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Offshore Wind Technology Scan

A review of offshore wind technologies and considerations in the context of Atlantic Canada

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Executive Summary

Offshore wind development offers an opportunity for a significant source of clean energy and has been explored by many countries around the world. In Canada, while interest has been expressed in offshore wind, no projects have been deployed to date. The *Canadian Energy Regulator Act*, which came into force in 2019, enables the Canada Energy Regulator to review and authorize offshore renewable energy activities, including wind, in Canada's offshore areas. Additional regulatory work and marine spatial planning activities underway support the realistic possibility of future offshore wind in Canadian waters.

The main focus of this report was an assessment of existing offshore wind technologies and a preliminary discussion on their applicability in Atlantic Canada. The report also identifies knowledge gaps where further scientific investigation is required.

The report is divided into five sections, each covering some of the major components of offshore wind technologies. Following the introduction, Sections 2 and 3 explore different turbine foundation types and construction methods, respectively. While fixed-bottom foundations remain dominant, floating wind is increasingly gaining attention across several jurisdictions. Canada's Atlantic offshore has limited areas that are obviously well-suited for fixed-bottom foundations, but further work is required to thoroughly characterize the geology with respect to offshore wind foundation suitability. Floating technologies could conceivably play a role in increasing the range of suitable areas.

Section 4 examines typical operating practices including the deployment of an effective maintenance regime that accounts for accessibility challenges to ensure maximum project availability. Methods for optimizing production through effective meteorological forecasting, avenues for the management of excess power, and meeting increasing load demands are discussed.

Section 5 describes known environmental impacts of offshore wind incurred over all three phases of the project lifecycle: construction, operation and decommissioning. Impacts from the construction phase are generally viewed as being intense, but short-lived, whereas impacts from the operation phase can often be longer-lasting and more complex. Canada has defined many different types of ecologically significant areas and the relevant legislation and administration of ecological protection laws and guidance is discussed, recognizing that further research will be required to characterize and mitigate ecological risk of offshore wind deployment in Canadian waters.

Finally, Section 6 presents an overview of specific conditions in Atlantic Canada relevant to offshore wind. Like many jurisdictions, Atlantic Canada's offshore region has a strong wind resource, with many locations that could be economically viable from a wind resource perspective. The geological conditions are potentially more challenging, as regions with similar geological characteristics to those where offshore wind has been developed in other jurisdictions are limited. Overall, the cold climate, coupled with complex geological and bathymetric conditions in Atlantic Canada result in a unique setting with various challenges for offshore wind, but learning from the industry developments in other jurisdictions, including recent development on the US Atlantic coast, can provide meaningful insight into a future Canadian offshore wind industry.

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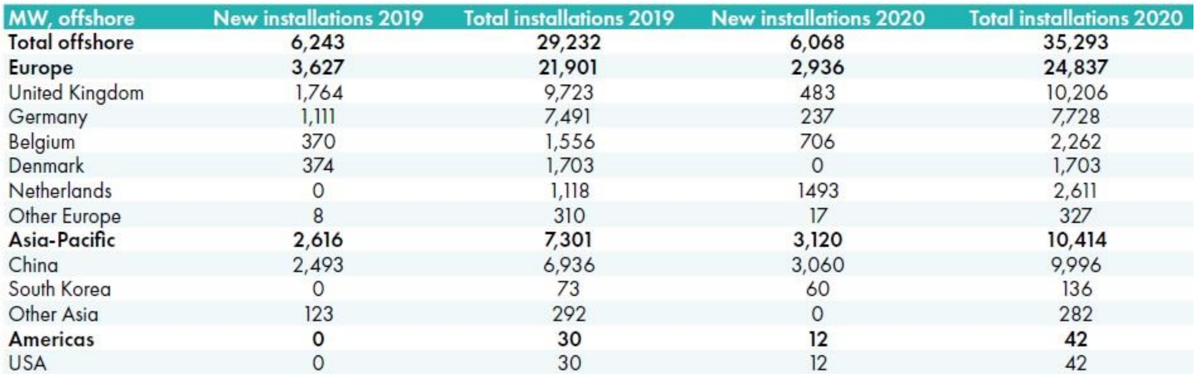
1. Introduction

1.1 Background

Offshore wind development offers an opportunity for a significant source of clean energy and has been used to displace fossil fuel based power generation in many jurisdictions around the world. Offshore wind generally offers higher capacity factors and lower variability relative to other variable renewable power sources such as onshore wind or solar [1]. Developers are also pursuing the possible benefits of co-locating offshore wind with other technologies such as hydrogen production or using offshore wind generation to decarbonize other carbon-intensive offshore activities. Figure 1.1.1 shows the breakdown of installed offshore wind capacity around the world as of the end of 2019 and 2020, respectively. Notably, the UK is still the world leader in terms of total capacity, but the fastest growing industry has been China in both years. In Canada, no projects have been deployed to date, however 3.6 GW of offshore wind has been proposed between the 400 MW Naikun project in BC to a number of projects totalling 3.2 GW proposed by Beothuk Energy in various locations in Atlantic Canada [2].



MW, offshore	New installations 2019	Total installations 2019	New installations 2020	Total installations 2020
Total offshore	**6,243**	**29,232**	**6,068**	**35,293**
Europe	**3,627**	**21,901**	**2,936**	**24,837**
United Kingdom	1,764	9,723	483	10,206
Germany	1,111	7,491	237	7,728
Belgium	370	1,556	706	2,262
Denmark	374	1,703	0	1,703
Netherlands	0	1,118	1493	2,611
Other Europe	8	310	17	327
Asia-Pacific	**2,616**	**7,301**	**3,120**	**10,414**
China	2,493	6,936	3,060	9,996
South Korea	0	73	60	136
Other Asia	123	292	0	282
Americas	**0**	**30**	**12**	**42**
USA	0	30	12	42

Figure 1.1.1: Global offshore wind installed capacity in 2019 an 2020 by country [3]

In 2019, the *Canadian Energy Regulator Act* (CERA)[1] came into effect, enabling the Canada Energy Regulator (CER) as the lifecycle regulator of offshore renewable energy projects in the federal offshore. The Department of Natural Resources Canada (NRCan) has since initiated the Offshore Renewable Energy Regulations (ORER)[2] Initiative, which aims to develop regulations that will apply to the exploration, construction, operation and decommissioning of offshore renewable energy projects including offshore wind. The Department of Fisheries and Oceans (DFO) is leading Marine Spatial Planning[3] efforts to better coordinate how marine spaces are used and managed to achieve ecological, economic, cultural and social objectives. Different branches of NRCan are performing work to further define the regulatory framework and characterise the geophysical environment. Canada is currently developing the Blue Economy

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[1] CERA: https://laws-lois.justice.gc.ca/eng/acts/C-15.1/

[2] NRCan's ORER: https://www.rncanengagenrcan.ca/en/collections/offshore-renewable-energy-regulations-initiative#s1

[3] DFO Marine Spatial Planning: https://www.dfo-mpo.gc.ca/oceans/management-gestion/msp-psm/index-eng.html

Strategy[4], which is expected to focus on a sustainable future harnessing of ocean energy resources. In the nearby jurisdiction of the US, the Department of Energy, Bureau of Ocean Management (DOE, BOEM) acts as the regulatory body for offshore wind in federal waters. It is expected that the CER will play a similar role as BOEM in reviewing and authorizing offshore wind activities in Canadian waters.

There are many aspects of an offshore wind industry that require more work to be done in Canada, particularly with respect to developing relevant policy, and understanding the technical considerations of offshore wind development. NRCan's CanmetENERGY-Ottawa (CE-O) and Renewable and Electrical Energy Division (REED) recognize the value in developing such knowledge. Following the report by CE-O titled *Jurisdictional scan of suitable area definition for offshore wind development*[5], which reviewed the regulatory processes for offshore wind in other countries, REED commissioned this report from CE-O to review the technology-centred aspects of offshore wind development with a particular focus on Atlantic Canada.

1.2 Objectives

This report examines current and emerging offshore wind energy technologies, specifically in consideration of the Atlantic Canada context, by:

- Reviewing typical construction methods and existing foundation technologies;
- Summarizing considerations during operation such as accessibility and plant balancing;
- Summarizing known interactions between offshore wind farms and their geophysical and biological environments along with Canada's methods for environmental protection; and,
- Reviewing current knowledge of the suitability of Canadian oceans for current and emerging offshore wind technologies, while identifying areas where further analysis is required.

The intention of this study is to provide background information and resources to policymakers, researchers and other stakeholders in the context of future offshore wind development in Canada. The main focus of the research was assessing existing offshore wind technologies and providing a preliminary discussion on their applicability in Atlantic Canada. The report also identifies knowledge gaps where further scientific investigation is required.

This report is not intended to provide an in-depth treatment of any particular topic but rather, it is intended to provide a broad stroke review of technical areas of interest, with a specific lens on the Canadian context. The report provides a number of references for more detailed analysis and review.

1.3 Scope

This report offers perspectives on considerations relevant to the industry as a whole, and where applicable, on considerations that are specific to a Canadian context. The geographic area of focus for this report is Canada's Atlantic region. Where applicable, references are made throughout the report to an initial study area generally encompassing the coastal waters between New Brunswick, Nova Scotia, Prince

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[4] Canada's Blue Economy Strategy: https://www.dfo-mpo.gc.ca/campaign-campagne/bes-seb/index-eng.html

[5] *Jurisdictional scan of suitable area definition for offshore wind* - https://doi.org/10.4095/328260

Edward Island, Southern Quebec and Western Newfoundland, extending into the Gulf of St. Lawrence, Sable Island Bank, and St. Pierre Bank. This area, referred to as the “study area” throughout this report, is expected to be relevant for possible early offshore wind considerations in Canada, however it should not be taken as a recommendation for offshore wind development in a particular location.

While the focus of this report is primarily offshore wind technologies that are currently in use in other countries, there is also some discussion of emerging technologies. As Canada’s offshore wind industry is currently undeveloped, technologies that are expected to be commercially available within the next ten years could be relevant to future development. The report is divided into sections discussing foundation technologies, construction methods, operating practices, environmental considerations, the offshore setting in Canada, and additional discussion.

2. Foundations

2.1 Overview

For offshore wind installations, the foundation acts to anchor the turbine in place and support its weight. Foundation types are generally categorized as either fixed or floating, each with several sub-types. As their names suggest, fixed foundations form part of a solid continuous structure extending from the seabed to the nacelle, while floating foundations employ a buoyancy mechanism allowing the turbine to float at the ocean's surface and a set of mooring lines secured to the ocean floor. While fixed foundations are currently much more common, as they are cheaper and simpler to implement in shallower waters, floating foundation technologies have the potential to unlock opportunities for offshore wind in deeper waters or under different subsea geological conditions where fixed foundations would not be feasible. Total potential capacity for floating wind turbines is high as approximately 80% of the world's offshore wind resource potential is found at depths greater than 60 metres [4].

2.2 Fixed Foundations

Figure 2.2.1 highlights the primary types of fixed foundations for offshore wind units. The foundations can be separated into two types of structures: base structures and support structures. For a fixed foundation system, both structure types are present, with the transition piece of the offshore wind unit connecting to the support structure, which is anchored or connected to the seabed through one or more base structures. Structure types vary in their usage, depths, and cost, as outlined in Figure 2.2.2 (with "suction bucket" referring to the same technology as "caisson" from Figure 2.2.1). Monopile foundations have been common in offshore wind development due to their versatility and simplicity in the shallower waters in which offshore wind has been deployed to date [5]. As offshore wind development extends to more distant and deeper waters, the increased stability of jacketed or tripod foundations has gained attention.

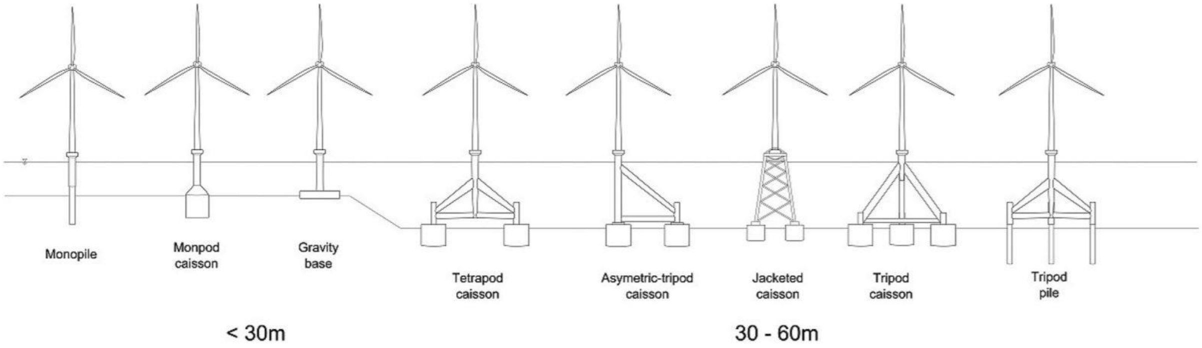
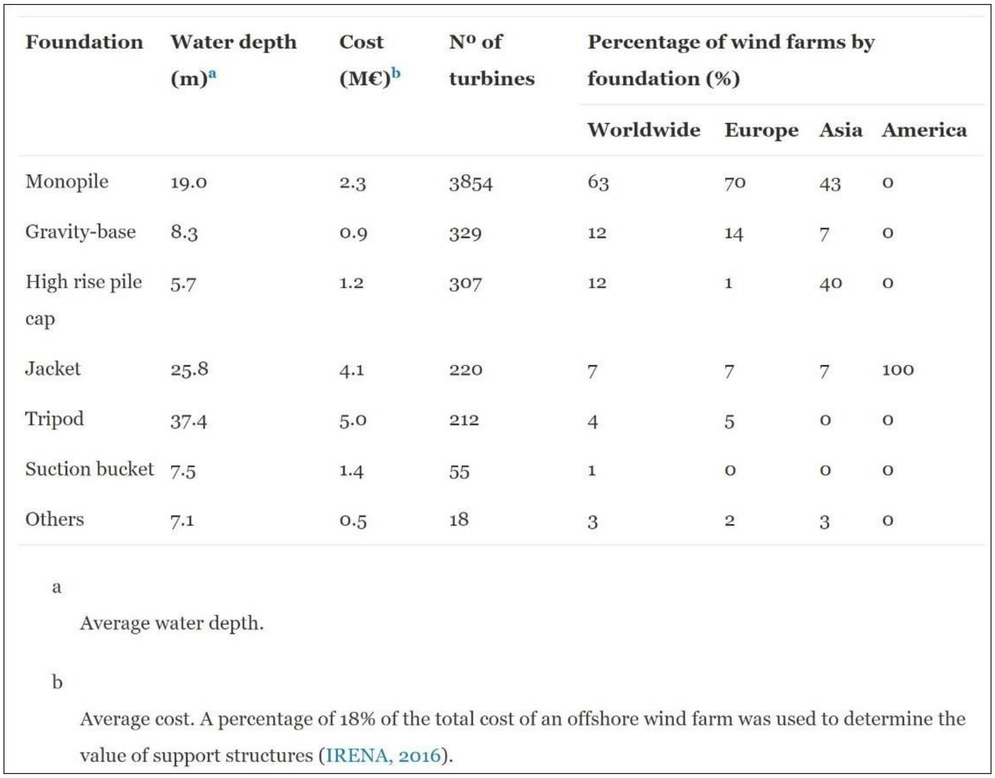


Figure 2.2.1: Fixed Foundation Types [6]



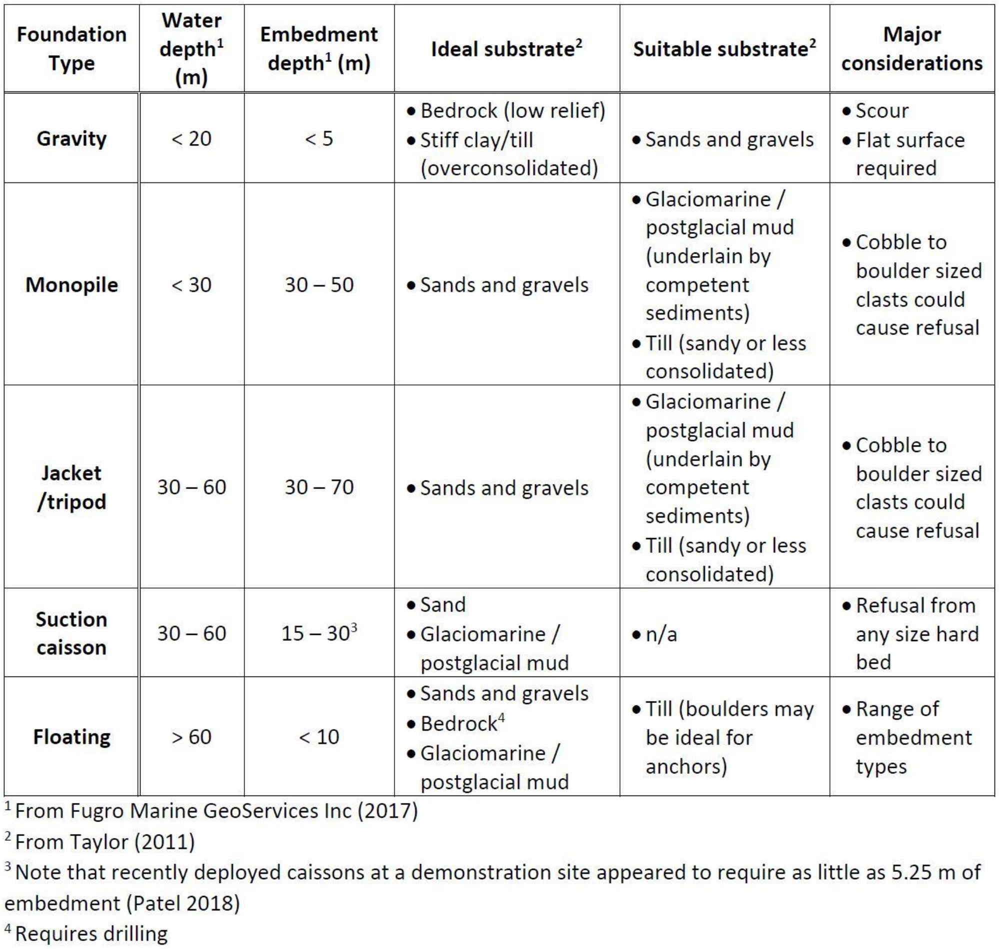
Foundation	Water depth (m)[a]	Cost (M€)[b]	Nº of turbines	Percentage of wind farms by foundation (%)			
				Worldwide	Europe	Asia	America
Monopile	19.0	2.3	3854	63	70	43	0
Gravity-base	8.3	0.9	329	12	14	7	0
High rise pile cap	5.7	1.2	307	12	1	40	0
Jacket	25.8	4.1	220	7	7	7	100
Tripod	37.4	5.0	212	4	5	0	0
Suction bucket	7.5	1.4	55	1	0	0	0
Others	7.1	0.5	18	3	2	3	0

[a] Average water depth.

