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Atlantic Offshore Wind Transmission Literature Review and Gaps Analysis

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Disclaimer

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List of Acronyms

AC	alternating current
BNOW	Business Network for Offshore Wind
BOEM	Bureau of Ocean Energy Management
BTM	behind the meter
CARIS	Congestion Assessment and Resource Integration Study
DER	distributed energy resource
FGRS	Future Grid Reliability Study
FERC	Federal Energy Regulatory Commission
G/T	generation and transmission
GW	gigawatt
HVAC	high-voltage alternating current
HVDC	high-voltage direct current
ISO	independent system operator
ISO-NE	Independent System Operator of New England
kV	kilovolts
LSE	load-serving entity
MA	Massachusetts
MISO	Midcontinent Independent System Operator
MW	megawatt
NE	New England
NEPOOL	New England Power Pool
NESCOE	New England States Committee on Electricity
NJ	New Jersey
NJBPU	New Jersey Board of Public Utilities
NY	New York
NYDPS	New York State Department of Public Service
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research & Development
OSW	offshore wind
PJM	PJM Corporation
POI	point of interconnection
RTEP	regional transmission expansion plan
RTO	regional transmission organization
SAA	State Agreement Approach
SPP	Southwest Power Pool
T&I	transmission and interconnection

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1 Purpose

U.S. Department of Energy, U.S. Department of the Interior, and U.S. Department of Commerce recently announced a shared goal to deploy 30 gigawatts (GW) of offshore wind energy in the United States by 2030. Achieving this target will also unlock a pathway to 110 GW by 2050. One of the central challenges with meeting these targets is transmission constraints, including both land-based interconnections and transmission and offshore transmission, for both near- and long-term offshore wind energy deployment.

Given offshore wind development, state goals (see Appendix A), mature technology for fixed-bottom offshore wind, and proximity to existing transmission infrastructure, most of the 30 GW of offshore wind energy by 2030 will be developed along the Atlantic Seaboard. Increased development along the Atlantic Coast will likely require additional Bureau of Ocean Energy Management (BOEM) lease areas farther from shore and advanced transmission technologies (e.g., high-voltage direct current [HVDC]). Nine eastern governors recently voiced their prioritization of offshore wind energy development including adequate transmission capacity. Reaching 110 GW or more of offshore wind by 2050 will likely involve development in the Atlantic, Pacific, Gulf of Mexico, and Great Lakes. Despite unique differences, improving understanding of offshore wind transmission options, establishing coordination and aligning processes among states and regions, and quantifying the long-term impacts of offshore wind transmission options will catalyze offshore wind energy's growth not only in the Atlantic by 2030 but also nationally by 2050.

To reach offshore wind development goals, this document reviews current publicly available transmission analysis along the Atlantic Coast and analysis gaps.

2 Background

Europe had over 25 GW of offshore wind energy completed by the end of 2020, with an additional 7 GW financed for future development. The United States can learn from Europe to address transmission challenges. In the United Kingdom, each offshore wind developer has used the closest, cheapest point of interconnection (POI) via a dedicated radial transmission line. However, a recent study shows that if the United Kingdom transitions to a shared transmission network by 2025, costs can be reduced by 18%, total assets by 70%, and landing points by 72% by 2050. Delaying that transition to 2030 significantly reduces benefits to: costs reductions of only 8%, total assets of only 40%, and landing points of only 38%. Multiple countries in the North and Baltic Seas are planning two energy islands using shared transmission. The United States could potentially reduce cost and impacts with coordinated offshore wind transmission development, as suggested by analysis from Tufts, The Brattle Group, and The Business Network for Offshore Wind (BNOW) yet benefits may be limited when applied more specifically as suggested by Levitan & Associates.

In the United States, offshore wind developers, regional transmission organizations (RTOs), independent system operators (ISOs), and utilities have been approaching transmission development on an individual project basis. Efforts are underway in New Jersey (NJ) and New England (NE) to consider and analyze transmission for multiple offshore wind energy projects. Structures for interregional coordination exist but as of August 2021 such coordinated analysis for offshore wind development has yet to be initiated (see more details in Appendix B). The current planning and interconnection processes identify transmission solutions for a particular offshore wind energy project, which may not necessarily be optimal for expanded development. Offshore wind developers interconnecting to the transmission system through interconnection processes are typically required to pay for necessary network upgrades to impacted, land-based transmission facilities, which may not be the transmission improvements that maximize long-term system benefits as compared to transmission planned to integrate anticipated offshore wind generation more broadly. How offshore wind generation connects to shore is still undergoing policy debate with objectives to encourage efficient use of resources, minimize environmental impact, and allow for future development. Recently, New Jersey entered a State Agreement Approach (SAA) with PJM. This is an unprecedented step to plan transmission proactively and competitively for all the state's 7.5 GW of offshore wind energy deployment by 2035. It could potentially become a role model for other states and RTOs/ISOs to follow and help determine the costs and benefits of different transmission configurations.

3 Offshore Wind Transmission Analysis

Numerous offshore wind studies have been conducted in the Atlantic. They have been used to inform policy decisions and are precursors to electricity infrastructure planning processes. Conducting *comprehensive, proactive* transmission analysis for offshore wind energy includes many aspects, each contributing essential information to future development and each requiring appropriate data. Careful attention must be given to assumptions and robust future scenarios across the broader interconnected system. Transmission development for offshore wind cannot be conducted in isolation but must include meeting all clean energy goals including electrification.

3.1 Criteria for Offshore Wind Transmission Analysis

Minimum criteria for comprehensive analysis are detailed as follows.

Offshore transmission design: Analyzing offshore transmission options requires understanding underlying design assumptions. Essential information includes:

- Identification of viable offshore wind energy **generation locations**. The BOEM lease areas provide an initial basis and were determined in conjunction with marine environment studies by state and stakeholder involvement. Beyond 30 GW, new lease areas are required.
- Identification of viable **landing points**, where offshore cables meet land.
- Identification of viable transmission **cable routes** from offshore wind energy generation to landing points.
- Identification of potential **POIs** to the existing transmission system, either via existing facilities or the development of new facilities.
- Determination of the feasibility, compatibility, and cost-effectiveness of **transmission technologies**, such as high-voltage alternating current (HVAC) or HVDC, to interconnect offshore wind generators.
- Equity and **energy justice** considerations in offshore wind transmission design.

System impact analyses: Connected system impact analyses assess the land-based and offshore transmission options to consistently evaluate the relative feasibility, cost, reliability, and resilience benefits of different options including:

- Numerous weather years of **data** over varying time scales in which all the weather-based generation resources are coincident with load to capture interdependencies, variability, and uncertainty over the range of expected outcomes.
- **Co-optimization of transmission** with necessary generation and storage technologies to holistically compare completely integrated alternatives that capture generation and transmission trade-offs to adequately meet customer demand and federal and state policy objectives while maintaining grid reliability and resilience.
- Subhourly economic analysis and operational **production cost** simulation for unit commitment and economic dispatch including curtailments, congestion, and emissions.

- **Transmission contingency analysis** to identify system upgrades that maintain transmission facility thermal and voltage limits, promote efficient flow, and maintain reliability according to North American Electric Reliability Corporation requirements.
- **Dynamic stability** analysis that considers angular stability, control interaction, and voltage and frequency response following a contingency event.
- **Resilience** analysis that considers potential weather events and potential common mode failure scenarios caused by interdependencies.

3.2 Recent and Ongoing Offshore Wind Transmission Analysis

Over 20 offshore wind (OSW) transmission analyses in the Atlantic region were reviewed as of August 2021 to determine their inclusion of the comprehensive elements described in the previous section. Select studies that are ongoing efforts or those recently published (2017 to 2021) are summarized in Table 1, with additional details in Appendix C. These studies cover areas of Maine through Virginia. As technology and policy are rapidly evolving, older analysis is not included due to relevance, which includes analysis conducted for the Carolinas.

Several themes appear in many existing studies shown in Table 1:

- Onshore transmission upgrades and expansion will be needed to reliably transmit offshore wind power to load. The extent of needed upgrades increases with installed offshore wind capacity. Congestion and curtailments significantly increase since offshore wind is not strongly correlated to load. Results depend on chosen assumptions including electrification and storage and the following factors:
    - ISO-New England (ISO-NE) can support 5.8 GW of offshore wind energy with minimal transmission upgrades. Costs increase significantly beyond that. Increasing offshore transmission development may alleviate onshore development. Curtailments are primarily a result of a temporal mismatch between offshore wind generation and consumer demand for electricity. Electrification and storage may relieve congestion and curtailment. Low-voltage conditions may be addressed with synchronous condensers.
    - New York Independent System Operator (NYISO) can integrate 9 GW of offshore wind energy by expanding Long Island bulk transmission and local upgrades in New York City. Issues include cable routing limitations in New York Harbor, space constraints in substations on Manhattan, and permitting complexities in both the harbor and along the Long Island coastline. A meshed offshore network[1] has been identified as a future option; however, is not a near-term solution because of the time required to study, design, and construct the network. NYISO studied additional transmission upgrades as well as demand response and energy efficiency to reduce congestion.

[1] A meshed network can link nearby offshore wind farms through shared multiterminal transmission facilities.

