



Identifying and Prioritizing Offshore Wind Knowledge Gaps for Oregon

Ocean Policy Advisory Council Scientific and Technical Advisory Committee

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Prepared For: Oregon Ocean Policy Advisory Council (OPAC)

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Cover image: 9.5 MW floating wind turbine being towed to Kincardine Offshore Wind project off coast of Aberdeen, Scotland. Photo courtesy of Principle Power.

Executive Summary

Scientific understanding of climate change and its impacts on natural and social systems have motivated policies to reduce our reliance on fossil fuels and to transition to clean energy sources. Until recently, new policies and federal support have been driving historic investments in clean energy technologies including renewable energy, electric vehicles, and energy efficiency. Starting in January 2025, federal energy policy reversed course. Oregon, and many other states, continue to pursue variety of ambitious clean energy targets to reduce greenhouse gas (GHG) emissions driving climate and ocean changes, and provide related economic growth opportunities, within the next few decades.

Oregon's Department of Land Conservation and Development is working on a legislatively mandated Offshore Wind Energy Roadmap to be completed in June 2026. Concurrently, the Ocean Policy Advisory Council (OPAC) directed the Scientific and Technical Advisory Committee (STAC) to deliver this report to identify knowledge gaps, research needs, and propose a research prioritization framework to inform responsible planning, adaptive management, and policy decisions.

This report synthesizes current scientific and technical understanding, identifies research needs across natural science, social science, and engineering, and proposes a transparent, stepwise framework for evaluating and prioritizing future research investments. It also includes a topically organized bibliography of recent and highly relevant ecological studies and related reports as a resource for developing research plans and siting assessments for floating offshore wind in Oregon.

Research Prioritization Framework

This STAC recommended approach ranks research priorities or questions following a two-step process that evaluates their relevance to Oregon research needs, their feasibility or likelihood of success, the level of effort required, and the likely impact of the information gained.

Step 1 — Relevance & Feasibility Scoring

Proposed research projects or questions are evaluated and scored by a designated group of experts (e.g., STAC) using a set of criteria, including relevance to offshore wind development, usefulness to decision-making, feasibility, Oregon specificity, likelihood of reducing uncertainty, and ability to leverage existing data. A simple three-point scoring system is used to evaluate the project against each criterion (0 - does not meet, 1 - meets somewhat, 2 - fully meets) and scores for each criterion are summed to yield a total score for the project.

Step 2 —Priority Matrix (“Quick Wins” and “Major Projects”)

A designated group of experts (e.g., STAC) evaluates the likely information gained ('impact') and the level of effort or funding ('effort') needed for a proposed research project. They use this to place it into a matrix (Figure 1) that classifies projects into four categories: quick wins (high impact, low effort), major projects (high impact, high effort), thankless tasks (low impact, high effort), or fill ins (low impact, low effort).

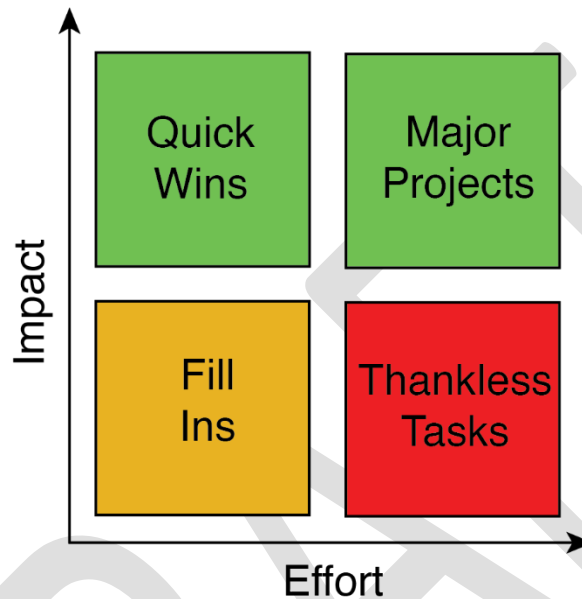


Figure 1. Priority matrix in which proposed projects can be evaluated based on the level of effort required, and the impact of the information produced by the work.

When evaluating a full suite of potential projects, the last step is to identify projects identified as 'Quick Win' and 'Major Project' that also scored above the median score from the first step. These projects would be recommended as the highest priority research projects.

Regionally Relevant Knowledge & Gaps and Research Needs

The breadth of expertise needed to address the full range of topics relevant to floating offshore wind energy projects in Oregon exceeded the STAC’s scope of expertise. We focused our efforts on 1) natural, social science, and engineering topics that were not already addressed in the Floating Offshore Wind Energy Infrastructure chapter of the Seventh Oregon Climate Assessment (submitted to the legislature in 2025) and 2) that also aligned with STAC member’s area of expertise and an ad hoc contributor recruited to address engineering topics. In the report, we summarize regionally relevant research and identify knowledge gaps in the domains of social sciences, natural sciences, and engineering in a series of short topical briefs. The summary list of research needs below is derived from the topical briefs in the report. It reflects the expertise of the subject matter experts who contributed to the report and is not an exhaustive summary of all potentially relevant research needs and questions for Oregon.

Summary of Identified Research Needs

Natural Sciences

- Establish fine scale coastal modeling tailored to Oregon's unique wind regime and topography.
- Combine model predictions with field programs measuring upwelling, nutrients, and plankton across offshore wind affected regions.
- Develop robust methods to detect cumulative and far-field impacts beyond the immediate turbine zone in the presence of natural variability and climate change.
- Longterm marine megafauna (e.g., marine mammals, seabirds) monitoring programs that include winter surveys and nocturnal behavior.
- Year-round monitoring programs for species distribution and collision risk including behavioral tracking inside and around floating arrays to validate collision risk models.
- Integration of seabird energetics and foraging ecology with oceanographic modeling.
- Targeted tagging and telemetry studies to assess migration, electromagnetic field exposure, and behavior within offshore wind areas, especially for salmon.
- Field studies examining species assemblages at floating structures, moorings, and anchors.
- Identification of fishes and fish communities that are attracted to or repelled by floating structures, cables and anchoring devices
- Habitat maps, including foraging areas and migration routes, need to be refined to model potential impacts, particularly for listed and sensitive species
- Baseline habitat surveys and long-term disturbance studies in cable corridors and landing sites.
- Monitoring to determine how local effects of floating offshore wind infrastructure manifest at larger spatial or population scales, and their cumulative impacts on focal species.
- Effects of planned mitigation strategies (chemical and mechanical) for reducing biofouling on infrastructure.
- Chemical weathering and corrosion studies that are specific to materials used in floating offshore wind infrastructure.
- Regional-scale monitoring of microplastics, metals, and coatings.
- Expanded noise monitoring and experimental studies linking noise profiles to species responses.

Social Sciences

- Qualitative studies of social-cultural impacts on fishing communities during times of fishery disruption and community response strategies.
- Analysis of community perceptions of fairness in offshore wind outcomes and engagement processes.
- Identification of fishing community members' trusted information pathways for receiving new evidence and what shapes trust in sources.

- Codeveloped research with Tribes on justice frameworks and culturally grounded governance models.
- Evaluation of current state Tribal consultation protocols using Tribal Caucus of the West Coast Ocean Alliance five essential guidelines and other Tribal approved guidance.
- Exploration of models for Tribal led relational sovereignty for offshore wind planning to build capacity for potential Tribal co-ownership, and shared scientific research and monitoring of wind development.
- Predict the economic impact of floating offshore wind construction and operation on commercial fisheries at the port level using existing fisheries data sets.
- Predict the potential regional economic impact of marine terminal construction.
- Forward looking cost modeling incorporating supply chain, port, and regulatory pathways.
- Analysis of offshore wind value to Oregon's grid under multiple decarbonization scenarios.

Engineering

- Comparative analysis of platform designs suitable for Oregon's offshore conditions.
- Design and analyses of modular, serial manufacturing ready, platforms.
- Certification pathways that enable innovation while ensuring safety.
- Modeling, laboratory testing, and field trials of innovative mooring configurations.
- Comparative lifecycle assessments of anchor technologies.
- Testing of dynamic cables at depths relevant to Oregon.
- Joint Oregon–California interconnection planning.
- Studies of seabed and nearshore routing constraints for cables and landing sites.
- Evaluation of offshore wind contributions to grid reliability and resilience.
- Engineering studies of required upgrades (cranes, quay walls, channel dimensions) for specific ports with specific opportunities.
- Workforce transition planning and maritime sector capacity analyses.
- Research partnerships with global offshore wind hubs to leverage real-world data.
- Pilot demonstrations of autonomous monitoring systems in Oregon waters.

