MAINE OFFSHORE WIND ANALYSIS

Offshore Wind Transmission Technical Review

Report to the Maine Governor's Energy Office and Maine Offshore Wind Roadmap

Date: August 2022

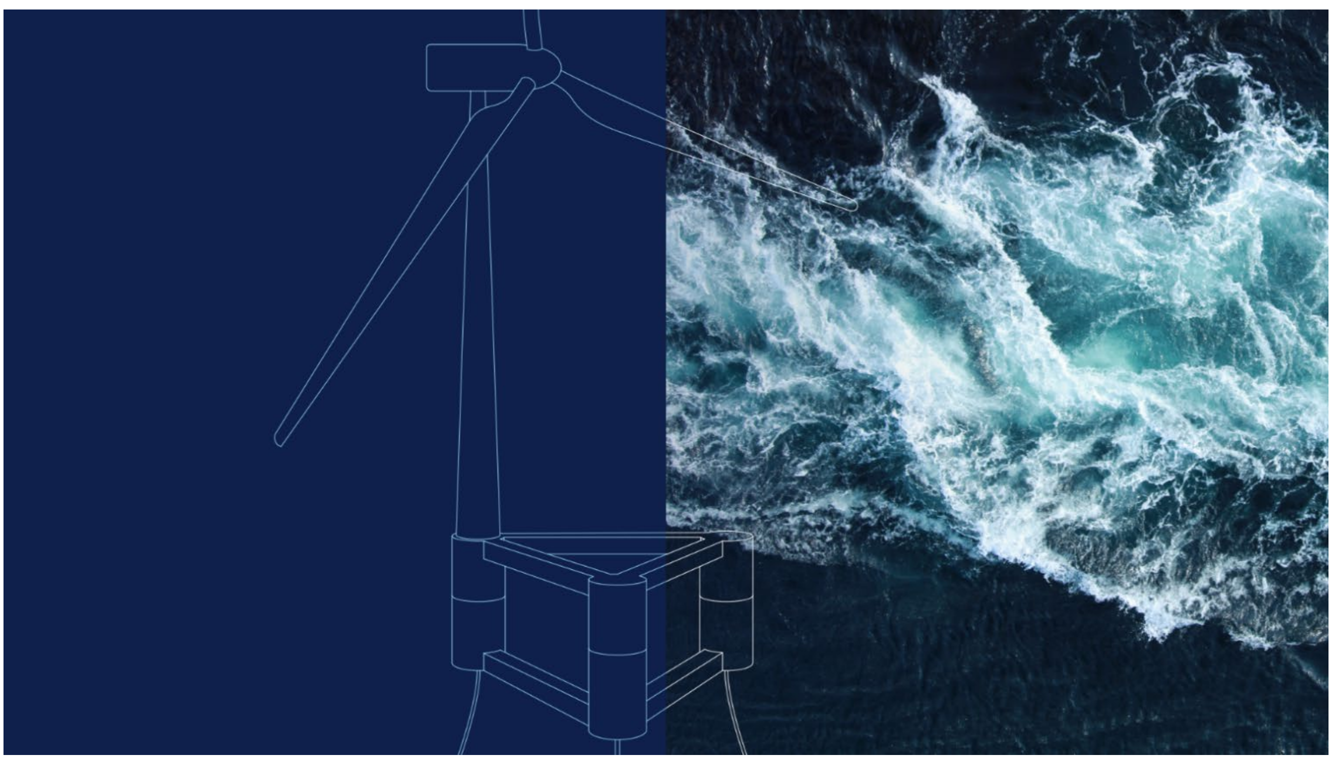

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Table 1-1. Acronyms and terms used in this report

Abbreviation	Definition
AIS	Air-insulated switchgear
BOEM	Bureau of Ocean Energy Management
CAPEX	Capital expenditures
CSC	Current-sourced converter
DOE	Department of Energy
DOER	Department of Energy Resources
EMF	Electric and magnetic field
FB	Full bridge (refers to a type of converter)
FCITC	First contingency incremental transfer capability
FERC	Federal Energy Regulatory Commission
FOWT	Floating offshore wind turbine
GIS	Gas-insulated switchgear
HB	Half bridge (refers to a type of converter)
HV	High voltage
HVAC	High voltage alternating current
HVDC	High voltage direct current
IGBT	Insulated-gate bipolar transistor

Abbreviation	Definition
ISO	Independent system operator
ISO-NE	Independent system operator-New England
MMC	Modular multi-level converter
NJBPU	New Jersey Board of Public Utilities
NOAA	National Oceanic and Atmospheric Association
NOPR	Notice of Proposed Rulemaking
NYISO	New York independent system operator
NYPA	New York Power Authority
OEM	Original equipment manufacturer
OFTO	Offshore transmission owner
OPEX	Operating expenditures
OSP	Offshore substation platform
OWF	Offshore wind farm
OSS	Offshore substations
PJM	Pennsylvania-New Jersey-Maryland Interconnection, now PJM LLC
POI	Point of interconnection
RTEP	Regional Transmission Planning Process
RTO	Regional transmission operator
SAA	State Agreement Approach
STATCOM	Static synchronous compensator
TLP	Tension leg platform
TSO	Transmission system operator
VSC	Voltage-sourced converter

1 EXECUTIVE SUMMARY

This executive summary highlights the approach and key results of DNV's offshore wind transmission technical review.

Supported by a $2.166 million grant from the US Economic Development Administration, the Governor's Energy Office (GEO) is developing an Offshore Wind Roadmap (the "Roadmap") to grow Maine's overall economy and improve its economic resilience through development of an offshore wind industry in Maine. The Roadmap is being developed by an advisory committee and four working groups with broad public input, focusing on energy markets and strategies, fisheries, environment and wildlife, and supply chain, workforce development, ports, and marine transportation.

This offshore wind transmission technical review report aims to inform the Roadmap by assessing various options for development of grid integration, including policy options, such as coordinated onshore and offshore transmission infrastructure. This includes an analysis of offshore and onshore transmission technology and design options, identification of opportunities for cost-effective, strategic approaches (including regional coordination) to develop necessary transmission assets, and identification of transmission-related best practices to mitigate impacts on people and the environment.

1.1 Key considerations for Maine and regional transmission planning

The choice of transmission technology, design, approach to planning, ownership and financing structures, and supportive policy all have an impact on the performance, cost, feasibility and environmental impacts of offshore transmission networks. In order to support the State of Maine in taking a well-informed approach to transmission planning, DNV has completed an extensive review of available, state-of-the-art transmission technologies and designs that are applied to both floating and bottom-fixed offshore wind projects and assessed their suitability for application in the future offshore transmission network serving Maine and the region.[1] The Gulf of Maine's bathymetry shows significant areas with water depths of 50 to 100 meters and vast areas with deeper water; at these depths, floating wind turbines will be necessary for commercial-scale wind project development in the Gulf of Maine.[2]

While several different approaches can be taken, these transmission considerations represent those most applicable to the State of Maine and the characteristics of the Gulf of Maine.

- **Stakeholder engagement early and often throughout transmission planning and development is critical to success.** Effective engagement should include the state, regional, and federal organizations with jurisdictional oversight for offshore transmission development, along with the development community and all affected and potentially affected parties, including fishing and ocean user communities as well as the general public.
- **Substation and cable technology choices in the Gulf of Maine are contingent upon regional and site-specific development needs and technology maturity.** The relatively large size (megawatt [MW] capacity) of the offshore wind projects anticipated in the Gulf of Maine and the potential distance of future lease areas from shore generally favors high voltage direct current (HVDC) technology over high voltage alternating current (HVAC), although it is possible to extend AC technology with additional reactive compensation and filtering measures. Floating offshore substation platforms (OSPs) are a viable choice based on Gulf of Maine bathymetry. Rapid innovation is occurring for OSPs as well as components such as dynamic high voltage cables needed to withstand fatigue due to ocean movements.
- **Future offshore wind development in the Gulf of Maine would likely employ multiple transmission designs to take advantage of geographical and resiliency benefits of project development.** Some projects would likely

[1] DNV is not involved in the ongoing offshore wind development projects in the Gulf of Maine. This report is not related to any specific project, but is designed to inform future offshore wind planning in the Gulf of Maine.

[2] Please see DNV's State of the Offshore Wind Industry Report, also developed to inform the State's Roadmap process, for additional discussion of the offshore wind industry and the various floating turbine technologies available and under development. https://www.maine.gov/energy/sites/maine.gov.energy/files/inline-files/Maine%20OSW%20DNV%20Task%201%20-%20State%20of%20the%20OSW%20Industry_Final.pdf.

connect directly to onshore points of interconnection (POIs) through bespoke or radial connections, while others would likely develop bundled and/or multi-terminal links to reduce cabling and provide offshore and onshore grid reliability benefits. Comprehensive cost benefit analyses and coordinated planning could enable state and regional entities to help determine the best transmission design approach within the context of overall long-term grid development.

- **Coordinated transmission planning is complex, but could provide an opportunity to strategically develop offshore wind in the Gulf of Maine.** The primary benefits of coordinated planning would be to ensure that the offshore transmission grid is flexible and capable of adapting with future needs and minimizing impacts on marine environments and ocean users. Coordinated planning is a complicated process that would require states and regional entities to work together and with many other stakeholders, including the regulated asset (utility) and developer communities, to best integrate offshore wind projects brought online by different entities and at different timelines as the industry matures. To date, coordinated offshore transmission has not been implemented in the United States, although some jurisdictions are exploring various approaches. Standardization of technologies and interconnection strategies is necessary to promote compatibility throughout and across multiple leasing and planning timetables. This type of approach would ideally minimize the amount of cable necessary to connect projects to the grid, thus mitigating impacts on marine environments and ocean users.
- **Offshore transmission ownership structures vary, and may have cost and deployment implications**. Regulated (such as utility or “Transco” owned) offshore transmission assets may have some advantages over merchant (developer) owned transmission. Regulated transmission structures may carry less risk to project completion, may have greater opportunities for standardization and coordination with other similar projects developed in the region, may have higher chances of allocation of costs to the wider region, and may have less cost recovery risk. Merchant owned transmission may work well for bespoke connections, and streamlined cost recovery mechanisms may minimize planning delays. Competitive, open processes tend to produce favorable financial results.
- **Selection of onshore POIs should consider numerous factors**. Key factors that affect onshore POI selection include the location of the offshore wind areas, grid reliability analyses, nearness of the substation to the shore, cost optimization of onshore and offshore cable lengths, onshore substation expandability, populated urban areas, impacts on the marine environment, and impacts on fishing and other near-shore activities.
- **Onshore grid updates may be required to provide grid reliability for the injection of significant new renewable energy, including offshore wind.** Prior state and regional analyses, as well as DNV’s high-level injection analysis in this report (Section 6), suggest that while there’s some availability, significant offshore wind development will necessitate some onshore grid upgrades to deliver energy and address grid reliability. There are ongoing studies, including at ISO-New England (ISO-NE) as well as the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) to examine grid upgrades necessary to support the integration of wind as well as other onshore resources through 2050.

2 INTRODUCTION

This offshore transmission technical review report describes offshore and onshore transmission planning, design, technologies, ownership and financing structures. This review analyzes renewable interconnection in Maine and is concluded by a set of transmission strategies potentially applicable to the state of Maine, understanding floating offshore wind farms in the Gulf of Maine would be located in deep, federal waters.

2.1 Objectives

The key objectives of this offshore wind transmission technical review report are to:

- Provide an independent review of available and emerging global transmission-related technologies and approaches
- Provide an understanding of transmission siting and interconnection locations customary for offshore wind projects, based on nearshore high voltage
- Describe the necessary steps and investment to meet onshore and offshore transmission needs associated with interconnection points, including methods of encouraging efficient transmission investment
- Consider the State's interconnection alternatives and the impact offshore wind may have on Maine's grid
- Provide best practices and state, regional, and federal planning around transmission options, including built projects, as well as those proposed but not yet developed
- Describe the potential for coordinated or regional offshore transmission infrastructure, and the associated cost and benefit impacts of those strategies
- Describe possible public and private transmission financing and ownership structures
- Recommend strategies to protect and reduce impacts to marine and environment and ocean users
- Present potential considerations to pursue transmission strategies

The results and conclusions presented herein are intended to inform the State of Maine's Offshore Wind Roadmap. DNV is not involved in the ongoing offshore wind development projects in the Gulf of Maine. This report is not related to any specific project but is designed to inform future offshore wind planning in the Gulf of Maine.

2.2 Report structure

The remainder of this assessment is structured as follows:

- Section 3 Offshore transmission technology review
- Section 4 Offshore transmission planning and design
- Section 5 Offshore transmission ownership and financing structures
- Section 6 Analysis of renewable interconnection in Maine
- Section 7 Transmission best practices to reduce impacts
- Section 8 Maine and regional transmission strategies

2.3 GEO's role

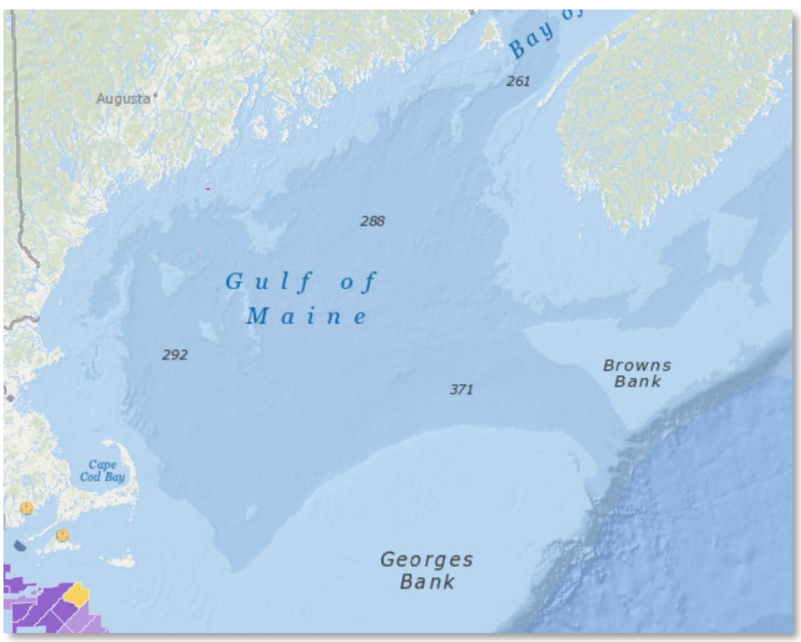
The GEO is the sponsor of this study and selected DNV to conduct this work. DNV prepared this technical review to inform current and future stakeholder work through the Maine Offshore Wind Roadmap. GEO worked with DNV to conduct initial coordination with working groups, participate in meetings between stakeholders and consultant, and prepare this report.

3 OFFSHORE TRANSMISSION TECHNOLOGY REVIEW

This offshore transmission technology review describes available and emerging offshore transmission-related technologies and approaches that may be considered for the Gulf of Maine. This includes a discussion of existing and emerging solutions for offshore substations, as well as a review of the two grid connection technologies - high voltage alternating and high voltage direct current (HVAC and HVDC) – available and under development to deliver power from the substations to the grid.

Floating wind turbines will be necessary for Gulf of Maine wind development. While nearly all existing offshore wind farms consist of bottom-fixed wind turbines, the ocean floor depth threshold for bottom-fixed turbines is typically considered to be about 60 meters (m). While it is technically possible to build bottom-fixed structures in much deeper water depths, the weight and cost of such structures increases exponentially as water depth increases, making a bottom-fixed wind farm commercially unfeasible in deep water. The Gulf of Maine has significant areas with water depths of 50 to 100 m and vast areas with deeper water (see Figure 3-1), as well as some of the best wind resources in North America. These conditions suggest that floating wind turbines will be necessary for commercial-scale offshore wind development in the Gulf of Maine.[3] Given this context, this initial report focuses on the transmission equipment likely to be used with floating turbines.

Figure 3-1. Gulf of Maine bathymetry



Source: 4C Offshore

[3] Please see DNV's State of the Offshore Wind Industry Report, also developed to inform the State's Roadmap process, for additional discussion of the offshore wind industry and the various floating turbine technologies available and under development. https://www.maine.gov/energy/sites/maine.gov.energy/files/inline-files/Maine%20OSW%20DNV%20Task%201%20-%20State%20of%20the%20OSW%20Industry_Final.pdf.

Highlights in this section

- With water depths typically between 100 m and 200 m, the federal waters of the Gulf of Maine are suited for floating turbine foundations. It is anticipated that commercial scale offshore projects will require floating offshore substation platforms (OSP) as well. These floating OSP technologies are still in development.
- In the shallowest parts of the Gulf of Maine, alternatives to floating OSPs could be considered, such as tall bottom-fixed foundations (jacket). A bottom-fixed OSP would use more proven technologies but would likely cost more due to foundation materials and installation costs.
- Regardless of OSP technology (floating or bottom-fixed), decisions must be made regarding the transmission link technology to use to connect the OSP to the grid; the two options are high voltage direct current (HVDC) or high voltage alternating current (HVAC) solutions. The choice is highly driven by distance from shore (export cable length) and the MW capacity of the offshore wind farm.
- High voltage dynamic export cables (both AC and DC) are one of the main technical bottlenecks for the implementation of floating substations. These technologies are currently under development but are expected to be commercially available as floating offshore wind technologies are deployed around the world.

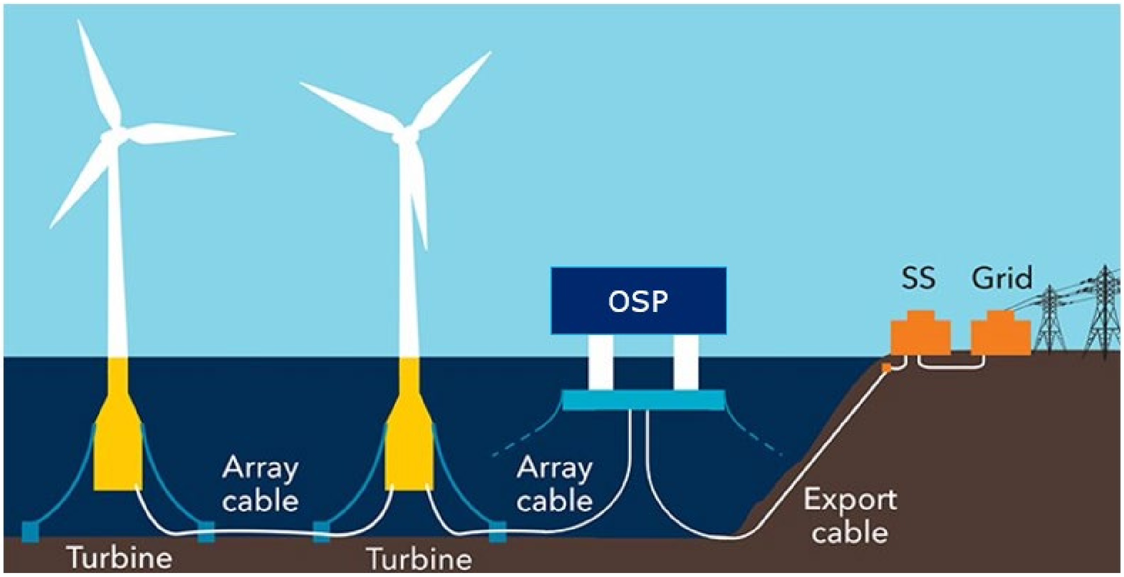
3.1 Offshore system components

Delivering offshore wind energy to an onshore grid requires various technologies and numerous pieces of equipment. As shown in Figure 3-2, the key components of a typical commercial-scale offshore transmission infrastructure (also commonly called a transmission link) include:

- **Array cables** (also commonly called inter array cables) to connect the individual wind turbines to each other and to offshore substations when necessary. These cables collect the generated energy from individual turbines and deliver it to offshore substations where the necessary adjustments will be made to transfer power to the shore. These are typically lower voltage AC cables.
- **Offshore substation platform (OSP)** that hosts the necessary equipment to export power at high voltage (HV) to the grid.
- **Export cables**, either HVAC or HVDC, typically buried under the seabed to connect the OSP to the onshore substation.
- **Onshore substation** to adjust the voltage of the electricity coming from the offshore wind development and integrate it into the onshore power grid.

This section focuses on the technologies currently available and under development for OSPs and export cables.

Figure 3-2. Typical components of an offshore wind energy transmission link for deep-water conditions*



Source: DNV
* Note: This figure shows the primary transmission components. It is not to scale and does not represent any specific project.