  - PJM has begun a transmission study of five scenarios with offshore wind capacities ranging from 9 GW in 2027 to 19.6 GW in 2035; results are expected later this year. Tufts reports that New Jersey's southeast coast lacks adequate POI capacity to handle offshore wind energy developers' needs; however, the New Jersey SAA with PJM will provide more clarity.

- Space, capacity, permitting complexities, and other constraints in existing POIs will necessitate careful planning of offshore wind within lease areas, transmission cable landfalls, onshore and offshore cable routes, and onshore POIs.
- Although some nonutility analyses suggest that planned offshore transmission meshed networks and backbones[2] may be more economical, increase reliability and resilience, and reduce environmental impacts compared to the project-by-project radial connections; the analyses are high-level economic comparisons and the results have not been validated using sufficient data and modeling, such as production costs and reliability and stability analysis. Additionally, even if a meshed or backbone approach is optimal from an economic and technical perspective, the studies may not fully appreciate the risks and costs to offshore wind energy developers due to waiting for a shared infrastructure to be in place. Other nonutility analysis suggests the benefits of shared transmission may be minimal and not achievable for particular study regions. As discussed earlier, there are many aspects of a comprehensive study that support infrastructure decisions. Without these aspects, the high-level results are inconclusive.

The analyses done to date have provided background for policy decisions, but modeling additional details is necessary to determine specific solutions with corresponding costs and benefits. The rapid transformation of the grid is also providing new alternatives and scenarios not conceived at the time of early studies. Additional comprehensive analyses can translate concepts and established goals into specific action plans for states and regions to promote efficient transmission solutions in support of offshore wind energy development.

[2] A backbone is a shared high-voltage transmission facility, several of which can form a longer backbone or a meshed network.

Table 1. Summary of Atlantic Coast Offshore Wind Energy Transmission Studies as of August 2021

Study	Region	Publish Year	Study Year	OSW Gen	Land Pts[3]	Cable Route[4]	POI[5]	HVAC HVDC [6]	Data Hours[7]	G/T Opt[8]	Prod Cost	Trans Cont[9]	Stability	Key Findings or Objectives
NE1 2019 NESCOE[10] Study	ISO-NE	2020	2030	8 GW	No	No	Exist	Both	8,760C	No	Yes	No	No	- Minimum transmission upgrades to 5.8 GW - Significant upgrades if tie to southeast NE - If HVDC tie to Boston, 2.2 GW without significant upgrades - Offshore wind does not provide steady supply in high- demand summer - Curtailment could be significant
NE2 2019 Anbaric Study	ISO-NE	2020	2030	8 GW, 10 GW, 12 GW	No	No	Exist	Both	8,760C	No	Yes	No	No	- Similar conclusion as of NE1 - Incremental cost savings are less than $100 million per 2 GW of offshore wind when total offshore wind energy is greater than 10 GW - The more offshore wind in southwest Massachusetts, the more curtailment - In the 10 GW scenario, electrification and storage near offshore wind reduces congestion of southwest Massachusetts and Rhode Island export as compared to storages elsewhere.

[3] Indicates whether study included analysis of specific landing points.

[4] Indicates whether study included analysis of specific cable routes.

[5] Indicates whether POIs are existing substations or include identifying new POIs. No indicates generic injection.

[6] Indicates whether transmission options included HVAC or HVDC or both.

[7] 8,760 refers to hourly data for 1 year and a C indicates coincident (i.e., the same weather year).

[8] Indicates whether generation and transmission were co-optimized. No indicates a transmission study with predefined generation options.

[9] Indicates whether an extensive transmission contingency analysis was performed. Peak indicates only for peak load hours (which may not correspond to the most critical transmission period).

[10] NESCOE – New England States Committee on Electricity

Study	Region	Publish Year	Study Year	OSW Gen	Land Pts[3]	Cable Route[4]	POI[5]	HVAC HVDC [6]	Data Hours[7]	G/T Opt[8]	Prod Cost	Trans Cont[9]	Stability	Key Findings or Objectives
NE3 2020 National Grid	ISO-NE Canada	2021	2035	8 GW	No	No	Exist	AC	8,760C	No	Yes	No	No	- Large oversupply of New England renewables - Energy banking significantly reduces spillage - Battery removal improves utilization of pumped hydro storage.
NE4 Future Grid Reliability Study	ISO-NE	2022	2040	8-17 GW	No	No	Exist	Both	8,760 C	No	Yes	No	No	- 2021 Economic Study and Future Grid Reliability Study (FGRS) Phase 1 - To understand the implication of future grid and market impact in resource revenues - Unconstrained energy banking with Quebec can alleviate curtailments
NE5 Transm. Pilot Study	ISO-NE	2021	2030	3.1 GW	No	No	Exist	No	4	No	No	Yes	Yes	- Transmission Planning Pilot Study - Understand reliability and cost trade-offs - High renewables result in low voltages - Concerns with distributed energy resource (DER) tripping for faults and voltage
NE6 2050 Transm. Study	ISO-NE	TBD[11]	2050	TBD	No	No	TBD	TBD	TBD	No	No	Yes	No	- 2050 transmission study for NESCOE - To determine how to expand the system to wind, hydropower, DERs
NE7 Pathways Study	ISO-NE	2022	TBD	TBD	No	No	TBD	TBD	TBD	No	Yes	No	No	-Pathways Evaluation: Forward clean energy and carbon pricing studies - Review market frameworks

[11] TBD (to be determined) in the table indicates the study is still being scoped and this element has not been publicly defined.

Study	Region	Publish Year	Study Year	OSW Gen	Land Pts[3]	Cable Route[4]	POI[5]	HVAC HVDC[6]	Data Hours[7]	G/T Opt[8]	Prod Cost	Trans Cont[9]	Stability	Key Findings or Objectives
NE8 FGRS Phase 2	ISO-NE	TBD	2040	TBD	No	No	TBD	TBD	TBD	No	No	TBD	Yes	- Future Grid Reliability Study Phase 2 - To study steady-state and dynamic stability - To conduct revenue sufficient analysis
MA Offshore Wind Study	MA[12]	2019	2027, 2030	1.6 GW	No	No	No	No	avg	No	Yes	No	No	- Staggered OSW procurement could capture additional economic benefit - Transmission should be considered prior to additional 1.6 GW procurement -Should consider paired storage with OSW
NY1 Power Grid Study	NYISO	2021	2035	9 GW	Yes	Yes	Exist	Both	8,760	No	Yes	peak	No	- 9 GW by 2035 achievable without major upgrade beyond Long Island and New York City - New York City interconnection advantageous - Cable routing, station space, and permitting complexities drive careful planning. - Meshed offshore network can increase reliability and resiliency
NY2 NYSERDA and NYDPS[13] Offshore Wind Policy Paper	NYISO	2018	2018, 2019	800 MW	No	No	No	Both	None	No	Yes	No	No	- Developer-owned transmission and interconnection (T&I) is most implementable for Phase 1 of offshore wind in New York - T&I as regulated asset could unlock moderate benefit but challenging to implement (timing and energy delivery risk) - Stand-alone obligation like zero-emission credit requirement would be suitable

[12] MA - Masshachusetts
[13] NYSERDA – New York State Energy Research and Development Authority; NYDPS – New York Department of Public Service

Study	Region	Publish Year	Study Year	OSW Gen	Land Pts[3]	Cable Route[4]	POI[5]	HVAC HVDC [6]	Data Hours[7]	G/T Opt[8]	Prod Cost	Trans Cont[9]	Stability	Key Findings or Objectives
NY3 Anbaric Study	NYISO	2020	2026, 2035	9 GW	No	Yes	Exist	Both	Peak only	No	No	No	No	- Phase 1 (1.8 GW) proceed as planned (radial), focus on Phase 2 (2.4 GW) and 3 (4.8 GW) - Planned approach reduces transmission cost by $500 million, can efficiently use POI and reduce environmental impacts - Curtailment challenges identified
NY4 Zero Emission Power System	NYISO	2020	2024, 2030, 2040	25 GW	No	No	No	No	720	No	No	No	No	- An additional 11 GW of offshore wind is needed for electrification scenario - Today's flows are primarily southbound; future flow pattern more variable, reverse - Unconstrained hours southbound generally increase
NY5 Cable Landfall Permit Study	NYISO	2017	2030	2.4 GW	Yes	Yes	Exist	No	None	No	No	No	No	- Considers opportunities and possible constraints for cable land fall in the Long Island and Hudson/HYC areas. - Hard constraints, locations to be avoided were found in both areas - Soft constraints that can be mitigated were also found in both areas - Unconstrained opportunity areas identified
NY6 CARIS[14] Report	NYISO	2020	2019-2028	6.1 GW	No	No	Exist	HVDC	10 yr. 8,760	No	Yes	Yes	No	-11% renewable energy curtailment in 2030 -Identified five renewable regions with constrained transmission including two zones