[b] Average cost. A percentage of 18% of the total cost of an offshore wind farm was used to determine the value of support structures (IRENA, 2016).

Figure 2.2.2: Global distribution of offshore wind foundations [7]

For many fixed foundation types, including monopoles and jackets, a layer of scour protection composed of dumped rocks is often placed before installation around the base to avoid seabed erosion [8]. Including the scour protection, the total foundation footprint can range from 113 m^2 to 2830 m^2 depending on the foundation design [9]. Figure 2.2.3 provides an overview of the major foundation types for offshore wind turbines and the conditions in which they are most effectively employed in addition to other notable considerations.



Foundation Type	Water depth[1] (m)	Embedment depth[1] (m)	Ideal substrate[2]	Suitable substrate[2]	Major considerations
Gravity	< 20	< 5	• Bedrock (low relief) • Stiff clay/till (overconsolidated)	• Sands and gravels	• Scour • Flat surface required
Monopile	< 30	30 – 50	• Sands and gravels	• Glaciomarine / postglacial mud (underlain by competent sediments) • Till (sandy or less consolidated)	• Cobble to boulder sized clasts could cause refusal
Jacket /tripod	30 – 60	30 – 70	• Sands and gravels	• Glaciomarine / postglacial mud (underlain by competent sediments) • Till (sandy or less consolidated)	• Cobble to boulder sized clasts could cause refusal
Suction caisson	30 – 60	15 – 30[3]	• Sand • Glaciomarine / postglacial mud	• n/a	• Refusal from any size hard bed
Floating	> 60	< 10	• Sands and gravels • Bedrock[4] • Glaciomarine / postglacial mud	• Till (boulders may be ideal for anchors)	• Range of embedment types

[1] From Fugro Marine GeoServices Inc (2017)

[2] From Taylor (2011)

[3] Note that recently deployed caissons at a demonstration site appeared to require as little as 5.25 m of embedment (Patel 2018)

[4] Requires drilling

Figure 2.2.3: Suitable conditions and considerations for offshore wind foundation types [10]

2.2.1 Base Structure

Table 2.2.1 summarizes common fixed foundation base structure technologies, providing brief descriptions, and summarizing key benefits and drawbacks of the technologies.

Table 2.2.1: Fixed Foundation Base Structure Overview

Technology	Description	Benefits	Drawbacks	References
Pile	Large hollow steel or concrete tube driven into subsea surface	Good for soft soils with thick sedimentation, to drive piles into the seabed Simplistic and economic design Minimal seabed preparation requirements	Installation causes significant vibration noise and suspended sediments Stable platform such as jacked up barges required for installation Challenging to remove for decommissioning	[8, 11, 12, 13]
Suction Caisson / Suction Bucket	Upside-down bowl shape made of steel and set on sea floor. Contents in bowl are pumped out to create a suction seal	Less noise, vibrations, and suspended sediments than piles due to pumps instead of hammers, and less heavy equipment Simplistic design and faster installation/ decommissioning	Not suitable for shallow bedrock or strata with boulders, cobbles, or coarse gravel Sensitive to scour and seabed mobility due to shallow penetration depth Possible liquefaction potential if any large earthquake events occur	[13, 14, 15, 16, 17]
Gravity Base	Relies on mass and coverage area as opposed to subsea intrusion to keep structure in place, often built from concrete	Good for homogenous soils with compact rocks and granites Depths between 0 to 30 m Easy to remove on decommissioning	Size and weight result in expensive and time-consuming installation and limit deeper deployment Large seafloor footprint Large port space required for construction Soil must be strong enough to resist load from the support structure Soft soils can result in settlement, possibly differential settlement in heterogeneous soil	[17, 14, 18, 13]
Micropile	Collection of many small piles driven into surface.	Economical alternatives to caissons without compromising on performance Tension (uplift) capacity is a high percentage of the compression capacity Versatile – can be installed various ways depending on geological conditions	Currently unproven in subsea environments, but initial testing shows promise	[19, 20]

2.2.2 Support Structure

Table 2.2.2 summarizes common fixed foundation support structure technologies, providing brief descriptions, and summarizing key benefits and drawbacks of the technologies.

Table 2.2.2: Fixed Foundation Support Structure Overview

Technology	Description	Benefits	Issues	References
Monopole	Turbine mast is continuous with monopile support in one vertical structure	Depths between 0 to 30 m Simple design to fabricate	Less economic in deeper waters due to increase in materials needed for similar performance Often heavier due to the increased materials required	[8, 11, 12]
Jacketed / Lattice	Turbine mast affixed to lattice-work This design can be twisted around the centre column	Depths from 30 to 80 m Typically lighter than monopole foundations Greater area and mass distribution creates rigid supports Lower installation costs as structural elements can be partially or fully assembled prior to being floated for installation	More complicated construction process and increased maintenance costs compared to monopoles Additional corrosion protection measures required to prevent fatigue in structural components	[8, 12, 17]
Tripod / Tetrapod	Turbine mast affixed to structure of three or four poles either in centre or directly over a single point with remaining poles as supports	Depths between 25 to 50 m Offer resistance to dynamic loads such as waves and currents Similar installation to jacketed foundations	Expensive as they are difficult to construct and transport	[17]

2.3 Floating Foundations

As of the end of 2019, floating wind accounted for 65.7 MW globally between the UK, Japan, Portugal, Norway, and France, with up to 19 GW forecasted to be installed by 2030 [21]. With floating offshore wind technology opening up deeper waters for possible development, total global offshore wind potential could increase by a factor of 10 [21]. Regions suitable for fixed offshore wind generally have a water depth of less than 50 metres while floating offshore wind turbines can be deployed in water depths ranging from 50 metres to 1000 metres. There is significant potential for generation of clean energy from floating wind turbines given approximately 80% of the world’s offshore wind resource potential is found at depths greater than 60 metres [4].

2.3.1 Substructure Design

Floating foundations require a base or anchor structure in addition to a substructure design that provides enough buoyancy and stability to support a turbine’s weight and restrict pitch, roll, and heave motions to maintain acceptable levels of stability [22]. These floating foundations are relatively undeveloped compared to the more familiar fixed foundations, with only a handful of proven technologies and companies currently developing projects with these foundations. Typical floating foundation substructure technologies are pictured in Figure 2.3.1 and summarized in Table 2.3.1. Other platform technologies exist, such as multi-turbine and hybrid wind-wave platforms but these options are currently even less mature [23].

Figure 2.3.1: Offshore wind floating substructure designs: spar buoy (left), semisubmersible (middle), and tension-leg platform (right) [24]

Table 2.3.1: Floating Foundation Substructure Design Overview

Technology	**Description**	**Advantage**	**Disadvantage**	**References**
Semi-submersible	Buoyancy stabilised platform which floats semi-submerged on the surface of the ocean. Uses a taut leg or catenary mooring system	Suitable for 10 – 40 m depths Low draft allows for more flexible application and simpler installation Shallow draft allows for onshore assembly and wet tow to installation site	Requires a large and heavy structure to maintain stability Large infrastructure required for complex steel structure fabrication and installation	[23, 25]
Spar buoy	Cylindrical ballast-stabilized structure which gains its stability from having the centre of gravity lower in the water than the centre of buoyancy	Suitable for depths greater than 100 m Relatively simple fabrication Better heave performance compared to semi-submersibles	Large draft requirement can create logistical challenges (transportation, assembly, installation, maintenance) Increased pitch and roll motions	[23, 25]
Tension leg	Semi-submerged buoyant structure anchored to the seabed with tensioned mooring lines	Suitable for depths less than 60 m Shallow draft and tension stability allow for smaller and lighter structure Good heave and angular motions Good for intermediate water depths due to limited platform motions	Increased stresses on tendon and anchor system, tension changes due to tidal variation Complexity and cost of the mooring installation Operational risks if tendon fails	[23, 25]

2.3.2 Anchors

Floating wind foundations require anchor systems to hold the platform in place and to resist forces applied to the turbine assembly. The most important factor when selecting an anchor is the load or holding capacity, which is influenced by a variety of factors including soil conditions, subsea geology, anchor embedment depth, direction of applied forces and placement of anchors relative to the platform [27]. For different platform systems discussed in the previous subsection, different mooring systems are required, which also affects the anchor selection. A summary of typical floating foundation anchor technologies is presented in Table 2.3.2. Figure 2.3.2 displays visual examples of different types of anchors.

Table 2.3.2: Floating Foundation Anchor Overview

Technology	**Description**	**Notes**	**References**
Gravity anchor	Heavy weights designed to resist vertical and horizontal forces	Inexpensive raw materials Often used in tension leg platforms	[27]
Drag embedment	Placed on the seabed and then dragged until a secure depth is reached	One of the lowest cost anchor types, but complex installation Great for catenary mooring systems Massive amounts of material for desired capacity	[28]
Driven pile anchor	Similar to the driven piles in fixed foundations, piles driven into the seabed	Proven ability in offshore oil and gas industry Great for vertical loading Precise and permanent installation	[27]
Suction anchor	Similar to caissons, water is pumped out of the upside-down bucket to create suction to the seabed	Most effective for catenary, much more effective for vertical loading than drag embedded anchors Simple to install accurately	[27, 29]
Driven anchor plate	This plate is inserted into the soil through the suction method or driven into place	Similar to the suction anchor but uses fewer materials Plate applies force against larger wedge of soil	[27]
Torpedo	This anchor drives itself into the sea floor from its own kinetic energy (with the help of a driven plate tip)	One of the least expensive options due to fewer materials and simple installation process	[27]
Drilled and grouted plate	Similar in shape to a driven pile, its anchoring spot is drilled, and the pile is grouted	Option for tough soil conditions or rock sea floors where the other methods are too expensive or aren't feasible Much more expensive than driven piles	[27]

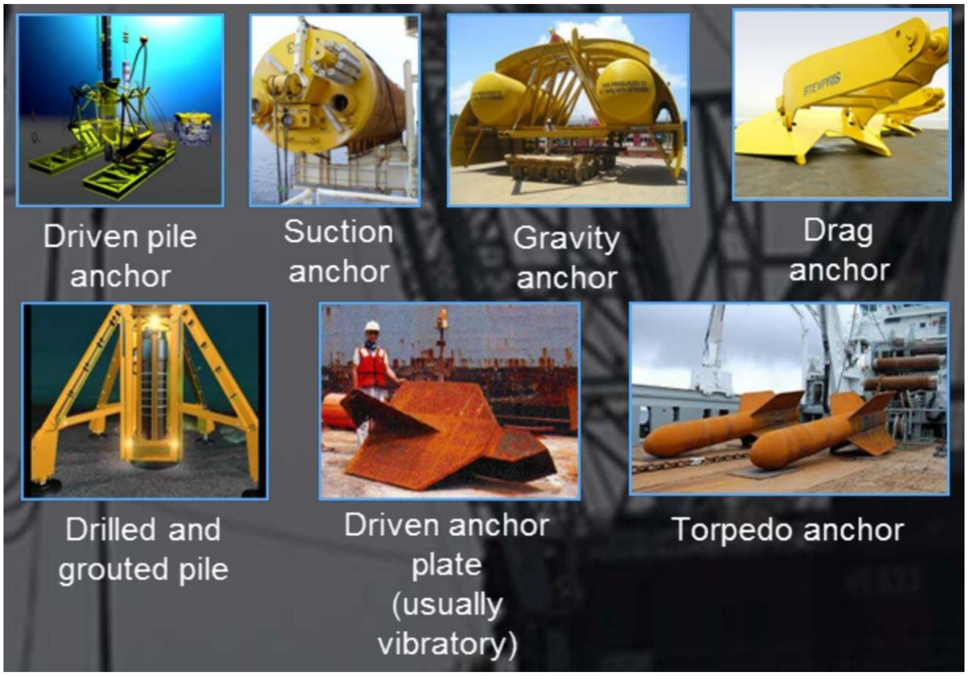
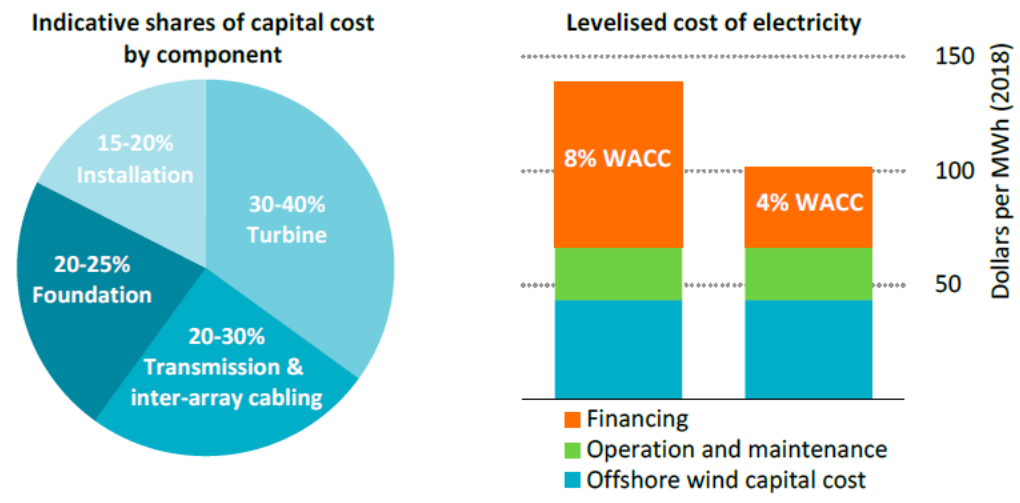


Figure 2.3.2: Floating wind anchor types [26]

3. Construction

3.1 Overview

Construction methods for offshore wind turbines vary depending on the type of foundation technology employed. Generally, for turbines with fixed foundations, components are transported to site and assembly is completed in situ while turbines with floating foundations can be fully fabricated onshore and floated to the site. Once floating wind turbines have been transported to the site, the foundations are moored to the seabed by anchor systems. The onshore construction of floating wind turbines saves time and reduces costs because it avoids the complexity of offshore construction. In the UK, the offshore wind construction process typically takes about three years, with some smaller projects only taking a single year to be built [30]. IRENA reported that as of 2019, the Levelized Cost of Energy (LCOE) of offshore wind had fallen to a global average below USD 150 / MWh[6], with the average cost breakdown by project component shown in Figure 3.1.1 [1]. Between capital and financing costs, offshore wind is very capital-intensive, although construction costs are projected to continue to fall as technologies and methods improve and greater economies of scale are achieved [1].



Offshore wind generation costs are heavily influenced by the cost of capital and were about $100/MWh for projects completed in 2018 based on low financing costs

Notes: WACC = weighted average cost of capital; Transmission includes offshore substations.

Source: IEA analysis based on IRENA (2019), IJGlobal (2019) and BNEF (2019).

Figure 3.1.1: Offshore wind capital cost and LCOE breakdown for projects completed in 2018 [1]

The first offshore wind farms constructed from 1991-2000 were almost exclusively built in waters less than 5 m deep and at distances of less than 3 km from shore. Since then, the average installation depth

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[6] Onshore wind was still reported being significantly cheaper, with an LCOE in 2019 of USD 53 / MWh, however Denmark had an average offshore wind LCOE of USD 87 / MWh and costs are projected to continue rapidly declining

and distance from shore has steadily increased; by 2014, the average water depth was over 20 m and the average distance from shore over 30 km [31]. Projects are currently being planned at depths of up to 215 m and at distances up to 200 km from shore.

The Canadian *Coasting Trade Act* is similar to the US's *Jones Act* where it limits the usage of foreign vessels, but the Canadian regulations have provisions to allow for foreign vessels to acquire licenses to operate in the offshore for a certain period of time or in circumstances where there are no Canadian-registered vessels available [32]. The *Coasting Trade Act* reserves coasting trade to Canadian duty paid vessels and provides coasting trade licences for temporary import of foreign or non-duty paid vessels when suitable Canadian vessels are unavailable [32]. Depending on the types of technologies being employed for possible Canadian developments, if they are being imported internationally, the *Coasting Trade Act* can result in complications that need to be considered for project development.

3.2 Turbine

For offshore wind projects, a staging port is often required for pre-assembly and construction. For floating wind turbines, a fully fabricated turbine and foundation can be constructed at the port and floated to the site by a towing vessel. Different locations may be used as staging grounds to supply foundations and wind turbine components to the wind farm [33]. Port location will influence several aspects of the construction process including time spent in shipment and sensitivity to weather windows [33]. Typical requirements for port facilities are identified as [33]:

- At least eight hectares suitable for laydown and preassembly of product;
- Quayside (side of platform either along or in the water used to load and unload vessels) of length 200–300 m with high load bearing capacity and adjacent access;
- Water access to accommodate vessels up to 140 m length, 45 m beam and 6 m draft with no tidal or other access restrictions; and,
- Overhead clearance to sea of 100 m minimum (to allow vertical shipment of towers); and sites with greater weather restrictions or for larger scale construction may require an additional laydown area, up to 30 hectares.

For fixed foundations, installation vessels typically have storage space to hold components as well as some lifting equipment to install the turbine. Once the components are loaded onto the vessel, they are transported to the site. The installation vessel needs to be jacked up above the water so it is unaffected by the movement of the water, allowing for smoother installation of components. A visual depiction of this type of installation vessel can be seen in Figure 3.2.1. Once the vessel is jacked up, the components can be lifted by crane and installed into place. This process involves installation of the foundation and tower sections first, followed by the nacelle and the hub, with the blades being installed on the hub last [34]. This may vary slightly if any turbine components are pre-assembled prior to arriving at the site. Due to the heavy lifting and cranes required, the offshore installation process can often be limited by wind speeds and other weather conditions, adding to the complexity of installation logistics. For installation approach and types of vessels used for fixed bottom foundations in deeper waters, the logistics are very similar, but the distance from shore and depths require heavier foundation designs which necessitate larger installation vessels and cranes. The installation phase is often a bottleneck for offshore wind projects, and a significant study area for reducing costs and solving logistical challenges [34].

Figure 3.2.1: Offshore wind turbine being erected by a crane from a jack up vessel [35]

3.3 Substations

Offshore substations are designed to collect the generated power while stabilizing and optimizing the voltage to reduce losses and effectively transmit the power to shore. This is accomplished in part by stepping up the voltage from the turbines through the array cables rated at around 33-36 kV, to the export cables rated at higher voltages such as 132 kV. Projects located farther than 15 km from shore generally require at least one substation, with the total number of substations dependent on the transmission distance and capacity requirements, as well as other design considerations such as redundancy and reliability, maintenance strategy, reactive compensation requirements, and overall substation network design [36]. Due to the large weight requirements for substation components, jacket foundations are typically used as they are the most economical for heavy load cases. Substations are typically installed using large installation barges and cranes, although there are some self-installing substations that can be employed to reduce the vessel requirements [36].