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Introduction

Karina Nielsen

Background

Scientific understanding of climate change and its impacts on natural and social systems have motivated policies to reduce our reliance on fossil fuels and to transition to clean energy sources. Until recently, new policies and federal support have been driving historic investments in clean energy technologies including renewable energy, electric vehicles, and energy efficiency. Starting in January 2025, federal energy policy reversed course. This sharp reversal included the elimination or reduction of tax credits and federal funding for clean energy, energy efficiency, and infrastructure projects. It also resulted in the withdrawal of offshore wind leasing, rescission of Wind Energy Areas on the Outer Continental Shelf previously approved by the Bureau of Ocean Energy Management (BOEM), including two off the Oregon coast, and review of existing offshore wind leases and permits (1). The U.S. also withdrew from the “Paris Agreement under the United Nations Framework Convention on Climate Change” for a second time, eliminating international commitments to climate actions (2).

Oregon and many other states continue to pursue variety of ambitious clean energy targets to reduce greenhouse gas (GHG) emissions driving climate and ocean changes, and provide related economic growth opportunities, within the next few decades. The combination of rising electricity demand, retirement of coal plants, and delays in building new energy infrastructure and resources was recently projected to create a nearly 9-gigawatt (GW) gap for the PNW (3 GW for Oregon and Washington alone) between electricity generated and anticipated need by 2030 (3). In addition, energy costs are rising due to a combination of higher wholesale power costs, wildfire risk reduction and insurance, maintenance and upgrades to aging infrastructure, inflation, and severe weather events (4). Climate related changes in annual precipitation patterns and drought are also affecting the Pacific Northwest’s hydropower.

Oregon, and the US West Coast, also have an abundance of potential offshore ocean energy from persistent and powerful ocean waves and winds. Oregon’s offshore waters continue to be of interest for emerging floating offshore wind and wave energy projects. An open-ocean, grid-connected wave energy testing facility off Newport, OR ([PacWave](#)) was recently completed(5). Planning for siting the PacWave facility started in 2012 in consultation with fishermen and other community members. In 2013, [Principle Power](#) proposed a pilot-scale floating offshore wind project off Coos Bay(6) that was qualified by BOEM in 2014 to proceed with their noncompetitive process to submit a plan for the proposed lease area (7). In 2016 the company requested that BOEM stop processing their application after the Oregon Utility Commission declined to purchase power from the project due to the high price (8).

In 2019, BOEM convened an Oregon Intergovernmental Renewable Energy Task Force and continued through 2024 to establish formal Wind Energy Areas (9). Five federally qualified developers expressed interest in the Call Areas BOEM initially proposed in 2022, setting the stage

for a competitive leasing process. The process generated strong interest from Tribes and many different communities in Oregon including the renewable energy sector, fishing industry, labor unions, environmental and coastal recreation groups, and others. Coastal communities, the fishing industry, and Tribes raised many concerns about the possible impacts of offshore wind energy development.

In 2023, Oregon Consensus facilitated an informal work group to explore the impacts and benefits of offshore wind energy along Oregon's coast and produced a set of recommendations, "Oregon Floating Offshore Wind Energy Roadmap with Exit Ramps: Considerations," about how Oregon might incorporate offshore wind energy with the environment, existing ocean uses, cultures, and communities (10). This effort led to the passage of House Bill 4080 in 2024 directing the Department of Land Conservation and Development to develop an offshore wind roadmap Oregon (11).

In 2024, the United States Department of Interior proposed two areas off the Oregon coast for offshore wind energy development along with auction details and lease terms (12). DLCD's Oregon Coastal Management Program conducted its Federal Consistency review of the proposed leasing action and determined it was consistent with the state's enforceable policies, provided multiple conditions were met related to species and habitat protection, ongoing state involvement in offshore surveys, protection of archaeological resources, and coordination with affected ocean resources users (13).

Ocean Policy Advisory Council Charge

The Ocean Policy Advisory Council (OPAC) is legislatively mandated to advise the Governor, state agencies, and local governments on ocean policy and resource management matters (ORS 196.433). On June 14, 2024, it charged its Scientific and Technical Advisory Committee (STAC) to "... synthesize existing relevant research, identify knowledge gaps, and prioritize research needs in a synthesis to inform adaptive management need for research and monitoring (specific to the BOEM offshore wind authorization process) STAC is also directed to explore the development of an independent technical committee to provide perspective on Oregon or regional research needs and recommendation." The report was to be delivered in June 2025.

However, in September 2024, BOEM postponed the lease auction due to insufficient bidder interest. Simultaneously, the Oregon Governor withdrew the state from BOEM's Intergovernmental Task Force, citing the need to complete its own offshore wind roadmap. Development of Oregon's Offshore Wind Energy Roadmap commenced in November 2024. While it was expected to be delivered by June 2025, the timeline was extended by a year and is on track to be completed by June 2026 (14).

Considering these changes, OPAC revised the charge to STAC at its meeting on May 7, 2025. The charge shifted from addressing BOEM's Oregon offshore wind authorization process to focusing on needs related to Oregon's Offshore Wind Energy Roadmap process. Additionally, California was already moving forward with development of a regional offshore wind research entity to inform their

immediate needs related to adaptive management and monitoring. The Humboldt and Morro Bay offshore wind leases had been auctioned off in 2022, and developers were already working on their construction and operation plans. OPAC dropped the portion of the charge "...to explore the development of an independent technical committee..." OPAC's revised charge directed STAC to focus on developing an offshore wind energy "research prioritization framework" to prioritize key knowledge gaps for further research or monitoring and summarizing regionally relevant research to identify current knowledge gaps. It also requested that STAC crosswalk its identified knowledge gaps with those identified by the offshore wind Roadmap work group(s) and then apply the "research prioritization framework" to identify priority research and monitoring needs for Oregon. The due date for the report was also extended to winter 2026.

STAC Approach to Developing this Report

Over the summer the STAC formed four work groups to 1) develop the research prioritization framework, summarize regionally relevant research and identify knowledge gaps in the domains of 2) social science and 3) natural science, and 4) identify new research, especially empirical studies from floating offshore wind facilities or other relevant settings.

The breadth of expertise needed to address the full range of relevant topics exceeded the scope of expertise of STAC members. We decided to focus on natural and social science topics that were not already addressed in the Seventh Oregon Climate Assessment chapter, Floating Offshore Wind Energy Infrastructure(15) and that also aligned with each STAC member's area of expertise. We were also able to recruit an ad hoc expert to address floating offshore wind engineering knowledge gaps relevant to deep water deployments off the Oregon coast.

For additional relevant scientific and technical information related to floating offshore wind in Oregon, we encourage readers to consult the Seventh Oregon Climate Assessment chapter focused on floating offshore wind. It includes a policy overview, detailed descriptions of floating offshore wind energy infrastructure, transmission, and ports, and sections on how the infrastructure interacts with the environment. Specific environmental topics addressed are wind-driven upwelling, underwater sound, secondary entanglement hazards, electromagnetic fields, and submerged cultural and archaeological resources. It concludes with information on societal responses and adaptive management principles.

This report does not include a compilation or list of Oregon specific research questions from the **STAC**, Roadmap or OPAC working group nor did it apply the research prioritization framework to a set of research questions aside from the two examples. The STAC recommends that OPAC consider forming a joint working group with a subset of members from each of these groups to identify and compile a list. That list could then be used by the STAC to apply the research prioritization framework and report on the outcome of the analysis.

Research Prioritization Framework

Will White, Veronica Dujon, and William Jaeger

Given limited time and resources, it is important to have a transparent framework that will guide decisions for funding research on the environmental and ecological impacts and engineering of floating offshore wind. We propose a framework that builds on one developed to prioritize research on ecological climate resilience in marine protected areas (16). This approach is to rank research priorities or questions following a two-step process that evaluates their relevance to Oregon research needs, their feasibility/likelihood of success, the level of effort required, and the likely impact of the information gained.

For any proposed research project, the STAC (or other designated scientific and technical entity) will first score the proposed work for relevance and feasibility (Step 1). They will then categorize the proposed work in a priority matrix (Step 2 below) based on their expert assessment. The purpose of the priority matrix is to identify scientific investigations that can be expected to yield high-value information that fills key information gaps, while balancing the difficulty, cost, or likelihood of success. Only projects that are scored in the 'green' areas of the priority matrix and above the median score from Step 1 will be recommended by STAC. Below we provide worked examples of how this framework could be applied to hypothetical proposed research questions.

Step 1: Score research on relevance & feasibility

Scores are 0 (does not meet), 1 (meets somewhat), 2 (fully meets)

- Applicability to offshore wind projects
- Importance to decision making by the relevant agencies (e.g., Oregon Department of Fish and Wildlife, Oregon Department of Energy)
- Feasibility to complete
- Addresses gaps in knowledge
- Addresses topics with a plausible hypothesis but limited evidence
- Likelihood of producing information that reduces uncertainty
- Addresses questions on a relevant time scale
- Addresses topics specific to Oregon
- Can be completed with existing data, or will collect all necessary data

Step 2: Evaluate priority

Experts will place proposed research into a matrix (Figure 1) that evaluates the likely information gained ('impact') given the level of effort or funding ('effort').

