How much energy can offshore wind farms in the U.S. produce? New study sheds light

April 25 2024, by Yvaine Ye

Offshore wind turbine blades. Credit: Julie Lundquist/CU Boulder

As summer approaches, electricity demand surges in the U.S., as homes and businesses crank up the air conditioning. To meet the rising need, many East Coast cities are banking on offshore wind projects the country is building in the Atlantic Ocean.

For electric grid operators, knowing how much wind power these offshore turbines can harvest is critical, but making accurate predictions can be difficult. A team of CU Boulder scientists and their collaborators are working to tackle the challenge.

In a paper published March 14 in *Wind Energy Science*, a team led by Dave Rosencrans, a doctoral student, and Julie K. Lundquist, a professor in the Department of Atmospheric and Ocean Sciences, estimates that offshore wind turbines in the Atlantic Ocean region, where the U.S. plans to build large wind farms, could take away wind from other turbines nearby, potentially reducing the farms' power output by more than 30%.

Accounting for this so-called "wake effect," the team estimated that the proposed wind farms could still supply approximately 60% of the electricity demand of the New England grid, which covers Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

"The U.S. is planning to build thousands of offshore wind turbines, so we need to predict when those wakes will be expensive and when they have little effect," said Lundquist, who is also a fellow at CU Boulder's Renewable and Sustainable Energy Institute.

Understanding the wake effect

When wind passes through turbines, the ones at the front, or upstream, extract some energy from the wind. As a result, the wind slows down and becomes more turbulent behind the turbines. This means the turbines downstream get slower wind, sometimes resulting in lower power generation.

The wake effect is particularly prominent offshore, because there are no houses or trees that stir up the air, which helps dissipate the wakes, said Rosencrans, the paper's first author.

Using computer simulations and observational data of the atmosphere, the team calculated that the wake effect reduces total power generation by 34% to 38% at a proposed wind farm off the East Coast. Most of the reduction comes from wakes formed between turbines within a single farm.

But under certain weather conditions, wakes could reach turbines as far as 55 kilometers downwind and affect other wind farms. For example, during hot summer days, the airflow over the cool sea surface tends to be relatively stable, causing wakes to persist for longer periods and propagate over longer distances.


WINDCUBE


WINDCUBE
HOT

Top: A wind LiDAR for collecting data on wind energy, weather and air movements. Bottom: Julie Lundquist (left), and her doctoral students Nathan Agarwal (center) and David Rosencrans (right) went to Block Island, south of Rhode Island, to set up the instrument for the Wind Forecast Improvement Project 3 experiment. Credit: Julie Lundquist/CU Boulder

"Unfortunately, summer is when there's a lot of electrical demand," Rosencrans said. "We showed that wakes are going to have a significant impact on power generation. But if we can predict their effects and anticipate when they are going to happen, then we can manage them on the electrical grid."

A balancing act

In early 2024, five looming wind turbines off the coast of Massachusetts from the country's first large-scale offshore wind project delivered the first batch of wind power to the New England grid. More turbines are under construction off the coasts of Rhode Island, Virginia and New York. The Biden Administration has set a goal to install 30 gigawatts of offshore wind capacity by 2030, which is enough to power more than 10 million homes for a year.

Compared with energy sources derived from fossil fuels, wind and solar power tend to be variable, because the sun doesn't always shine and the wind doesn't always blow.

This variability creates a challenge for grid operators, said Lundquist. The power grid is a complex system that requires a perfect balance of supply and demand in real-time. Any imbalances could lead to devastating blackouts, like what happened in Texas in 2021 when power outages killed nearly 250 people.

As the country continues to expand renewable energy projects and integrates more clean electricity into the power system, grid operators need to know precisely how much energy from each renewable source they can count on.

To better understand how the wind blows in the proposed wind farm area, Lundquist's team visited islands off the New England coast and installed a host of instruments last December as part of the Department of Energy's Wind Forecast Improvement Project 3. The project is a collaboration of researchers from CU Boulder, Woods Hole Oceanographic Institute and several other national laboratories.

The instruments, including weather monitors and radar sensors, will collect data for the next year or more. Previously, offshore wind power prediction models usually relied on intermittent data from ships and satellite observations. The hope is that with continuous data directly from the ocean, scientists can improve prediction models and better integrate more offshore wind energy into the grid.

In addition to the growing demand for air conditioning and heat pumps, electricity consumption in the U.S. has been rising rapidly in recent years because of the increasing prevalence of electric vehicles, data centers and manufacturing facilities. Over the next five years, analyses project that electricity demand in the U.S. will increase by nearly 5%, a substantial increase compared with the estimated annual growth rate of 0.5% over the past decade.

"We need a diverse mix of clean energy sources to meet the demand and decarbonize the grid," Lundquist said. "With better predictions of wind energy, we can achieve more reliance on renewable energy."

More information: David Rosencrans et al, Seasonal variability of wake impacts on US mid-Atlantic offshore wind plant power production, *Wind Energy Science* (2024). DOI: 10.5194/wes-9-555-2024

Provided by University of Colorado at Boulder