Air Quality, Health and Ecosystem Co-Benefits of Policy Options for a U.S. Power Plant Carbon Standard

• Outline
  – Background co-benefits of power plant carbon management
  – Phase 1 initial evaluation of policy options
  – Phase 2 current evaluation of Clean Power Plan
  – Summary
Mission: increase the influence of science on environmental policy & conservation

Founders:

Partners:
WHAT ARE CO-BENEFITS?

GLOBAL CLIMATE CHANGE

Carbon dioxide

Other pollutants:
- Nitrogen oxides
- Sulfur dioxide
- Particulate matter

POWER PLANT EMISSIONS

AIR QUALITY:
- ground-level ozone, smog, fine particle matter

HEALTH CO-BENEFITS:
- Fewer premature deaths, heart attacks, hospitalizations

ECOSYSTEM CO-BENEFITS:
- Improved timber, crops, streams, visibility
Health and Ecosystem Co-benefits: Bottom line

• Shifting to cleaner energy sources and expanding energy efficiency not only helps mitigate climate change, it improves air quality and provides immediate health and ecosystem co-benefits to local communities across the U.S.

• The economic value of these co-benefits tend to far exceed the costs of new policies.
Clean Energy Transition is Underway in the US

**Federal Policies:**
- Federal Acid Rain Program
- Mercury and Air Toxics Standards (MATS) - under revision
- Cross State Air Pollution Rule (CSPR)
- Federal Regional haze rule
- Federal wind power production tax credits (PTC)
- Clean Power Plan – in courts

**State and Regional Action:**
- State Renewable Energy Portfolio Standards
- State Energy Efficiency Programs from “public benefit charges”
- Regional Greenhouse Gas Initiative (RGGI)
- CA Assembly Bill 32 (AB32)

**Market Drivers:**
- Lower natural gas prices
States with Power Plant Carbon Cap Programs

- 9 states collaborating under Northeast Regional Greenhouse Gas Initiative (RGGI)
- California: Cut global warming pollution economy-wide to 1990 levels by 2020

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States with Renewable Electricity Standards

- 29 states + DC
- RES projected to drive 3,000-7,000 MW* of new renewables capacity each year through 2020

*Depending on availability of existing renewable energy capacity.

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States with Energy Efficiency Resource Standards

Note that Florida, Indiana, and Ohio repealed their EERS policies within the last year. The impact of the repeals is included in our analysis, but these states still see small improvements from previously implemented efficiency measures.
Shifts in Fossil Electricity Generation

Annual share of total U.S. electricity generation by source (1950-2016)
percent of total

- 2016 forecast
  - natural gas (33%)
  - coal (32%)
  - nuclear (19%)
  - nonhydro renewables (8%)
  - hydro (6%)
  - other (1%)

Year:
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

Legend:
- Coal
- Nuclear
- Nonhydro renewables
- Hydro
- Other

Source: EIA
Trends in Power Sector Emissions
(metric tons)

- Carbon dioxide
- Sulfur dioxide
- Nitrogen oxides

- 2005
- 2013
- Business as usual 2020
- Power plant carbon standards 2020

<table>
<thead>
<tr>
<th>Year</th>
<th>Carbon dioxide (million)</th>
<th>Sulfur dioxide (thousand)</th>
<th>Nitrogen oxides (thousand)</th>
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<tr>
<td>2020</td>
<td>2,000</td>
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Power Plant Carbon Standards: Clean Air and Health Co-Benefits
Where We Are Now

- August 2015 released final Clean Power Plan
  - Includes proposed Federal Plan
- States have one year to indicate planning approach and until 2018 to develop plan
- Compliance begins in 2022
  - Expected 32% GHG emissions reduction from 2005 by 2030 in power sector
  - CPP is a central component of the US pledge for 26-28% reductions by 2025
- Stay in CPP ordered by Supreme Court 2/2016
The Clean Power Plan is a Systems Approach

- Section 111d of the Clean Air Act is intended to ratify and accelerate trends that are happening already
- The CPP has applied the statutory term “best system of emissions reduction” to the electricity system
- Clean Power Plan is a state-driven process
- States have maximal opportunity to exercise flexibility through averaging or trading
- 111d calls for consideration of multiple factors including other environmental outcomes
- Public participation is a key element of state plans
About the Clean Power Plan

• Cut carbon dioxide emissions from the power sector by 32% from 2005 levels by 2030.

