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Cleaning the grid

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Author
Millstein, Dev

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Lawrence Berkeley National Laboratory

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Dev Millstein

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Renewable energy

Cleaning the grid

Wind and solar power plants emit no air pollution while operating, but how effectively do they lower overall emissions from the electric grid? New research traces wind and solar impacts through the grid, even across regional boundaries.

Dev Millstein
Lawrence Berkeley National Laboratory, Berkeley, CA
e-mail: dmillstein@lbl.gov

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The United States electric sector is undergoing a transformation.[1] Two decades ago, wind and solar resources provided a negligible amount of electricity in most regions. In 2019, they generated 10% of total electricity[2], with some individual states having much higher levels of penetration. In two decades from now, many regions expect these resources to generate the majority of electricity.[3]

Electric generation systems are heterogeneous. The mix of energy sources used (coal, nuclear, gas, wind, hydropower, solar, etc.) varies strongly by region. This means that the types and quantity of pollutant emissions avoided by adding wind and solar also varies depending on where these are added. The emissions avoided by adding renewable generation also vary over time, following changes in infrastructure, regional mix of energy sources, pollution standards, and the relative operating costs of natural gas and coal plants. Understanding the resulting variation in emission reductions from adding wind and solar can help decision makers tailor actions to maximize benefits across multiple environmental and economic goals. Using data that has only recently become available, Fell and Johnson[4] have developed new estimates of how wind and solar generation impacts regional emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2), and for the first time, have taken into account cross-regional trade in electricity.

One challenge to understanding the emissions offset by wind and solar is that change in the electric system has been so rapid and multi-dimensional that any estimates of impact quickly become outdated. Four areas are key to this understanding. First, the relative cost of natural gas generation versus coal changed dramatically: between 2010 and 2019, the share of electricity from natural gas generation increased from 24% to 38%, surpassing coal, whose share decreased from 45% to 23%.[2] Second, emission regulations for existing coal power plants–the largest source of electric sector SO_2 emissions– became more stringent. Tighter emission control requirements and reduced dependence on coal power led to an 80% decline in electric sector SO_2 emissions during this past decade,[5] and of 30% and 60% in CO_2 and NO_x respectively.[5] Third, wind and solar deployments expanded rapidly, offsetting a larger set of generators than in the past. A new set of impacted generators can expand or reduce the pollutants that are offset. Fourth, regional electricity markets and wholesale trade expanded geographically to facilitate interregional transmission of renewable generation[6]. This expansion means renewables can offset far away generators that were not previously impacted. In the western U.S., for example, the Western Energy Imbalance Market was created in 2014 and has continued to gain participants, and the Southwest Power Pool is embarking on a similar effort. This expansion increased the importance of interregional transmission in estimating the impacts from wind and solar.

The value of the emissions offset by wind and solar varies by location. SO_2 and NO_x (but not CO_2) have relatively short atmospheric lifetimes, so the emission location influences the size of the population exposed to them. Regional wind patterns also influence population exposure. As a result, the impacts of SO_2 and NO_x are distributed over a wide area: a majority of premature deaths from electric sector air pollution occurs outside the state from which the emissions originated.[7] The importance of emission location and wind patterns further elevates Fell and Johnson's efforts to determine the interregional export of electricity generated from wind and solar, which increases the geographic range of potential consumers of electricity from renewable sources.

Given the recent changes to the electricity system, Fell and Johnson's update of avoided emissions from wind and solar in the last three years is particularly important. They find that wind and solar generation continues to reduce emissions of CO_2 everywhere, and SO_2 and NO_x in most regions. Their results show lower emissions avoided per unit of added renewable generation compared to older studies. The difference is primarily due to the recent changes to the electric sector mentioned above, though the studies are not perfectly comparable due to methodological differences. Notably, they find that accounting for interregional trade can significantly increase the total avoided emissions in certain regions compared to assuming generation only impacts generators within the same region. This finding is most dramatic in California, where a significant amount of wind generation was exported. Wind power offset roughly equal amounts of CO_2 emissions within and outside this state, and offset more SO_2 and NO_x emissions outside than within. Other examples of the export of wind and solar power were seen throughout the west and in the Midwest and Mid-Atlantic regions.

This study finds the relationship between wind or solar generation, exports and emissions, drawing from hourly data on plant-level emissions, regional renewable generation profiles, and regional electricity exports. This approach shows how the existing electricity grid responds to wind and solar generation. In the future, the methodology may need to incorporate growing battery storage or binding tradable pollution permit markets. Both energy storage and binding pollutant caps allow for solar and wind generation to shift the timing of emissions. Under tradable pollution permits, for example, emissions lowered by wind and solar generation during certain hours create room for higher emissions at other times.

Looking further afield, a different approach would be required to investigate how wind and solar affect new-build or retirement decisions for other power plants. New methods would also be needed to address potential inter-sectoral emission impacts. For example, the transportation sector can achieve lower emissions if electric vehicles are powered by renewable-based electricity rather than combustion-based electricity.

Fell and Johnson uncover the dynamics of regional transfers of wind and solar energy generation. In some cases, the exported electricity reduces emissions as much or more in neighboring regions as the electricity consumed locally. Despite many recent changes to the electricity system, wind and solar continue to provide significant emission reductions in most regions. The approach developed by Fell and Johnson may be replicated periodically to quantify the impacts of ongoing changes within the electric system.

The authors declare no competing interests.

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