Public Health Outcomes and Economic Benefits of 50% Emission Reduction of Particulate Matter Precursors across the United States and in Wisconsin

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Introduction

- Energy production and consumption can emit different kinds of air pollutants, and thus have negative effects on the air quality that harms human health. The public health outcomes can be evaluated as economic benefits.
- As shown in Figure 1, co-benefits models serve as tools to estimate the options of energy plans by simulating the interactions among energy, emissions, air quality, human health and economic impacts (Bridges et al., 2015).

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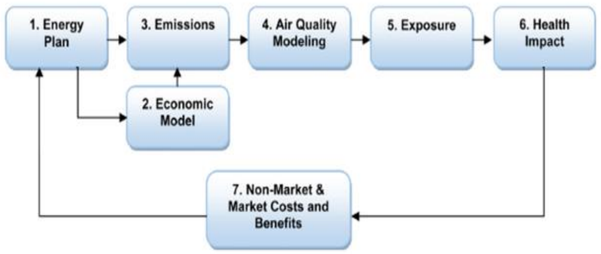


Figure 1. High-level integration of economic and human health-effect modeling in strategic energy planning (source: Bridges et al., 2015)

- Compared to sophisticated models, the reduced-form co-benefit models are more computationally effective and easy to use. They simplify the reality because they avoid the complicated feedback loops and can directly display the key variables of interest(Timmins & Schlenker, 2009).
- This study is to use COBRA **to study how 50% reduction of different PM precursors affect $PM_{2.5}$ concentrations in the U.S. as well as public health outcomes and economic benefits of the local and nearby states due to 50% reduction of PM precursors in Wisconsin.**

Methodology

- COBRA was used rather than GAINS because:

i. This research is to study the PM precursors only in the United States. Different from GAINS, COBRA can be implemented in the scenarios within the contiguous United States;
ii. The output of COBRA is at the state/country level, not in the grid. This can provide more easy-to-view tables/maps to the locals, many of whom are not experts in the environmental problems.

- As shown in Figure 2, COBRA inputs the change of emission from the energy plans, simulate the change of air quality, calculate the changes of health outcomes and monetized benefits taking the discount rates into accounts(U.S.EPA, 2020).
- After users create scenarios by specifying the changes of emissions, COBRA will run to calculate the differences between the users' scenarios and the baseline scenario. There are three baselines(2016, 2023, 2028) preloaded in COBRA. Since the COVID pandemic has significantly decreased the emissions and population in the United States, the baseline of 2023 and 2028 are no longer reliable and valid.
- Based on the 2016 baseline about the PM precursors emissions from the electricity utility in fuel combustion, I created six scenarios across the United States where:

I. Primary PM2.5 was decreased by 50%;
II. $SO_2$was decreased by 50%; a
III. NOx was decreased by 50%;
IV. NH_3 was decreased by 50%;
V. VOC was decreased by 50%;
VI. Primary $PM_{2.5}$, SO_2, NOx, NH_3, and VOC were decreased by 50% respectively.

- There was only one scenario of Wisconsin where all PM precursors were decreased by 50%.

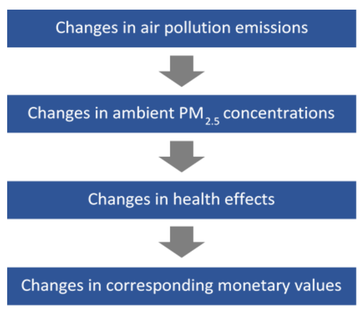


Figure 2. Process of COBRA (source: U.S.EPA, 2020).