• Estimated to reduce sulfur dioxide emissions from power plants by 90% from 2005 levels.

• Estimated to reduce nitrogen oxides emissions from power plants by 72% below 2005 levels.
Phase 1: Nature Climate Change Study

- Charles Driscoll – Syracuse University
- Jonathan Buonocore – Harvard School Public Health
- Dallas Burtraw – RFF
- Habib Fakhraei – Syracuse University
- Kathy Fallon Lambert – Harvard Forest, SPE
- Jon Levy – BU School Public Health
- Steve Reid – Sonoma Technology
- Joel Schwartz – Harvard Public School Health

Grant funding from: William & Flora Hewlett Foundation, Grantham Foundation

Driscoll et al. 2015. Nature Climate Change. eng-cs.syr.edu/cleanair
The Co-benefits of Carbon Standards Study

Assumptions:
- Reference Case
- Scenario 1: Power Plant
- Scenario 2: Electricity Sector
- Scenario 3: Cost of Carbon

Emissions Changes
IPM Model

Air Quality Changes
CMAQ Model

Human Health Co-Benefits
BenMAP Model

Ecosystem Benefits
- Acid Rain
- Crop & timber production
- Visibility Improvements

Co-Benefits of Carbon Standards Study
## Scenarios Compared to 2020 Reference Case

### Reference Case
- EIA 2013 Annual Energy Outlook determines energy demand
- All current air quality policies fully implemented
- Wind power production tax credit (PTC) expires
- Nuclear units re-licensed, 20-year extension
- $CO_2$ emissions estimated to decrease by 15.2% from 2005 by 2020

### Scenario 1: Power Plant Improvements
- Low stringency, low flexibility
- Limited to compliance measures “inside the fenceline”
- Coal plants invest in on-site efficiency (heat rate) retrofits
- Decreases $CO_2$ emissions by 17.4% from 2005, 2.2% from 2020 Reference Case by 2020
### Scenario 2: Electricity Sector Improvements

- Moderate stringency, high flexibility
- Establishes benchmark emissions rate for each state
- Allows states many compliance options
- Also allows averaging and trading
- Decreases CO$_2$ emissions by 35% from 2005, 23% from 2020 Reference Case by 2020

### Scenario 3: Cost of Carbon Improvements

- High stringency, moderate flexibility
- Requires supply-side measures that achieve CO$_2$ reductions up to a cost of $43 per metric ton in 2020
- Doesn’t allow demand-side energy efficiency
- Decreases CO$_2$ emissions by 49% from 2005, 39% from 2020 Reference Case by 2020
A note about baselines

• The following results represent improvements in air quality and health outcomes relative to a reference case in the year 2020.
• EPA has updated the reference case to include greater energy efficiency and renewable energy adoption.
• We are updating our analysis to reflect the revised reference case.
Fossil Fuel Generation in 2020

- Combined Cycle (Gas)
- Combustion Turbine (Gas)
- Coal (without CCS)
- Biomass co-firing
- Coal (with CCS)

CCS = carbon storage and sequestration

Renewable Generation and Efficiency in 2020

- Nuclear
- Hydro
- Wind
- Biomass
- New Energy Efficiency
- Other Renewables

Reference case
Scenario 1
Scenario 2
Scenario 3
Annual Power Sector Emissions in 2020

MMST (CO2) and TST (SO2 and NOx)

- Reference case
- Scenario 1
- Scenario 2
- Scenario 3

MMST = million short tons
TST = thousand short tons

Annual Power Sector Mercury Emissions in 2020

- Pounds

Total Hg
“Weaker” Standard = Scenario #1

- Decreases CO$_2$ by 2.2% from Reference Case by 2020
- *Increases* SO$_2$ by +3%
- Decreases NO$_x$ and mercury by 3%

“Stronger” Standards = Scenarios #2, #3

- Decrease CO$_2$ by 23% to 39% from Reference Case by 2020
- Decrease SO$_2$ by 27%
- Decrease mercury by 27%
- Decrease NO$_x$ by 22% and 16%
AIR QUALITY CO-BENEFITS: FINE PARTICULATE MATTER ($PM_{2.5}$) IN THE YEAR 2020

SCENARIO 2: ENERGY SECTOR IMPROVEMENTS

Units: $PM_{2.5}$ concentration in micrograms per cubic meter ($\mu g m^{-3}$)

Legend:
- Major Cities (>500,000)
- Operating Coal Plants

This map shows:
Changes in concentrations of $PM_{2.5}$ in Scenario 2 from the 2020 reference case. Scenario 2 is the moderate stringency, high flexibility & energy efficiency option and it results in widespread clean air co-benefits.