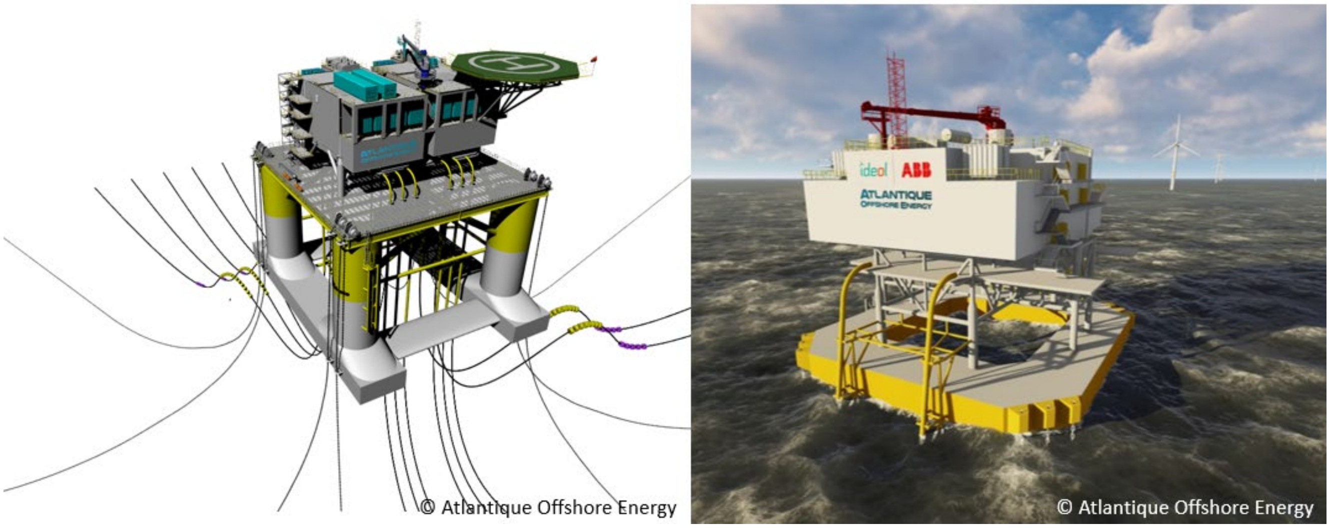
3.2 Offshore substation platform (OSP)

In recent years, floating offshore wind technologies have undergone swift development. Following the successful deployment of prototypes and demonstration projects, the industry is now transitioning to commercial projects. While demonstration projects have generated limited amounts of power that can be delivered via cables directly to shore, a commercial-scale project will require an OSP. The OSP will host a step-up transformer and the equipment necessary to export power in high voltage (HV). Like the wind turbines, the most adapted OSP concept for the water depths in the Gulf of Maine is to use a floating foundation. As of today, all the OSPs installed in the world are bottom-fixed (rigidly fixed to the sea floor) and most of them are HVAC. In recent years, offshore HVDC technology has accelerated with a few HVDC OSPs installed in the North Sea and others under development and construction, also with bottom-fixed foundations. Because no commercial scale floating windfarm has been built yet, no floating OSPs have been installed. Floating OSPs and related components face several technological challenges but those are expected to be overcome by the time of first floating windfarm construction.

3.2.1 Floating OSP

To date, the only floating OSP in the world was installed as a demonstration project in 2013 in Fukushima, Japan, and has been connected to 3 turbines. The Fukushima OSP handles a total of 16 MW and exports power at 66 kV, which is not comparable to a commercial-scale windfarm. However, floating OSPs are expected to be widely used in future floating offshore wind development, as it is typically the most viable solution for deep water.

Figure 3-3. Semi-submersible (on the left) and Barge (on the right) floating OSP concepts

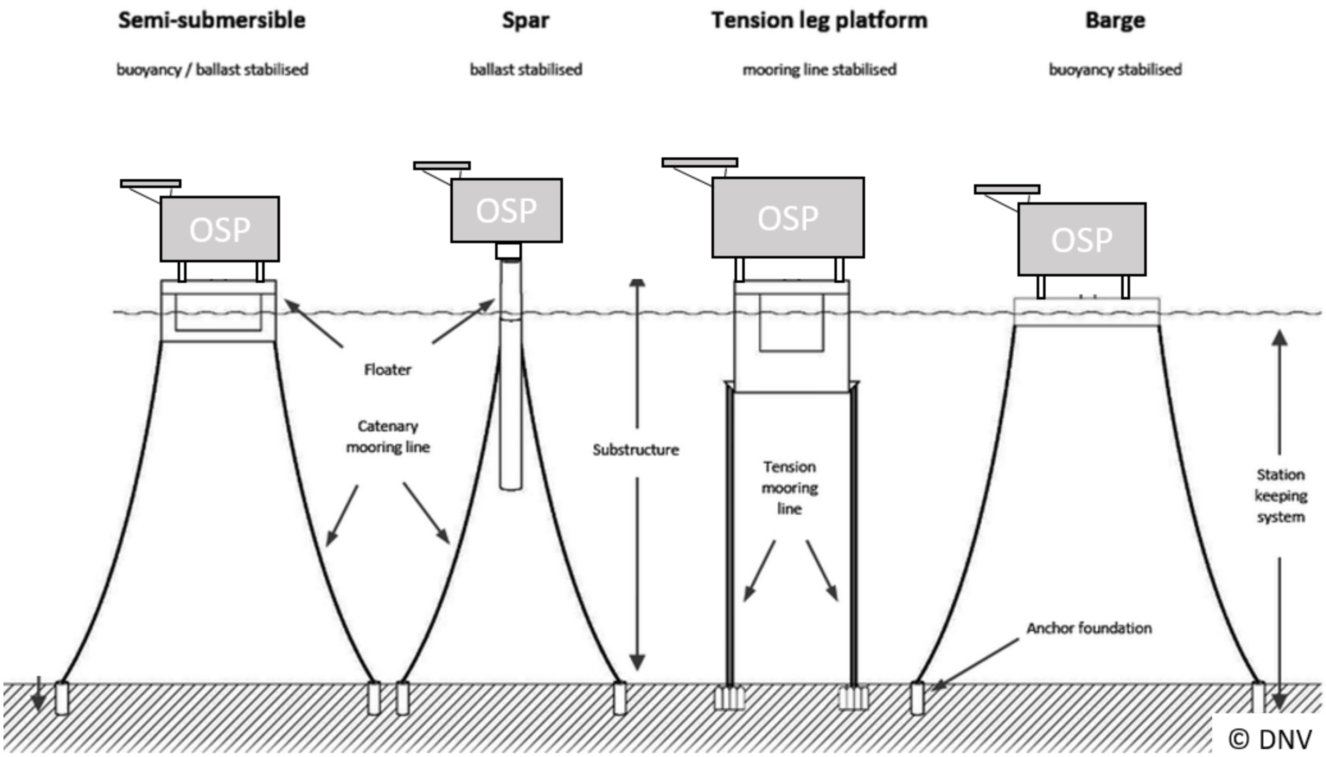


Source: Atlantique Offshore Energy

The different design concepts for floating OSP foundations are similar to those used for wind turbines: semi-submersibles, tension leg platforms (TLP), barge, and spars (see Figure 3-3 and Figure 3-4 for examples of design concepts). The barge, semi-submersible, and spar buoy are moored to the seabed with chains, steel cables, or fiber ropes connected to anchors. A TLP is vertically moored with tethers or tendons (i.e., tension legs). Very strong cables, pipes, or rods link the TLP's legs to seabed anchoring. Across all types of floating foundations, different anchor types can be used depending on the type of mooring system, soil conditions, and expected environmental loads.

The constraints of an OSP require different designs from the floating foundations used for the wind turbines. First, the OSP topside can be significantly heavier (2,000 MT to 4,500 MT or more) than a wind turbine (~1,200 MT for a 12 MW wind turbine assembly), and the weight distribution is also very different, with the OSP having a lower center of gravity. These factors directly impact the floater's stability and seakeeping, requiring different floater dimensions or even different concepts altogether. Second, an OSP has a multitude of connected subsea cables, which are sensitive to displacement and can create single points of failure.

Figure 3-4. Design concepts for floating substations



Source: DNV

3.2.1.1 Floating OSP technical challenges

While many of the components of floating OSP are proven technologies developed for the oil and gas or maritime industries, there are several technical challenges facing floating OSP development: the need for dynamic cables that can connect floating substations to fixed structures, and HV equipment capable of withstanding the stresses inducted by ocean movement. These challenges are being addressed by the equipment manufacturers and are expected to be available for the first commercial floating offshore wind developments.

To link the floating OSP to the shore, the HV export cable needs to be “dynamic,” as it will connect a moving structure (the OSP) to a fixed element (the seabed). Unlike standard HV subsea cables used for bottom-fixed offshore substations, the dynamic cables must be able to accommodate the extreme displacements of the substation during storms and have sufficient fatigue endurance to handle a lifetime of cyclic movements (>20 years). This kind of dynamic cable currently exists for voltages up to 66kV, but are still under development for the higher voltages required for power export in commercial-scale projects. One of the primary challenges faced by cable manufacturers is finding an alternative material to the lead sheaths surrounding each cable core. The lead sheath protects cable cores from moisture ingress but has poor fatigue endurance.

The repetitive movements and acceleration generated by a floating platform that is subject to wind and waves requires additional innovation in the equipment contained in the platform. This could have an impact on the HV equipment, especially the main power transformer and the high voltage gas-insulated switchgear (HV GIS). Although most of the utility systems and medium-voltage equipment have proven their reliability in the oil & gas and maritime industries, the HV GIS and power transformers currently in the market have not been designed for the repetitive accelerations anticipated onboard a floating OSP. Although the equipment is typically designed for seismic motions, this is not directly transferable to floating structures, which move with larger amplitude and have many more fatigue cycles. New innovations to address the dynamic cable and the HV equipment need to be qualified and field tested before being implemented in commercial-scale projects.

For high voltage direct current (HVDC) main transmission equipment, including power electronics and converter valves, there are major engineering challenges in designing equipment that can function and operate as intended on a floating foundation (or on a fixed foundation in deeper water with significant dynamics). This is an area of ongoing research and development in the industry, but the implementation timeline will likely include significant research efforts and have significant associated uncertainties. Floating HVDC substation technologies should therefore likely be available later than floating high voltage alternating current (HVAC) technologies, although it is expected that these technologies will be available by the time they are needed to deploy for commercial-scale floating offshore wind projects. See Section 3.3 below for deeper discussion of the differences between AC vs DC technologies.

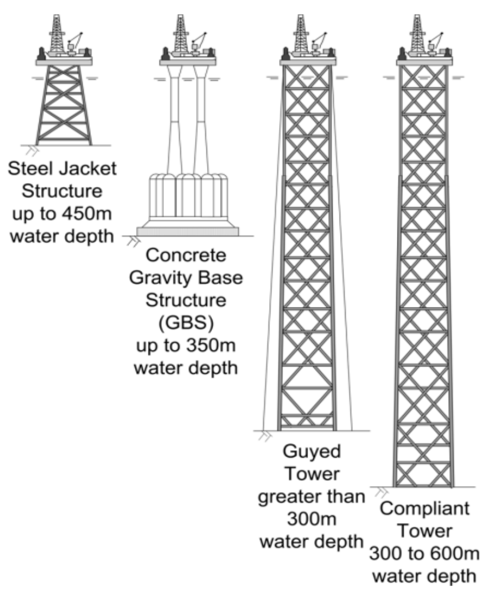
3.2.2 Alternatives to floating OSP

There are several alternatives to floating OSP, including bottom-fixed and subsea OSP concepts.

3.2.2.1 Deep water fixed foundations

A floating wind farm would typically be installed in depths greater than 60 m, where a bottom-fixed monopile or jacket would not be economically feasible due to the high material (typically steel) and installation costs that would be necessary for each of the turbines. While commercial-scale floating wind farms can include 50 or more turbines, each wind farm will likely contain only one or two OSPs, which are specifically designed and built for each project and could leverage bottom-fixed structures as an approach to mitigate some of the technical challenges mentioned in Section 3.2.1.1. While there are several technically feasible bottom-fixed solutions (see Figure 3-5) for an OSP, a bottom-fixed foundation could potentially be competitive as deep as approximately 100 m (a depth not unusual for oil & gas fixed platforms). In some areas of the Gulf of Maine, the water depths could allow for bottom-fixed substations (using tall jacket foundations), which could limit the risks and costs inherent to new technologies such as high-voltage dynamic cables or HVDC convertors.

Figure 3-5. Deep water fixed foundation types



Source: DNV

Table 3-1 provides water depth ranges for different types of offshore substation concepts. The limits shown should not be regarded as fixed values, as they would depend on factors such as topside weight, AC vs. DC, environmental conditions, soil conditions, and cost. The limits are approximate values of what is considered technically feasible and are based on DNV's experience with offshore wind and oil and gas projects.

Table 3-1. Overview of deep water fixed foundation

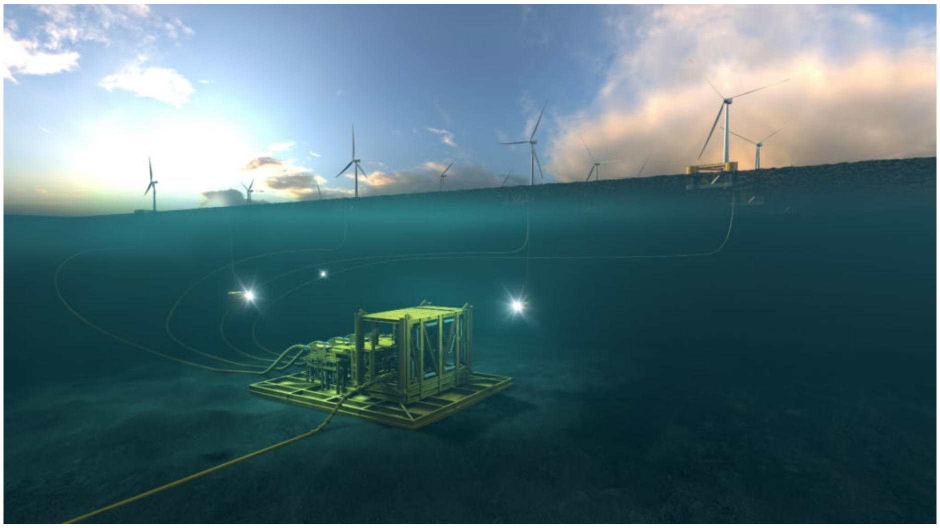
OSP concept	Approx. water depth limits	Key challenge with respect to. increased water depth	Implementation timeline (AC platforms)	Comment
Monopile	<50m	Structural capacity in foundation due to topside weight/monopile length	Available technology	
Gravity-based	50m - 150m	Fatigue capacity of topside components from structural dynamics, Cost of foundation	3-5 years (up to 100m)	
Tall Jacket	50m - 300m	Fatigue capacity of topside components from structural dynamics, Cost of foundation and installation.	3-5 years (up to 100m)	Longer implementation timeline for DC
Guyed/compliant tower	300m - 600m	Fatigue capacity of topside components from structural dynamics, Cost of foundation	5-8 years	Longer implementation timeline for DC

3.2.2.2 Subsea substations

Another concept under development for OSPs is a subsea substation, where all the substation elements are installed directly on the sea floor, underwater (see Figure 3-6). The export cable would be laid on the sea floor and would be static, as well as the HV equipment. In 2015, the world's first subsea gas compression facility Åsgard (Norway) began operating, and there has been increased interest in electrifying oil and gas installations in the recent years. This has contributed to accelerated developments within complex subsea power/processing systems, and there are research initiatives exploring the potential for developing future subsea offshore substations. Given the current research and development (R&D) stage, it is expected that many years of development, testing and qualification are still required to make such a solution viable in commercial-scale wind projects. Moreover, due to the inaccessibility of the substation, the equipment would need to reach a level of maintenance-free reliability that current technologies have not yet reached. If successfully implemented, such a solution would likely have lower capital expenditures (CAPEX), operating expenditures (OPEX), and maintenance requirements than a fixed or floating solution. Further, no dynamic export cable would be required.

Given the technology maturity for floating OSP and limited available information regarding these technologies, DNV's remaining technology review will focus on offshore transmission solutions with floating or bottom-fixed technologies.

Figure 3-6. Underwater offshore electrical substation concept



Source: Aker Offshore Wind

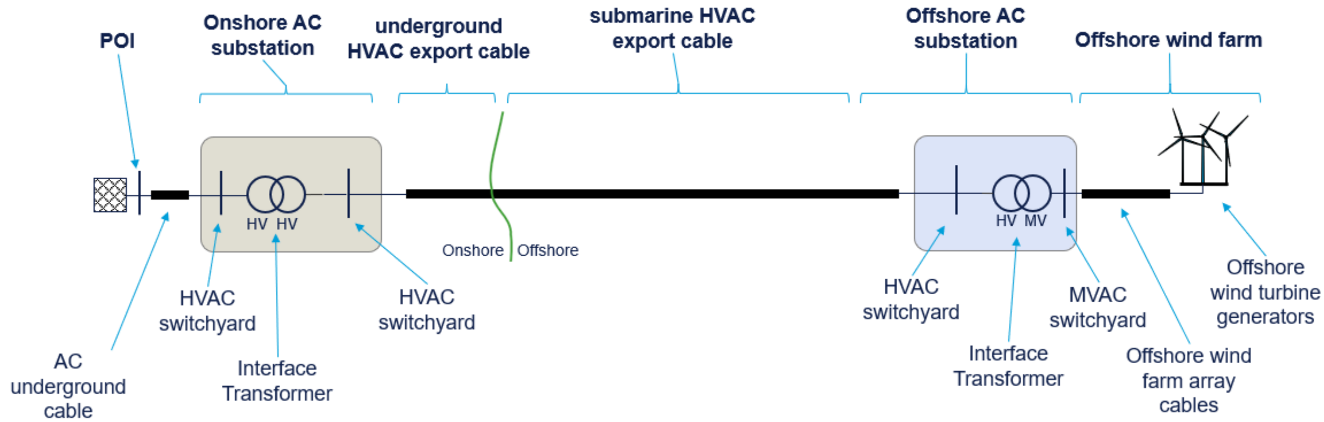
3.3 Grid connection technology (alternating current versus direct current)

Due to their marine environment, offshore wind farms are connected to the transmission grid by a submarine export cable. The export cable is typically a significant cost driver and often presents a bottleneck or single point of failure. Several cable transmission technologies are available, and this section explains the various options for alternating current (AC) and direct current (DC) technologies along with advantages and disadvantages of each choice. Both AC and DC cables are currently used in bottom-fixed offshore wind transmission links, and both will likely apply to future floating offshore wind transmission.

3.3.1 AC grid connection

In an AC grid connection solution, all the electrical components use AC technology. The AC array cables collect the wind energy from individual turbines and deliver it to the OSP, which houses the high voltage step up transformer and AC switchgears. The step-up transformer changes the array voltage from medium voltage (MV) to high voltage alternating current (HVAC) which is more suitable for power transfer. Then, the HVAC submarine export cable is utilized to deliver the power to an onshore substation (SS) which converts the voltage to the grid voltage. Depending on the length of HVAC export cables, this solution may require additional equipment that could result in additional cost, footprint and environmental impacts. Figure 3-7 provides a schematic of a typical HVAC grid connection. It should be noted the AC cable in Figure 3-7 is for illustrative purpose to show the connection. In real projects, multiple parallel AC cables might be needed to deliver the power to onshore (depending on project size and voltage level).

Figure 3-7. Typical Offshore HVAC radial link

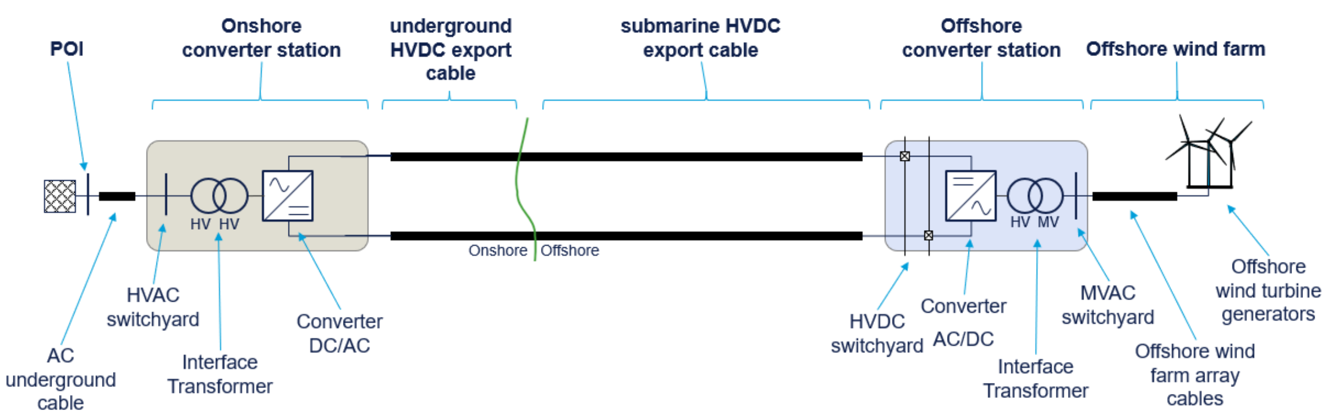


Source: DNV

3.3.2 DC grid connection

Similar to the AC solution, for DC grid connections, MV array cables are utilized to collect energy from individual turbines and deliver it to the offshore platform. In the HVDC solution, the OSP houses a converter station that steps-up the array medium voltage to high voltage and then converts it to high voltage DC. The HVDC submarine export cable delivers the power to the onshore converter station, where it is again converted to the grid voltage. Similar to HVAC, there are different configurations for HVDC transmission links with different features that may affect cost and footprints. Figure 3-8 provides a schematic of a typical HVDC grid connection solution for offshore applications.