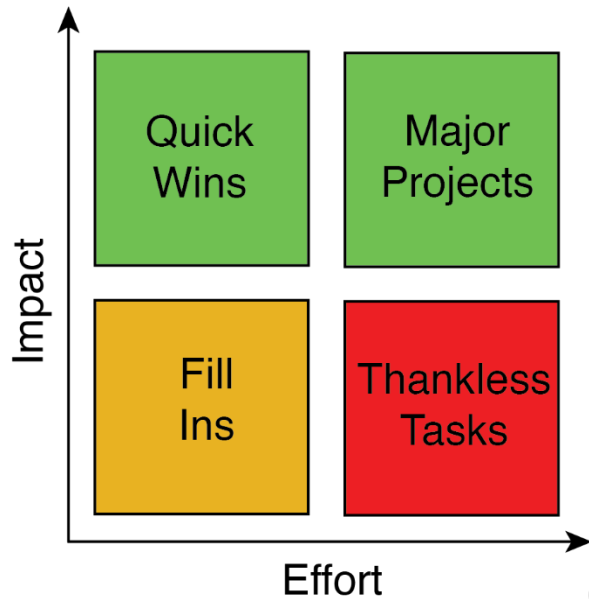


Figure 1. Priority matrix in which proposed projects can be evaluated based on the level of effort required, and the impact of the information produced by the work.

Examples

Two potential research questions (RQs) that could be prioritized in this framework are:

1. Will floating offshore wind infrastructure cause a reduction or relocation of primary productivity because of interference with wind-driven upwelling circulation?
2. Will electromagnetic fields generated by offshore wind infrastructure or transmission cables affect navigation, orientation, or prey detection of marine species, particularly anadromous species in or near estuaries?

Step 1 Scoring

Scores are 0 (does not meet), 1 (meets somewhat), 2 (fully meets)

Scoring question	RQ1	RQ2	Comments
Applicability to offshore wind projects	2	2	
Importance to decision making by ODFW	1	1	Unclear how this information would influence state-level regulatory processes
Feasibility to complete	2	1	RQ1 could be simulated with existing biophysical models; RQ2 would require experimental deployments in lab and field.

Scoring question	RQ1	RQ2	Comments
Addresses gaps in knowledge	2	2	
Addresses topics with a plausible hypothesis but limited evidence	2	1	There is already a body of literature on EMF effects on fish, but it would be important to assess the specific proposed cable designs on species relevant to Oregon.
Likelihood of producing information that reduces uncertainty	2	1	It is uncertain whether lab or field investigations on EMF effects could scale up to the magnitude or spatial scale of proposed developments, or whether it is possible to assess effects on the full life cycle of species (e.g., anadromous salmonids).
Addresses questions on a relevant time scale	2	1	It may be impossible to fully assess RQ2 until full-scale infrastructure is in place.
Addresses topics specific to Oregon	2	2	
Can be completed with existing data, or will collect all necessary data	2	2	
Total	17	14	

Step 2 Scoring

RQ1 could be addressed on a short time scale using simulations with existing, validated biophysical models. For example, this type of analysis has already been conducted for California waters (17). The results would be important in assessing the overall ecosystem impacts of floating offshore wind, as wind-driven upwelling is the primary driver of ecosystem productivity on the Oregon continental shelf. This would classify the project as a 'Quick Win'.

RQ2 has already been addressed in a variety of laboratory and field studies on various species (18) but the state of knowledge in the field points to the need to evaluate the specific proposed cable layout design and the species of particular concern in Oregon (15). This is because the magnitude and location in the water column of induced magnetic fields depends heavily on how the cables will be deployed in the array, and because species differ substantially in their sensitivity to those fields. Addressing this question would produce valuable Oregon-specific knowledge but would

require challenging experimental work to provide answers at ecologically relevant spatial and temporal scales. Hence the project would be classified as a 'Major Project'.

Had we evaluated a full suite of potential projects in this example, the next step would be to identify projects in the 'Quick Win' and 'Major Project' categories that also scored above the median in Step 1. These projects would be recommended as the highest priority research projects to pursue.

DRAFT

Regionally Relevant Knowledge & Gaps

Natural Science

Ocean Ecosystem: Winds, Upwelling, Circulation, and Lower Trophic Levels

James Lerczak

Various research groups have utilized an atmosphere/ocean/ecological modeling framework to assess the impacts of offshore wind turbines on wind circulation and turbulence in the atmosphere, circulation of the coastal ocean in the vicinity of wind energy sites, as well as impacts on nutrients and lower trophic level ecosystem dynamics (see for example, Farr et al. (19)). Some recent modeling studies have focused on European sites such as in the North Sea (for example, Daewel et al. (20)). Whereas others have focused on impacts to the U.S. West coast California Current Large Marine Ecosystem (17,21,22) (CCLME). As part of the 7th Oregon Climate Assessment, variability in wind forcing, coastal topography, and resultant variability in upwelling along the Oregon coast is described and potential impacts to upwelling circulation from offshore floating wind energy farms are outlined (15). Further, the report emphasizes the challenges in detecting impacts on upwelling and the coastal ecosystem by wind farms and distinguishing them from natural variability and changes associated with long-term climate change. More recent, unpublished studies, have advanced the modeling and quantification of impacts of floating offshore wind sites on upwelling and ecosystems in the CCLME system (for example, see the National Academy of Science sponsored meeting on *Impacts on Shipping and Commercial, Tribal, and Recreational Fisheries from Development of Renewable Energy on the West Coast* (23)).

These studies have high relevance to assessing impacts on circulation and ecosystems at potential floating offshore wind energy sites off Oregon with some direct assessment of impacts at potential Oregon sites (for example, offshore of Coos Bay, OR). However, the emphasis of much of current work has focused on potential California offshore wind energy sites. U.S. West coast modeling has utilized models with horizontal resolution of >1 km. Thus, wind turbines and their resultant impacts on wind circulation and turbulence must be parameterized, and important physical and biological processes of upwelling systems may not be effectively resolved (for example, the physics and biological productivity in regions with strong fronts).

Impacts on upwelling circulation by floating offshore wind sites within models have been quantified by the coastal upwelling transport index (CUTI). These impacts can be positive or negative and are limited to a region where the wind field is directly impacted (~10s km downwind of the wind farm site). Impacts on nutrient supply have been quantified by the biological effective upwelling transport index (BEUTI). Similar to CUTI, impacts on BEUTI were limited to regions where wind fields are directly modified by the floating offshore wind energy site.

Within the modeling studies noted above, impacts on phytoplankton and zooplankton concentrations were as large as ~20% relative to baseline studies. These impacts have broader

spatial scales compared to those on CUTI and BEUTI, due to both local impacts of nutrient supply and by larger scale transport of plankton by the coastal circulation.

There are a host of historical and ongoing modeling studies of the CCLME system along the U.S. West Coast, including Oregon, as well as impacts on this system due to climate change (22,24,25). Studies specific to impacts on the Oregon system due to floating offshore wind energy devices are limited. The recent studies on wind energy sites along the U.S. West coast impacts on winds, upwelling, nutrients, and lower trophic levels represent the state-of-the-art approach and provide a sound framework for assessing impacts of Oregon floating offshore wind energy sites on coastal circulation and lower trophic level ecosystems. However, we identify **some knowledge and assessment gaps** that should be considered:

- Adequacy of **model resolution and physics parameterizations** need to be assessed.
 - Is the ~3 km horizontal resolution used in recent studies sufficient to resolve the impacts on relevant and important physical and biological processes in the upwelling system (e.g., the physics and productivity in regions of strong fronts)?
 - Is the parameterization of wind turbines and resultant impacts on wind momentum and turbulence accurate and sufficient?
- **Development of robust observational and modeling methods and strategies** is needed to directly measure and distinguish wind energy farm impacts from natural variability and long-term climate change.
- **Impacts on higher trophic level species** (e.g., fish) and important **biogeochemical tracers** (e.g., dissolved oxygen) need to be assessed.

Offshore wind energy site impacts have focused on proposed California sites, with limited assessment of Oregon sites. This represents a significant gap in **direct Oregon offshore wind impacts assessment**, given Oregon's unique wind field and topographically driven circulation relative to California.

Marine Mammals & Seabirds

Jan Hodder and Selina Heppell

Marine Mammals

Robust information on cetacean abundance including “hot” and “cold” distribution spots in Oregon waters are expected to be available soon from three projects, still in progress, conducted by members of the Marine Mammal Institute at OSU:

1. HALO: Holistic Assessment of Living marine resources off Oregon (26)
2. MOSAIC: Marine Offshore Species Assessments to Inform Clean Energy (27)
3. OPAL: Overlap Predictions About Large whales (28)

These projects will provide several years of observations from April to October off Oregon and Northern California (29). Winter abundances and hot/cold spots are less well documented other than for the nearshore gray whale migration.

