Analysis of Lease Area Delineation Options in the Brookings Wind Energy Area

Aubryn Cooperman, Patrick Duffy, Donna Heimiller, and Walt Musial

National Renewable Energy Laboratory

Produced under direction of the U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific Regional Office by the National Renewable Energy Laboratory (NREL) under Interagency Agreement M19PG00025_P00007.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Strategic Partnership Project Report
NREL/TP-5000-89955
July 2024

Analysis of Lease Area Delineation Options in the Brookings Wind Energy Area

Aubryn Cooperman, Patrick Duffy, Donna Heimiller, and Walt Musial

National Renewable Energy Laboratory

Suggested Citation
Cooperman, Aubryn, Patrick Duffy, Donna Heimiller, and Walt Musial. 2024. *Analysis of Lease Area Delineation Options in the Brookings Wind Energy Area*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-89955. https://www.nrel.gov/docs/fy24osti/89955.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Strategic Partnership Project Report
NREL/TP-5000-89955
July 2024

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Support for the work was also provided by U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific Regional Office under Interagency Agreement M19PG00025_P00007. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Acknowledgments

This study was funded by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Pacific Regional Office, through interagency agreement number M19PG00025 with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). The authors thank the many people who contributed to the content of this report, including BOEM staff: Jean Thurston-Keller, Jennifer Miller, Lisa Gilbane, and Necy Sumait. We also appreciate the assistance of Arlene Merems at the Oregon Department of Fish and Wildlife in providing geographic data related to benthic habitat.

Additionally, we thank several people at NREL who contributed to this report: Katie Wensuc, who provided technical editing; Kendall Hartman, who assisted with geographic data collection; and Michael Sinner, who advised the selection of wake models. Any errors or omissions are the sole responsibility of the authors.

List of Acronyms

AEP	annual energy production
BOEM	Bureau of Ocean Energy Management
CTV	crew transfer vessel
FLORIS	FLOw Redirection and Induction in Steady state (model)
GCF	gross capacity factor
GW	gigawatt
IEA Wind	International Energy Agency Wind Technology Collaboration Programme
MW	megawatt
NCF	net capacity factor
NOW-23	National Offshore Wind (dataset)
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OCS	Outer Continental Shelf
OEDI	Open Energy Data Initiative
S&I	staging and integration
TLP	tension-leg platform
TWh	terawatt-hours
UTM	Universal Transverse Mercator
WEA	wind energy area
WIND Toolkit	Wind Integration National Dataset Toolkit
WRF	Weather Research and Forecasting
WTG	wind turbine generator

Executive Summary

The Bureau of Ocean Energy Management (BOEM) has announced plans to hold a lease auction for wind energy areas (WEAs) offshore the coast of Oregon (U.S. Department of the Interior 2024). The two areas identified in the preliminary sale notice are the Coos Bay WEA along the central Oregon coast and the Brookings WEA off the south coast. The Brookings area is more than twice as large as the Coos Bay area, and it is also significantly larger than the areas leased offshore California. BOEM commissioned the National Renewable Energy Laboratory (NREL) to develop and propose options for dividing the Brookings WEA into two lease areas of approximately equal value and analyze each option for its merits and shortcomings, including assessment of the generation potential of the areas within each option.

Multiple options were considered and two were selected for detailed analysis. The two delineation options are shown in Figure ES-1. The east-west option is divided approximately along the prevailing wind direction, reducing the potential for wakes from wind turbines in the adjacent lease area to impact the power generation of its neighbor. However, the western lease would be disadvantaged by deeper water and greater distance to shore. The north-south option divides the deeper, farther aliquots more evenly between the two lease areas, but the prevailing wind from the north places the southern area downstream and subject to wakes from the neighboring wind turbines. Due to these disadvantages, neither option is ideal.

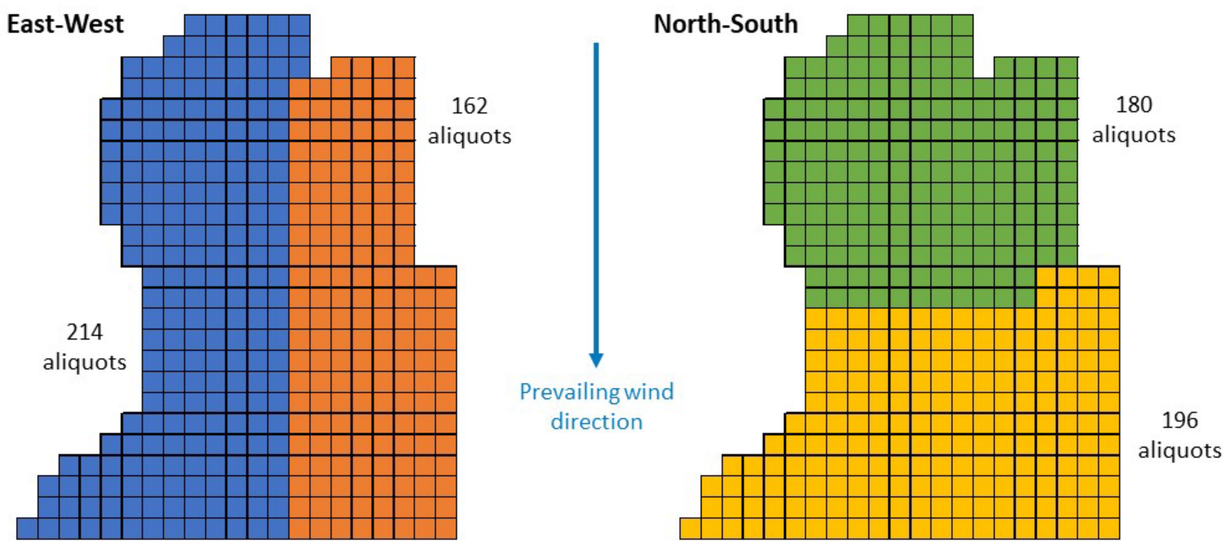

Figure ES-1. Proposed lease area options

Various physical characteristics affect the relative value of each aliquot[1] within a lease area for offshore wind development. Attributes such as higher wind speeds and better exposure to the prevailing wind direction increase the value of some locations, whereas conditions such as

[1] BOEM defines offshore boundaries in terms of Outer Continental Shelf lease blocks and aliquots. Each aliquot is a 1,200-meter (m) by 1,200-m square, and each lease block contains 16 aliquots in 4 rows of 4, with some exceptions related to the projection of a rectangular grid onto spherical coordinates. For more details, see https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data.

deeper water or a rocky seabed can make the installation of a wind power plant more challenging. We considered the following attributes within each aliquot:

- Mean wind speed
- Exposure to prevailing wind
- Distance to ports and potential grid connections
- Proximity to the lease area boundary
- Mean water depth
- Mean seabed slope
- Seismic ground motion risk and fault lines
- Hard rock seabed
- Coral habitat suitability
- Observed bubble streams indicating methane seeps.

Each attribute was assigned a score between 0 and 1, with 0 being the least favorable and 1 being the most favorable. The maps shown in Figure ES-2 were produced using equal weighting of the 10 attributes listed above. Based on the individual aliquot scores, the two lease areas within each option have approximately equal value. In the east-west option, the east area scores 49% and the west area scores 51%. In the north-south delineation option, the balance is 49% for the north area and 51% for the south area. These scores are well within our margin of error for obtaining equal value.

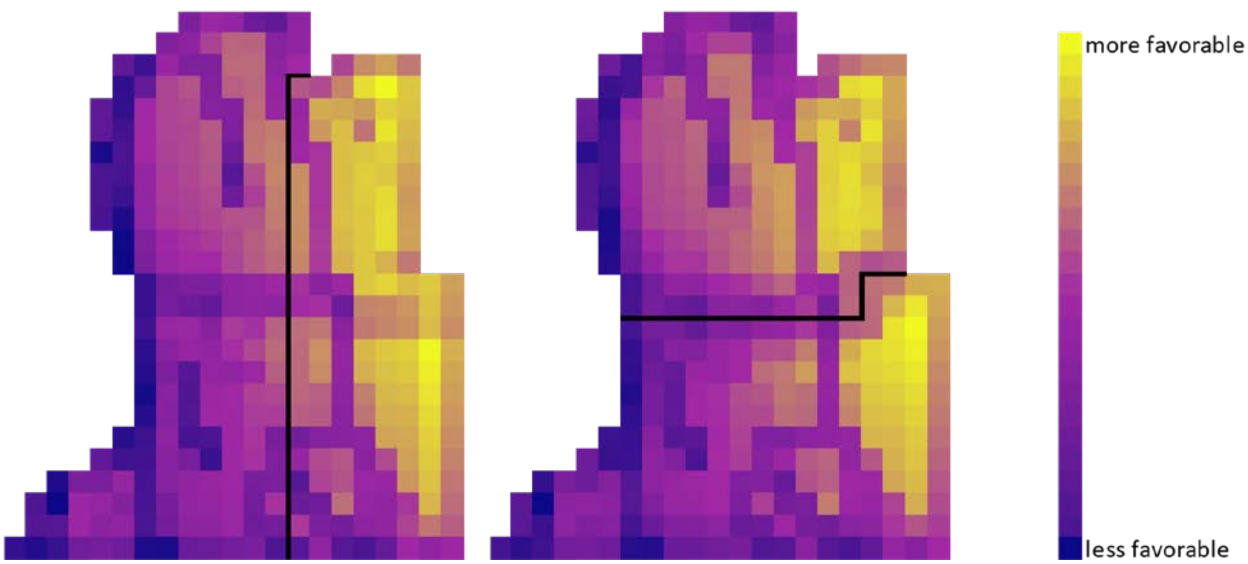

Figure ES-2. Aliquot scores in the Brookings WEA for equal weighting of physical characteristics

To assess the generating potential of each lease area in the two delineation options as well as the full Brookings WEA, we modeled power production for hypothetical wind plants in each lease area. Each power plant was made up of 15-MW wind turbines arranged in a rectangular grid spaced 4 rotor diameters (D) along the east-west axis and 10D along the north-south axis. We considered different setbacks from the lease area boundaries representative of tension-leg platform (TLP) and semitaut mooring systems. We used NREL's FLOw Redirection and Induction in Steady state (FLORIS) model to estimate power production.

Table ES-1 presents the results of the FLORIS analysis of generation potential for each delineation option. For the TLP layouts, the total capacity is the same in each case. Using semitaut mooring setbacks, the east-west delineation has a larger reduction in capacity than the north-south delineation relative to the full WEA because the boundary between the two areas is longer. The annual energy production (AEP) decreases as the number of turbines is reduced; however, the net capacity factor slightly increases because the wake losses are lower with fewer turbines. For a spacing of 4 × 10 rotor diameters, we estimate a total generating capacity up to 3.6 GW, or 1.2–2.1 GW per lease area.

Table ES-1. Generation Potential by Delineation and Mooring Type

Parameter	Unit	Mooring Type	Full WEA	East-West	North-South
Capacity	GW	TLP	3.67 (242 WTGs)	3.67 (242 WTGs)	3.67 (242 WTGs)
Capacity	GW	Semitaut	2.99 (197 WTGs)	2.76 (182 WTGs)	2.81 (190 WTGs)
Capacity density	MW/km^2	TLP	6.79	6.79	6.79
Capacity density	MW/km^2	Semitaut	5.52	5.10	5.33
Gross annual energy production	TWh	TLP	20.1	20.1	20.1
Gross annual energy production	TWh	Semitaut	16.4	15.2	15.8
Gross capacity factor	%	All	61.8	61.8	61.8
Net annual energy production	TWh	TLP	15.9 (15.3–16.7)	15.9 (15.3–16.7)	15.9 (15.4–16.7)
Net annual energy production	TWh	Semitaut	13.0 (12.6–13.6)	12.1 (11.7–12.6)	12.5 (12.2–13.1)
Net capacity factor	%	TLP	49.5 (47.6–51.8)	49.5 (47.6–51.8)	49.5 (47.8–51.8)
Net capacity factor	%	Semitaut	49.7 (48.0–51.9)	50.0 (48.3–52.0)	49.8 (48.1–51.9)

Notes: WTG = wind turbine generator; TWh = terawatt-hour. The reported values are estimated with the cumulative-curl wake model. The values in parentheses represent the range from the high (TurbOPark) and low (Gauss-curl hybrid) wake loss estimates.