[14] CARIS – Congestion Assessment and Resource Integration Study

Study	Region	Publish Year	Study Year	OSW Gen	Land Pts[3]	Cable Route[4]	POI[5]	HVAC HVDC [6]	Data Hours[7]	G/T Opt[8]	Prod Cost	Trans Cont[9]	Stability	Key Findings or Objectives
														due to offshore wind
NY7 Offshore Wind Injection	NYISO	2017	2030	2.4 GW	No	No	Exist	No	8,760	No	No	Yes	No	- Studied interconnections in New York City and Long Island - Feasible to integrate 2.4 GW of offshore wind with no thermal limit violation
PJM Offshore Transm. Study	PJM	TBD	2035	9-20 GW	TBD	TBD	TBD	TBD	TBD	No	TBD	TBD	TBD	- PJM Offshore Transmission Group - To analyze regional transmission solutions for offshore wind - Five scenarios: 2027 9 GW and 2035 17.6–19.6 GW
NJ Offshore Wind Transm. Options	New Jersey	2020	2035	7.5 GW	Yes	No	Exist	Both	None	No	No	No	No	-SAA can encourage innovation and cost-effective transmission - Centrally led transmission development can provide long-term benefit - HVDC has benefit but higher converter cost - Cheap POIs will be depleted soon - Ocean grid 's extrinsic benefits may not be achievable due to implementation challenges
PJM/NJ PJM Two-Phase Study on New Jersey Grid	PJM/ New Jersey	2020	2035	7.5 GW	No	Yes	Exist & new	Both	Not known	No	No	Yes	No	- Results are critical energy/electric infrastructure information (CEII) - Phase 1: 100 potential POIs, 2025 regional transmission expansion plan (RTEP) base case; based on single-generator deliverability - Phase 2: full-generator deliverability analysis,

Study	Region	Publish Year	Study Year	OSW Gen	Land Pts[3]	Cable Route[4]	POI[5]	HVAC HVDC[6]	Data Hours[7]	G/T Opt[8]	Prod Cost	Trans Cont[9]	Stability	Key Findings or Objectives
Injection														full contingency analysis, and high-level stability reviews using 2028 RTEP and Phase 1 scenarios; all triggered expensive upgrades

4 Gaps Assessment

Existing offshore wind energy and transmission planning studies in the Atlantic have been inadequate to plan for transmission requirements to realize the administration's 2030 offshore wind goals and beyond. Based on the relevant studies and analyses critical to plan, invest, build, and operate offshore wind and transmission, we identified four main gaps. Addressing these gaps (as follows) is necessary to create pathways toward an affordable, clean, and reliable energy future with offshore wind.

<u>Isolated geographic and oceanic planning for resources and coordination.</u> Almost all existing studies have been for a single state or RTO/ISO, with an assumption that each state has a claim on certain offshore wind resources. There is a wide range of study years and regional offshore wind deployment scenarios that do not quite align with the national offshore wind goals in 2030 and 2050. This misalignment creates a gap in understanding the Atlantic Coast and Eastern Interconnection implications of how offshore wind transmission will be utilized by different states. Maryland and North Carolina are currently the only two states contemplating using another state for landfall and POIs. Multistate and multiregional coordination efforts to support national goals have not been considered in current planning processes.

<u>No coordination between offshore wind generation and transmission.</u> Although some ideas of optimizing offshore wind energy and transmission have been conceptualized (such as meshed or backbone designs), these possibly more efficient approaches have not been widely or deeply studied. RTOs/ISOs use the generator interconnection queue to address deployment-specific requests to determine transmission requirements associated with each individual project. The RTOs/ISOs have only recently initiated long-term transmission planning activities related to state offshore wind public policy goals. Traditional transmission planning has missed potential collaborative solutions and instead primarily identifies solutions for individual projects. Examples include coastal POIs becoming saturated and/or incurring increasingly expensive onshore upgrades. Most studies consider a dedicated transmission line interconnecting each offshore wind farm. Expanding solutions to include shared transmission or shared right-of-way approaches may minimize cost and impacts. Coordinated analysis for offshore wind generation and transmission is needed.

<u>Limited scope and breadth in technical analysis and studies conducted.</u> Initial sets of techno-economic analysis and scenarios (production cost modeling) have been widely conducted across the Atlantic Coast. However, few states and areas have analyzed landfall points, transmission cable routing, and points of interconnection. While included in generator interconnection studies, no current long-term analysis includes robust transmission planning with contingency and stability analysis, although some regional efforts are being initiated. Some analysis assumes technology availability even though additional technology development is still needed. For example, there are currently few HVDC breakers in operation globally. There is a significant amount of technology maturity required before HVDC breakers can be fully utilized in meshed offshore HVDC transmission networks. Without such breakers, it would be challenging for a HVDC meshed network to achieve the reliability benefits of an offshore network by isolating problem areas and maintaining maximum generation output. Without comprehensive analysis, solutions can be suggested that are infeasible or considerably more costly because of crucial constraints or impacts (which may also include supply chain constraints, not specifically addressed in this analysis but potentially limiting to deployment goals). Comprehensive analysis

that connects each type of necessary technical study using appropriate modeling tools and timescales has not been completed along the Atlantic Coast. Comprehensive analysis should include the exchange and alignment of modeling assumptions, inputs, and outputs across multiple models and consider interregional synergies.

Lacking reliability and resilience considerations. Reliability and resilience depend on standards and metrics to define acceptable practices and limits. As a result, standards development should include transmission planning standards for meshed offshore HVDC transmission networks, critical contingencies, and interconnection. Studies should be conducted in a robust manner that sufficiently captures reliability and resilience events. For example, most of the reviewed studies use 1 year of wind resource data or less to represent a project into the future. This small sample of wind resource data creates a misrepresentation of the possible futures that may be realized, like wind resources, missed weather-based interdependencies, extreme weather, and future infrastructure topologies. Use of average or single-year weather misses natural patterns of variability and uncertainty that occur over longer periods and for which the system should be designed. Additionally, low-probability, high-impact events such as hurricanes and tropical cyclones, which occur regularly in the Atlantic, should be considered as a cause for common mode outages of offshore wind and onshore transmission. Infrastructure decisions should weigh the risks of such events and the cost of potential transmission solutions that may mitigate those risks. Use of probabilistic methods and models to capture the substantial uncertainty were limited in studies of the future grid.

5 Acceleration and Alignment

The benefits of offshore wind energy can be accelerated and maximized if stakeholders, including offshore wind developers, states, RTOs/ISOs, utilities, and regulators, are convened, and coordinated to discuss transmission options (e.g., different scales and configurations), analyze these options, weigh all benefits, and identify chronological solutions across regions for time frames out to 2030 and 2050. There is currently no single entity responsible for such coordination, not locally, regionally, or nationally. The federal government is recognized as an appropriate entity to convene stakeholders and potentially, to establish frameworks to evaluate offshore wind transmission options. The Federal Energy Regulatory Commission (FERC) collected stakeholder comments after an offshore wind technical conference and formed a joint federal-state task force in June 2021 with the National Association of Regulatory Utility Commissioners to "explore transmission-related issues to identify and realize the benefits that transmission can provide, while ensuring that the costs are allocated efficiently and fairly." In July 2021, FERC announced "Advance Notice of Proposed Rulemaking: Building for the Future Through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection." With improved coordination and alignment, the different assumptions, categories, and processes that each region has for transmission planning and development could be streamlined and consistent across multiple regions.

Next, with such coordination, stakeholders could identify pathways that can achieve local, state, and federal offshore wind energy goals. All stakeholders could jointly find beneficial alignment for electric consumer, grid, environmental, and institutional benefits. Using interregional, well-vetted data sets and models, comprehensive and coordinated capacity expansion, feasibility, production cost, power flow, reliability, resilience, and stability studies could be performed alongside extensive environmental and community studies to compare transmission options and system impacts in various scenarios. System impacts at different levels of offshore wind penetration should be determined, including the contribution to resource adequacy, grid services, reliability, and resilience. Actively presented and publicly discussed, results of these studies would inform and guide transmission planners and other decision makers to reach short-term transmission investment decisions that also support economical, long-term, reliable, and resilient infrastructure requirements. Finally, the convening and coordination in such an effort would likely establish relationships and methods that endure because of the observed benefits of such collaboration, such as those developed through the Eastern Interconnection Planning Collaborative.

6 Conclusion

This document summarizes the recent and ongoing offshore wind transmission analyses along the U.S. Atlantic Coast, with content from publicly available transmission studies from states, the offshore wind industry, RTOs/ISOs, and other grid stakeholders. There is a lack of comprehensive evaluation across all the necessary aspects of transmission analysis to support offshore wind energy development at scale. Current reactive processes that evaluate individual offshore wind projects may not optimize benefits to support deployment of 30 GW by 2030 and beyond. As a result, comprehensive interregional studies of possible offshore wind transmission options are needed. Addressing critical gaps of aligning Atlantic Coast stakeholders over broader geographic regions, coordinating offshore wind generation with transmission development, conducting robust planning through broader connected technical analysis, developing standards, and including reliability and resilience implications will enhance decision-making for transmission infrastructure to support offshore wind energy development in the United States to reach 2030 and 2050 goals and beyond.

Appendix A: Offshore Wind Energy Policies and Development

Individual states along the Atlantic coast have developed unique policies regarding offshore wind development, as detailed in this section. Based on these policies, the total anticipated offshore wind planning figure for 2035 is 37.5 gigawatts (GW) as of September 2021.