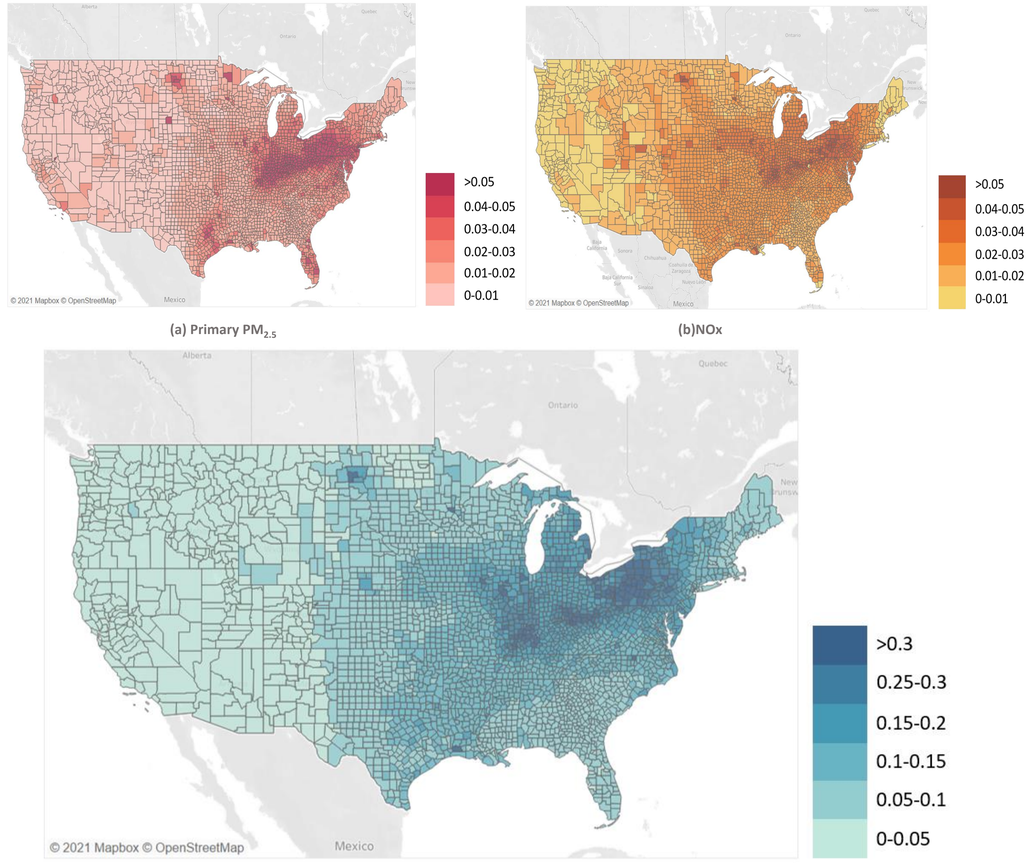
Results

- ***Scenarios of emission reductions across the United States (Figure 3)***

Across the United States, the emission reductions of all five PM precursors (Primary $PM_{2.5}$, SO_2, NOx, NH_3, and VOC) from the electricity utility in fuel combustion mitigated the $PM_{2.5}$ concentrations the most. Among the scenarios where only one kind of PM precursors was decreased by 50%, reductions of Primary $PM_{2.5}$, SO_2, and NOx reduce the $PM_{2.5}$ level the most in Kentucky, Ohio, and Pennsylvania while the other two had minimal effects. Additionally, compared with $PM_{2.5}$ and NOx, SO_2 emission reduction alleviated the most $PM_{2.5}$ levels in the whole U.S.

- ***Scenario of emission reductions in Wisconsin (Figure 4)***

Michigan gained the most health benefits and associated economic benefits from Wisconsin's 50% reduction of all kinds of emissions from fuel combustion for electricity use, followed by Wisconsin and Illinois. The monetized benefits from avoided mortality made up of the most economic benefits.



(a) Primary $PM_{2.5}$ (b)NOx

(c) SO_2

Figure 3. Changes of $PM_{2.5}$ concentrations in each country of the United States under 50% emission reduction of six different kinds of pollutants: (a)Primary $PM_{2.5}$; (b)NOx; (c) SO_2. All three maps are made by Tableau using the outputs of COBRA. Colors show the change of $PM_{2.5}$ level. Details are shown for state and county.

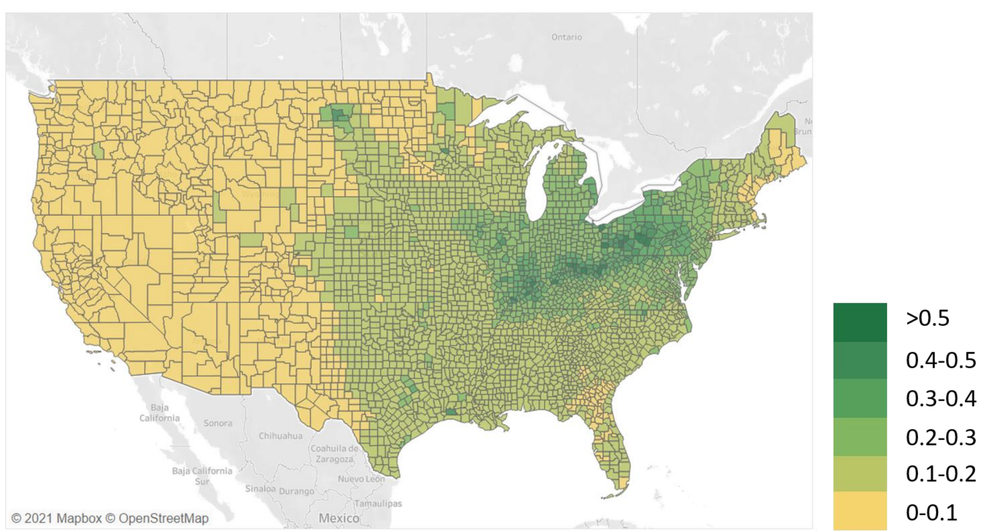


Figure 4. Changes of $PM_{2.5}$ concentrations in each country of the United States under 50% emission reduction of all kinds of pollutants. The map is made by Tableau using the outputs of COBRA. Colors show the change of $PM_{2.5}$ level. Details are shown for state and county.

