How will offshore wind developments affect the U.S. power grid?

By Maria Scheller, Thomas Rostad, Akanksha Goyal, Ameya Ghodke, ICF
Acknowledgments: Josh Ghosh, Amit Agrawal, ICF

Introduction

The United States is on the verge of a large-scale buildout of offshore wind projects. These projects are fueled by state-sponsored programs to incentivize development. Additionally, the Biden administration plans to facilitate the development of at least 30 GW of offshore wind in U.S. waters by 2030 toward a long-term goal of 110 GW by 2050. The growing support for offshore wind projects is motivated by increasing support for sustainable clean energy resources on the part of electricity customers, investors, government entities, and private companies.

Abstract

As state and federal goals for offshore wind development materialize, the dynamics of the electric grid in coastal regions will likely change. These changing dynamics require consideration to maximize the benefits of a large-scale offshore wind buildout. This paper provides an overview of the potential effect on U.S. power markets from the theoretical addition of 28 GW of offshore wind in the Northeast and Mid-Atlantic regions, assuming market conditions from recent representative historical supply and demand conditions. This analysis aims to highlight how offshore wind capacity additions would impact locational marginal prices (LMPs), transmission line congestion, and regional power flows, and to examine the potential curtailment resulting from such an injection.

Results show that offshore wind capacity additions under the current power system configuration could have the following general impacts:

- Decrease LMPs significantly in states with offshore wind additions
- Increase transmission congestion significantly in PJM and NYISO, but less so in ISO-NE
- Reverse the recent historical direction of energy flows between zones in coastal areas and inland areas
- Cause varying levels of energy curtailment depending on where the offshore wind projects inject energy

The analysis further identifies that the modeled offshore wind additions would displace a significant amount of fossil generation in PJM, NYISO, and ISO-NE, avoiding roughly 49 million metric tons of CO_2 emissions in the scenario considered. For context, this is equivalent to eliminating emissions from over 10 million passenger vehicles for one year.

The analysis herein represents a “What if?” scenario for a point in time intended to highlight the potential benefits and constraints resulting from the introduction of large-scale offshore wind to the power grid. It is not intended to be a forecast and is not reflective of expected future conditions. However, we expect the high-level trends identified in the results of this modeling to hold true. Therefore, we limit our discussion of results in this analysis to broad trends rather than specific details.

Background

Offshore wind facilities offer significant benefits to society including job creation, local economic development, and a non-emitting domestic energy source with limited water consumption. Key characteristics that distinguish offshore wind farms from onshore facilities may justify relatively high capital costs, including:

- High capacity factors: Relative to onshore wind, offshore facilities often experience higher average wind speeds with lower turbulence levels, resulting in a significant output gain.
- Predictability: Offshore wind speeds tend to be more consistent than on land. A consistent supply of wind means a more reliable and predictable source of energy.
- Proximity to coastal load centers: Building offshore wind farms near high-load areas, which tend to also have high population concentrations, can help meet energy needs locally. These areas often are limited in the ability to site and permit large, onshore utility-scale renewable facilities.

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State support for offshore wind

States in the Northeast and Mid-Atlantic regions, where shallow waters and large coastal load centers make the resource particularly attractive, are paving the way for offshore wind development in the U.S. Several states proactively set offshore wind targets and/or established mechanisms for providing payments to developers as a form of make-whole compensation, including bi-lateral contracts and state-sponsored offshore renewable energy credits (ORECs).[1] Both procurement instruments are awarded competitively based on price offers and other criteria (e.g., economic development, ratepayer, and environmental impacts). The stable source of revenue provided by power purchase agreements (PPAs) and ORECs helps offshore wind projects secure financing and a sufficient return on investment. Table 1 shows which states announced offshore wind development targets or goals, along with the amount of capacity already contracted through solicitations.

Table 1: Offshore Wind Development by State as of December 2021

State	Announced Targets & Goals (MW)	Contracted Capacity (MW)	Target Year	State Program
Connecticut	2,000	1,108	2030	PPA
Massachusetts	5,600	3,236	NA	PPA
Rhode Island	NA*	430	NA	PPA
New York	9,000	4,316	2035	OREC
Maryland	1,568	2,023	2030	OREC
New Jersey	7,500	3,758	2035	OREC
Virginia	5,200†	12	2034	NA
North Carolina	8,000‡	0	2040	NA
Total	**38,868**	**14,883**		

*In October 2020, the Governor of Rhode Island announced plans for the state to procure up to 600 MW of new offshore wind capacity. A final RFP, issued by National Grid upon approval by the Public Utilities Commission, is expected to come out in 2022.

† The Virginia Clean Economy Act of 2020 identifies 5,200 MW of offshore wind development off of the state's coast to be in the public interest. Unlike other states examined here, Virginia does not have a specific implementation program.

‡ In July 2021, the North Carolina governor signed an executive order calling for the state to develop 2.8 GW of offshore wind projects by 2030 and 8 GW by 2040. The state does not have a specific implementation program.

