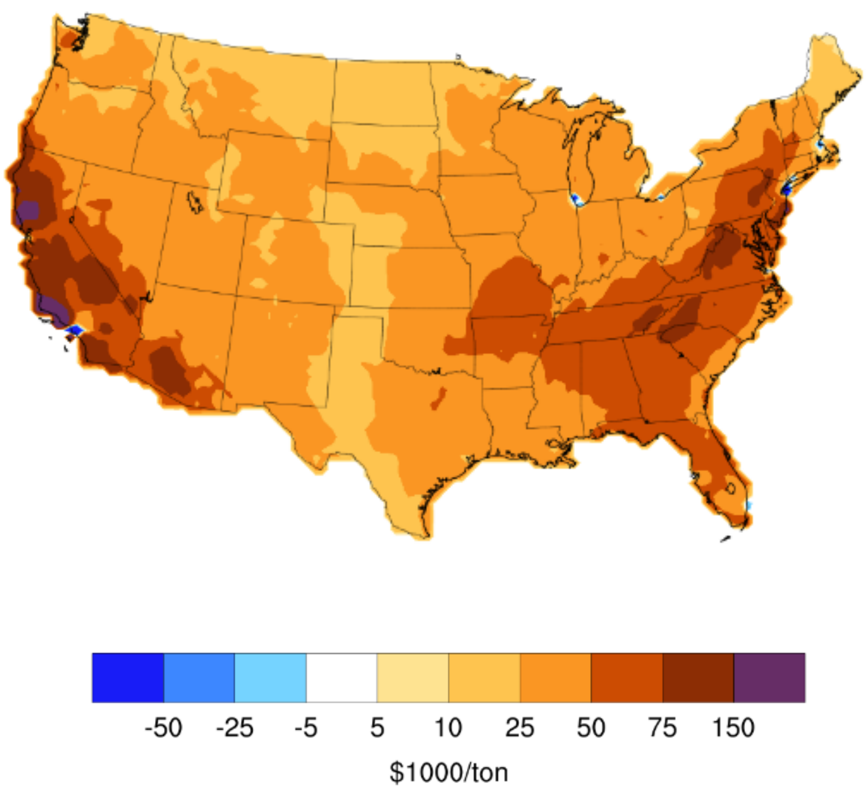
- Influences on nationwide mortality are traced back to individual sources (*Pappin and Hakami, 2013)*
- Full CMAQ-Adjoint (gas-phase for O_3/NO_2 simulations)
- 36 km CONUS domain
- 34 vertical layers
- O3/NO_2 Modeled over ozone season of May-September 2007 (153 days)
- $PM_{2.5}$ is modeled over 1 month (April) of 2008 (30 days)

Adjoint-based MBs

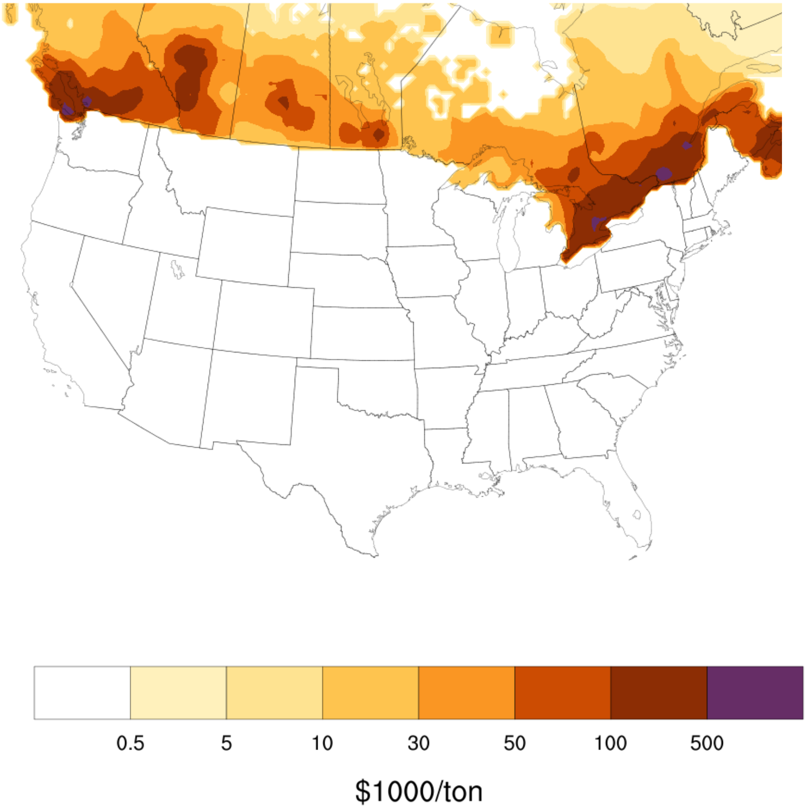
- Full CMAQ adjoint
- Adjoint of aerosol processes is working (finally!) and seems stable
    - Currently undergoing further evaluation