Figure 3-8. Typical Offshore HVDC radial link



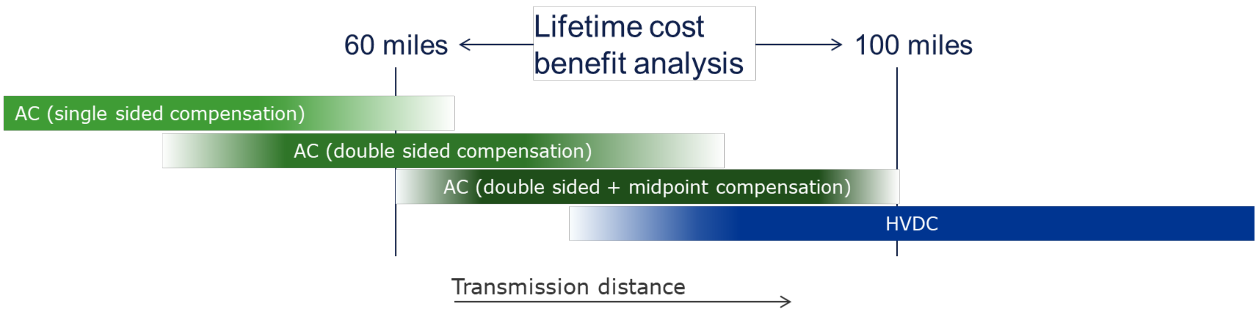
Source: DNV

3.3.3 Choosing HVAC vs. HVDC for grid interconnection

The choice of whether to use HVAC or HVDC for grid interconnection is predominantly determined by the length of the cable route to the onshore point of interconnection (POI) and the capacity of the offshore wind farm. In general, AC solutions tend to be more suitable (e.g., economic) for short transmission distances below 60 miles and capacities below 1 GW because at these specifications, the benefits of using DC such as fewer number of cables and more operational flexibility do not yet outweigh the increased cost of the required HVDC technology. Therefore, HVDC is the technology of choice for larger capacities and transmission distances longer than 100 miles. It is possible to extend the reach of AC technology from 60-

100 miles using additional compensation and filtering measures, but in this range, the choice should ideally be based on an analysis of the total lifetime cost. In almost all cases, the choice for HVDC is underpinned by limitations of AC cable technology at high capacities and long transmission distances (see Figure 3-9).[4]

Figure 3-9. Choosing AC versus DC based on transmission distance



Other aspects that can drive a choice toward DC include performance requirements of permissible electrical losses in the export cables, restrictions on the available cable corridor, onshore substation siting constraints and limitations arising from AC onshore grid integration.

3.3.4 HVDC components

As of the date of this report, HVDC equipment has been designed and qualified for implementation with a bottom-fixed platform. There are still considerable challenges facing the commercial use of HVDC technology with a floating substation. Therefore, longer implementation timelines are expected as the main transmission equipment (especially power electronics and converter valves) would be particularly sensitive to accelerations associated with dynamic structures. However, it is anticipated that the main principles of converter technology employed for bottom-fixed development will apply to floating offshore wind. Bottom-fixed converters will also still be used in onshore converter stations. It is also possible that dynamic cable technology could be used only at the termination point or for a smaller portion of export cable length, while the rest of the cabling be static submarine HVDC cables. The following subsection briefly discusses the available bottom-fixed technologies that are expected to apply to floating offshore wind transmission.

3.3.4.1 HVDC converter technology

The expected increases in offshore wind project sizes and in the distance from onshore points of interconnection, make the HVDC solution more attractive than the HVAC solution, provided that ongoing HVDC technology development continues. The HVDC converter technology is the key element that converts electricity from the AC to DC, enabling the transfer of power with high voltage direct current. There are several HVDC converter technologies and the selection of the technology is highly driven by the size of the project and commercially available ratings, application and the required functionality (e.g., black-start functionality, i.e., formation of an AC voltage), the strength of the upstream AC grid, costs, and environmental footprint. Considering the technical requirements and technology maturity, **modular multi-level converters (MMCs)** are recommended as the converter technology of choice for offshore wind connections. MMCs are the state-of-the-art voltage sourced converter (VSC) technology; they offer excellent control capabilities, low losses, a small footprint, high reliability, good scalability, and low harmonic distortion. There are several different MMC designs, distinguished by the type of submodule they use.[5]

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[4] Low-frequency AC (LFAC) systems have been proposed for long-distance cable transmission for offshore wind farms; however, these systems do not offer a significant benefit over modern HVDC technology and suffer from a very limited (or virtually non-existent) supply chain and market availability.

[5] The types of MMCs include half-bridge (HB), full-bridge (FB), and hybrid MMCs. Each has likely applications for future offshore wind HVDC transmission links.

This fully modular technology can easily be scaled to higher voltage ratings by connecting more modules in the series. Higher voltages lead to higher stresses on primary equipment, but this is not seen as a limiting factor as many entities have operational experience with different converter types ranging up to 1,100 kV, which use similar primary equipment. In Europe, MMC-voltage-source converters with voltage ratings up to 525 kV and power ratings up to 1.4 GW are in operation and power ratings up to 2 GW are qualified and in development. In Asia, ratings of 800 kV and 5 GW have been achieved. Relatively few European and Asian manufacturers are capable of supplying MMC-VSC HVDC converters.

3.3.4.2 Cable technologies

For power cables, there are several different insulation and conductor materials in use in commercial developments, a result of industry research to provide higher voltage levels and transmission capacities.

Insulation material

Paper-insulated cables are currently available for almost all AC and DC applications. The main drawback of paper-based insulation is the risk of leakage. The insulation material used is a combination of paper and oil or polypropylene laminated paper. Paper-insulated cables are available and in operation up to a voltage level of 600 kV DC.

Extruded cables are in widespread use for all AC and DC applications. Currently they are available on the market up to a voltage rating of 525 kV DC. One HVDC connection in Europe is realized with a voltage of 400 kV DC. Some manufacturers have pre-qualified (PQ tested) cable systems with a 525 kV DC rating and type tested cables with 640 kV DC rating, but so far, no project with these cables is realized yet. One of the leading extruded cable insulation technologies is cross-linked polyethylene (XLPE) insulation.

Conductor material

The two conductor materials used for energy cables are copper and aluminum. Copper conductors have a higher current rating at the same cross section, but come with a higher weight and price. If a high transmission capacity per cable is required, copper conductors are usually chosen. Most of the submarine cables have copper conductors due to aluminum's inferior corrosion resistance. In case of external faults, the radial and longitudinal water tightness cannot be guaranteed. Nevertheless, water can infiltrate the cable and damage the aluminum conductor. From a reliability perspective, there is no difference between cables with a copper or aluminum conductor.

3.3.4.3 HVDC link available rating

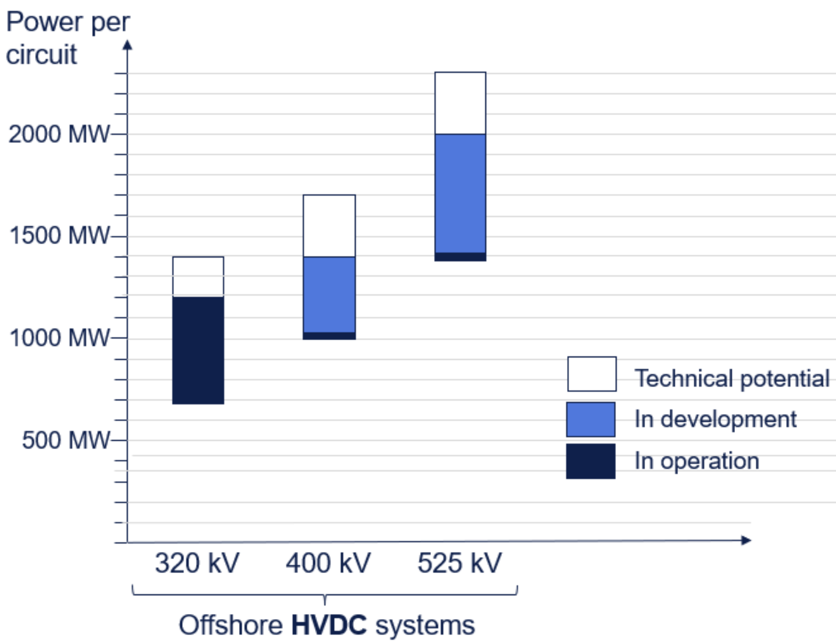
The maximum achievable power rating of an HVDC link is determined by the maximum current and voltage ratings of the converter stations and the HVDC cable. The limits for bottom-fixed HVDC OSP and static cables are shown in Figure 3-4.

Table 3-2. Limiting factors in HVDC link power ratings

	Current	Voltage	Power
MMC-VSC converter	Limited, limited by IGBT rating, 2300 A – 3000 A depending on vendor	Scalable, ±800 kV in operation	< 5 GW
XLPE cable	Limited, typically around 2000 A, subject to installation and environmental factors	Limited, ±400 kV is highest rated XLPE cable in operation, ±525 kV has been qualified	< 2 GW

The HVDC cable ratings are the limiting factor. Hence, at different voltage levels, different maximum circuit power ratings result. Some of these power ratings have already been realized in other offshore wind projects; others are currently in development. Figure 3-10 shows the HVDC ratings and claimed technical potential.

Figure 3-10. Available ratings of VSC-HVDC-based transmission technologies



Source: DNV

Cables with extruded polymer insulation (in particular XLPE) are gaining popularity, but thus far operational experience is limited to 400 kV and below. Currently 320 kV DC cables are widely used for HVDC projects. Three 320 kV HVDC offshore wind connections in Germany were successfully put into operation in 2015. Also, in the following years, several HVDC offshore and onshore projects with a voltage of 320 kV DC went in operation. Further projects with a voltage level of 320 kV DC are planned or under construction already. There is only one project in Europe in operation with a voltage level of 400 kV DC. This is the NEMO Link project between Belgium and the United Kingdom. The HVDC link has been fully operational since January 31, 2019.

In Europe, the first 525 kV systems have been fully qualified and commercially procured, but not yet put in service. Developments are ongoing up to 640 kV cable ratings, but these are unlikely to be fully qualified and accepted in the next decade. Relatively few European and Asian manufacturers are capable of supplying HVDC cable connections. Due to a large demand for HVDC cables at this time, and limited production capacity, obtaining a production slot and aligning this with the project schedule is a major concern.

3.3.5 HVAC components

As of today, the main bottleneck for using HVAC technologies with a floating OSP is dynamic HVAC cabling. While dynamic cabling exists for voltages up to 66 kV (this technology is normally used for array cables), it is still under development for the higher voltages required to export power in commercial-scale projects. One of the primary challenges faced by cable manufacturers is finding an alternative material to the lead sheaths surrounding each cable core. The lead sheath protects cable cores from moisture ingress but has poor fatigue endurance. From the perspective of a transmission original equipment manufacturer (OEM), there are fewer challenges anticipated for HVAC equipment such as HV transformers and shunt reactors with floating applications; some OEMs have announced that they already have a complete and qualified range of this equipment for floating applications.[6] As with HVDC cables, it is likely that dynamic HVAC cable technology can be used just at termination points or for some portion of export cable length, and that the rest can use static submarine HVAC cable technology. The following section focuses on this static HVAC submarine cable.

3.3.5.1 HVAC cable technology

As discussed in Section 3.3.4.2, like HVDC cables, HVAC cables are available with different types of insulation and conductor materials. In general, the real power capacity of both AC and DC cables is determined by their voltage and current rating. The current rating is based on the losses that occur in the cable, the thermal dissipation of these losses into the environment, and an upper limit on the insulation material's operating temperature. AC cables suffer from several power frequency-related phenomena that limit the effectiveness and distance over which real power can be transported. These phenomena and their associated impacts are summarized in Table 3-3.

Table 3-3. Phenomena impacting AC cable power rating

Phenomenon	Description	Impact
Skin and proximity effect	This physical effect is proportional to frequency and reduce the ampacity and thus the power rating of the cable.	Reduces cable power rating
Induced losses	The alternating magnetic field in AC cables induce eddy current in other conductive components of the cable, such as the metallic screen. These losses increase the cable temperature and therefore reduce the ampacity and power rating of the cable.	Reduces cable power rating
Capacitive charging	Due to capacitive nature of AC cables, these cables produce reactive power that reduces the cable's available real power rating. The amount of reactive power produced is proportional to cable length, and quadratically proportional to the operating voltage.	Reduces cable power rating

For HVAC cable connections, the maximum system voltage rating is limited by the state-of-the-art nature of the cable technology. Beside the voltage level, the transmission capacity is also restricted by the maximum ampacity of the cable. Technically, the maximum cross section of the cable conductor is limited. Additionally, the ampacity is influenced by the conditions of installation (e.g., laying depth, ground temperature, ground thermal resistivity). Currently available HVAC cables have a maximum capacity of approximately 900 MW at 400 kV.

3.3.5.2 HVAC link reactive power compensation

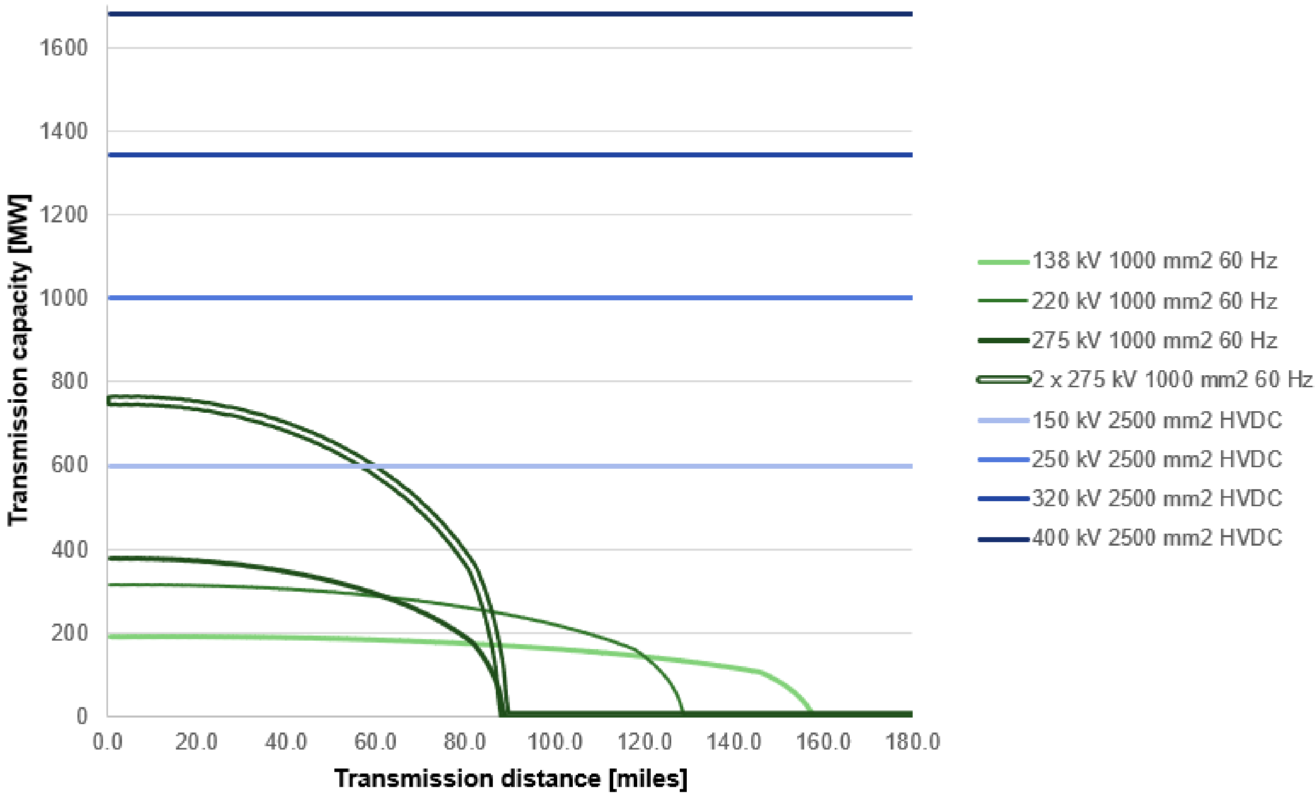
The main challenge of lengthy HVAC cable systems for offshore wind is to compensate the reactive power generated by the cable (capacitive charging) while still complying with the reactive power grid code requirement. In these cases, the long HVAC cable is a source of reactive power, which can negatively impact the voltage profile and power transfer capability. The amount of reactive power produced is proportional to cable length, and quadratically proportional to the operating voltage. This means that at a certain cable length, a technical limit is reached where the amount of reactive power produced by the cable consumes the cable's entire apparent power rating, and no more real power can be transported.

With DC technology, because the currents and voltages are not alternating, the above-mentioned effects are absent and only purely resistive effects are present. Hence, using DC technology optimally exploits cable use by maximizing the power rating per cable while practically removing the limit on transmission distance.

The above-mentioned effects are best illustrated with power-distance curves, as shown in Figure 3-11.

[6] Floating Portfolio Leaflet (abb.com)

Figure 3-11. Cable transmission power-distance curves



Source: DNV

The figure shows how enlarging the conductor cross section and increasing the voltage of AC cables (assuming three-core, three-phase cable, and double-ended compensation) leads to an increased transmission capacity at small transmission distances. It also shows that as the transmission distance increases, the transmission capacity of AC cables drops to zero, and that this effect occurs closer to shore for higher voltage cables. By contrast, the capacity of HVDC cables is generally higher due to the absence of phenomena like the skin effect, and only reduces slightly with distance due to the resistive power losses in the cable, practically removing the limit on the distance over which power can be transported. This figure illustrates that beyond a certain distance, there is a technical feasibility limit to the use of AC cable transmission technology.

In the case of long AC cables, the general compensation approach is to include reactive shunt devices at both ends and in the middle by using a midspan compensation platform (if applicable) to reduce voltage, specifically during the energization stage. Mostly, the shunt reactors are connected directly to the cable. Switching operation of the cable occurs only in combination with the shunt reactor.

Additionally, offshore HVAC transmission solutions require static synchronous compensator (STATCOM) in onshore substations to be able to comply with reactive power grid code requirements. All of these result in an increased CAPEX, OPEX, footprint, and environmental impact for a lengthy HVAC transmission link.

4 OFFSHORE TRANSMISSION PLANNING AND DESIGN

This section discusses the offshore transmission design approaches available for connecting offshore wind developments, both for individual wind farms as well as multiple interconnected projects. This section also includes a discussion of the key considerations for coordinated transmission planning.

Highlights in this section

- Although relatively new to the United States, offshore wind and the associated transmission infrastructure have been deployed in Europe for more than thirty years. While more regulators and grid planners are considering the use of an offshore grid and coordinated planning over a traditional radial line connection (bespoke design) to transfer offshore power to the onshore grid, coordinated transmission has not yet been fully planned or executed in the U.S.
- In the traditional approach (radial connection), offshore wind farm developers design, build, own and operate the transmission link. While this approach generally poses minimal risk to the developer, it has the potential to have downsides for the footprint, environmental and ocean user impacts, and the cost of an offshore wind project. These traditional projects are also not “future-proof” in numerous ways.
- A coordinated approach to offshore transmission infrastructure can avoid many of the problems associated with the traditional approach. Under this approach, the transmission infrastructure is developed with flexibility to adjust to future system needs. Coordinated approaches to offshore transmission are complex and in early stages in the United States. It is important to consider that since individual wind farms will likely be developed in multiple phases over an extended period of time, coordination must evolve and increase as additional projects are integrated into the transmission infrastructure.
- A coordinated approach could be explored for any offshore transmission planning involving more than one wind farm. The final decision to use a traditional or coordinated approach should be made based on a detailed cost-benefit analysis and the levelized cost of energy.

