Associated IPFs: Sub-IPFs	Ongoing Activities	Future Non-Offshore Wind Activities Intensity/Extent	Future Offshore Wind-related Activities Intensity/Extent	Vineyard Wind 1 Project-related Activities Intensity/Extent	Conclusion
Climate change	The construction, operation, and decommissioning of offshore wind projects would produce GHG emissions (nearly all CO_2) that can contribute to climate change; however, these contributions would be minuscule compared to aggregate global emissions. CO_2 is relatively stable in the atmosphere and generally mixed uniformly throughout the troposphere and stratosphere. Hence the impact of GHG emissions does not depend upon the source location. Increasing energy production from offshore wind projects would likely decrease GHGs emissions by replacing energy from fossil fuels.	Development of future onshore wind projects would produce a small overall increase in GHG emissions over the next 30 years. However, these contributions would be very small compared to the aggregate global emissions. The impact on climate change from these activities would be very small. As more projects come online, some reduction in GHG emissions would be expected from modifications of existing fossil-fuel facilities to reduce power generation. Overall, it is anticipated that there would be no collective impact on global warming as a result of onshore wind project activities.	Development of offshore wind projects and the construction, implementation, operation, maintenance, and the eventual decommissioning would cause some minuscule GHG emissions increases primarily through emissions of CO_2. Overall there should be some net reduction on both GHG emissions and criteria pollutants, including ozone precursors such as NOx, through reduction in emissions from fossil-fuel power generating facilities. In general, the GHG emissions associated with the construction, maintenance, and eventual decommissioning of future offshore wind projects can be assumed to contribute to climate change. However, these contributions would be minuscule compared to the aggregate global emissions of GHGs; therefore, they cannot be deemed significant, if their impact could even be detected.	The construction, operation, and decommissioning activities associated with the Proposed Action would produce GHG emissions (nearly all CO_2) that can contribute to climate change; however, these contributions would be minuscule compared to aggregate global emissions. CO_2 is relatively stable in the atmosphere and generally mixed uniformly throughout the troposphere and stratosphere. Hence the impact of GHG emissions does not depend upon the source location. Increasing energy production from offshore wind projects would likely decrease GHGs emissions by replacing energy from fossil fuels. In general, the GHG emissions associated with the construction, maintenance, and eventual decommissioning of the Proposed Action can be assumed to contribute to climate change. However, these contributions would be small compared to the aggregate global emissions of GHGs; therefore, they cannot be deemed significant, if their impact could even be detected. The additional GHG emissions anticipated from the Proposed Action over the 30-year period would have a **negligible** incremental contribution to existing GHG emissions. Therefore, the Proposed Action would have **negligible** impacts on climate change during these activities and an overall **minor beneficial** impact on both GHG emissions and criteria pollutants, including ozone precursors such as NOx, compared to a similarly sized fossil-fuel power generating station or to the generation of the same amount of energy by the existing grids.	The Proposed Action would produce GHG emissions as stated above; however, the contributions would be minuscule compared to aggregate global emissions. The additional GHG emissions anticipated from the Proposed Action over the 30-year period would have a **negligible** incremental contribution on existing GHG emissions. Therefore, the Proposed Action would have **negligible** impacts on climate change during these activities and an overall **minor beneficial** impact on GHG emissions compared to the generation of the same amount of energy by the existing grids. Because GHG emissions spread out and mix within the troposphere, the climatic impact of GHG emissions does not depend on the source location. Therefore, regional climatic impacts are a function of global emissions. Development of offshore wind projects and the construction, implementation, operation, maintenance, and the eventual decommissioning activities would cause some GHG emissions increases primarily through emissions of CO_2. However, these contributions would be minuscule compared to aggregate global emissions. In context of reasonably foreseeable environmental trends, the combined GHG emissions on air quality from ongoing and planned actions, including the Proposed Action, would likely result in a **minor beneficial** impact from the net decrease in both GHG emissions and criteria pollutants, including ozone precursors such as NO_x, as fossil-fuel-type facilities reduce operations as a result of increased energy generation from offshore wind projects. Overall, it is anticipated that there would be no collective impact on global warming as a result of offshore wind projects, including the Proposed Action alone, though they may beneficially contribute to a broader combination of actions to reduce future impacts from climate change.

% = percent; BOEM = Bureau of Ocean Energy Management; CAA = Clean Air Act; CO = carbon monoxide; CO_2 = carbon dioxide; DEIS = Draft Environmental Impact Statement; GHG = greenhouse gas; HAP = hazardous air pollutant; hazmat = hazardous materials; IPF = impact producing factor; NAAQS = National Ambient Air Quality Standards; NO_2 = nitrogen dioxide; NO_x = nitrogen oxides; O&M = operations and maintenance; $PM_{2.5}$ = particulate matter with diameters 2.5 microns or smaller; PM_{10} = particulate matter with diameters 10 microns or smaller; ppb = parts per billion; SO_2 = sulfur dioxide; USC = United States Code; USEPA = U.S. Environmental Protection Agency; VOC = volatile organic compounds; WDA = Wind Development Area

The Harvard Gazette

SCIENCE & TECHNOLOGY

The down side to wind power

Wind farms will cause more environmental impact than previously thought

BY Leah Burrows
SEAS Communications

DATE October 4, 2018

When it comes to energy production, there's no such thing as a free lunch, unfortunately.