Table of Contents

List of Figures

List of Tables

1 Introduction

This study was funded under an interagency agreement between the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and the Department of the Interior's Bureau of Ocean Energy Management (BOEM) Pacific Region. It is intended to provide BOEM with key information to inform their decision making about upcoming lease sales planned for designated areas on the Outer Continental Shelf (OCS) off the coast of Oregon. The report will also benefit state governments, developers, research institutions, and members of the public seeking technical information about the unique characteristics of the proposed leases.

The purpose of this study is to develop and assess options for delineating offshore wind energy lease areas within the Brookings wind energy area (WEA). The Brookings WEA is one of two areas (Coos Bay and Brookings) offshore the Oregon coast that have been proposed for leasing. The Coos Bay WEA is comparable in size to existing offshore wind lease areas in Northern California, whereas the Brookings WEA is more than twice as large as the Coos Bay WEA. This study considers possible ways that the Brookings WEA can be divided to obtain two lease areas of relatively equal value, which would result in three Oregon lease areas of approximately equal size.

1.1 Background

The coast of Oregon has excellent wind resources that could potentially contribute to meeting the state's electricity needs (Musial et al. 2019). In the near term, studies have identified opportunities for approximately 3 gigawatts (GW) of offshore wind to be integrated into Oregon's electricity system without significant transmission upgrades (Douville et al. 2020; Novacheck and Schwarz 2021). The Oregon legislature set a planning goal of 3 GW of offshore wind by 2030, and the Oregon Department of Energy identified key benefits and challenges for meeting that goal (Sierman et al. 2022; Smith 2021). A crucial step toward developing offshore wind energy facilities is obtaining access to a suitable site. BOEM is responsible for the development of offshore resources, including offshore wind, on the OCS of the United States. BOEM worked with the Oregon Department of Land Conservation and Development to gather information on a planning area that encompassed the full extent of the Oregon coast (BOEM and Oregon Department of Land Conservation and Development 2020). Following this public engagement and information collection effort, BOEM designated two Call Areas: the Coos Bay Call Area and the Brookings Call Area, shown in Figure 1. The National Centers for Coastal Ocean Science carried out a detailed spatial analysis of the Oregon Call Areas that informed the final designation of the Coos Bay and Brookings WEAs (Carlton et al. 2024; BOEM 2024). In April 2024, BOEM announced the proposed auction details and lease terms for these two areas (U.S. Department of the Interior 2024).

The Coos Bay WEA (OCS-P 0566) contains 172 aliquots[2] covering 61,203 acres (248 km^2) approximately 32 miles (mi) (50 km) from shore. The Brookings WEA (OCS-P 0567) contains

[2] BOEM defines offshore boundaries in terms of OCS lease blocks and aliquots. Each aliquot is a 1,200-meter (m) by 1,200-m square, and each lease block contains 16 aliquots in 4 rows of 4, with some exceptions related to the projection of a rectangular grid onto spherical coordinates. For more details, see https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data.

376 aliquots covering 133,792 acres (540 km^2) approximately 18 mi (29 km) from shore. Based on the capacities of the offshore wind plants being developed in the northeastern United States, we assume an average capacity density of 4 MW/km^2 (Mulas Hernando et al. 2023), which corresponds to a generating potential of 1 GW for a 250-km^2 (61,800-acre) lease area, or a total of approximately 3 GW in the Oregon lease areas.

The only other Pacific offshore wind lease areas are the five areas off the coast of California, which range in size from 63,300 acres to 80,400 acres. The two Northern California lease areas are similar in size to the Coos Bay WEA. The Brookings WEA is larger than any of the other Pacific lease areas, and it is more than twice as large as the Coos Bay WEA. Dividing the Brookings WEA in two would result in a total of three Oregon lease areas, each of which could potentially be developed into approximately 1 GW of offshore wind capacity.

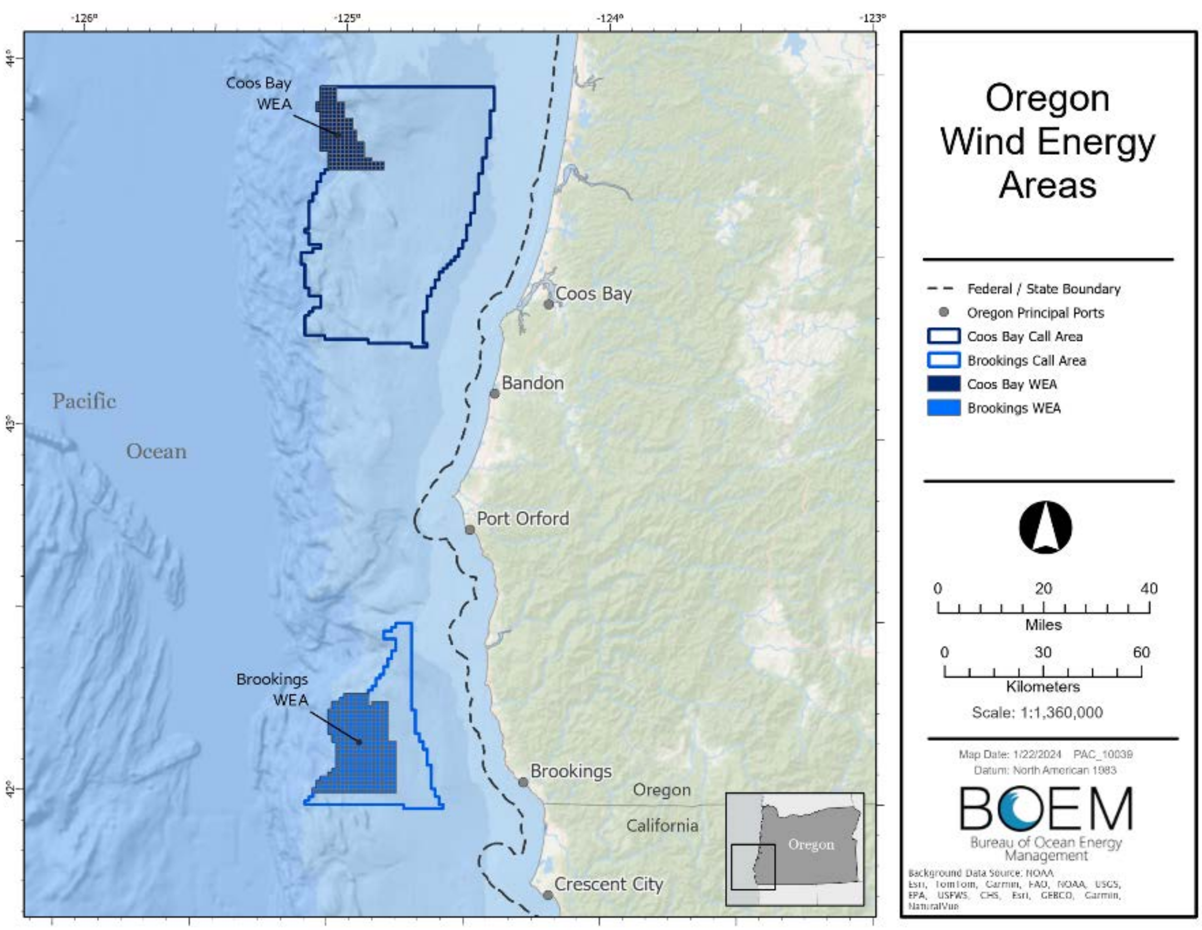

Figure 1. Oregon call areas and WEAs.

Figure from BOEM

1.2 Objectives and Summary of Work

NREL prepared this report summarizing options for delineating lease areas from the Brookings WEA with boundaries following the OCS aliquot boundaries. The objectives of this analysis are to inform BOEM's decision making in the upcoming lease auction in Oregon, scheduled for late

2024, by assessing viable options to divide the WEA into lease areas of approximately equal size and value. This report provides several delineation options for BOEM to consider. BOEM will make the final decision on lease area delineation, considering the information herein.

NREL performed a similar analysis for offshore wind lease areas on the California coast (Cooperman et al. 2022). We followed the same methodology to develop options for the Brookings WEA, reviewing publicly available information on relevant characteristics of the Oregon OCS, including published literature and data repositories (e.g., OpenEI, MarineCadastre). NREL's analysis considers factors including:

- Wind speeds and distribution of wind directions using the best available data
- Qualitative assessment of wake effects on power production
- Effect of mooring type on the space available for wind turbine placement
- Proximity to infrastructure, including ports and points of interconnection to the electric grid
- Bathymetry and geohazards, including seabed slopes, canyons, and seismic fault lines
- Seabed substrate characteristics.

The scope of the analysis does not include environmental interactions and competing uses that were considered in BOEM's designation of the WEA (BOEM 2024). In consultation with BOEM, two alternatives were selected for more detailed analysis of potential annual energy production (AEP) under different technology assumptions. The results of this analysis are presented in tables and graphically in detailed maps.

2 Physical Site Assessment

In this section, we discuss the physical characteristics that are relevant to the development of offshore wind energy facilities. Variations in site conditions affect the cost and complexity of installing floating wind turbines, which, in turn, impact the value of lease areas.

2.1 Wind Resource

NREL's first nationwide offshore wind resource assessment was part of the Wind Integration National Dataset (WIND) Toolkit (Draxl et al. 2015). Since 2015, there have been several efforts to update wind resource datasets to account for technical advancements in atmospheric modeling. The most recent is the National Offshore Wind (NOW-23) dataset (Bodini et al. 2023). The NOW-23 dataset is subdivided into several regions covering the coastline of the contiguous United States and Hawaii. The Brookings WEA is located close to the boundary between the North Pacific (Washington and Oregon) and South Pacific (California) regions and is included in both datasets. The data for each region cover slightly different time periods (2000–2019 for the North Pacific and 2000–2021 for the South Pacific) and use a different planetary boundary scheme to parametrize atmospheric turbulence in the Weather Research and Forecasting (WRF) model. The South Pacific data were updated in 2022–2023 to incorporate insights gained from floating lidar buoy measurements taken offshore California (Bodini et al. 2022). Wind speeds in the updated model were found to be closer to those measured by the floating lidar than the original model, which used the same setup as the North Pacific region (Liu et al. 2024). We opt to use the South Pacific data in the following wake modeling analysis to reduce the chance of model bias impacting the results. Although the Brookings WEA is close to the boundary, inspection of the NOW-23 South Pacific wind speed time series yielded no evidence of boundary distortions. The average wind speed at 160 m above sea level from the NOW-23 South Pacific model is shown in Figure 2.