Backgrounds

- During the production and consumption of energy, PM is often emitted or created. Primary PM directly comes from both human and natural activities. Secondary PM is formed in the atmosphere from air pollutants including sulfur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3), and volatile organic compounds(VOC). Since the precursors are gaseous pollutants and wind can carry both precursors and primary PM for a long distance, focusing on the control of emissions of PM precursors and primary PM can lead to positive environmental, human health-related, and economic benefits not only in the local but also in the nearby places.
- Most of the coal-fired power plants are built in Kentucky, Ohio, and Pennsylvania (Figure 5).
- Wisconsin is situated to the north of Illinois, to the northeast of Iowa, and the west of Minnesota and Michigan's Upper Peninsula. Even though the Wisconsin government is proactive in establishing the energy goals and adjusting the energy structures to achieve the goals, coal-fired power plants still serve as the largest providers to generate electricity (EIA, 2020). Coal combustion emits some PM precursors and primary PM into the atmosphere. Therefore, Wisconsin needs to reduce the emission of PM precursors and primary PM to mitigate the air pollution to avoid some health outcomes in the state and the nearby states.

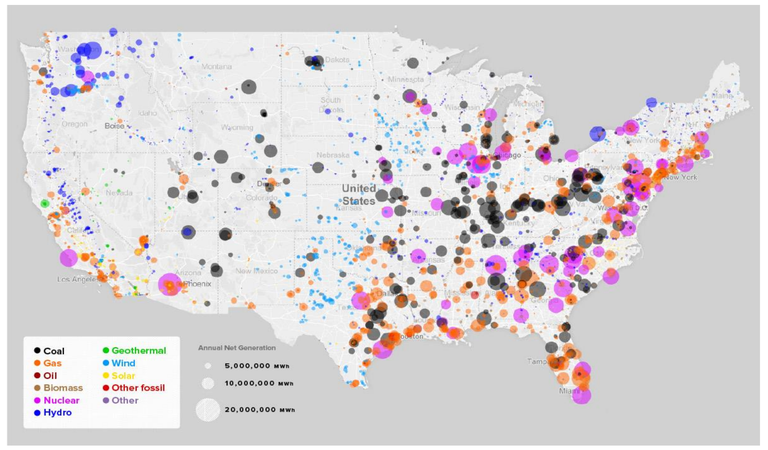


Figure 5. Different kinds of power plants in the United States. Source: Desjardins, 2019

Discussions and Conclusions

- My research illustrates that 50% emission reduction of all five PM precursors had the biggest effect on $PM_{2.5}$ concentrations across the United States, which is understandable because of the common sense that the more amount of emission reduction, the greater impact on the level of air pollution.
- Decreasing the emission of SO_2 across the United States mitigated the $PM_{2.5}$ level the most in Kentucky, Ohio, and Pennsylvania. This can be explained by the distribution of power plants in the U.S. Most of the coal-fired power plants are built in Kentucky, Ohio, and Pennsylvania. Decreasing the emissions of SO_2 that are often emitted from coal combustion, makes these three states the biggest beneficiary.
- The scenario in Wisconsin emphasizes that efforts to decrease local emissions can contribute to the health benefits of nearby states. Michigan could even gain more public health outcomes and economic benefits from the reduction of Wisconsin's PM precursors emission than Wisconsin itself. This is probably because prevailing winds moving from the west to the east carry most pollutants from Wisconsin to Michigan which is to the east of Wisconsin.
- Two kinds of limitations occurred in this research:

I. Not based on a realistic energy policy, and thus lack of practical significance.
II. Uncertainties come from the COBRA model that overlooks the chemical reactions and transport of different kinds of PM precursors (U.S.EPA, 2020) and does not consider ozone which also contributes to illnesses and mortality (Nuvolone et al., 2018).

References

- Bridges, A., Felder, F. A., McKelvey, K., & Niyogi, I. (2015). Uncertainty in energy planning: Estimating the health impacts of air pollution from fossil fuel electricity generation. Energy Research and Social Science, 6. https://doi.org/10.1016/j.erss.2014.12.002
- Britannica. (n.d.). *Economy of Wisconsin*. https://www.britannica.com/place/Wisconsin/Economy
- EIA. (2020). *Wisconsin Profile State Profile and Energy Estimate*. https://www.eia.gov/state/analysis.php?sid=WI#63
- Desjardins, J. (2019). *Mapped: Every Power Plant in the United States*. https://www.visualcapitalist.com/mapped-every-power-plant-in-the-united-states/
- Nuvolone, D., Petri, D., & Voller, F. (2018). The effects of ozone on human health. *Environmental Science and Pollution Research*, *25*(9). https://doi.org/10.1007/s11356-017-9239-3
- Timmins, C., & Schlenker, W. (2009). Reduced-Form Versus Structural Modeling in Environmental and Resource Economics. *Annual Review of Resource Economics*, *1*(1), 351–380. https://doi.org/10.1146/annurev.resource.050708.144119
- U.S.EPA. (2020). *User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)* (Issue June).