Threats to cetaceans from floating offshore wind activities include vessel strikes, noise production and entanglement. Noise type and levels are dependent on the specific design of floating offshore wind structures (30). Primary entanglement where an animal would be directly impacted by the floating offshore wind structure is unlikely but secondary entanglement, where debris such as ghost fishing gear becomes caught on a structure and subsequently catches an animal, is a possibility for both cetaceans and pelagic pinnipeds. The potential of secondary entanglement may become a more significant concern if fishing is permitted within floating offshore wind sites. NOAA does not anticipate and has not authorized—or proposed to authorize—death or serious injury of cetaceans for any wind-related action. The majority of take authorized for offshore wind activities has been for Level B harassment, which is a disruption of behavioral patterns or a temporary reduction in hearing sensitivity. These impacts are expected to be relatively short in duration(31).

The distribution of pinnipeds in Oregon is well known for those that haul-out on land in Oregon. Less well known is the distribution of the more pelagic Northern and Guadeloupe fur seals which do not come to land in the state and are the most likely species to be impacted by secondary entanglement. The design of floating offshore wind structures may impact the likelihood that pinnipeds could use them as haul-out opportunities.

Seabirds

An understanding of the Oregon offshore abundance and distribution of seabirds has increased because of surveys conducted in spring (May/June) of 2014, 2015, and 2016 (32) and six, two-week surveys conducted during April – October 2023 and 2024 by OSU's Marine Offshore Species Assessments to Inform Clean Energy (MOSAIC) project (27). Abundance and distribution heat maps for eleven marine bird species are included in Orban et al. (32). The data analysis from the MOSAIC surveys is still in progress but bird distribution and hot/cold spots for twenty-two species are being developed (pers comm. Rachel Orben, OSU). These data, however, also only covers the April - October period. There are very few data on the presence and distribution of seabirds offshore in Oregon in winter. Other gaps include information on distribution and abundance of species that migrate through Oregon's ocean such as loons and phalaropes, those that breed elsewhere but use Oregon's ocean in their non breeding season such as Cassin's Auklets, jaegers, and Endangered Species Act listed Short-Tailed Albatross, and the travel corridors and feeding areas of Leach's Storm Petrels during the breeding season that feed over 100 km offshore bringing them into the floating offshore wind space.

An understanding of seabird flight heights and structure attraction and avoidance is needed to estimate collision vulnerability to offshore wind energy development. Modelling seabird collision vulnerability by Wallach et al. (33) included data from Oregon. Of the forty-four types of seabirds examined most are predicted to remain within 10 meters of the sea surface. Only about 8% of the seabird community, including sooty shearwater (a dynamic soaring species) and various gull species, are likely to be present at heights exceeding 10 meters above the sea surface where interference with rotor blades might occur. Recent work in Scotland looking at larid (gulls and kittiwakes) flight vulnerability **within** a floating offshore wind array indicated a strong avoidance

response but cautioned that the pattern may breakdown in situations of strong turbine-induced turbulence and high wind speeds(34). Gaps in understanding of collision vulnerability include an understanding of finer detail of within-array wind dynamics and for effects on species that are more active during twilight and darkness such as Rhinoceros and Cassin’s Auklets. There is a potential for seabird distributions to be impacted by floating offshore wind structures if species are attracted to roost or to feed in the area if a fish “reef” effect is present (see Fishes and Fish Habitat section below). There is considerable research about the impacts of lighted structures on seabirds. The U.S. Fish and Wildlife Service maintains a collection of information sources focusing on this topic including mitigation measures for the floating offshore wind industry (35).

With respect to more nearshore impacts of floating offshore wind development such as cable routes and landing sites there is a robust understanding of the distribution and abundance of the breeding seabird community (36) and of snowy plover nesting sites (37).

Additional gaps

The impact of floating offshore wind on food sources for these top predators is not possible to assess currently. Changes to the food web could be positive or negative depending on multiple factors including physical oceanography effects, fisheries exclusion effects, or the artificial reef potential of floating offshore wind structures.

Fishes and Fish Habitat

Selina Heppell

While the effects of offshore energy development on fishes and invertebrates have been studied for several decades, particularly the influence of support structures on fish habitat (38–40), the effects of *floating* offshore wind devices on fishes are poorly studied due to its relatively new development. Installation, operation, and maintenance of floating offshore wind can impact fishes in a number of different ways, depending on fish behavior and ecology, trophic level, habitat use, sensitivity to pollutants, commercial value, and other factors (18,41). Not all effects are expected to be negative; for example, the structures may serve as fish habitat and accumulate seaweeds and invertebrates that contribute to the nearshore food chain, as documented for offshore oil platforms in California (42). Scale is also important to consider, as many fishes in Oregon have broad geographic ranges, but local changes may be apparent in the number and diversity of fish species in and around the farms. The value of fish resources in Oregon is high, and a precautionary approach based on well-designed studies is important to anticipate impacts to fish and invertebrates and their habitats.

While peer-reviewed studies of floating offshore wind impacts are growing, the oldest facilities have been in place for less than a decade. Recent literature that reviews field and laboratory studies of the effects of offshore wind development on fishes includes a special issue of the journal *Oceanography* (43). Reports from 11 field studies of floating offshore wind (Hywind farms in Scotland and Norway) included six of which evaluated fish communities at the sites relative to reference areas or distances from the sites (30). Five of the six studies found no significant differences in fish or plankton relative to distance from the farm, while limited environmental DNA

sampling in a report from Scotland found evidence of higher concentrations of baitfish (sprat and herring) within the farm site compared to reference sites. Research needs identified by Gill et al. (44) are similar to those identified by the Oregon Department of Fish and Wildlife and the Pacific Fisheries Management Council (PFMC), who have considered effects and uncertainties of floating offshore wind on Oregon's coastal fish and invertebrate species.

As the most valuable fisheries in the state, salmon, Dungeness crab, and Pacific whiting are species of concern for potential floating offshore wind development. Habitat impacts that affect groundfish (sablefish, flatfish (including halibut), rockfish and lingcod) and the potential for structures to attract pelagic species such as mackerel and albacore tuna should also be evaluated.

Critical uncertainties to study in Oregon include:

- the attraction of local species to floating structures and anchors, which may serve as artificial reefs with positive or negative effects
- measurable effects of floating offshore wind on the migration behavior of salmonids and crab due to noise, electromagnetic fields, or the structures themselves
- short and long-term impacts of installation on fish habitat
- effects of planned mitigation strategies to reduce biofouling of structures and cables (chemical or mechanical)
- scale of impact – the relevance of local effects of floating offshore wind infrastructure at larger spatial or population scales, and cumulative impacts on focal species

The siting of the wind infrastructure requires local expertise to identify potential impacts and minimize harm to marine resources. Habitat Areas of Particular Concern (HAPCs) identified by NOAA and PFMC need to be avoided, including critical estuarine habitats that will be impacted by onshore infrastructure and power transmission. Installation impacts fish communities and habitat may be transient (e.g., noise (45)) or long-lasting (e.g., disruption of soft sediments or rocky reef habitats), but may have a small footprint, particularly if anchoring devices are small and well-secured.

The shape and size of structures introduced into the marine environment, particularly in locations where physical structure is absent, will affect how those structures act as artificial reefs and alter fish behavior and marine communities. There is a growing body of literature on the costs and benefits to fishes of manmade structures in the marine environment (41), including stationary (fixed bottom) offshore wind farms (39,46). The fish aggregation attraction of floating objects is well-known (47), and pelagic stages of Oregon groundfish are attracted to certain devices in the upper water column (48), but the potential for attraction of floating offshore wind platforms for pelagic fishes in Oregon has not been evaluated.

The effects of electromagnetic fields on fishes have been studied in some species and are generally believed to be highly localized and minimal (18). However, Klimley et al. (49) specifically called for more research on the effects of subsea cables on migratory species that use the Earth's magnetic

field for homing, including salmonids. Additional research and monitoring of salmon near floating offshore wind infrastructure and cables is likely needed to identify any substantial change in behavior or distribution of out-migrating juveniles and, importantly, returning adults.

It will be important to learn from impact monitoring studies in Northern California following the construction of floating offshore wind projects, as that region has significant overlap with Oregon in the species and distribution of nearshore fishes and invertebrates.

Altered Physical and Chemical Conditions

Elise Granek

There is a body of literature on physical and chemical effects of floating offshore wind, however many of these studies are place-based and are dependent on both the local conditions and the characteristics of a particular floating offshore wind array. Therefore, to determine the effects of floating offshore wind developments in the region, a number of variables need to be considered.

Physical and chemical components

The types and quantities of plastic, metal, etc. used in the manufacturing and installation of the structures will dictate what materials may be generated and released during the infrastructure installation and over time through weathering. Chemical agents applied to the structures during manufacturing or utilized in the hydraulics of the structures vary across manufacturers. Therefore, the chemicals utilized and quantities that might be released during installation and weathering of the infrastructure may vary. Previous studies on structures from relevant manufacturers can be used to assess potential effects.