As the world begins its large-scale transition toward low-carbon energy sources, it is vital that the pros and cons of each type are well understood and the environmental impacts of renewable energy, small as they may be in comparison to coal and gas, are considered.

In two papers — published today in the journals Environmental Research Letters and Joule — Harvard University researchers find that the transition to wind or solar power in the U.S. would require five to 20 times more land than previously thought, and, if such large-scale wind farms were built, would warm average surface temperatures over the continental U.S. by 0.24 degrees Celsius.

"Wind beats coal by any environmental measure, but that doesn't mean that its impacts are negligible," said David Keith, the Gordon McKay Professor of Applied Physics at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) and senior author of the papers. "We must quickly transition away from fossil fuels to stop carbon emissions. In doing so, we must make choices between various low-carbon technologies, all of which have some social and environmental impacts."

Keith is also professor of public policy at the Harvard Kennedy School.

One of the first steps to understanding the environmental impact of renewable technologies is to understand how much land would be required to meet future U.S. energy demands. Even starting with today's energy demands, the land area and associated power densities required have long been debated by energy experts.

In previous research, Keith and co-authors modeled the generating capacity of large-scale wind farms and concluded that real-world wind power generation had been overestimated because they neglected to accurately account for the interactions between turbines and the atmosphere.

> "The direct climate impacts of wind power are instant, while the benefits of reduced emissions accumulate slowly."
>
> – David Keith

In 2013 research, Keith described how each wind turbine creates a "wind shadow" behind it where air has been slowed down by the turbine's blades. Today's commercial-scale wind farms carefully space turbines to reduce the impact of these wind shadows, but given the expectation that wind farms will continue to expand as demand for wind-derived electricity increases, interactions and associated climatic impacts cannot be avoided.

What was missing from this previous research, however, were observations to support the modeling. Then, a few months ago, the U.S. Geological Survey released the locations of 57,636 wind turbines around the U.S. Using this data set, in combination with several other U.S. government databases, Keith and postdoctoral fellow Lee Miller were able to quantify the power density of 411 wind farms and 1,150 solar photovoltaic plants operating in the U.S. during 2016.

"For wind, we found that the average power density — meaning the rate of energy generation divided by the encompassing area of the wind plant — was up to 100 times lower than estimates by some leading energy experts," said Miller, who is the first author of both papers. "Most of these estimates failed to consider the turbine-atmosphere interaction. For an isolated wind turbine, interactions are not important at all, but once the wind farms are more than five to 10 kilometers deep, these interactions have a major impact on the power density."

The observation-based wind power densities are also much lower than important estimates from the U.S. Department of Energy and the Intergovernmental Panel on Climate Change.

For solar energy, the average power density (measured in watts per meter squared) is 10 times higher than wind power, but also much lower than estimates by leading energy experts.

This research suggests that not only will wind farms require more land to hit the proposed renewable energy targets but also, at such a large scale, would become an active player in the climate system.

The next question, as explored in the journal Joule, was how such large-scale wind farms would impact the climate system.

> "If your perspective is the next 10 years, wind power actually has — in some respects — more climate impact than coal or gas. If your perspective is the next thousand years, then wind power has enormously less climatic impact than coal or gas."
>
> **— David Keith**

To estimate the impacts of wind power, Keith and Miller established a baseline for the 2012-2014 U.S. climate using a standard weather-forecasting model. Then, they covered one-third of the continental U.S. with enough wind turbines to meet present-day U.S. electricity demand. The researchers found this scenario would warm the surface temperature of the continental U.S. by 0.24 degrees Celsius, with the largest changes occurring at night when surface temperatures increased by up to 1.5 degrees. This warming is the result of wind turbines actively mixing the atmosphere near the ground and aloft while simultaneously extracting from the atmosphere's motion.

This research supports more than 10 other studies that observed warming near operational U.S. wind farms. Miller and Keith compared their simulations to satellite-based observational studies in North Texas and found roughly consistent temperature increases.

Miller and Keith are quick to point out the unlikeliness of the U.S. generating as much wind power as they simulate in their scenario, but localized warming occurs in even smaller projections. The follow-on question is then to understand when the growing benefits of reducing emissions are roughly equal to the near-instantaneous impacts of wind power.

The Harvard researchers found that the warming effect of wind turbines in the continental U.S. was actually larger than the effect of reduced emissions for the first century of its operation. This is because the warming effect is predominantly local to the wind farm, while greenhouse gas concentrations must be reduced globally before the benefits are realized.

Miller and Keith repeated the calculation for solar power and found that its climate impacts were about 10 times smaller than wind's.

