MODELING THE CO-BENEFITS OF CARBON STANDARDS FOR EXISTING POWER PLANTS

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1. INTRODUCTION

Fossil fuel-fired power plants are the single largest source of anthropogenic carbon dioxide (CO_2) emissions in the United States, accounting for about 40% of total CO_2 emissions nationwide (U.S. Environmental Protection Agency, 2014a). On June 2, 2014, the U.S. Environmental Protection Agency (EPA) released the Clean Power Plan, a proposed rule for reducing carbon emissions from existing power plants. The intent of this plan is for EPA to establish federal carbon standards and for individual states to design programs to achieve the necessary carbon emission reductions.

Because these power plants are also significant sources of additional pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury (Hg), policies intended to address climate change by reducing CO_2 emissions can also reduce emissions of these co-pollutants, thereby providing important co-benefits to human and environmental health. For example, SO_2 and NO_x contribute to the formation of fine particulate matter ($PM_{2.5}$), and NO_x is a precursor to ground-level ozone. These pollutants contribute to increased risk of premature death, heart attacks, and other human health effects (Pope et al., 2002). For ecosystems, these pollutants contribute to the formation of acid rain and to ozone damage to trees and crops (Driscoll et al., 2001; Karlsson et al., 2004).

To evaluate the co-benefits associated with various approaches to carbon pollution standards, a project team led by Syracuse and Harvard Universities conducted a three-part study to quantify the (1) air quality; (2) human health; and (3) ecosystem co-benefits of three different carbon policy scenarios (Fig. 1).

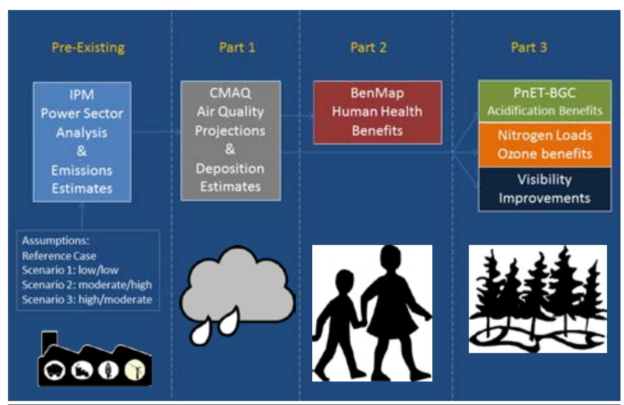

Fig. 1. Diagram of the carbon standards co-benefits study.

The three policy scenarios for power plant carbon standards represent different CO_2 emissions reduction stringencies, compliance options, and investments in demand-side energy efficiency. These scenarios were designed prior to the release of the Clean Power Plan and are intended to capture the range of alternatives under consideration as the final rule is being formed. The project team identified co-benefits by performing air quality modeling for the year 2020 with power plant emissions estimates for each of the policy scenarios and comparing model results with results from a simulation using business-as-usual emissions for 2020.

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2. CARBON STANDARD SCENARIOS

The starting point for the study was existing energy sector scenarios for 2020 developed by the Bipartisan Policy Center (BPC) and the Natural Resources Defense Council (NRDC). These scenarios, which are described below, were selected before the Clean Power Plan was released, and Scenarios 1 and 2 are most relevant to the current policy discussion.

Reference Case – The 2020 business-as-usual scenario was benchmarked to the Energy Information Administration's (EIA) Annual Energy Outlook of 2013 and assumes full implementation of current clean air policies (e.g., EPA's Mercury and Air Toxics Standard).

Scenario 1 – This scenario is a low-stringency alternative with compliance options limited to "inside the fenceline" changes. Scenario 1 is an emissions rate-based standard that uses heat rate (BTU/kWh) improvements at existing power plants to comply with the carbon standard and results in national average emission rates of 907 kg/MWh for coal plants and 454 kg/MWh for gas plants.

Scenario 2 – This is a moderate-stringency scenario with a wide range of compliance options and substantial investments in demand-side energy efficiency. Scenario 2 achieves CO_2 reductions through state-specific emission rate performance standards based on targets of 680 kg/MWh for coal plants and 454 kg/MWh for gas plants.

Scenario 3 – This is a high-stringency scenario designed to mimic the impacts of a national tax on CO_2 emissions. Scenario 3 requires supply-side emission reductions that can be implemented at a cost of up to $43 per metric ton in 2020. It results in national average emission rates of 544 kg/MWh for coal plants and 385 kg/MWh for gas plants.