NO_X Marginal Benefit (no PM): Surface Sources

USA

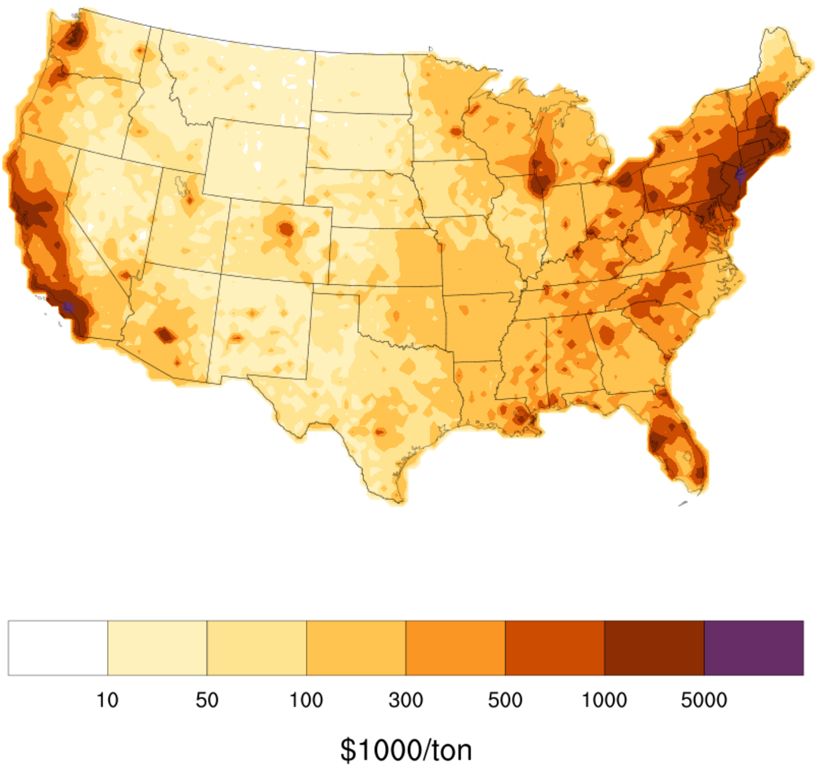


Canada



$PM_{2.5}$ Marginal Benefit: Surface Sources

USA



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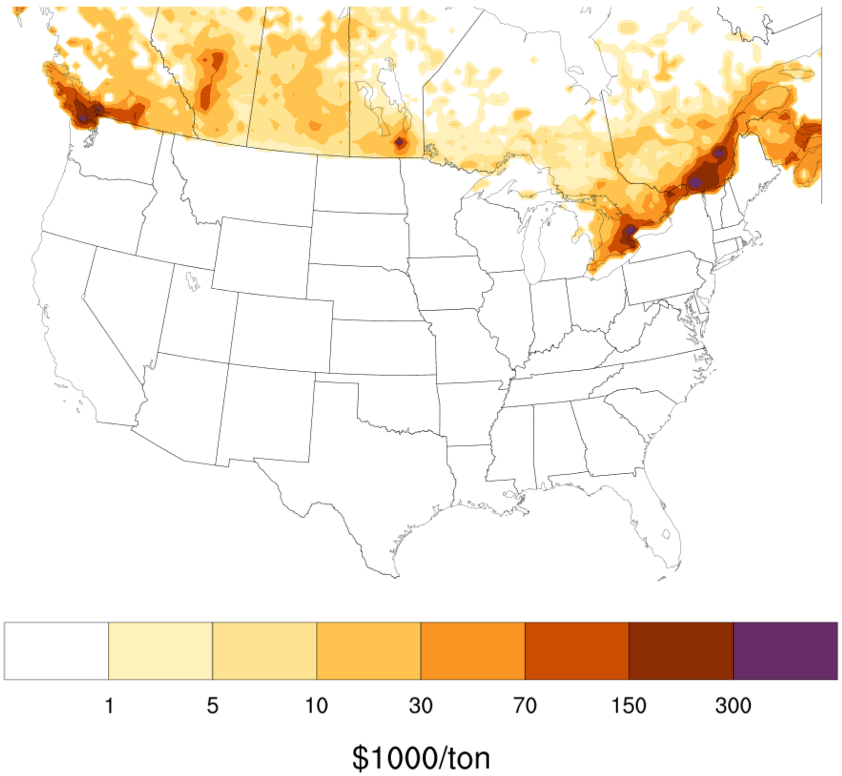
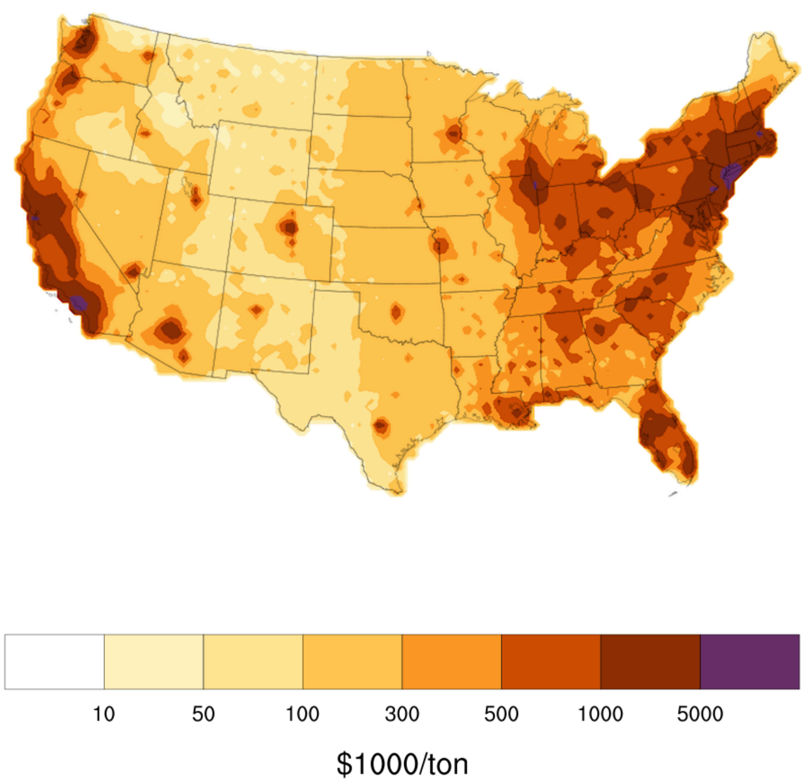


PEC Marginal Benefit: Surface Sources

USA



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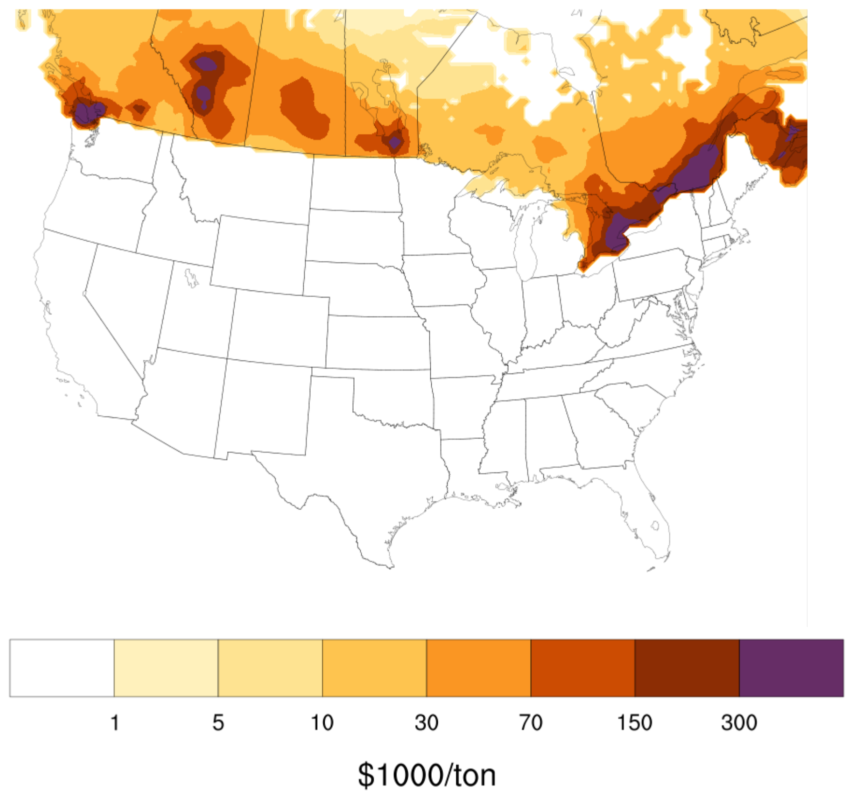
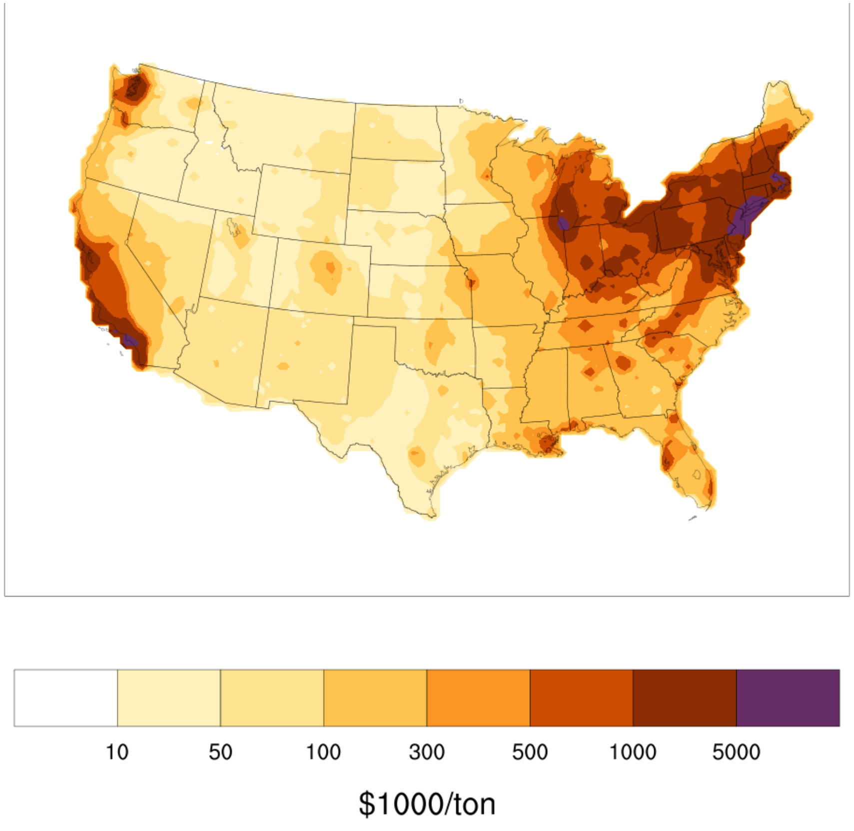