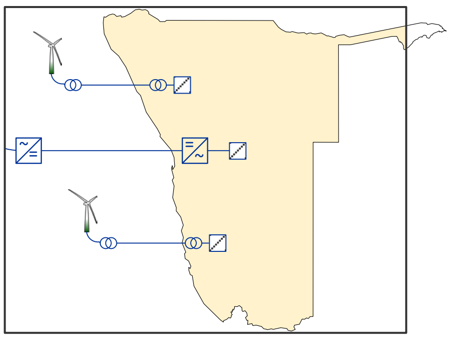
4.1 Offshore transmission connection concepts

Offshore grids consist of interconnected transmission elements that can be built at different phases over an extended period. Since transmission needs may change over time, an ideal offshore grid is expected to be flexible and capable of adjusting with future transmission needs. This means it is unlikely that an offshore grid will be completely and centrally planned a priori, but instead must be able to grow incrementally and organically over time, similar to how the onshore grid itself continuously evolves. This subsection describes several different approaches to building/evolving the offshore grid, including bespoke or radial design, bundled design, and multi-terminal design.

4.1.1 Bespoke design (radial connection)

In the traditional approach for building offshore wind export transmission links, the offshore wind developer would design, build, own, and operate the link to their own offshore wind farm. This approach was adopted in many early offshore wind farms in European countries and in the first offshore wind farms in the United States. In this “bespoke” grid building philosophy, each link is optimized for each offshore wind farm, and does not take into account other projects unless they are owned by the same offshore wind farm developer. As a result, different links may have different power ratings that are optimized to match the offshore wind farms they connect, as shown in Figure 4-1. The links are likely to have different voltage ratings based on the power and distance of the offshore wind farm. The system designs are likely to be different, and they may even use different transmission technologies; this results in different OSP designs.

Figure 4-1. Bespoke (radial) transmission schematic*



Source: DNV

* Note: in this graphic, each wind turbine and line to shore represents a full offshore wind farm, not a single turbine. The middle cable represents an HVDC transmission link, while the other two represent HVAC links.

The bespoke approach has both advantages and disadvantages compared to other connection approaches. From an offshore wind developer’s perspective, this approach may result in an optimal transmission link: it is custom designed for the offshore wind farm ratings and its execution and operation are under the offshore wind farm owner’s control, which minimizes interface and delivery risks. As additional offshore wind projects are planned and developed over time, bespoke connections may ease interconnection analysis and integration.

There are several disadvantages to this approach, particularly with respect to the flexibility of the export cables and the transmission grid. The export cables in bespoke connections are typically rated based on the offshore wind farm power, and not on the maximum available cable rating, which means that scarce cable corridor and POI capacity may not be used optimally. It also can result in a greater number of cables than necessary to connect the offshore wind farms to shore, creating higher costs, more landfalls, and higher impacts on the environment and local communities. Additionally, the different export links are typically not designed with additional space or equipment to enable future expansions, and the different characteristics also mean that they may not be compatible with one another, hindering opportunities to interconnect multiple developments to improve offshore grid performance.

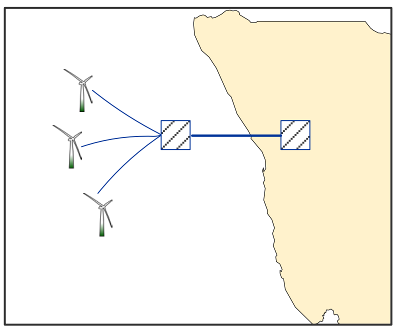
The OSPs are typically placed in a location that minimizes cost for the developer but may not fully reflect other impacts on society, such as visibility from shore and impacts to marine environments and ocean users. The onshore POIs may not be selected with a system optimization in mind, and through the combined impact of multiple OWFs, may lead to higher onshore grid upgrade costs.

In cases where the transmission equipment is owned and operated by the offshore wind developer, it is possible that they will be decommissioned as the offshore wind farm reaches end of life at about 25 years. Because the transmission equipment often has a 40-year economic lifetime, decommissioning it at 25 years could effectively waste a substantial part of its economic life. While there are no current examples of offshore wind farms reaching the end of their economic life, there are several plausible scenarios. Developers may have an opportunity to re-bid for or extend offshore wind area leases and if granted, redevelop the offshore wind farms to avoid decommissioning of the transmission assets. Depending on the state of the offshore grids at the end of the economic life of the offshore wind farm, developers may also attempt to sell the offshore transmission assets to other developers or utilities. However, such arguments are speculative and would need to be considered on a case-by-case basis along with numerous other considerations.

4.1.2 Bundled design (power corridor)

To overcome some of the shortcomings of the bespoke design offshore grid building paradigm, several European countries have adopted the bundled design approach. In this approach, as shown in the schematic in Figure 4-2, several different offshore wind farms share routes and infrastructure by using the same export transmission link, which is often designed, built, and operated by a transmission owner. This enables the optimal utilization of the available limited cable corridors (especially in narrow submarine passages) and POIs to maximally exploit their potential capacity within the limits of state-of-the-art cable technology and maximum loss of infeed. This approach may minimize the number of export transmission cables going onshore, minimizing adverse impact on the environment and local communities and achieving cost reductions through coordination.

Figure 4-2. Bundled offshore transmission design*



Source: DNV
* Note: in this graphic, each wind turbine represents a full offshore wind farm, not a single turbine.

Compared to radial or bespoke connection, using shared cable corridors and onshore POIs reduces permitting and surveying costs, streamlines the permitting process by reducing the number of parties requiring engagement, and concentrates construction activities geographically. Adopting a power corridor approach can also minimize the onshore interconnections for example, siting the OSPs and cable corridors to reduce impacts on marine environments and ocean users.

Shared transmission infrastructure is typically owned and operated by a transmission owner and not an offshore wind developer. This allows the transmission infrastructure's longer economic lifetime to be used to provide transmission capacity for future offshore wind development after the first wind farm is decommissioned or repowered, thereby improving the return on investment and ultimately improving the benefit for the rate payer.

This coordinated approach to offshore transmission infrastructure development requires a careful regulatory and contractual framework to appropriately, transparently, and realistically allocate risks and liabilities between the offshore wind owner(s) and the offshore transmission owner. Even in Europe, where most of the offshore development has taken place to date, radial cables are predominantly used to transmit power from offshore wind farms to shore. A few examples of power corridors exist in Germany, where power from multiple offshore wind farms in assigned wind energy areas is transmitted over single cable. TenneT GmbH, the German Transmission System Operator (TSO), has used this concept in North Sea for the Borssele and Hollandse Kust wind energy areas.[7]

Table 4-1 presents some key considerations for the planning of coordinated transmission development.

[7] "Programme 2023 - TenneT." n.d. Www.tennet.eu. Accessed January 25, 2022. https://www.tennet.eu/our-grid/offshore-grid-netherlands/programme-2023/.

Table 4-1. Key considerations for coordinated transmission development

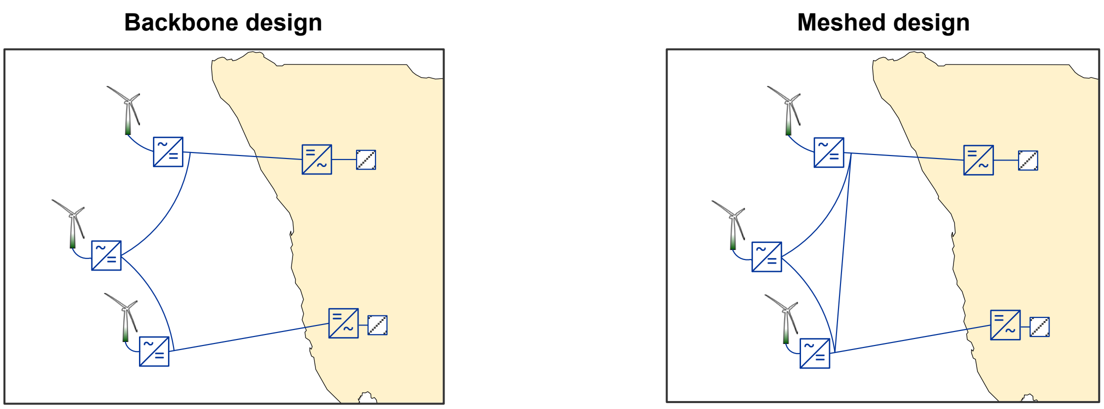
Coordination opportunities for wind farm and transmission owners
Open (Non-discriminatory) access (transmission capacity allocation) to the offshore transmission infrastructure
Liability for lost income due to delayed realization of offshore transmission capacity or planned or unplanned unavailability of offshore transmission capability beyond reasonable industry standards
Coordination of maintenance outages, and shared use of marine vessels for construction and maintenance
Interface between offshore wind owners and offshore transmission owner, specifically relating to offshore platforms and cable routes. Open exchange of information and design to ensure compatibility of interface and control systems
Access of offshore wind owner to offshore transmission facilities for the purpose of installation, testing, and operation of array cables up to interface
Coordination of availability of testing power (commissioning) before commercial operation date

The bundled design approach can be applied to both radial export links and more extensive offshore transmission networks consisting of higher power links to shore. Using offshore transmission networks instead of radial export links can alleviate some of the above-mentioned risks while still realizing the benefits of the bundled design.

4.1.3 Multi-terminal grid design

When designing offshore wind farms, offshore platform interlinks and multi-terminal functionality can be added to enable designs such as backbone, where multiple offshore wind projects are connected offshore, and meshed network, where multiple offshore wind projects are connected by shared transmission lines. These are illustrated in Figure 4-3.

Figure 4-3. Offshore grid with offshore platform interlink*



Source: DNV
* Note: in these graphics, each wind turbine represents a full offshore wind farm, not a single turbine.

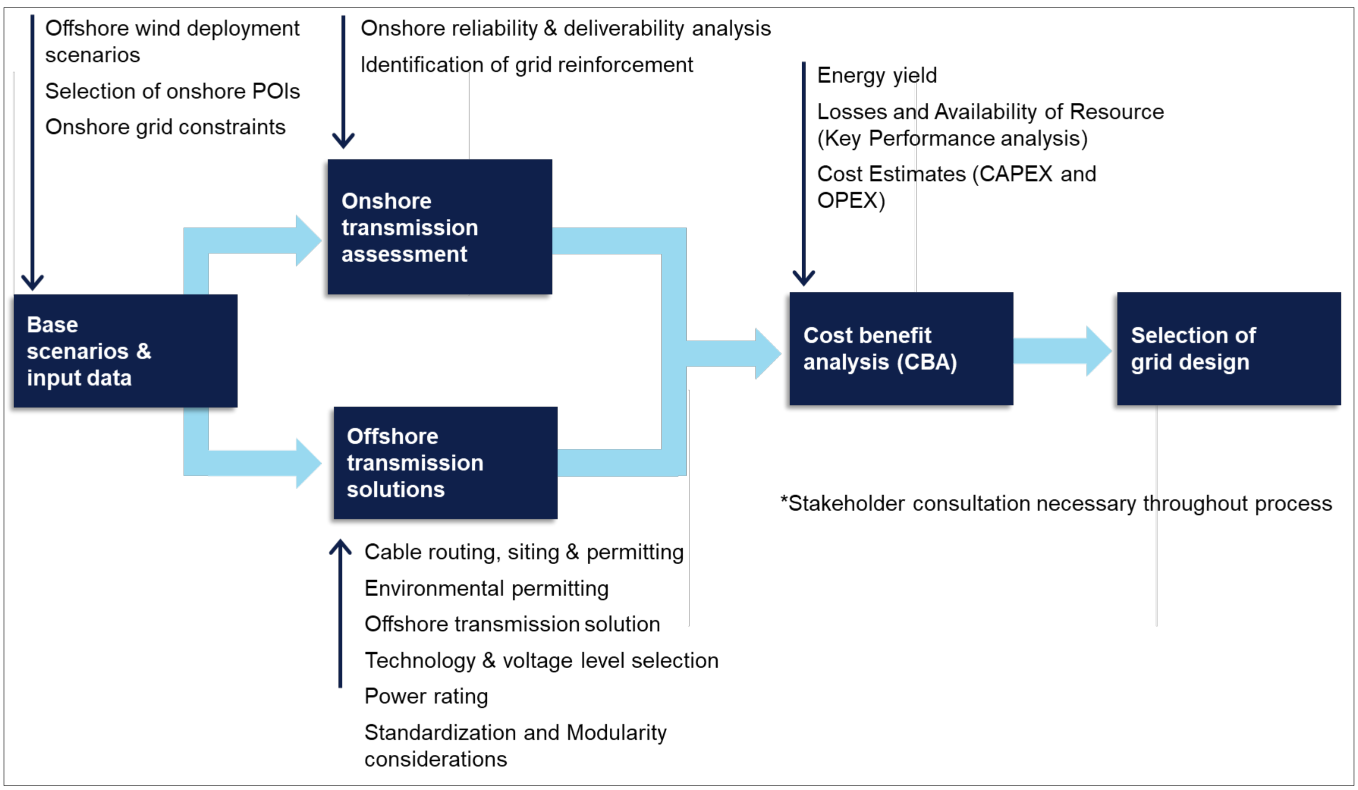
A platform interlink design carries the same challenges as bundled designs. It can, however, improve reliability while also allowing the offshore transmission infrastructure to be used for purposes other than offshore wind export, such as an alternative transmission path for onshore congestion or to supply offshore loads.

Despite all the claimed benefits of offshore grid designs, true offshore grids haven't been used in Europe to-date. European offshore transmission developers sometimes refer to their projects as "network grids" which could mean bespoke or bundled designs. In 2021, TenneT GmbH presented a concept paper that introduced the idea of centralized and distributed hub connection concepts (Hub-and-spoke concept) for connections between multiple European countries.[8]

4.2 Design considerations for coordinated offshore transmission planning

With increasing federal and state mandates towards deploying offshore wind as a zero-carbon energy resource, regulators and grid planners are considering the use of offshore grid concepts and coordinated planning rather than traditional bespoke design to transfer the offshore power to the onshore grid. While offshore grid networks can provide significant long-term benefits to both grid operators and end consumers, they will require careful planning to avoid unnecessary burdens and extra capital and operational expenditures. This section explores key design considerations for coordinated transmission planning; Figure 4-4 shows a typical planning process and highlights the concepts discussed in this section.

Figure 4-4. Typical coordinated transmission planning process



4.2.1 Standardized and modular designs

A key aspect of coordinated transmission development is ensuring that the components used in the offshore transmission design are future-ready, can be developed cost-effectively, and can be deployed across multiple applications without the need for extensive research and development. This can be achieved by using two key concepts: standardizing the various system parameters and modularizing the design.

[8] "Towards the first hub-and-spoke concept." May 2021, TenneT GmbH. https://northseawindpowerhub.eu/sites/northseawindpowerhub.eu/files/media/document/NSWPH_Concept%20Paper_05_2021_v2.pdf

4.2.1.1 Standardized design

A standardized design approach enables compatibility between different export links by coordinating rated voltage levels, basic insulation levels for the cables, system grounding and protection philosophies, requirements for platform expandability and defining grid functional behavior to enable multi-terminal and multi-vendor readiness. Standardizing parameters provides numerous benefits, including the ability to connect different export links offshore to improve availability and performance, and simplifying procurement and management of replacement parts.

In this approach, some of the link ratings would still be tailored to meet the power ratings of individual offshore wind farms or clusters of offshore wind farms. This means that OSPs have different designs. One implementation of a standardized approach is a system in which different transmission developers design and build different offshore links on a competitive basis, but where a design standard is imposed by another regulating body/authority or system operator, similar to what is done for onshore grid reinforcements.

4.2.1.2 Modular design

In a further step towards standardization, under a modular design, not only the system parameters but also the individual OSP power ratings and OSP designs are standardized. In order to increase capacity, OSPs are simply added in modular fashion, incrementally increasing the overall capacity. Project-specific parameters such as cable lengths and water depths are adjusted for each OSP. The modular design should accommodate a design envelope that covers all possible ratings and variations that could occur within the possible portfolio of future OSPs.

This offshore transmission design approach allows OSP designs to be replicated across different projects, reducing risks and uncertainties by building on the return of experience. In case multiple OSPs are required within a short time frame, fabrication can be optimized by opening up the possibility of series production. Standardized parameters and ratings also enable the simplification and optimization of spare parts management. All together, these factors can lead to a substantial efficiency gain during project execution, and subsequently during the operational phase, realizing significant CAPEX and OPEX reductions.

The standardization and modularization of parameters ensure compatibility between different OSPs and enable their offshore interconnection to build an offshore transmission network.

4.2.2 Offshore wind build-out scenarios

The main design considerations for an offshore transmission system include the location of the offshore wind farms, the capacities to be transported, the onshore POIs, and the dates when the offshore wind farms should go into commercial operation (COD). While there are various government and private sector parties involved in the planning and developing of offshore wind and offshore transmission, regional transmission planning would be strengthened by knowing where the offshore wind farms are located, how much energy will be produced, and the associated offshore wind farm project’s development status and CODs. Then, in the regional transmission planning process, possible build-out scenarios should be developed based on the timing and capacities proposed in state and regional offshore wind solicitation schedules. In developing build-out scenarios, the best practices are to utilize predicted future offshore wind turbine generator sizes and account for potential upcoming lease areas that might go to auction through the United State Bureau of Ocean Energy Management (BOEM) process. All in all, the deployment scenarios inform transmission planners and developers regarding the location of offshore wind farms, their MW capacities to be transported, and the dates when the offshore wind farms should go into commercial operation.

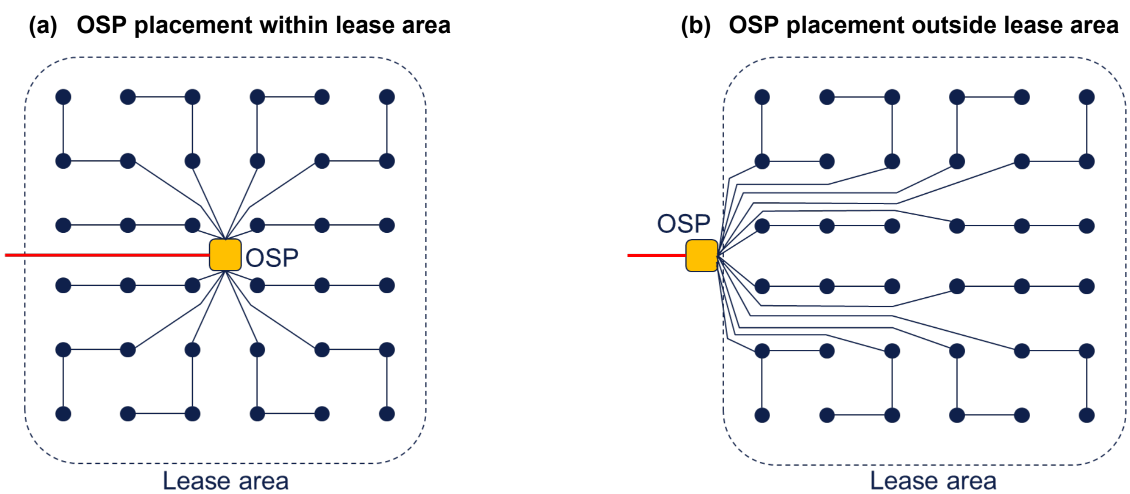
4.2.3 OSP location

After identifying the potential wind energy areas, the next step is to decide on the location of the OSPs. The location of these platforms determine the applicable permits, the export cable length and the water depth and selection of technology (floating or bottom-fixed). Key considerations in OSP siting are their location in relation to the lease area border, and their orientation in relation to the offshore wind farms themselves.

The OSPs are ideally placed as close as possible to the wind turbine generators (WTGs) to minimize the total length of the array cable. For this reason, typically, the OSP is placed centrally within the offshore wind farm, as shown in the left illustration in Figure 4-5(a). In the case of an offshore transmission grid, it may not be possible to centrally place the OSP, as the offshore wind lease areas will be controlled by the offshore wind farm developers, who may not permit transmission developers to build infrastructure within their lease area. Alternatively, the OSP can be placed right at the edge of the offshore wind lease area, as shown in the right illustration of Figure 4-5(b). The edges of the lease area might also have shallower water depth that allows for the installation of a bottom-fixed OSP.

The orientation of the OSP with respect to the lease area should be chosen considering the geography of the offshore wind energy areas (WEAs) and lease areas, potential cable routes (for both export and interlink submarine cables), and opportunities to minimize environmental and ocean user impacts.

Figure 4-5. Illustrative placement of OSP relative to offshore wind lease area*



Source: DNV
* Note: These layouts are illustrative of where OSP could be placed and don't reflect actual lease area and/or wind farm designs.

4.2.4 Selection of onshore POIs

Another key element for offshore transmission planning is identifying onshore POIs that can absorb the offshore wind energy with minimal onshore grid upgrade cost and without jeopardizing the grid reliability or violating grid code requirements. This could be achieved by performing both reliability and economic analyses. In the case of regional coordinated planning where the number of potential POIs increases, a high-level screening is recommended to narrow down the list and then perform the detailed analysis for the shortlisted POIs. The following criteria should be considered for the screening process:

- **Interconnection voltage** – POIs with higher voltage levels are normally better at integrating offshore wind. A higher voltage level typically means more available capacity and thus lower onshore grid upgrade requirements.
- **Total onshore and offshore lengths** – It is preferable to have POIs whose location relative to the OSP minimizes onshore and offshore cable lengths. Cable length is a key driver for project CAPEX, so POIs that are physically closer to an OSP often result in lower project costs.