For example: seawater corrosion can release metals and anti-corrosion organic coatings can release organic matter (50,51). Previous research has measured the metal body burden of mussels colonizing wind turbines (52) and trace elements released from wind turbines (53).

Wind farms can entrain and release ocean microplastics (54) and microplastics can be released from turbine blade erosion (55–57). Monitoring microplastic releases in the regional environment may be informative.

Sound

Floating offshore wind structures can generate sound that may affect some marine animals. The frequency, duration, and types of sound generated will vary depending on environmental conditions, such as wind speed. It is notable that installation of floating offshore wind produces less sound than fixed. There is limited data on the effects of floating offshore wind operational sounds on marine and avian species, though some research has been conducted on the effects on fisheries and wildlife (58–63).

Light

The inclusion of lighting on floating offshore wind structures is important for aviation (red) and marine navigation safety (yellow). Aircraft detection lighting systems can mitigate aviation lighting. Studies on the effects of structure lighting on marine and avian species are limited, with some previous research on light pollution effects on wildlife and humans (64–66).

Electromagnetic fields

Many marine species respond to and can be affected by electromagnetic fields, e.g., fish behavior. Previous studies indicate no evidence of harm from electromagnetic fields at existing densities of high voltage subsea cables. At higher cable densities, including inter-array cables connecting individual turbines suspended in the water column that may be part of a field of floating offshore wind structures, migratory species of concern should be monitored (15).

Scale of impact

Changes in physical and chemical conditions around floating offshore wind sites may affect species living adjacent to the structures. Monitoring for larger scale effects that cannot be assessed in advance through modeling or smaller scale studies is warranted.

Social Science

Oregon Coast Fishing Community

Kelsey Emard

Studies of the impacts of offshore wind on fisheries globally have not accumulated a sufficient base of evidence to confirm impacts. A recent systematic literature review of 1,268 documents found that there was insufficient direct evidence to determine impacts, owing to inconclusive results and inconsistent effects (30). While the study identified indirect impacts to fisheries, such as changes in the benthic ecosystem, those indirect impacts have not been studied long enough to determine the final relationship with fish populations and fishing livelihoods. Despite the insufficient evidence base, early studies in Oregon provide preliminary evidence that offshore wind could impact fisheries and fishing livelihoods in important ways. Warlick et al. (67) analyzed the exposure, adaptive capacity, and sensitivity of groundfish (Dover sole, Thornyheads, and Sablefish) trawling fisheries to the proposed offshore wind areas near Coos Bay and Brookings and found comparatively high levels of risk compared to proposed offshore wind areas in California.

The fishing community has voiced concerns regarding the impacts of offshore wind on fish and shellfish behavior and movement, habitat provisioning for commercial species, and their ability to use their current fishing practices (68). In fact, of 1,718 public comments on BOEM's offshore wind proposals for Coos Bay and Brookings, approximately half of the comments that were opposed to the proposal cited concerns for local fishing (69). While most of the concerns are ecological and biological in nature and will be addressed through relevant environmental assessment and scientific research, there is also a need to understand the fishing industry's resilience to changes in the fishery, including changes wrought by offshore wind. Accordingly, a key research gap pertains to our limited understanding of the economic, social, and cultural impacts if the fishery were to experience population declines, behavior changes, or spatial shifts, or if fishers were required to fish using new methods.

While few studies have examined these questions in relation to offshore wind, we can draw from the work on the resiliency of Oregon's fishing community to other ecological and economic pressures. Conway and Cramer (70) draw on two decades of scholarship with Oregon's coastal communities and document myriad ways that Oregon fishing families and communities adapt to changes and demonstrate cultural and community resilience. Yet, in another study with the same authors, Haugen et al. (71) found that when compounding factors impact Oregon coast fishing communities, such as climate change and economic shifts simultaneously, the resilience and adaptive capacity of the fishing industry and community become notably strained. This suggests that offshore wind impacts, if compounded with other drivers of change, could test the resiliency of the fishing community. There is much more that should be investigated to better understand how Oregon's fishing industry and communities would respond to offshore wind impacts, including what alternative livelihoods, fishing methods, or other economic strategies they would employ to adapt, as well as the cultural and social loss that may accompany these changes.

Oregon's fishing community also raised concerns about a lack of meaningful engagement in the process that would determine offshore wind project siting and parameters (68). Thus, a second key research gap is our lack of evidence regarding what processes and plans the fishing community would find acceptable as meaningful engagement. While we have limited research in the context of Oregon, we can learn from studies done in other regions. For example, a study of offshore wind projects and fisheries in the UK and the Eastern United States identified the following as key to meaningful offshore wind planning processes and outcomes for communities: 1) financial assistance provided in the forms of community funds and matching grants to support fisheries in the wake of offshore wind implementation; 2) the provision of alternative employment opportunities related to the wind energy operations; 3) collaborative negotiation of alternative livelihoods, as being on the sea can hold meaning that goes beyond simply economic; and 4) engagement that is done in person, early, and throughout the process (72,73). These findings need to be evaluated in the specific context of Oregon to know if they remain consistent here.

A final research gap is our limited understanding of the trusted knowledge sources and information pathways for Oregon's fishing community that would allow for knowledge sharing and dialogue on offshore wind in the future. While there are studies of fishers' knowledge sources (74), the particular networks of trusted information for Oregon fishing communities who would be impacted by the proposed offshore wind projects have not been evaluated and is highly pertinent to future project development.

Tribal Consultation and Collaboration

Jenna Tilt

Tribal consultation and engagement are fundamentally different from community engagement. *"From a Tribal perspective, the goal of Tribal consultation is to achieve decision making through consensus. Meaningful consultation using a consensus-seeking decision-making approach acknowledges that Tribal Governments are sovereign governments, not stakeholders"* (75). Every Tribe has a different process for Tribal consultation; however, all Tribes have a formal government-to-government (G2G) consultation process that is situated in a broader consultation process. Overly focusing only on the formal G2G does not provide for the adequate time and space for the development of a meaningful and productive process. Thus, the Tribal Caucus of the West Coast Ocean Alliance (WCOA) defines Tribal consultation as *"the overall process of sharing information, coordination, engagement, and dialogue that occurs between Tribal Governments and governmental or administrative entities within the United States"* (75). It is the job of agencies to educate themselves regarding Tribal communication and consultation protocols, not the Tribe. Being highly knowledgeable of specific Tribal history and treaty rights is critical to understanding any proposed actions and impacts to a Tribe. Taking the time to continue to educate new staff about Tribal governance and cultural world views can be extremely frustrating and wasteful of Tribal resources. To assist in this learning process, WCOA provides five essential guidelines to a meaningful Tribal consultation (75). These guidelines are summarized below.

- 1. Engaging in early and frequent communication with Tribal Governments.** Agencies should reach out as early as possible in the process (e.g., proposal submission, rule change, research question). Communication should not be just a “Dear Tribal Leader” letter/email but include follow up in-person conversations and phone calls. Notifying Tribes after a process has begun (e.g., engaging first with other communities, hiring consultants, initiating planning or initiating a scope of work) leaves the impression that Tribal input does not matter and they have no impact on the action or decision. Tribal governments do not like to be asked to change their decision-making timeframes to fit within agency timeframes; agencies should recognize that 60- or 90-day comment periods are often inconsistent with Tribal government time frames. It is recommended that agencies initiate consulting with Tribes before non-Tribal public comment periods open.
- 2. Ensuring the presence of appropriate representatives for a given stage of the process.** While Tribal Council is the official point of contact for G2G consultation, the consultation process may involve multiple Tribal roles from Tribal technical expertise, alternative points of contact, and others. Agencies should coordinate with the Tribal liaison within their own agency or meet with Tribal technical staff to identify the most appropriate Tribal representative to initiate early conversations. Tribes may not immediately respond to request for consultation given limited capacity or other issues. It is up to the agency to continue to reach out in multiple modalities and provide assistance to overcome capacity issues (e.g., summary documents, travel stipends).
- 3. Having an understanding of and respect for Tribal decision-making processes.** Tribal decision-making processes are unique in their structure and represent unique cultural worldviews. Agencies should become highly knowledgeable in how Tribal governance decisions are made in order to establish effective communication channels and partnerships with Tribes. Communication with Tribal members and staff outside of formal G2G consultation meetings can facilitate understanding of the decision-making processes and issues at hand. However, this informal communication cannot be interpreted as formal G2G consultation.
- 4. Adopting a consensus-seeking approach to Tribal consultation.** A consensus-seeking approach requires an understanding of the FPIC principles—governments should obtain free, prior, and informed consent (FPIC) from Tribes before enacting policies or actions that may affect their rights, lands, and resources (76). As such, it is the Tribal government that determines the impact of a proposed action will have, not the agency. Together, agencies and Tribes need to identify and establish the endpoint goal of G2G consultation and how to determine if Tribal needs are met.
- 5. Ensuring a transparent and accountable process that provides clarity on agency decision making and the potential for Tribal Governments to affect the final decision.** Agencies need to understand their own consultation and communication rules and reconcile these with those of Tribal governments. Agencies need to maintain clear and

confidential data management agreements with Tribes and adopt transparent consultation protocols such as timely development and distribution of meeting summaries after approved by Tribal Governments. These agreements and policies will help with continuity in the consultation process, especially with changes in leadership and staff.