For the various 2020 scenarios described above, ICF International used the Integrated Planning Model (IPM) to simulate changes in power generation and to estimate 2020 energy sector emissions for the United States. IPM outputs showed that all three scenarios resulted in significant CO_2 reductions relative to 2005 levels; however, only Scenarios 2 and 3 resulted in significant CO_2 reductions when compared to the 2020 reference case (Table 1).

Table 1. Changes in CO_2 emissions by scenario.

Scenario	From 2005 levels	From 2020 reference case
1	-17%	-2%
2	-36%	-24%
3	-49%	-40%

For co-pollutants, Scenario 1 resulted in modest changes to SO_2 (+3%), and NO_x (-3%) emissions relative to the 2020 reference case (Fig. 2). SO_2 emissions increased slightly under Scenario 1 due to "emissions rebound," which refers to an increase in emissions that can occur when power plants that emit larger amounts of SO_2 per BTU of energy are made more efficient, emit less carbon, and therefore rise in the dispatch order and run more frequently and for longer periods of time.

Scenario 2 resulted in emission reductions of 27% for SO_2 and 22% for NO_x compared to the 2020 reference case, and Scenario 3 resulted in emission reductions of 27% for SO_2 and 16% for NO_x (Fig. 2).

These results indicate that Scenario 2, with a 36% reduction, is most similar to the standards proposed by EPA in the Clean Power Plan, which calls for a 30% reduction in CO_2 emissions from 2005 levels by 2030. Also, like the EPA proposal, Scenario 2 offers flexibility for compliance through power plant heat rate improvements, switching to renewable energy sources, and adding demand-side energy efficiency measures.

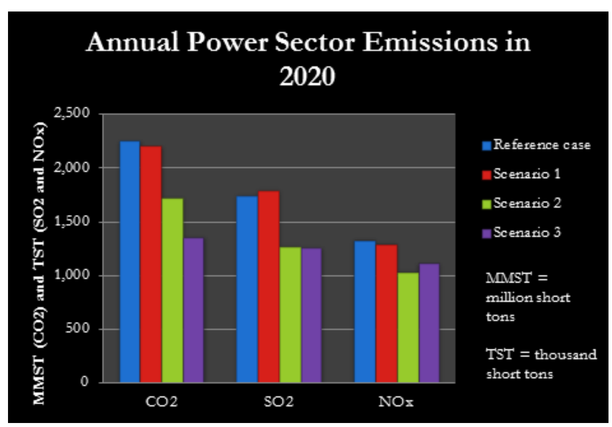

Fig. 2. Modeled 2020 emissions of CO_2, SO_2, and NO_x by scenario.

3. METHODS

3.1 Air Quality Modeling

Analysis of impacts of the three carbon standard scenarios on air quality, human health, and ecosystem health were based on results of Community Multiscale Air Quality (CMAQ) model simulations. The starting point for the air quality modeling was EPA's 2007/2020 modeling platform, which was used to conduct the regulatory impact analysis (RIA) for revisions to the National Ambient Air Quality Standards (NAAQS) for particulate matter (U.S. Environmental Protection Agency, 2012). The 2007/2020 platform features CMAQ version 4.7.1 and a 12-km CONUS modeling domain (Fig. 3). Use of the EPA platform provided a national-scale modeling system that had already undergone a model performance evaluation and been validated for regulatory analysis.

Fig. 3. CMAQ modeling grid used for this study (12-km grid resolution).

CMAQ meteorological inputs for EPA's modeling platform were developed for 2007 using version 3.1 of the Weather Research and Forecast (WRF) model.

Emissions inputs for the modeling platform were based on the 2008 National Emissions Inventory (NEI), version 2. EPA adjusted some portions of the 2008 data to better represent the 2007 base year, and for the future year of 2020, base case emissions projections were based on forecasted economic changes and federal and state control measures already promulgated.

For this study, unit-level power plant emissions in EPA's 2020 base case emissions inventory were replaced by the IPM results for the reference case and three policy scenarios described above. For all other source sectors, 2020 base case emissions from EPA's modeling platform were used directly.

Annual CMAQ runs for 2020 were performed for the reference case and three policy scenarios, and CMAQ outputs were used to quantify the impact of the policy scenarios on atmospheric pollutant concentrations and surface deposition rates.

3.2 Human Health Co-Benefits

The second part of the study used gridded air quality results from CMAQ to quantify and map the health co-benefits associated with each of the three policy scenarios. This analysis was done with the Benefits Mapping and Analysis Program (BenMAP) Community Edition v1.0.8, which was developed by EPA (U.S. Environmental Protection Agency, 2014b). BenMAP is a Geographic Information System (GIS)-based software tool designed to calculate the health benefits of air quality management scenarios.