"The direct climate impacts of wind power are instant, while the benefits of reduced emissions accumulate slowly," said Keith. "If your perspective is the next 10 years, wind power actually has — in some respects — more climate impact than coal or gas. If your perspective is the next thousand years, then wind power has enormously less climatic impact than coal or gas.

"The work should not be seen as a fundamental critique of wind power," he said. "Some of wind's climate impacts will be beneficial — several global studies show that wind power cools polar regions. Rather, the work should be seen as a first step in getting more serious about assessing these impacts for all renewables. Our hope is that our study, combined with the recent direct observations, marks a turning point where wind power's climatic impacts begin to receive serious consideration in strategic decisions about decarbonizing the energy system."

This research was funded by the Fund for Innovative Climate and Energy Research.

Science News

from research organizations

Large-scale US wind power would cause warming that would take roughly a century to offset

Date: October 4, 2018

Source: Cell Press

Summary: Extracting energy from the wind causes climatic impacts that are small compared to current projections of 21st century warming, but large compared to the effect of reducing US electricity emissions to zero with solar. Researchers report the most accurate modelling yet of how increasing wind power would affect climate, finding that large-scale wind power generation would warm the Continental United States 0.24 degrees Celsius because wind turbines redistribute heat in the atmosphere.

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FULL STORY

All large-scale energy systems have environmental impacts, and the ability to compare the impacts of renewable energy sources is an important step in planning a future without coal or gas power. Extracting energy from the wind causes climatic impacts that are small compared to current projections of 21st century warming, but large compared to the effect of reducing US electricity emissions to zero with solar. Research publishing in the journal *Joule* on October 4 reports the most accurate modelling yet of how increasing wind power would affect climate, finding that large-scale wind power generation would warm the Continental United States 0.24 degrees Celsius because wind turbines redistribute heat in the atmosphere.

"Wind beats coal by any environmental measure, but that doesn't mean that its impacts are negligible," says senior author David Keith, an engineering and public policy professor at Harvard University. "We must quickly transition away from fossil fuels to stop carbon emissions. In doing so, we must make choices between various low-carbon technologies, all of which have some social and environmental impacts."

"Wind turbines generate electricity but also alter the atmospheric flow," says first author Lee Miller. "Those effects redistribute heat and moisture in the atmosphere, which impacts climate. We attempted to model these effects on a continental scale."

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EARTH & CLIMATE

To compare the impacts of wind and solar, Keith and Miller started by establishing a baseline for the 2012-2014 US climate using a standard weather forecasting model. Then they added in the effect on the atmosphere of covering one third of the Continental US with enough wind turbines to meet present-day US electricity demand. This is a relevant scenario if wind power plays a major role in decarbonizing the energy system in the latter half of this century. This scenario would warm the surface temperature of the Continental US by 0.24 degrees Celsius.

Their analysis focused on the comparison of climate impacts and benefits. They found that it would take about a century to offset that effect with wind-related reductions in greenhouse gas concentrations. This timescale was roughly independent of the specific choice of total wind power generation in their scenarios.

"The direct climate impacts of wind power are instant, while the benefits accumulate slowly," says Keith. "If your perspective is the next 10 years, wind power actually has -- in some respects -- more climate impact than coal or gas. If your perspective is the next thousand years, then wind power is enormously cleaner than coal or gas."

More than ten previous studies have now observed local warming caused by US wind farms. Keith and Miller compared their simulated warming to observations and found rough consistency between the observations and model.

They also compared wind power's impacts with previous projections of solar power's influence on the climate. They found that, for the same energy generation rate, solar power's impacts would be about 10 times smaller than wind. But both sources of energy have their pros and cons.

"In terms of temperature difference per unit of energy generation, solar power has about 10 times less impact than wind," says Miller. "But there are other considerations. For example, solar farms are dense, whereas the land between wind turbines can be co-utilized for agriculture." The density of wind turbines and the time of day during which they operate can also influence the climatic impacts.

Keith and Miller's simulations do not consider any impacts on global-scale meteorology, so it remains somewhat uncertain how such a deployment of wind power may affect the climate in other countries.

"The work should not be seen as a fundamental critique of wind power. Some of wind's climate impacts may be beneficial. So rather, the work should be seen as a first step in getting more serious about assessing these impacts," says Keith. "Our hope is that our study, combined with the recent direct observations, marks a turning point where wind power's climatic impacts begin to receive serious consideration in strategic decisions about decarbonizing the energy system."

Keith and Miller also have a related paper, "Observation-based solar and wind power capacity factors and power densities," being published in Environmental Research Letters on October 4, which validates the generation rates per unit area simulated here using observations.

Story Source:

Materials provided by **Cell Press**. *Note: Content may be edited for style and length.*

Journal Reference:

1. Lee M. Miller, David W. Keith. **Climatic Impacts of Wind Power**. *Joule*, 2018; DOI: 10.1016/j.joule.2018.09.009

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