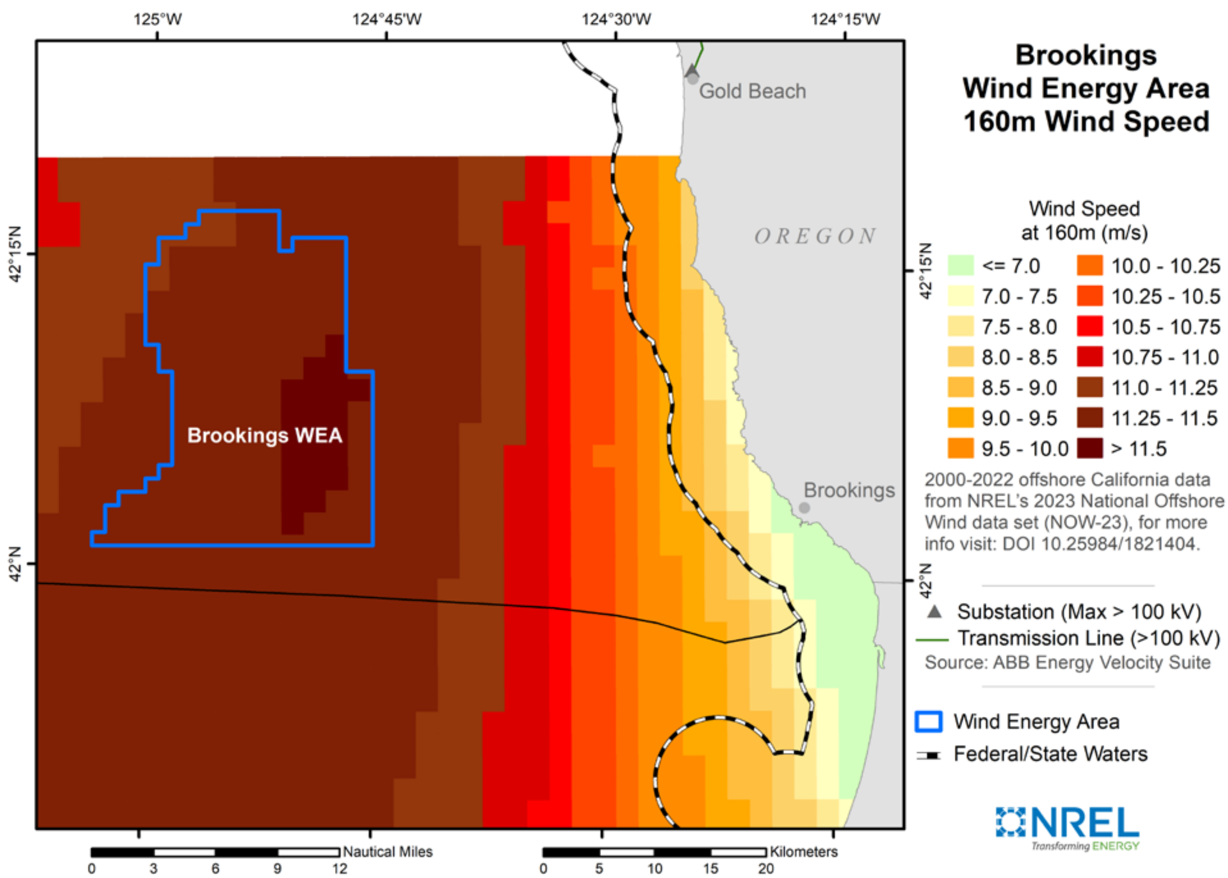

Figure 2. Average wind speed from 2000 to 2022 at 160 m above mean sea level

Figure 3 displays the modeled wind rose at a height of 160 m above the centroid of the Brookings WEA from 2000–2022. The prevailing wind direction is due north.

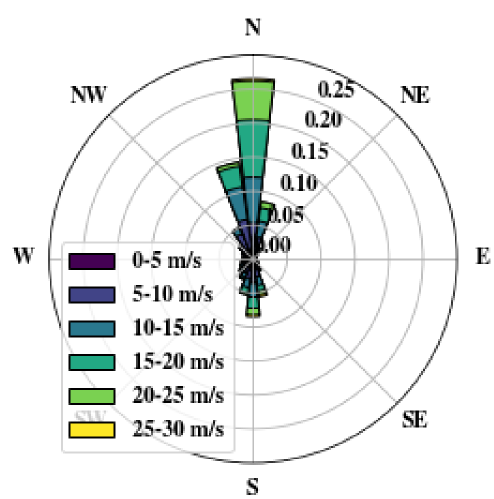

Figure 3. Wind rose at 160 m above the centroid of the Brookings WEA from 2000 to 2022

Figure 4 presents seasonal average diurnal profiles for the same location as Figure 3. These profiles show strong and consistent winds throughout the day, peaking in the late afternoon. The wind speeds are notably higher in the summer months, which might be complementary to other generation sources (Novacheck and Schwarz 2021).

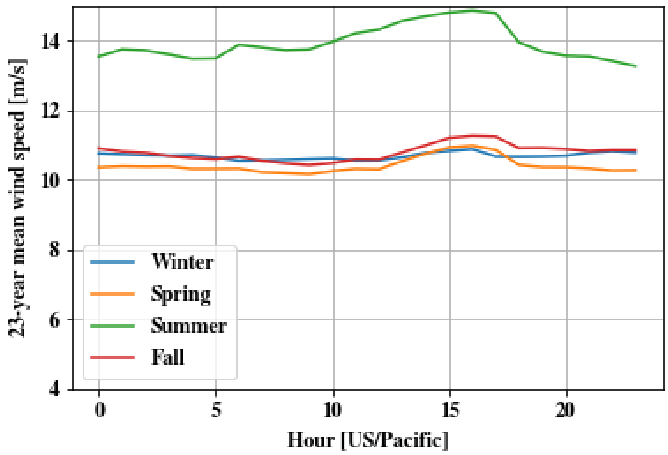

Figure 4. Diurnal wind speed profiles at 160 m above the centroid of the Brookings WEA from 2000 to 2022

Figure 5 shows how the average wind speed changes with height at the centroid of the WEA. There is more shear (change in wind speed with height) at lower elevations, and this effect decreases at the upper elevations shown. Hub heights for 15- to 25-MW wind turbines are likely to be from 145–180 m, with average wind speeds exceeding 11 m/s in the Brookings WEA.

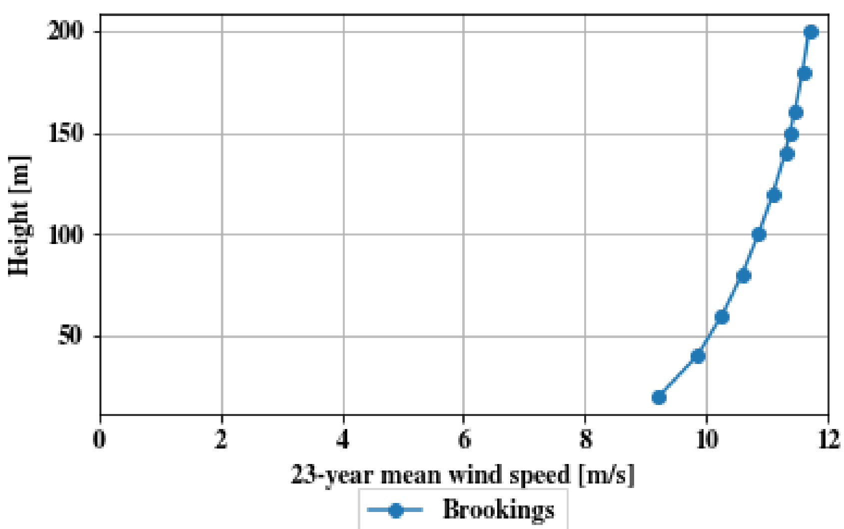

Figure 5. Vertical wind shear profile at the centroid of the Brookings WEA

Figure 6 presents a histogram of the wind speed distribution at 150 m above the centroid of the WEA. Most of the time, wind speeds are within the typical operating limits for offshore wind turbines of 3–25 m/s. The mean wind speed is above the point at which wind turbines typically reach their rated power output, approximately 10 m/s, indicating that the turbines could frequently operate at full power.

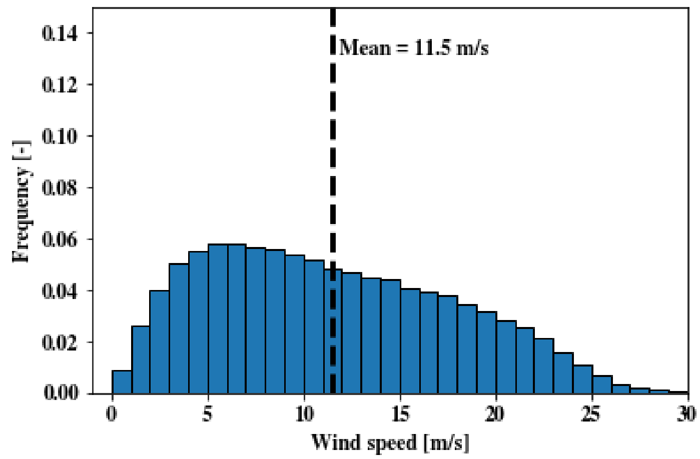

Figure 6. Wind speed distribution at 160 m above the centroid of the Brookings WEA

2.2 Bathymetry and Seafloor Characteristics

The water depth and seabed conditions are important factors in the design of an offshore wind plant. Water depth is the primary determinant between fixed-bottom and floating wind turbines. Depths in the Brookings WEA are all beyond the range of fixed foundations, so, instead, floating platforms will be considered. Deeper water requires longer mooring lines that—unless they are vertical—will extend farther outward from each floating platform. The slope and sediment characteristics of the seafloor will affect the selection of the anchor positions and the type of anchors that can be used. More detailed information about the seabed conditions would be needed to develop site-specific layouts; in this study, we rely on available data to identify locations across the WEA that might be more challenging for development.

We obtained bathymetric data from the National Centers for Environmental Information Coastal Relief Models (National Geophysical Data Center 2003), which have a spatial resolution of 3 arc-seconds (approximately 70 m, or 225 ft). Figure 7 shows the bathymetry of the Brookings WEA and surrounding region. We used these data to calculate the mean water depth and the mean seabed slope within each aliquot. Mean water depths in the WEA are between 570 and 1,430 m (1,870–4,690 ft), and mean slopes are between 0° and 12°, as shown in Figure 8. Steeper slopes have a higher likelihood of instability, which is an important consideration for anchor placement (Tajalli Bakhsh et al. 2020). Unstable slopes might require anchors that can penetrate more deeply in the seabed, or mooring system layouts might need to be designed to avoid unstable areas.