Source: Compiled by ICF

[1] ORECs represent the environmental attributes of one megawatt-hour of electricity generation from an offshore wind project and are used to comply with state offshore wind-specific renewable portfolio standards.

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Federal support for offshore wind

Federal subsidies for offshore wind primarily take the form of tax incentives. Recent legislation added a new federal investment tax credit (ITC) category for offshore wind projects. The offshore wind ITC is worth 30% of a project's cost if the construction of the project begins before January 1, 2026. Prior to this, offshore wind projects qualified for a production tax credit (PTC), or a less valuable ITC subject to a reduction and expiration over time corresponding to the statutory phase-out schedule for federal tax credits.[2]

Federal policy discussions are also advancing offshore wind. The Biden administration announced goals to deploy 30 GW of offshore wind in the United States by 2030 toward a long-term goal of 110 GW by 2050.[3] The Federal Energy Regulatory Commission (FERC) is also advancing discussions aimed to facilitate offshore wind interconnection, including technical conferences and a federal-state task force.

To support efforts to meet the 2030 goal, the Bureau of Ocean Energy Management (BOEM) plans to complete reviews of at least 16 construction and operations plans by 2025. Additionally, BOEM announced plans to potentially hold up to seven new offshore lease sales by 2025 in the Gulf of Maine, New York Bight, Central Atlantic, and Gulf of Mexico, as well as offshore the Carolinas, California, and Oregon.[4] Figure 1 shows active BOEM lease areas along the Atlantic Outer Continental Shelf (OCS).

[2] https://www.mwe.com/insights/covid-19-stimulus-bill-includes-key-renewable-energy-tax-credits/
[3] https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/
[4] https://www.doi.gov/pressreleases/secretary-haaland-outlines-ambitious-offshore-wind-leasing-strategy

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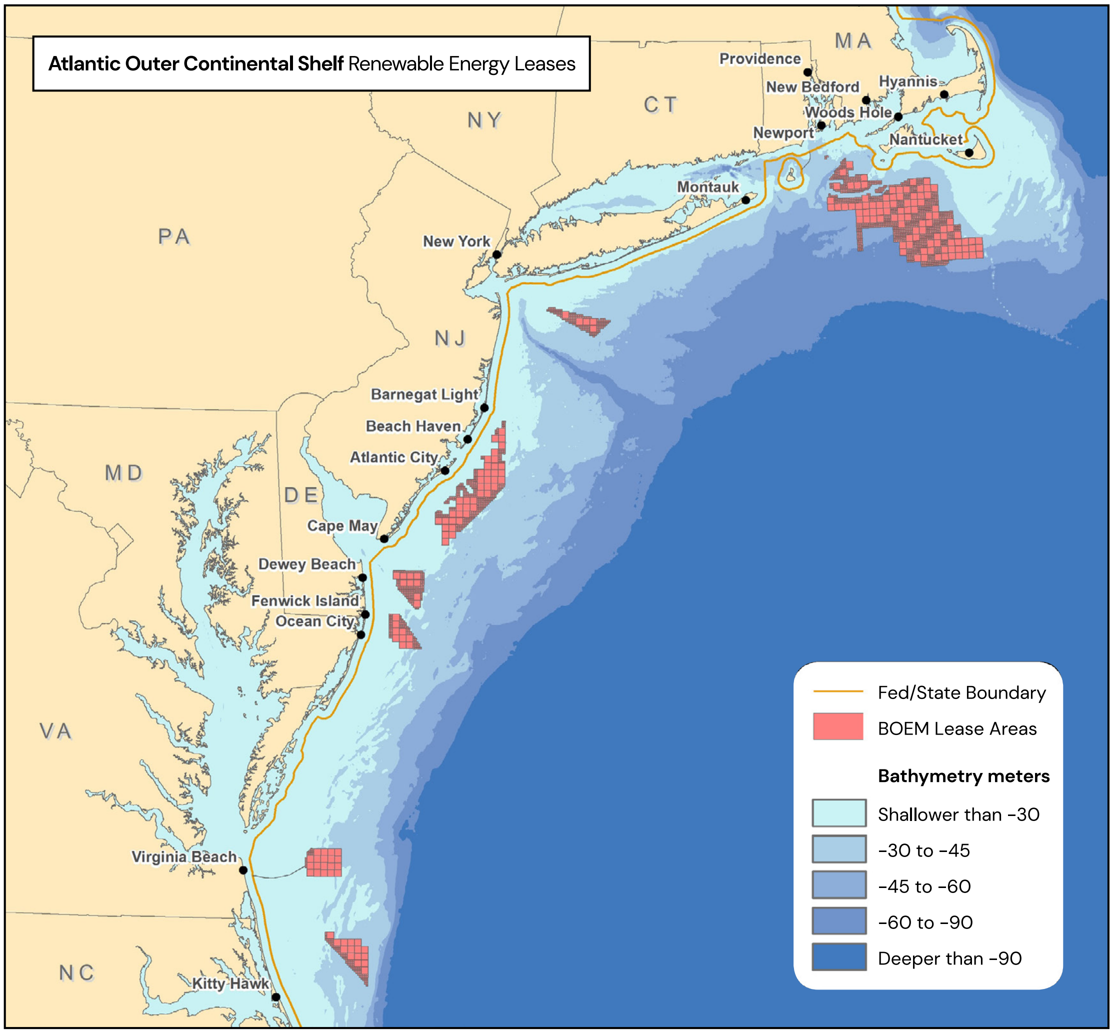
Figure 1: Atlantic OCS – BOEM Active Lease Areas