NH3 Marginal Benefit: Surface Sources

USA



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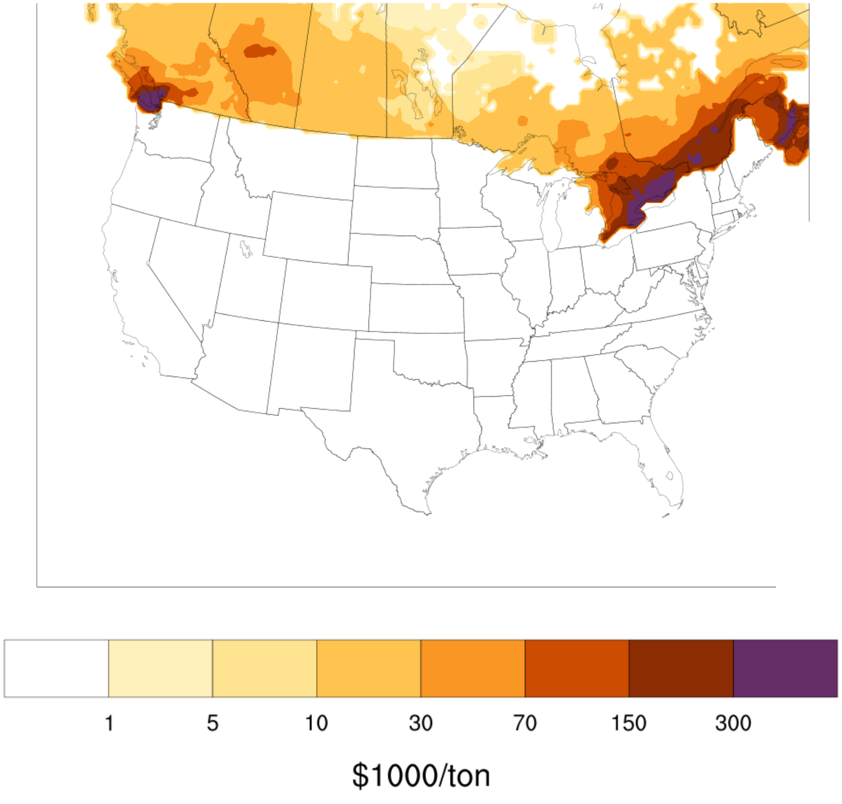
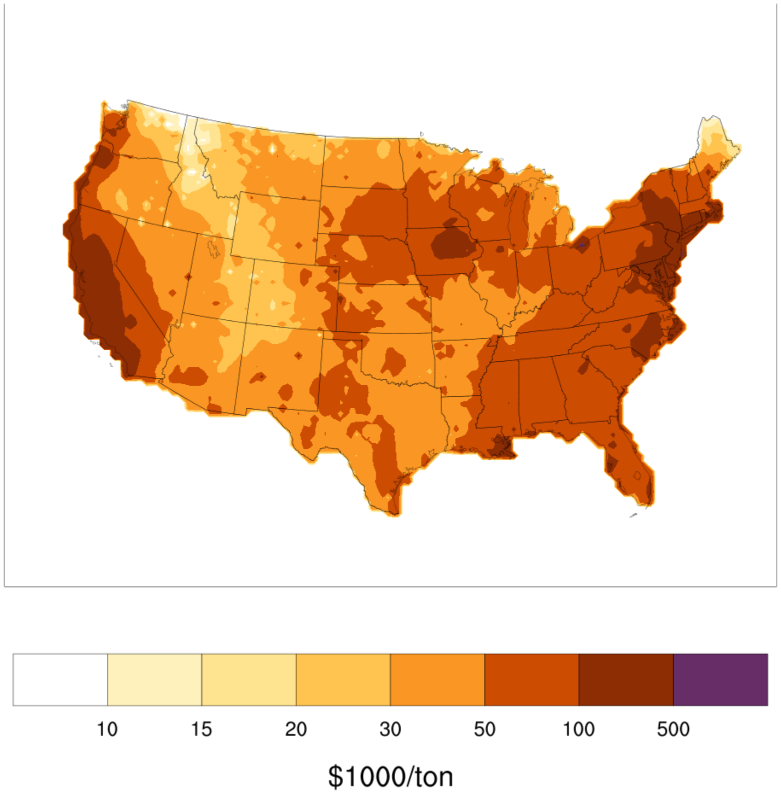
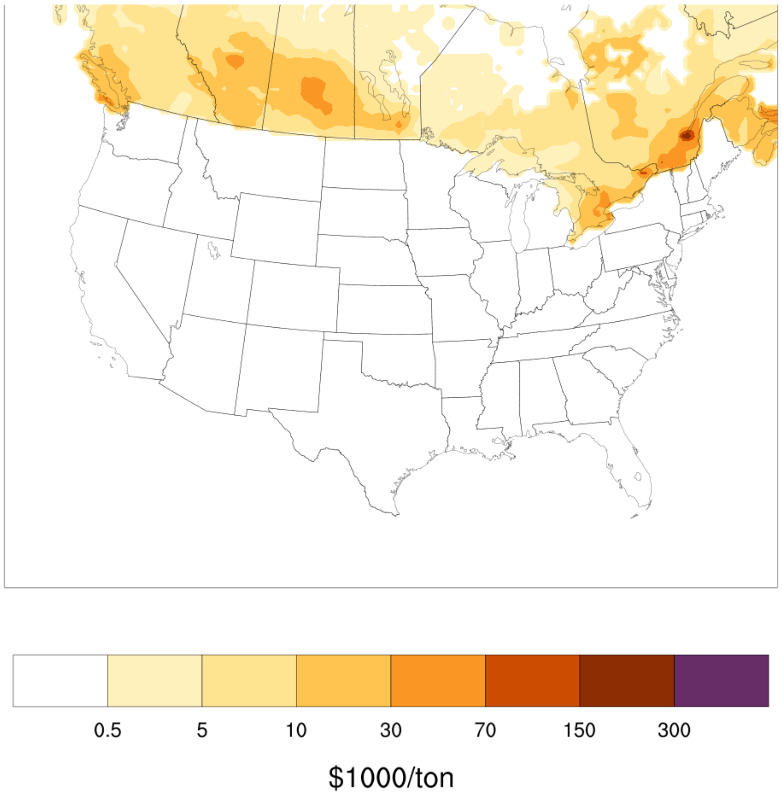