Maine: 11-megawatts (MW) demonstration project approved. Analysis to establish goal.
New Hampshire: Task force established
Massachusetts: 1,604 MW procured and legislative mandate of 3,200 MW by 2035
Connecticut: 804 MW procured and legislative mandate of 2,000 MW by 2030
Rhode Island: Existing Block Island 30 MW, 400 MW approved, 600 MW solicitation
New York: 4316-MW projects awarded, legislative mandate of 9,000 MW by 2035
New Jersey: 1,100-MW project awarded and 2,658 MW awarded, exceeding the legislative mandate of 3,500 MW by 2035 and increased by Executive Order to 7,500 MW
Maryland: Approved development of 368 MW, legislative mandate of 1,568 MW by 2030
Virginia: 12 MW constructed (in service June 29, 2020), proposed 2,600 MW and legislative mandate of 5,200 MW by 2034
North Carolina: Executive order of 2.8 GW by 2030 and 8 GW by 2040.

To meet state demand for offshore wind, developers have projects in various stages of development. Figure 1 provides the breakdown of development phase by state.

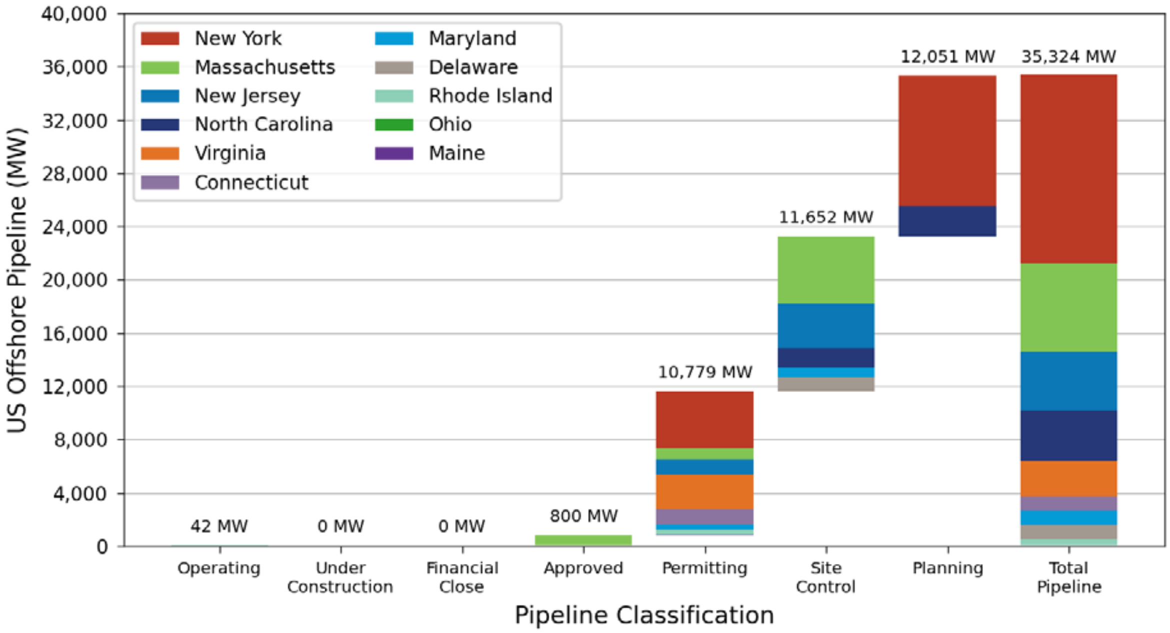

Figure 1. U.S. offshore wind energy project pipeline by status. ***Offshore Wind Market Report: 2021 Edition***

As of May 11, 2021, one offshore wind energy project (800 MW) has been approved, 15 offshore wind energy projects (10,779 MW) have site control and have made major permitting progress, or secured a power offtake contract or are expected to obtain one. In 16 BOEM lease areas, offshore wind developers have the rights to develop projects (11,652 MW). Seven unleased BOEM areas have the potential to support 12,051 MW.

Appendix B: Transmission Planning Process and Offshore Wind

The transmission system is crucial to transfer power between generation and demand. Interconnecting any new large electric generator requires transmission interconnection studies that examine the technical impacts by the local utility and the RTO/ISO. This process is generally defined through the FERC's Large Generator Interconnection Agreement and Small Generator Interconnection Agreement, North American Electric Reliability Corporation's TPL-001-4, and any transmission owner, utility, and planning authority standards and requirements.

FERC issued Order 888 in 1996 to promote wholesale competition across interstate transmission lines in the electric power industry. Order 888 includes an open-access rule and a stranded cost rule. The open-access rule requires public utilities with interstate transmission lines to provide nondiscriminatory transmission services. The stranded cost rule allows utilities to seek recovery of "legitimate and verifiable" costs that could not be recovered because of the transition to competitive markets.[15]

To support broad area transmission needs beyond what a single-generator interconnection requires, FERC Order Nos. 890 and 1000 established requirements that transmission regions must follow in planning and allocating costs of new transmission facilities. Order No. 890, issued in 2007, outlined general requirements for local as well as regional transmission planning practices and procedures.

Order No. 1000, issued in 2011, lays out specific requirements for regional transmission planning, including: (1) the consideration of transmission needs driven by public policy requirements, (2) nonincumbent transmission development, and (3) cost allocation for transmission facilities that have been selected in a regional transmission plan for purposes of cost allocation.[16] Order No. 1000 also required interregional transmission coordination. Some stakeholders believe that Order No. 1000 has not adequately facilitated interregional and competitive transmission planning that would yield the reliability, operational, and economic benefits identified in the order. Order No. 1000 requires adjacent RTOs/ISOs to coordinate transmission but not necessarily proactively plan transmission. Instead, stakeholders must request interregional studies from multiple RTOs/ISOs to demonstrate that an interregional transmission project meets regional needs in multiple regions more efficiently or cost-effectively than separate, single-region projects. As of their June 2021 meeting, no offshore wind energy projects had been brought to the ISO-New England/New York ISO/PJM Inter-regional Planning Stakeholder Advisory Committee.

On October 27, 2020, FERC convened Docket No. AD20-18-000 a technical conference to discuss whether and how existing transmission planning, interconnection, and merchant transmission facility frameworks in RTOs/ISOs can accommodate anticipated growth in offshore wind generation in an efficient and cost-effective manner that safeguards open-access transmission principles. It also considered possible changes or improvements to the current frameworks to accommodate such growth. Transmission and interconnection were described by all panelists to be essential for enabling offshore wind energy, but they largely described

[15] Excerpt from An Analysis of FERC's Final Environmental Impact Statement for Electricity Open Access and Recovery of Stranded Costs

[16] Excerpt from Regional Transmission Planning: A review of practices following FERC Order Nos. 890 and 1000

different institutional, process, or other mechanism barriers to integrating offshore wind. On March 11, 2021, FERC issued a request for post-conference comments that included additional questions following the conference discussion.

In November 2020, the New Jersey Board of Public Utilities made New Jersey the first state to fully align its offshore wind transmission goals with its regional grid operator's planning process. New Jersey has a goal of 7,500 megawatts of offshore wind energy by 2035, and it has requested the inclusion of this state public policy into the regional transmission planning process of PJM through a competitive solicitation process known as the State Agreement Approach, established by FERC Order No. 1000. On April 15, 2021, PJM opened a competitive solicitation for transmission options for New Jersey's offshore wind energy goals. As the process is only specific to New Jersey's goal, there are unclear implications of this one state study and design process on the nearby states and other offshore wind resources.

An example of public-policy-led transmission design is the Texas competitive renewable energy zones. Based on preliminary transmission analysis and wind developer interest, the Texas Public Utility Commission identified five competitive renewable energy zones in 2007 and the Electric Reliability Council of Texas began to develop a transmission optimization study. Ultimately, the Public Utilities Commission selected a scenario that would accommodate 18.5 gigawatts of wind energy at a cost of $6.8 billion and construction was initiated in 2010. The implementation of competitive renewable energy zones has helped enable the addition of more than 18 gigawatts of wind energy generation capacity to Texas's power system while overcoming technical issues such as curtailment and transmission congestion.[17] The general process is documented in the Renewable Energy Zone (REZ) Transmission Planning Process: A Guidebook for Practitioners for how to integrate transmission expansion planning and renewable energy generation planning.

Additional good practices from land-based wind regions come from the Midcontinent Independent System Operator (MISO) and Southwest Power Pool (SPP). In February 2021, MISO completed a multiyear Renewable Integration Impact Assessment that included stakeholder input and comprehensive analysis of high-penetration renewable development. The impact assessment studied resource and energy adequacy as well as steady-state and dynamic operating reliability in the MISO system and the broader Eastern Interconnection. Also, MISO and SPP are in the midst of a 1-year study that aims to improve processes and capture market efficiencies through strategic transmission development across the seam between the two that will enable additional renewable interconnections by cost sharing network upgrades with load-serving beneficiaries.