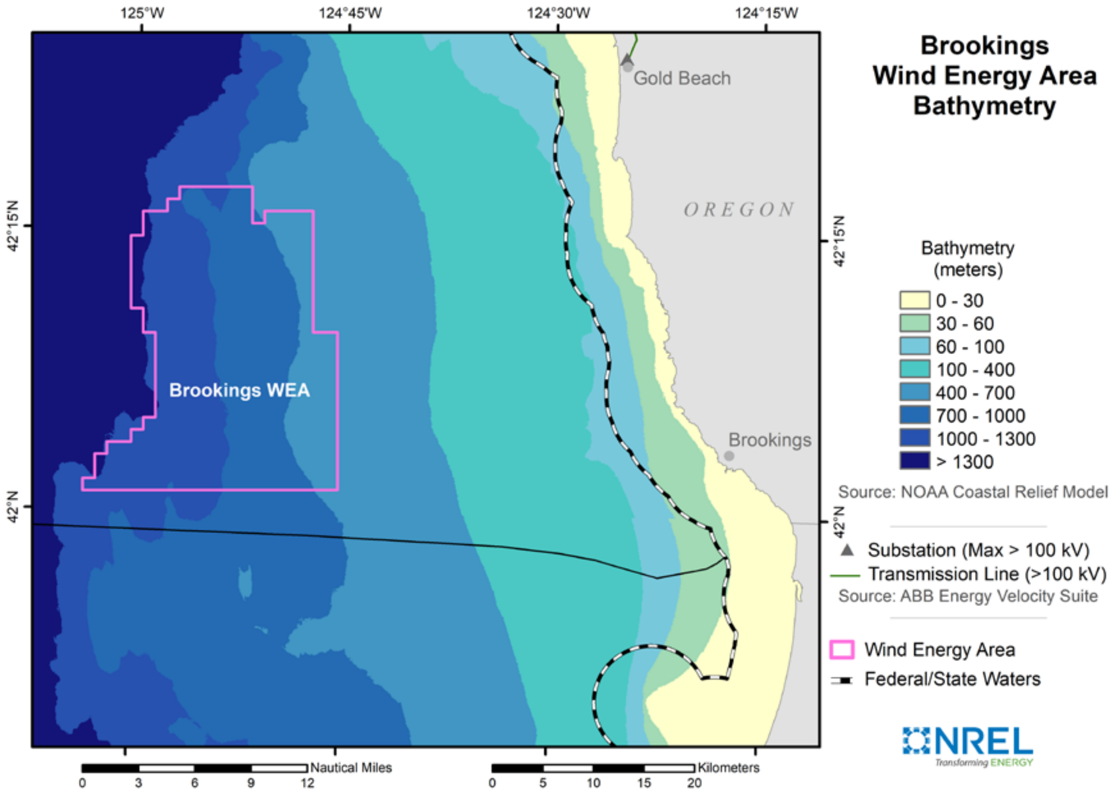

Figure 7. Bathymetry

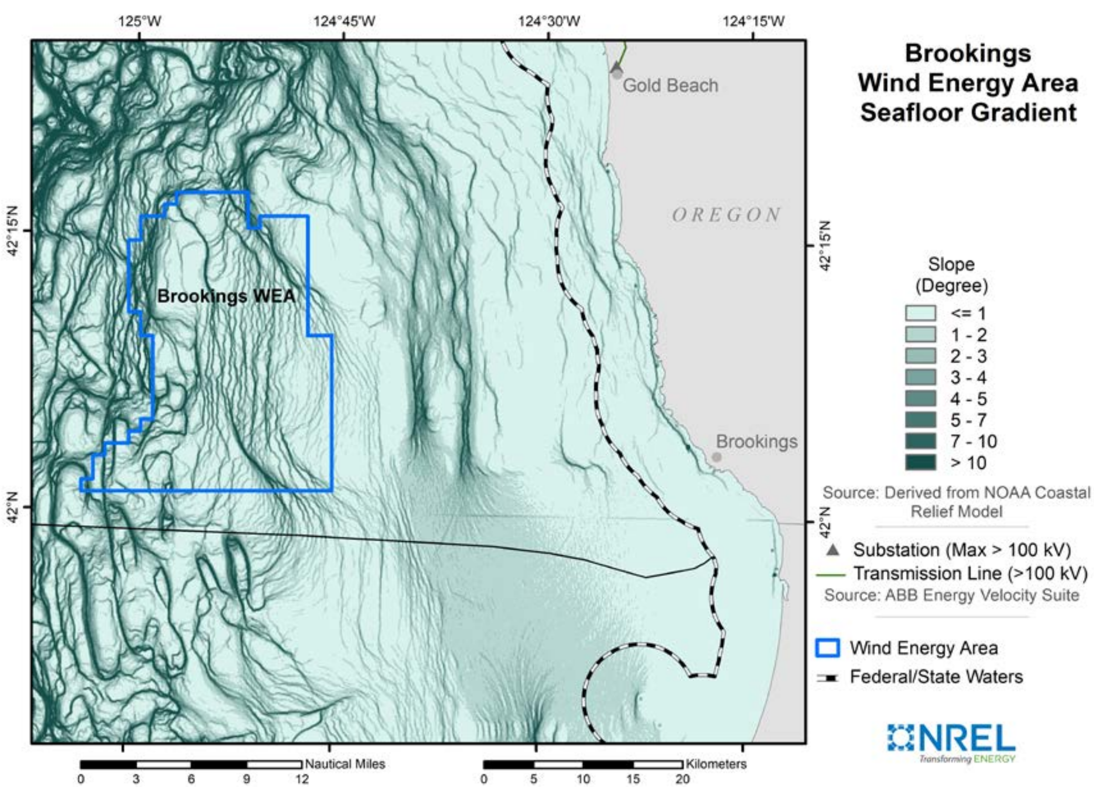

Figure 8. Seafloor gradient

Seafloor conditions are also an important consideration for the design of an offshore wind plant. More detailed site investigations will be required to select the appropriate anchor types and determine the placement of the mooring lines, anchors, and cables; however, some data are available that provide initial information about the seabed in the Brookings WEA. A broad survey of the Pacific Northwest OCS (Goldfinger et al. 2014) characterized the sediment throughout the Brookings WEA as mud. Subsequent studies identified areas with high backscatter indicating the presence of hard rock (Merle et al. 2021), bubble plumes that correspond with methane seeps (Merle et al. 2021; Conrad and Rudebusch 2023), and areas that are potentially suitable habitat for coral (Poti et al. 2020). These features are shown in Figure 9.

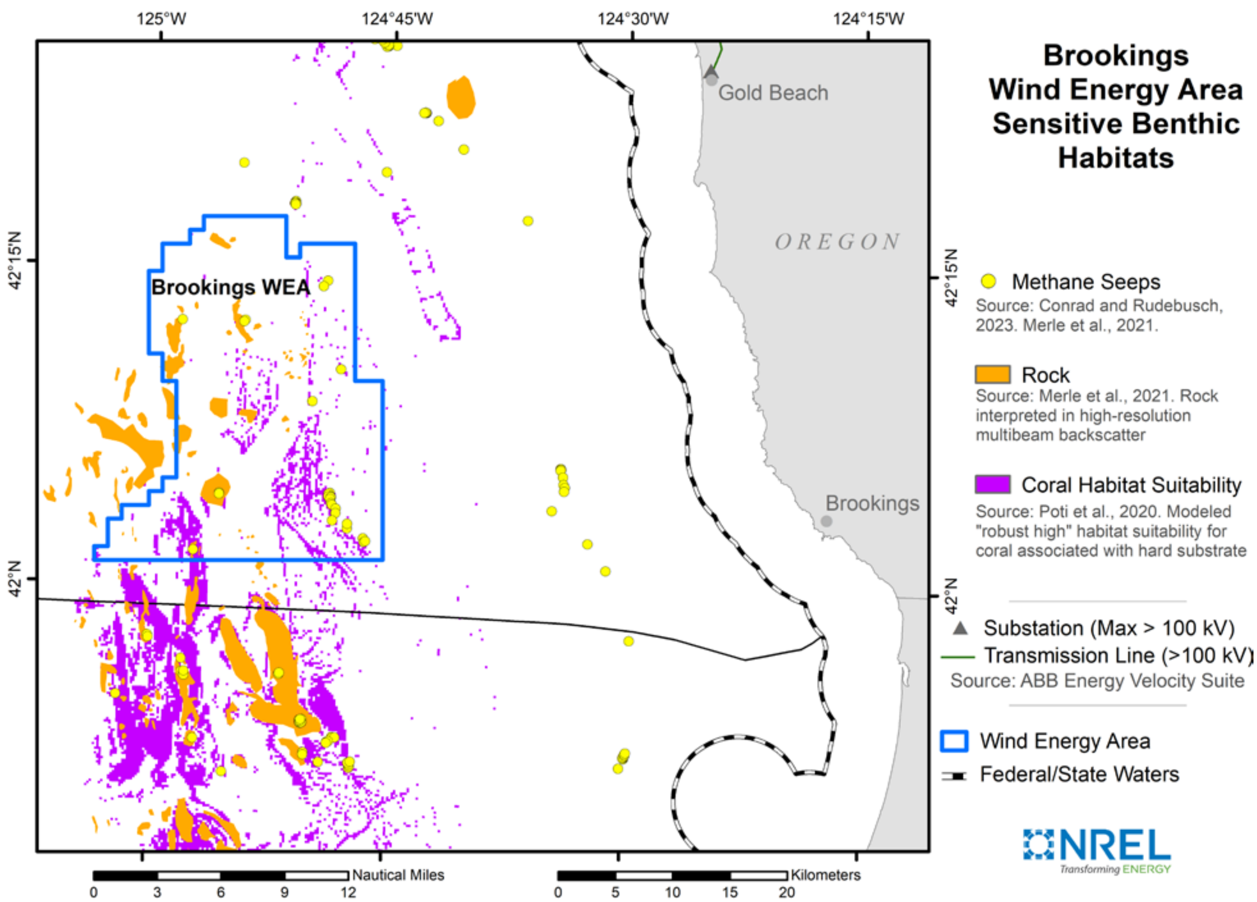

Figure 9. Benthic habitat features

2.3 Seismic Conditions

The Brookings WEA is located within the Cascadia subduction zone that extends along the Pacific coast of Oregon, Washington, and Northern California. Seismic activity is relatively frequent in this area, and offshore wind development will need to consider seismic hazards in the design process. The U.S. Geological Survey produces maps of peak ground acceleration (Petersen et al. 2023) and quaternary fault lines (U.S. Geological Survey 2017). Figure 10 shows the peak ground acceleration with a 10% probability of exceedance within 50 years. Throughout the Brookings WEA, this peak ground acceleration is close to 30% of gravitational acceleration (*g*). The motion of the seafloor during a seismic event could precipitate landslides or soil liquefaction in unstable sediment or sloped regions. The locations and orientations of fault lines should also be considered when siting anchors and routing cables.

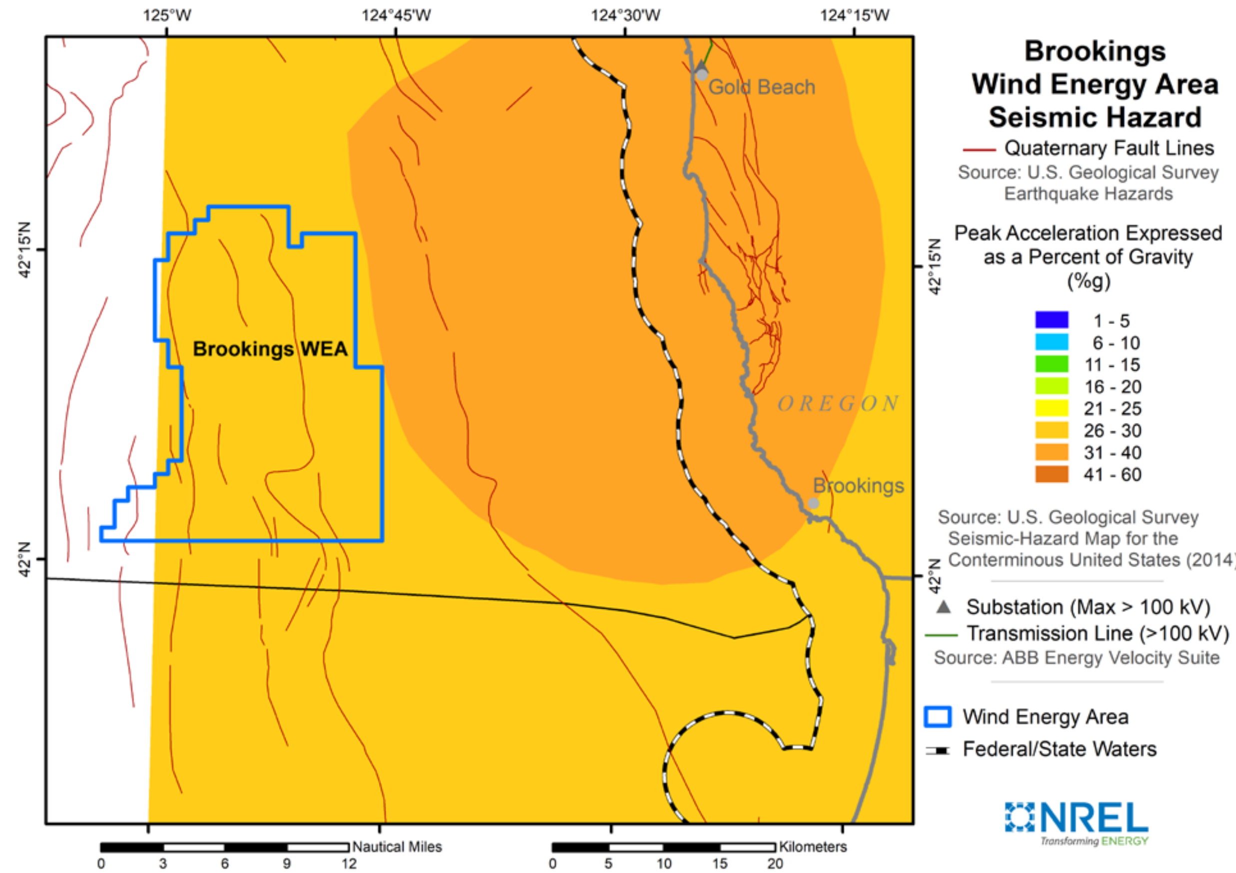

Figure 10. Seismic hazards

2.4 Proximity to Infrastructure

2.4.1 Ports

Port access is an important consideration throughout the lifetime of an offshore wind plant. Ports provide an operational base for all of the vessels involved in site preparation, installation, operation, and decommissioning. During the installation phase, staging and integration (S&I) ports play the key role as the location where major components are staged and wind turbines are integrated with floating platforms before being towed out to the wind plant site. S&I ports are large facilities—at least 30–100 acres—that are equipped to meet requirements including high-capacity wharf loading, heavy-lift cranes, and deep draft berths (Trowbridge et al. 2023). Although their primary role is installation support, S&I ports might also be needed during the operations phase to perform major component replacements for wind turbines that are towed back to port. Additional port facilities will be needed during the installation phase for activities such as staging moorings, cables, and manufacturing subcomponents; however, there is somewhat more flexibility in the location and facility requirements for these activities. Because the list of candidate ports is much longer and the uncertainty about which ones would be involved in the development of offshore wind in the Brookings WEA is much higher, we do not specify supporting port locations in this analysis.