SO_2 Marginal Benefit: Surface Sources

USA

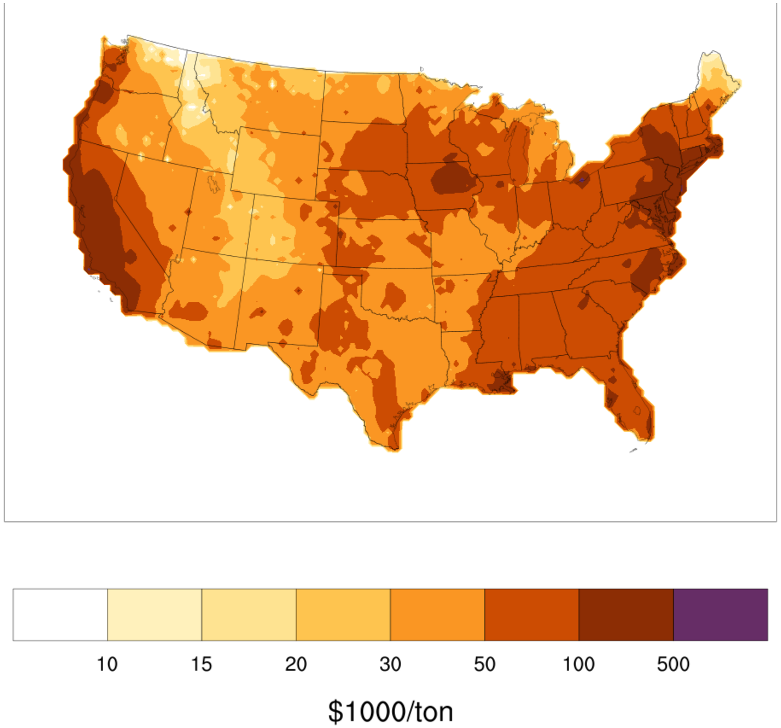


Canada

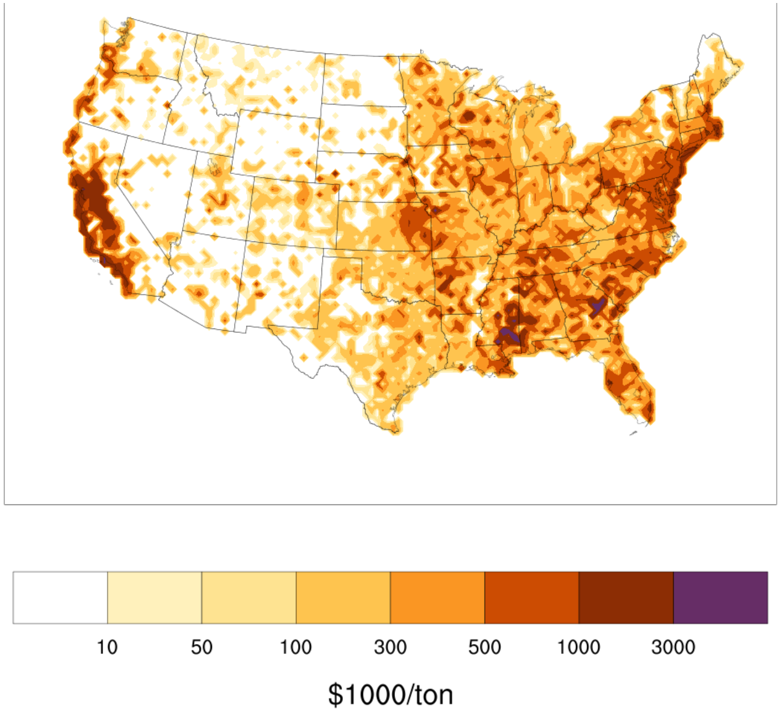


SO_2 Marginal Benefit: Surface vs. Point Sources

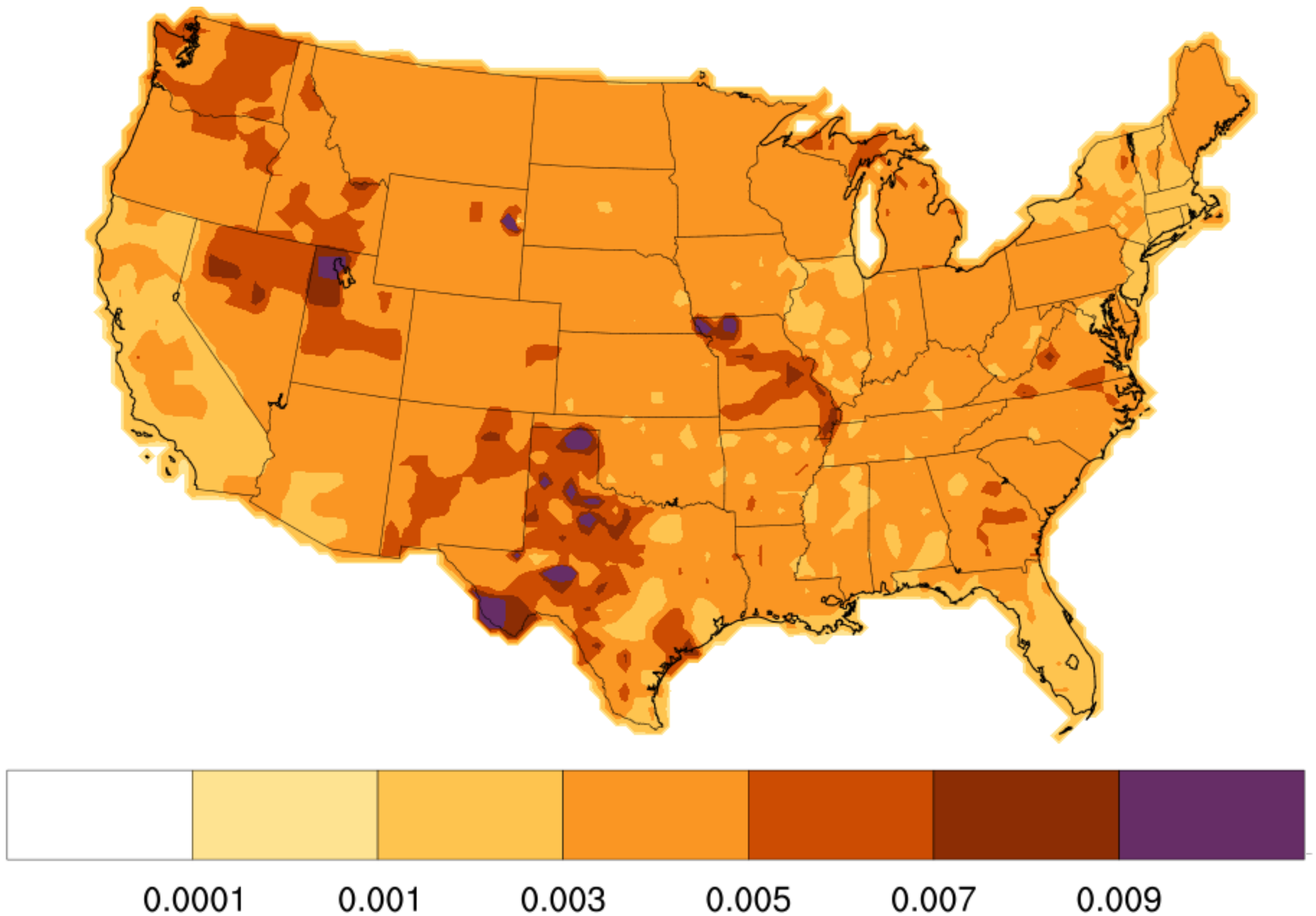
Surface



Point



NO_X/CO_2 Emission Ratio: Mobile On-road



Major sectors

NO_X	$PM_{2.5}$	SO_2	NH_3	CO_2
1.Mobile-DH	1.Fires	1.EGUs (coal)	1.Agriculture	1.EGUs (coal)
2.Mobile-GL	2.Dust	2.Industrial boiler	2.Fires	2.Mobile-GL
3.EGUs (coal)	3.EGUs (coal)	3.Industrial processes	3.Mobile-GL	3.Mobile-DL

Three sectors associated with the highest pollutant and CO_2 emissions

MBs in comparison with literature

Urban Area	Primary PM (PEC + POC) MBs, Mobile ($/ton)	
	Fann et al. (2009)	This work
Atlanta	$590,000	$1,000,000
Chicago	$580,000	$3,460,000
Dallas	$790,000	$290,000
Denver	$450,000	$1,270,000
NY/Phi	$710,000	$7,920,000
Phoenix	$1,700,000	$2,410,000
Seattle	$570,000	$2,330,000

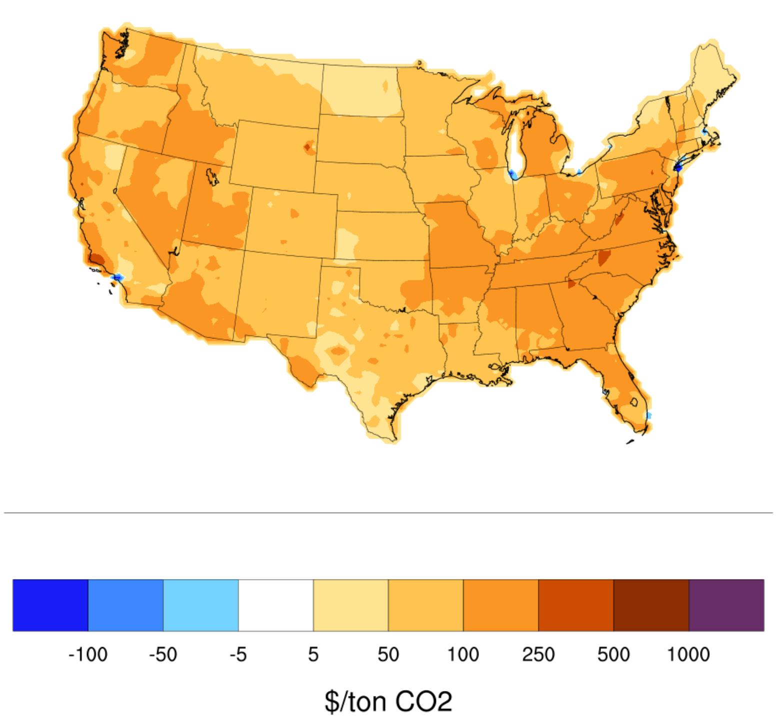
Results - I
Mobile On-road

Emissions Data Sources - Mobile Sector

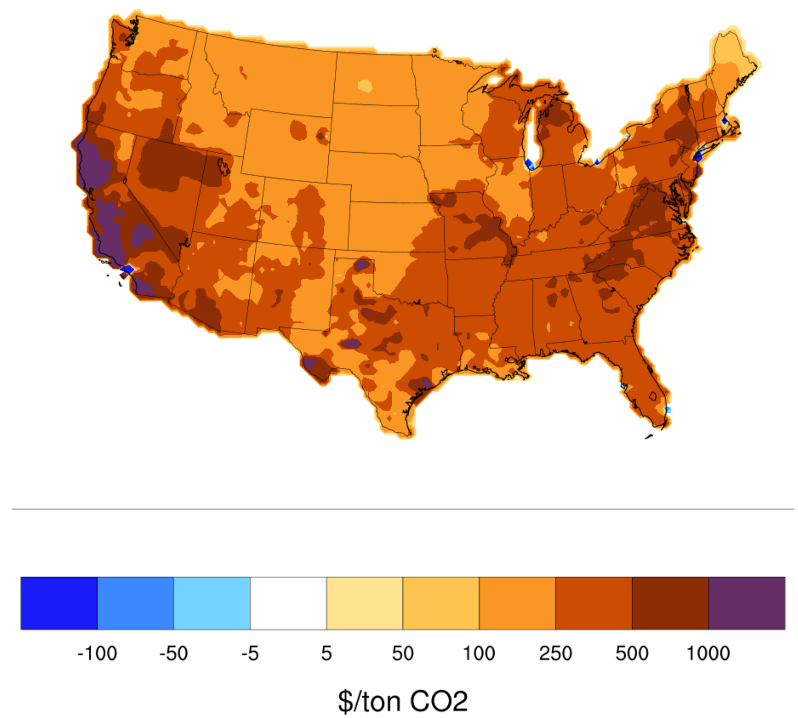
- USA
  - NO_X, $PM_{2.5}$, NH_3, SO_2 and CO_2 from 2011 NEI
  - County-level data gridded to 36-km resolution
- Canada
  - Criteria pollutants: Environment & Climate Change Canada. Air Pollutant Emission Inventory Online Data Query (APEIODQ)
  - CO_2: Canadian national inventory reports(2011)