[17] Excerpt from Texas as a National Model for Bringing Clean Energy to the Grid

Appendix C: Analysis Summaries

Analysis updates as of August 2021

ISO New England

NE1: 2019 Economic Study: OSW Transmission Interconnection Analysis (NESCOE)
NE2: 2019 Economic Study: OSW Transmission Interconnection Analysis (Anbaric)
NE3: 2020 Economic Study: OSW Transmission Interconnection Analysis (Nat Grid)
NE4: 2021 Economic Study & Future Grid Reliability Study Phase 1: NEPOOL
NE5: Transmission Planning for the Clean Energy Transition: Pilot Study
NE6: 2050 Transmission Study for New England States
NE7: Pathways Evaluations - Forward Clean Energy and Carbon Pricing Studies
NE8: Future Grid Reliability Study - Phase 2 (NEPOOL)
MA: Massachusetts Department of Energy Resources Offshore Wind Study

New York ISO

NY1: Initial Report on the New York Power Grid Study: Appendix D- Offshore Wind Integration Study Final Report
NY2: Offshore Wind Policy Options Paper
NY3: Offshore Wind Transmission: An Analysis of Options for New York
NY4: New York's Evolution to a Zero Emission Power System
NY5: New York State Offshore Wind Master Plan Cable Landfall Permitting Study
NY6: 2019 CARIS Report: Congestion Assessment and Resource Integration Study
NY7: Offshore Wind Injection Assessment

PJM Interconnection

PJM: Offshore Transmission Study & Working Group
NJ: Offshore Wind Transmission Study Comparison of Options
PJM/NJ: PJM Two-Phase Study of New Jersey Grid Injection Locations

Interregional Analysis

Tufts: Comments to FERC Technical Conference regarding Offshore Wind Integration in RTOs/ISOs (Docket No. AD20-18-000)
The Brattle Group: Offshore Wind Transmission: An Analysis of New England and New York Offshore Wind Integration
BNOW: Offshore Wind Transmission Whitepaper
NOWRDC: Tufts: Transmission Expansion Planning Models for Offshore Wind Energy

NE1 - 2019 Economic Study: OSW Transmission Interconnection Analysis (NESCOE)

Published: June 30, 2020, by Independent System Operator-New England

Purpose: Economic study requested by the New England States Committee on Electricity to consider the interconnection of as much as 8,000 megawatts (MW) of new offshore wind energy by 2030. Provides information on several transmission configurations, at different points of interconnection into southern New England, and estimates transmission upgrade costs. NESCOE considered this to be informative for developing or implementing state policies aimed at maximizing ratepayer benefits as the New England power grid continues to evolve to incorporate offshore wind energy.

Study year: 2030.

Time increments: One year, 8,760 hourly, augmented with 1-minute analysis during low load.

Data used: Primarily used 2006 weather to align wind, solar, and load profiles (scaled to 2030). For the 8,000-MW scenarios, 2015 wind, solar, and load profiles (scaled to 2030) were used.

Geographic region considered: ISO-NE system.

Offshore wind region considered: The primary locations of new offshore wind resources were in BOEM lease areas, off the shores of Massachusetts and Rhode Island, and in wind energy areas on the Outer Continental Shelf.

Offshore wind integration level: The study included offshore wind energy projects under development at the time of the NESCOE request, including Vineyard Wind (800 MW) and Revolution Wind (200 MW), and considered 1,000 MW increments up to an additional 7,000 MW of offshore wind strategically placed in southern New England. The 8,000-MW case included electrification and storage.

Transmission options considered: Offshore HVAC and HVDC were evaluated using generic cable routing.

Interconnection points considered: Cape Cod - Bourne/Barnstable (Massachusetts): 2,400 MW; Brayton Point (Massachusetts): 1,600 MW; Montville (Connecticut): 800 MW; Kent County/Davisville (Rhode Island): 1,000 MW; and Mystic (Massachusetts): 1,200 MW.

Analysis conducted: The economic study provides information on system performance, estimated production costs, load-serving entity (LSE) energy expenses, transmission congestion, and environmental emission levels.

Tools used: ABB GridView (New-England-constrained single area) for hourly, Dartmouth College's Electric Power Enterprise Control System (EPECS) simulation tool for 1-minute operating reserves and regulation.

Summary of findings:

- There's significant potential for spilling offshore wind energy—primarily a temporal mismatch between offshore wind generation and electricity demand.
- Minimal upgrades are needed, up to 5,800 MW OSW. Significant upgrades at higher levels if in south New England (~$1 billion per 1,200 MW). If HVDC is used to Boston, an additional 2,200 MW can be added without significant upgrade.
- Offshore wind energy does not provide a steady supply of electricity in the high-demand months of July and August.

NE2 -2019 Economic Study: OSW Transmission Interconnection Analysis (Anbaric)

Published: October 5, 2020, by ISO-NE.

Purpose: Economic Study requested by Anbaric Development Partners, LLC to consider the interconnection of 8,000, 10,000, and 12,000 MW of offshore wind energy including from an offshore collection substation directly to the Mystic substation in Boston, Massachusetts. Anbaric requested additional interconnection cases that spread offshore wind along the Connecticut shore, but these cases were not studied to increase study efficiencies and focus on optimal injection locations. The study aim is for the results to inform developers, consumer interest groups and advocates, policymakers, and regulators and be useful as they develop strategies to meet the region's renewable energy goals.

Study year: 2030.

Time increments: One year, 8,760 hourly, augmented with 1-minute analysis during low-load operation.

Data used: 2015 wind, solar, and load profiles (scaled to 2030). Energy storage (i.e., pumped storage and batteries) are used to level the load. The net loads reflect adjustments to account for all energy efficiency, active demand resources, all photovoltaic (behind the meter [BTM] and non-BTM), plug-in hybrid electric vehicles, wind energy, hydropower (excluding pumped storage), and imports.

Geographic region: ISO-NE system.

Offshore wind region: The BOEM lease areas, off the shores of Massachusetts and Rhode Island, and in wind energy areas on the Outer Continental Shelf.

Offshore wind integration level: Wind projects under development at the time of the request, including Vineyard Wind (800 MW) and Revolution Wind (200 MW). Three offshore wind penetration scenarios: 8,000 MW, 10,000 MW, and 12,000 MW. In addition, a no new offshore wind reference case was developed. The 10,000-MW level was considered with and without electrification.

Transmission options considered: Offshore HVAC and HVDC were evaluated using generic routing.

Interconnection points considered: Cape Cod - Bourne/Barnstable (Massachusetts): 3,400 MW; Brayton Point (Massachusetts): 1,600 MW and 2,600 MW; Montville (Connecticut): 800 and 1,300 MW; Kent County/Davisville (Rhode Island): 1,000 and 1,500 MW; Mystic (Massachusetts): 1,200 and 2,200 MW; and Millstone (Connecticut): 1,000 MW.

Analysis conducted: The economic study provides information on system performance, such as estimated production costs, LSE energy expenses, transmission congestion, and environmental emissions.

Tools used: ABB GridView (New-England-constrained single area) for hourly, Dartmouth College's EPECS simulation tool for 1-minute operating reserves and regulation.

Summary of findings:

- The incremental savings in production costs are less than $100 million per each 2,000 MW of additional offshore wind capacity in the 10,000-MW and 12,000-MW offshore wind scenarios.
- As more offshore wind energy is interconnected into southeastern Massachusetts, spillage increases because of oversupply. The retirement of large baseload generation would lower spillage. In one scenario, the increased electrification and installation of more storage in areas with a large amount of offshore wind energy development would reduce congestion of the southeastern Massachusetts/Rhode Island export interface compared with installing storage resources elsewhere.

NE3 - 2020 Economic Study: OSW Transmission Interconnection Analysis (Nat Grid)

Presentations: Planning Advisory Committee April 23, 2020, May 20, 2020, June 17, 2020, July 22, 2020, November 19, 2020, December 16, 2020, and February 17, 2021.

Published: Analysis is ongoing. Report to be completed the second quarter of 2021 by ISO-NE.

Purpose: Economic study requested by National Grid. The study is to provide stakeholder analyses of potential pathways to best use the megawatt-hours of clean energy resources to meet state goals cost-effectively, leveraging transmission and/or storage as needed. Evaluate economic benefits of transmission/storage deployment, using existing and new ties to reduce renewable spillage, and assess changes to thermal dispatch. Study allows for bidirectional flows with Canada.

Study year: 2035.

Time increments: One year, 8,760 hourly.

Data used: 2015 wind and solar profiles. Load from 2020 Capacity, Energy Loads, and Transmission using 2029 (scaled to 2035). Load components that are impacted by weather use 2015. The net loads reflect adjustments to account for all energy efficiency, active demand resources, all photovoltaic (BTM and non-BTM), plug-in hybrid electric vehicles, wind energy, hydropower (excluding pumped storage), existing imports, and new imports.

Geographic region considered: ISO-NE system and interchange with Canada.

Offshore wind region considered: As in the NESCOE 2019 study NE1.

Offshore wind integration level: 8,000 MW, as in the NESCOE 2019 study - NE1.

Transmission options considered: New tie line to Canada.

Interconnection points considered: Not specified. Previous NESCOE study for 8,000 MW- NE1.

Analysis conducted: Study examined transmission system and wholesale market impacts associated with adding storage and allowing energy banking in Canada. Study included increased electrification. Provides information on system performance, such as estimated production costs, energy storage utilization, and renewable curtailments. Ancillary service simulations were not conducted but instead will be part of the Future Grid Reliability Study Phase 1.

Tools used: ABB GridView (New-England-constrained single area) for hourly.

Summary of findings:

- Large oversupply of New England renewables.
- Energy banking significantly reduces spilled energy. Reduction in imports.
- Removing battery storage improves utilization of pumped storage.

NE4 - 2021 Economic Study & Future Grid Reliability Study Phase 1: NEPOOL

Presentations: New England Power Pool (NEPOOL) Participants Committee Presentations on February 18, 2021 and Planning Advisory Committee April 14, 2021, May 19, 2021, June 16, 2021 (assumptions and production cost results), and July 22, 2021 and Markets and Reliability Committee February 26, 2021.