3.4 Cables

Connecting the substations, turbines and onshore equipment, cables deliver the power output from the wind turbines to shore. Cable systems consist of array cables, export cables, and cable protection. Array cables connect the turbines and the offshore substation, with the total length per turbine being around 1 km, and they are generally rated at 33-36 kV [33]. Array cables can be laid out in a variety of configurations, such as a spider arrangement with a small number of turbines per cable connected to the substation, or in a longer series of chains with 6-10 turbines on each. Often, as it is not possible to plow close to the turbine and substations using the large equipment typically used, a remotely operated trenching vehicle is used to bury the cables.

Export cables exist between the onshore and offshore substations and are installed by being buried in the seabed (typically 1.5-3 m in depth). They are typically rated at 132 kV, although there have been some cables deployed at 245 kV as emerging high voltage cables become increasingly viable although they are not as commercialized [33]. As minimizing subsea connections is desirable, export cable sections are laid so as to maximize their length (up to 70 km per section). Currently, installation of these cables are seen as a significant constraint to the sector as there are a limited number of vessels equipped to do this and very few companies with the necessary expertise [33]. Typically, a cable ship tows a plough and cable laying machine that ploughs through the soil and separates the sediment while providing room for the cables to be placed at the desired depths [33]. One minimally invasive and common alternative to mechanical ploughing is a process called 'hydro-ploughing' where a high-powered jet fluidizes the pathway, with the cables being laid and buried as the sediment settles as can be seen in Figure 3.4.1.

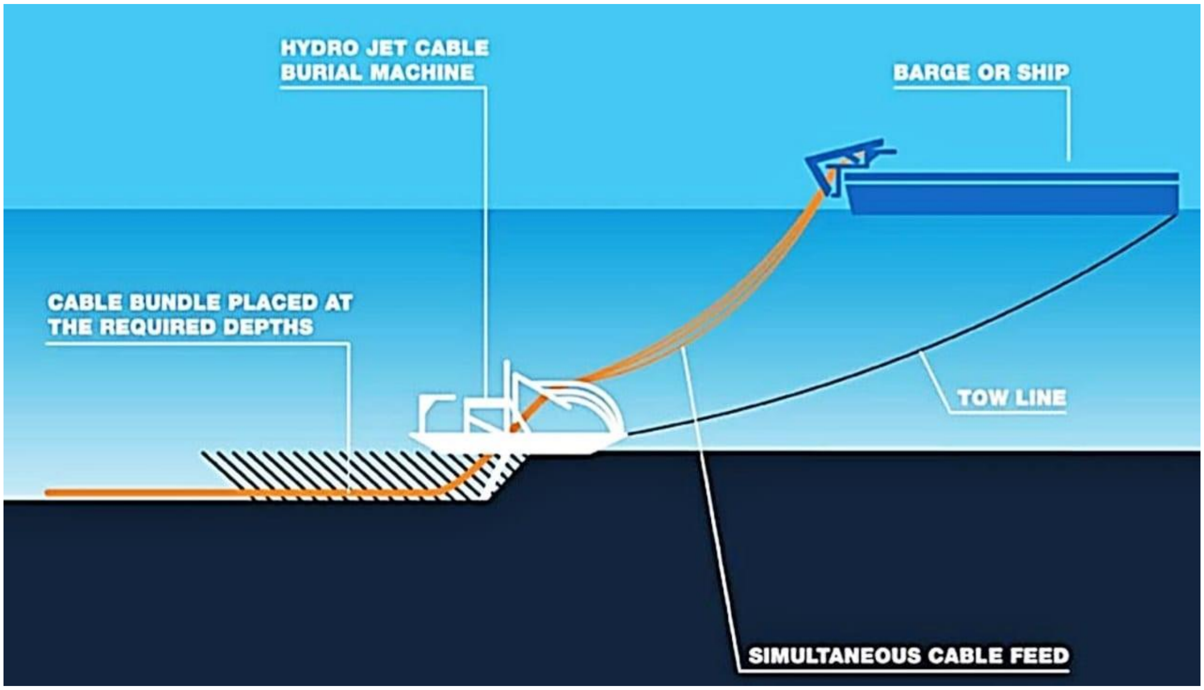

Figure 3.4.1: Subsea cable installation [37]

As cable integrity can often be a problem area that has resulted in several significant insurance claims,[7] cable protection is necessary at various vulnerable points in the system [33]. J-tube seals (which can be passive or active) are used to protect the cabling between the bottom of the sea and the top of the turbine, to prevent the cables from contact with seawater. Bend restrictors prevent damage caused by excessive bending. Cable stiffeners are used for protection and can weigh down the exposed cable. Finally, cable mats also protect the exposed areas of cable, particularly in locations where they cannot be buried.

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[7] For example, this recently occurred at Block Island Wind Farm in the US: https://www.ecori.org/renewable-energy/2019/5/24/wind-farm-power-cables-exosed-at-block-island-beach

4. Operating Practices

4.1 Maintenance and Accessibility

Once an offshore wind farm has been fully commissioned, it enters into the operational stage of its project lifecycle. Due to the technical challenges with accessing offshore wind turbines, an effective operation and maintenance (O&M) strategy is an important aspect of project planning [38]. A selected O&M strategy is employed to balance various considerations including availability, revenue generation, personnel health and safety, and asset health [38]. A typical O&M lifecycle involves the following phases [38]:

- **Pre-Operations** – planning and development of strategies, plans, and systems
- **Warranty Operations** – standard operation
- **Post-Warranty Operations** – standard operation with additional integrity review and planning of possible corrective actions
- **Extended Life/End of Life** – assessing and implementing life extension plan, or proceeding with decommissioning

As offshore wind farms move steadily to waters farther from shore, accessibility becomes a greater challenge, and O&M activities can end up contributing up to 30% of the LCOE for a project [39]. When a turbine is in need of maintenance and shuts down, the accessibility challenges can result in extended downtime for a turbine thus there has been significant incentive in the industry to develop access systems that can maximize turbine availability [39]. The distance from an offshore wind farm to port impacts the relative cost and logistics of O&M activities, with 70 nm cited as a cut-off for near vs. offshore operations in Europe [39]. For near-shore operations, medium-sized crew transfer vessels (CTVs) are generally employed, with helicopter support if conditions would make a boat transfer too long or difficult [39]. As it is beneficial to minimize technician travel time, wind farms operating increasingly farther from shore employ Dynamic Positioning (DP) vessels[8] as offshore bases for operations [39]. Common features of DP vessels include [39]:

- Accommodations for up to 75 technicians;
- Large size, longer than 50 m;
- Storage of common small-sized spare parts; and,
- Helicopter landing capabilities.

4.2 Meteorological Forecasting

While offshore wind is an inherently variable power source based on wind speeds, newer offshore wind projects can achieve capacity factors of 40-50% and can experience less hourly variability than onshore wind or solar photo-voltaic technologies [1]. Even with more consistent wind speeds offshore, being able to predict the meteorological conditions in a given location allow wind farm operators to optimize availability, protect personnel and equipment, and plan access schedules for maintenance. In Canada, ECCC provides marine meteorological monitoring, modelling, and forecasting services [40]. The

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[8] Most common DP vessels are referred to as Service Operation Vessels (SOV) or Walk-to-Work (W2W) vessels [39]

forecasting process involves analysing meteorological conditions twice a day for ECCC's numerical weather prediction models to develop predictions based on this data [40]. ECCC produces a wide range of forecast types, including regional and global deterministic prediction systems, along with models targeting more specific conditions like air quality, wave conditions, or severe weather [40]. Figure 4.2.1 displays ECCC's meteorological radar station locations in Atlantic Canada and their coverage including offshore areas in and around the Maritimes [41]. Similar services also exist in other jurisdictions, such as the Maritime & Coastguard Agency's (MCA) Met Office in the UK, or the National Oceanographic and Atmospheric Administration's National Weather Service (NOAA/NWS) in the US [42, 43].

In addition to publicly available ECCC services, there are also a number of other meteorological models that can be employed for forecasting services. A few examples of global wind forecast models (with the exception of the rapid refresh models which cover North America exclusively) can be found in Table 4.2.1.

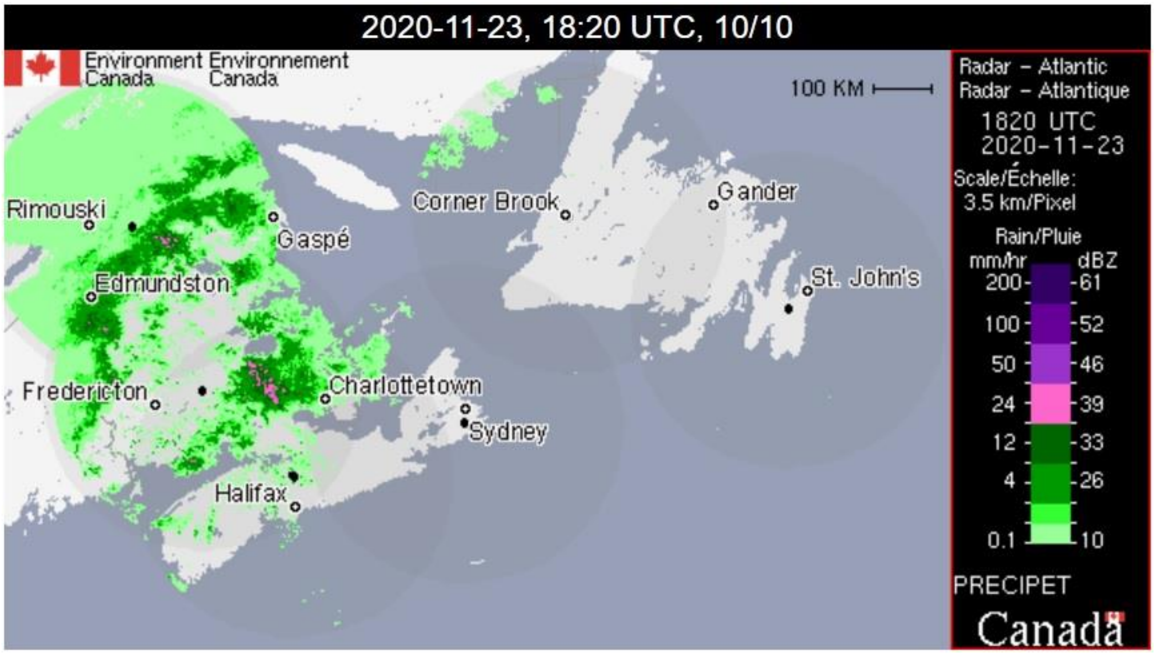

Figure 4.2.1: ECCC meteorological radar station coverage in Atlantic Canada [41]

Table 4.2.1: Meteorological Forecast Models

Dataset[9]	**Distributor**[10]	**Spatial Resolution**	**Link**
WRF-ARW	NCAR	Flexible (tens m - thousands km)	https://www2.mmm.ucar.edu/wrf/users/
RAP	NOAA/NCEP	13 km	https://rapidrefresh.noaa.gov/
HRRR	NOAA/NCEP	3 km	https://rapidrefresh.noaa.gov/
IFS	ECMWF		https://www.ecmwf.int/en/forecasts/accessing-forecasts
GFS	NCEP	28-70 km	https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs

4.3 Production Management

Offshore wind farms have the potential to produce significant amounts of energy, however due to fluctuating loads, wind speeds, and instances of transmission congestion, the electricity grid may not always be able to accept it. The power output from an offshore wind farm must be managed effectively to ensure grid stability and to maximize efficiency. Smaller quantities of offshore wind generation can be simpler from an energy management point of view, but there are multiple options available for handling excess availability.

The most straight-forward method for handling power supply in excess of an identified demand is to curtail an offshore wind farm's turbines so that they are producing less power. While simple and effective, during the time when a farm is curtailed, it typically means the power supplier and/or buyer are losing money depending on the details of the power purchase agreement in place. Under many of these agreements in Canada for onshore wind, the supplier is compensated for power produced by the facility that cannot be accepted by the grid [38].

Some work has been done in the Atlantic Canada region to quantify the areas where potential offshore wind power could be most efficiently integrated into nearby power systems [44]. In such areas, new wind power can be developed while minimizing the need for additional balancing services in the form of dispatchable generation that represents an economic cost to a given electricity system [44]. In their review of potential wind power locations in Atlantic Canada, Pearre and Swan identify a number of offshore areas that could be most suitable for wind power integration into nearby systems based on correlation to existing wind, correlation to net loads, time shift from existing wind resource, and relative capacity value of wind resource [44]. An indication of the results is displayed in Figure 4.3.1, where promising locations

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[9] Advanced Research Weather Research and Forecasting Model (WRF-ARW); 13-km Rapid Refresh (RAP); 3-km High-Resolution Rapid Refresh (HRRR); Integrated Forecast System (IFS); Global Forecast System (GFS)

[10] National Centre for Atmospheric Research (NCAR); US National Oceanographic and Atmospheric Administration (NOAA); US National Centre for Environmental Prediction (NCEP); European Centre for Medium Range Weather Forecasts (ECMWF)

are represented as areas where the consideration layers overlap. Of particular note are the regions around the mouth of the Bay of Fundy (~ 44.5°, -67°) and surrounding Sable Island (~ 44°, 60°).

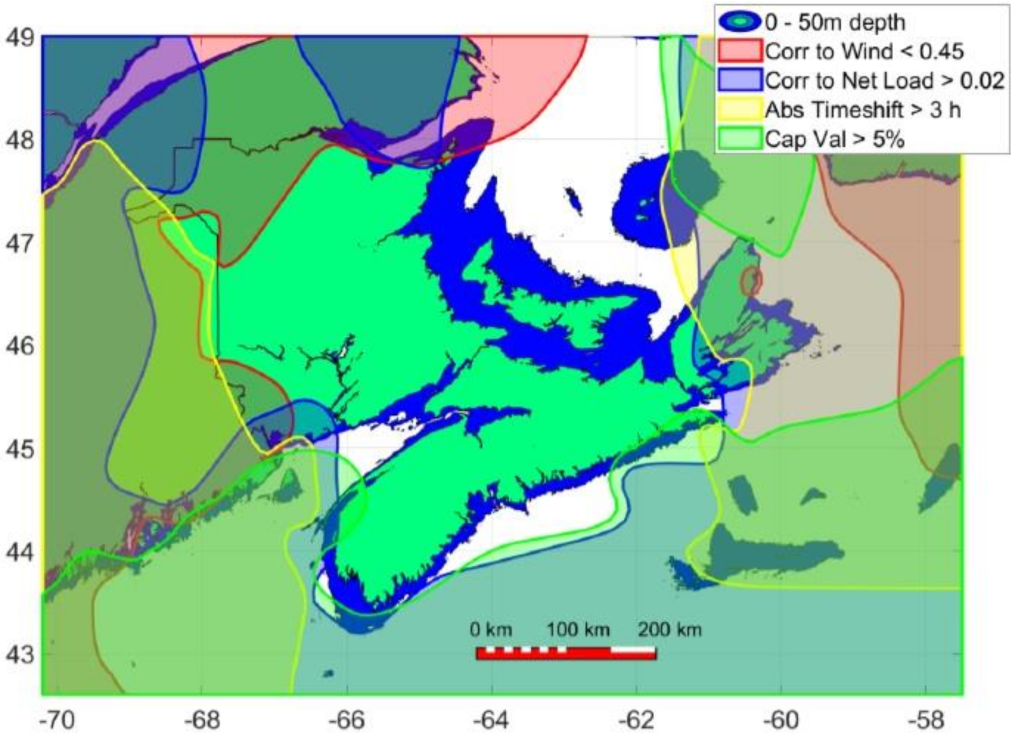

Figure 4.3.1: Geo-spatial Venn diagram indicating areas of shallow water, low correlation to existing wind, high correlation to load, high time shift, and high relative capacity value in Atlantic Canada [44]

4.4 Alternative Demand for Electricity Production

4.4.1 Hydrogen Production

One option being explored in other jurisdictions is the use of offshore wind energy for the production of hydrogen fuel to manage overall production and to offer an avenue to increase overall production in response to increases in demand. In the UK for example, with the highest offshore wind capacity in the world, potential hydrogen production is a significant element of its offshore wind integration plan [45]. With the correct infrastructure in place, the production of hydrogen fuel can offer promising options for the storage and transportation of offshore wind energy, possibly leveraging decommissioned oil and gas (O&G) assets, with the possibility of reusing the pipelines to transport hydrogen being assessed, although simply leveraging an existing right-of-way underwater could itself provide significant benefits to new infrastructure [46]. Table 4.4.1 presents a few example projects in Europe that are pursuing the idea of offshore wind to hydrogen generation.

Table 4.4.1: Example of offshore wind to hydrogen projects in planning or development

Project	**Country**	**Points of Interest**	**Ref.**
Gigastack	UK	Ørsted, ITM Power, Phillips 66 ltd, and Element Energy performing Front-End Engineering Design study on a 100 MW electrolyser system	[47]
Hyoffwind	Belgium	Parkwind, Fluxys, and Eoly developing a 25 MW electrolyzer in Zeebrugge planned to be commissioned early 2023	[48]
NortH2	Netherlands	Shell and Gasunie developing 10 GW of offshore wind by 2040 powering green hydrogen	[49]
Port of Rotterdam	Netherlands	Shell planning to build a 200 MW green hydrogen plant for 2023	[50]
O&G Decarb innovation project	Denmark	Various Danish organizations and French company Total exploring including hydrogen production for a floating wind and wave plant to be used to power O&G infrastructure	[51]
Dolphyn	UK	Environmental Resources Management received go ahead for 2 MW floating offshore wind to hydrogen prototype facility, expected in the early-mid 2020s	[52]

4.4.2 Fossil Fuel Displacement

Offshore wind offers avenues for the decarbonisation of existing O&G industries by being well-suited for powering offshore O&G rigs or possibly through carbon capture processes. Hywind Tampen, slated for construction 140 km off the Norwegian coast beginning in 2022, will be the world's first renewable power dedicated to powering O&G platforms [53]. At 88 MW, the wind farm will also be the largest floating wind farm in the world when completed and is expected to offset about 35% of the annual power demand of the connected O&G platforms (Snorre A and B; Gullfaks A, B, and C) representing about 200,000 tonnes CO_2 equivalent emissions reductions per year [53]. The project aims to advance offshore wind technology while simultaneously demonstrating the opportunity available for offshore wind in the O&G industry [53]. Carbon capture and storage or utilisation is also an option that has begun to gain interest in the offshore wind industry as a way to pull carbon dioxide from the atmosphere or industrial processes which can work to decarbonize fossil fuel activities or offer an avenue for additional energy demand in a renewable energy-focused project [54]. The carbon dioxide collected in this process can be used as a resource for various products and services, or be stored underground in geological formations [54]. Various companies and organizations are exploring carbon capture in conjunction with offshore wind such as the Crown Estate, and their Offshore Wind and Carbon Capture Usage and Storage Forum (CCUS)[11], and Ørsted's planned addition of carbon capture to their Aflandshage offshore wind farm[12] in conjunction with a straw-fired boiler.