Once the wind plant is operational, the focus of activities shifts to an operations and maintenance (O&M) port that serves as the base for vessels that conduct day-to-day maintenance activities. Wind plant operators might opt to use different types of vessels for O&M, and the choice of vessel impacts the requirements for O&M port selection. Crew transfer vessels (CTVs) are smaller vessels (65–90 ft [20–27 m] long with 5–10 ft [2–3 m] draft) that are used for day trips to the wind plant site, returning to a berth at the O&M port each night. Service operation vessels are larger vessels (200–400 ft [30–40 m] long with 16–25 ft [5–8 m] draft) that have onboard accommodations and can remain at the wind plant site for 1–2 weeks before returning to an O&M port (Trowbridge, Lim, and Knipe 2023). Service operation vessels require more extensive port facilities than CTVs—including a longer wharf and deeper berth—however, they can also operate at a farther distance from their home port. For CTVs, a port should be located within 1.5 hours of travel (approximately 50–75 km [27–40 nautical miles]) to effectively support operations (American Clean Power 2023).

Several recent studies have looked at potential offshore wind port sites within California and along the West Coast (Trowbridge et al. 2023; Shields et al. 2023; Trowbridge, Lim, and Knipe 2023; Lim and Trowbridge 2023). Based on these assessments, Table 1 lists the closest potential port sites to the Brookings WEA, ordered from north to south, along with an indication of their suitability for S&I, manufacturing, or O&M activities. The two closest ports—Brookings and Gold Beach—are within range to provide CTV support for O&M, and the nearest potential site for a service operation vessel is Crescent City. The Brookings WEA is nearly equidistant from the ports of Coos Bay and Humboldt Bay, each of which were identified as feasible candidates for S&I sites.

Table 1. Selected Results From the West Coast Port Screening

Source: Shields et al. 2023

Port Location	Distance to WEA B (km)	Capabilities			Notes
		S&I	MF	O&M	
Coos Bay	135–168	X	X	X	Best option in Oregon (challenges with airport and dredging)
Bandon	100–132			X	Coquille River depth is 13 ft, CTV only for O&M site
Port Orford	57–91				No protected harbor
Rogue River (Gold Beach)	35–67			X	CTV only due to channel depth
Brookings Harbor/Chetco	40–64			X	CTV only due to channel depth
Crescent City Harbor	55–86			X	(1) <10-acre O&M site
Humboldt Bay	144–174	X	X	X	(4) 80-acre S&I/MF sites and (6+) <10-acre O&M sites

Notes: Green indicates a good candidate site, yellow indicates a moderate candidate site, and red indicates an unlikely candidate site. S&I = staging and integration; MF = manufacturing/fabrication; O&M = operations and maintenance; CTV = crew transfer vessel

2.4.2 Grid Interconnection

Interconnection to the electric grid is a key requirement for a wind plant to deliver power. Several studies (Douville et al. 2020; Novacheck and Schwarz 2021; Zoellick et al. 2023) have identified possible points of interconnection for offshore wind along the Oregon coast. The closest potential points of interconnection among those considered in these studies is the Rogue 230-kilovolt (kV) substation near Gold Beach (approximately 55 km from the Brookings WEA) (Douville et al. 2020; Zoellick et al. 2023); however, the 230-kV Fairview substation near Coos Bay (approximately 150 km from the Brookings WEA) has also been identified as a potential point of interconnection (Novacheck and Schwarz 2021). Another alternative would be the construction of a new substation; for example, Zoellick et al. (2023) considered scenarios including a new 500-kV substation near Crescent City, California (approximately 70 km from the Brookings WEA).

3 Preliminary Lease Area Delineation

In this section, we present two contrasting options for dividing the Brookings WEA into two lease areas. Many other options were considered but no clear winners were found. All options require tradeoffs among many characteristics that impact lease value. The site conditions described in Section 2 informed the development of lease area options with approximately equal value.

3.1 Possible Lease Area Delineations

Figure 11 presents two delineation options for lease areas in the Brookings WEA. The option on the left divides the WEA along a line that approximately aligns with the prevailing northerly wind direction, resulting in eastern and western lease areas. This option minimizes the possibility of wake losses and wind blockage effects from the neighboring wind plant but leaves the western area with more challenges for development including deeper water and longer distances to port and grid interconnection.

The option on the right divides the WEA into northern and southern lease areas. This option distributes the deeper and shallower aliquots more evenly and provides more equal access to shore-based infrastructure, but places one lease area directly downwind of the other, reducing the power generation potential of the downstream lease area. Options divided diagonally across the WEA were also considered, but were not recommended because the long, stairstep boundaries significantly reduced the area available for turbine placement, limiting the total generating capacity.

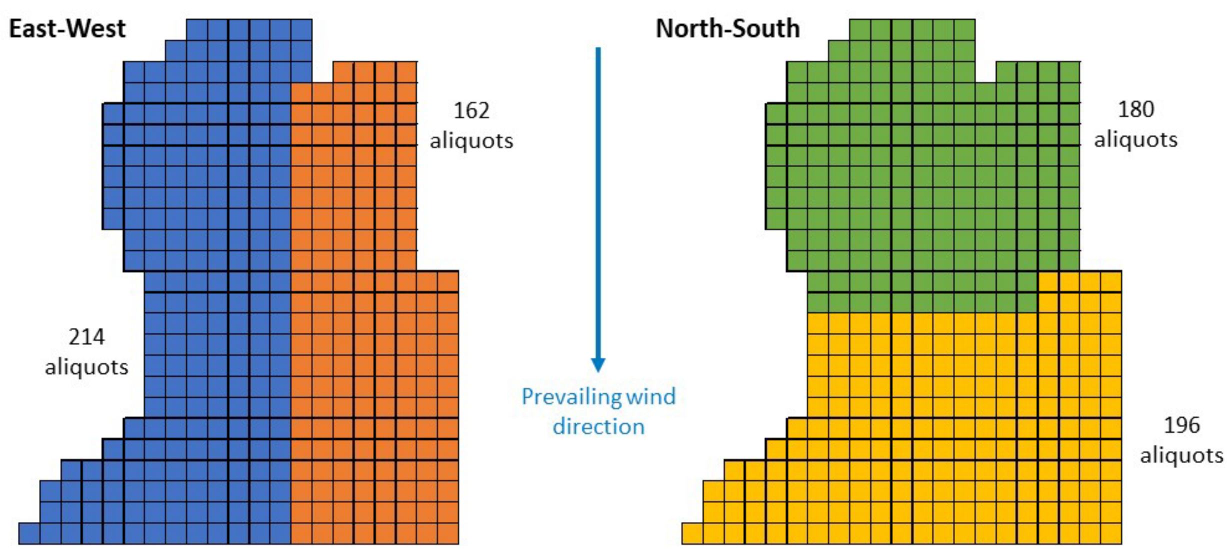

Figure 11. Proposed lease area options

3.2 Distribution of Physical Site Characteristics

Each aliquot was characterized based on the following attributes:

- **Wind speed**: The mean wind speed at a height of 160 m modeled for the years 2000–-2022, in meters per second (Bodini et al. 2023)

- **Exposure to prevailing wind**: Distance in kilometers from the northern edge of the WEA
- **Distance to land-based infrastructure**: Distance in kilometers to port facilities at Coos Bay, Humboldt Bay, and Gold Beach. The closest potential point of interconnection to the electric grid is also located near Gold Beach.
- **Total area**: Area in square kilometers of each lease area
- **Border**: Indicates whether an aliquot is adjacent to the lease area boundary in the specified delineation option
- **Depth**: Mean water depth within each aliquot, in meters (National Geophysical Data Center 2003)
- **Mean slope**: Mean seabed slope within each aliquot, in degrees (calculated from the U.S. Coastal Relief Models)
- **Mapped fault line**: Presence of a quaternary fault line (U.S. Geological Survey 2017)
- **Rock**: Presence of a high-backscatter region interpreted as rock (Merle et al. 2021)
- **Coral**: High concentration of area assessed as suitable for coral habitat (Poti et al. 2020)
- **Methane seeps**: Presence of one or more bubble streams indicating methane seeps (Merle et al. 2021).

Table 2 summarizes the distribution of each attribute between the east-west and north-south delineation options.

Table 2. Summary of Physical Parameters for Brookings WEA

Lease area			East	West	North	South
Average wind speed		m/s	11.5	11.4	11.4	11.5
Average wind exposure		km	11	11	6	15
Average distance	Coos Bay	km	146	148	140	153
	Humboldt Bay	km	156	160	166	152
	Gold Beach	km	52	58	51	60
Total area		km^2	233	308	259	282
Border		# aliquots	58	77	60	61
Water depth	700–900 m	# aliquots	156	4	70	90
	900–1100 m	# aliquots	6	138	82	62
	1100–1300 m	# aliquots	0	72	28	44
Average seabed slope	0°–4°	# aliquots	148	160	143	165
	>4°	# aliquots	14	54	37	31
Mapped fault line		# aliquots	35	61	41	55
Rock		# aliquots	0	25	16	9
Coral habitat		# aliquots	25	17	1	41
Methane seeps		# aliquots	11	5	8	8

The characteristics in Table 2 were each assigned scores on a scale from 0 to 1, with 0 being the least favorable and 1 being the most favorable. The distances to Coos Bay and Humboldt Bay were combined into a single "distance to port" metric, and the presence of rock, coral habitat, or methane seeps were combined into a single seabed metric. The resulting list of 10 scores were equally weighted to produce the maps shown in Figure 12. Appendix A contains maps of the individual metric scores. Summing all of the individual aliquot scores and dividing them by the total results in a score of 49% for the east area and 51% for the west area. For the north-south delineation option, the north area scores 49% and the south area scores 51%. We also compared several alternative weightings of the metrics shown in Appendix A to investigate the sensitivity of the results to the weighting scheme and found that the balance of scores between the two areas remained relatively similar, from 48%–52%. This provided confidence that the two delineation options represent equal divisions of the Brookings WEA.