Positive values = Increase in $PM_{2.5}$ | Negative values = Decrease in $PM_{2.5}$ | Coal plants locations from U.S. Energy Information Administration 2012, 2013
AIR QUALITY CO-BENEFITS: FINE PARTICULATE MATTER (PM$_{2.5}$) IN THE YEAR 2020
SCENARIO 1: POWER PLANT IMPROVEMENTS

Units: PM$_{2.5}$ concentration in micrograms per cubic meter ($\mu g \, m^{-3}$)

LEGEND
- Major Cities (>500,000)
- Operating Coal Plants

THIS MAP SHOWS:
THE CHANGE IN CONCENTRATION OF FINE PARTICULATE MATTER UNDER SCENARIO 1 FROM THE 2020 REFERENCE CASE. SCENARIO 1 IS THE LOW STRINGENCY, LOW FLEXIBILITY OPTION LIMITED TO POWER PLANT UPGRADES AND IT RESULTS IN FEW CLEAN AIR CO-BENEFITS.
AIR QUALITY CO-BENEFITS: PEAK SUMMER OZONE IN THE YEAR 2020
SCENARIO 2: ENERGY SECTOR IMPROVEMENTS

Units: Ozone concentration in parts per billion (ppb)

-3.60 to -1.41
-1.40 to -1.01
-1.00 to -0.71
-0.70 to -0.51
-0.50 to -0.31
-0.30 to -0.01
0 to 0.70

LEGEND
- Major Cities (>500,000)
- Operating Coal Plants

THIS MAP SHOWS:
CHANGE IN CONCENTRATIONS OF PEAK SUMMER OZONE IN SCENARIO 2 FROM THE 2020 REFERENCE CASE. SCENARIO 2 IS THE MODERATE STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND IT RESULTS IN WIDESPREAD CLEAN AIR CO-BENEFITS.

Positive values = Increase in summer ozone | Negative values = Decrease in summer ozone | Coal plants locations from U.S. Energy Information Administration 2012, 2013
AIR QUALITY CO-BENEFITS: PEAK SUMMER OZONE IN THE YEAR 2020
SCENARIO 1: POWER PLANT IMPROVEMENTS

This map shows changes in concentrations of peak summer ozone in Scenario 1 from the 2020 reference case. Scenario 1 is the low stringency, low flexibility option limited to power plant upgrades and it results in few clean air co-benefits.

Positive values = Increase in summer ozone | Negative values = Decrease in summer ozone | Coal plants locations from U.S. Energy Information Administration 2012, 2013

LEGEND
Major Cities (>500,000)
Operating Coal Plants

Units: Ozone concentration in parts per billion (ppb)

-3.60 to -1.41
-1.40 to -1.01
-1.00 to -0.71
-0.70 to -0.51
-0.50 to -0.31
-0.30 to -0.01
0 to 0.70
Health Co-Benefits in this Study

Lower Fine Particulate Matter ($PM_{2.5}$) Benefits
- Premature deaths avoided (i.e., lives saved)
- Heart attacks avoided
- Other cardiovascular hospital admissions avoided
- Respiratory hospital admissions avoided

Lower Ground-level Ozone Benefits
- Premature deaths avoided (i.e., lives saved)
- Respiratory hospital admissions avoided
HEALTH CO-BENEFITS: LIVES SAVED IN THE YEAR 2020
SCENARIO 2: ELECTRICITY SECTOR IMPROVEMENTS

THIS MAP SHOWS:
THE CHANGE IN NUMBER OF PREMATURE DEATHS AVOIDED PER YEAR UNDER SCENARIO 2 FROM THE 2020 REFERENCE CASE BY STATE. SCENARIO 2 IS THE MODERATE STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND IT RESULTS IN THE LARGEST HEALTH CO-BENEFITS.