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[11] Crown Estate CCUS: https://renews.biz/70816/crown-estate-launches-offshore-wind-carbon-capture-forum/

[12] Aflandshage carbon capture: https://www.offshorewind.biz/2021/06/15/orsted-adds-carbon-capture-to-its-offshore-wind-powered-project-in-denmark/

In Canada, offshore oil has historically been produced by four projects in the Newfoundland and Labrador offshore region (Hibernia, Terra Nova, White Rose, and Hebron), in addition to two crude oil producing satellite fields (North Amethyst connected to White Rose and Hibernia South as an extension of Hibernia) [55]. In 2020, these projects produced about 7% of Canada's total oil (~285,000 barrels/day) [56]. There are also plans in place for a fifth project, The Bay du Nord, which could be operational in 2025 pending upcoming investment decisions [57]. While Canada has also had offshore natural gas production off the coast of Nova Scotia, the two projects, Deep Panuke and Sable Offshore Energy Project, both ceased operations in 2018 with plans in place to abandon the projects leaving the pipelines in place [58]. Canada's existing and potential future offshore oil infrastructure may provide possible synergies for offshore wind, where on-site renewable power can help offset the energy requirements for extraction and production.

5. Environmental Considerations

5.1 Environmental Impacts of Offshore Wind Projects

5.1.1 Overview

Environmental impacts of offshore wind projects are incurred over all three phases of the project lifecycle: construction, operation, and decommissioning. Impacts from the construction phase are generally viewed as being intense, but short-lived, whereas impacts from the operation phase can often be longer-lasting and more complex. To date, very few offshore wind farms have been decommissioned, therefore the impacts of this phase are not well documented, but are expected to be comparable to those of the construction phase [59]. This section reviews research from other jurisdictions with offshore wind industries, and should not be considered a comprehensive review of ecological considerations for offshore wind.

Short-term local ecological effects of offshore wind projects are better documented than long-term effects in the literature, and can vary significantly according to the type of technology being implemented, local seabed composition and hydrology, and the ecological community within the region affected by the project. In contrast, long-term and cumulative effects, such as impacts on the food web, are not well understood and require further study. Many studies conducted to date have focused on responses in single species, rather than at the ecosystem level, and the effects of behavioural response to project activity on long-term population levels are poorly understood in many cases [59, 60]. A lack of baseline data for species in a given area can hold back understanding of the resultant impacts to changes in the environment, so proactively collecting data prior to project-related disturbance is an important consideration for any new developments.

Studies examining the environmental effects of offshore wind projects often categorize impacts into four main biological groups: benthic organisms, fish, marine mammals and aerial species (primarily birds and bats), with additional consideration given to the ecosystem as a whole. This table provides examples but these groupings can be made differently for different applications, for example to emphasize the different risks posed to migratory birds compared to bats, or to include invertebrates which have similar exposure to impacts of fish but potentially different risk levels. Table 5.1.1 provides examples of documented impacts of offshore wind projects on their surrounding environment, classified by biological group as well as project phase in which the impact is expected to occur. Negative impacts are followed by (-), and positive impacts by (+), although positive impacts are not expected to directly offset negative impacts as they can each apply to different species, geographic areas, and time periods. This table is not intended to be an exhaustive list of all impacts, but provides a high-level overview of some of the environmental impacts observed at existing offshore wind farms, mainly in Europe. More detailed reviews of the potential impacts from offshore wind development can be found in the references listed in Table 5.1.1[13]. Some impacts, such as noise, light, or increased turbidity, may have more widespread effects that are

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[13] [31] Kaldellis et al, 2016; [59] Bergström et al, 2014; [60] Bailey et al, 2014; [68] Bradbury et al, 2014; [69] Dannheim et al, 2020; [70] Cook et al, 2018; [71] Furness et al, 2013; [72] Mendel et al, 2019; [73] Dierschke et al, 2016

difficult to quantify and more research is needed in these areas to understand the full extent to which offshore wind turbines can affect their surroundings any relevant species.

The New York State Energy Research and Development Authority's (NYSERDA) 2020 State of the Science Workshop[14] is an excellent resource for more exhaustive discussions of known potential direct, indirect, and cumulative impacts from offshore wind. Overall, the groups at this workshop were focused on the cumulative effect impacts of offshore wind development, and have identified widespread needs for better baseline data, along with standardization of study, survey, and monitoring methodologies. The working groups were broken down as follows, and a number of additional examples have been provided with respect to focus points identified by each group:

- Bats [61]
    - Exploration of new technologies and mitigation approaches
    - Better understanding of the interactions between offshore wind turbines and bats
- Benthos [62]
    - Assessment of the positive and negative effects of offshore wind area development, including which species to focus on when assessing impacts
    - Understanding new or modified area use for various species, electromagnetic field effects, and trophic level interactions
- Birds [63]
    - Prioritize taxa of concern at potential development areas with a risk matrix along with better understanding of collision risks and potential for population-level effects
    - Better understanding of behavioural impacts including how habitat and prey drivers, or migratory movements can be influenced by offshore wind infrastructure and activities
- Environmental Change [64]
    - Coordinate efforts to maximize utility of resources and conduct feasibility studies
    - Examine impacts of development on ocean stratification and light conditions
- Fishes and Aquatic Invertebrates [65]
    - Concerns revolve around sound and vibration effects, and potential cumulative impacts
    - Require understanding of behavioural responses and potential community alterations
- Marine Mammals [66]
    - Need for delineation of high priority species by region and vulnerability
    - Identification of dynamic environmental variables driving behavioural patterns
- Sea Turtles [67]
    - Work required to fill spatial and temporal gaps in understanding of sea turtle distributions and sensitivities in wind energy areas
    - Research and mitigation efforts from oil and gas industry can help inform further study

While mitigation methods may be employed throughout the project lifecycle, proper assessment and selection of project sites remains critical to avoid or minimize adverse environmental impacts to the extent possible. Experience from developments in the North Sea have highlighted the value of demonstration sites prior to widespread development to better understand the interactions the technologies will have on species in a given area [60].

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[14] NYSERDA's State of the Science Workshop, 2020: https://www.nyetwg.com/2020-workgroups

Table 5.1.1: Examples of known environmental impacts of offshore wind projects [59, 60, 31, 68, 69, 70, 71, 72, 73]

Biological group	Project stage	Impact source	Example of Potential Impacts
Benthic organisms	Construction	Disturbance of sediment	Increased turbidity, reducing light penetration limiting growth (-)
			Smothering of benthic organisms and suspension of pollutants (-)
		Pile-driving noise and vibrations	Further review required to properly quantify (-)
		Footprints of turbine bases and cable areas	Displacement and loss of species and habitats (-), reduction of abundance and diversity
	Operation	Operational noise and vibration	Further review required to properly quantify (-)
		Reduction of fishing activity	Population increase (+), changes in community composition (-)
		Artificial reef affect	Colonization, attraction of fish (+)
		Structure presence	Hydrographic changes, impacts on stratification affect local primary production and carbon flow to benthos (-) (Dannheim et al 2020)
Fish	Construction	Disturbance of sediment	Smothering of eggs, exposure to re-suspended pollutants (-)
		Pile-driving noise and vibrations	Displacement, physical injury (-)
	Operation	Electromagnetic fields from cables	Impairment of orientation, avoidance behaviour (-)
		Operational noise and vibration	Potential permanent relocation (-)
		Turbine foundations	Reduction of fishing impacts (+)
Marine mammals	Construction	Noise and vibration from pile-driving	Hearing damage, disturbance, impaired communication, temporary displacement (-)
		Construction vessel traffic	Collisions causing physical damage or mortality (-)
	Operation	Operational noise and vibration	Potential permanent relocation (-)
		Maintenance vessel traffic	Collisions causing physical damage or mortality (-)
Birds	Construction and operation	Noise emission	Disturbance of breeding and staging (-)
	Construction	Construction vessel traffic	Displacement, light attraction (-)
	Operation	Rotating blades	Collision fatalities (-)
		Wind turbine obstacles	Displacement, habitat loss, flight avoidance, migration disruption (-)
		Light emission	Attraction to navigational lights (-)
		Maintenance vessel traffic	Displacement, light attraction (-)
		Artificial reef affect	Attraction (-/+)

5.1.2 Construction Phase

The construction phase of offshore wind farms is widely viewed as the project phase with the highest potential for severe adverse impacts on aquatic marine life [60, 74]. Specific impacts are significantly dependent on the project location, whereby habitats and species communities may determine the type and number of species affected, and local oceanographic features may affect the degree of impact, for example by influencing the propagation of noise.

Most offshore wind farms to date have used fixed-bottom foundations, with the most common types being monopile, jacket, and gravity base. For monopile foundations, noise produced from pile driving can cause significant adverse impacts to marine mammals and fish, including physical damage, impairment of acoustic interpretation abilities, masking of communication among species, and temporary reduction of habitat size [38]. Impact assessments of marine mammals for offshore wind projects in Europe have often considered harbour porpoises and harbour seals, but large whales such as the North Atlantic right whale, blue whale, humpback whale and fin whale are also considered sensitive to pile driving noise [60]. For marine mammals, avoidance behaviour due to construction noise is expected to be more likely than direct mortality, and further research on understanding these long-term consequences is required [60]. Monitoring a potential project site for the presence of marine mammals through visual or acoustic observation methods is necessary to provide information on distribution, abundance and trends. This may be challenging however, given the large potential area affected and the wide migratory range of some species [60]. Ideally, effective baseline data will be available prior to construction from monitoring activities that could involve methods ranging from visual or acoustic, boat-based or aerial, and potentially automated for certain applications.

Several studies on fish indicate that pile-driving noise may cause physical injury, behavioural responses and masking of communication and orientation, and that endangered species or those with lower reproductive levels may be particularly vulnerable [60]. Sea turtles may also be affected through pile-driving noise and behavioural changes, but current understanding of physiological and behavioural impacts is fairly limited due to the scarcity of sea turtles at existing offshore wind farms [60, 67].

Measurements carried out during construction of an offshore wind farm in the UK showed peak noise levels from pile hammering to be in the range of 260 dB. However, noise levels can vary depending on the size of the hammer used, the foundation specifications and the seabed properties [74]. The sound produced during pile driving is capable of traveling large distances underwater, possibly tens of kilometers, creating a large region over which marine mammals and fish may be affected [75]. A standard method of mitigating the impacts of sudden introductions of noise is to integrate a ‘soft-start’ or ‘ramp-up’ of hammering frequency. A gradual increase of hammering can provide marine life, especially noise-sensitive mammals, enough time to leave the site of installation to avoid the damaging noise levels [60]. If pile-driving is used, air-bubble curtains or cofferdams can assist in dampening noise around the installation site [76].

Implementation of floating wind technology would allow for project locations in deeper waters and farther from shore, and may result in fewer adverse environmental impacts, particularly reduced construction noise and less overall disruption to the seabed and benthic communities. There is a possible risk to marine species of entanglement in mooring cables, although this may be low, given the cables would be under tension and similar to those used in floating offshore oil platforms [60].

5.1.3 Operation and Decommissioning

Compared to the construction phase, impacts during operation are regarded as more variable, and may be positive or negative depending on local conditions and marine planning objectives [59]. The risk of permanent or transient hearing impairment to marine mammals and fish from operational noise appears to be low relative to the construction phase and, in some cases, offshore wind farms can be allowed to operate within marine protected areas [31, 74]. While few offshore wind farms have been decommissioned to date, impacts and risks are expected to be similar to those of the construction phase during decommissioning [59].

Risks to aerial species are expected to be highest during the operation phase, and include potential collisions with rotating blades, displacement from important foraging areas (resulting in habitat loss) and colonies, stranding due to light attraction, the creation of barriers to migration, and risks associated with increased vessel traffic [60, 31]. Risks to bird species can be highly variable between species and locations, so the existing literature from European wind farms is not ideal for evaluating the risks posed to many North American bird species [77]. Assessing bird species mortality and disruption due to wind farms can be challenging in offshore areas and requires the use of remote sensing technologies. BOEM has been undertaking studies to improve the flight pattern data on several shorebird species that have migratory pathways along the Atlantic outer continental shelf using individual-based tagging systems [77]. With sufficient data on which bird species are expected to be present in an area, and characteristics of each species regarding how often they would be expected to fly within the operating area of a wind turbine, it may be possible to assess the risk posed to birds in any given offshore area of interest [68]. The actual risk to a given population from interactions with offshore wind farms and related activities also depends on weather, distance from shore, and feeding behaviour, while slow maturation, low numbers of offspring and long lifespans[15] may contribute to increased population-level impacts in certain species [31].

Migratory bats have also been detected at offshore locations, however there is little understanding about the potential for collision with, or displacement by offshore wind turbines, compared to onshore wind facilities [78]. Common mitigation methods for bird species have historically included project siting to avoid high risk areas, grouping turbines to avoid alignment perpendicular to flight paths, timing construction to avoid sensitive periods, and timing and routing maintenance trips to reduce disturbance [79]. Effective monitoring can also be employed to allow for adaptive management plans, whereby mitigation measures (such as acoustic or visual deterrents) can be adjusted depending on the presence of birds or bats [80].

Another concern raised in literature is the potential risk posed by electromagnetic fields from submarine power cables, where some marine species may experience impaired orientation or may exhibit avoidance behaviour. However, the data gathered to date is too limited or variable to draw many meaningful conclusions, indicating the need for further study [31].

In terms of potential positive impacts, there is a growing body of evidence that turbine bases and associated scour protection can act as artificial reefs, providing a vertical substrate for macro-invertebrates. The growth of benthic communities can attract more fish and mammals, ultimately leading

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[15] For example, seabirds exhibit many characteristics of K-selected species and can be more sensitive to population-level impacts from detrimental additions to their environment - https://www.britannica.com/science/K-selected-species

to increased biodiversity [31]. At the Horns Rev wind farm in Danish waters in the North Sea, researchers found evidence of new species and increased population levels across several species, compared to pre-construction levels. Seven years after project construction, no adverse impacts on fish life were observed, and turbine foundations were shown to have provided habitat for a range of new species, and good breeding conditions for fish [81]. Another study examined fish populations at five offshore wind farms in Sweden, and found large communities of fish aggregated around the turbine bases [82]. On the other hand, offshore wind farms can also promote the introduction of non-indigenous species, which may be invasive and cause cumulative effects that can impact various levels of the ecosystem [83]. The hard substrates introduced by offshore wind farms can attract fish species from new areas, or act as stepping-stones for species to spread over large distances through shorter colonization events [83]. Increased biodiversity or population levels of certain species can also be detrimental if these factors result in increased activity of species, such as certain marine birds, that can be put at increased collision risk by being drawn towards a wind farm.

5.1.4 Direct Impacts on Humans

The potential impacts from offshore wind projects that can directly impact humans are similar to onshore projects, and include noise, which can cause stress symptoms and sleep disturbance to people living nearby, and visual disturbance from an aesthetic perspective. For offshore wind however, the severity of these impacts is generally low given the typically few people living within audible and visible range of offshore turbines. For observers on the shore, operational noise from turbines located several kilometres out to sea is generally expected to be masked by the ambient noise of ocean waves. Several studies indicate that the public has a more favourable perception of offshore wind compared to onshore but that public opposition to offshore wind projects on visual grounds may still arise [84, 85].

An additional factor for offshore wind is the possibility of collision between vessels and turbines, although this is generally considered a minor risk [31]. Socioeconomic impacts of restricted shipping lanes and impact on emergency operations may also arise, but are expected to be managed through proper marine spatial planning. In general, the risk of ship collisions is mitigated through project siting by means of reviewing navigational risk assessments, and implementing lighting on turbines, although there are concerns that these may become inadequate as certain areas become more developed or populated which may require further risk mitigation measures [86].

5.2 Environmental Legislation and Defined Areas in Canada

5.2.1 Overview

Understanding existing ecosystem sensitivities and vulnerabilities is necessary to assess how potential impacts could intensify and amplify current issues [87]. This section provides an overview of currently defined ecologically sensitive areas in Canada’s oceans which may be relevant for planning of future offshore wind. This includes areas backed by legislation, as well as those without, as the presence of documented environmental sensitivities in a region may increase the likelihood of stakeholder pressure to implement additional mitigation measures, for example, even if there is no legal framework in place. It is vital for any project to be aware of areas that have had particular attention due to their ecological significance, but that does not mean that such areas are the only ecologically significant areas in Canada's waters. From a project development perspective, avoiding currently defined areas of environmental protection and significance does not necessarily translate into reduced ecological risk, particularly with respect to temporal and cumulative effects. This section aims to provide a high-level review of defined ecological areas and considerations expected to be relevant to offshore infrastructure development in Canada, but is not exhaustive[16], nor does it describe how the various pieces of legislation referenced are employed in detail. Maps of the different defined areas are provided below as examples within the previously defined study area for this report, generally encompassing the Gulf of St. Lawrence, Sable Island Bank, and St. Pierre Bank in Canada's Atlantic region.

5.2.2 Impact Assessment

There is ongoing work to characterize certain aspects of Canada's marine settings, with DFO currently leading marine spatial planning (MSP) initiatives[17] and various other ecologically-focused activities underway. A better understanding of the nature and extent of the interactions between offshore wind turbines and Canadian ecosystems at a regional level[18] will be necessary prior to defining potential areas for offshore wind power production in Canadian waters. In many jurisdictions, environmental assessments are conducted in several stages. In Europe, any large projects, including wind farms, which may impact marine and coastal environments require an initial Strategic Environmental Assessment (SEA) under EU Directive 2001/42/EC. During this stage, biodiversity and cumulative impacts are assessed and unsuitable areas for development are excluded. Subsequently, Environmental Impact Assessments (EIAs) under EU Directive 85/337/EEC are conducted to determine individual and cumulative effects on the local project environment [74]. Whether or not designated leasing areas for offshore wind are established in Canada, any proposed projects would be required to undertake site-specific environmental assessments and acquire approvals from various regulatory bodies to move forward.

The Impact Assessment Agency of Canada (IAAC) leads federal impact assessments under the *Impact Assessment Act* (IAA) in addition to regional and strategic assessments [88]. Project-specific impact assessments follow the process described in Figure 5.2.1, indicating the five phases and the key participants in the process. In general, the IAAC leverages sound science along with public and Indigenous consultation to consider the environmental, health, social, and economic impacts of proposed projects and acts to verify compliance following project completion [88].

