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Expanded modelling scenarios to understand the role of offshore wind in decarbonizing the United States

Beiter, P,. T .Mai, M. Mowers, J. Bistline. 2023. "Expanded Modelling Scenarios to Understand the Role of Offshore Wind in Decarbonizing the United States." Nature Energy 8 (11): 1240–49.

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IEA Wind TEM on 'Net Zero Electricity System Studies' | April 8, 2024

Studying decarbonization brings into focus the limitations of energy modeling

Background

Key limitations in energy modeling arise from computational, resolution, or scoping boundaries:

- Time and space
- Uncertainty and transparency
- Growing complexities
- Integration of human behavior and social risks/opportunities

Relevance

These modeling limitations are particularly relevant for the analysis of deep **decarbonization scenarios** and **new power system assets** because trade-offs in siting, transmission, power system interaction become more severe

Question

How sensitive is **offshore wind (OSW)** deployment to factors that shape deep decarbonization pathways in the US power system?

Approach

Using NREL's **capacity expansion model** ReEDS,[1] we address several modeling limitations by **simultaneously** introducing very **high spatial and temporal resolution** in combination with various **uncertainties from transmission, load growth, technology costs, and energy-sector policies**


nature energy

Article

https://doi.org/10.1038/s41560-023-01364-y

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Received: 23 September 2022

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[1] Regional Energy Deployment System Model (ReEDS); Image source: Musial et al. (2023).

Factors shaping offshore wind deployment

Clean-energy policies expand opportunities for offshore wind

Scenarios

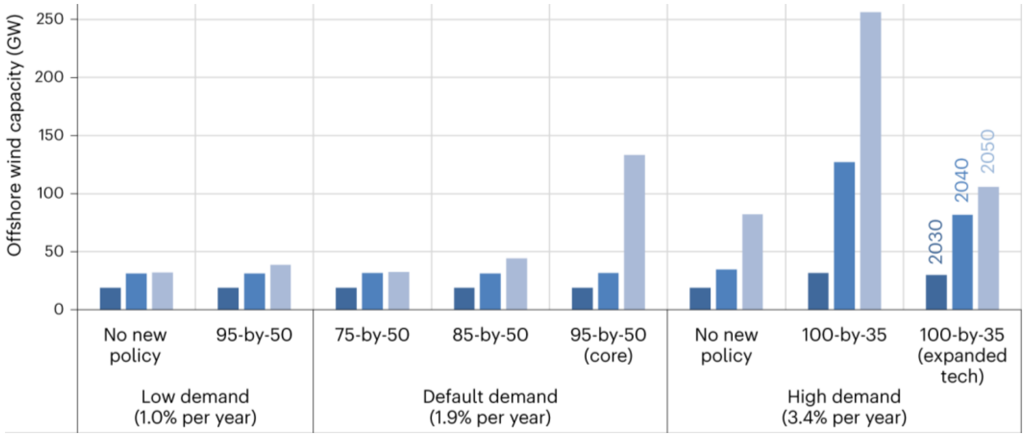
- Existing (state/federal) policies only; national CO_2 reductions of 75%, 85%, and 95% in 2050 (from 2005 levels)
- Degree of energy system electrification (1% and 3.4% load growth p.a.) and demand profiles (e.g., more winter peaks)

Intent

- Representing OSW in highly decarbonized power system through 2050
- Focus on single technology to increase usefulness of decarbonization analysis for (siloed) stakeholder groups

Findings (by 2050)

- Limited OSW deployment beyond U.S. state commitments (19 gigawatt [GW] by 2030)[1] in most scenarios
- If power-sector emissions decline by >80% by 2035 (95% by 2050) and electrification-driven demand growth nearly doubles from today, OSW capacity reaches **133 GW ('core scenario')**
- Electrification shifts peak-demand periods to winter season which aligns more closely with typical OSW generation profiles



[1] As of July, 2021

Lower costs and fewer technology alternatives favor offshore wind

Scenarios

- Restrict availability of carbon capture and sequestration (CCS), concentrating solar power (CSP), geothermal, and advanced nuclear power

Intent

- Capturing some of the uncertainty of technology readiness and costs surrounding ‘new’ technologies (including OSW)

Findings (by 2050)

- Shifting from mid- to low-cost scenario results in additional OSW deployment of 78 GW
- If CSP and geothermal are not included as generation technologies, OSW deployment grows by 24 GW
- Reversely, if CCS and advanced nuclear are options for deployment, OSW deployment is reduced by 50 GW

Note: Estimates in comparison to ‘core scenario’ (133 GW), which assumes CO_2 reduction of 95% by 2050 (from 2005 levels) and 3.4% p.a. load growth (‘EFS High’)

Transmission alters the competitive landscape for offshore wind

Scenarios

- Limit transmission expansion to within only 12 transmission planning zones
- Alter the cost of bulk transmission

Intent

- Capturing some of the uncertainty surrounding future transmission expansion

Findings (by 2050)

- With more stringent transmission expansion (i.e., limiting expansion to within planning regions and more costly transmission costs), OSW deployment grows by 16 GW
- Relaxed transmission constraints leads to more competition from interior resources (even with cost of transmission build), reducing OSW capacity by 62 GW
- Even more flexibility in transmission expansion (i.e., high-voltage direct-current macrogrid) further reduces OSW deployment by another 24 GW