Literature Findings related to offshore wind development and Tribal engagement

- Energy justice involves three tenets of justice: 1) distributive justice—how costs and benefits of energy transition to offshore wind are distributed throughout geographic and interest communities; 2) procedural justice—how different groups—Indigenous and Non-Indigenous are included in the decision-making process; and 3) Recognition justice: acknowledgement of the disproportional impacts of energy transitions (77). More research is needed in identifying how these three tenets of justice are uniquely conceptualized by Oregon Tribes for offshore wind energy projects and how the state can ensure just and equitable outcomes (78,79).
- Tribes are more likely to oppose offshore wind if they cannot negotiate shared power with the federal government through a co-management agreement or similar approaches(80–83). For example, North Coast California Tribes want to share ownership and control of the offshore wind development to promote their own economic development while stewarding their kinship with the ocean (84). Additionally, shared jurisdictional authority over, and Tribal management of, offshore renewable energy activities is supported by The National Congress of American Indians (83).
- Tribal-led relational sovereignty could inform and guide negotiations between Tribes and governments in offshore spaces. This approach focuses on alternative strategies for shared decision-making centered on relationships between sovereign governments and wind leaseholders and developers. These partnerships are essential to build Tribal capacities and priorities for co-ownership, as well as scientific research and monitoring of wind development activities(85). Essential to relational sovereignty is the concept of reciprocity and interconnectedness between humans and nonhumans, particularly the ocean and species that rely on its health (84).
- Indigenous concerns have been co-opted through formal and legal decision-making processes in the U.S. (86). In a review of public comments for the Cape Wind and Vineyard projects, a majority of public comments by non-Indigenous stakeholders misrepresented views of and interests of the Tribes to promote their own positions and interests. More research is needed to understand how non-Tribal public engagement could be misrepresenting Tribal positions and interests.

Potential Research Directions

- How are the three key tenets of justice (e.g., distributive, procedural, and recognition) are conceptualized by Oregon Tribes for offshore wind energy projects and how can the state ensure just and equitable outcomes?

- How could state agency consultation and communication practices and protocols with Tribal governments better incorporate the WCOA five essential guidelines?
- What are the benefits and challenges to developing a Tribal-led relational sovereignty for offshore wind in Oregon?
- How can state agencies ensure that Tribal interests and positions are not being misrepresented by non-Tribal members in state-led community engagement efforts?

Economic Impacts on Fisheries

David Kling

Offshore wind infrastructure development may affect both recreational and commercial fisheries in Oregon for a variety of reasons, including spatial overlap with fishing areas, navigation channels, and changes to fishing ports. Potential impacts may occur as soon as construction commences on offshore wind infrastructure and continue through the operational life of an installation, with varying effects over time (87). Not all impacts will necessarily be negative. For example, areas of the ocean closed to fishing may create a positive marine reserve effect, eventually leading to higher catch rates in areas open to fishing.

There is a very large economic literature on the economic effects of marine reserves on commercial fisheries, which has produced a range of estimates regarding the impact of reserves on fisheries both before (including preemptive fishing), during, and in some cases after a reserve has been removed. Offshore wind, and in particular floating offshore wind that may eventually be built off the coast of Oregon may share some similarities to marine reserves in terms of the impacts on commercial fisheries, particularly during construction. However, the effective footprint of floating offshore wind once it is in place and operating will be determined by regulations, interactions with other non-fishery factors (e.g., protected species), and technical and preference characteristics of the fisheries themselves. For example, all else being equal trawl vessels may be more limited by floating offshore wind due to the logistics of deploying trawl gear compared to other fisheries(88).

For offshore wind development off of Oregon, Feist et al. (89) provide a sophisticated analysis of the overlap of viable offshore wind zones and recent areas of fishing activity for several fisheries, drawing on the main regulatory data sets (e.g., fish tickets and vessel monitoring system data). The authors examine trade-offs for offshore wind siting in terms of the levelized cost of energy ([defined in the section below](#)) from the installations versus fishery “exposure” or overlap with fishery revenue-weighted areas of the ocean. Oregon’s exposure by this metric appears to be modest, with the at-sea hake and albacore fisheries having the greatest overlap, particularly under ambitious mid-century targets for power generation.

While the Feist et al. analysis (89) is an important step toward quantifying potential economic effects of floating offshore wind on Oregon fisheries, it falls short of the bar for *ex ante* economic analysis of this floating offshore wind for at least two reasons. First, while informative, exposure is not a sufficient measure of because it does not correspond to economic profit from fishing;

instead, it is essentially a quantification of past fishing revenue. Second, this analysis, like similar work done in support of offshore wind planning(88) does not account for multiple margins of adjustment fleets may exhibit, including: anticipatory fishing ahead of offshore wind construction, within-season spatial or temporal adjustment, home and landing port choice, and across-season portfolio adjustment (90,91) This is a missed opportunity because the fisheries potentially affected are all data-rich, and in principle analyses that would allow for these margins to be analyzed econometrically. A broad knowledge gap category for floating offshore wind in Oregon is therefore the expected cost of development for Oregon fisheries using contemporary empirical methods in economics.

A second knowledge gap area is the potential link between reserve effects of floating offshore wind and fisheries. Predicting the potential for a reserve effect ahead of floating offshore wind development which would require original research connecting econometric fishery models with spatial fish population models (89,92). Once the first floating offshore wind installation is built, it may be possible to use econometric methods to conduct an initial analysis of the impacts on affected fisheries, using data on fleet activity pre- and post-construction.

Fishing ports and onshore businesses like seafood processors would also more than likely be affected by floating offshore wind construction and maintenance. In one scenario, a marine terminal facility could be built in Coos Bay, with accompanying dredging of the navigation channel (93). This development would bring radical changes to the port and a great deal more economic activity overall. With respect to the local fishery, seafood processors, and support businesses, the effects are uncertain and depend on factors including level of disruption to port operations in different phases and effects on the local labor pool. For example, expansion of the Port of Coos Bay may bring in more workers into the area but may increase competition for vessel crew and onshore business labor.

Scenarios for port-level impacts may be explored through a few different methods prior to floating offshore wind construction. The draft of the Oregon Offshore Wind Energy Roadmap summarizes a few studies that have attempted to quantify economic impact and job creation from floating offshore wind (93). Economic impact analysis methods can be used to place bounds on potential changes in economic activity in other industries in what might be called “high disruption” and “low disruption” scenarios (94). Another approach to placing bounds on the short-run economic effects of floating offshore wind development on Oregon fisheries would be to use existing fisheries data sets to construct a model of vessel-level port choice for landings. Similar to an empirical study aimed at predicting the effect of reduced access to some fishing areas, the approach would be to run empirical models that predict whether congestion or port disruptions (whether in Coos Bay or elsewhere) induce vessels to switch ports, and where they switch (95). This analysis would measure shifts in landings through the season and associated effects on vessel-level revenue (with an accompanying model of demand for landings). Because floating offshore wind development would likely lead to permanent shifts in the coastal economy, *ex ante* predictions for port choice and landings using this methodology would necessarily be short-run and need to be updated annually using new data after construction commences.

Economic Competitiveness of Offshore Wind Energy in Oregon

William Jaeger

A critical aspect of offshore wind development is the economics of energy development. Will these investments pay off for private investors? Are the benefits from both private and social perspectives significant in relation to the costs but also in relation to the ecological and social effects (both positive and negative).

The costs and returns to renewable energy technologies vary greatly across types of technologies and their location. The productivity and competitiveness of renewables have been declining at a fast pace in recent years, which is an encouraging sign for future investments. These trends are reflected in Table 1, reproduced below, from the International Renewable Energy Agency (IRENA), Renewable Power Generation Costs in 2024 (96). The Levelized Cost of Energy (LCOE) measures the lifetime costs of an energy technology divided by its energy production. This is done by calculating the present value of the total costs (which will occur in different time periods over the technology's lifetime, including capital costs, operating costs and maintenance costs), and dividing by a similarly discounted sum of energy production across all years. The result can be interpreted as an averaging of the costs per unit of energy over the lifespan of a given technology.