Source: Outer Continental Shelf Renewable Energy Leases Map Book, March 2019, BOEM

The Biden administration further unveiled several investment and funding opportunities to facilitate the 30 GW deployment goal:

- The Department of Energy (DOE) unlocked access to $3 billion in funding for offshore wind projects through its Innovative Energy Loan Guarantee Program.
- The National Offshore Wind Research and Development Consortium, created by the DOE and the New York State Energy Research and Development Authority, announced an award of $8 million to 15 offshore wind research and development projects.
- The U.S. Department of Transportation's Maritime Administration announced a Notice of Funding Opportunity for port authorities and other applicants to apply for $230 million for port and intermodal infrastructure-related projects through the Port Infrastructure Development Program.[5]

[5] https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

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Methodology

To quantify the impacts of the offshore wind additions, we used a production cost model to compare a one-year snapshot view of the electric grid from a representative historical year against a change case that added 28 GW of offshore wind to the electric grid across the Northeast and Mid-Atlantic regions, all else equal.[6] We compared results from the two cases to identify the implications to LMP, transmission congestion, net imports, and curtailment.

- **Status Quo Case (SQ Case):** This case simulated the existing electric system based on historical conditions with a focus on the Northeast and Mid-Atlantic U.S.
- **Offshore Wind Case (OSW Case):** This case inserts 28 GW of offshore wind builds at various points of interconnection (POI) along the U.S. east coast. POIs were selected within states with existing offshore wind development activities.

The analysis performed is a high-level approximation designed to capture likely impacts of large additions of offshore wind capacity. As such, several simplifications are used in the modeling. The results presented are not intended to reflect a comprehensive outlook for the implications of offshore wind additions to the electric grid. Rather, the OSW Case represents a "What if?" construct to highlight potential benefits and constraints resulting from the introduction of large-scale offshore wind to the power grid with no other changes assumed.

The modeling simulation relied on historical conditions to represent the SQ Case. The OSW Case included the addition of 28 GW of offshore wind at various interconnection points in coastal areas within PJM, NYISO, and ISO-NE. No specific offshore wind projects were identified or modeled in this analysis. The interconnection points were selected based on the following criteria:

- Limited to coastal areas within states with existing offshore wind activities (e.g., procurement processes)
- Limited to high-capacity nodes in PJM, NYISO, and ISO-NE
- Nodes identified in the grid operator interconnection queues for offshore projects

We modeled all offshore wind builds to come online at the beginning of the year to capture the impact of offshore wind in every month. Any difference in results between the two cases is directly attributable to the offshore wind capacity additions. Table 2 compares the capacity mixes modelled in the SQ Case and the OSW Case for PJM, NYISO, and ISO-NE.

[6] ICF utilized ABB's PROMOD IV, a security-constrained economic dispatch model.

Table 2: Capacity Mix by ISO – SQ Case & OSW Case (Percentage of Total Nameplate Capacity)