BenMAP contains data on population, demographics, and incidence and prevalence rates of health outcomes, and we used BenMAP in conjunction with published concentration-response functions and CMAQ results to estimate the health benefits of our three policy scenarios. Because the BenMAP analysis focused on pollutant concentration differences between the reference case and the policy cases, the co-benefits identified are additional benefits associated with the carbon standard that go beyond the benefits anticipated to occur with the continued implementation of existing air policies.

To quantify and map the health co-benefits for each scenario, we analyzed the six health outcomes listed below. We calculated both the change in mortality rate (premature deaths avoided per capita) by county and the change in the total number of premature deaths avoided per year nationwide and in each state. All results are for the year 2020 based on the difference from the reference case.

$PM_{2.5}$-related health co-benefits

1. Premature deaths avoided (i.e., lives saved)
2. Heart attacks avoided
3. Other cardiovascular hospital admissions avoided
4. Respiratory hospital admissions avoided

Ozone-related health co-benefits

5. Premature deaths avoided (i.e., lives saved)
6. Respiratory hospital admissions avoided

The health outcomes listed above were chosen because there is extensive evidence that air pollution causes them; in addition, these outcomes account for most of the monetized benefits associated with air pollution control strategies.

3.3 Ecosystem Health Co-Benefits

In the third part of this study, which is still under way, the pollutant concentration and surface deposition results from CMAQ are being used to estimate ecosystem benefits using various models, including the PnET forest ecosystem model (Aber et al., 1997). Analyses include the recovery of streams and forests from acid deposition, reduced ozone damage to crops and timber, and improved visibility in focal landscapes. Results from this part of the study are expected to be ready by the end of 2014.

4. RESULTS

4.1 Air Quality

The CMAQ results show marked differences in air quality impacts among the three policy scenarios; these differences correspond to the estimated changes in annual emissions previously shown in Figure 2.

For annual average $PM_{2.5}$, changes from the reference case results (Fig. 4) were modest for Scenario 1, as shown in Figure 5. In general, annual average $PM_{2.5}$ concentrations increased by up to 0.4 μg/m^3 due to the increase in SO_2 emissions associated with that scenario. For Scenario 2, which had significant SO_2 and NO_x reductions relative to the reference case, annual average $PM_{2.5}$ concentrations decreased by 0.15 to 1.35 μg/m^3 across much of the eastern United States (Fig. 6).

For Scenario 3, changes in annual average $PM_{2.5}$ concentrations (not shown) were similar to results for Scenario 2, but at a much higher cost.

For ozone, peak 8-hr concentrations during the summer months (June 1–August 31) were evaluated. For Scenario 2, changes from the reference case results (Fig. 7) were most evident in the Ohio River Valley and the Central U.S., with average peak 8-hr ozone concentrations decreasing by 0.7 to 3.6 ppb across those regions (Fig. 8).

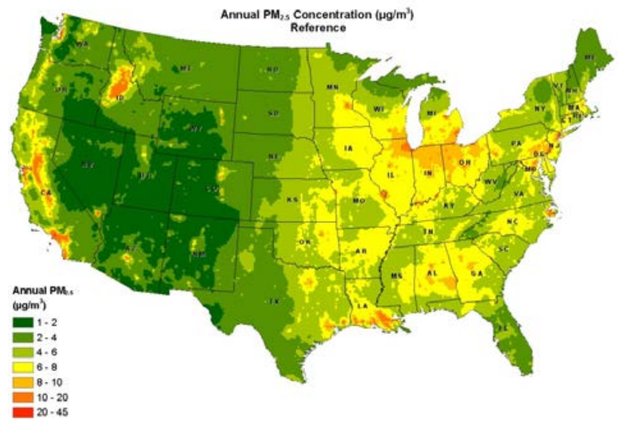

Fig. 4. Annual average $PM_{2.5}$ concentrations for the 2020 reference case.