Note: Estimates in comparison to ‘core scenario’ (133 GW), which assumes CO2 reduction of 95% by 2050 (from 2005 levels) and 3.4% p.a. load growth (‘EFS High’)

Limited siting of onshore resources means more offshore wind

Modeling

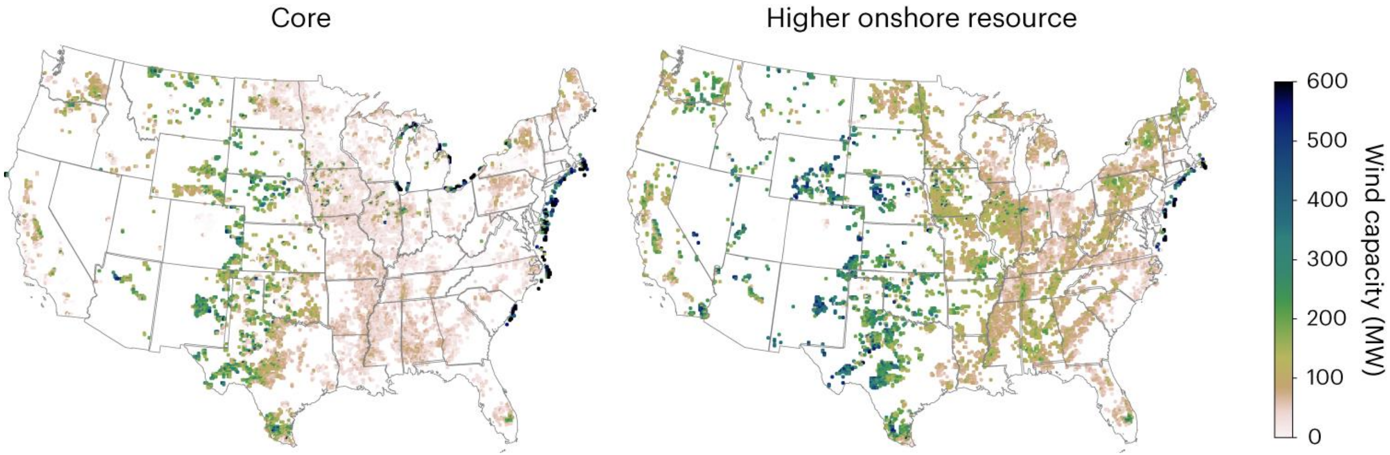
- Introduce siting regimes with constraints for land-based and offshore resources from regulatory restrictions on protected lands, state and county ordinances and other factors (e.g., setback requirements, shadow flicker, physical limitations)

Intent

- Represent investment options for about 60,000 land-based and 8,000 offshore 'sites' and technology-specific restrictions

Findings (by 2050)

- Less restrictive onshore siting regimes results in considerable reduction of OSW deployment (102 GW less deployment)
- More restrictive siting offshore (from e.g., shipping, marine wildlife, etc.) results in a reduction of 52 GW



Note: Estimates in comparison to 'core scenario' (133 GW), which assumes CO2 reduction of 95% by 2050 (from 2005 levels) and 3.4% p.a. load growth ('EFS High')

Conclusions

Offshore wind

- Up to 20% of total generation in Atlantic coastal regions served by OSW by 2050
- On national scale, more modest role for OSW (~4% of total generation vs. onshore wind [27%] and solar PV [46%])
- Range in OSW deployment of 1–8% of total generation (31–256 GW) by 2050 reflects broader uncertainties

Decarbonization modeling

- Omitting exploration of ‘modeling constraints’ from a single technology perspective can yield starkly different conclusions
- Limitations remain in decarbonization modeling and its ability to inform decision-making, such as:
  - More fundamental limitations in energy modelling may constrain the domain of possible solutions (e.g., scope of the energy model itself, near-optimal solutions for OSW deployment, levels of uncertainty with key variables)
  - Chance that decision-makers prefer to procure from within the regions they have (some) jurisdiction over
  - Omission of key factors in our scenario analysis, such as widespread sector coupling or demand flexibility

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Received: 23 September 2022

Accepted: 31 August 2023

Published online: 9 October 2023

Check for updates

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An assessment of decarbonization pathways in energy models reveals fundamental limitations in representing factors that are relevant for practical decision-making. Although these modelling limitations are widely acknowledged, their impact on the deployment of individual power generation types is not well understood. As a result, the societal value from such generation types could be vastly misrepresented. Here we explore a wide spectrum of factors that impact offshore wind deployment in the United States using a detailed capacity expansion model. Many factors prescribe a large future role for offshore wind, yet this diverges from what models often show. We extend the typically narrow modelling context through high spatial resolution, several cost and transmission possibilities and various energy-sector policies. We estimate offshore wind to constitute 1–8% (31–256 gigawatts) of total US generation by 2050. This wide range suggests an uncertain but potentially important regional role. Our expansive scenarios demonstrate how to address many limitations of decarbonization modelling.

Access our research at:
https://doi.org/10.1038/s41560-023-01364-y

Thank you.

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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Results summary for key scenarios