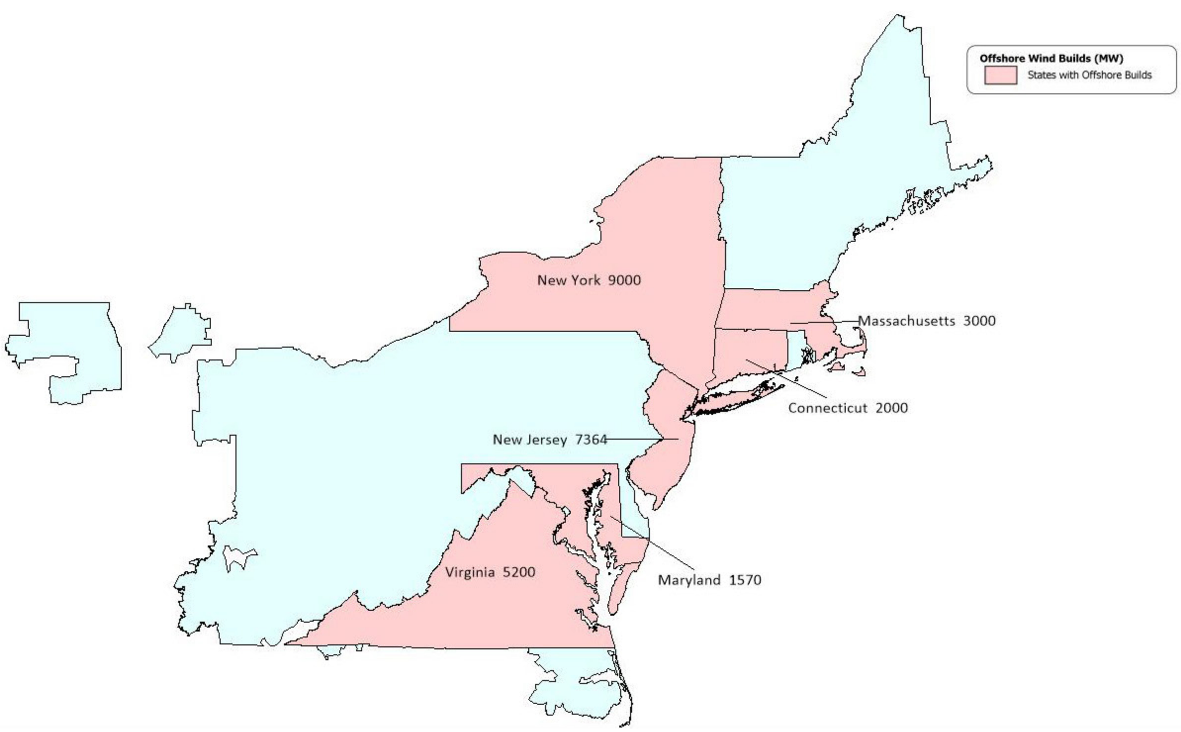
Capacity Type	PJM		NYISO		ISO-NE	
	SQ	OSW	SQ	OSW	SQ	OSW
Fossil	70%	67%	67%	54%	68%	59%
Nuclear	17%	16%	10%	9%	9%	9%
Solar	2%	2%	1%	1%	4%	4%
Onshore Wind	5%	5%	5%	5%	4%	4%
Other Renewables	5%	5%	17%	14%	14%	12%
Offshore Wind	– –	6%	– –	17%	– –	12%

Note: Totals may not sum to 100% due to rounding.

Source: ICF

Figure 2 displays where offshore wind builds were added for the OSW Case at the state level.

Figure 2: State Allocation of Offshore Wind Builds in OSW Case



Source: ICF

Results: Locational Marginal Prices (LMP)

Lower energy prices

The large-scale offshore wind additions have a dampening effect on local energy prices due to their near-zero energy bid costs. The decline in LMP can be examined from both a geographical and a temporal perspective.

Figures 3 and 4 show that in areas where offshore wind additions inject energy in the OSW Case, LMP prices generally decrease. This trend is consistent across all three ISOs, though to a lesser extent in PJM.

Figure 3: SQ Case Annual Average LMP Heat Map

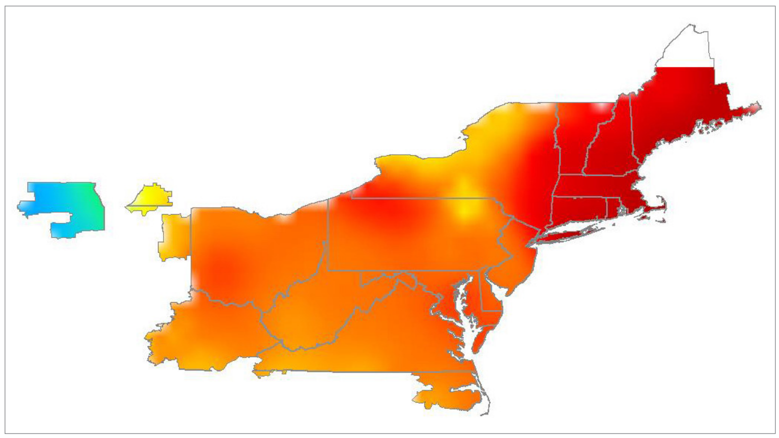
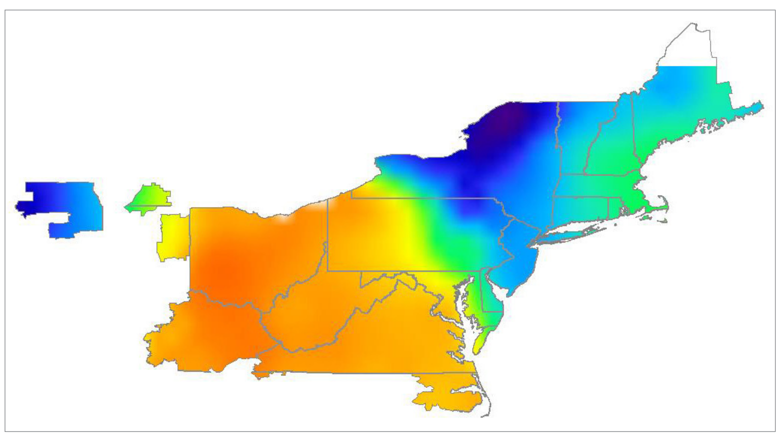
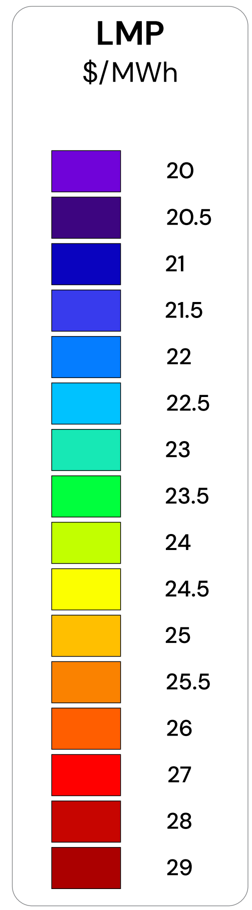