Published: Analysis is ongoing. Report to be completed in second quarter of 2021 by ISO-NE.

Purpose: Economic study requested by NEPOOL to better understand the implications of the substantially changed future grid including how the New England power system could operate with current state energy and environmental policies. Specifically, to examine whether revenues from the existing markets will likely be sufficient to attract and retain the new and existing resources that will be needed to continue to operate the system reliably. The study will also identify what operational and reliability challenges needs to be addressed in the future grid and identify possible solutions.

Study year: 2040.

Time increments: One year, 8,760 hourly, augmented with 1-minute analysis during low load.

Data used: 2019 weather year, wind, and solar profiles. Load from 2021 Capacity, Energy, Loads, and Transmission .

Geographic region considered: ISO-NE system.

Offshore wind region considered: The primary locations of new offshore wind resources were in BOEM lease areas, off the shores of Massachusetts and Rhode Island, and in wind energy areas on the Outer Continental Shelf. As in NESCOE 2019 Study - NE1.

Offshore wind integration level: 8,000 MW to 17,000 MW; 7,200 MW–1,200 MW at each of the following: Cape Cod, Boston, Seabrook, Wyman, Bar Harbor, and Calais. Existing DNV-GL sites in the BOEM lease area off Martha's Vineyard and Nantucket. Includes fixed-bottom and floating offshore wind technologies.

Transmission options considered: Not specified.

Interconnection points considered: Not specified.

Analysis conducted: Economic study included production cost and ancillary services to forecast market revenue sufficiency. Engineering analysis included ancillary services, resource adequacy, and probabilistic availability and system security to determine under what conditions operational or reliability issues occur.

Tools used: ABB GridView (New-England-constrained single area) for hourly and EPECS simulation tool for 1-minute operating reserves and regulation. Probabilistic – Multi-Area Reliability Simulation Software Program.

Preliminary results:

- Scenario 1: Renewable oversupply in 11% of hours. OSW energy highest curtailments.
- Unconstrained tie to Quebec for energy banking eliminates curtailments.

NE5 – Transmission Planning for the Clean Energy Transition: Pilot Study

Presentations: Planning Advisory Committee September 24, 2020, November 19, 2020, December 16, 2020, January 21, 2021, June 16, 2021, and July 22, 2021.

Published: Analysis is ongoing. Report to be completed in 2021 by ISO-NE.

Purpose: Pilot study to explore reliability concerns and to quantify trade-offs between system reliability/flexibility and transmission costs and to develop new assumptions for use in planning studies. Rethink transmission planning to address different system conditions driving transmission planning needs (DER, offshore wind energy, HVDC, battery energy storage system) and new approaches to data collection required for accurate modeling. Study low-inertia conditions and incorporate stability in developing transmission solutions.

Study year: 2030.

Time increments: Four different load levels will be examined: two summer peak-load scenarios (maximum consumption, maximum net load) and two spring minimum-load scenarios (minimum consumption, minimum net load).

Data used: Forecasted 2030. Load from 2020 Capacity, Energy, Loads, and Transmission . 7,800 MW distributed solar. New HVDC to Quebec.

Geographic region considered: ISO-NE system.

Offshore wind region considered: All future generation projects with forward capacity market commitments or with financially binding contracts in place or under negotiation.

Offshore wind integration level: 3,100 MW.

Transmission options considered: Not specified.

Interconnection points considered: Vineyard (800 MW at Barnstable 115 kilovolts [kV]), Revolution (704 MW at Davisville 115 kV), Mayflower (804 MW at Bourne 345 kV), Park City (790 MW at West Barnstable 345 kV).

Analysis conducted: Engineering analysis included steady state single contingency (n-1) and stability. Eastern Interconnection Planning Collaborative to conduct frequency analysis across the entire Eastern Interconnection.

Summary of findings:

- Steady state. High voltage with high renewables, lack of synchronous generation on-line to control voltage. Bulk transmission overloads in some scenarios—these can be relieved by reducing generation.
- Stability. Indicated need for additional dynamic devices (likely synchronous condensers).
- DERs. Faults on 115 kV or lower lines and line-to-ground faults have longer clearing times and result in higher DER tripping. Photovoltaic outages can be as high as 1,850 MW, which exceeds the single largest generator outage. New England could impact New York and PJM. Temporary 5,300 MW DER reduction until voltage is restored. Need for transmission voltage support.

NE6 - 2050 Transmission Study for New England States

Presentations: NEPOOL Participants Committee Presentations on February 18, 2021.

Published: Analysis is initiating. Report to be completed by ISO-NE.

Purpose: Request by NESCOE. NESCOE vision statement seeks a transmission study that can help states determine how to expand the system to incorporate wind, hydropower, and DERs. Develop high-level transmission scenarios to evaluate large-scale renewable energy integration and cost estimates.

Study year: 2050.

NE7 - Pathways Evaluations: Forward Clean Energy and Carbon Pricing Studies

Presentations: NEPOOL Participants Committee Presentations on February 18, 2021.

Published: Analysis is initiating. Report to be completed in the first quarter of 2022 by ISO-NE.

Purpose: Stakeholder effort to review market frameworks that may help evolve the future power grid to reflect states' policies.

Study year: 2040.

NE8 - Future Grid Reliability Study Phase 2

Presentations: NEPOOL Participants Committee Presentations on February 18, 2021.

Published: Analysis awaiting other ongoing studies. Report to be completed by ISO-NE.

Purpose: Study that contemplates whether revenues from existing markets could be sufficient to attract and retain the new and existing resources necessary to continue operating the system reliably (resource adequacy) under stakeholder-defined scenarios.

Study year: 2040.

Analysis conducted: Transmission system security: thermal, voltage, and stability analysis. Revenue sufficiency analysis.

MA: Massachusetts Department of Energy Resources Offshore Wind Study

Published: May 2019 by Massachusetts Department of Energy Resources and Levitan & Associates.

Purpose: To analyze the cost-effectiveness of an additional 1,600 MW of offshore wind energy, the optimal timing of any future procurements, and other impacts on the environment and economy from the growth of offshore wind in Massachusetts.

Study years: 2025–2030.

Analysis conducted: Stakeholder outreach and quantitative energy sector modeling.

NY1: Initial Report on the New York Power Grid Study: Appendix D - Offshore Wind Integration Study Final Report

Published: December 2020 by DNV GL, PowerGEM, and WSP Global for New York State Department of Public Service (NYDPS) and New York State Energy Research & Development.

Purpose: A study of offshore and onshore bulk-power transmission infrastructure scenarios, and related environmental permitting considerations, to illustrate solutions to integrate 9,000 MW of offshore wind energy. Identify points of interconnection. Compare radial versus networked offshore transmission. Assess transmission reliability during summer high loads.

Study year: 2035.

Time increments: One year, 8,760 hourly.

Data used: NYISO—load flow models, including base dispatch profiles, NYSERDA—hourly zonal demand profiles, offshore wind profiles, onshore wind profiles, and solar profiles. Colocation of 1,700 MW of battery storage at the New York City area and Long Island substations.

Geographic region: New York.

Offshore wind region: New York City and Long Island.

Offshore wind integration level: 9 gigawatts (GW).

Transmission options considered: Radial and meshed.

Interconnection points considered: New York City: Farragut (1.4 GW), Rainey (1.25 GW), Mott Haven (1.25 GW), West 49th St. (1.2 GW) and Long Island: New Bridge (600 MW), Shore Rd. (500 MW), Northport (400 MW), Syosset (300 MW), Brookhaven (270 MW), Ruland (970 MW) and East Garden City (300–915 MW).

Analysis conducted: Production cost, power flow and steady-state reliability security analysis.

Tools used: PowerGEM, PROBE LT software. PowerGEM Transmission Adequacy and Reliability Assessment (TARA) software.

Summary of findings: Integrating 9,000 MW of offshore wind generation by 2035 is achievable without major onshore bulk transmission upgrades beyond expanding Long Island bulk transmission links and local upgrades in New York City. Interconnecting a maximum amount of offshore wind in the New York City area would be advantageous given the large load and strong bulk transmission system. However, overcoming cable routing limitations in New York Harbor, space constraints in substations on Manhattan, and permitting complexities in both the harbor and along the Long Island coastline (including approaches to New York City through the Long Island Sound) will require careful planning of offshore wind transmission cable routes and points of interconnection. Creating the option for a meshed offshore network by linking the offshore substations of several individual offshore wind power plants near each other is valuable because a meshed configuration can achieve a more reliable and resilient delivery of offshore wind energy generation.

NY2: Offshore Wind Policy Options Paper

Published: January 29, 2018, by NYSERDA.

Purpose: To explore transmission and interconnection procurement strategies by taking into consideration timing mismatch risk between the construction of generation and transmission systems, delivery responsibility (liability in case of inability to deliver offshore wind energy generation due to constraints or failures in the transmission and interconnection [T&I] infrastructure), cost of financing, cost recovery mechanism (through transmission or supply charges), and policy implementation practicalities.

Study year: 2018 and 2019.

Time increments: Hourly.

Data used: Capital expenditures and operational expenditures are based on offshore wind in the European market modified to reflect New York.

Geographic region: New York City and Long Island.