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[16] This section attempts to stick to well-established and defined areas, while some less common area definitions have been excluded. For example, DFO has previously defined topics which have not been included such as depleted species or degraded areas in guidance for conservation priorities: https://waves-vagues.dfo-mpo.gc.ca/Library/327409.pdf

[17] MSP Initiatives: https://www.dfo-mpo.gc.ca/oceans/management-gestion/msp-psm/index-eng.html

[18] For example, the Scotian Shelf, Sable Island Bank, or Gulf of St. Lawrence could be regions within the current study area, although the extent of what regional review processes could cover is unknown at this time

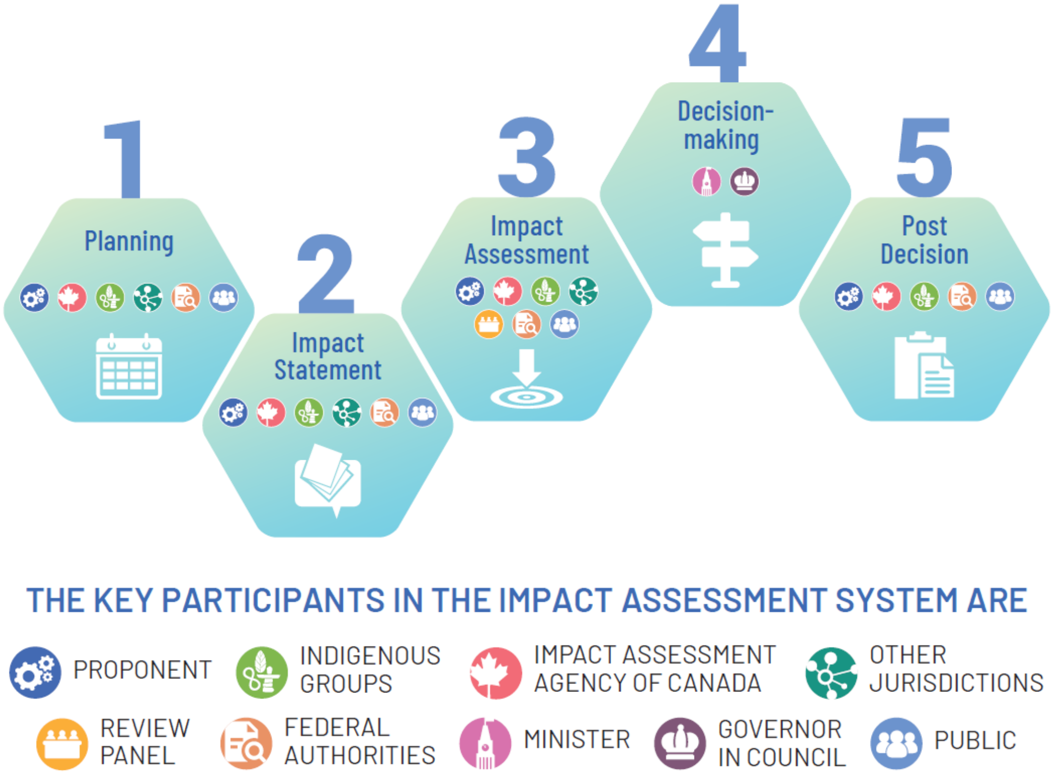
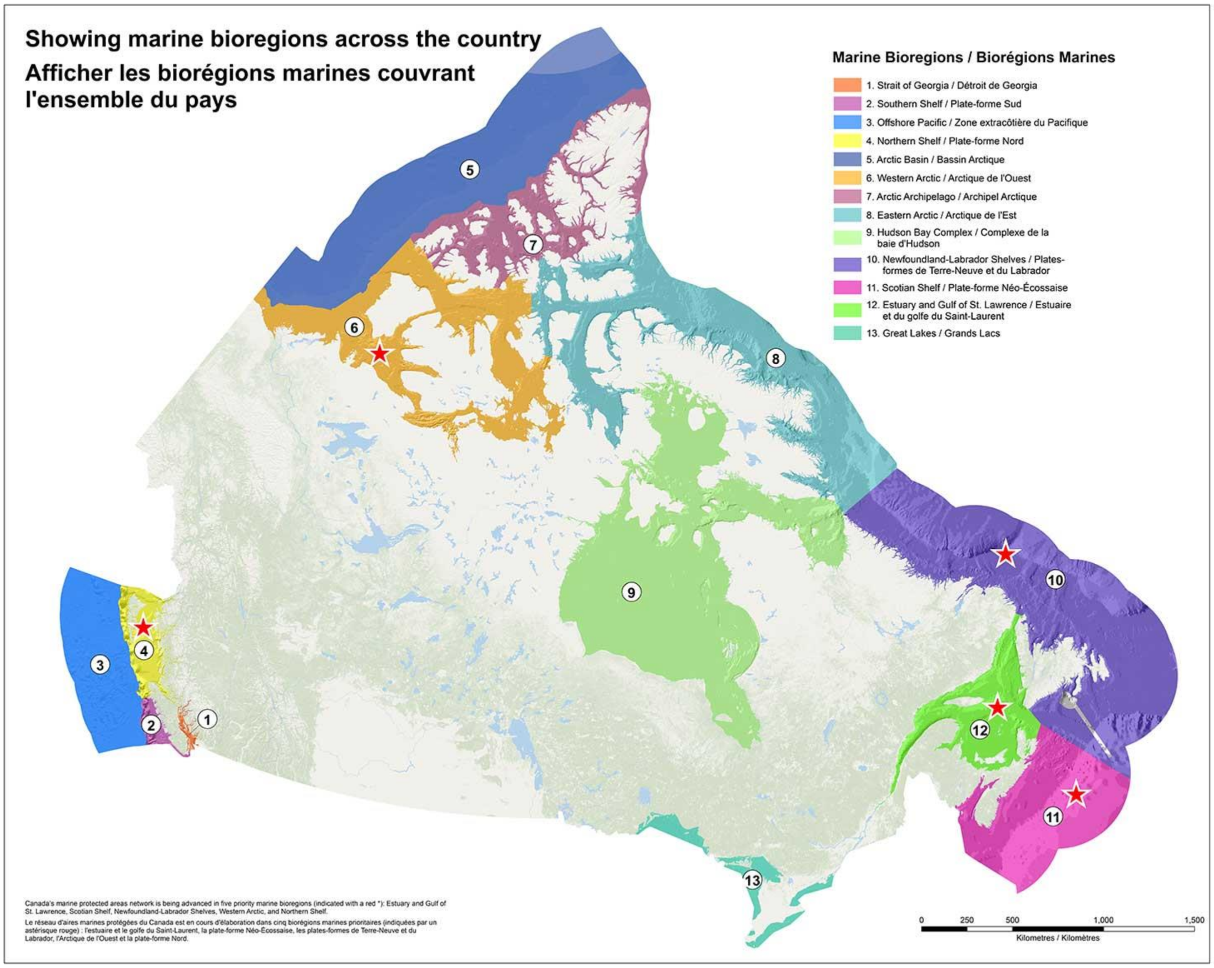


Figure 5.2.1: IAAC impact assessment process overview [88]

Under the IAA, the Minister of Environment and Climate Change may either establish a committee or authorize the IAAC to conduct a regional or strategic assessment. Regional assessments are targeted at existing or future physical activities undertaken in a region while strategic assessments often examine broader issues as well as the government's policies, plans, or programs relevant to impact assessment [88]. The IAAC provides more information on how to request a regional or strategic review, in addition to information on completed or ongoing assessments [88].

5.2.3 Canada's Bioregions and Marine Spatial Planning

Ocean management is an important concept in Canada, where past initiatives have focused on aspects such as existing integrated management plans, conservation area networks, and different types of protected areas, such as those described later in this section [89]. Marine spatial planning (MSP) is a process that allows for collaboration between different levels of government and stakeholders to consider the range of possible human activities in a marine area and leverage the subsequent economic opportunities while advancing conservation objectives [89]. In Canada, MSP activities are organized into 13 bioregions which are displayed in Figure 5.2.2, with bioregions 11 and 12, the Scotian Shelf and Estuary and Gulf of St. Lawrence corresponding most closely with the current study area [89]. Discussions are ongoing in these Eastern bioregions (along with the Newfoundland and Labrador shelves) between federal, provincial, and Indigenous governments for the development of spatial plans for marine use, which is expected to be relevant for any existing or upcoming activities in these areas, such as potential offshore wind development [89].



Canada's marine protected areas network is being advanced in five priority marine bioregions (indicated with a red *): Estuary and Gulf of St. Lawrence, Scotian Shelf, Newfoundland-Labrador Shelves, Western Arctic, and Northern Shelf.

Le réseau d'aires marines protégées du Canada est en cours d'élaboration dans cinq biorégions marines prioritaires (indiquées par un astérisque rouge) : l'estuaire et le golfe du Saint-Laurent, la plate-forme Néo-Écossaise, les plates-formes de Terre-Neuve et du Labrador, l'Arctique de l'Ouest et la plate-forme Nord.

Figure 5.2.2: Canada's marine bioregions [89]

5.2.4 Marine Protected Areas and Areas of Interest

A Marine Protected Area (MPA) is an area defined by Canada's Oceans Act that is legally protected and managed to achieve long-term conservation of nature [90]. There are currently 14 MPAs across Canada, accounting for over 6% of Canada's marine and coastal areas, located in both the territorial sea and Canada's exclusive economic zone. MPAs offer legal protection for a range of species, habitats and features from various activities with the current MPA standards specifically prohibiting four industrial activities in new federal MPAs: oil and gas activities, mining, dumping, and bottom trawling [91]. Under Section 35 of the Oceans Act, MPAs can be designated to conserve and protect one or more of [92]:

- Commercial and non-commercial fishery resources, including marine mammals, and their habitats;
- Endangered or threatened marine species, and their habitats;
- Unique habitats;
- Marine areas of high biodiversity or biological productivity;
- Any other marine resource or habitat as is necessary to fulfil the mandate of the Minister; and,
- Marine areas for the purpose of maintaining ecological integrity.

When an area is under consideration for becoming an MPA under the *Oceans Act*, it is referred to as an Area of Interest (AOI) [93]. An AOI is the first step of developing an MPA, which includes the establishment of the MPA Advisory Committee, and ecological/biophysical, social, cultural and economic overview and assessment. Following these steps, the regulatory process is created, followed by the designation of the MPA, which is then managed accordingly [93].

The question of a minimum distance from which wind farms should be located from MPAs is not straightforward, and could depend in large part on the results of environmental assessments conducted to determine the expected impact on aspects such as biodiversity, hydrology, acoustic environment, and the seabed. In Europe, the presence of an existing MPA does not necessarily preclude wind farm development in the same region, but additional steps may need to be taken for project approval. For example, projects may undergo further assessment under the Habitats Directive (92/43/EEC) if they may disturb Natura 2000 sites, a network of core breeding and resting sites for rare and threatened species [94]. There are notable examples in Europe of offshore wind farms and MPAs existing in the same place, or adjacent to one another, as well as examples where projects have been stalled or canceled due to the proximity of MPAs [74]. Figure 5.2.3 displays MPAs and AOIs in Canada's Atlantic region within the study area.

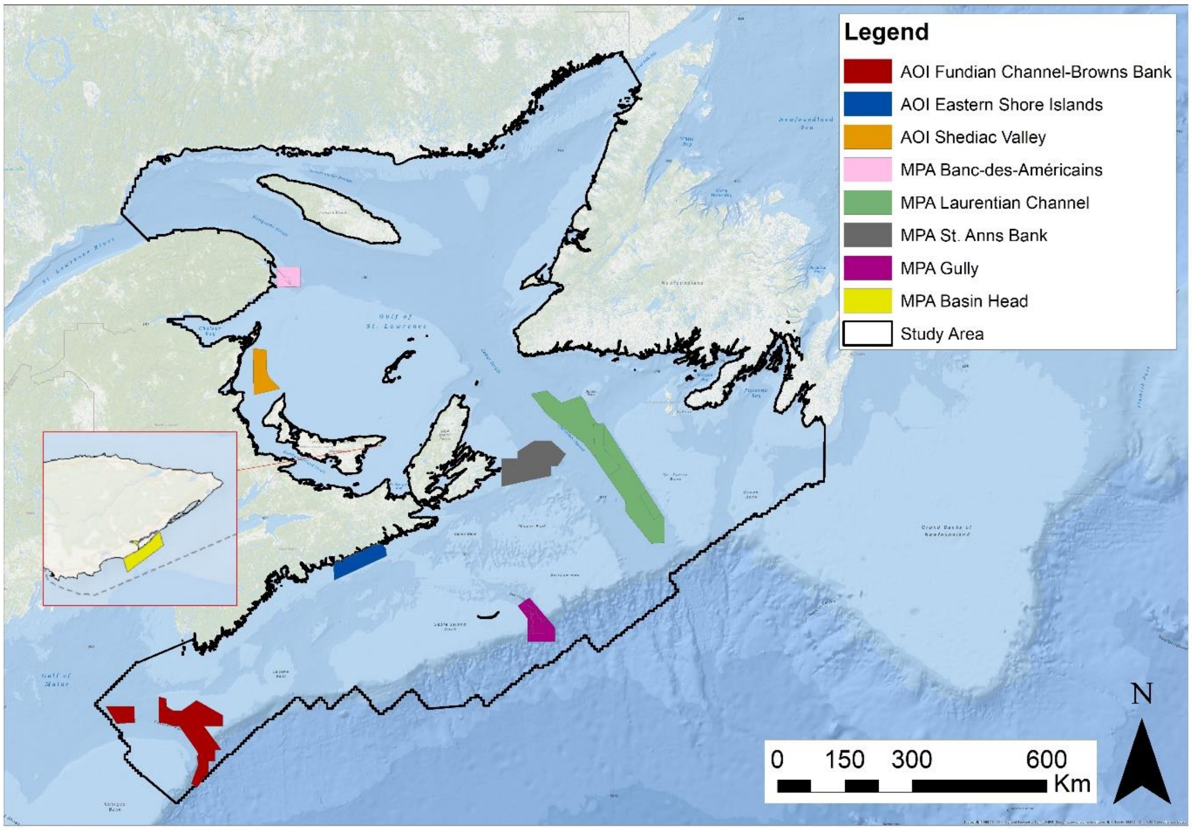


Figure 5.2.3: MPAs and AOIs in Atlantic Canada study area

5.2.5 Ecologically and Biologically Significant Areas

An Ecologically and Biologically Significant Area (EBSA) is an area within Canada's oceans that has been identified as having particular biological or ecological significance through scientific assessment [95]. While areas that are not defined as EBSAs should not be considered as ecologically unimportant, EBSA status indicates that any activities undertaken in a given area should take extra care to avoid risks to the area's ecological sensitivities [95]. EBSAs are generally identified in two phases: the compilation of scientific data and knowledge of a given marine area's ecosystems, followed by assessment against five established science-based criteria which include uniqueness, aggregation of species, criticality of area to species present, the level of existing human disturbance, and resilience [95]. While EBSAs do not hold regulatory authority over actions that can be undertaken within their boundaries, they are an effective tool to inform project proponents of any particular ecological sensitivities in a given location and to guide management practices. EBSAs support ocean governance in many ways including [95]:

- Providing information for marine planning and the siting of marine activities;
- Informing and guiding project-specific or regional environmental assessments;
- Informing and guiding industry and regulatory decision-making;
- Planning routes for submarine cables;
- Informing and guiding Integrated Oceans Management[19] processes; and,
- Serving as a basis for identifying AOIs and MPAs.

More information on the specific EBSAs that exist in Canada's oceans along with a geographic dataset are available from the Open Government portal [95]. Figure 5.2.4 displays EBSAs in Canada's Atlantic region that fall within the study area.

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[19] DFO's Integrated Oceans Management activities: https://www.dfo-mpo.gc.ca/oceans/management-gestion/index-eng.html

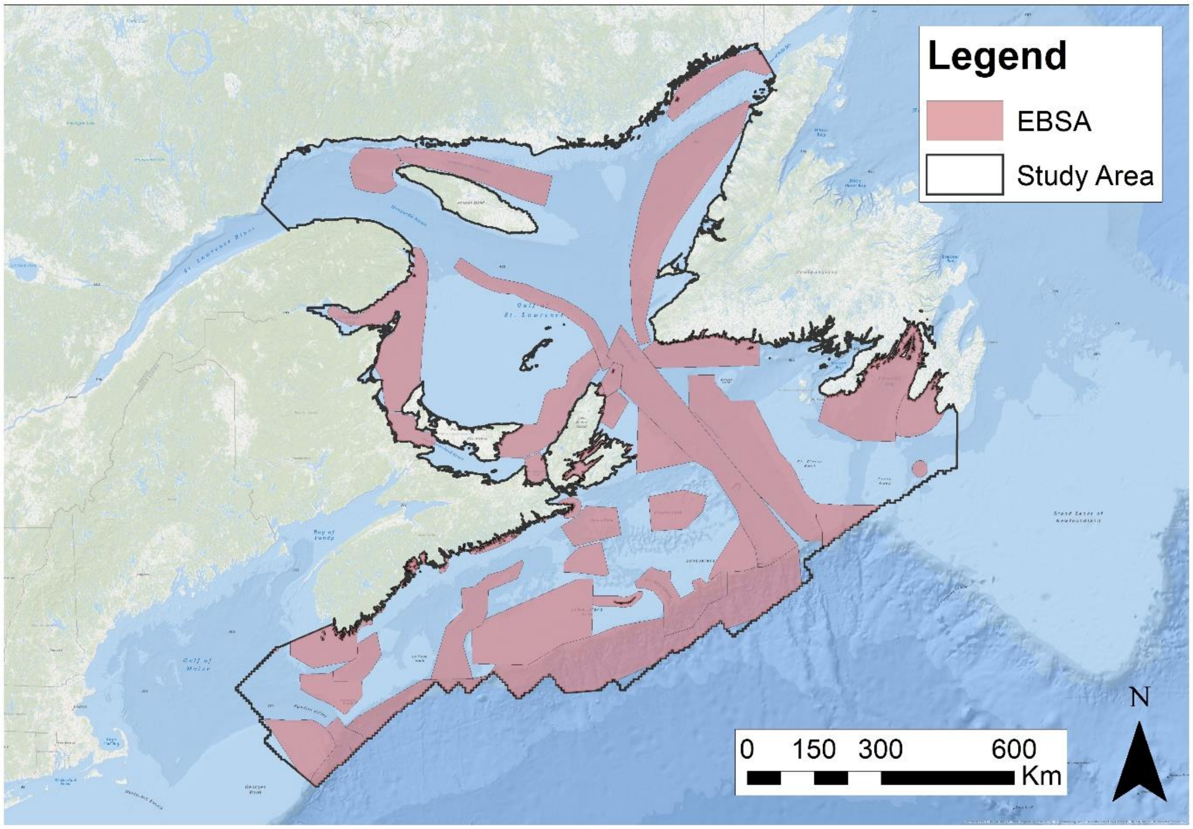

Figure 5.2.4: EBSAs in Atlantic Canada study area

5.2.6 Species at Risk Act

The *Species at Risk Act* (SARA) serves to prevent the extinction of Canadian wildlife species and applies to species at risk which are defined as any of the following [96]:

- **Endangered Species** – a wildlife species that is facing imminent extirpation or extinction
- **Extirpated Species** – a wildlife species that no longer exists in the wild in Canada, but exists elsewhere in the wild
- **Threatened Species** – a wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction
- **Species of Special Concern** – a wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats

SARA is enacted through a series of different measures that range from collaboration between government, organizations, and individuals, to specific assessment processes to ensure protection and recovery of species, including some which provide sanctions for offences under SARA [96]. SARA can impact a project if a species at risk is found at any time throughout the year on a given property [96].