Figure 4: OSW Case Annual Average LMP Heat Map

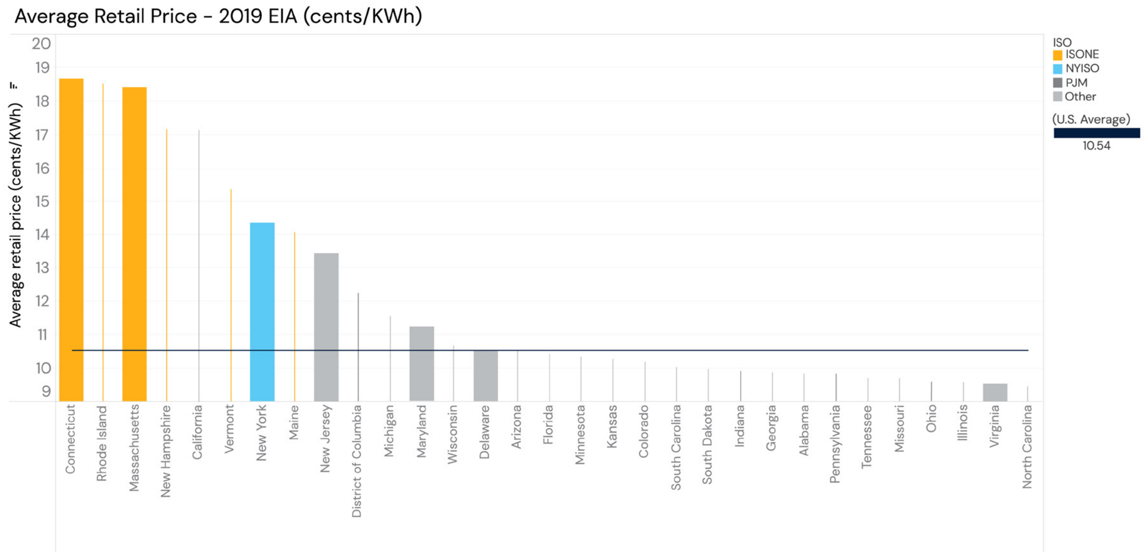




Source: Created by ICF using ABB: Ventyx

The price decrease is most notable in New England and New York, which historically have among the highest retail electricity rates in the country (see Figure 5). While this analysis is not intended to be a forecast of expected retail electricity prices, it does highlight the potential benefit to electricity consumers in these states since the most significant portion of retail electric bills is often the generation component.

Figure 5: Average Retail Electricity Price by State – EIA 2019



Source: ICF using EIA 2019 data

While hourly offshore wind production may vary from day to day and across seasons, on average production tends to peak in the evening and overnight hours. For this analysis, we assumed on-peak hours ran between 7 a.m. and 11 p.m. inclusive, Monday through Friday. Table 3 shows how annual average LMPs changed between the SQ Case and OSW Case for on-peak, off-peak, and around-the-clock (ATC) hours.

Table 3: Change in Annual Average LMP from SQ Case to OSW Case

LMP ($/MWh) (OSW – SQ)			
State	**On-peak***	**Off-peak†**	**Around-the-Clock (ATC)**
Maryland	0.04	-1.42	-0.72
Virginia	-0.56	-1.35	-0.97
New Jersey	-2.96	-5.39	-4.23
Connecticut	-1.86	-3.81	-2.88
Massachusetts	-1.65	-3.64	-2.69
New York	-2.53	-4.53	-3.57

*The hours between 7 a.m. and 11 p.m. inclusive, prevailing Eastern Time, Monday through Friday, except for NERC-defined holidays.
†The hours between 11 p.m. and 7 a.m., prevailing Eastern Time, Monday through Friday, and all-day Saturday and Sunday, and NERC-defined holidays.

Source: ICF

For each state with offshore wind additions, annual average ATC LMPs decreased between the two modeling scenarios. New York and New Jersey saw the largest decrease in ATC LMP. Maryland and Virginia saw relatively smaller declines. This is in part attributable to an increase in positive congestion in the states experienced in the OSW Case, a topic that we examine more closely in the following section.