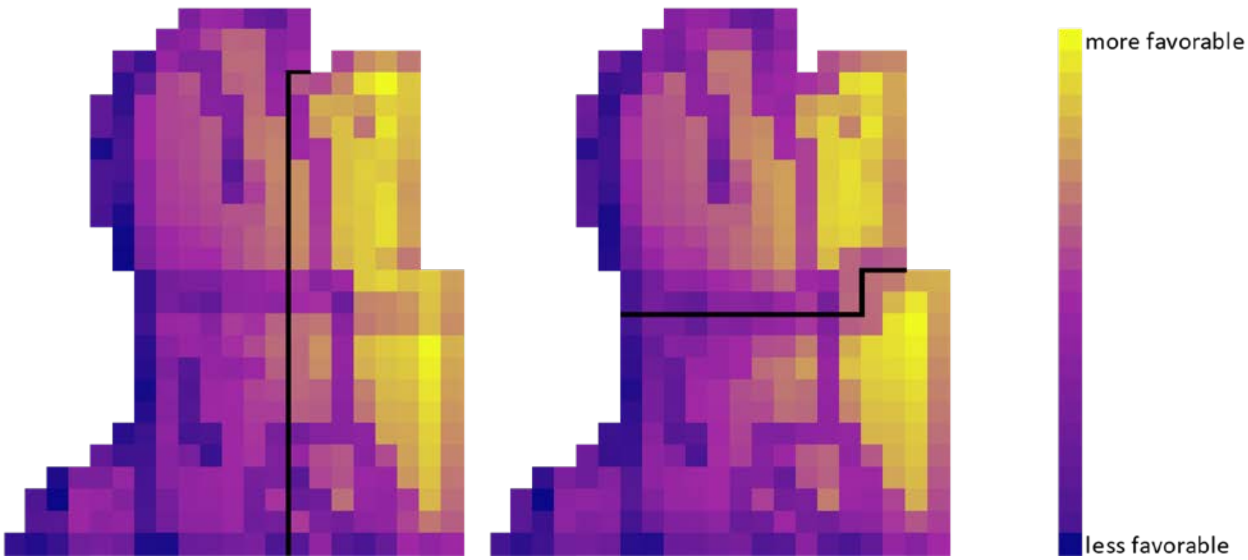

Figure 12. Aliquot scores in the Brookings WEA using equal weighting of 10 inputs for two delineation options

4 Lease Area Generating Potential and Wake Loss Analysis

This section presents an analysis of the generating potential and wake losses based on the delineation options outlined in Section 3.

4.1 Approach

We used the FLOw Redirection and Induction in Steady state (FLORIS[3]) model to analyze the wake losses for different delineation options while accounting for the site-specific wind resource in the Brookings WEA (NREL 2023). We also considered mooring footprints for different mooring technology choices to estimate how the delineation boundaries might affect the location of turbines near the boundaries. We summarized the generation potential and wake losses for each delineation option and mooring technology choice and examined how the wake losses in each area are affected by the presence of an adjacent wind plant.

4.1.1 Turbine Technology Assumptions

For this analysis, we used the International Energy Agency Wind Technology Collaboration Programme (IEA Wind) 15-MW reference wind turbine[4] (Gaertner et al. 2020). The main physical turbine characteristics are summarized in Table 3. A power curve generated with FLORIS for the IEA Wind 15-MW reference wind turbine is presented in Figure 13.

Table 3. IEA Wind 15-MW Reference Wind Turbine Characteristics

Parameter	Value
Nominal turbine rating	15 MW
Rotor diameter	242 m
Hub height	150 m
Specific power	325 W/m^2

[3] Access the FLORIS model on GitHub: https://github.com/NREL/floris.
[4] Access data and documentation on GitHub: https://github.com/IEAWindTask37/IEA-15-240-RWT.

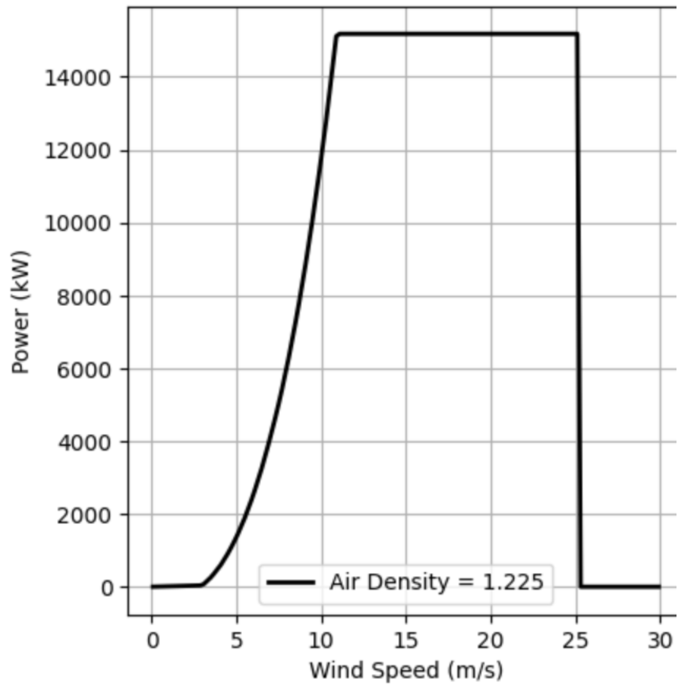

Figure 13. Power curve for the IEA Wind 15-MW reference wind turbine at an air density of 1.225 kg/m^3

4.1.2 Mooring System Technology Assumptions

The mooring system footprint can impact a developer's placement of anchors and turbines along the edges of a lease area boundary because anchors must not disturb the seabed outside the lease. Cooperman et al. (2022) showed how the mooring technology setback changes with mooring technology type and water depth; these impacts are summarized in Figure 14 and Table 4.

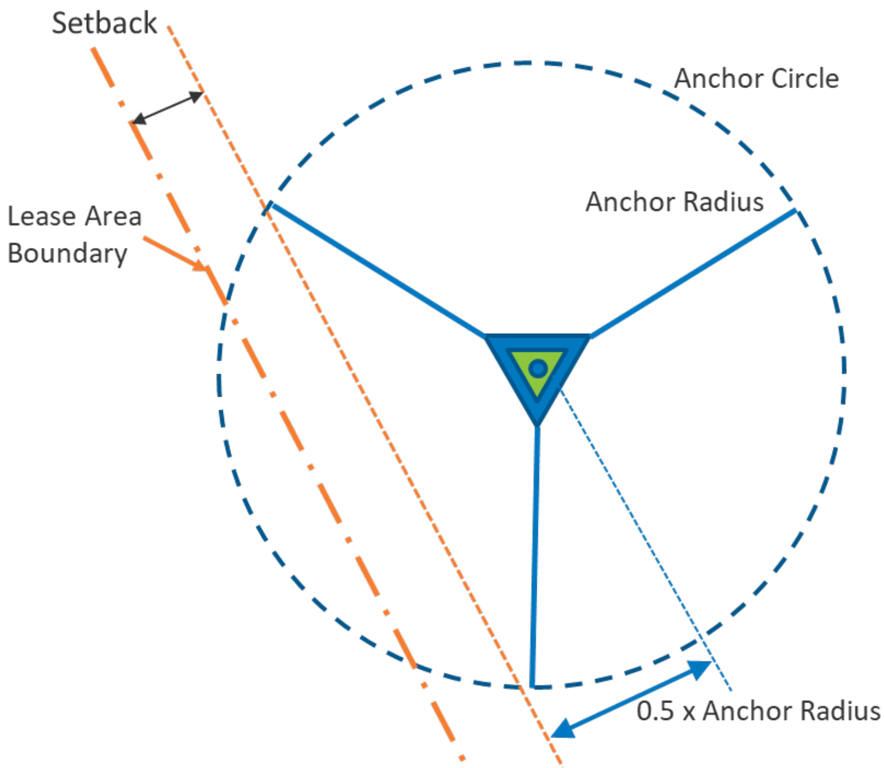

Figure 14. Conceptual diagram of anchor placement near the lease area boundary. The setback and anchor radius vary by mooring type; Table 4 lists the total distance for each type.

Source: Reproduced from Cooperman et al. 2022

Table 4. Minimum Distances From Turbine to Lease Area Boundary by Mooring Type

Source: Reproduced from Cooperman et al. 2022

Mooring Type	Minimum Turbine-to-Boundary Distance
Catenary	1,100 m
Semitaut	0.35 × water depth + 500 m
Taut	0.35 × water depth
Tension-leg platform	100 m

In this analysis of wake losses and generation potential, we considered only the impacts of the exterior boundary setbacks for semitaut and tension-leg platform (TLP) mooring configurations. Catenary mooring configurations are unlikely to be preferred at the water depths present in the Brookings WEA due to the weight and lengths of chain required. The boundary setbacks for taut moorings would likely fall between those of the other two configurations. Semitaut and TLP mooring configurations represent reasonable bounds to the range of potential setbacks that could be seen in the Brookings WEA.

4.1.3 Wind Plant Layout Assumptions

We developed wind plant layouts that completely fill each lease area option with wind turbines in a uniform grid. Although the actual process of developing a wind plant layout involves more sophisticated optimization, accounting for multiple factors such as water depth, soil conditions, cable routing, and wake losses, we take a simplified approach that still allows us to understand relative differences between potential delineations. We arranged the turbine positions on a rectangular grid spaced 4 rotor diameters (D) apart in the east-west direction and 10D apart in the north-south direction. The assumed layout is consistent with feedback from developers regarding the likely turbine spacing in the California WEAs (Cooperman et al. 2022), which exhibit similar wind resource characteristics to the Brookings WEA. A total of 14 cases are modeled using FLORIS: 2 mooring setbacks applied to the full WEA, each of the 4 potential lease areas alone, and the 2 pairs of lease areas combined.

4.1.4 Wake Modeling With FLORIS

To calculate the generation potential and wake losses with FLORIS for each delineation, we created layouts for each case by arranging the IEA 15-MW turbines on a 4D × 10D rectangular grid after accounting for boundary setbacks based on the selected mooring technology and water depth along the boundary. The wind resource data used in the generation potential and wake loss analysis is taken from NREL's NOW-23[5] dataset covering the period from 2000–2022 (Bodini et al. 2023). Refer to Section 2.1 for the analysis of the modeled wind resource in the Brookings WEA.

FLORIS is configured based on recommendations from the FLORIS development team at NREL. For this analysis, we used three different engineering wake models to examine the potential range of wake losses. Each model is formulated to better represent certain physical structures (Doekemeijer, Simley, and Fleming 2022). The TurbOPark wake model (Nygaard et al. 2020) is intended to capture the effects over larger length scales relevant for clusters of wind plants. The Gauss-curl hybrid model is intended to be tuned to high-fidelity simulation data and capture physical effects over smaller length scales for individual wind plants (Bastankhah and Porté-Agel 2014). The cumulative-curl model lies between the other two in terms of the intended length scales, but it still attempts to represent the interaction of wakes from one wind plant to another (Bay et al. 2023). A rotor-averaged wind speed is calculated with three vertical points over the rotor plane, and the turbulence intensity is assumed to be 6% across all three models.

Gross generation, or AEP without losses, is calculated first. Wake losses are obtained from FLORIS and combined with the other loss categories listed in Table 5 to estimate the total losses used to calculate the net AEP.

[5] Access the data through the Open Energy Data Initiative (OEDI): https://data.openei.org/submissions/4500.

Table 5. Summary of Losses Used for Net AEP Calculations

Loss Category	Assumed Value for Brookings WEA (% of Gross Generation)
Wake losses	Calculated using FLORIS
Environmental losses	1.6%
Technical losses	1.2%
Electrical losses	3.9%
Availability losses	5.0%

Notes: The nonwake losses obtained for the Brookings WEA are from Musial et al. (2021). See Beiter et al. (2020; 2016) for more information on the loss categories and methodology.

4.2 Results

Table 6 summarizes the gross and net generation potential for each delineation option, accounting for the effect of wakes from wind turbines in both potential leases in the divided options. The total capacity, capacity density, and gross capacity factor (GCF) for each delineation option are also listed. The net AEP and net capacity factor (NCF) are reported based on the wake loss estimated with the cumulative-curl wake model. The values in parentheses represent the range from high (TurbOPark) and low (GCH) wake loss estimates.