Positive values = increase in # of lives saved per year | Coal plant locations from U.S. Energy Information Administration 2012, 2013
HEALTH CO-BENEFITS: PRESENT CHANGE IN LIVES SAVED IN YEAR 2020
SCENARIO 2: ELECTRICITY SECTOR IMPROVEMENTS

THIS MAP SHOWS:
THE CHANGE IN RATE OF LIVES SAVED UNDER SCENARIO 2 FROM THE 2020
REFERENCE CASE BY COUNTY. SCENARIO 2 IS THE MODERATE
STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND
RESULTS IN THE LARGEST HEALTH CO-BENEFITS.

Positive values = increase in rate of premature deaths avoided | Coal plant locations from U.S. Energy Information Administration 2012, 2013
HEALTH CO-BENEFITS: HOSPITAL ADMISSIONS AVOIDED IN THE YEAR 2020
SCENARIO 2: ELECTRICITY SECTOR IMPROVEMENTS

Units: hospitalizations avoided per year

LEGEND

- Major Cities (>500,000)
- Operating Coal Plants

THIS MAP SHOWS:

THE CHANGES IN NUMBER OF HOSPITALIZATIONS RELATED HEART AND LUNG DISEASE UNDER SCENARIO 2 FROM THE 2020 REFERENCE CASE. SCENARIO 2 IS THE MODERATE STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND IT RESULTS IN THE LARGEST HEALTH CO-BENEFITS.

Positive values = increase in # of hospital admissions avoided per year | Coal plant locations from U.S. Energy Information Administration 2012, 2013
LOWER EMISSIONS = CLEANER AIR & IMPROVED HEALTH

**Policy Scenario: Electricity Sector Improvements**

- **US Powerplant Emissions**
  - CO₂: ↓24%
  - NOX: ↓22%
  - SO₂: ↓27%

- **Major Improvements in Ozone**
  - SMOG: ↑45 states

- **Major Improvements in PM 2.5**
  - SOOT: ↑26 states

- **Our Health**
  - Lives Saved Per Year: 3500
  - Hospitalizations Prevented Per Year: 1000
  - Heart Attacks Prevented Per Year: 220
Co-benefits vs. Costs (2010 USD)

Scenario 2: similar to Clean Power Plan

• Estimated health co-benefits = $29 billion per year (95% CI $2.3-68 B/yr)
• Carbon benefits = $21 billion per year
  – (social cost of carbon $40/short ton)

• Estimated annual costs = $17 billion (in 2020)
  (- $450 M/yr - $39 B/yr)
• Estimated net benefits: $33 billion per year

Buonocore et al. In review.
Ecosystem Benefits

![Graph showing the mean number of fish species by pH class.](image)

Acid Deposition Effects on Trees

- Red Spruce:
  - Calcium leached from needle membranes
  - Decreased cold tolerance
  - Increased freezing injury

- Sugar Maple:
  - Calcium & magnesium leached from soil
  - Aluminum mobilized & taken up by tree

![Images of mountainous landscapes.](image)
Visibility Co-benefits of Carbon Standards in Class I Areas

- Results are for Scenario 2, most similar to proposed CPP standard
- The results are put into the context of the RHR for each class I area
- Meeting the RHR goals will require accumulation of small improvements and these co-benefits will aid states
Crop Distribution

- **Corn Production** (bu):
  - Scale: 0 to 3x10^6

- **Cotton Production** (bales):
  - Scale: 0 to 30x10^3

- **Potato Production** (cwt):
  - Scale: 0.0 to 2.5x10^6

- **Wheat Production** (bu):
  - Scale: 0 to 600x10^3
Timber Distribution

Ponderosa Pine (tons ha\(^{-1}\))

Eastern Cottonwood (tons ha\(^{-1}\))

Beech (tons ha\(^{-1}\))

20  40  60  80  100

2  4  6  8  10

10  20  30  40  50  60
Crop Loss Totals

Potential Productivity Loss in Reference Scenario (% of NASS-estimated biomass) (left axis)
Relative Change in Productivity Loss from Reference (right axis): ○ Scenario 1 □ Scenario 2 △ Scenario 3

Productivity Reduction in Reference Scenario (%)