Given the generation profile of offshore wind facilities, the magnitude of LMP impacts were greater during off-peak hours than on-peak hours. While this analysis does not examine the implications of increasing electric vehicle load or increasing solar penetration combined with offshore wind, it does illustrate that offshore wind is likely complementary to these two trends. If unmanaged, increases in electric vehicle load would likely occur overnight, when offshore wind production is often high, giving the offshore wind resources higher load coincidence. Similarly, it shows the complementary potential that offshore wind has to provide a firming resource to solar, which is expected to have a more significant price dampening effect during the daytime.

Results: Transmission congestion

Increased congestion

LMP is comprised of three elements:

1. The system marginal price otherwise known as the marginal generation cost
2. The congestion component which represents the price of congestion for binding transmission constraints
3. The marginal loss component, which prices transmission losses according to marginal loss factors and reflects the percentage increase in system losses relative to a specific bus

The congestion component of LMP can either be positive or negative. Positive congestion implies that load is not being served at the lowest possible cost due to one or more transmission constraints. Negative congestion, which takes place on the opposite end of the transmission constraint(s), indicates that generators are unable to send power to where it is needed most in the system. With positive congestion, local power prices are higher than the broader grid while the opposite is true for negative congestion. Positive and negative congestion are inextricably linked, and therefore you cannot have one without the other.

Figures 6 and 7 show that changes in annual average congestion caused by the offshore wind additions in the OSW Case were significant in PJM and NYISO, but negligible in ISO-NE. Negative congestion increased in most coastal areas where offshore wind capacity was added. Positive congestion generally increased for inland areas, especially in PJM.

Figure 6: SQ Case Annual Average Congestion Heat Map

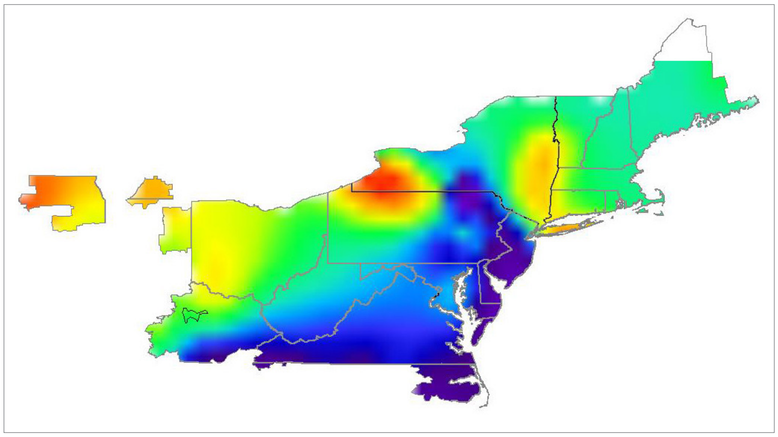
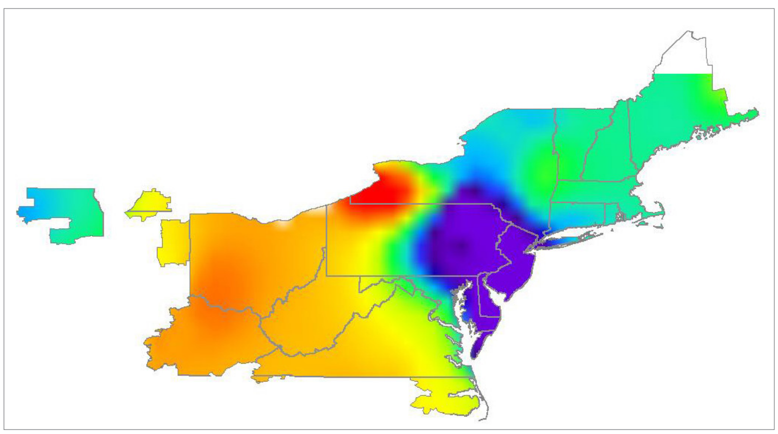
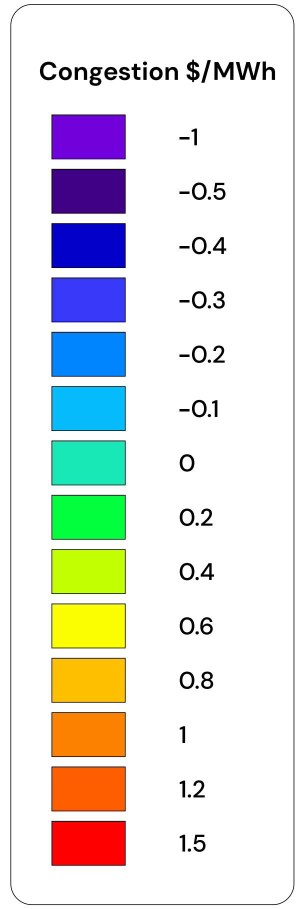


Figure 7: OSW Case Annual Average Congestion Heat Map





Source: Created by ICF using ABB: Ventyx

Increases in system-wide congestion can be attributed to transmission constraints that prevent the transfer of offshore wind generation from coastal areas to inland areas, essentially locking in offshore wind generation near the source. As a result, LMPs in most coastal areas decrease, lowering the energy revenues received by offshore wind generators, while LMPs in most inland areas increase, raising the cost of serving load in corresponding zones.