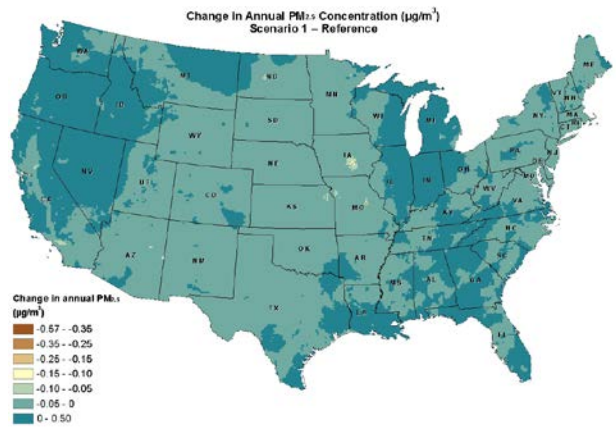

Fig. 5. Changes in annual average $PM_{2.5}$ concentrations between the reference case and Scenario 1.

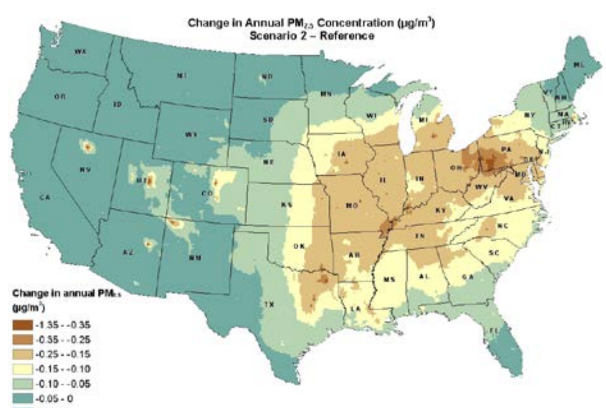

Fig. 6. Changes in annual average $PM_{2.5}$ concentrations between the reference case and Scenario 2.

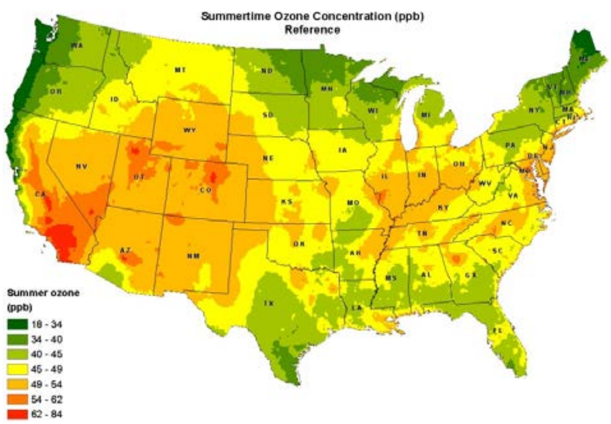

Fig. 7. Average summer (June 1–August 31) peak 8-hr ozone concentrations for the 2020 reference case.

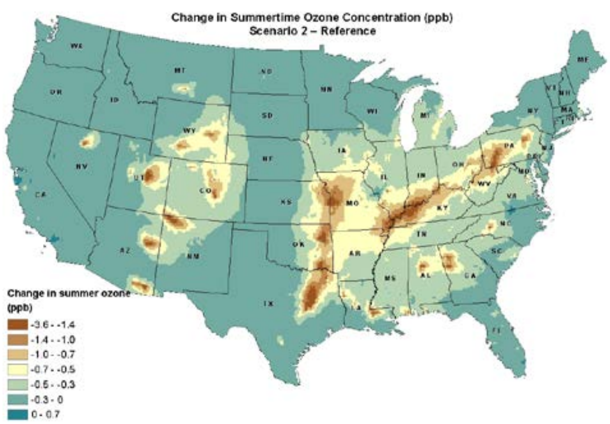

Fig. 8. Changes in average summer peak 8-hr ozone concentrations between the reference case and Scenario 2.

4.2 Human Health

We used the BenMAP model to estimate expected changes in health outcomes due to changes in exposure to both $PM_{2.5}$ and ozone in the year 2020.

On a national scale, Scenario 1 resulted in a slight increase in premature deaths and heart attacks and a slight decrease in respiratory and cardiovascular hospitalizations compared to the 2020 reference case (Table 2). The adverse results are related to the slight increase in annual power plant SO_2 emissions projected to occur under this scenario. Reduced respiratory hospitalizations related to ozone benefits associated with NO_x reductions offset the adverse effects of the SO_2 increase.

For Scenario 2, BenMAP results indicate that health benefits include 3,200 premature deaths avoided, 220 heart attacks avoided, and 1,000 hospitalizations avoided. Health benefits for Scenario 3 are similar to those for Scenario 2, though slightly lower across all outcomes.

Our results also show that all states will receive some health co-benefits due to the pollutant concentration reductions associated with Scenario 2 (Figs. 9-11). The magnitude of health changes is related to both the concentration of changes and the size of the exposed population. On a per-capita basis, the greatest benefits generally occur in states in the Ohio River Valley.