SARA also defines critical habitat that is necessary for the survival or recovery of an endangered or threatened species [97]. The destruction of critical habitat is illegal under SARA and the act can impose additional restrictions on development and construction, making awareness of critical habitats and the presence of potential species at risk in a given area vital for any project being developed in Canada [97]. Listed species, their residence, and their critical habitat are protected under sections 32, 33, and 58 of SARA, respectively [96].

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is an independent body of experts that, under SARA, identifies and assesses wildlife species considered to be at risk as the first step towards protecting species at risk [98]. After assessment, COSEWIC reports its results to the Canadian government and public and, upon an official response from the Minister of the Environment, wildlife species designated by COSEWIC may qualify for legal protection under SARA [98]. When a species is identified as endangered, threatened, or extirpated, the competent minister, in cooperation with others, prepares a recovery strategy and action plan that identifies what needs to be done to arrest or reverse the decline of a species [96]. For species of special concern, the competent minister, in cooperation with others, prepares a management plan setting goals and objectives for maintaining sustainable population levels of one or more species [96].

A dataset of currently defined SARA Critical Habitats is available on the Open Government portal, although critical habitat has not been defined for every species at risk [97]. ECCC also maintains a public registry of documents related to the administration of SARA [99]. Figure 5.2.5 displays SARA critical habitats in Canada's Atlantic region within the study area. There are other species listed under SARA that are known to be present in the area that don't have defined critical habitat, such as the blue whale and leatherback turtle, and some species have critical habitat defined along the shoreline and are technically not in the study area, but due to their use of nearby areas or flights over coastal waters may still require considerations for potential turbine placements (such as Roseate Tern, Piping Plover, and Bank Swallow). In the case of some species such as the blue whale, important habitat may be defined, which can be a precursor to critical habitat definition depending on how a species' SARA listing may develop, so these should also be accounted for during site selection for offshore projects [100].

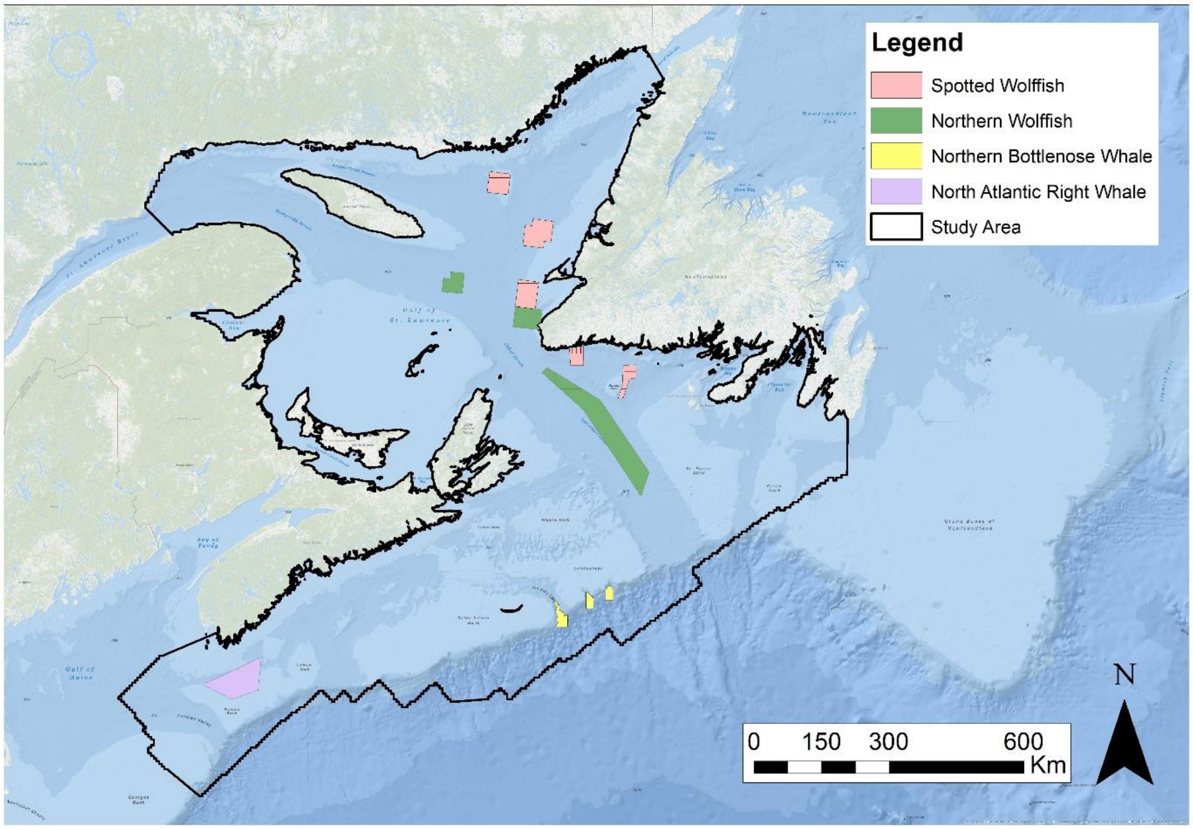

Figure 5.2.5: SARA critical habitat in Atlantic Canada study area

5.2.7 Other Effective Area-Based Conservation Measures

Other Effective Area-Based Conservation Measures (OEABCM), often referred to as "other measures" in the context of ocean area protection, restrict human activity within their boundaries that would threaten what a given area was established to protect [101]. "Other measures" are evaluated regularly based on the guidance documentation produced by Canada's government and using the most recent available information to ensure the continued conservation of valued ecological components [101]. For an OEABCM to be defined, it must have the following five characteristics [101]:

1. A clearly defined geographic location;
2. Conservation or management objective(s) related to at least one species or habitat important to biodiversity;
3. The presence of an important habitat and important species that uses it;
4. Long-term planned implementation, either entrenched in legislation or regulations, or with a clear plan to be in place for 25+ years; and,
5. Effective conservation of ecological components of interest.

Typical "other measures" in Canada are established in the form of marine refuges which manage fishing activities to protect various species and their habitats with a database of current marine refuges available from DFO [102]. "Other measures" will also be relevant for any activity within their boundaries that would interfere with their conservation target, which could include offshore wind development. Figure 5.2.6

displays OEABCMs in Canada's Atlantic region that fall within the study area, although the Eastern Canyons is currently still being finalised.

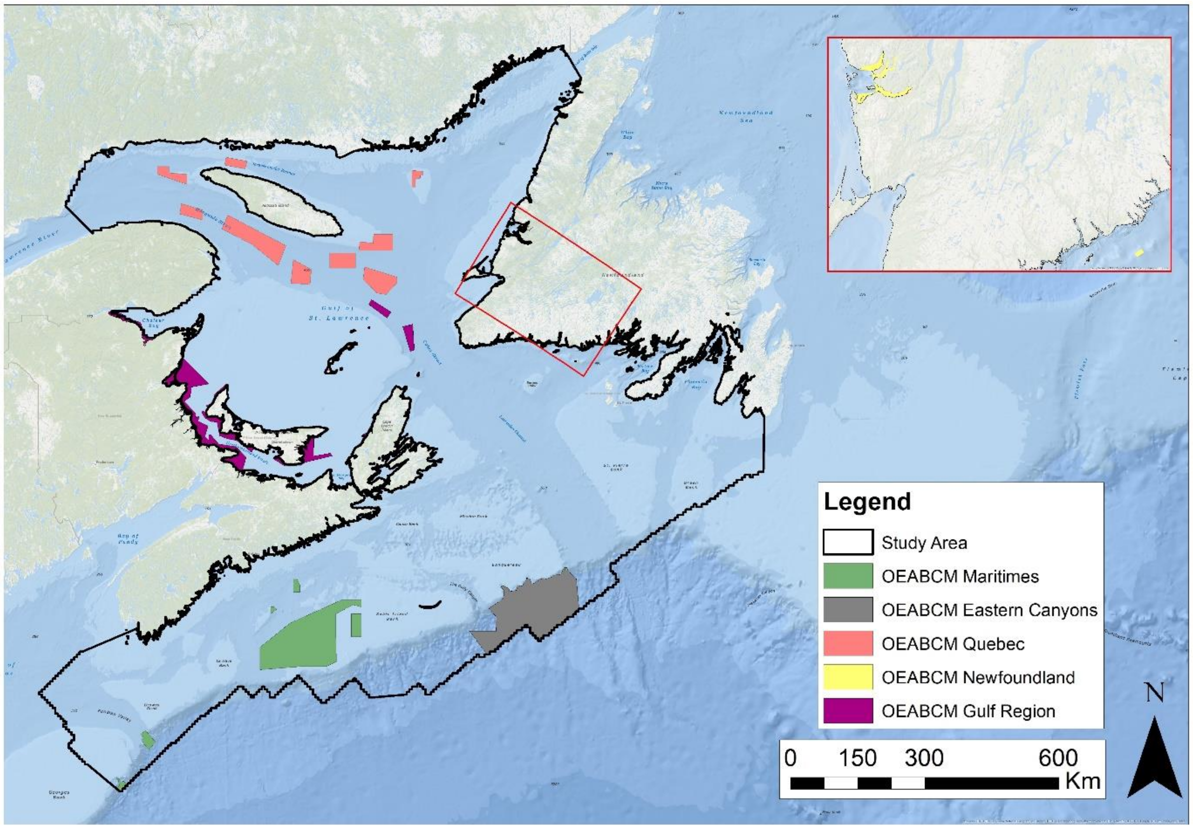

Figure 5.2.6: OEABCMs in Atlantic Canada study area

5.2.8 Significant Benthic Areas

A Significant Benthic Area (SiBA) is an ocean area defined by DFO that contains sponges, corals, and/or sea pens as dominant and defining features [103]. SiBAs can also be further delineated into Sensitive Benthic Areas which are particularly vulnerable to proposed or ongoing fishing activities [103]. While SiBAs do not set out official regulations, they offer insight into areas that may be particularly sensitive to benthic disturbances from offshore project developments.

In Atlantic Canada, DFO has defined SiBAs for coral and sponge populations in a dataset available on the Open Government portal [104]. Atlantic Canada is home to around 25 to 30 species of coral and over 30 species of sponge, with sponges generally being found in shallower waters than corals [105]. Sponges and corals have notable impacts on their surrounding environment such as modifying water currents, and creating habitat or reef structures which are used by other aquatic species [105]. The importance of corals and sponges in the benthic environment make them a priority for protection in Canada's oceans. Figure 5.2.7 displays coral and sponge SiBAs in Canada's Atlantic region that fall within the study area.

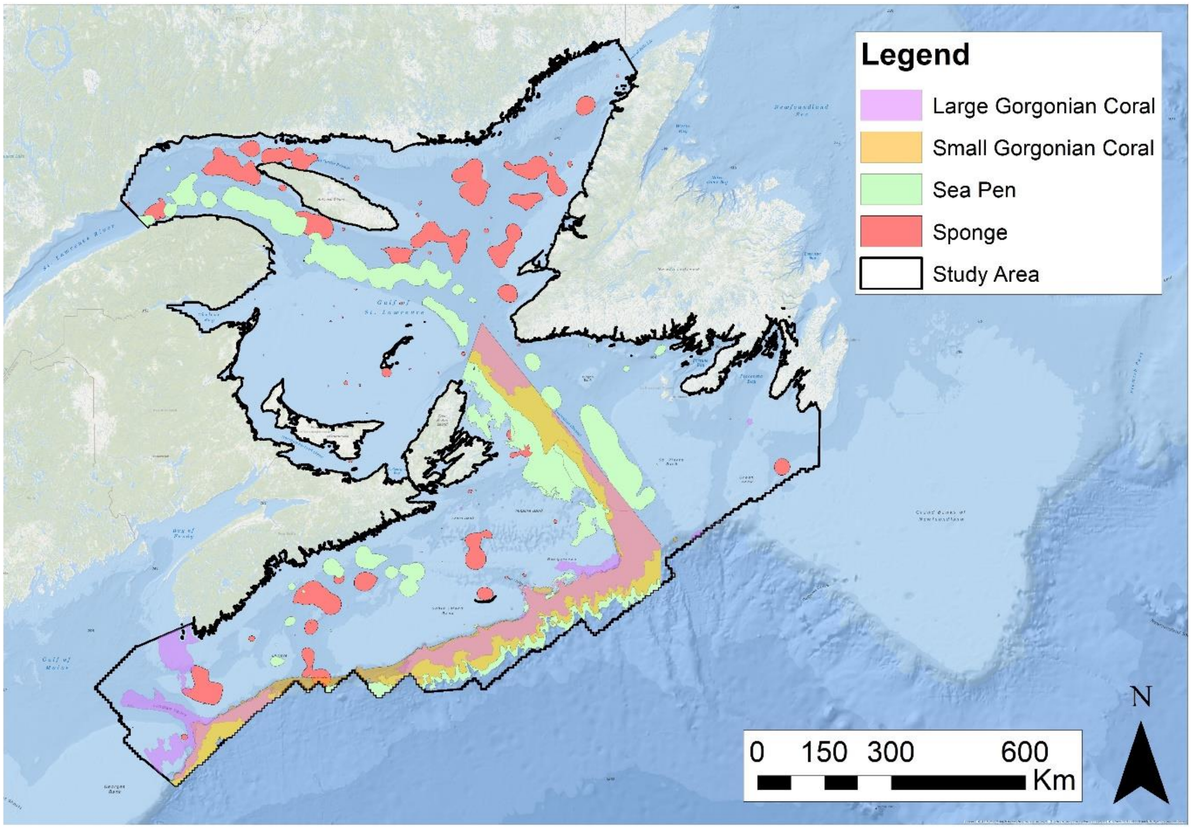

Figure 5.2.7: Coral and Sponge SBAs in Atlantic Canada study area

5.2.9 Fisheries Act and Fishing Activity

DFO is responsible for the administration of the *Fisheries Act* which is one of Canada's oldest laws and is in place to protect fish and fish habitat from threats including [106]:

- Habitat degradation;
- Habitat modification;
- Aquatic invasive species;
- Overexploitation of fish;
- Pollution; and,
- Climate change.

DFO has the authority to apply fish and fish habitat protection provisions in the Act to regulate or authorize potentially harmful activities [106]. The provisions of the *Fisheries Act* include [106]:

- A prohibition against causing death of fish by means other than fishing;
- A prohibition against harmful alteration, disruption or destruction of fish habitat;
- A framework of considerations to guide the Minister's decisions; and,
- Ministerial powers to ensure fish habitat and passage with respect to existing obstructions.

In 2013, DFO and the Canadian Energy Regulator (CER) established a memorandum of understanding (MOU) that allows CER to assess potential impacts to fisheries from CER-regulated energy project applications. If the CER determines permitting will be required for proposed activities, DFO is notified to handle the permitting process [107]. DFO provides additional information for ensuring compliance with the *Fisheries Act* and the project review process with their *Projects Near Water*[20] website. The proponent of such a project is responsible for understanding and avoiding or mitigating potential impacts of their project, or acquiring appropriate authorization and abiding by the relevant conditions if a project's impacts cannot be avoided or mitigated [106].

Fishing and aquaculture is a central part of the Atlantic Canada culture and economy, therefore the potential adverse effects an offshore wind development could have on these activities must be assessed prior to project approval. The shelves of the Atlantic are home to some of the richest fishing resources in the world, with the most productive areas being the Grand Banks, the Scotian Shelf, and the Bay of Fundy [108]. Economically, the most important seafood species are lobster, queen snow crab and shrimp: when combined they account for 80% of Atlantic Canada's commercial fishery harvest [108]. Fish stocks are currently threatened by unsustainable fishing practices, pollution, and by climate change which has intensified ocean acidification, ocean temperatures, and habitat loss [109]. With offshore wind power generation potentially imposing a new factor in Canada's ocean space that could impact Canada's fisheries, adhering to fish protection regulation and working alongside Canada's fishing industry will be vital for any potential development. Current fishing activity in Canada's Atlantic region based on vessel monitoring system (VMS) vessel density data[21] provided by DFO is presented in Figure 5.2.8.

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[20] Projects near water: http://www.dfo-mpo.gc.ca/pnw-ppe/index-eng.html

[21] VMS data on Open Maps: https://open.canada.ca/data/en/dataset/273df20a-47ae-42c0-bc58-01e451d4897a

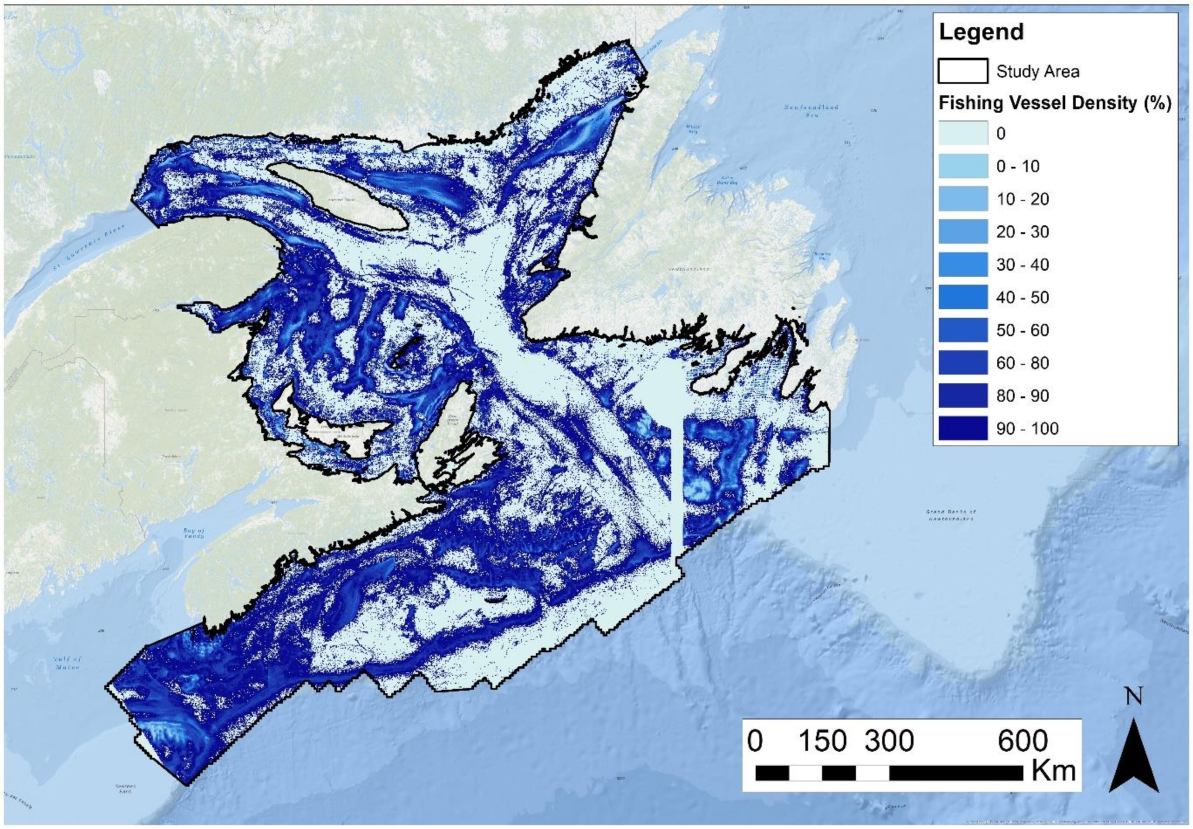

Figure 5.2.8: VMS fishing vessel density in Atlantic Canada study area

5.2.10 Migratory Bird Convention Act

The *Migratory Bird Convention Act* (MBCA) protects bird species in Canada along with their habitat and nesting grounds. The MBCA was updated in 1994 and 2005 to implement the *Migratory Birds Convention*, a treaty signed with the US. Under the MBCA, ECCC has a legal basis for the regulation of relevant activities through the Migratory Birds Regulations and the Migratory Birds Sanctuary Regulations for Canadian bird species [110]. Migratory birds to be protected under the MBCA are defined by the following criteria [111]:

1. Species listed directly or indirectly in Article I of the *Migratory Birds Convention;*
2. Species native or naturally occurring in Canada; and,
3. Species known to have regularly occurred in Canada.