NO_X Co-benefit (O_3): Mobile On-road

Gasoline Light Duty

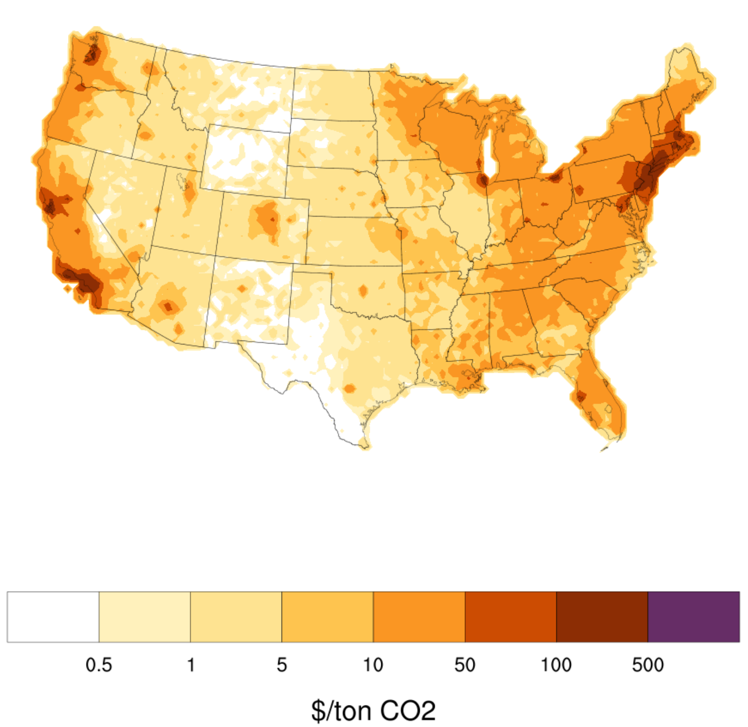


Diesel Heavy Duty

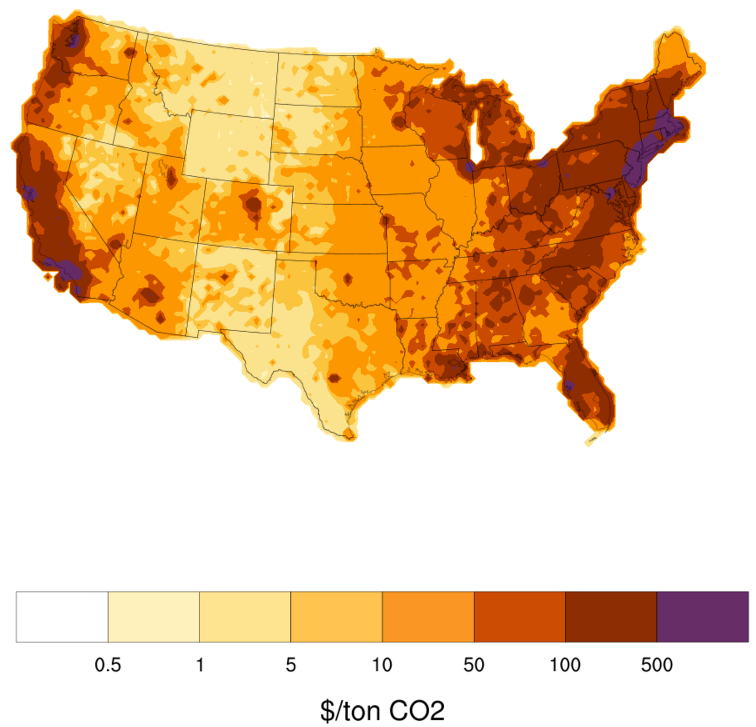


$PM_{2.5}$ Co-benefit (primary): Mobile On-road

Gasoline Light Duty

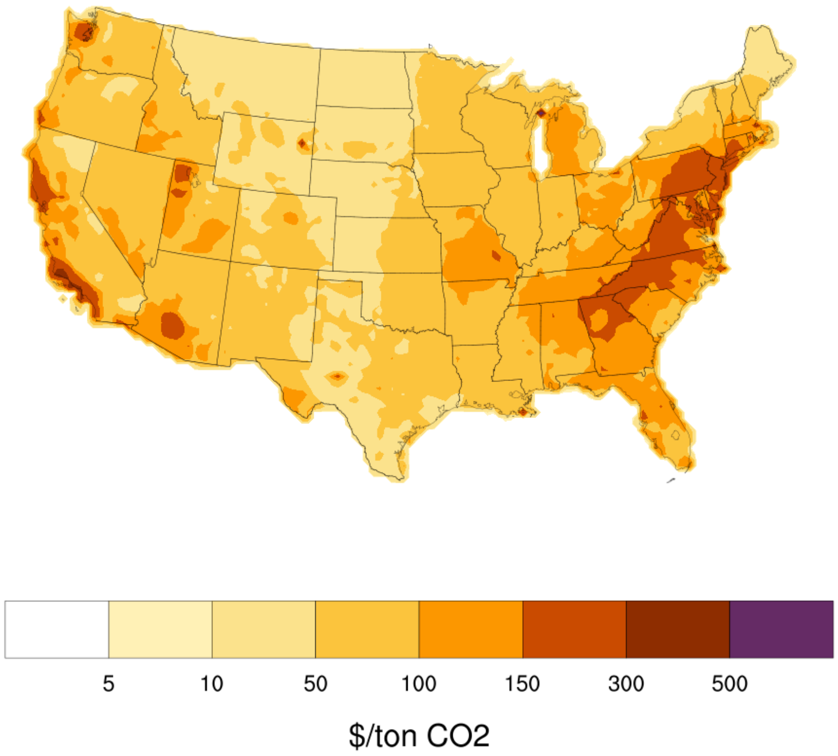


Diesel Heavy Duty

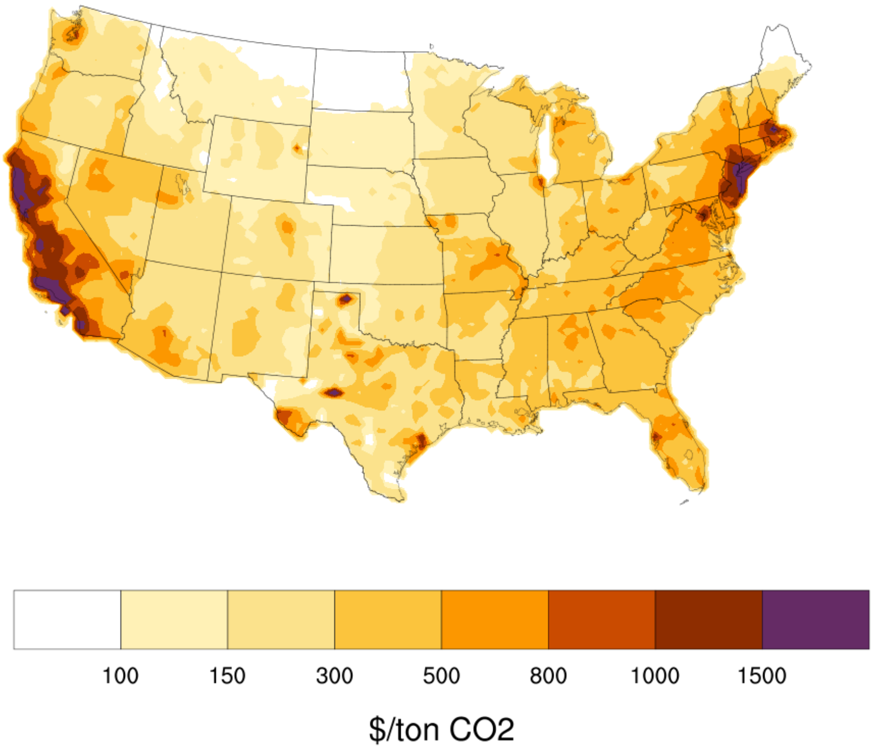


Total Co-benefit: Mobile On-road

Gasoline Light Duty

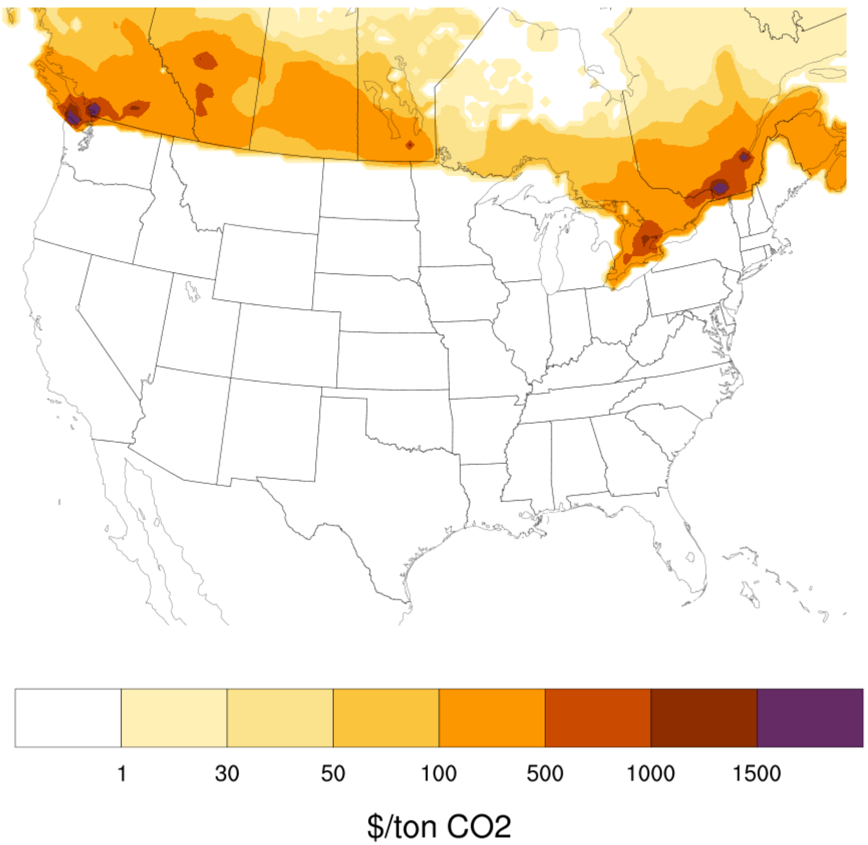


Diesel Heavy Duty