Offshore wind region considered: 16,740 square-mile area of the ocean from the south shore of Long Island and New York City to the continental shelf break.

Offshore wind integration level: 1%.

Interconnection points considered: N/A.

Transmission options considered: Developer-owned, independently owned, and regulated asset.

Analysis conducted: Anticipated benefits and drawbacks of transmission and interconnection procurement options.

Tools used: Integrated Planning Model, PROMOD, and Co-Benefits Risk Assessment.

Study assumptions and scenarios: Analysis is limited to the "wet transmission," which includes the onshore substation, offshore substation, and export cable. NYSERDA limits its assessment of Phase I procurement options to "direct radial" structures. NYSERDA expects that procurement options would be expanded during Phase II to include evaluation of the feasibility of "backbone" to serve future projects.

Summary of findings:

- Developer-owned transmission and interconnection provides the most easily implementable and feasible option for Phase I of offshore wind development in New York.
- Transmission and interconnection, as a regulated asset, could unlock moderate cost benefits through lower cost of finance, which potential benefits must be weighed against significant implementation challenges, including around the scoping of offshore wind T&I projects to ensure eligibility as regulated assets, potentially cumbersome and untested procurement processes, and issues related to construction timing risk and energy delivery risk.
- Phase I procurement to proceed based on direct radial transmission and interconnection infrastructure, but projects could be scoped as network projects to serve multiple offshore wind energy projects, should this be considered preferable.
- NYSERDA recommends that a stand-alone obligation like the zero-emission credit requirement would be most suitable. Offshore wind procurement quantities should be set separately from the renewable energy standard Tier 1 procurement targets, or the aggregate of the Tier 1 procurement and offshore wind procurement volumes would be increased. New York State's LSEs must purchase zero-emission credits from NYSERDA each year, based on an LSE's proportional amount of statewide load. (See more on LSE obligations under the Clean Energy Standard.)

NY3: Offshore Wind Transmission: An Analysis of Options For New York

Published: August 6, 2020, by The Brattle Group for Anbaric.

Purpose: To compare potential costs and benefits of OSW transmission options: 1) project-specific approach and 2) "planned" approach with independent transmission development.

Study year: 2026 and 2035 for production simulation.

Time increments: One year, 8,760 hourly.

Data used: Wind and solar units within NY were modeled with hourly generation curves based on 2016 CARIS and represented as zero cost and must-take energy, with a provision for curtailment.

Geographic region considered: New York. The study evaluated the impact of offshore wind energy on the NY Bulk Power System in the ConEd and PSEGLI regions for facilities rated 69 kV and higher.

Offshore wind region considered: New York.

Offshore wind integration level: 9 GW in phases: 1,826 MW, plus 2,400 MW, and plus 4,785 MW.

Transmission options considered: Projects already selected proceed as planned using project specific approach while the two transmission approaches are compared for future development. HVAC lines.

Interconnection points considered: Holbrook (880 MW), Deepwater (136 MW), Gowanus (880 MW, 1,200 MW), Rainey (1,200 MW), Ruland Rd (1,200 MW), East Garden City (1,100 MW), Fresh Kills (1,700 MW), Brookhaven (1,200 MW), and Barrett (1,184 MW).

Analysis conducted: (a) solo injection–power flow models measuring the injection capability for offshore wind energy at selected POIs with no other offshore wind in service, (b) evaluate potential for larger-sized offshore wind interconnections, (c) evaluation of offshore wind sequence of development (e.g., energy resource interconnection service, associated system upgrade facilities, capacity resource interconnection service, and associated system deliverability upgrades; planned and unplanned development sequences), and (d) production simulation to show how much offshore wind energy fits in a load duration curve and how much wind gets dispatched across seasons.

Tools used: Steady-state power flow solution and contingency analysis were used to determine the thermal impact of the offshore wind injection on the underlying system. PowerGEM's TARA software. The security-constrained redispatch function of TARA was utilized in performing the analysis in addition to normal AC contingency analysis. No reliability must-run generators were designated. Generation production simulations were performed with ABB-Hitachi's Gridview software.

Summary of findings:

- Cost differential analysis: Planned approach estimated to reduce total transmission costs by at least $500 million, not counting additional competitive benefits.
- Utilization of POI: Planned transmission maximizes offshore wind integration with efficient utilization of POIs, whereas the project specific approach risks limiting ability to meet clean energy standards cost-effectively.
- Environmental impact: Planned transmission significantly reduces the impact on the fishing industry, coastal communities, and marine environments.
- Curtailments: Curtailment challenges were identified that need to be addressed to reduce developer risk from future projects.

NY4: New York's Evolution to a Zero-Emission Power System

Published: June 22, 2020, by The Brattle Group for NYISO stakeholders.

Purpose: To simulate the resources that can meet state policy objectives and energy needs through 2040 to inform separate inquiries into reliability and market design issues.

Study years: 2024, 2030, 2040.

Time increments: Hourly operations across 30 representative days in 2024, 2030, and 2040.

Data used: Load forecasts from Climate Change and Resilience Study – Phase I, Installed Capacity Working Group, December 17, 2019. Gross load forecasts exclude BTM solar generation.

Geographic region considered: New York.

Offshore wind region considered: New York.

Offshore wind integration level: 25 GW = 34% New York load in 2040.

Transmission options considered: Zonal pipe and bubble topology.

Interconnection points considered: Not specifically identified.

Analysis conducted: Capacity expansion. Production cost.

Tools used: GridSIM: Designed to simulate highly decarbonized systems; detailed representation of New York power system and NYISO markets; co-optimized modeling of energy, ancillary, and capacity markets. Chronological commitment and dispatch to robustly model storage.

Summary of findings:

- More capacity, including 11 GW additional offshore wind, needed to support electrification and renewable natural gas production.
- Reference and electrification cases diverge starting in 2030; before then two cases are similar.
- Today, transmission flows are primarily southbound, transferring power from upstate to downstate. In the future, flow patterns become more variable, with flows occasionally reversing direction. The frequency of constrained hours southbound generally increases.

Study gaps: Predictable and unpredictable changes in net load may also create ramping challenges requiring flexibility, but this is not addressed in this study.

NY5: New York State Offshore Wind Master Plan - Cable Landfall Permitting Study

Published: November 2017 by Ecology and Environment Engineering, Inc. for NYSERDA.

Purpose: To provide analysis of the potential onshore and nearshore opportunities and environmental, physical, and social constraints to be considered when siting future cable landfall sites. This study is intended to provide a baseline for initiating site-selection and routing processes, reduce project planning costs, and facilitate future onshore permit application processes.

Data: Publicly available geospatial data from a variety of federal, state, and local agency databases and websites. These data were used to identify and characterize environmental, physical, and social resources in the study areas through a desktop analysis using geographic information systems (GIS). In addition to utilizing publicly available geospatial data, several resource-specific public databases were used to obtain information on resources located within the study areas where GIS data were not available. These included the U.S. Fish and Wildlife Service Information for Planning and Conservation; Department of Environmental Conservation Nature Explorer; Office of Parks, Recreation, & Historic Preservation Cultural Resource Information System; and National Oceanic and Atmospheric Administration Office of Coast Survey Wrecks and Obstructions Database.

Geographic region considered: Long Island/Rockaway Peninsula area and Hudson and East Rivers/New York City area. Each area is subdivided into a shoreline/nearshore zone and an onshore zone to facilitate a more detailed understanding of potential opportunities and constraints associated with the future siting of cable landfall sites and the routing of future onshore cables. The shoreline/nearshore zone extends a half-mile landward from the shoreline and 1,000 feet seaward from the shoreline.

Interconnection points considered: N/A.

Offshore wind region considered: New York.

Analysis conducted: A desktop analysis of relevant and available geospatial data and online databases.

Summary of findings: For Long Island area, five resources are associated with hard potential constraints (publicly owned lands, local zoning, marine infrastructure and uses, sediment/soil types/steep slopes, and areas of contamination), and four are associated with soft potential constraints (Indigenous Nations lands/rights of ways/conservation easements, threatened and endangered species, other sensitive habitats, and wetlands/surface waters/floodplains). Six resources are associated with constraints related to the creation of avoidance, and three resources are associated with constraints due to added costs (marine infrastructure, other sensitive habitats, and wetlands, surface waters, and floodplains). NYC area has five resources with hard potential constraints, and four with soft potential constraints). Two of the resources—coastal zone and cultural resources—would be associated with both hard and soft potential constraints because of the specific elements within those resource headings. Eight resources are associated with constraints because of time, six are associated with constraints related to avoidance areas, and three are associated with constraints resulting from added costs. Three resources in NYC area have opportunities for either siting a cable landfall site or routing a future onshore cable from the cable landfall to a substation.

NY6: 2019 CARIS Report: Congestion Assessment and Resource Integration Study

Published: July 24, 2020, by NYISO.

Purpose: The objectives of the economic planning process are to:

- Project congestion on the New York State Bulk Power Transmission Facilities over the period 2019–2028
- Identify factors that produce or increase congestion
- Provide a process whereby projects to reduce congestion are evaluated on a comparable basis in a timely manner, considering the process for regulated transmission projects for cost recovery with the NYISO tariff
- Provide an opportunity for developing market-based solutions to reduce identified congestion
- Coordinate ISO's congestion assessments and economic planning process with neighboring control areas.