- **High-level onshore and offshore routing complexity** – POIs that can be connected via simpler submarine and underground cable routes should be prioritized. Simpler cable routes avoid crossings of other infrastructure where possible, avoid horizontal directional drilling (HDD) sites where possible, naturally sensitive areas, and populated urban environments, etc.
- **High-level substation expandability** – POIs which have spare breaker positions or can easily be expanded with additional breaker positions are natural selection choice.
- **High-level MW capacity** – POIs with higher connected transmission line capacity are preferred.
- **Locational Marginal Prices** (LMP) – POIs with a higher LMP score better, as injection at that POI will relieve congestion and result in better project profitability. This could be also interpreted as POIs in proximity of load centers without sufficient nearby generation.

The onshore analysis should provide the injection level for each of the shortlisted POIs and the associated grid reinforcement costs. Methodology and results of a high-level injection capacity analysis for Maine are provided in Section 6 of this report.

4.2.5 Cable routes

To connect the OSPs with the onshore POIs, transmission link routes must be identified where submarine and underground cables lines can be constructed. Cables, both underground and submarine, are the largest components of an offshore transmission system and are one of the primary cost drivers. Any design as part of planning process should focus on minimizing the total number of cables and the total length of cable required to serve offshore wind development in the Gulf of Maine. This key design objective is largely determined by the selection of feasible power corridors that could deliver the offshore wind energy to the selected POIs and cable technology (DC vs AC). Typically, transmission planners perform a detailed desktop analysis during the planning phase to determine suitable offshore routes, taking into account the seabed bathymetry, soil types, conservation areas, subsea obstacles, existing submarine infrastructure, fishery zones, navigational zones, sand borrow areas, and boundaries of U.S. maritime limits, state and federal waters, and lease areas. The selection of onshore cable routes should minimize community impacts, ease permitting, minimize crossings with rail, waters, and roadways to reduce the need for trenchless crossings, and minimize the total length. The routing also should consider the available corridor for laying the cable underground. One of the major benefits of HVDC cable over HVAC is its smaller footprint in both submarine and underground cabling.

4.2.6 Developing offshore transmission solutions

After shortlisting onshore POIs, developing plausible deployment scenarios and identifying potential cable routes, the offshore network design philosophy and the knowledge of available technologies (AC, DC, etc.) could be utilized to develop different offshore transmission solutions. Here, the technology compatibility and interoperability need to be factored in for any potential coordinated solution. Given the number of candidate POIs, total MW of planned offshore capacity, distances from shore and grid code requirement, it is possible to end-up having numerous options which make it impossible to perform detailed performance and cost benefit analysis for all the identified solutions. In these cases, high-level qualitative and quantitative screening analysis are recommended to shortlist high performance solutions for further detailed analysis. The criteria and associated weight for screening could vary based on project specifics and needs; a few examples of screening criteria are included in Table 4-2.

Table 4-2. Example screening criteria to determine the optimal offshore transmission solution

Screening criteria	Key considerations
What is the estimated cost of the solution?	Offshore CAPEX + Onshore upgrade costs
What are the expected impacts on marine environments and ocean users?	Total cable length, number of cables, and number of offshore platforms
What is the technical complexity?	AC versus DC, radial solutions versus multi terminal and multi-vendor solutions
What is the operational flexibility?	Redundancy, backbone functionality, ease of O&M

4.2.7 Cost estimates

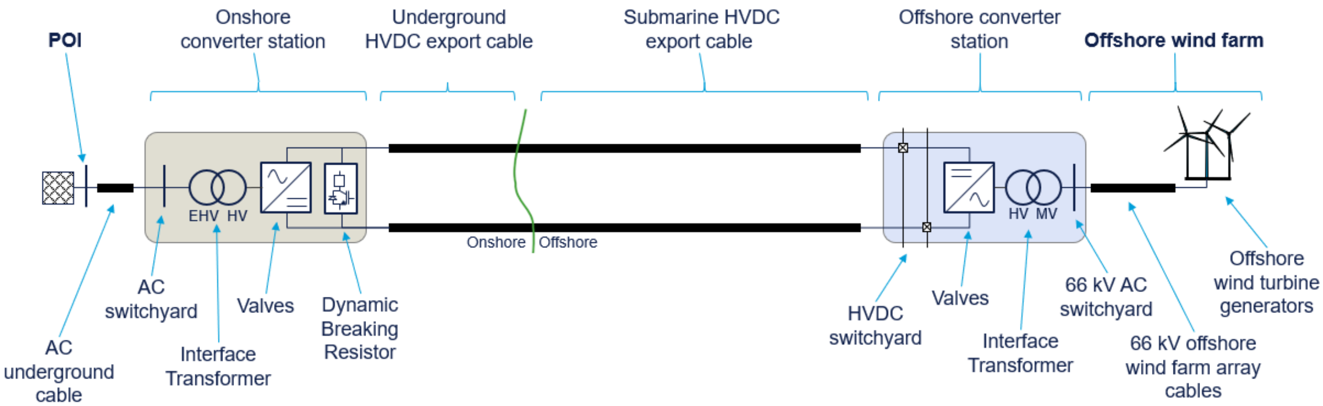
One of the key factors in offshore transmission planning is the CAPEX for each proposed solution. Since final decision-making is based on a detailed cost-benefit analysis, solutions with a lower CAPEX are the natural choice. A bottom-up cost estimate approach could be used to estimate the offshore transmission cost. Some of the key cost drivers are:

- **Offshore transmission power and voltage rating**: Typically, the higher the power rating and voltage, the higher the cost.
- **Choice of technology (AC vs DC, monopole or bipolar, HB or FB converter, etc.)**: Normally AC solutions cost less than DC solutions, but create technical difficulties at longer distances from shore (see Section 3.3.3). The choice of technology cannot be made only based on the simple comparison of CAPEX but requires a detailed cost-benefit analysis.
- **Distance from POIs**: Longer distance from POIs requires more cable and consequently a higher cost of materials.
- **Platform foundation concept (fixed or floating)**: Floating offshore wind farms are under development and costs are expected to continue to decline rapidly.
- **Water depth (in case of bottom-fixed foundation)**: Deeper water depth results in higher costs for the OSP.
- **Seabed conditions**: Seabed conditions can affect the cable design and installation costs, as different construction and burial methods are necessary for different seabed substrates.
- **Onshore upgrade cost**: Injection of offshore wind energy into the onshore grid may require some upgrades on the onshore facility as well. This cost must be factored into the cost-benefit analysis.
- **Grid code requirements**: More stringent grid code requirement (such as reactive power requirements, harmonic requirements, etc.) often result in additional equipment and design considerations which may increase the cost of the project.

4.2.7.1 HVDC link cost component

As discussed in Section 3.3, an HVDC solution is the natural choice for offshore wind farms with the longer distances from shore and higher power ratings. Figure 4-6 provides an illustrative example of an asymmetric HVDC link, the most commonly used offshore HVDC configuration.

Figure 4-6. Generic illustration of offshore symmetric monopole HVDC link



Source: DNV

The main cost components for HVDC offshore link are as follow:

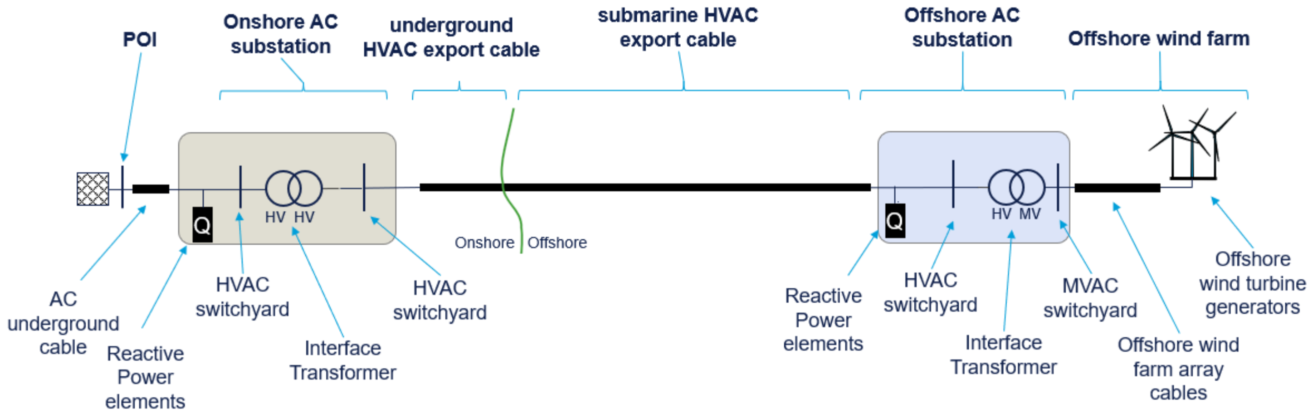
- **Offshore voltage source converter:** The offshore converter station includes step-up transformer and the voltage sourced converter (VSC), which convert the AC voltage to the DC voltage. The cost of the offshore voltage converter highly depends on power rating, voltage level, technology, and the expected functionality. For example, if in a coordinated planning approach when an offshore interlink is foreseen, the offshore converter station should be equipped with additional features and elements for the multi-terminal functionality.
- **Offshore HVDC platform**: The OSP costs will primarily depend on ocean depth and other factors that may influence the design concept (floating or bottom-fixed) selected. Modularity is another component that may influence HVDC OSP costs, especially for bundled and/or multi-terminal designs.
- **HVDC submarine cable:** One of the main cost drivers of the offshore HVDC link is the HVDC submarine cable. The cost of the cable is primarily derived by its power rating, voltage level and its length. Additional factors affecting cable cost include equipment selection, transportation and mobilization requirements, surveying, planning for crossings, cable protection, joint requirements, and testing and commissioning. As a simplistic approach, the equipment cost, laying and protection, joint and termination works could be scaled based on the cable length for similar projects but the remaining costs should be evaluated per project.
- **Underground (land) cable:** The underground cable delivers power from landfall to the POIs. This cable could be AC, DC, or a combination depending on the design and location of onshore substation. Integrating underground cabling into existing land-based infrastructure can also have a significant impact on costs.
- **Onshore voltage source converter:** The onshore converter station is responsible to convert the DC to AC voltage level of the grid and similar to offshore VSC the cost depends on the rating, voltage level, technology of converter and switchgears (air-insulated or AIS vs. GIS). Additionally, the cost of onshore VSC might be affected by special grid code requirements such stringent reactive power support and voltage ride-through criteria.
- **Integration to the existing POIs:** There are some costs associated with integrating offshore wind at the existing grid POIs. These costs depend on the expansion capability of the selected POI; where there is available spare bay and space in a POI, these costs will be minimal, while they could be significant for a POI substation without available space and an expansion feeder.

4.2.7.2 HVAC link cost component

Many of the cost drivers for HVDC links apply to HVAC, including the OSP, submarine and underground cabling, and integration to existing POIs. As discussed in Section 3.3, HVAC links do not need converters stations, and HVAC cable is an ideal choice for offshore wind farms closer to the shore and lower capacity.

An additional significant cost driver for HVAC is reactive power compensation (denoted as "Q" in Figure 4-7 below and described in Section 3.3.5.2). Reactive power compensation is needed to maintain proper voltage throughout the transmission line, and typically increases in costs as the HVAC cable lengths increase. Figure 4-7 illustrates an offshore HVAC radial link with reactive power compensation.

Figure 4-7. Generic illustration of offshore HVAC radial transmission link



Source: DNV

4.2.8 Key performance analysis

After shortlisting the offshore transmission solution based on the high-level screening described in Section 4.2.6, it is necessary to conduct a key performance analysis for each solution to calculate yearly energy loss and energy not transmitted due to planned and unplanned outages for each proposed transmission scenario. These data will serve as inputs in detailed cost benefit analyses which will help select the transmission solution with maximum benefits and lowest cost.

4.2.9 Cost-benefit analysis

In a coordinated transmission planning approach, following the selection of offshore wind buildout amounts and locations, offshore platform locations, onshore landfalls, potential onshore grid reinforcements and offshore transmission connection concept, it is advisable to perform a cost-benefit analysis for the holistic solution(s). A cost-benefit analysis of various transmission networks could include determination of annualized costs of transmission and offshore wind generation and calculation of expected potential benefits that may, at least partly, offset the costs. Devising a cost-benefit approach may require state and regional entities to work closely together to carefully consider the range of applicable benefits and the impacts to ratepayers and the environment.

For example, in New Jersey's State Agreement Approach (discussed in Section 7.1.2), PJM and New Jersey devised a cost-benefit approach to calculate the net offshore wind transmission costs on a levelized and net present value basis. The net offshore wind transmission costs methodology intended to capture the total CAPEX and OPEX for the offshore wind transmission projects over the life of the transmission assets, offset by the benefits provided by such projects, including NJ Gross Load Payment Reduction, increased value of delivering offshore generation, higher availability/reliability, reduction in

PJM capacity market payments and risk mitigation, when compared against a benchmark reference solution. PJM proposed that the benchmark reference solution would be developed using radial export links from the offshore projects to shore.

Advantages of the Cost-benefit analysis (CBA)

- CBA can help ensure that the net costs of offshore transmission are reasonably captured by considering the total benefits provided by the transmission solutions to the ultimate ratepayers.
- Under the levelized and net present value approach, typically employed in CBA analyses, the levelized annual benefits and costs calculated over the transmission project's useful life can be accurately reflected in the calculation of levelized cost of energy (LCOE) of the offshore wind generation. Transmission projects with different lifetimes, different start dates, different capacities and different proposed rate structures can be compared using this approach.
- Cost allocation mechanisms between multiple states and/or regions can be implemented based on the proportional benefits received by each state/region, since benefits of offshore transmission may not be restricted to the local area. Cost allocation mechanisms for offshore wind transmission could be built upon the existing ISO/RTO framework in place for onshore transmission projects with some modifications implemented to accommodate other tangible and non-tangible benefits provided by the offshore wind development.

Limitations of the CBA approach

- Cost allocation among multiple utilities and/or states/regions has been historically a challenging issue in interregional coordination and has caused drawn-out interregional transmission planning cycles that have led to significant delays in transmission development. New Jersey addressed the issue by not considering allocation of the costs of the 7.5 GW offshore wind outside the state.
- Typically, only tangible benefits and costs may be considered in the calculation. Less-tangible benefits such as long-term health benefits due to emissions reduction and economic development benefits may not be captured in this metric.

5 OFFSHORE TRANSMISSION OWNERSHIP AND FINANCING STRUCTURES

This section reviews offshore transmission ownership and financing structures, identifying the benefits and limitations of each approach, and the risks from a ratepayer perspective.

Highlights in this section

- There are 3 major offshore transmission ownership structures currently in existence in Europe:
  - Transmission System Operator (TSO) owned
  - Developer owned
  - Third Party Owned
- The TSO model has not been implemented in the United States. In Europe, a TSO plans, develops, owns, operates and maintains the transmission system and in some cases is owned by government entities. Typically, these functions are spread out across multiple entities in the United States. In terms of owning the transmission asset, the entity that comes closest to a TSO in the United States is a utility.
- In the UK, transmission assets are usually developed by the developer and then auctioned off to Offshore Transmission Owners (OFTO) who competitively bid for the transmission assets and act as a third-party in owning the transmission assets. In the United States, non-incumbent transmission providers (including independent transmission companies also known as Transcos) serve the function of competitively bidding for transmission (albeit in the planning stages) and have the flexibility of offering creative rate and cost structures to win transmission bids. Utilities and Transcos can recover costs through formula-based rates.
- Traditionally, two transmission development and ownership scenarios exist in the United States: merchant (developer owned) or regulated (Utility/Transco owned).
- Advantages of utility or Transco-owned offshore transmission may include standardization of transmission designs, opportunity to take advantage of cost allocation mechanisms and ease of financing.
- Advantages of developer-owned offshore transmission assets may include potentially faster timelines to build offshore projects due to involvement of fewer parties, flexibility in financing structures and cost optimization by custom building transmission assets to fit the size of the offshore wind resources (i.e., avoiding overbuilding).

5.1 Ownership and development

There are 3 primary offshore transmission system ownership models used in Europe:[9]

1. **Transmission system operator (TSO) owned**: TSO plans, constructs, owns, operates and maintains the offshore transmission assets
2. **Developer owned**: Developer responsible for planning, construction, operation and maintenance

[9] “Offshore Wind a European Perspective.” 2019, NYPA. https://www.nypa.gov/-/media/nypa/documents/document-library/news/offshore-wind.pdf.

3. **Third-party owned**: Prevalent only in the UK. A developer may plan and construct the transmission assets. At commercial operation, the developer auctions the transmission assets to a third-party offshore transmission owner (OFTO) to operate and maintain the assets.

The third-party owned concept, which exists only in the United Kingdom, is mandated under the U.K.'s Energy Act. It requires that the transmission asset, developed by an offshore wind developer, be sold to an OFTO via competitive auction process that is conducted by the U.K. Office of Gas and Electricity Markets (OFGEM). OFTO's are competitively licensed to operate transmission assets.[10] The advantage of having an offshore wind developer construct the offshore transmission assets is that it supports timely commercial operation while allowing the costs of transmission to be borne and recovered by private entities such as OFTOs.

In the United States, post- Federal Energy Regulatory Commission (FERC) Order 1000, non-incumbent transmission development entities (including independent transmission companies, also known as Transcos) have been bidding competitively for transmission projects beyond their traditional footprint. Such entities essentially perform a similar function as third-party OFTOs, in terms of ownership of the offshore assets. However, a key difference is that the utilities and non-incumbent transmission developers can be involved in the planning and development process at a much earlier stage and can recover the investment in the offshore transmission assets through regulated formula-based rates – depending on the provisions set by the individual states and/or ISO. Rights-of-first-refusal (ROFR), which is the right of incumbent utilities to refuse transmission development in their footprint based on the rules set by the state or the ISO, may still be applicable in some cases for onshore reliability upgrades.

In Europe, the TSO is responsible for planning, development, construction, operation and maintenance of transmission and distribution assets. TSO's can be owned by the government, as is the case in some countries. In the United States, there is no direct equivalent of the TSO's, as the transmission systems are planned, developed, owned, operated and regulated by different entities. The involvement of ISO/RTO's, utilities, federal, state and local regulatory entities at various stages of transmission development along with stakeholder involvement add complexities to coordinated transmission planning processes in the United States.

Traditionally, two transmission development and ownership scenarios exist in the United States: merchant (developer owned) or regulated (Utility/Transco owned). The costs of merchant transmission asset(s) are typically recovered through long term lease agreements of the transmission assets, while the costs of regulated assets are recovered through formula-rate mechanisms via the Utility/Transco rate base. The following factors are the key distinguishing aspects between the two ownership structures:

- In some cases, regulated ownership structures may achieve a reduction in the overall costs of development, construction, and/or operation and maintenance of transmission assets, ultimately benefiting ratepayers. Utilities and Transcos are more likely to have the appetite to develop multiple projects, potentially standardizing the designs and thus reducing the overall costs.
- A merchant ownership structure is feasible for bespoke designs (radial connections). For bundled designs (power corridors), merchant ownership is feasible if the wind farms connecting to the same power corridor are concurrently developed. However, meshed networks would likely require coordination between multiple transmission developers, states and even regions. In such cases, the cost recovery of merchant transmission assets may prove to be difficult. Regulated ownership, with existing and future cost allocation mechanisms suitable to address interregional offshore transmission, may be more suitable for meshed networks.

[10] "Offshore Wind a European Perspective." 2019, NYPA. https://www.nypa.gov/-/media/nypa/documents/document-library/news/offshore-wind.pdf.

- Cost allocation methods tend to be complex and have historically faced numerous challenges in regional and interregional planning processes, leading to significant delays in development timelines for onshore transmission projects. Similar challenges are expected for offshore transmission development for both radial and meshed connection configurations. Merchant owned transmission, typically recovered through bundled rates, would not be expected to face such delays.
- Developer built transmission assets tend to be designed optimally to just meet the needs of the offshore wind projects connected to them (i.e., developers tend not to overbuild transmission), thus achieving potential cost savings for the project.
- Offshore wind farms are expected to have at least a 25-year economic life, while transmission assets tend to have longer life ranging up to 40 years. For merchant owned transmission assets, the costs of the transmission assets will be expected to be recovered via bundled rates over the 25-year economic life of the offshore wind farm leading to higher annual costs in the near term. For regulated assets, the costs could be distributed over the economic life of the offshore transmission asset. Although this may lead to lower annual costs, it could mean that the cost of the potentially unused (stranded) transmission asset would still be recovered long after the offshore wind farm is decommissioned.