In addition to the federal MBCA, Canadian bird species are also protected under provincial and territorial statutes, including some species that are not defined for protection under the MBCA. In general, such birds can include grouse, quail, pheasants, ptarmigan, hawks, owls, eagles, falcons, cormorants, pelicans, crows, jays, kingfishers, and some blackbirds. In Atlantic Canada, relevant provincial statutes include [111]:

- *Wildlife Acts* of Nova Scotia and Newfoundland and Labrador;
- *Wildlife Conservation Act* of Prince Edward Island;
- *Fish and Wildlife Act* of New Brunswick; and,
- *An Act Respecting the Conservation and Development of Wildlife* of Quebec.

Any project with the potential to harm migratory birds must account for their presence in the form of sanctuaries or expected migratory pathways. More information including geographic data on migratory bird sanctuaries across Canada is available from ECCC [112].

5.3 Lessons from Offshore Oil and Gas

For decades, offshore oil and gas has played an important role in Atlantic Canada and the following four projects are currently active, with the year of operation and structure type indicated in brackets: Hibernia 1 (1997, Gravity Base Structure), White Rose 3 (2005, Floating Production, Storage and Offloading Vessel), Terra Nova 2 (2002, Floating Production, Storage and Offloading Vessel) and Hebron 4 (2017, Gravity Base Structure) [113]. Lessons learned from regulating, developing and operating offshore O&G infrastructure in Canadian waters can be adapted to offshore wind developments to minimize impacts, particularly in the benthic environment [113]. Above-water, the potential for bird interactions with physical structures and related vessels present in Canadian waters can also inform practices for future developments. Evidence has shown that land and sea birds can be attracted to the lights of these offshore installations which can result in stranding, among other risks associated with the proximity to operating infrastructure, with factors such as weather or time of day also potentially playing a role in determining the level of attraction [114]. Historically, O&G developers in Canada's waters have made efforts to account for ecological benthic impacts of the construction and planned operation of O&G infrastructure including [115]:

- Benthic species present in an area;
- Community-level linkages such as food web;
- Cumulative impacts from new developments; and,
- Indirect impacts to other species due to benthic species disruptions.

The industry accounts for the need to treat developments on a case-by-case basis, considering the different phases of a project (exploration, drilling, and extraction/operation) and their differing potential impacts on the environment [115]. Mitigation practices are organized in a hierarchy of descending priority according to: avoidance, mitigation, or offsetting, although it is recognized that offsetting ecological impacts is not compatible with certain conservation objectives [115, 114].

While the Canadian offshore O&G industry has adopted a series of best practices over time, there are notable gaps in the understanding of Canada's ocean environment and risks posed by O&G activities including the following [115]:

- Incomplete or sparse data mapping in many areas of Canada's benthic environment;
- Impacts of noise on fish and marine invertebrates, in addition to these species' ability to respond to potentially harmful sources of sound;
- Indirect effects on species that rely on those directly impacted by infrastructure in a given area;
- Canada-specific best practices, given that many were developed based on Norwegian activities;

- Many studies have been lab-based and directed toward shallow water environments, limiting relevance to data collection and operation in deep-water environments;
- Effectiveness of special technical mitigation measures in settings with defined benthic conservation objectives; and,
- Current mitigation practices may not effectively account for impacts on an ecosystem scale.

Strategic environmental assessments (SEA) have been undertaken in various locations of Canada's Atlantic region by the Canadian NL and NS Offshore Petroleum Boards (CNLOPB[22] and CNSOPB[23], respectively).

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[22] CNLOPB SEAs: https://www.cnlopb.ca/sea/

[23] CNSOPB SEAs: https://www.cnsopb.ns.ca/what-we-do/environmental-protection/environmental-assessments/public-registry-seas

6. Canadian Geophysical Considerations

6.1 Wind Resource

Wind speeds in offshore areas are generally higher and more consistent than on land [38]. Environment and Climate Change Canada's wind atlas[24] modelled meteorological dataset indicates that Canada's Atlantic region has a strong offshore wind resource. Figure 6.1.1 shows that, with the exception of a few areas near the coast, the average annual wind speed offshore at 100 m above sea level is over 7 m/s, a typical threshold for offshore wind viability [116]. The manner in which the wind speed varies over time can also differ between offshore and onshore locations, and can inform decisions on integrating offshore wind into the electricity system. The possibility of developing offshore wind infrastructure in locations with production profiles that are complementary to existing wind and load profiles is an aspect that can make certain offshore installations more attractive. Pearre and Swan performed an assessment of such areas in Atlantic Canada (refer to Figure 4.3.1) and identified the offshore locations surrounding Sable Island and around the mouth of the Bay of Fundy as having particularly promising characteristics to complement existing wind power and load in Atlantic Canada [44].

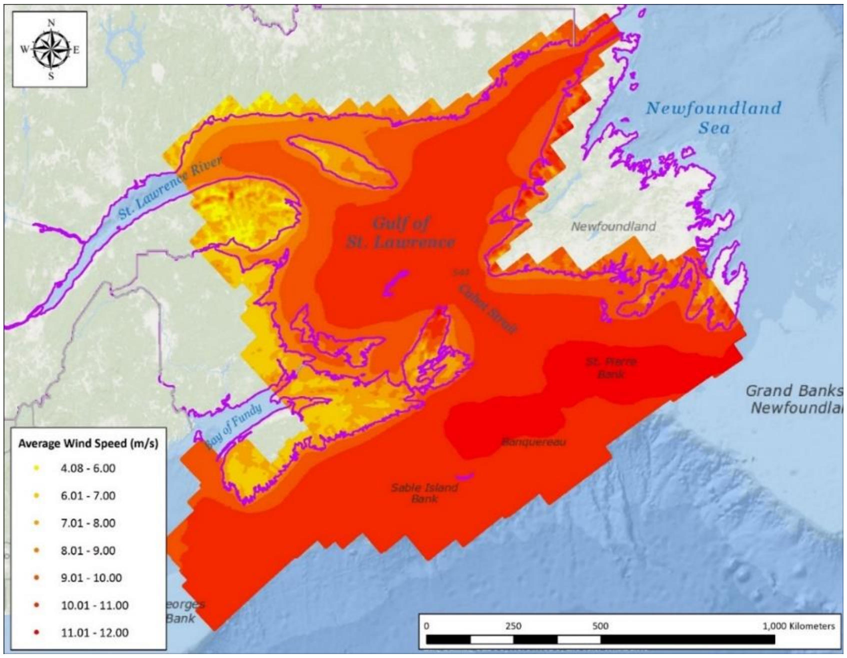

Figure 6.1.1: Average Annual Wind Speed at 100 m in Atlantic Shelf (Modelled data from 2008, ECCC)

6.2 Geology and Bathymetry

Existing offshore wind infrastructure in other jurisdictions has been installed predominantly in areas with shallow waters and relatively deep sedimentation. These conditions are ideal for monopile foundations, which have provided a relatively cheap and straightforward construction option in areas such as the North

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[24] ECCC's wind atlas: http://windatlas.ca/

Sea. The Geological Survey of Canada (GSC) has recently begun to study the subsea geology conditions in Atlantic Canada for the purpose of determining potential suitability for offshore wind foundations. By comparing these conditions to areas in other countries with developed or developing offshore wind industries, it is possible to provide some insight into Canada's potential for offshore wind development from a foundation compatibility perspective. The process undertaken by GSC involved reviewing the geology of Canada's Atlantic region as 23 sub regions, shown in Figure 6.2.1, separated based on geographical and geological distinctions. Overall, the areas identified with geological conditions conducive to the most common offshore wind foundation types installed to date have been relatively limited, however much of Canada's inner shelf remains largely unquantified. Further surveys and data collection could yield additional sites that show promise for offshore wind development. The area surrounding Sable Island (region 12), located about 170 km off the South-East coast of Nova Scotia, is currently the only region identified as being widely suitable for monopole developments. While the Banquereau region still remains relatively data-poor and has not yet been fully characterized, the GSC has noted that it is another potentially suitable area for monopole deployment. The Northumberland Strait (region 5) also provides some smaller-scale areas that could be suitable for monopoles, while also having shallow waters suggesting some promise for gravity-based foundations.

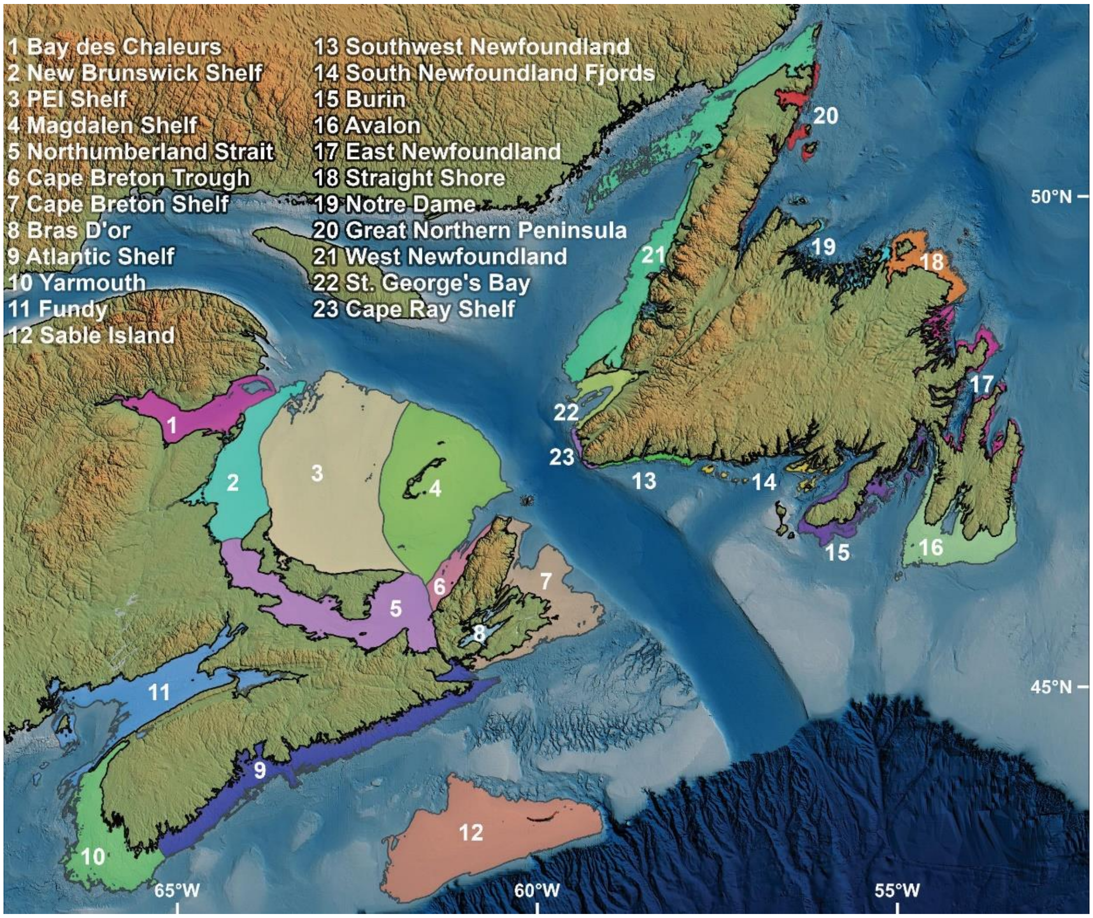

Figure 6.2.1: Geological sub-regions in Canadian Atlantic reviewed by the GSC [10]

While the potential for monopole technologies appears to be limited, there may be other regions suitable for emerging technologies. Baie des Chaleurs / Chaleur Bay (region 1) may offer an opportunity for suction caisson foundations with thick packages of mud, although it is difficult to make a direct analogy with existing locations of offshore wind installations. Gravity-based installations may be possible in regions 2, 3, 4, and 6 and parts of 16, 18, and 21 off NL coast due to thin overburden, shallow water, and low relief. St. George's Bay (region 22) appears to have geology similar to areas in the US Atlantic Coast and North Sea where jacketed foundations are in use or being deployed for upcoming projects. In general, Canada's offshore regions are largely covered by thin sand and gravel layers over bedrock with numerous areas of thick glacial till, including the St. George's Bay region.

Much of Canada's Atlantic region has deeper waters than what is present in the North Sea, meaning the prevalent conditions may be more suitable to the anchoring of floating foundation turbines. This technology, while demonstrated at a few locations, has not been widely deployed and there is still significant work required before firm conclusions can be made regarding the benefits and drawback of floating offshore wind in Canadian waters. The GSC review only surveyed waters of depths less than 100 m and many shallower areas (less than ~30 m) remain data poor due to higher time and cost commitments [10]. A summary of the potential geological suitability for offshore wind technologies based on technologies used in other jurisdictions can be found in Figure 6.2.2 using the same delineation and numbering as Figure 6.2.1. The sub-region classifications not indicating a type of fixed foundation technology are described as follows:

- The highly variable class refers to an area where more data is required to assess foundation conditions, or multiple foundation types may be possible;
- The floating class implies only that fixed foundations are very unlikely in these regions, not necessarily that floating offshore wind is feasible given seabed conditions; and,
- The challenges class represents regions where the environmental conditions pose distinct challenges to any offshore wind installation.

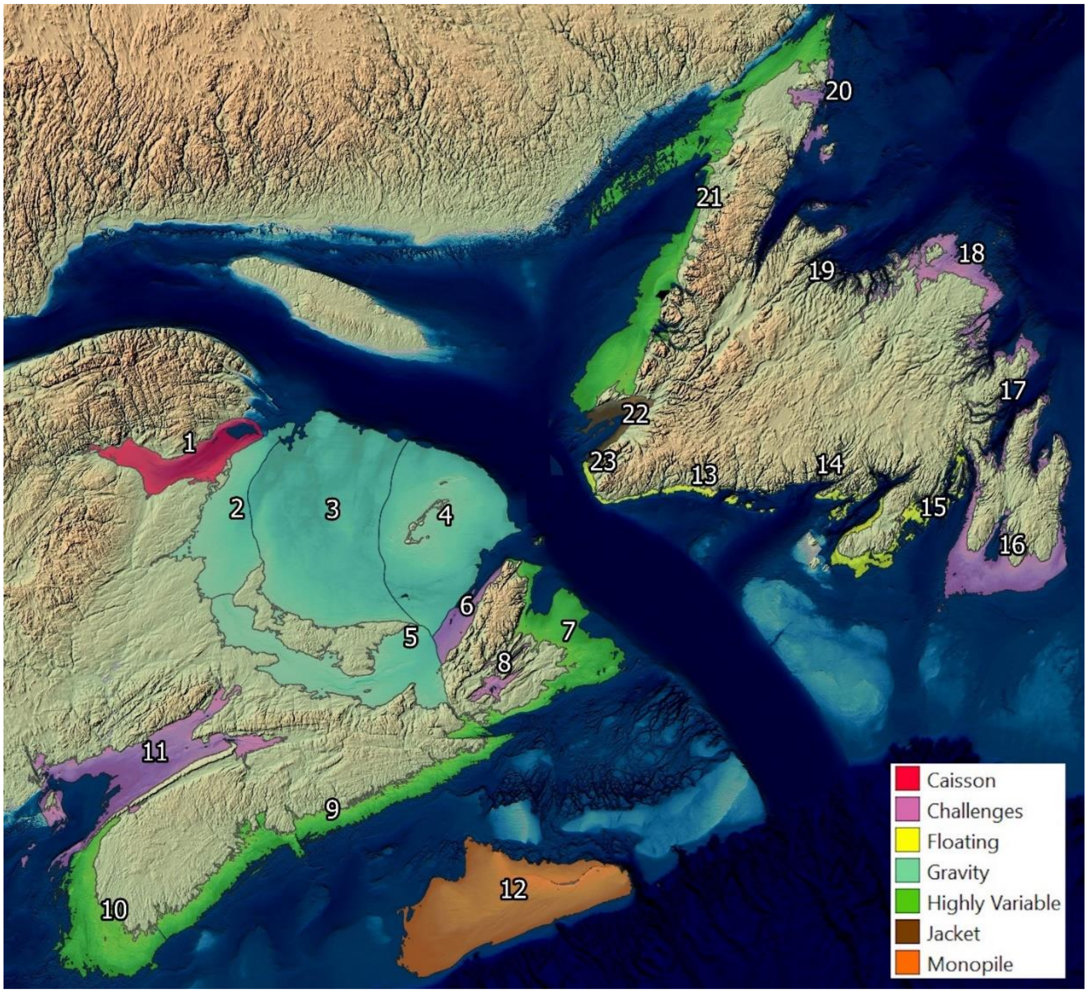

Figure 6.2.2: Delineation of potential geological suitability for offshore wind technologies in Atlantic Canada regions surveyed by the GSC

6.3 Other Geophysical Challenges

6.3.1 Extreme Winds

As offshore wind developments continue to expand into water bodies beyond the established industry in the North Sea, projects are beginning to need to account for more extreme weather conditions, such as the hurricanes common along the Eastern coast of the US. Onshore and offshore wind turbines currently employ built-in mechanisms to protect against high wind speeds. When wind speeds exceed a wind turbine’s maximum operating speed (the cut-out speed), generally 25 m/s (40 km/hr, 55 mph), a turbine will lock and feather its blades, reducing the surface area pointing into the wind until wind speeds drop back to an operable range [117]. In the event of extreme wind speeds, the Block Island wind farm off the coast of Rhode Island, US, has previously demonstrated the ability to withstand wind speeds in excess of 31 m/s (112 km/hr, 70 mph) [117]. Additional research is being performed to mitigate damage to wind farms in hurricane-prone regions. Under extreme conditions, wind farms could be exposed to winds greater than 50 m/s (180 km/hr, 112 mph), particularly if climate change allows stronger storms to travel farther North than they have in the past or generally increases the frequency of extreme wind events

[118]. Research is being done to improve modelling of offshore wind turbines exposed to hurricanes, but expectations are that the impacts to the industry will not be severe even in the event that turbines are unable to handle the worst wind conditions due to the rarity of the most extreme winds (such as the eye wall of a category 3+ hurricane) at any given location along the Atlantic coast [118]. While these hurricane-level winds are much less likely in Canada's Atlantic regions, any potential offshore wind farms still need to account for the high wind speeds that will be expected.