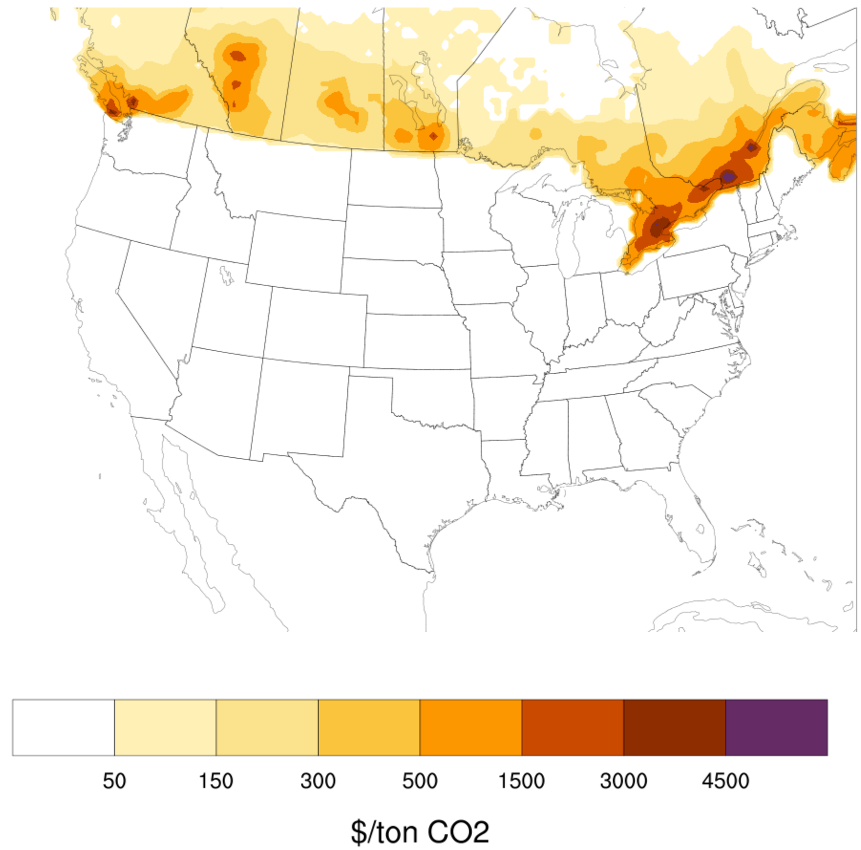


Total Co-benefit: Mobile On-road

Gasoline Light Duty



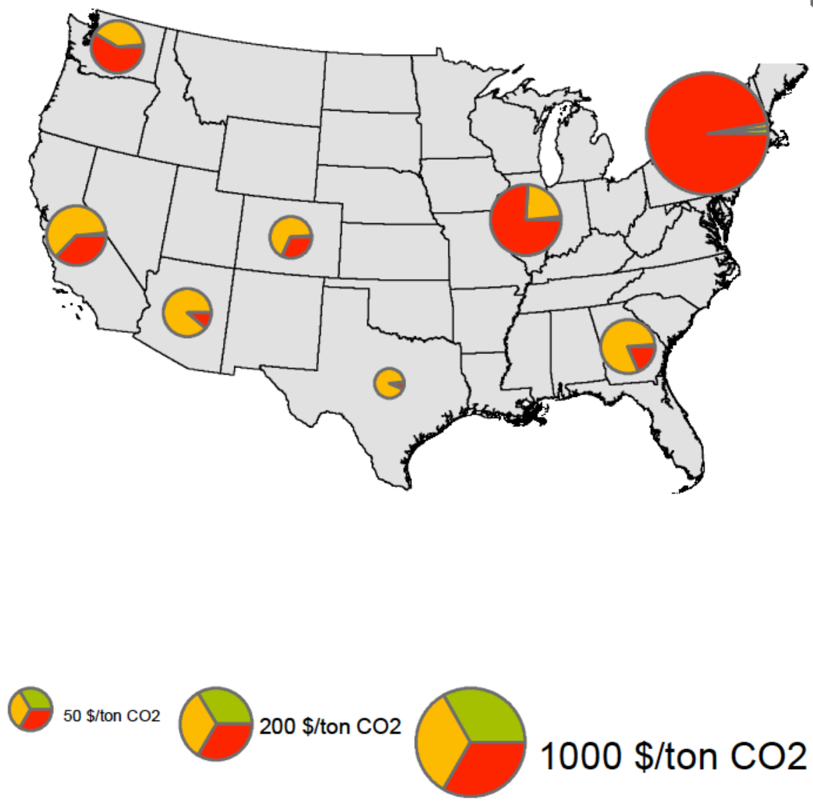
Diesel Heavy Duty



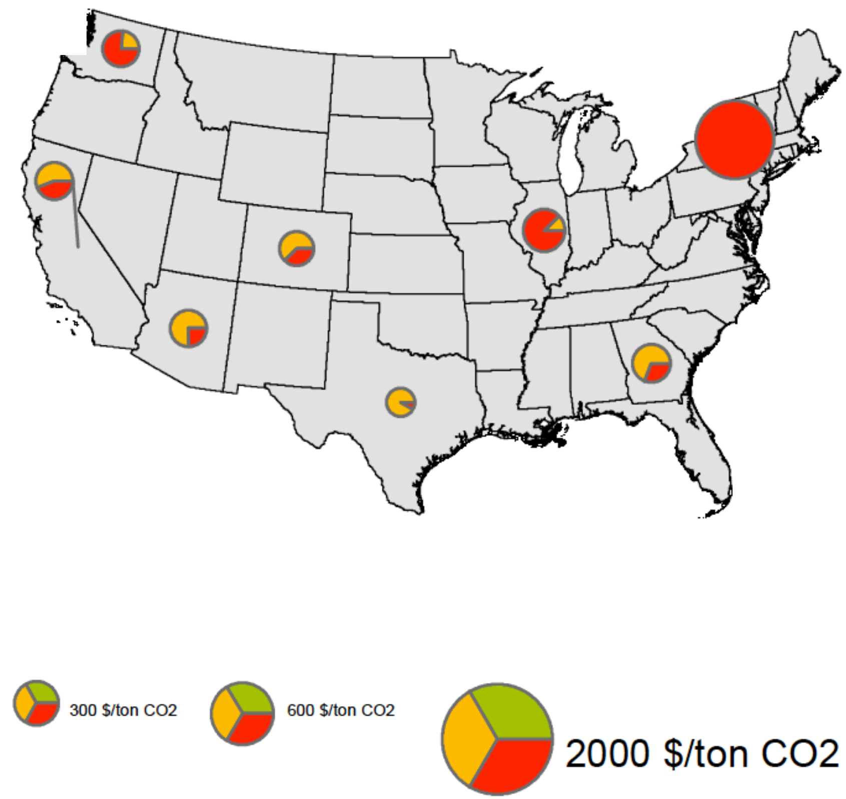
Total Co-benefit : Mobile On-road

SO2
NOX
PM

Gasoline Light Duty

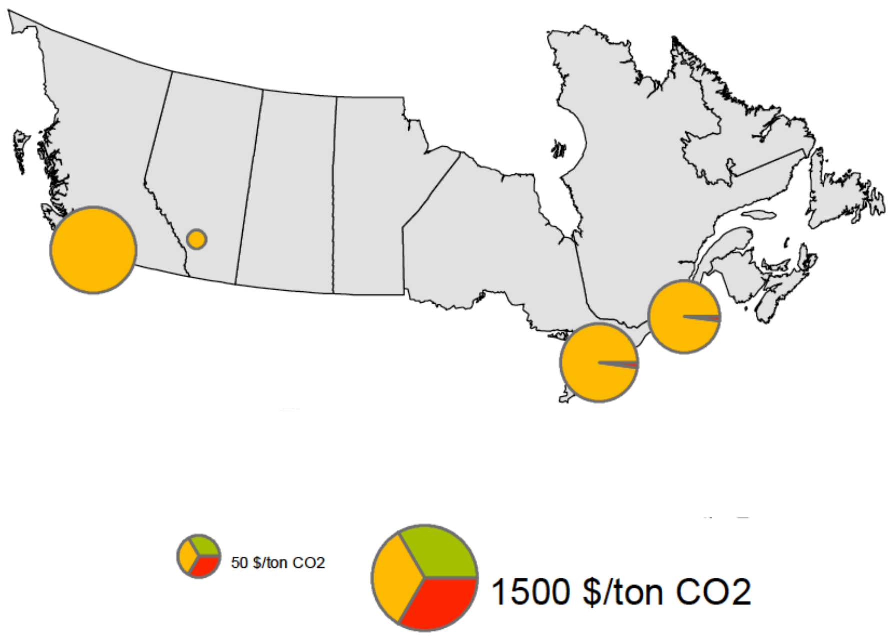


Diesel Heavy Duty

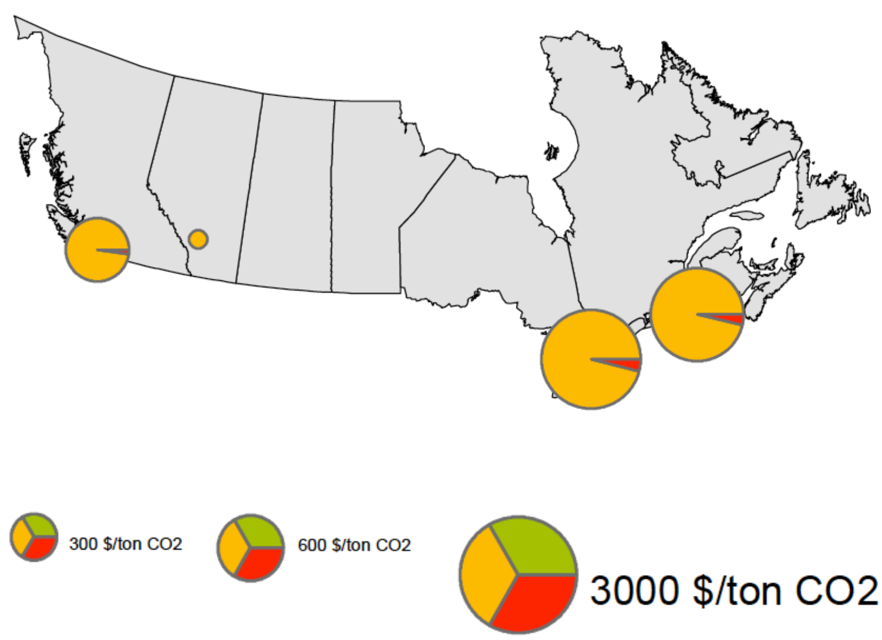


Total Co-benefit : Mobile On-road

Gasoline Light Duty



Diesel Heavy Duty



Results - II
Point Sources