Table 6. Generation Potential by Delineation and Mooring Type

Parameter	Unit	Mooring Type	Full WEA	East-West	North-South
Capacity	GW	TLP	3.67 (242 WTGs)	3.67 (242 WTGs)	3.67 (242 WTGs)
Capacity	GW	Semitaut	2.99 (197 WTGs)	2.76 (182 WTGs)	2.81 (190 WTGs)
Capacity density	MW/km^2	TLP	6.79	6.79	6.79
Capacity density	MW/km^2	Semitaut	5.52	5.10	5.33
Gross annual energy production	TWh	TLP	20.1	20.1	20.1
Gross annual energy production	TWh	Semitaut	16.4	15.2	15.8
Gross capacity factor	%	All	61.8	61.8	61.8
Net annual energy production	TWh	TLP	15.9 (15.3–16.7)	15.9 (15.3–16.7)	15.9 (15.4–16.7)
Net annual energy production	TWh	Semitaut	13.0 (12.6–13.6)	12.1 (11.7–12.6)	12.5 (12.2–13.1)
Net capacity factor	%	TLP	49.5 (47.6–51.8)	49.5 (47.6–51.8)	49.5 (47.8–51.8)

Parameter	Unit	Mooring Type	Full WEA	East-West	North-South
Net capacity factor	%	Semitaut	49.7 (48.0–51.9)	50.0 (48.3–52.0)	49.8 (48.1–51.9)

Notes: WTG = wind turbine generator; TWh = terawatt-hour. The reported values are estimated with the cumulative-curl wake model. The values in parentheses represent the range from high (TurbOPark) and low (Gauss-curl hybrid) wake loss estimates.

The total AEP and estimated wake loss depend on the total number of turbines and how densely they are deployed. For layouts using TLPs, the net AEP is nearly the same regardless of delineation, but it changes with delineation for layouts using semitaut mooring systems because the total number of turbines changes with different boundaries.

The predicted wake losses for each delineation and mooring technology scenario are presented in Figure 15. The wake loss estimates are lower for layouts using the semitaut mooring technology than for layouts using TLPs because the setbacks from the boundaries reduce the number of turbines deployed, regardless of delineation. The wake losses are lower for each lease area alone than when considering the effects of the neighboring lease area.

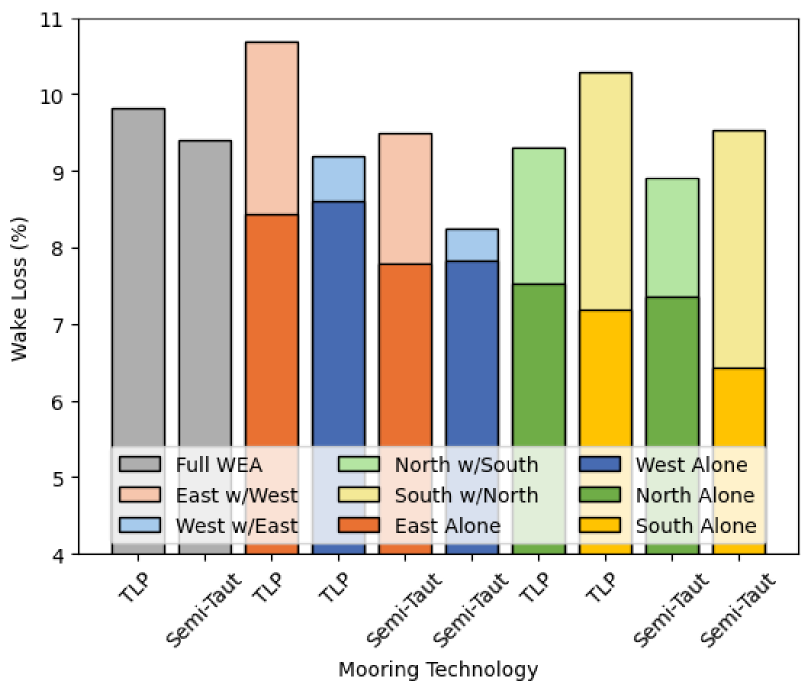

Figure 15. Predicted wake losses by mooring technology and delineation option using the cumulative-curl wake model in FLORIS. Wake losses are presented for each area alone and with its neighbor for the east-west and north-south delineation options.

Figure 16 shows the magnitude of additional wake loss for each area with the presence of its neighbor compared to the area alone. The east and south areas have greater additional wake losses because they are downstream when winds are coming from the north or northwest. The wind speed distribution from those directions (see Figure 3) shows a greater frequency of winds below the rated wind speed, where the velocity deficits from wakes are more likely to impact power production.

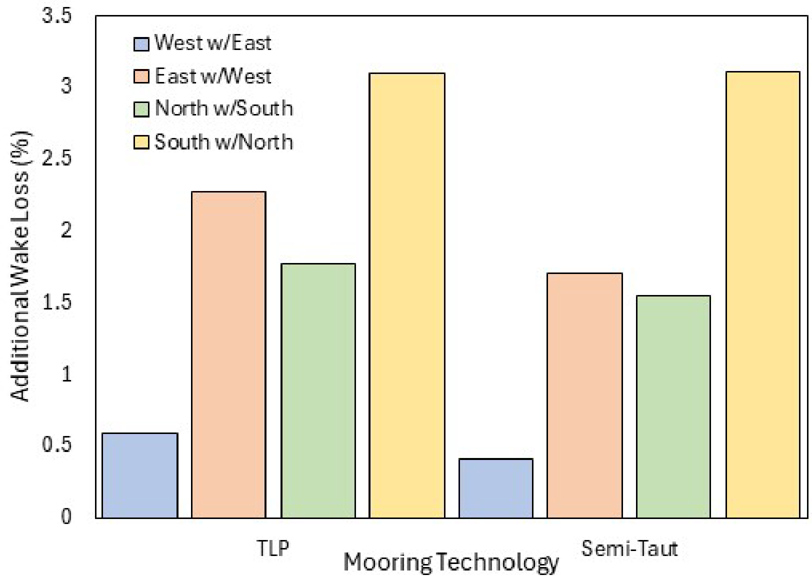

Figure 16. Additional wake loss using the cumulative-curl model for each area with neighbor present relative to the area alone

Figure 17 displays the total net generation, or total AEP, for each delineation and technology scenario. The relative generation for each option follows the total capacity for each scenario, with the highest number of turbines in the full WEA TLP layout and the lowest number in the east-west semitaut layout. The number of turbines in each layout is influenced by the length of the lease area boundary, which is the longest in the east-west delineation option. Dividing the AEP by the total capacity gives the NCF. The western and northern lease areas have higher NCFs than the eastern and southern lease areas. All else being equal, a higher NCF will result in a lower levelized cost of energy, or, conversely, a site with a higher NCF can achieve the same cost of energy despite higher capital and/or operating expenses.

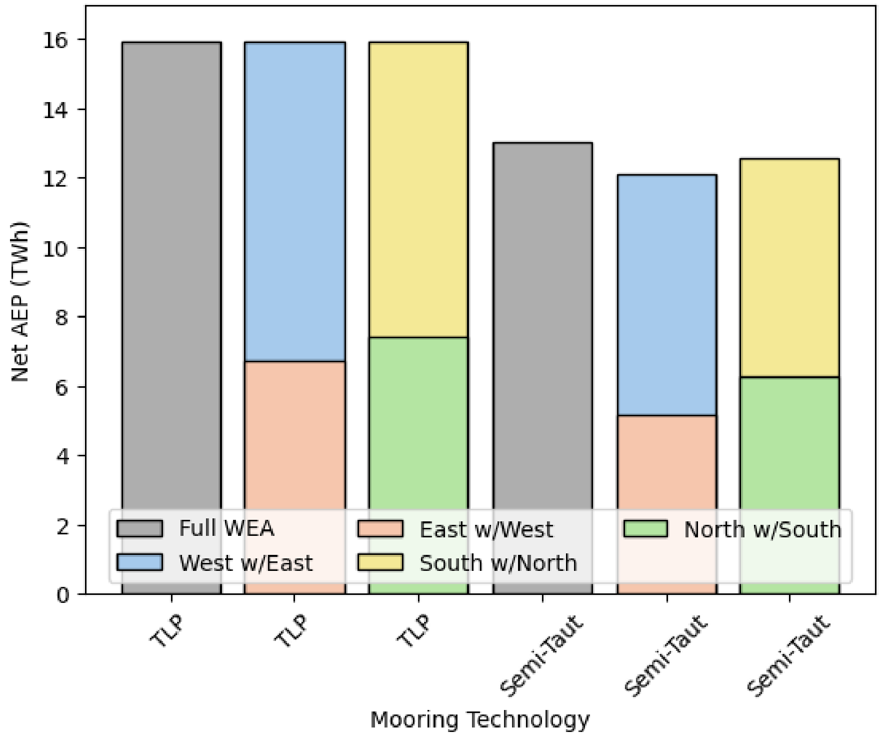

Figure 17. Comparison of total AEP for the Brookings WEA by mooring type and delineation option using the cumulative-curl model

4.3 Caveats and Limitations to the FLORIS Analysis

Although well-tuned engineering wake models can perform as well as more resolved but computationally intensive, high-fidelity modeling approaches to obtain the initial estimates of AEP and wake losses (Nygaard et al. 2022), be cautious of the following when interpreting the results:

- This analysis largely relies on the default wake model tuning parameters per the recommendation of the FLORIS team because, to the authors' knowledge, no observational or high-fidelity simulations exist for the region. This limits our ability to tune to site-specific conditions.
- We used modeled wind resource data (Bodini et al. 2023). Atmospheric stability (or the amount of vertical mixing in the wind) influences the wake recovery and therefore the wake losses. This needs to be considered more carefully when assessing wind plant performance offshore Northern California and Southern Oregon due to the coastal upwelling of cold water that can affect the stability conditions in the region (Liu et al. 2024).
- Wind plant layout optimization and wind plant control, or "wake steering," can reduce wake losses, leading to AEP gains of 1.3%–2.3% (Fleming et al. 2023). Neither of these capabilities was used in this analysis, but the value of wind plant control increases with the wake loss and in energy markets with the strength of the inverse correlation between wind speed and electricity price (Simley et al. 2024).

5 Summary and Conclusions

In this study, we analyzed two contrasting options for delineating two lease areas from the Brookings WEA and compared them with the full, undivided WEA. We considered several physical characteristics that affect the value of the individual aliquots within the WEA, including wind resource, bathymetry, seismic hazards, seabed features, and distance from infrastructure. Although the distribution of these characteristics varies, the two delineation options provide a relatively equal balance of value based on the ten factors we considered. For both of the two-area options, the power-generating capacity for each lease area is close to 1 GW, assuming a capacity density of 4 MW/km^2. Higher capacity densities are possible, depending on the wind turbine layout and mooring technology. For a spacing of 4 × 10 rotor diameters, we estimate a total generating capacity up to 3.6 GW, or 1.2 GW–2.1 GW per lease area. The study did not find a superior option for delineation of the Brookings WEA. Both options offered some advantages and disadvantages, but neither option was ideal.

References

American Clean Power. 2023. "Offshore Wind Vessel Needs." https://cleanpower.org/wp-content/uploads/2021/09/OffshoreWind_Vessel_Needs_230104.pdf.

Bastankhah, Majid, and Fernando Porté-Agel. 2014. "A New Analytical Model for Wind-Turbine Wakes." *Renewable Energy: Special Issue on Aerodynamics of Offshore Wind Energy Systems and Wakes* 70 (October):116–23. https://doi.org/10.1016/j.renene.2014.01.002.

Bay, Christopher J., Paul Fleming, Bart Doekemeijer, Jennifer King, Matt Churchfield, and Rafael Mudafort. 2023. "Addressing Deep Array Effects and Impacts to Wake Steering with the Cumulative-Curl Wake Model." *Wind Energy Science* 8 (3): 401–19. https://doi.org/10.5194/wes-8-401-2023.

Beiter, Philip, Walt Musial, Patrick Duffy, Aubryn Cooperman, Matt Shields, Donna Heimiller, and Mike Optis. 2020. *The Cost of Floating Offshore Wind Energy in California Between 2019 and 2032*. Golden, CO: National Energy Technology Laboratory. NREL/TP-5000-77384. https://www.nrel.gov/docs/fy21osti/77384.pdf.

Beiter, Philipp, Walter Musial, Aaron Smith, Levi Kilcher, Rick Damiani, Michael Maness, Senu Sirnivas, et al. 2016. *A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-66579. https://doi.org/10.2172/1324526.