Table 2. National-scale health co-benefits by scenario.

Outcome	Sc. 1	Sc. 2	Sc. 3
Premature deaths	+11	-3500	-3200
Heart attacks	+3	-220	-210
Hospitalizations	-15	-1000	-860

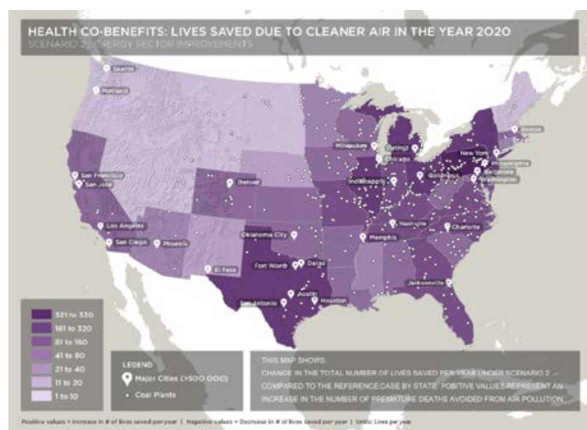

Fig. 9. Reduction in premature deaths due to air pollution between the reference case and Scenario 2.

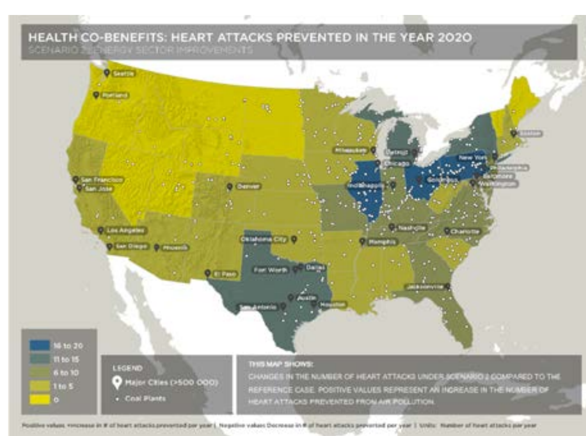

Fig. 10. Reduction in heart attacks due to air pollution between the reference case and Scenario 2.

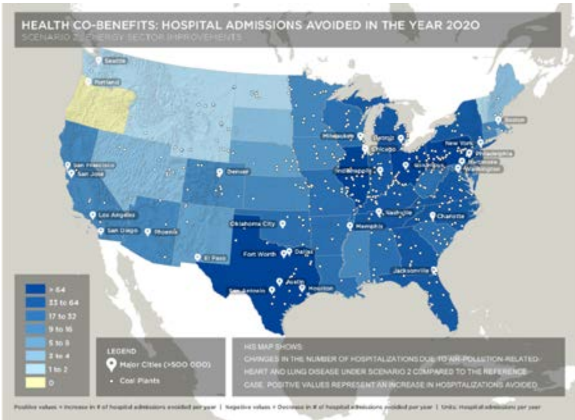

Fig. 11. Changes in hospital admissions due to air pollution between the reference case and Scenario 2.

5. CONCLUSION AND DISCUSSION

Results of this study indicate that carbon standard Scenario 2, which has a moderate stringency, a wide range of compliance options, and is most similar to the EPA-proposed Clean Power Plan, provides the greatest air quality and human health co-benefits of the scenarios evaluated. Scenario 2 reduces SO_2 emissions by 474,000 short tons (27%) and NO_x emissions by 299,000 short tons (22%) relative to the 2020 reference case. These emissions reductions result in annual average $PM_{2.5}$ concentration decreases of 0.15 to 1.35 µg/m^3 across much of the eastern United States. In addition, average summer peak 8-hr ozone concentrations decrease by 0.7 to 3.6 ppb across large portions of the Ohio River Valley and the Central United States.

Analysis of health outcomes indicate that Scenario 2 results in 3,500 avoided premature deaths in 2020 and provides human health benefits to all states, particularly those in the Ohio River Valley.

Results also show that Scenario 1, which is focused strictly on "inside the fenceline" power plant retrofits, could increase co-pollutant emissions and have a net negative impact on air quality and human health.

These findings indicate that, in addition to addressing CO_2 emissions, a strong carbon pollution standard for existing power plants will reduce emissions of co-pollutants that contribute to local and regional air pollution. The results also show that the design of power plant carbon standards strongly influences the amount and distribution of air quality and human health co-benefits that accrue to states and local communities.

6. REFERENCES

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