6.3.2 Sea Ice and Icing

In cold climates, sea ice and atmospheric ice can significantly affect wind turbine performance in offshore locations [119]. Sea ice can cause additional static and dynamic forces resulting in additional operational loads including the risk of mechanical shocks or vibration from collisions [119]. While there is no existing offshore wind in Canada, future installations would likely have regulations built upon previous offshore O&G experience. Canadian offshore platforms are designed to withstand some design level of ice loads and, in the case of mobile platforms (such as potential floating wind turbines), can be moved from their standard production site when necessary during ice conditions that threaten major damage to the platform [120]. The Canadian Ice Service (CIS)[25] works to provide information on ice presence in Canadian navigable waters. The SIGRID[26] sea ice charts provide shape file data on the presence of ice in Canadian waters as the median of ice concentration on a scale of tenths of percentiles with Figure 6.3.1 showing historical averages over the past 30 years [121]. For an offshore installation, the expected ice extent and thickness at various time of the year is expected to inform design and construction methods. During operation, data provided by the CIS could be used to monitor and mitigate risks from sea ice.

In addition to sea ice, the frequently cold temperatures and high moisture content in the air above the ocean's surface can produce atmospheric icing. The formation of atmospheric icing is influenced by several variables including precipitation, humidity, sea spray and cloud presence. [119]. The implications of atmospheric icing on offshore wind turbines include [119]:

- Inefficient or failure of wind measurement;
- Rapid performance degradation;
- Increased noise;
- Increased mechanical fatigue;
- Excessive vibrations;
- Ice throw risks; and,
- Limited time availability during installation.

For cold climate sites, it is generally prudent to adopt cold weather packages from turbine manufacturers that can lower a turbine's minimum operational and stand-still temperatures. While some technologies can reduce ice formation or ease efforts to de-ice wind turbine blades, further technology developments may be required for effective cold climate performance in Canadian offshore regions. In terms of design specifications, the IEC's offshore wind turbine standards (IEC 61400-3-1 and -2) provide more detailed commentary on cold climate considerations [122, 123].

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[25] CIS: https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/about-ice-service.html

[26] The word "SIGRID" is derived from "Sea Ice Grid"

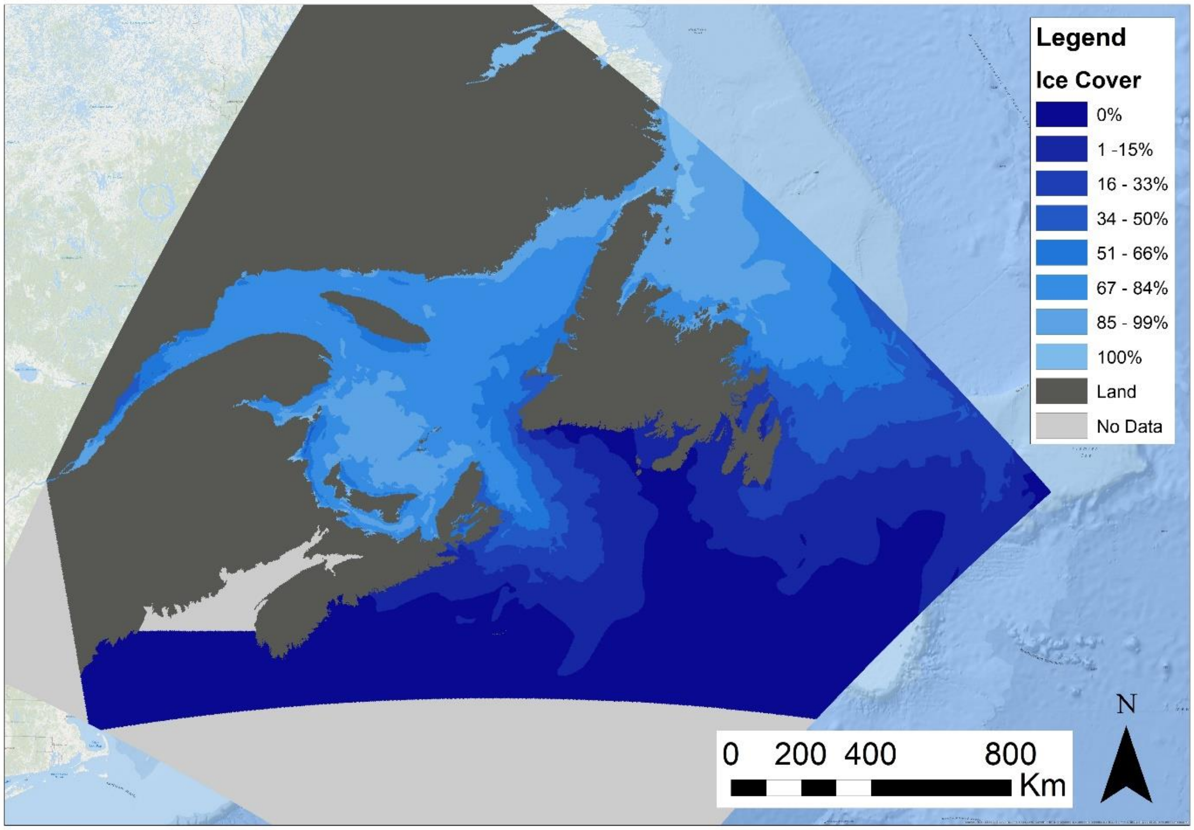

Figure 6.3.1: SIGRID-3 historic average ice coverage along Canadian east coast [121]

6.3.3 Tides

The rise and fall of sea levels will have some impact on the wind shear profile above the water's surface which changes where in the wind shear profile a turbine's hub height rests above sea level [124]. The wind shear profile relates wind speed with height, with greater heights generally associated with higher average wind speeds, which means sea levels may have an impact on wind speeds experienced by a turbine. One study off the East coast of the UK at a location that experiences a tidal range of about 7 m produced the results displayed in Figure 6.3.2 [124]. On average, the tidal variation appeared to have a small but distinct effect on wind speed measured at the turbine's hub height, although the results had a high level of variance [124]. Tidal ranges vary by time of year and location, with location-based tidal ranges primarily affected by surrounding geological conditions, such as funnel or basin shapes, as well as the volume of the bordered body of water [125]. Atlantic Canada borders the Atlantic Ocean and has areas of complex coastline geography resulting in areas of high tides. The Bay of Fundy, Nova Scotia, experiences the highest tides in the world with an average tidal range of about 11.7 m and maximum heights up to 16 m [125]. For fixed foundation wind turbines, tidal effects typically won't have a significant impact on a turbine's lifetime, aside from introducing a small error in modelling production and a minor time-scaled variation in output [124]. As floating offshore wind turbines are still uncommon, the implications of extreme tide heights can possibly be informed by other floating offshore infrastructure. In Canada, DFO provides a service monitoring marine conditions, including tides and water levels along the coastline[27]. Some

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[27] DFO's water level service: www.waterlevels.gc.ca

research has been done looking into the effect offshore wind turbines have interacting with ocean currents and tides on the currents themselves and seafloor stratification, but it is expected to generally have minimal impact although this should be considered for larger-scale development scenarios [126]. Increased turbulence and mixing can result in cascading effects on the ecosystem due to the impacts on phytoplankton growth, however the specific impacts from offshore wind turbines are not well defined and may require additional research [126].

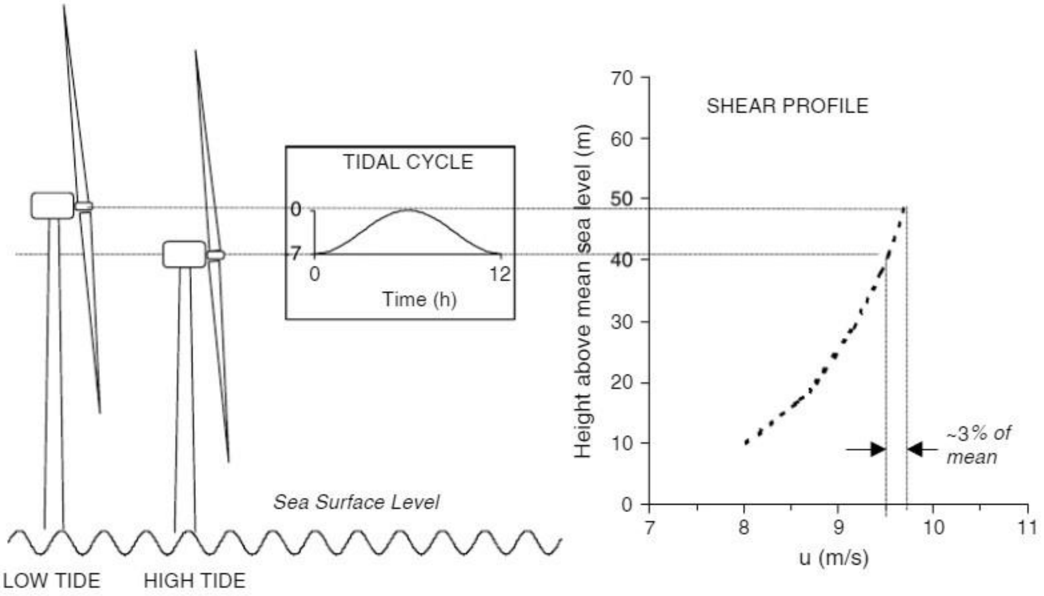

Figure 6.3.2: Tidal effects on average wind speed from a typical location in the North Sea [124]

6.3.4 Wave Conditions

From an operations point of view, site accessibility is paramount, and wave height can have a significant influence on whether a site can be accessed at any given time [39]. The accessibility of a site can therefore be approximated by determining the frequency of a selected significant wave height [39]. Studies have suggested that to maintain an availability of over 90%, the wind farm site must be accessible at least 80% of the time [39]. In terms of the implications of wave conditions, ocean waves pose challenges to transportation and increased risks in the transfer of personnel from a vessel to a turbine platform. One of the most common methods of accessing an offshore wind farm is via transfer with a small vessel. Even if a vessel is able to travel effectively in certain conditions, uneven waters can place undue stresses on workers with increased risk of seasickness. After an uncomfortable voyage, there is still be the prospect of a potentially challenging transfer to a platform if the vessel is unable to remain steady due to waves [39].

The Meteorological Service of Canada provides historical wave data through its “50 North Atlantic Wave Hindcast” covering Canada’s Atlantic coast. An example of this dataset showing the frequency of 3 m wave exceedance is shown in Figure 6.3.3. Understanding the expected average wave conditions for a given location can help inform what a reasonable significant wave height will be for accessibility considerations. Balancing access methods that can handle various wave conditions and the potentially avoided costs of turbine downtime are vital aspects of offshore wind farm planning. Effective forecasts are vital for understanding wave conditions. An example wave model forecast for Canada is available on the Canadian Government webpage titled "Wave Model Charts"[28].

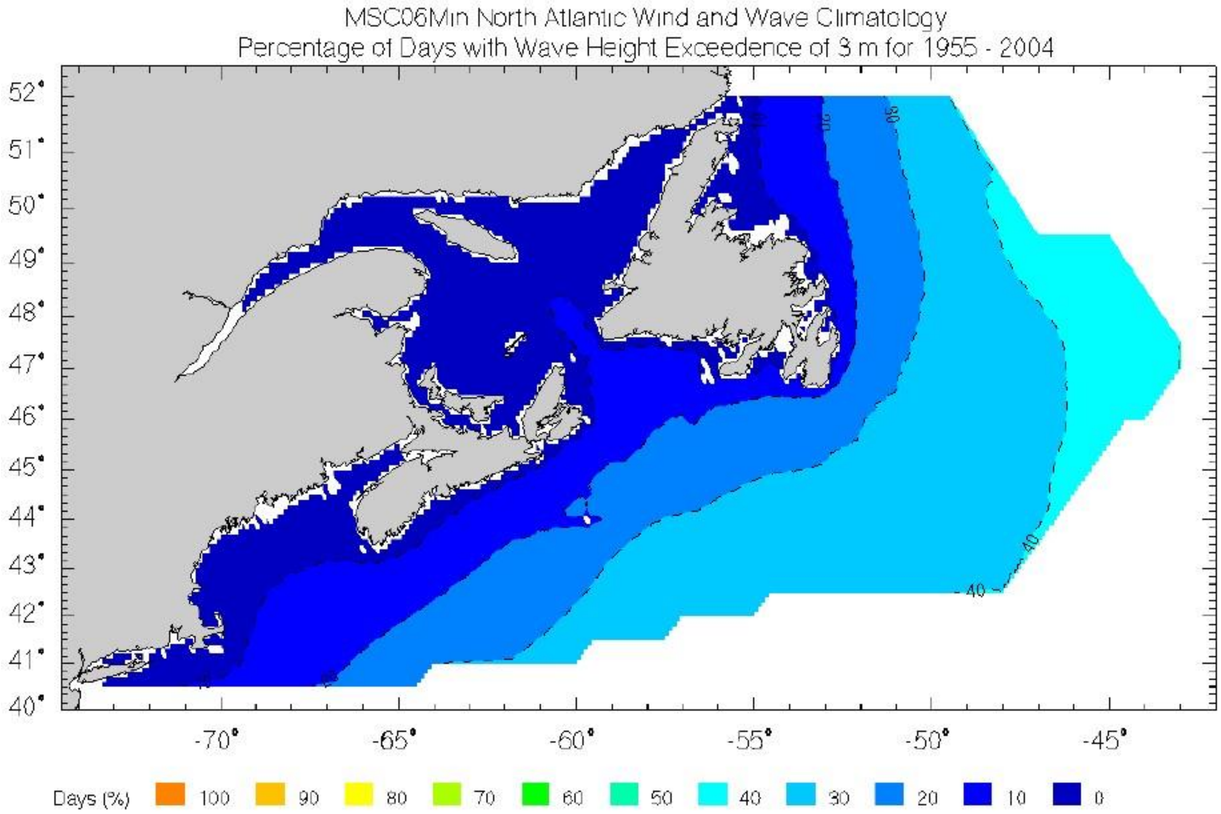

Figure 6.3.3: 50-year 3 m wave exceedance frequency for 1955-2004 [127]

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[28] Government of Canada's wave model charts: https://weather.gc.ca/model_forecast/wave_e.html

7. Discussion and Summary

The intention of this study was to provide background information and resources to policymakers, researchers and other stakeholders in the context of future offshore wind development in Canada. This report provided high level information on five aspects of offshore wind: construction methods, foundation technologies, environmental protection, operational considerations, and a summary of Canada's offshore setting. It is expected that this review can inform future policy and decision-making activities concerning offshore wind by summarizing a broad range of relevant topics and providing links and references to other useful sources of information. While this report does not provide a comprehensive review of any individual topic, it should be regarded as a starting point with which someone unfamiliar with the subject matter can gain an overview of many offshore wind considerations and their relevance to Canada, and a foundation upon which detailed or regional studies can be built.

Construction methods for offshore wind turbines vary depending on the type of foundation technology employed. Generally, for turbines with fixed foundations, components are transported to site and assembly is completed in situ. While floating turbine technologies are still relatively undeveloped, floating foundations can be fully fabricated onshore and floated to an offshore site where they are then moored to the seabed by anchor systems. The onshore construction of floating wind turbines offers opportunities for cost savings compared to in situ assembly. However, while the construction costs of floating offshore wind are projected to rapidly decline in coming years, the increased system complexities and distance to shore result in lifetime costs of electricity that are currently much higher than fixed offshore or onshore wind technologies.

For Atlantic Canada specifically, the geophysical environment results in a number of considerations for offshore wind that must be accounted for. The geological conditions provide notable challenges, as regions with analogous characteristics to zones where offshore wind has been developed in other jurisdictions are limited. While not a perfect comparison, experiences on the US Atlantic coast could provide valuable insight into how a potential Canadian industry could proceed. Compared to the North Sea, where many offshore wind projects are located, Canada's offshore waters are much deeper, providing challenges for common existing foundation types. According to current understanding of the suitability of Atlantic Canada's subsea geology for various offshore wind technologies, floating wind turbines could be an attractive option for unlocking the wind power resource in more challenging areas. In terms of fixed foundations, suitability for monopiles, currently most common worldwide, appears to be limited, while other areas may hold promise for different foundation types such as suction caissons, gravity bases, or jacketed foundations. Increased understanding of Canada's subsea geological regions and their respective suitability for offshore wind turbine foundations will be required before more concrete conclusions can be made.

Like most areas around the world, Atlantic Canada's offshore region has a strong wind resource, with wide ranges of locations that could be economically viable from a wind resource perspective. Canada's climate is also colder than many other countries with offshore wind projects and locating any offshore infrastructure in Canadian waters will need to consider additional factors including possible atmospheric icing and iceberg presence. During operation, an effective maintenance regime that accounts for accessibility challenges will help to ensure maximum availability and minimum operating costs. Capacity factors can be maximized with effective meteorological forecasting and possibly other avenues for the management of excess power. While Atlantic Canadian waters may not experience the same frequency of extreme weather events as locations such as the US Atlantic coast, the capability for a given technology to survive extreme wind speeds will be an important consideration, particularly in the event of potentially changing weather patterns due to climate change.

Environmental impacts of offshore wind are incurred over all three phases of the project lifecycle: construction, operation and decommissioning. Impacts from the construction phase are generally viewed as being intense, but short-lived, whereas impacts from the operation phase can often be longer-lasting and more complex. To date, very few offshore wind farms have been decommissioned, therefore the impacts of this phase are not well documented, but are expected to be comparable to those of the construction phase. In Canada, there are many regulations for environmental protection in place, as well as areas with known ecological sensitivities that have been summarized in this report, but do not by themselves address the conservation and mitigation measures that should be taken into account for future offshore wind projects. While a detailed review of ecological considerations in Atlantic Canada was outside of the scope of this report, the process for developing offshore wind projects will likely follow existing practices for established industries and is expected to include multiple phases of environmental assessment. Canada has many avenues for ecological protection, which any potential offshore wind projects will need to consider in terms of project siting and required mitigation activities. While work is required to more appropriately understand the ecological implications of offshore wind in a Canadian setting, possible offshore wind planning activities can benefit from past Canadian project planning experiences in industries such as onshore wind or offshore oil and gas.

Offshore wind development offers an opportunity for a significant source of clean energy and has been explored by many countries around the world. While additional foundational work is required to increase the likelihood of successful deployment in Canada, the ensuing opportunities for clean power generation and economic development are significant. In many respects, Canada’s oceans present a favourable offshore wind resource, and with rapidly advancing technology around the world, there is a wealth of knowledge to draw upon.

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