Emissions Data Sources – EGUs

USA

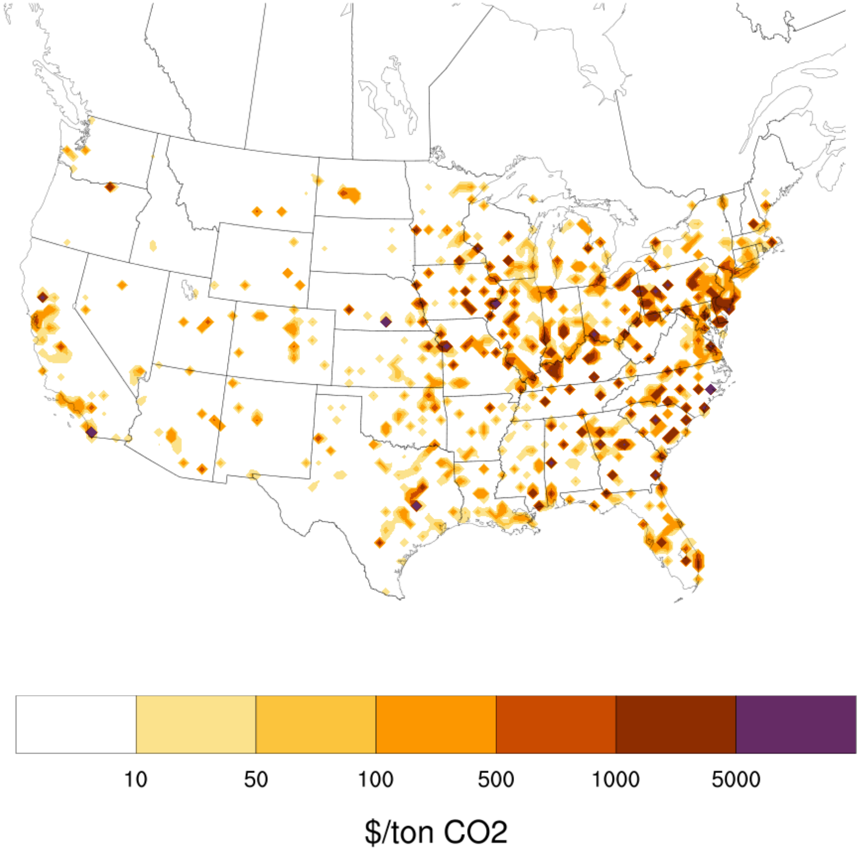
- For SO_2,NO_X, and CO_2: Air Markets Program Data (AMPD)
- For $PM_{2.5}$ and NH_3: EPA Google fusion tables and maps
- For CO_2: EPA Facility Level GHG emission Data (Flight)

Canada

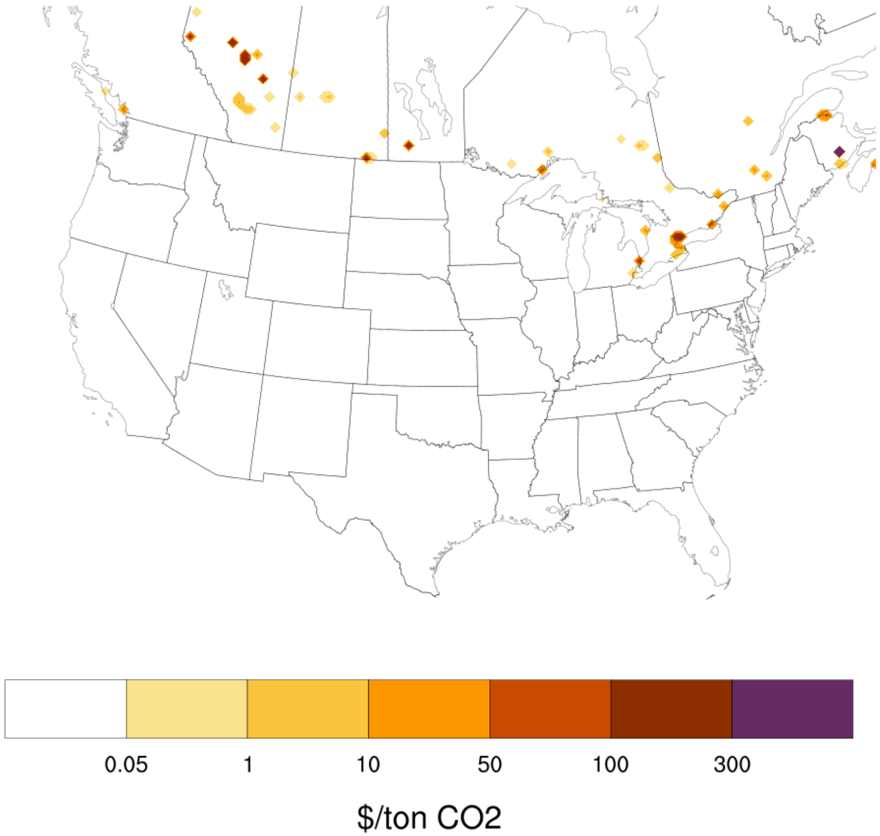
- For SO_2, NO_X, and CO_2: National Pollutant Release Inventory (NPRI)
- For CO_2: Canada's GHG emission inventory
- Cross-reference between NPR ID and GHGRP ID