Potato
Soybean
Corn
Wheat
Cotton
Timber Loss Totals

The graph shows the potential biomass loss in the reference scenario (% of FIA-estimated biomass) (left axis) and the relative change in biomass loss from the reference (right axis) for different species and scenarios. The x-axis represents the species, and the y-axis represents the biomass reduction in the reference scenario (%). Different markers represent different scenarios.
Policy Choices Make Big Difference
Phase 2: Overarching Question

Will different implementation approaches to the Clean Power Plan influence the magnitude and distribution of clean air and associated health and ecosystem co-benefits?
Four Clean Power Plan Scenarios

2030 Reference case (no Clean Power Plan)

1. Mass-based standard, existing units, 1% EE, national trading
2. Mass-based standard, existing & new units, 1% EE, national trading
3. Dual rate-based standard, 1% EE, national trading
4. Mass-based standard, existing & new units, 1% EE, in-state trading
1. Mass-based versus rate-based standards
2. Existing only or existing & new units under mass-based standard
3. National trading or state-by-state compliance under mass-based standard for new & existing units
Change in CO₂ emissions compared to Reference Case in 2030 (Million Short Tons)

Scenario 1: Mass-based, existing only, 1% EE, national trading

Scenario 2: Dual rate-based, 1% EE, two trading zones

Scenario 3: Mass-based, existing & new, 1% EE, national trading

Scenario 4: Mass-based, existing & new, 1% EE, state-by-state trading
Change in SO$_2$ emissions compared to Reference Case in 2030 (Thousand Short Tons)

Scenario 1: Mass-based, existing only, 1% EE, national trading

Scenario 2: Dual rate-based, 1% EE, two trading zones

Scenario 3: Mass-based, existing & new, 1% EE, national trading

Scenario 4: Mass-based, existing & new, 1% EE, state-by-state trading
Summary of Findings

• The clean air and health ecosystem co-benefits of stringent & flexible power plan carbon standards like the Clean Power Plan are widespread with all lower 48 states experiencing improvements.

• Top 12 states for premature deaths avoided are: PA, OH, TX, IL, MI, NY, NC, GA, MO, VA, TN, and IN.

• Conservative estimates of the value of the health co-benefits alone exceed policy costs.
Shifting to cleaner energy sources and expanding energy efficiency not only helps mitigate climate change, it improves air quality and provides immediate health co-benefits to local communities across the U.S.

The economic value of these co-benefits tend to far exceed the costs of new policies.
• When the Clean Power Plan is fully in place in 2030, carbon pollution from the power sector will be 32 percent below 2005 levels, securing progress and making sure it continues.

• The transition to cleaner sources of energy will better protect Americans from other harmful air pollution, too. By 2030, emissions of sulfur dioxide from power plants will be 90 percent lower compared to 2005 levels, and emissions of nitrogen oxides will be 72 percent lower. Because these pollutants can create dangerous soot and smog, the historically low levels mean we will avoid thousands of premature deaths and have thousands fewer asthma attacks and hospitalizations in 2030 and every year beyond.

• Within this larger context, the Clean Power Plan itself is projected to contribute significant pollution reductions, resulting in important benefits, including:
  – Climate benefits of $20 billion
  – Health benefits of $14-$34 billion
  – Net benefits of $26-$45 billion

• Because carbon pollution comes packaged with other dangerous air pollutants, the Clean Power Plan will also protect public health, avoiding each year:
  – 3,600 premature deaths
  – 1,700 heart attacks
  – 90,000 asthma attacks
  – 300,000 missed work days and school days
HEALTH CO-BENEFITS: HEART ATTACKS PREVENTED IN THE YEAR 2020
SCENARIO 2: ELECTRICITY SECTOR IMPROVEMENTS

THIS MAP SHOWS:
THE CHANGE IN THE NUMBER OF HEART ATTACKS PREVENTED UNDER SCENARIO 2 FROM THE 2020 REFERENCE CASE BY STATE. SCENARIO 2 IS THE MODERATE STRINGENCY, HIGH FLEXIBILITY & ENERGY EFFICIENCY OPTION AND IT RESULTS IN THE LARGEST HEALTH CO-BENEFITS.

Units: heart attacks prevented per year

Legend:
- Major Cities (>500,000)
- Operating Coal Plants
- Positive values = increase in # of heart attacks prevented per year

Coal plant locations from U.S. Energy Information Administration 2012, 2013