5.2 Financing and cost recovery

Significant offshore transmission costs may necessitate access to new financing mechanisms not seen in traditional onshore transmission development. Federal and state incentives could potentially be key to support the planning, development and construction of offshore transmission facilities. In April 2021, Senator Ron Wyden reintroduced the "Clean Energy for America Act", which proposes a 30 percent investment tax credit for qualified offshore transmission assets. The "Bipartisan Infrastructure Law" passed in November 2021, incorporates some of the key provisions outlined in the "Clean Energy for America Act" including funding to build thousands of miles of new transmission lines to unlock clean energy resources.[11]

Financing offshore transmission can be challenging. The construction phase is the highest risk for a transmission project due to technical risks and potential delays arising from permitting and public processes. The regulatory framework could support the provision of revenues during construction to reduce investor risk, to make financing more readily available at lower interest rates during these riskier periods, and to reduce the interest accrued during construction.[12]

Allocating the costs of the offshore transmission assets is a key consideration for cost recovery mechanisms. The FERC is evaluating the need to build upon the provisions of FERC Order 1000 in light of the changing generation mix and increased renewable penetration. Specifically, FERC is considering that current cost allocation mechanisms in the U.S. for traditional onshore transmission development may be insufficient to capture the benefits provided by the interconnection of large clean energy projects. It is important to acknowledge that the benefits of offshore wind could be realized by more than one state or region. Therefore, cost allocation mechanisms may need to be evaluated further to ensure that the cost to ratepayers is commensurate with the benefits.

[11] "FACT SHEET: Biden-Harris Administration Races to Deploy Clean Energy That Creates Jobs and Lowers Costs." 2022. The White House. January 12, 2022. https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/12/fact-sheet-biden-harris-administration-races-to-deploy-clean-energy-that-creates-jobs-and-lowers-costs/.

[12] "Semenyuk, Maksym, Cornelis Plet, and Paul Raats. 2020. Review of Progress on Meshed HVDC Offshore Transmission Networks (PROMOTioN) Final Report. DNV GL. https://www.dnv.com/research/power-and-renewables/pr-promotion.html.

6 ANALYSIS OF RENEWABLE INTERCONNECTION IN MAINE

One of the key considerations for offshore transmission planning is the selection of onshore POI candidates for potential landfall. As discussed in Section 4.2.4, there are numerous criteria for selection of onshore POIs, including the location of offshore wind energy areas, onshore substation interconnection voltages, MW injection capacity feasible at onshore POIs based on technical analysis, onshore substation expandability, onshore and offshore transmission routing considerations, average market prices at the POI, and minimizing impacts to marine environment and ocean users.

This section examines DNV's estimates of offshore wind development in the Gulf of Maine and its implications in the context of the offshore transmission planning considerations. This includes results from DNV's high-level injection analysis performed to evaluate the injection capability of near-shore and interior high-voltage substations in Maine for evaluating potential interconnection offshore and onshore renewable resources.

Highlights in this section

- Selection of onshore POIs for offshore wind projects involves the consideration of multiple criteria. Key factors include the location of the offshore wind energy areas, onshore substation interconnection voltages, the MW injection capacity and expandability feasible at onshore POIs, onshore and offshore transmission routing considerations (including avoiding onshore transmission bottlenecks), and potential impacts to the marine environment and ocean users.
- Injection capacity analysis was performed using the ISO-NE 2030 Needs Assessment database for non-concurrent injections at high voltage substations (>=115 kV).
- No onshore upgrades were assumed beyond the ISO-NE 2030 Needs Assessment scenario. Results of the analysis may vary if onshore grid reliability upgrades are made either in the state of Maine or in the ISO-NE footprint as a whole.
- Injection analysis results suggest that high voltage substations downstream of Coopers Mills 345 KV that are closer to the load centers have higher capabilities for interconnection of renewable resources.
- Substations closer to the shore with higher injection capacity may be more suitable POIs for offshore wind resources.

6.1 Projected offshore wind development in the Gulf of Maine

As part of the Maine Offshore Wind Initiative and the Maine Offshore Wind Roadmap, DNV developed an assessment of how offshore wind in the Gulf of Maine can contribute to filling both Maine and New England's long-term renewable energy needs. This analysis builds on the targets set in statute and prior analyses conducted in the state, including the Renewable Energy Goals Market Assessment (REGMA) and the Maine Climate Council. This analysis projected annual electricity demand through 2050 for Maine, and for two New England scenarios, a base-case demand and a decarbonization demand. For each demand projection, DNV developed three supply scenarios that varied constraints on onshore development to estimate the amount of renewable energy development, including offshore wind in the Gulf of Maine, that could be developed to meet Maine and regional demand needs.

The full report with all scenarios is available on the Maine Offshore Wind initiative website, but for the purposes of this report, the results of the Diverse Portfolio scenario are included in Table 6-1 to illustrate potential future volumes of offshore wind interconnecting in Maine. It should be noted that ISO-NE and other New England states may assume alternative amounts and timing of offshore wind development based on other analyses and assumptions. Accounting for both renewable projects already planned in Maine, as well as an assumption of 3,000 MW of additional onshore wind and/or solar not yet in development, this scenario projects 3,750 MW of onshore development and estimates additional offshore wind development to meet Maine and New England demand. It is important to note that these projected values are based on annual demand estimates and thus may understate the volume of offshore wind necessary for Maine and the New England region to fully achieve the established decarbonization objectives on an hourly basis when accounting for reliability and resource adequacy considerations.

Table 6-1. DNV Diverse Portfolio projections of additional renewable capacity by resource (MW)

Resource	Maine			New England – base demand			New England – decarbonization demand		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Solar PV	1,100	2,250	2,250	1,100	2,250	2,250	1,100	2,250	2,250
Onshore wind	51	1,500	1,500	51	1,500	1,500	51	1,500	1,500
Offshore wind (Gulf of Maine)	155	305	2,086	155	305	3,312	155	1,619	11,216

6.2 Injection capacity analysis for Maine near-shore and interior high-voltage substations

The objective of this analysis is to illustrate the relative capability of various high voltage substations for the interconnection of renewable resources with existing or approved onshore transmission infrastructure. The analysis is only one of the multiple selection criteria used in determination of the onshore POIs and does not make any assumptions about the other criteria mentioned above. The analysis is based on a single snapshot of the system conditions based on available generation, transmission and load data at the time of this study. Multiple factors such as the penetration of onshore renewable generation, non-wires alternatives options, transmission improvements, and load changes including the pace of electrification-driven load growth can affect the outcome of this preliminary analysis.

Following future wind energy area auctions by BOEM, potential landfall locations would have to be re-evaluated considering the onshore reliability and cost-effectiveness of specific transmission projects. The injection limits identified at the substations in Maine were based on non-concurrent injection analyses – the injection limits were calculated for each substation separately. Concurrent injection, performed iteratively using permutations and combinations of the substations where renewable injection is likely, will be necessary during future transmission design. Further analysis should also include a consideration of state and regional policies regarding renewables and stakeholder input and coordination.

First Contingency Incremental Transfer Capability (FCITC) analysis was performed for existing Maine near-shore substations rated 115 kV and higher. The analysis was performed using the ISO-NE 2030 Needs Assessment database by transferring power from each substation to the aggregate of the loads located in Maine. For the rest of the ISO-New England system, DNV assumed that onshore and offshore renewable needs are distributed based on the load ratio share of the load-serving entities in the region.

6.2.1 Methodology and assumptions

Using the ISO-New England 2030 Need Assessment database, a FCITC injection analysis was performed with transferring power from each individual substation to the aggregate of the loads located in the State of Maine.

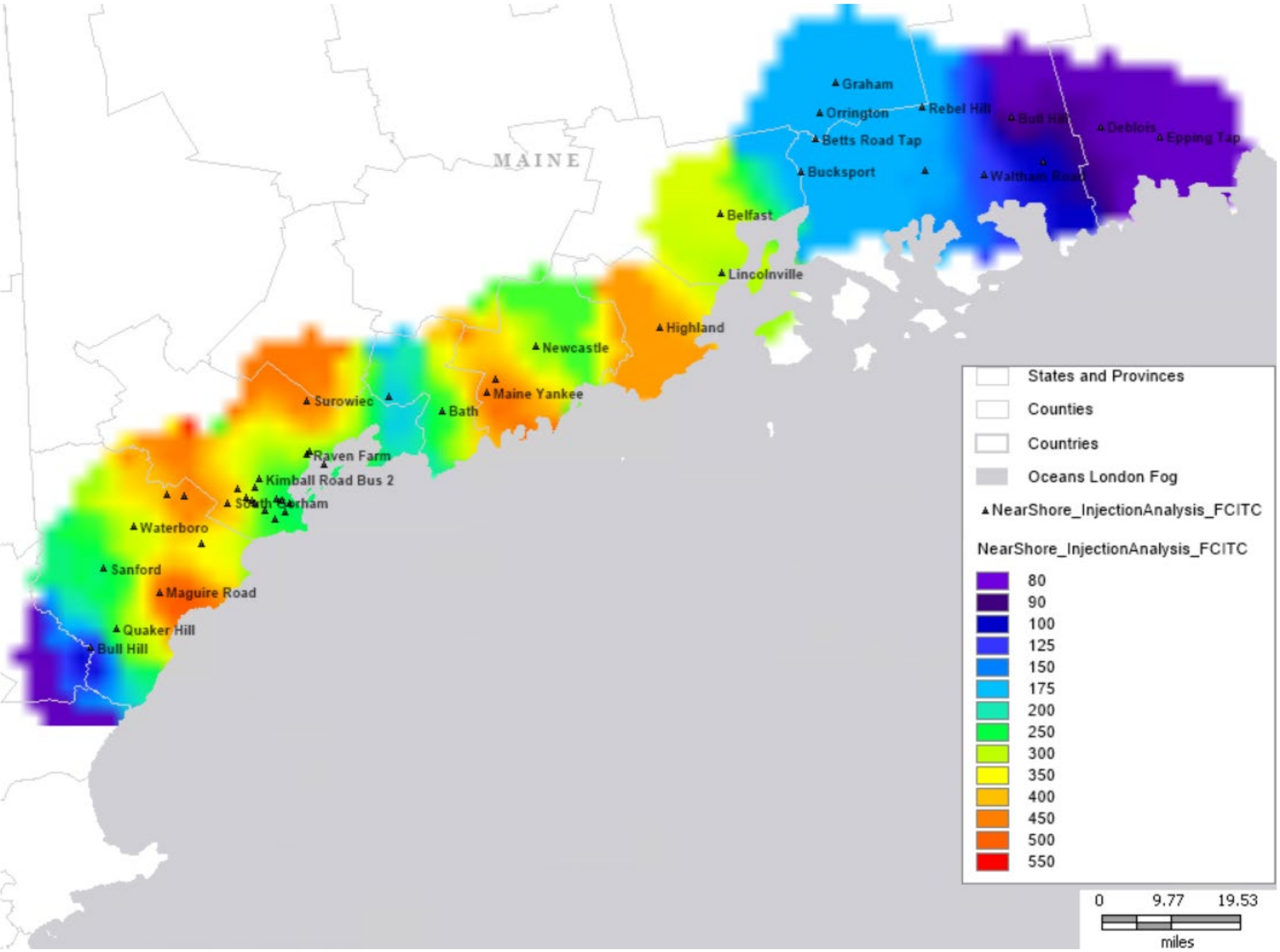
For each individual substation, injected MW value was gradually increased until a transmission facility reached its pre- or post-contingency thermal limit. MW injection value associated with the first new overload determined injection limit of the substation under the test. Analysis was primarily focused on high voltage substations located in Maine.

6.2.2 Simulation results

Figure 6-1 illustrates injection limits obtained for 115 kV and 345 KV substations. Injection analysis results suggest that high voltage substations downstream of Coopers Mills 345 KV that are closer to the load centers have higher capabilities for interconnection of renewable resources. Geographical locations of these substations are highlighted in Figure 6-1. Near-shore substations may be more suitable points for interconnection of offshore wind resources. While the specific locations of these offshore wind developments are yet to be determined (See Section 6.3), this analysis suggests that there appears to be some headroom at several onshore substations for some level of offshore wind development before transmission infrastructure investments are necessary.

Caution must be exercised for interpretation of FCITC injection analysis results. FCITC injection limits do not represent concurrent injection capability of the transmission network. The MW injection limit associated with each substation was calculated individually without any generation dispatch and/or control optimizations. Therefore, injection MW limits may not represent actual MW values that can be interconnected at each substation at the same time.

Figure 6-1. Injection MW limits of 345 KV and 115 kV high voltage substations



Source: DNV (created using ABB Velocity Suite)

6.3 Necessary future activities to determine transmission investment

The results of the FCITC based injection analysis presented in the previous section indicate the potential candidate locations for offshore wind landfall in Maine. However, the determination of landfall locations still requires many other factors to be considered prior to ensuring that the chosen landfall locations are a viable choice. This section highlights the key steps and offshore wind interconnection considerations that need to be addressed and how they may relate to Maine's stakeholders.

New Jersey context: Throughout this section, we highlight examples from the ongoing offshore wind process in New Jersey to provide additional context regarding the activities anticipated in the Gulf of Maine and their inherent complexities and interdependencies. In 2021, The New Jersey Board of Public Utilities (NJBPU), together with PJM Interconnection LLC (PJM), initiated solicitation of innovative and coordinated transmission solutions for potential procurement of 7.5 GW of offshore wind off the coast of New Jersey to satisfy its renewables goals via the State Agreement Approach (SAA). The New Jersey SAA is first of its kind in utilizing PJM's existing tariff provisions to competitively solicit for transmission projects. The examples in the following sections are intended to illustrate how key milestones in the development process affect project siting and configuration decisions, and the intricacies involved in the timing and scope of key future decisions as they may relate to the Gulf of Maine.

6.3.1 Determination of Wind Energy Areas

BOEM oversees the development of renewable energy on the outer continental shelf of the United States along with the transmission of electricity generated by the offshore renewable resources. Through its thorough stakeholder process and environmental assessments, BOEM determines the call areas and finally the wind energy areas, which can then be leased to potential bidders, typically comprised of offshore wind developers. The Planning & Analysis phase and the leasing phase in BOEM's process could take anywhere from 2 to 5 years. For the Gulf of Maine, given a goal of holding a commercial lease sale in 2024, BOEM released a Request for Interest (RFI) Development Framework in May 2022 in advance of the May 19, 2022 meeting of the Gulf of Maine Intergovernmental Renewable Energy Task Force Meeting. In this RFI framework document, BOEM defined the Gulf of Maine planning area and outlined during the meeting that later this summer BOEM will issue an RFI to seek information on a wide variety of topics to help inform subsequent phases of the planning and leasing process.

Determination of the wind energy areas is a critical phase in the development of the offshore wind buildout scenarios. Offshore wind buildout scenarios typically consist of several permutations of wind development in the various offshore wind energy areas over several years. The location of potential wind energy areas in the Gulf of Maine will be critical to further determine wind solicitation schedules, offshore wind design and sizing considerations, distance of offshore wind energy areas from shore, transmission routing, and cable design considerations. The development of wind buildout scenarios does not include the development of transmission solutions necessary to transmit the energy from offshore wind to the onshore substations. Transmission buildout is a separate process coordinated with regulated or deregulated transmission developers, as discussed in Section 5.

New Jersey context: BOEM published a call for information in New Jersey in April 2011 to request information about site conditions and assess interest in development of offshore wind facilities. This request included an initial map of the call areas, which have been refined through subsequent analyses, reports, and environmental assessments. A commercial lease auction was conducted in 2015, with two leases signed in February 2016.[13]

6.3.2 Offshore Wind Solicitation

Following the offshore wind energy area determination, state and local governmental entities may determine the amount of wind to be solicited. This may depend on the regional requirements for renewable energy based on policy mandates or goals, environmental factors, and/or socioeconomic factors. Depending on the regional requirements of offshore wind, the solicitation awards by states could be granted at once or in various phases over a number of years (as in the case of New Jersey). The complexity of this process may be greatly enhanced if there are multiple states involved in the solicitation process, with potentially competing objectives to procure the limited offshore wind resource from a common area, as is likely the case with Gulf of Maine.

New Jersey context: In case of the New Jersey offshore wind solicitation process, Ocean Wind filed an application with BOEM to assign the lease area OCS-A0498 off the coast of Atlantic City, NJ in April 2016. Subsequently, the first wind solicitation was awarded by New Jersey to Ocean Wind in June 2019, in the amount of 1,100 MW, approximately 3 years after the application was first filed by Ocean Wind. For the second solicitation, the New Jersey Board of Public Utilities had

[13] Commercial Wind Leasing Offshore New Jersey, BOEM. https://www.boem.gov/renewable-energy/state-activities/commercial-wind-leasing-offshore-new-jersey.

initially evaluated awarding up to 1,200 MW of offshore wind. This was later revised to 1,200 – 2,400 MW for Solicitation 2, introducing significant uncertainties in the State Agreement Approach process with PJM, wherein the NJBPU was separately soliciting transmission solutions to the potential award. Ultimately, after careful consideration of the bids by offshore wind developers, NJBPU awarded 2,658 MW of offshore wind across two different lease areas.

6.3.3 Regional Coordination

Both ISO level and interstate coordination is necessary to ensure efficient offshore transmission and generation investment in the Gulf of Maine. A non-coordinated approach may lead to higher overall costs to regional ratepayers. An "every state for itself" approach may lead to lower costs in the shorter term, while not considering future wind siting and/or transmission routing considerations.

New Jersey context: The need for a holistic approach to offshore transmission siting became evident early on in the New Jersey State Agreement Approach process. This led to PJM and NJBPU requesting transmission solutions to integrate all 7,500 MW of offshore wind into New Jersey, even though only 1,100 MW of offshore wind solicitations were awarded at the time of commencement of the PJM transmission solicitation window in early 2021. In all, PJM received about 80 transmission proposals from 13 offshore transmission developers or subsidiaries which included new transmission facilities and/or upgrades to existing onshore transmission facilities. PJM and NJBPU opened the offshore transmission solicitation window on April 15, 2021 and closed it on September 17, 2021, making it one of the longest transmission solicitation windows in recent PJM open solicitation window history. As of the date of this report, PJM is still evaluating the proposals submitted in the process and expects to award by the end of summer of 2022.[14]

Gulf of Maine context: Regional coordination not only involves determination of the offshore wind requirements by state, but also an agreement on the cost allocation principles for offshore transmission between states and utilities. For example, based on DNV's projections in Table 6-1, in addition to the 155 MW from the research array and Monhegan projects, an additional 150 MW of offshore wind is projected to be in service by 2040 in Maine, while the entire New England region is projected to have additional 1,464 MW of offshore wind capacity. Depending on the distance from the shore and the choice of connection technology used (HVAC vs HVDC), an offshore wind energy area of 1,464 MW could potentially be interconnected using a single transmission link. This would probably be best served by the wind energy developer working in tandem with the transmission developer to develop the offshore wind project. In such cases, the offshore transmission rates could be potentially bundled with the offshore wind energy rates to provide a single $/MWh rate for the energy served by the offshore wind. In the case of New Jersey, such financial instruments were termed as Offshore Renewable Energy Credits (OREC). OREC's may also include the cost of onshore transmission upgrades necessary to support the transmission of offshore wind energy to the onshore grid.

As seen in the Table 6-1 above, offshore wind is projected to grow substantially by 2050 to a total of 11,216 MW for the New England region. If such offshore wind penetration is to be realized, the total offshore wind capacity could be potentially distributed across 8 to 12 different wind energy areas, which would be located at varying distances from the shore in the Gulf of Maine. In such a scenario, it would be highly important to apply the design principles presented in Section 3 and 4 of this document to develop coordinated standardized and modular transmission plans across the region at the inception of the planning process for efficient and economical transmission development. Regional cost allocation, based on the benefits realized by the various states from the offshore wind, could also be implemented to ensure that the allocated costs are commensurate with the benefits regardless of landfall locations for the offshore wind.

[14] "FERC approves offshore wind transmission pact between PJM, New Jersey." 2022. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/ferc-approves-offshore-wind-transmission-pact-between-pjm-new-jersey-69882231

7 TRANSMISSION BEST PRACTICES TO REDUCE IMPACTS

This assessment of transmission strategies focuses on two primary areas:

1. Global, federal, state, and regional level best practices developed around building offshore transmission options, including built projects and projects that are proposed but not yet developed. Best practices encouraging offshore transmission development are discussed, along with the state/regional coordination approaches that have worked best to drive competitive offshore transmission planning.
2. Best practices in offshore transmission planning to reduce the impacts of offshore wind on species, habitats, the marine environment and ocean users.

Highlights in this section

- Key marine environment and ocean user impact considerations and best practices related to transmission development are based on potential changes to benthic habitat, particularly in nearshore areas and at landfall.
- Adhering to best practices during the siting and project layout planning phase is most essential for reducing impacts to the environment and ocean users.
  - Because offshore floating wind is a relatively new industry in the U.S., planning and development must be dynamic and allow for the active integration of emerging research and guidelines for environmental impact reduction.
- Key areas of emerging research are from the cumulative impacts of offshore wind development and climate change impacts in the GOM, the implications of increased subsea cable burial depths, and the potential impacts of electric and magnetic fields (EMF) on benthic, demersal, and pelagic marine species and their movements.
- Coordinated transmission planning should focus on both offshore transmission infrastructure as well onshore grid reliability reinforcements needed to support offshore wind interconnection to reduce costs and lead times.