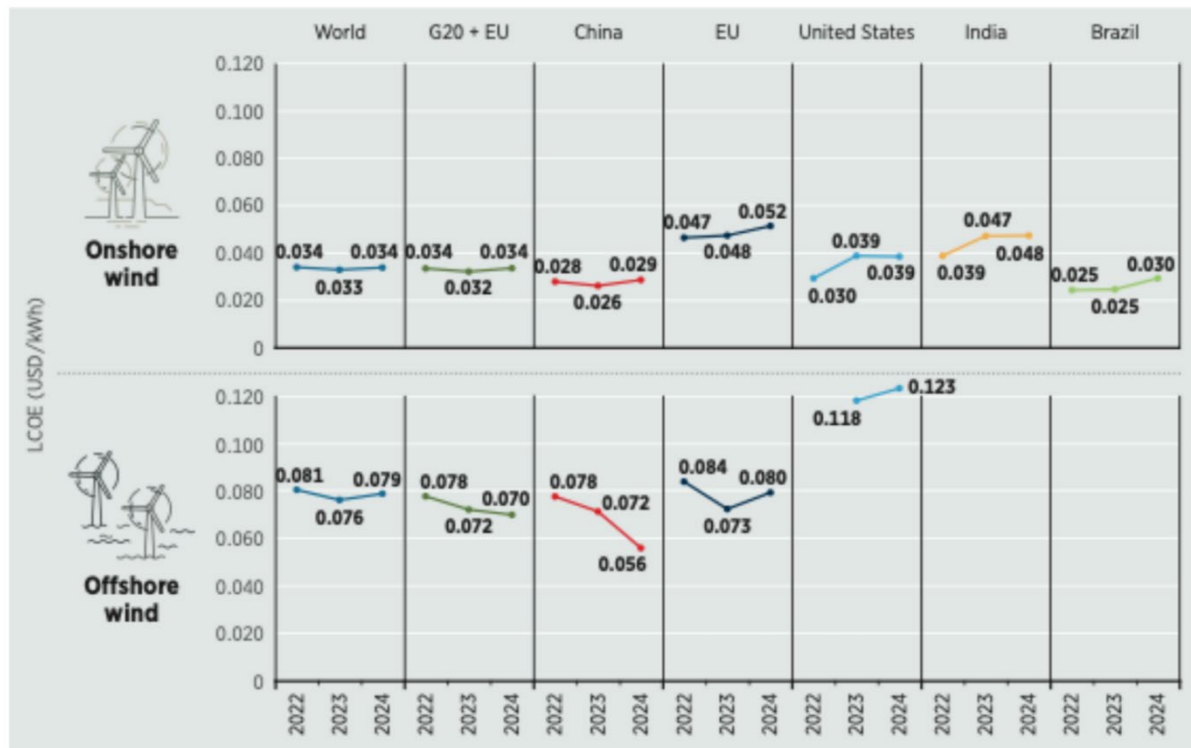
Conditions are changing quickly. Just a few years ago there were few commercially viable offshore wind facilities operating anywhere, now there are numerous. Especially for floating offshore wind turbines, there was a prototype in 2009 in Norway, with additional projects in Portugal, England, France, Japan, and the U.S. (97). However, there remains a lack of existing large-scale floating offshore wind arrays (89).

Table 1. Total installed cost, capacity factor and LCOE trends by technology, 2010 and 2024.
Source: International Renewable Energy Agency (2025)

	Total Installed costs			Capacity factor			Levelised cost of electricity		
	(2024 USD/kW)			(%)			(2024 USD/kWh)		
	2010	2024	Percent change	2010	2024	Percent change	2010	2024	Percent change
Bioenergy	3 082	3 242	5%	72	73	1%	0.086	0.087	1%
Geothermal	3 083	4 015	30%	87	88	1%	0.055	0.060	9%
Hydropower	1 494	2 267	52%	44	48	9%	0.044	0.057	30%
Solar PV	5 283	691	-87%	15	17	13%	0.417	0.043	-90%
CSP	10 703	3 677	-66%	30	41	37%	0.402	0.092	-77%
Onshore wind	2 324	1 041	-55%	27	34	26%	0.113	0.034	-70%
Offshore wind	5 518	2 852	-48%	38	42	11%	0.208	0.079	-62%

Notes: CSP = concentrated solar power; kW = kilowatt; kWh = kilowatt hour; USD= United States dollars.

The LCOE comparing onshore and offshore wind globally and in different countries (96) (Figure 2) suggests offshore costs around \$0.07 to \$0.08 per KWH in many countries, but 50% higher in the U.S. for offshore wind. Given the limited number of operational **floating** offshore wind projects to date, this section has focused on fixed-bottom offshore wind developments.



Notes: EU = European Union; G20 = Group of 20; kWh = kilowatt hour; LCOE = levelised cost of electricity; USD = United States dollar.

Figure 2. Wind power weighted average LCOE: Global, G20, EU and selected countries, 2022-2024. Source: International Renewable Energy Agency (2025)

The projected scaling up of U.S. domestic floating offshore wind is growing at a slower pace than for fixed-bottom technologies, National Renewable Energy Laboratory (NREL; recently renamed the National Laboratory of the Rockies) reports a development pipeline of 25,116 MW as of May 2024, including lease areas and proposed lease areas (98). Projections regarding the pace of offshore wind development has become much more uncertain since the recent policy changes by the U.S. Administration.

Globally, floating offshore wind installations nearly doubled capacity in 2023, bringing the total to 231.4 MW (98). Given the nascent state of the floating offshore wind industry in the U.S., reliable cost estimates are few. A recent study focused on California estimated LCOE for floating offshore wind between 2019 and 2032 at commercial project scale (99). Their analysis is summarized in Figure 3. Given the date of the study (2020), the available estimates at that time would appear to be \$0.10 to \$0.11 per KWH range.

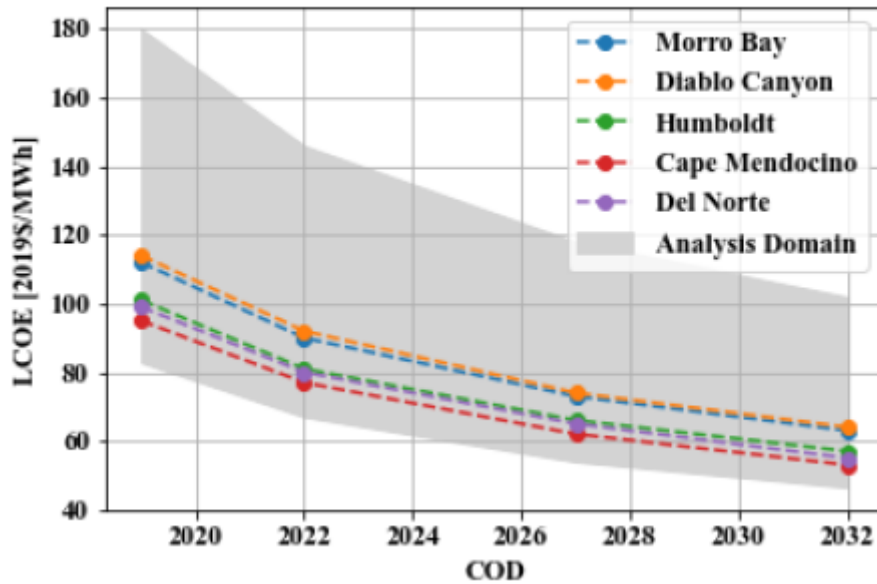


Figure 3. Estimated LCOE trajectory between 2019 and 2032 (COD). Source: Beiter et al. 2020

These costs and trends suggest that the following observations can be made:

- Costs and returns to renewable energy technologies vary by type and location
- Cost competitiveness of renewables has been declining at a fast pace since 2010
- Levelized costs of energy from offshore wind have declined 62% from 2010 to 2024
- Globally, offshore wind remains more than double the cost of onshore wind
- For the US, offshore wind costs are triple the cost of onshore wind

Engineering

Bryson Robertson

Globally, an estimated 60–80% of offshore wind resources are located in water depths exceeding 60 meters (100)—the conventional boundary between fixed-bottom and floating offshore wind turbines – thus requiring floating offshore wind turbines. Positively, over the past decade, the technical feasibility of floating offshore wind has been clearly demonstrated, with approximately 220 MW of cumulative installed capacity across Europe alone (including projects in Portugal, Norway, the UK, and France). These pre-commercial deployments have validated fundamental engineering feasibility, confirmed loading assumptions, quantified performance, and demonstrated system survivability. These are all major successes – but were achieved at above-market electricity costs.

As the sector matures, the primary focus is on reducing the Levelized Cost of Energy (LCOE) and increasing the electrical grid utility value through system scale-up (larger turbines), performance improvements, and cost reductions across the value chain. Some projections suggest that installed floating offshore wind capacity could reach approximately 10 GW by 2030 (98), achieve cost competitiveness with fixed-bottom offshore wind around the same time, and continue to realize cost reductions thereafter. That said, achieving these reductions depends on significant process industrialization, billions of dollars in port and infrastructure investments, transmission accessibility, and a range of other enabling factors.