Exceptions to this trend are seen in Virginia and Maryland where, despite adding offshore wind builds in the OSW Case, positive congestion increases in the OSW Case (see Table 4). One possible explanation for why the two states see increased positive congestion in the OSW Case is that the massive increase in low-cost power from New Jersey overrides the increase in supply in Virginia and Maryland. Given that the OSW Case does not model network upgrades to accommodate the offshore wind builds, there remain transmission constraints preventing the oversupply of power in New Jersey from feeding into high load pockets within Virginia and Maryland.

Table 4: Change in Annual Average Congestion from SQ Case to OSW Case

Congestion ($/MWh) (OSW – SQ)			
State	On-peak*	Off-peak†	Around-the-Clock (ATC)
Maryland	0.70	0.16	0.42
Virginia	0.19	0.50	0.35
New Jersey	-1.66	-2.49	-2.09
Connecticut	-0.12	-0.05	-0.09
Massachusetts	0.00	0.01	0.00
New York	-0.71	-0.62	-0.66

*The hours between 7 a.m. and 11 p.m. inclusive, prevailing Eastern Time, Monday through Friday, except for NERC-defined holidays.
†The hours between 11 p.m. and 7 a.m., prevailing Eastern Time, Monday through Friday, and all-day Saturday and Sunday, and NERC-defined holidays.

Source: ICF

Connecticut and Massachusetts saw relatively small amounts of congestion as a result of offshore wind additions in the OSW Case. This is consistent with findings in the offshore wind integration scenarios of the 2019 ISO New England Economic Study, which reported that "approximately 5,800 MW of offshore wind can be interconnected to points along the southern shores of Massachusetts, Rhode Island, and Connecticut without significant upgrades to the onshore transmission network[7]."

The results generally are indicative of the need for consideration of transmission system upgrades, particularly in PJM and NYISO, in support of large amounts of offshore wind injections. In areas with negative congestion, added transmission would help increase market-based revenue for the offshore power plants, reducing the magnitude of required out-of-market support. In areas with positive congestion, increasing energy transfer capabilities from areas where offshore wind generation is injected into the grid would likely reduce the average cost of serving load.

Directional change in power flows between zones

Another evident trend when comparing transmission results between the SQ Case and OSW Case is directional changes in the flow of energy between certain zones in PJM, NYISO, and ISO-NE. While the SQ Case shows a general flow of energy from inland areas toward coastal load centers, the OSW Case shows a reversal of this trend in several zones. With offshore wind meeting much of the energy demand for coastal load centers, exports from the corresponding zones increase while their imports decline. This trend is especially evident in Zones J and K of NYISO, where net imports decreased substantially between cases. Significant changes in flows were also seen in Southeast Massachusetts where 3,000 MW of offshore wind capacity additions changed the zone from a net importer in the SQ Case to a net exporter in the OSW Case.

[7] https://www.iso-ne.com/system-planning/system-plans-studies/economic-studies/

Results: Curtailment

Offshore wind curtailment varies by location

Curtailment occurs when there is insufficient transmission capacity to move energy from generation sources to load centers, or when there is insufficient demand. In the OSW Case, we see some curtailment of offshore wind generation due to an oversupply of energy in certain hours, and a lack of available transmission capacity to move that energy to load sinks.

Table 5 shows offshore wind curtailment as a percentage of total offshore wind generation among states with offshore wind additions in the OSW Case. Of these states, New York showed the greatest amount of offshore wind curtailment. Offshore wind curtailment as a percentage of total offshore wind generation was negligible for all other states. The results presented herein are intended to be indicative only to highlight the areas where curtailment is more likely to be a concern.[8]

Table 5: Offshore Wind Curtailment

State	Percentage of Offshore Wind Generation Curtailed (%)
Maryland	2.26%
Virginia	0.00%
New Jersey	0.46%
Connecticut	1.46%
Massachusetts	1.23%
New York	33.89%

Source: ICF

As mentioned, the basis for this analysis is to consider the impact of offshore wind on the existing power system. As such, no transmission network upgrades, no new supply or storage, and no change in demand due to electrification were assumed. Any of these assumptions would affect the resulting offshore wind curtailment in each state. In particular, each would have some potential to reduce or prevent curtailment.