7.1 Review of transmission best practices and government policies

A key component of developing offshore wind involves identifying offshore and onshore transmission solutions that will need to be developed to reliably and cost-effectively interconnect the offshore wind energy to the electric grid while minimizing the impact on ratepayers, the environment, and ocean users.

Europe had over 25 GW of offshore wind installations at the end of 2020 and over 3.7 GW are expected to have been installed in 2021. Primarily, efforts to build offshore wind have relied on point-to-point transmission using radial HVDC or HVAC cables. A recent transmission study conducted by National Grid ESO in UK highlights the importance of using a meshed transmission network, which could reduce the costs of integration by as much as 19% and reduce the number of cables and landfall locations by as much as 50%.[15]

[15] "Offshore Coordination Phase 1 Final Report." 2020. https://www.nationalgrideso.com/document/183031/download.

From a technical perspective, the Gulf of Maine offers significant potential for offshore wind development. Studies have shown up to 156 GW of technical potential for offshore wind development in the Gulf of Maine.[16] Based on DNV's ongoing analysis for the State's Roadmap process, as well as other analyses conducted for New England states, achievement of the decarbonization policy objectives in New England could likely necessitate substantial offshore wind in the Gulf of Maine, with a portion of that potentially making landfall in the state of Maine.

This section reviews best practices at global, federal, state, and regional levels around building offshore transmission options including federal incentives and loan programs that may assist in offshore transmission development.

7.1.1 Federal policies and programs

In 2011, the FERC issued Order No. 1000 to improve transmission planning processes and cost allocation mechanisms to ensure that the rates, terms, and conditions of service provided by public utility transmission providers are just and reasonable and not unduly discriminatory or preferential. Among other things, FERC Order 1000 instituted a number of reforms to ensure that non-incumbent transmission providers have an opportunity to participate in the regional transmission development process. This effectively increased competition among the transmission providers to offer the most cost-effective innovative transmission solutions to address reliability and economic and public policy needs. In 2021, FERC recognized the need to re-evaluate the principles set forth in Order 1000 to ensure that future transmission planning and cost allocation processes can be just and reasonable in light of changing generation mix and penetration of renewables in the system in its Notice of Proposed Rulemaking (NOPR) Docket RM21-17-000. Concurring with the observations in the NOPR, Chairman Richard Glick noted:

> *In particular, we are concerned that existing regional transmission planning processes may be siloed, fragmented, and not sufficiently forward-looking, such that transmission facilities are being developed through a piecemeal approach that is unlikely to produce the type of transmission solutions that could more efficiently and cost-effectively meet the needs of the changing resource mix. Regional transmission planning processes generally do little to proactively plan for the resource mix of the future, including both commercially established resources, such as onshore wind and solar, as well as emerging ones, such as offshore wind.*[17]

This may potentially result in new or modified rules on transmission planning processes set forth by Order 1000 that could incentivize building offshore wind projects beyond the current national goal of 30 GW by 2030.

Federal Programs

In March 2021, the Biden Administration released a fact sheet to facilitate access to US $3 billion in loan guarantees available to support innovative transmission projects, including offshore wind projects, through the Department of Energy's Loan Programs Office.[18] The availability of low-cost government loans could result in lowering the cost of debt for transmission projects, favoring the cost-benefit assessment for potential offshore transmission projects.

The Consolidated Appropriations Act of 2021, signed into law on December 27, 2020, provided a standalone investment tax credit (ITC) equal to 30 percent, for any qualified wind projects where construction begins after 2016 and before 2026.[19] Additionally, in April 2021, Oregon Senator Ron Wyden reintroduced the Clean Energy for America Act, which, among other provisions, proposes a 30 percent ITC for investments in grid improvements, such as high-capacity transmission lines, that

[16] "Floating Offshore Wind in Maine - Advanced Structures & Composites Center - University of Maine." n.d. Advanced Structures & Composites Center. Accessed January 16, 2022. https://composites.umaine.edu/offshorewind/#

[17] Department of Energy Federal Energy Regulatory Commission, Notice of Proposed Rulemaking, "*Building for the Future through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection*", 2021, FERC Stats and Regs, 18 CFR Part 35

[18] The White House. 2021. "FACT SHEET: Biden Administration Jumpstarts Offshore Wind Energy Projects to Create Jobs." The White House. March 29, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/.

[19] "Financing US Offshore Wind | White & Case LLP." n.d. Www.whitecase.com. https://www.whitecase.com/publications/insight/fast-forward-us-offshore-wind/financing-us-offshore-wind.

support clean energy objectives.[20] The “Bipartisan Infrastructure Law” passed in November 2021, incorporates some of the key provisions outlined in the “Clean Energy for America Act” including funding to build thousands of miles of new transmission lines to unlock clean energy resources.

7.1.2 State and regional policies

Transmission planning is underway in many states throughout the U.S. to support offshore wind development in existing and future lease areas. This section highlights recent activities and best practices from ongoing transmission planning activities in Massachusetts, New York, and New Jersey.

In 2018, Massachusetts passed an Act to Advance Clean Energy aimed at allowing transmission to be developed independent of offshore wind development and enabling offshore transmission to be used by multiple offshore wind farms while maintaining that offshore transmission must be developed in a reliable and cost-effective manner.[21]

In January 2022, the New York State Public Service Commission (NYPSC) issued an order[22] that directs the New York State Energy Research and Development Authority (NYSERDA) to require that future offshore wind proposals be designed with the capability of interconnecting offshore wind resources in a meshed network configuration. The NYPSC notes:

> *… the Commission finds that NYSERDA should take steps to preserve the future mesh offshore grid option. The cost of including this flexibility in project design at this stage is modest and would reduce the cost of retrofitting facilities in the future if the Commission concludes that such a network will benefit New York’s ratepayers.*[23]

In PJM, the Regional Transmission Planning Process (RTEP) allows for planning and construction of new transmission facilities to meet market efficiency standards, improve reliability or, upon request by a state, to meet state-mandated public policy requirements.[24] In 2021, The New Jersey Board of Public Utilities (NJBPU), together with PJM, initiated solicitation of innovative and coordinated transmission solutions for potential procurement of 7.5 GW of offshore wind off the coast of New Jersey to satisfy its renewables goals via the State Agreement Approach (SAA). The New Jersey SAA is first of its kind in utilizing PJM’s existing tariff provisions to competitively solicit for transmission projects. Moreover, in 2021, FERC approved New Jersey and PJM’s SAA and stated:

> *To the extent that states or public utility transmission providers believe there are barriers to Voluntary Agreements in Commission-jurisdictional tariffs or other agreements, we encourage them to identify those barriers and, as necessary, consider making filings before this Commission to address those barriers.*[25]

FERC also held that it found that the SAA did not conflict or otherwise replace PJM’s Order 1000 competitive transmission planning process, rather supplemented it. Similar to PJM, the ISO New England (ISO-NE) tariff includes a voluntary process by virtue of the Public Policy Transmission Upgrades in ISO-NE tariff (ISO-NE Schedule 12, Section B.6), that enables the New England States Committee on Electricity (NESCOE) and state PUCs to plan and pay for transmission facilities.[26]

Following a joint statement from the Governors of Maine, Connecticut, Massachusetts, Rhode Island, and Vermont calling for a clean, affordable, and reliable 21st century regional electric grid, NESCOE issued a Vision Statement that declares the

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20 “Senate Finance Chairman Wyden Introduces Energy Tax Bill.” n.d. Taxnews.ey.com. Accessed January 16, 2022. https://taxnews.ey.com/news/2021-0818-senate-finance-chairman-wyden-introduces-energy-tax-bill.

21 Department of Energy Resources. Letter to Joint Committee on Telecommunications, Utilities, and Energy (TUE). 2020. Review of Offshore Wind Energy Transmission under Section 21 of Chapter 227 of the Acts of 2018 (an Act to Advance Clean Energy), July 28, 2020.

22 State of New York Public Service Commission, “Order on Power Grid Study Recommendations”, Issued: January 20, 2022

23 State of New York Public Service Commission, “Order on Power Grid Study Recommendations”, Issued: January 20, 2022

24 NJ Board of Public Utilities, Letter to NJ Division of Rate Counsel, “In the matter of Offshore Wind Transmission.” Accessed January 16, 2022. https://www.nj.gov/bpu/pdf/boardorders/2020/20201118/8D%20-%20ORDER%20Offshore%20Wind%20Transmission.pdf.

25 Department of Energy Federal Energy Regulatory Commission, Notice of policy statement, “*State Voluntary Agreements to Plan and Pay for Transmission Facilities”*, 2021, FERC Docket PL21-2-000

26 ISO New England Open Access Transmission Tariff (OATT), Schedule B, Section B.6, “Public Policy Transmission Upgrade Costs”

necessity for significant changes in three core segments of the shared energy system: Wholesale Electricity Market Design, Transmission System Planning, and ISO-NE Governance.[27] In June 2021, NESCOE released the New England Energy Vision Statement Report to the Governors: Advancing the Vision, offering an update on progress related to elements within the Vision Statement.[28]

It is worth noting that at the time of opening the NJ SAA competitive transmission solicitation process window, only 1,100 MW of offshore wind in New Jersey was awarded to the developers as a part of the State's first offshore wind solicitation. This left transmission developers to make assumptions around how and when future offshore awards could happen and guess the order in which they would happen. Furthermore, there was uncertainty around the potential amount of award in New Jersey's second solicitation of offshore wind. Despite the numerous uncertainties, the SAA built upon the traditional planning processes to solicit transmission infrastructure needed to interconnect large amounts of offshore wind to the PJM grid in a reliable and cost-effective manner.

Best practices from the SAA approach:

- Leveraged the combined policy expertise of the State and the technical expertise and established planning processes of the regional transmission operator (RTO) to create an effective coordinated transmission solicitation approach.
- Coordinated transmission solicitation focused not only on the offshore transmission infrastructure, but also the onshore grid reliability reinforcements needed to support the large amounts of offshore wind.
  - Transmission solicitation categorically requested proposers to only address incremental onshore transmission needs, that were not a part of PJM's existing reliability needs.
  - At the same time, existing reliability and/or market efficiency needs mitigated by potential offshore transmission solutions were considered as a benefit from an avoided cost perspective
- New Jersey Board of Public Utilities (NJBPU) and PJM allowed submittal of full and partial solutions, subject to the assumptions made by the transmission developers with respect to the expected offshore solicitation amounts, expected timeline of such solicitations and the order in which the offshore lease areas may receive the awards from future solicitations. NJBPU and PJM also left the door open for them to combine parts of potential transmission bids from multiple entities, unlike PJM's RTEP process. This approach encouraged submittal of modular solutions with standardized design approach within the limitations of the information available at the time.
- The cost benefit approach employed in the SAA urged consideration of multiple energy market benefits, capacity market benefits, public policy benefits and reliability benefits

Competitive transmission solicitation processes have historically elicited cost effective and innovative proposals from developers that can factor in cost caps and rate caps to minimize ratepayer impact.

7.2 Best practices to reduce impacts on the marine environment and ocean users[29]

7.2.1 Methods and approach

The primary approach for this assessment was to examine environmental considerations throughout the offshore wind lifecycle, from as early as the siting and project layout design considerations that occur during the project permitting process, to the various activities involved in transmission cable installation, maintenance, and removal. There is limited research on

[27] https://nescoe.com/resource-center/vision-stmt-oct2020/

[28] https://newenglandenergyvision.files.wordpress.com/2021/06/advancing-the-vision-report-to-governors-2.pdf

[29] Public Law 2021, Chapter 327 requires the Public Utilities Commission, in consultation with the Governor's Energy Office and the Office of the Public Advocate to report on ways to protect species, habitats and marine users from imprudent development while encouraging efficient transmission investment.

transmission-specific environmental impact considerations separate from the offshore wind projects for which transmission is developed, but overall environmental impact analyses were reviewed for their discussion and recommendations that are most applicable to offshore wind transmission activities. After the environmental impact considerations were identified, industry standard and emerging best practices were collected from the best available knowledge and research for floating wind development. An overview of documentation reviewed include the following:

- **Environmental impact statements from prior projects**. A particular focus on the Hywind Pilot Park in Scotland, the most established floating offshore wind facility in the world.
- **State of the science workshops and databases.** Online resources that synthesize the most-up-to date research from experts working to further understand the potential impacts from offshore wind development were reviewed. Notable State of the Science workshops reviewed include those managed by BOEM, National Oceanic and Atmospheric Association (NOAA), and Responsible Offshore Development Alliance ("Fisheries and Offshore Wind Energy: Synthesis of the Science"), New York State Energy Research Authority (NYSERDA), and the New York State Environmental Technical Working Group ("State of the Science Workshop"). The Tethys Offshore Wind Knowledge Database developed by Pacific Northwest National Laboratory and U.S. Department of Energy was also reviewed for the most up-to-date research available on offshore wind environmental impacts.
- **Literature review.** A review of over 60 journal articles and reports was utilized to analyze impact considerations and best practices for offshore wind transmission development in the Gulf of Maine.
- **Industry standard and in-house knowledge.** Along with the avoidance and minimization measures and best practices established by BOEM and NOAA, knowledge gained from developing site assessment plans and construction and operations plans (COPs) for other offshore wind developments along with collaborating with European colleagues leveraged this review to bring together both established and emerging impact considerations and best practices from a global and federal perspective.

Table 7-1 summarizes the key literature that was synthesized for this assessment. The results of the assessment are discussed for each key phase of offshore wind development in the sections below.

Table 7-1. Key synthesized literature and data sources

Source	Title	Citation
BOEM	National Environmental Policy Act Documentation for Impact-Producing Factors in the Offshore Wind Cumulative Impacts Scenario on the North Atlantic Outer Continental Shelf	BOEM. "National Environmental Policy Act Documentation for Impact-Producing Factors in the Offshore Wind Cumulative Impacts Scenario on the North Atlantic Continental Shelf." US Dept. of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Sterling, VA (United States). OCS Study 2019- 036, 2020.
Equinor ASA	Hywind Scotland Pilot Park: Artificial Substrate Colonization Survey	Equinor ASA. *Hywind Scotland Pilot Park: Artificial Substrate Colonization Survey*. 300152-EQU-MMT-SUR-REP-ENVIRORE. Scotland, 2020.
Equinor ASA	Hywind Scotland Pilot Park: Environmental Statement	Equinor ASA. *Hywind Scotland Pilot Park: Environmental Statement*. A-100142-S35-EIAS-001. Scotland, 2015.
NYSERDA	The State of the Science on Wildlife and Offshore Wind Energy Development: Workshop Proceedings	New York State Environmental Technical Working Group. 2020. "2020 State of Science Workshop." Accessed December 2021 at: https://www.nyetwg.com/2020-workgroups
Ocean Energy Systems	State of the Science Report, Chapter 8: Encounters of Marine Animals with Marine	Garavelli, Lysel. *2020 State of the Science Report, Chapter 8: Encounters of Marine*

Source	Title	Citation
	Renewable Energy Device Mooring Systems and Subsea Cables	*Animals with Marine Renewable Energy Device Mooring Systems and Subsea Cables*. No. PNNL-29976CHPT8. Pacific Northwest National Lab. (PNNL), Richland, WA (United States), 2020.
PHAROS4MPAs	A Review of Solutions to Avoid and Mitigate Environmental Impacts of Offshore Windfarms	Defingou, M., F. Bils, B. Horchler, T. Liesenjohann, and G. Nehls. "PHAROS4MPAs- A Review of Solutions to Avoid and Mitigate Environmental Impacts of Offshore Windfarms." *BioConsult SH on behalf of WWF France* (2019): 264.

*Note: this table is not an exhaustive list of sources reviewed

7.2.2 Siting & project layout

7.2.2.1 Impact considerations

According to the best available literature and knowledge reviewed, the following are the key impact considerations during the siting and project layout planning phase of offshore wind development.

Cable routing

Determining the appropriate cable route for the transmission line is arguably one of the most important steps when reducing environmental risk due to the amount of hard, biodiverse substrates in the Gulf of Maine; additionally, strategically placing the transmission infrastructure will reduce difficulties for maintenance activities during the operations phase of a project. Due to the wide variety of sandy, muddy, gravelly, and hard substrates found throughout the Gulf of Maine, it is highly biodiverse with benthic organisms which support a rich biodiversity of marine life of higher trophic levels.[30] This benthic biodiversity, in turn, is an attractant for other marine species that utilize benthic habitat for key spawning and nursery grounds and foraging areas for migratory marine species. Research has shown that sessile and attached epifaunal organisms have the lowest tolerance and highest mortality rate from sedimentation, with effects becoming more pronounced in areas with harder substrates due to longer lengths of time required for recolonization.[31] Therefore, avoiding hard substrate benthic habitat when cable routing to the best extent feasible is likely to reduce environmental impacts.

Navigation safety

Navigation safety is a universally significant impact consideration for any offshore development. Offshore wind development could impact various maritime activities that occur in the Gulf of Maine, such as transportation, shipping, and commercial and recreational fishing, and other recreational marine activities. The impact of an offshore wind farm's infrastructure on existing nearby navigation is typically addressed in the permitting process through a Navigation Safety Risk Assessment (NSRA). The NSRA is included in the COP process and is reviewed by the U.S. Coast Guard (USCG). Prior to the submission of a NSRA and COP, when developers are determining the location of offshore wind infrastructure, existing navigation safety measures need to be considered. The main influences on where structures can be constructed include minimum setback guidelines from existing routing measures, and ongoing USCG studies to identify if additional measures are needed to assure navigation safety.

[30] Thompson, C. "The Gulf of Maine in context: state of the Gulf of Maine report." Gulf of Maine Council on the Marine Environment, Dartmouth, NS (2010).

[31] Hiddink, Jan Geert, Simon Jennings, Marija Sciberras, Claire L. Szostek, Kathryn M. Hughes, Nick Ellis, Adriaan D. Rijnsdorp et al. "Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance." *Proceedings of the National Academy of Sciences* 114, no. 31 (2017): 8301-8306.

Landfall Planning

Determining the landfall location for a transmission export cable is constrained not only by sensitive benthic habitat along the Maine coastline, but also sensitive coastal bird habitat (particularly for federally protected piping plover [*Charadrius melodus*] and roseate tern [*Sterna dougallii*]), river outlets used by diadromous fish species (notably, federally-protected Atlantic sturgeon [*Acipenser oxyrhynchus oxyrhynchus*] and Atlantic salmon [*Salmo salar*]), commercial and recreational fishing activity, vessel traffic, potential sensitive onshore habitat, and limited developed onshore infrastructure. After the landfall location is chosen, further consideration needs to be taken for how the transmission cable is installed. Typically, offshore wind cables are installed in previously disturbed areas, such as near coastal industrial areas and along roads.

7.2.2.2 Best practices

The following measures are notable best practices for reducing potential environmental impacts during the siting and project layout phase of offshore wind development:

- **Conduct review of best available data and literature.** This best practice applies not only to siting and project layout, but also has positive implications on the other phases of the project. Information and data collected on marine population dynamics in the Gulf of Maine will be valuable when determining where to develop offshore wind. However, due to climate change having a significant impact on population shifts in the North Atlantic, it will be essential to continue to review emerging literature on how oceanic changes are causing marine populations to shift and impacting more vulnerable marine species.
- **Conduct comprehensive, spatially-explicit ecological surveys to understand baseline conditions.** It is important to collect environmental and biological data throughout project development in order to have scientifically-robust baseline conditions to utilize during assessment to determine the ecological impact of offshore wind during construction and operation.
- **Consult various stakeholders early and often.** While there is a wealth of literature and guidance documentation for offshore wind development on a federal level, offshore wind development is still a relatively new industry in the United States and, therefore, a unified effort to reduce overall impacts on existing resources is essential during development. Regarding environmental impacts and best practices, utilizing the expertise of local environmental scientists and fishing communities will be invaluable to gaining a deep understating of baseline conditions in the area prior to determining project siting and layout.

7.2.3 Construction phase

7.2.3.1 Impact considerations

According to the best available literature and knowledge reviewed, the following are the key impact considerations during the construction phase of offshore wind development. For the purposes of this initial report, the construction phase also includes the decommissioning phase, due to the relatively similar coverage of impact considerations for the two phases.

Project construction schedule

While the Gulf of Maine is a generally biodiverse environment that sustains a high abundance of marine life, the abundance and distribution of marine species in the region is largely driven by seasonal changes; therefore, the general occurrence of many marine species can be predetermined and considered when developing a project schedule.