A few contextual points are important when reviewing this material. First, Oregon is unlikely to be an early adopter or global leader in floating offshore wind deployment. Instead, the State stands to benefit from international experience, including accumulated performance data, environmental monitoring, and insights from social engagement efforts worldwide. Second, LCOE is a necessary, but insufficient, metric (101). It does not capture all generation attributes that are valuable to, and considered by, grid operators when considering costs and reliability to customers. Additional benefits of floating offshore wind include access to stronger and more consistent wind resources, higher capacity factors (which can reduce the need for overbuilding other generation assets), and siting farther offshore - which may help mitigate viewshed and coastal community concerns (102).

The following non-exhaustive review of outstanding research needs is organized thematically, moving from offshore to shoreline considerations. It broadly covers: (1) turbines and platforms, (2) anchors and moorings, (3) transmission and interconnection, (4) port systems, and, finally, (5) industrialization of the overall development process and supply chain.

Turbine and Platform

In 2017, Hywind Scotland became the world's first floating offshore wind farm, deploying five 6-MW turbines with 154-meter rotor diameters (103). Just 7 years later, in 2024, turbines rated at 26 MW (with rotor diameters approaching 310 meters) are undergoing testing (104). While these advancements highlight rapid innovation, substantial challenges remain before such turbines can be commercialized at scale.

The downside of this continued turbine size innovation is a lack of clarity for developers, communities, utilities and regulators when trying to assess a project. Calls for standardization of a single size of turbine are growing. Standardization can enable industrialization across serial manufacturing, installation, vessels, ports, and workforce training, ultimately driving faster cost reductions. For example, the onshore wind industry's focus on deploying standardized 2-MW turbines contributed to a 63% cost reduction between 2008 and 2021 (98). More recently, and specifically for floating offshore wind, GE Vernova announced its intention to prioritize its 15.5-MW Haliade-X offshore turbine, stepping away from pursuing larger 17–18-MW variants (105). Note that much of the remaining turbine-specific innovation will continue to be led by original equipment manufacturers (OEMs) with company specific IP.

While floating and fixed-bottom offshore wind systems often use similar turbines, floating platforms remain highly bespoke and largely unindustrialized. Most existing floating systems are effectively one-off designs, which significantly increases costs due to single case mobilization, specialized tooling, workforce training, geographically dispersed suppliers, and associated demobilization. Accelerated global innovation in the design, testing, and analysis of floating platforms is therefore essential.

To date, deployed floating offshore wind systems have largely resulted from integrating independently designed turbines and floating platforms. Co-designing integrated turbines and platforms as a unified system offers significant potential to reduce costs and improve performance. In parallel, innovation in platform materials—traditionally, steel and concrete—and manufacturing methods will be critical. Modular platform designs that can be manufactured in existing facilities, along with improved anti-corrosion technologies, could further lower costs.

It is important to remember that independent certification plays a vital role in commercializing new technologies. However, certification bodies are naturally risk-averse, while technology developers must test novel concepts to demonstrate cost and performance gains. This tension can slow innovation and increase costs, even as it reduces risk. Developing innovation-friendly policies and processes that better align certification and development objectives would provide substantial value to the floating offshore wind sector.

Anchors and Moorings

Current floating offshore wind projects largely rely on anchoring and mooring approaches adapted from the offshore oil and gas industry. These systems typically use taut or semi-taut moorings, primarily polyester lines, and anchors capable of sustaining vertical, or near-vertical, loads.

However, the dynamic behavior of floating offshore wind systems differs significantly from oil and gas platforms. Floating wind turbines experience larger horizontal offsets due to aerodynamic thrust on the turbine and tower, thus transferring non-vertical loads to anchors. As deployment depths increase - currently around 100–200 meters but will need to increase to ~1,000 meters for Oregon - floating offshore wind-specific mooring designs and materials will become increasingly critical. In addition, anchors with longer lifespans, improved performance, and lower lifecycle costs

are needed for deep-water applications. Considerable numerical and economic research has explored the concept of shared anchors, but these systems must still be proven, de-risked, and certified before commercial deployment (106).

Similarly, the dynamic in-water electrical transmission cables used to connect individual floating turbines require further testing and analysis to confirm their performance, durability, and suitability for deep water and high-motion environments. Advancements in this area are essential to reducing the cost of large floating wind arrays.

Transmission and Interconnection

While offshore wind resources can be effectively absorbed and converted into electricity, transmitting that power to terrestrial demand centers remains a major cost challenge. Fully realizing the full potential of floating offshore wind will require the development of floating offshore substations, offshore high-voltage direct current (HVDC) networks, and upgraded onboard transmission systems (107). Encouragingly, the California Energy Commission is funding work on floating substations (108), the Pacific Northwest National Laboratory (PNNL) has conducted comprehensive offshore transmission studies (109), and the Bonneville Power Administration (BPA) is actively working to reduce timelines (110) for new transmission development in the Pacific Northwest.

PNNL's analysis indicates that up to 33 GW of floating offshore wind could be deployed and interconnected along the U.S. West Coast by 2050 (109). Developing an optimized transmission network to support this buildout is estimated to cost approximately \$10 billion but would yield roughly \$35 billion in savings through interregional coordination between Oregon and California. The results from the PNNL should be integrated within the Oregon Department of Energy and Oregon-based utilities to understand implications across the grid and associated customers. Broadly speaking, transmission development in the Pacific Northwest remains costly, slow, and complex, despite its widely recognized benefits for reliability, affordability, and regional economic development. This needs to change for many reasons beyond a potential floating offshore wind sector

Port Infrastructure and Supply Chain

To date, floating offshore wind demonstration projects have been too small to justify major investments in port infrastructure needed for serial, industrial-scale, manufacturing and deployment. Ports supporting floating offshore wind assembly and commissioning require high-capacity cranes capable of lifting loads exceeding 100 tonnes at heights greater than 150 meters, quaysides with depths of 8–10 meters, channels wider than 100 meters, and minimal overhead restrictions (111). As a result, West Coast ports capable of supporting floating offshore wind development are limited, with primary candidates including the Port of Los Angeles (CA) and ports in Puget Sound (WA). Humboldt Bay, California, presents a potential opportunity but would require billions of dollars in federal investment.

Building on previous National Renewable Energy Laboratory port studies, detailed assessments of Oregon ports' existing and potential future capabilities (112) - ranging from manufacturing, component delivery, to operations and maintenance - could help identify targeted economic development opportunities associated with floating offshore wind development along Oregon's coastlines. Given the scale of investment required, collaborative, port-driven initiatives along the West Coast should focus on compatibility and load-sharing, as no single port is likely to meet all needs independently.

One positive aspect of floating offshore wind is that much of the construction occurs at the quayside, thus allowing the use of smaller and less expensive vessels for installation and maintenance (when compared to fixed-bottom offshore wind) (113). This might align better with the existing Oregon-based vessel fleet. Better understanding the vessel requirements and workforce needs for West Coast floating offshore wind development will be critical for long-term procurement planning and workforce training.

Industrialization

Achieving the scale of cost reductions projected for floating offshore wind will require a transition from bespoke, single-unit projects to rapid serial production. Manufacturing, transportation, installation, and operations and maintenance processes must all be industrialized to capture efficiencies, economies of scale, and learning effects. Fortunately, floating offshore wind shares many components with fixed-bottom offshore wind, providing a strong foundation of existing data, experience, and supply chain capacity to support future commercialization.

New technologies will be key enablers of this transition. Targeted research into remote sensing to reduce operations and maintenance costs, autonomous offshore operations to limit vessel use and human exposure, and digital twins for predictive maintenance will all play important roles.

Encouragingly, the international research community is actively advancing innovation across all of these areas. Oregon is well positioned to partner with these institutions, and leverage global expertise, data, and tools to inform future opportunities within the state. For interested readers, the '*Considerations for the Global Commercialization of Floating Offshore Wind*' By Robertson et al. is well worth a review (102).

Appendix A: Recent and Highly Relevant Ecological Studies of Floating Offshore Wind

We searched for recent peer-reviewed publications that could be valuable resources for development of research plans and siting assessments for floating offshore wind in Oregon. The literature on the effects of **floating** offshore wind is growing, but these are relatively new technologies that have had minimal time for empirical study. We expect that reports and journal publications on living marine resources, coastal economies, and physical processes will emerge as more floating offshore wind networks are put in place, and that research will contribute to filling the gaps and reducing the uncertainties identified in this report.

Our literature review focuses primarily on data-driven evidence from existing wind energy projects (many of which are in Europe), recent reviews that include observational studies, and recent modeling studies and other papers and reports that are relevant to potential ecological effects of floating offshore wind in Oregon. It was not an exhaustive search.

The bibliography that follows is organized starting with relevant regional and national reports and followed by specific topics. Some of the references cited here overlap with the ones cited in our report, but some are only listed here.

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