Some offshore developers are actively seeking ways to provide value to generation that may otherwise be curtailed. One such example is Atlantic Shores, a 50-50 joint venture between EDF Renewables North America and Shell New Energies U.S., proposing to build a 10 MW green hydrogen pilot project as part of its offshore wind project bid to the New Jersey Board of Public Utilities (NJBPU) in the state's second offshore wind solicitation. The pilot project would draw electricity from the offshore wind plant in the hydrogen production process and serve as a load source that could reduce or prevent curtailment. In June 2021, NJBPU awarded Atlantic Shores a contract to develop 1,510 MW of offshore wind capacity.[9]

[8] The OSW case does not consider load growth, transmission expansion, unit additions and retirements, or other factors likely to change the grid configuration as offshore wind facilities are added.
[9] https://www.nj.gov/bpu/newsroom/2021/approved/20210630.html

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Conclusion

Given current levels of government support for offshore wind development, as well as the existing pipeline of projects with approved contracts for offtake, a large-scale buildout of offshore wind capacity in U.S. waters seems inevitable. We conducted this analysis to better understand the impacts of such a buildout on wholesale power markets in the Northeast and Mid-Atlantic regions.

Our results suggest that a 28 GW buildout of offshore wind capacity in the Northeast and Mid-Atlantic regions could change the dynamics of wholesale power markets in the following ways:

- Decrease LMPs in states with offshore wind additions
- Increase transmission congestion significantly in PJM and NYISO, but less so in ISO-NE
- Directional shift in energy flows between inland areas and coastal load centers
- Varying levels of offshore wind curtailment depending on where projects inject energy

While we expect these broader trends to hold true, further analysis using more refined assumptions is necessary to fully understand impacts at a granular level. For instance, extending the time horizon of the analysis would allow for a more gradual and realistic buildout of capacity to take place in the model. Limiting the scope of the analysis to just one offshore wind project would also allow for a closer examination of project-specific impacts.

These trends point to the potential for both significant benefits and significant risks associated with offshore wind development. As with all renewables, one key benefit is the ability to provide carbon reductions to the power system. Likewise, the trends identified herein indicate that there could be significant benefit to ratepayers in the costs for electric generation. However, the trends also signal the importance of transmission to achieving these benefits. In particular, addressing transmission as a means to ensure the deliverability of offshore output to demand areas.

ICF is a recognized leader in providing multidisciplinary consulting services to support the development, environmental assessment, design, financing, construction and operation of offshore wind power generation facilities and transmission infrastructure. As offshore wind development within the U.S. progresses, new challenges are likely to surface demanding well-informed solutions. We look forward to continuing to offer those solutions to our clients along with new insights into the future of the offshore wind industry.

More information on our offshore wind experience is available here.

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About the authors

Maria Scheller

Vice President, Energy Markets – Power

Maria.Scheller@icf.com

Maria is a Vice President and Director in ICF's Energy Advisory group with more than 25 years helping clients improve the planning for and operation of the electric sector. Her specialty is energy planning and policy impact work with a focus on the electric power sector. She is an expert in electric market economic and fundamentals analysis including, power price forecasting, cost/benefit analysis, reliability and resiliency planning, valuation, policy and regulatory analysis, competitive procurement, and integrated resource planning. Maria has testified in multiple jurisdictions on issues including offshore wind procurement, distribution and transmission planning, and environmental emissions policy impact.

Thomas Rostad

Energy Markets Researcher

Thomas.Rostad@icf.com

Thomas joined ICF in 2020 after graduating from Boston College with a degree in Environmental Studies. As a Research Assistant, Thomas has supported on several projects advising government, utility, and private sector clients within the power sector. His areas of expertise include market research, policy and regulatory analysis, electric power system modeling, and technical writing.

About the authors

Akanksha Goyal

Energy Markets Analyst

Akanksha.Goyal@icf.com

Akanksha Goyal is an Energy Markets Analyst in ICF's Policy and Planning team. Her work focuses on modeling and analyzing decarbonization pathways for power sector clients in U.S. wholesale electricity markets such as SERC, ISO-NE and NYISO. Prior to joining ICF, Akanksha was a Master's student concentrating in International Economics and Energy, Resources & Environment at the Johns Hopkins University School of Advanced International Studies.

Ameya Ghodke

Energy Markets Consultant – Power

Ameyaulhas.Ghodke@icf.com

Ameya Ghodke joined ICF in 2018 as an Energy Markets Analyst. He has worked with utilities, independent power providers, and public utility commissions in providing wholesale power market analysis, transmission planning, asset valuation and financing support.

For the last three years, he has developed expertise in production cost modeling, providing clients with power price projections, cash flow projections and transmission and power flow analyses. He also has experience in power purchase agreements and transmission congestion analysis. During his tenure at ICF, he has focused on the SERC, PJM and NYISO markets.

Ameya holds a master's degree in Energy Systems from Northeastern University, and holds a Bachelor's degree in Production Engineering from College of Engineering Pune.

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Maria Scheller
Maria.Scheller@icf.com
+1.703.934.3372

Thomas Rostad
Thomas.Rostad@icf.com
+1.703.225.5777

Akanksha Goyal
Akanksha.Goyal@icf.com
+1.703.225.5775

Ameya Ghodke
Ameyaulhas.Ghodke@icf.com
+1.857.544.8724

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