Vessel traffic

Project transmission construction will require increased use from vessel traffic to transport infrastructure, equipment, and personnel between a port location and the project area. This increased vessel traffic may have impacts on marine life sensitive to noise and collisions, such as marine mammals and sea turtles. Vessel noise and vessel strikes may cause injury or habitat displacement to impacted marine species; however, these potential impacts are likely variable and would be contingent on species activity level, the proximity to the vessels, and its habituation to vessel traffic noise and vessel movements. Vessel strikes resulting in serious injury or death is a common cetacean mortality risk that can occur, mainly due to large commercial shipping container vessels; however, a variety of vessel classes have been involved in recorded strikes of marine animals, ranging from vessels less than 49 feet (ft; 15 meters [m]) to large, motorized vessels greater than 262 ft (80 m).[32]

Entanglement considerations

Marine entanglements have not been officially recorded at any offshore wind facilities; however, the risk may be increased as offshore wind development continues in coastal waters.[33,34] Entanglement risk is of particular consideration for marine mammals and sea turtles which are commonly impacted from entanglement in fishing gear debris and other anthropogenic detritus.[35] Based on the knowledge on marine life entanglement with marine debris, the potential for secondary entanglement (occurring when debris caught on equipment causes entanglement as opposed to the equipment alone) is predicted to be higher than primary entanglement (direct entanglement between marine life and the project equipment). While the diameter of industry standard mooring lines and equipment used at OSW facilities are generally seen to be too large to carry a notable entanglement risk for marine mammals and sea turtles,[36] the incidental attachment of derelict fishing gear and other marine debris could increase the likelihood of entanglement. Along with secondary entanglement, there is also emerging research on the potential impacts of tertiary entanglement, where entanglement risk is increased when the marine species is already impacted by entangled marine debris prior to coming in contact with the offshore wind equipment.

Cable placement, installation, & removal

While there is cabling infrastructure from various existing commercial industries within the Gulf of Maine,[37] the potential impacts of subsea cabling from OSW development must be assessed for transmission planning. The installation and removal of transmission infrastructure will alter some of the benthic habitat, resulting in effects associated with mortality and displacement of benthic marine life. These alterations are expected to be generally temporary, but some permanent impacts may occur for harder-substrate habitats; research has shown that benthic recolonization following disturbance can take several months for soft-bottom benthic habitats while it can take one to three years for hard-bottom benthic communities to fully recover.[38,39,40] These disturbances to benthic habitat are not expected to cause population-level impacts due to the relatively small disturbance footprint for subsea cabling. Seabed disturbance (and resulting sediment dispersion and re-sedimentation) is known to have physiological and behavioral impacts on benthic and shellfish organisms, with varying levels of tolerance depending on species sediment/substrate preferences. Sediment dispersion may smother sessile benthic species (i.e., epifauna) that are unable to unbury themselves once the excess sediment has settled back on the seafloor. Additionally, research has shown that sessile epifaunal organisms attached to hard seafloor substrates have the lowest tolerance and highest mortality rate from sedimentation and other habitat disturbances due to the longer lengths of time

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32 Schoeman, Renée P., Claire Patterson-Abrolat, and Stephanie Plön. "A global review of vessel collisions with marine animals." *Frontiers in Marine Science* 7 (2020): 292.

33 Farr, Hayley, Benjamin Ruttenberg, Ryan K. Walter, Yi-Hui Wang, and Crow White. "Potential environmental effects of deepwater floating offshore wind energy facilities." *Ocean & Coastal Management* 207 (2021): 105611.

34 Copping, A., and M. Grear. "Humpback whale encounter with offshore wind mooring lines and inter-array cables." *Report by Pacific Northwest National Laboratory, PNNL-27988* (2018): 34.

35 NOAA. "National Report on Large Whale Entanglements." (2018). Available online at: https://media.fisheries.noaa.gov/dam-migration/noaa_fisheries_whale_entanglement_report_web_final.pdf. Accessed January 2022.

36 Benjamins, Steven, Violette Harnois, H. C. M. Smith, Lars Johanning, Lucy Greenhill, Caroline Carter, and Ben Wilson. "Understanding the potential for marine megafauna entanglement risk from renewable marine energy developments." (2014).

37 Whitman, Joel. "A unified approach to Energy and Marine use planning when considering offshore wind cable infrastructure." Webinar from the Northeast Regional Ocean Council and Mid-Atlantic Regional Council on the Ocean,

38HDR. Benthic and Epifaunal Monitoring During Wind Turbine Installation and Operation at the Block Island Wind Farm, Rhode Island – Project Report. OCS Study BOEM 2020-044. (Washington, D.C.: U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, 2020).

39 Guarinello, M., D. Carey & L.B. Read. Year 1 Report for 2016 Summer Post‐Construction Surveys to Characterize Potential Impacts and Response of Hard Bottom Habitats to Anchor Placement at the Block Island Wind Farm (BIWF). (Newport, RI: INSPIRE Environmental, 2017).

40 Bureau of Ocean Energy Management. Commercial Wind Lease Issuance and Site Assessment Activities on the Atlantic Outer Continental Shelf Offshore Rhode Island and Massachusetts Revised Environmental Assessment. OCS EIS/EA BOEM 2013-1131. (Washington, D.C.: U.S. Department of the Interior Bureau of Ocean Energy Management Office of Renewable Energy Programs, 2013).

required for recolonization.[41] Benthic suspension feeders (i.e., infauna) are also sensitive to sediment deposition because increased turbidity in the water column can interfere with feeding and development.[42]

7.2.3.2 Best practices

The following measures are notable best practices for reducing potential environmental impacts during the construction phase of offshore wind development:

- **Develop construction schedule with seasonal and spatial considerations.** Consultation with federal and state wildlife agencies, environmental stakeholders, and fishing communities will be necessary to determine which time of year restrictions are required by federal law and are overall appropriate for the least amount of potential environmental and fisheries impacts due to construction activities.
- **Employ seasonal vessel speed restrictions and utilize vessel-based, NOAA-designated Protected Species Observers for monitoring throughout construction activities.** These best practices will likely be required by NOAA during construction in order to satisfy applicable permitting requirements, such as acquired incidental harassment authorization from NOAA for marine species that may be impacted by offshore wind construction activities.
- **Employ mooring line equipment expected to minimize entanglement risk and conduct regular monitoring of equipment for entangled marine gear/detritus and wildlife.** Preliminary research on marine entanglement risk indicates that catenary mooring line configurations that employ chains and nylon ropes pose the highest risk to megafauna due to injury from entanglement and abrasions; alternately, taut mooring line configurations were shown to be low risk for megafauna at floating offshore wind facilities.[43]
- **Employ industry standard construction methods to reduce benthic habitat disturbances.** Utilizing jet plowing to the extent possible has been shown to reduce sediment-related mortality and injury to benthic species, particularly those that occur in soft sediment areas. Burying transmission cabling to the greatest extent possible is considered best practice for reducing benthic habitat impacts; however, in areas where burial may not be possible, it is best practice to use concrete mattresses or rock dumping to reduce impacts from cable installation.
- **Leverage burial techniques with least environmental impact if cable installation through rocky substrates is necessary.** Horizontal directional drilling has been shown to be the least disruptive for cable installation through rocky areas and can facilitate the preservation of commercially and recreationally significant shellfish beds in the nearshore area.

7.2.4 Operations & maintenance

7.2.4.1 Impact considerations

According to the best available literature and knowledge reviewed, the following are the key impact considerations during the operations & maintenance (O&M) phase of offshore wind development.

Vessel traffic

Vessel traffic impacts from transmission maintenance will be similar (but likely to a lesser extent) to those that may occur during transmission installation and removal activities at the offshore wind facility (see Section 7.2.3).

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[41] Hiddink, Jan Geert, Simon Jennings, Marija Sciberras, Claire L. Szostek, Kathryn M. Hughes, Nick Ellis, Adriaan D. Rijnsdorp et al. "Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance." *Proceedings of the National Academy of Sciences* 114, no. 31 (2017): 8301-8306.

[42] Topçu, Nur Eda, Emre Turgay, Remziye Eda Yardımcı, Bülent Topaloğlu, Ahsen Yüksek, Terje M. Steinum, Süheyla Karataş, and Bayram Öztürk. "Impact of excessive sedimentation caused by anthropogenic activities on benthic suspension feeders in the Sea of Marmara." *Journal of the Marine Biological Association of the United Kingdom* 99, no. 5 (2019): 1075-1086.

[43] Harnois, Violette, Helen CM Smith, Steven Benjamins, and Lars Johanning. "Assessment of entanglement risk to marine megafauna due to offshore renewable energy mooring systems." *International Journal of Marine Energy* 11 (2015): 27-49.

Benthic habitat modifications

Benthic habitats that overlap with the offshore wind facility will likely be altered due to the prolonged presence of offshore wind infrastructure in the area and impacts associated with project O&M, such as water contamination and the introduction of non-native marine species. The introduction of offshore wind infrastructure in the ocean provides hard substrates which are suitable for colonization, particularly by epifaunal organisms. This occurrence has the potential to be a positive impact of offshore wind development due to the possibly increased species richness and biodiversity at the offshore wind facility due to what is often referred to as the "artificial reef effect." Research has shown that increased benthic species abundance and distribution does occur – in varying degrees – on or near offshore wind farms.[44,45] Further benthic habitat research efforts at operating offshore wind facilities are required due to the significant environmental differences and climate chance impacts of oceanic waters. The findings of the floating offshore wind research array proposed for the Gulf of Maine will likely provide a more accurate representation of expected reef effects following project construction.[46]

Because of the corrosive effects of saltwater on offshore wind infrastructure, chemical protection is often employed to prevent the corrosion and biofouling of the submerged offshore wind components. Typical corrosion and biofouling preventatives are epoxy-based coatings, a polyurethane topcoat, and cathodic protection.[47] These chemical coatings may potentially cause contamination to benthic organisms that colonize the submerged structures.[48] Research has shown that anti-corrosion substances may release inorganic compounds and metals such as zinc, aluminum, copper, and indium which can accumulate in epifauna attached to the structure, such as blue mussels. This increased accumulation of metals in benthic organisms can have direct or indirect effects on marine species; for example, a study found that copper pyrithione can induce morphological changes and oxidative stress in juvenile brook trout (*Salvelinus fontinalis*).[49] Limited research assessing the impacts of anti-biofouling substances on benthic habitat surrounding offshore oil and gas platforms have shown that low levels of toxicity can be recorded near the platforms, but they did not appear to have a notable impact on benthic colonization in those areas.[50] Further research is required to determine the actual effects of these biofouling protection substances which may cause regulatory changes to its usage at floating offshore wind facilities.

Significantly high anthropogenic activity in shallow and coastal waters increases the opportunities for the proliferation of non-native marine species. Particularly, vessel ballast water is a key vector for transmitting these species, which can have detrimental impacts on native marine species due to excessive predation, the spread of disease, and other factors that impact native marine species survivability.[51] While the risk of introducing invasive and non-native species exists during construction activities, the risk is enhanced during O&M due to the increased availability of colonization on offshore wind infrastructure.[52]

[44] Hutchison, Zoë L., Monique LaFrance Bartley, Steven Degraer, Paul English, Anwar Khan, Julia Livermore, Bob Rumes, and John W. King. "Offshore Wind Energy and Benthic Habitat Changes." *Oceanography* 33, no. 4 (2020): 58-69.

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[47] Price, Seth J., and Rita B. Figueira. "Corrosion protection systems and fatigue corrosion in offshore wind structures: current status and future perspectives." *Coatings* 7, no. 2 (2017): 25.

[48] Farr, Hayley, Benjamin Ruttenberg, Ryan K. Walter, Yi-Hui Wang, and Crow White. "Potential environmental effects of deepwater floating offshore wind energy facilities." *Ocean & Coastal Management* 207 (2021): 105611.

[49] Borg, Damon Andrew, and Louis David Trombetta. "Toxicity and bioaccumulation of the booster biocide copper pyrithione, copper 2-pyridinethiol-1-oxide, in gill tissues of Salvelinus fontinalis (brook trout)." *Toxicology and industrial health* 26, no. 3 (2010): 139-150.

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[51] Austen, M. C., T. P. Crowe, M. Elliott, D. M. Paterson, M. A. Peck, and S. Piraino. "VECTORS of change in the marine environment: Ecosystem and economic impacts and management implications." *Estuarine, Coastal and Shelf Science* 201 (2018): 1-6.

[52] De Mesel, Ilse, Francis Kerckhof, Alain Norro, Bob Rumes, and Steven Degraer. "Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species." *Hydrobiologia* 756, no. 1 (2015): 37-50.

Introduced electric and magnetic fields (EMF)

At offshore wind facilities, there is some introduction of EMF to the water column from energized inter-array cables and the transmission export cable which transports the generated electricity between the turbines and the offshore and onshore substations. With the projected significant development of offshore wind along the U.S. coastlines, there is an increased interest in the potential cumulative impacts of EMF on electro-magnetosensitive marine species; benthic and demersal invertebrate species are thought to be particularly vulnerable due to their proximity to the seafloor. However, the current literature has yet to identify notable potential impacts to EMF-sensitive species from introduced EMF. There is no evidence of marine species being impacted by the introduced EMF from an already extensive network of various subsea cabling in the Gulf of Maine. The current research has shown that some invertebrate species are able to detect changes in EMF, particularly lobster and crab species,[53,54,55] but the majority of research on EMF impacts are focused on assessing behavioral parameters for EMF-sensitive species and are based on modelling or *in situ* experiments as opposed to field research using realistic EMF expected from OSW transmission.[56] Regarding the potential difference in EMF impacts between DC and AC cabling, research is still in preliminary stages. Current studies indicate that DC cables may be more impactful to EMF-sensitive species because they emit EMF at a higher intensity and over a greater distance than AC cables.[57] Alternately, AC cables may be more impactful because they emit EMF similar to those naturally emitted by marine species and may affect the ability of some species to navigate or hunt (e.g., mimic prey bioelectric fields with no food to be gained). AC cables may be more frequently encountered than DC cables, which could also increase these impacts.

Because of industry-standard armored sheathing of subsea cables, electric fields are not expected to be emitted in the water column, but limited magnetic fields will be emitted from the cables. Research has shown that invertebrate species may be able to detect these magnetic fields and may redirect locomotion in response to the changes in the magnetic environment.[58] The use of geomagnetic fields for orientation and migration, however, is integrated with other environmental cues such as seabed slope, light, currents, and water temperature. Additionally, magnetic fields significantly decrease with distance from the cable which further minimizes potential exposure and detection.[59] Therefore, industry standard burial of subsea cables (generally at depths of two meters) will likely decrease the already limited magnetic fields expected to reach the water column.

7.2.4.2 Best practices

The following measures are notable best practices for reducing potential environmental impacts during the O&M phase of offshore wind development:

- **Employ industry standard vessel ballast water treatment methods.** Treatment of vessel ballast water is conducted to reduce the probability of introducing non-native and invasive marine species to project infrastructure.
- **Conduct multi-year monitoring of the epifaunal colonization of offshore wind facility structures, cables, and lines.** While the colonization of offshore wind infrastructure from some benthic species may occur relatively quickly (in less than a year), some benthic species – particularly sessile individuals that colonize hard substrates – will likely

[53] Hutchison, Z., P. Sigray, Haibo He, A. B. Gill, J. King, and C. Gibson. "Electromagnetic Field (EMF) impacts on elasmobranch (shark, rays, and skates) and American lobster movement and migration from direct current cables." *Sterling (VA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM* 3 (2018): 2018.

[54] Love, Milton S., Mary M. Nishimoto, Linda Snook, Donna M. Schroeder, and Ann Scarborough Bull. "A comparison of fishes and invertebrates living in the vicinity of energized and unenergized submarine power cables and natural sea floor off southern California, USA." *Journal of Renewable Energy* 2017 (2017).

[55] Tricas, Timothy C. *Effects of EMFs from undersea power cables on elasmobranchs and other marine species*. No. 9. DIANE Publishing, 2012.

[56] Hutchison, Zoë L., David H. Secor, and Andrew B. Gill. "The interaction between resource species and electromagnetic fields associated with electricity production by offshore wind farms." *Oceanography* 33, no. 4 (2020): 96-107.

[57] Gill, Andrew B., Ian Gloyne-Philips, Joel Kimber, and Peter Sigray. "Marine renewable energy, electromagnetic (EM) fields and EM-sensitive animals." In *Marine renewable energy technology and environmental interactions*, pp. 61-79. Springer, Dordrecht, 2014

[58] Gill, Andrew B. "Offshore renewable energy: ecological implications of generating electricity in the coastal zone." *Journal of applied ecology* 42, no. 4 (2005): 605-615.

[59] Hutchison, Zoë L., David H. Secor, and Andrew B. Gill. "The interaction between resource species and electromagnetic fields associated with electricity production by offshore wind farms." *Oceanography* 33, no. 4 (2020): 96-107.

require at least one to three years to complete the colonization of the infrastructure. Not only should monitoring occur to better understand this colonization process, but it should also be conducted to prevent the colonization or occurrence of potentially harmful, nonnative marine species.

- **Bury subsea cables to industry standard depths and use standard cable sheathing.** Magnetic fields in the water column have been shown to decrease as the above and lateral distances between the subsea cabling and sea bottom increase. Industry standard cable burial is typically 6 ft. (2 m) beneath the seafloor.

8 MAINE AND REGIONAL TRANSMISSION STRATEGIES

This section summarizes key strategies for consideration in transmission development in the Gulf of Maine. These strategies can be implemented by the State of Maine in coordination with stakeholders, other state and regional entities, developers, ISO-New England, and other relevant parties.

- **Stakeholder engagement early and often throughout transmission planning and development is critical to success.** Effective engagement should include the state, regional, and federal organizations with jurisdictional oversight for offshore transmission development, along with the development community and all affected and potentially affected parties, including fishing and ocean user communities as well as the general public.
- **Substation and cable technology choices in the Gulf of Maine are contingent upon regional and site-specific development needs and technology maturity**. The relatively large size (MW capacity) of the offshore wind projects anticipated in the Gulf of Maine and the potential distance of future lease areas from shore generally favors HVDC technology over HVAC, although it is possible to extend AC technology with additional reactive compensation and filtering measures. Floating offshore substation platforms (OSPs) are a viable choice based on Gulf of Maine bathymetry but the dynamic HV cables needed to withstand fatigue due to ocean movements require additional innovation to reach maturity.
- **Future offshore wind development in the Gulf of Maine would likely employ multiple transmission designs to take advantage of geographical and resiliency benefits of project development**. Some projects would likely connect directly to onshore points of interconnection (POIs) through bespoke or radial connections, while others would likely develop bundled and/or multi-terminal links to reduce cabling and provide offshore and onshore grid reliability benefits. Comprehensive cost benefit analyses and coordinated planning could enable state and regional entities to help determine the best transmission design approach within the context of overall long-term grid development.
- **Coordinated transmission planning is complex, but could provide an opportunity to strategically develop offshore wind in the Gulf of Maine.** The primary benefits of coordinated planning would be to ensure that the offshore transmission grid is flexible and capable of adapting with future needs and minimizing impacts on marine environments and ocean users. Coordinated planning is a complicated process that would require states and regional entities to work together and with many other stakeholders, including the regulated asset (utility) and developer communities, to best integrate offshore wind projects brought online by different entities and at different timelines as the industry matures. To date, coordinated offshore transmission has not been implemented in the United States, although some jurisdictions are exploring various approaches. Standardization of technologies and interconnection strategies is necessary to promote compatibility throughout and across multiple leasing and planning timetables. This type of approach would ideally minimize the amount of cable necessary to connect projects to the grid, thus mitigating impacts on marine environments and ocean users.
- **Offshore transmission ownership structures vary, and may have cost and deployment implications**. Regulated (such as utility or “Transco” owned) offshore transmission assets may have some advantages over merchant (developer) owned transmission. Regulated transmission structures may carry less risk to project completion, may have greater opportunities for standardization and coordination with other similar projects developed in the region, may have higher chances of allocation of costs to the wider region, and may have less cost recovery risk. Merchant owned transmission may work well for bespoke connections, and streamlined cost recovery mechanisms may minimize planning delays. Competitive, open processes tend to produce favorable financial results.
- **Selection of onshore POIs should consider numerous factors.** Key factors that affect onshore POI selection include the location of the offshore wind areas, grid reliability analyses, nearness of the substation to the shore, cost optimization of onshore and offshore cable lengths, onshore substation expandability, populated urban areas, impacts on the marine environment, and impacts on fishing and other near-shore activities.

- **Onshore grid updates may be required to provide grid reliability for the injection of significant new renewable energy, including offshore wind.** Prior state and regional analyses, as well as DNV's high-level injection analysis in this report (Section 6), suggest that while there's some availability, significant offshore wind development will necessitate some onshore grid upgrades to deliver energy and address grid reliability. There are ongoing studies at ISO-NE to examine grid upgrades necessary to support the integration of wind as well as other onshore resources through 2050.

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