Total Co-benefit: EGUs

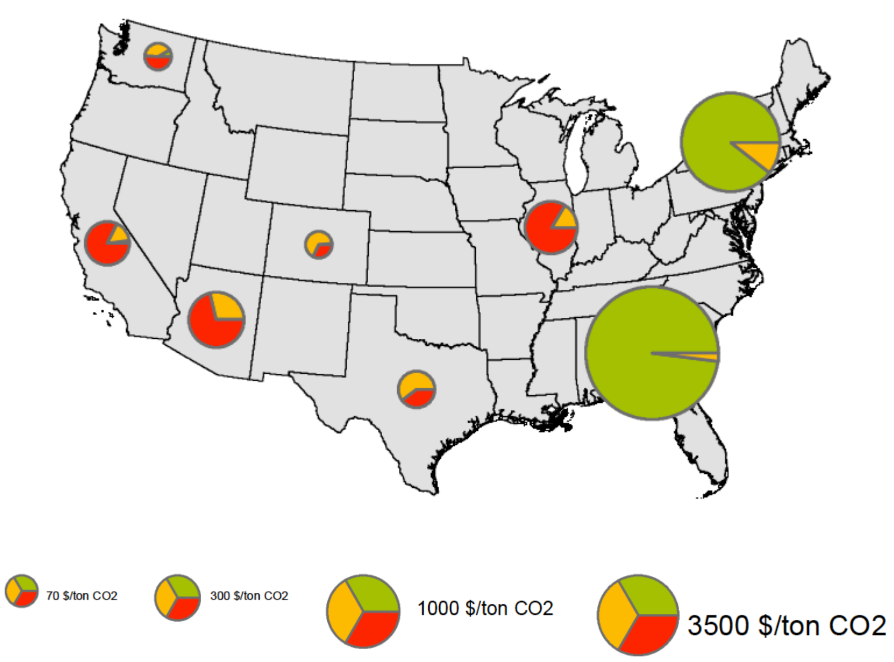
USA

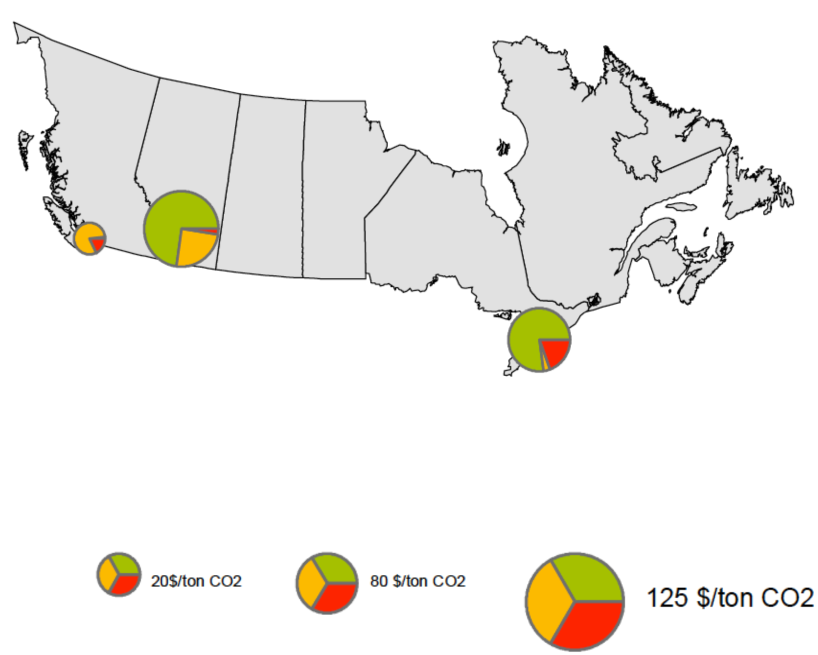


Canada

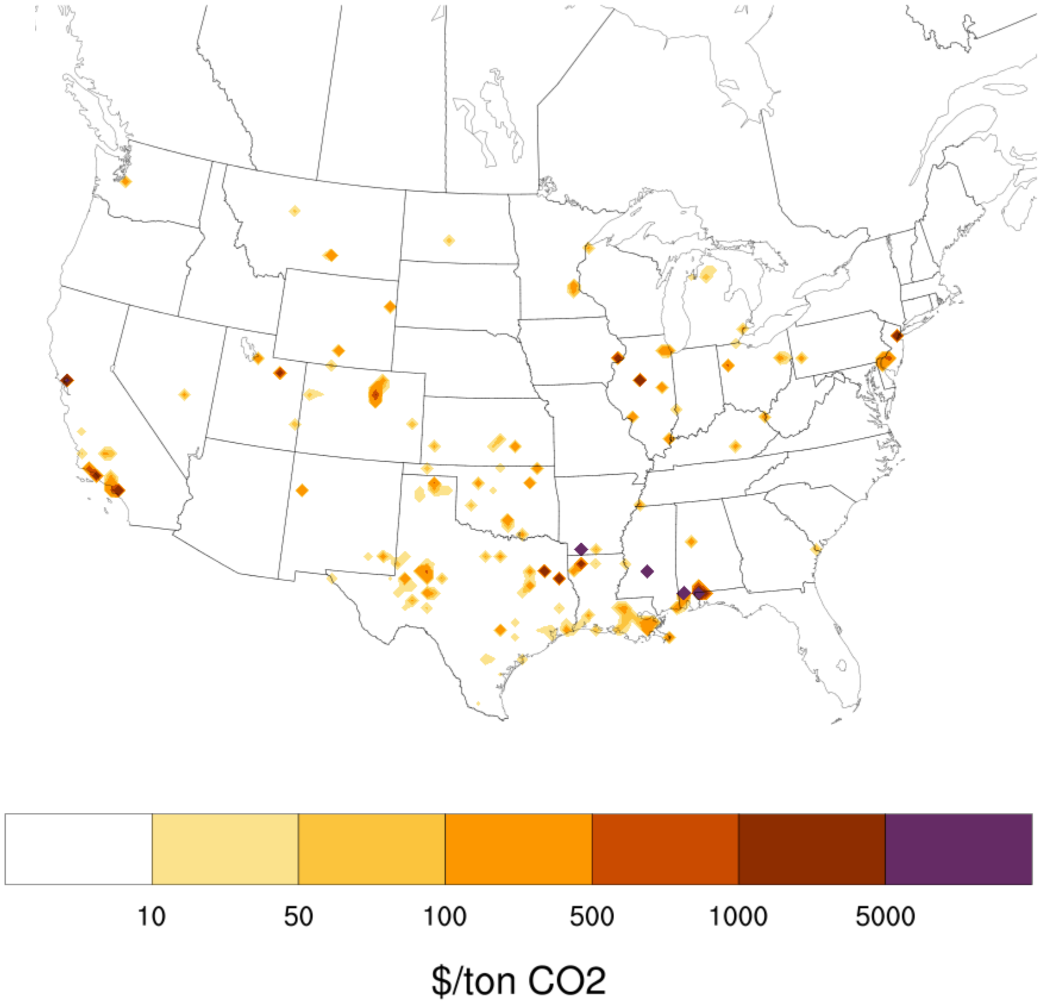


Total Co-benefit : EGUs





Total Co-benefit: Oil & Gas



Policy Relevance Example: Clean Power Plan

EGUs along the Ohio River Valley have total co-benefits ranging $80-5000.

- Adjoint-based co-benefits provide an opportunity for coordinating climate and air quality policies.

- A grand plan to reduce CO_2 emissions from EGUs without consideration of co-benefits and exploiting their wide range is likely to miss a great opportunity for synergistic cost-effectiveness.

Policy Relevance Example: Electrification of Transportation

MBs for New York City mobile sources are:

LDGV: $1350

HDDV: $3300

- Targeted electrification can be far more beneficial than previous studies have indicated.
  - Would require more thorough examination (LCA, demand constraints, transmission, etc).
- Due to the wide range of co-benefits across various locations, targeted electrification seems more beneficial than across-the-board measures.
  - Adjoint, due to its source specificity, is particularly suitable for guiding targeted electrification.

Discussion

- Co-benefit values are comparable to those found previously in scenario-based studies (e.g. Nemet et al., 2010), but significantly larger at specific locations.

- Estimated co-benefits are larger than the price of carbon or its social cost.

- Co-benefits provide a great opportunity for coordinating climate and air quality policies in a cost-effective manner.
  - Such coordination would benefit from uniform criteria pollutant and GHG modelling tools – how can SMOKE model GHGs?

Acknowledgments

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THANK YOU