Study years: 2019–2028. Time increments: hourly of each year from 2019 through 2028.

Data used: The concurrent load and capacity forecast was based on the 2019 Gold Book and accounts for the impact of programs such as the Energy Efficiency Portfolio Standard.

Geographic region: New York.

Offshore wind region: New York City and Long Island.

Offshore wind integration level: 8% (6,098 MW).

Transmission options considered: Adding transmission lines.

Interconnection points considered: Central East, Volney-Scriba, Central East-Knickerbocker.

Analysis conducted: Production cost.

Tools used: GE-MAPS.

Summary of findings:

The following renewable resource regions were found, each with constrained transmission pockets:

- Western New York: Constraints mainly 115 kV in Buffalo and Rochester areas
- North Country: Constraints include the 230-kV and 115-kV facilities in North Country
- Capital Region: Eastern New York constraints are mainly 115-kV facilities in the Capital Region
- Southern Tier: Constraints are mainly the 115-kV facilities in the Finger Lakes area
- Offshore Wind: offshore wind generation connected to New York City and Long Island .

In this 70-by-30 scenario, ~ 11% of the annual total potential renewable energy production of 128 terawatt-hours is curtailed. Generation pockets result from both the existing and added renewable energy. Within the four major pockets that are observed for land-based renewable resources, constrained transmission subpockets arise. North Country pockets exhibit the highest level of curtailment by percentage, the highest curtailed energy by gigawatt-hour, and the most frequent congested hours in the bulk power and local system levels. Two additional pockets in areas of offshore wind energy connecting to New York City and Long Island due to transmission constraints on the existing grid after the power is onshore. The solutions studied for the top three congested transmission corridors decreased congestion and saved money.

NY7: Offshore Wind Injection Assessment

Presented: December 1, 2017, by NYISO for New York State Department of Public Service.

Purpose: To determine a sample set of injection points into various locations in New York City and Long Island that can accommodate the injection of 2,400 MW of offshore wind energy without thermal violations.

Study year: 2030.

Time increments: N/A.

Data used: Transmission and generation resources were modified based on NYDPS/NYSERDA inputs to approximate year 2030. Summer peak and summer light load conditions based on 2016 Gold Book.

Geographic region considered: New York.

Offshore wind region considered: Injection locations in New York City and Long Island.

Offshore wind integration level: 3% (2.4 GW).

Transmission options considered: Flexible vs. fixed offshore wind dispatch.

Interconnection points considered: Those in New York City and Long Island.

Analysis conducted: Injection assessment with focus on whether thermal violations occur.

Tools used: Models were developed from the NYISO 2016 Reliability Needs Asset representation of 2022.

Study assumptions and scenarios: Injection locations in New York City and Long Island were selected by NYDPS staff and NYSERDA to serve as proxy injection points for this assessment. The assessment only evaluated the impact of injecting offshore wind energy on bulk power transmission facilities, with a focus on thermal violations. To inject 2,400 MW into the various points, the power output from existing generators must be reduced to maintain the balance of generation and load within the model. Flexible and fixed offshore wind dispatch methods were used.

Summary of findings:

- Sample combinations of injection points were identified that would not cause thermal violations on bulk power transmission facilities .
    - Other combinations are also possible
    - It is feasible to integrate 2,400 MW of offshore wind energy from a thermal bulk transmission security perspective.

Study gaps: This is not an interconnection study. System- and substation-specific upgrades will be identified based on project proposals in the interconnection process.

The assessment did not review:

- Thermal impacts to non- bulk power transmission facilities
- Voltage or stability impacts
- Deliverability of year-round energy or capacity to loads
- Operability and expandability of the transmission system
- Impact to the New York system reserve margin.

PJM: PJM Offshore Transmission Study Group

Published: Study is being scoped; results expected in later 2021 by PJM Transmission Expansion Advisory Committee.

Purpose: Analyze and identify regional transmission solutions to accommodate the coastal states' offshore wind energy goals.

Study year: 2027, 2035.

Geographic regions: PJM.

Offshore wind region considered: PJM (Delaware, Maryland, North Carolina, Virginia, New Jersey).

Offshore wind integration level: 9 GW (2027) to 19.6 GW (2035).

Transmission options considered: considering regional transmission solutions.

Interconnection points considered: Unknown POI assumption.

Types of study conducted: To be determined (TBD).

Tools used: TBD.

Study assumptions and scenarios:

- Assess the impact to the PJM transmission system
- Identify system upgrades on a regional basis
- Estimate costs and timelines
- Identify regional transmission solutions and associated costs including any overlap between state boundaries
- Demonstrate how PJM's State Agreement Approach can be used as a complementary process to the generator interconnection process.

NJ - Offshore Wind Transmission Study Comparison of Options

Published: December 29, 2020, by Levitan & Associates for New Jersey Board of Public Utilities.

Purpose: To evaluate the range of commercial, technical, environmental, and operational advantages/disadvantages of offshore wind transmission options including radial, ocean grid, and power corridor designs that integrate New Jersey's offshore wind energy target of 7,500 MW through 2035.

Study year: 2035.

Geographic region considered: New Jersey.

Offshore wind region considered: Ocean Wind, Atlantic Shores, and Garden State lease areas plus at least one large offshore wind project in either Equinor's remaining lease area or the proposed Hudson South lease area.

Offshore wind integration level: 7,500 MW.

Transmission options considered: Offshore HVAC and HVDC were evaluated using generic cable routing.

Interconnection points considered: Specifics not determined. Included in PJM two-phase study.

Analysis conducted: Capital cost comparison of transmission designs, project risk analysis, environmental impacts during construction and operation, technology risk, cable reliability, losses.

Summary of findings:

- By soliciting competitive transmission solutions through the state agreement approach (SAA), New Jersey can encourage innovative and cost-effective transmission projects.
- Centrally led transmission development with strong oversight can be appropriate in early-stage OSW energy development to provide long-term grid benefits. PJM's SAA offers similar benefits.
- HVDC cable technology can transmit large amounts of power over long distances with lower losses but converters are expensive and incur their own losses.
- Inexpensive headroom at coastal POIs will be depleted in early procurement rounds, leaving coordinated transmission developers with the same engineering and economic challenges that offshore wind applicants (with bundled generation and transmission) face.
- Ocean grid claims of extrinsic benefits, such as improving system resiliency, lowering operation and maintenance costs, reducing congestion, and lowering market energy prices have potential but may not be significant or achievable. Radial export cables would not provide extrinsic benefits. Power corridors may be able to provide some extrinsic benefits.

PJM/NJ: PJM Two-Phase Study of New Jersey Grid Injection Locations

Presented: September 28, 2020, by PJM to New Jersey Board of Public Utilities. The results of this study are confidential; however, mention of scope is described in Levitan's Report.

Purpose: To study possible grid injection locations to support NJ OSW energy targets through 2035.

Scope: Phase 1 included a screening analysis of over 100 potential in-state POIs from 138 kV to 500 kV using first contingency transfer capability analysis with 2025 regional transmission expansion plan base cases for summer, winter, and light load conditions. All the scenarios assumed the Ocean Wind project would install its own radial export cables to the BL England (138 kV) and Oyster Creek (230 kV) substations. PJM also performed a single-generator deliverability analysis to determine transmission system upgrades and costs. Phase 2 also included full contingency analyses to identify voltage issues, and high-level stability reviews. All three 7.5-GW scenarios triggered expensive upgrades, primarily to resolve thermal violations outside of New Jersey in winter conditions.

Tufts - Comments to FERC Technical Conference Regarding Offshore Wind Integration in RTOs/ISOs (Docket No. AD20-18-000)

Published: October 26, 2020.

Purpose: A review of regional transmission organization interconnection queues and the regional transmission topology. Advocates for proactive federal leadership around energy market reform, inter-RTO coordination and transmission planning, and the development of HVDC technology standards to stimulate the U.S. supply chain.

The Brattle Group - Offshore Wind Transmission: An Analysis of New England and New York Offshore Wind Integration

Published: October 23, 2020.

Purpose: Demonstrate the benefits of a planned offshore wind transmission approach with an evolution toward a meshed offshore grid.

BNOW - Offshore Wind Transmission White Paper

Published: October 2020 by Brandon W. Burke (The Business Network for Offshore Wind) and Michael Goggin and Rob Gramlich (Grid Strategies LLC).

Purpose: To outline grid and transmission recommendations to inform grid operators and U.S. policymakers in the many local, state, and federal regulatory bodies that possess some degree of regulatory responsibility for U.S. offshore wind development and electric transmission.

Key findings/recommendations:

- Proactive planning could achieve economies at scale
- Coordinate state, regional, and federal transmission planning and cost allocation
- Proactive planning over long time scales should incorporate public policy and all benefits.

NOWRDC: Tufts – Transmission Expansion Planning Models for Offshore Wind Energy

Published: Project awarded but pending scope and contract negotiations with National Offshore Wind Research and Development Consortium.

Purpose: To develop transmission expansion planning models that support the exploration of topologies for a future integrated onshore/offshore electricity grid. The new transmission expansion planning models will be based on state-of-the-art reduced bus models of the Eastern Interconnection that facilitate rapid scenario power flow, reliability, and production-cost assessments, and which the project team is currently modifying to suit this project. Develop topologies that integrate the full capacity of existing BOEM lease and call areas.

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