Bodini, Nicola, Alex Rybchuk, Mike Optis, Walter Musial, Julie K. Lundquist, Stephanie Redfern, Caroline Draxl, Raghavendra Krishnamurthy, and Brian Gaudet. 2022. *Update on NREL's 2020 Offshore Wind Resource Assessment for the California Pacific Outer Continental Shelf*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-83756. https://www.boem.gov/sites/default/files/documents/regions/pacific-ocs-region/environmental-analysis/BOEM-2022-072.pdf.

Bodini, Nicola, Mike Optis, Michael Rossol, Alex Rybchuk, and Stephanie Redfern. 2023. "2023 National Offshore Wind Data Set (NOW-23)." National Renewable Energy Laboratory. Open Energy Data Initiative (OEDI). https://doi.org/10.25984/1821404.

Bureau of Ocean Energy Management (BOEM) and Oregon Department of Land Conservation and Development. 2020. *Data Gathering and Engagement Plan for Offshore Wind Energy in Oregon*. Kearns & West. https://www.boem.gov/sites/default/files/documents/regions/pacific-ocs-region/BOEM-OR-OSW-Engagement-Plan.pdf.

Bureau of Ocean Energy Management (BOEM). 2024. "Memo: Oregon Area Identification Pursuant to 30 C.F.R. § 585.211(b)0.5." https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Oregon%20Area%20ID%20Memo.pdf.

Carlton, Jessica L., Jonathan A. Jossart, Frank Pendleton, Necitas Sumait, Jennifer Miller, Jean Thurston-Keller, Desray Reeb, et al. 2024. *A Wind Energy Area Siting Analysis for the Oregon Call Areas*. Washington, D.C.: U.S. Department of the Interior, Bureau of Ocean Energy Management. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Appendix%20B_NCCOS%20Final%20WEA%20Report_Oregon.pdf.

Conrad, James E., and Jane A. Rudebusch. 2023. "Methane Seep Locations Derived from Water-Column Acoustic Backscatter Data Collected Along Cascadia Margin Offshore Oregon and Northern California, 2018–2021: USGS Data Release." U.S. Geological Survey. https://doi.org/10.5066/P9TW2X7Y.

Cooperman, Aubryn, Patrick Duffy, Matt Hall, Ericka Lozon, Matt Shields, and Walter Musial. 2022. *Assessment of Offshore Wind Energy Leasing Areas for Humboldt and Morro Bay Wind Energy Areas, California*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-82341. https://www.nrel.gov/docs/fy22osti/82341.pdf.

Doekemeijer, Bart M., Eric Simley, and Paul Fleming. 2022. "Comparison of the Gaussian Wind Farm Model with Historical Data of Three Offshore Wind Farms." *Energies* 15 (6). https://doi.org/10.3390/en15061964.

Douville, Travis C., Dhruv Bhatnagar, Rebecca S. O'Neil, and Kendall Mongird. 2020. *Exploring the Grid Value Potential of Offshore Wind Energy in Oregon*. Richland, WA: Pacific Northwest National Laboratory. PNNL-29935, 1618872. https://doi.org/10.2172/1618872.

Draxl, Caroline, Andrew Clifton, Bri-Mathias Hodge, and Jim McCaa. 2015. "The Wind Integration National Dataset (WIND) Toolkit." *Applied Energy* 151 (August 1, 2015): 355–66. https://doi.org/10.1016/j.apenergy.2015.03.121.

Fleming, Paul, David Dunn, Patrick Duffy, Christopher Bay, Matthew Churchfield, Rebecca Barthelmie, and Sara Pryor. 2023. *Wind Farm Control and Layout Optimization for U.S. Offshore Wind Farms*. Golden, CO: National Renewable Energy Laboratory. Prepared for the National Offshore Wind Research and Development Consortium. https://nationaloffshorewind.org/wp-content/uploads/NREL-147506_Final_Report.pdf.

Gaertner, Evan, Jennifer Rinker, Latha Sethuraman, Frederik Zahle, Benjamin Anderson, Garrett Barter, Nikhar Abbas, et al. 2020. *Definition of the IEA 15-Megawatt Offshore Reference Wind Turbine*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-75698. https://www.nrel.gov/docs/fy20osti/75698.pdf.

Goldfinger, C., S. K. Henkel, C. Romsos, A. Havron, and B. Black. 2014. *Benthic Habitat Characterization Offshore the Pacific Northwest Volume 1: Evaluation of Continental Shelf Geology*. Washington, D.C.: U.S. Department of the Interior, Bureau of Ocean Energy Management. BOEM 2014-662. https://espis.boem.gov/final%20reports/5453.pdf.

Lim, Jennifer, and Matt Trowbridge. 2023. *AB 525 Port Readiness Plan*. Sacramento, CA: California State Lands Commission. https://slcprdwordpressstorage.blob.core.windows.net/wordpressdata/2023/07/AB525-Port-Readiness-Plan_acc.pdf.

Liu, Ye, Brian Gaudet, Raghavendra Krishnamurthy, Sheng-Lun Tai, Larry K. Berg, Nicola Bodini, Alex Rybchuk, and Andrew Kumler. 2024. "Identifying Meteorological Drivers for Errors in Modeled Winds along the Northern California Coast." *Monthly Weather Review* 152 (2): 455–69. https://doi.org/10.1175/MWR-D-23-0030.1.

Merle, Susan G., Robert W. Embley, H. Paul Johnson, T.-K. Lau, Benjamin J. Phrampus, Nicole A. Raineault, and Lindsay J. Gee. 2021. "Distribution of Methane Plumes on Cascadia Margin and Implications for the Landward Limit of Methane Hydrate Stability." *Frontiers in Earth Science* 9. https://www.frontiersin.org/articles/10.3389/feart.2021.531714.

Mulas Hernando, Daniel, Walt Musial, Patrick Duffy, and Matt Shields. 2023. *Capacity Density Considerations for Offshore Wind Plants in the United States*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-86933. https://www.nrel.gov/docs/fy24osti/86933.pdf.

Musial, Walt, Patrick Duffy, Donna Heimiller, and Philipp Beiter. 2021. "Updated Oregon Floating Offshore Wind Cost Modeling." Sept. 24, 2021. https://www.nrel.gov/docs/fy22osti/80908.pdf.

Musial, Walt, Philipp C. Beiter, Jacob Nunemaker, Donna M. Heimiller, Josh Ahmann, and Jason Busch. 2019. *Oregon Offshore Wind Site Feasibility and Cost Study*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-74597, 1570430. https://doi.org/10.2172/1570430.

National Geophysical Data Center. 2003. "U.S. Coastal Relief Model - Central Pacific." National Centers for Environmental Information, National Oceanic and Atmospheric Administration. https://doi.org/10.7289/V50Z7152.

National Renewable Energy Laboratory (NREL). 2023. "FLORIS. Version 3.5." https://github.com/NREL/floris.

Novacheck, Josh, and Marty Schwarz. 2021. *Evaluating the Grid Impact of Oregon Offshore Wind*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-81244. https://doi.org/10.2172/1827315.

Nygaard, N. G., L. Poulsen, E. Svensson, and J. G. Pedersen. 2022. "Large-Scale Benchmarking of Wake Models for Offshore Wind Farms." *Journal of Physics: Conference Series* 2265 (2): 022008. https://doi.org/10.1088/1742-6596/2265/2/022008.

Nygaard, Nicolai Gayle, Søren Trads Steen, Lina Poulsen, and Jesper Grønnegaard Pedersen. 2020. "Modelling Cluster Wakes and Wind Farm Blockage." *Journal of Physics: Conference Series* 1618 (6): 062072. https://doi.org/10.1088/1742-6596/1618/6/062072.

Petersen, Mark D., Allison M. Shumway, Peter M. Powers, Ned Field, Morgan P Moschetti, Kishor Jaiswal, Kevin R Milner, et al. 2023. "Data Release for the 2023 U.S. 50-State National Seismic Hazard Model - Overview." U.S. Geological Survey. https://doi.org/10.5066/P9GNPCOD.

Poti, Matthew, S. K. Henkel, J. J. Bizzarro, T. F. Hourigan, M. E. Clarke, C. E. Whitmire, Abigail Powell, et al. 2020. *Cross-Shelf Habitat Suitability Modeling: Characterizing Potential Distributions of Deep-Sea Corals, Sponges, and Macrofauna Offshore of the U.S. West Coast*. Washington, D.C.: U.S. Department of the Interior, Bureau of Ocean Energy Management. BOEM-2020-021. https://espis.boem.gov/final%20reports/BOEM_2020-021.pdf.

Shields, Matt, Aubryn Cooperman, Matilda Kreider, Frank Oteri, Zoe Hemez, Liz Gill, Ashesh Sharma, et al. 2023. *The Impacts of Developing a Port Network for Floating Offshore Wind Energy on the West Coast of the United States*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-86864. https://www.nrel.gov/docs/fy23osti/86864.pdf.

Sierman, Jason, Todd Cornett, Deanna Henry, Jessica Reichers, Adam Schultz, Rebecca Smith, and Max Woods. 2022. *Floating Offshore Wind: Benefits & Challenges for Oregon*. Salem, OR: Oregon Department of Energy. https://www.oregon.gov/energy/Data-and-Reports/Documents/2022-Floating-Offshore-Wind-Report.pdf.

Simley, E., D. Millstein, S. Jeong, and P. Fleming. 2024. "The Value of Wake Steering Wind Farm Flow Control in US Energy Markets." *Wind Energy Science* 9 (1): 219–34. https://doi.org/10.5194/wes-9-219-2024.

Smith, D. B. 2021. *House Bill 3375*. https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB3375/Enrolled.

Tajalli Bakhsh, Tayebeh, Mahmud Monim, Kent Simpson, Tony Lapierre, Jason Dahl, Jill Rowe, and Malcom Spaulding. 2020. *Potential Earthquake, Landslide, Tsunami, and Geo-Hazards for the U.S. Offshore Pacific Wind Farms*. BOEM 2020-040. Kingstown, RI: U.S. Department of the Interior, Bureau of Ocean Energy Management. https://www.rpsgroup.com/media/5565/potential-earthquake-landslide-tsunami-and-geohazards-for-the-us-offshore-pacific-wind-farms.pdf.

Trowbridge, Matthew, Jennifer Lim, and Ashley Knipe. 2023. *Alternative Port Assessment to Support Offshore Wind*. Sacramento, CA: California State Lands Commission. https://efiling.energy.ca.gov/GetDocument.aspx?DocumentContentId=83268&tn=248750.

Trowbridge, Matthew, Jennifer Lim, Shane Phillips, and Ashley Knipe. 2023. *California Floating Offshore Wind Regional Ports Assessment*. BOEM 2023-010. Washington, D.C.: U.S. Department of the Interior, Bureau of Ocean Energy Management. https://www.boem.gov/sites/default/files/documents/renewable-energy/studies/BOEM-2023-010.pdf.

U.S. Department of the Interior. 2024. "Interior Department Proposes Offshore Wind Sales in Oregon, Gulf of Maine." Press Release. April 30, 2024. https://www.doi.gov/pressreleases/interior-department-proposes-offshore-wind-sales-oregon-gulf-maine.

U.S. Geological Survey. 2017. "Quaternary Fault and Fold Database for the United States." https://doi.org/10.5066/F7S75FJM.

Zoellick, James, Greyson Adams, Ahmed Mustafa, Aubryn Cooperman, Rahul Anilkumar, Patrick Duffy, A. Sparks, et al. 2023. *Schatz Center Northern California and Southern Oregon Offshore Wind Transmission Study Volume 1*. Arcata, CA: Cal Poly Humboldt. https://www.energy.ca.gov/data-reports/reports/ab-525-reports-offshore-renewable-energy.

Appendix A. Physical Characteristic Scoring Maps

Figure A-1–Figure A-5 show the scoring maps for the individual physical characteristics. For combined scoring, light (yellow) aliquots receive a value of 1, which is more favorable. The darkest aliquots receive a score of 0. Combined scores using an equal weighting of factors are shown in Figure 12 in the main text.

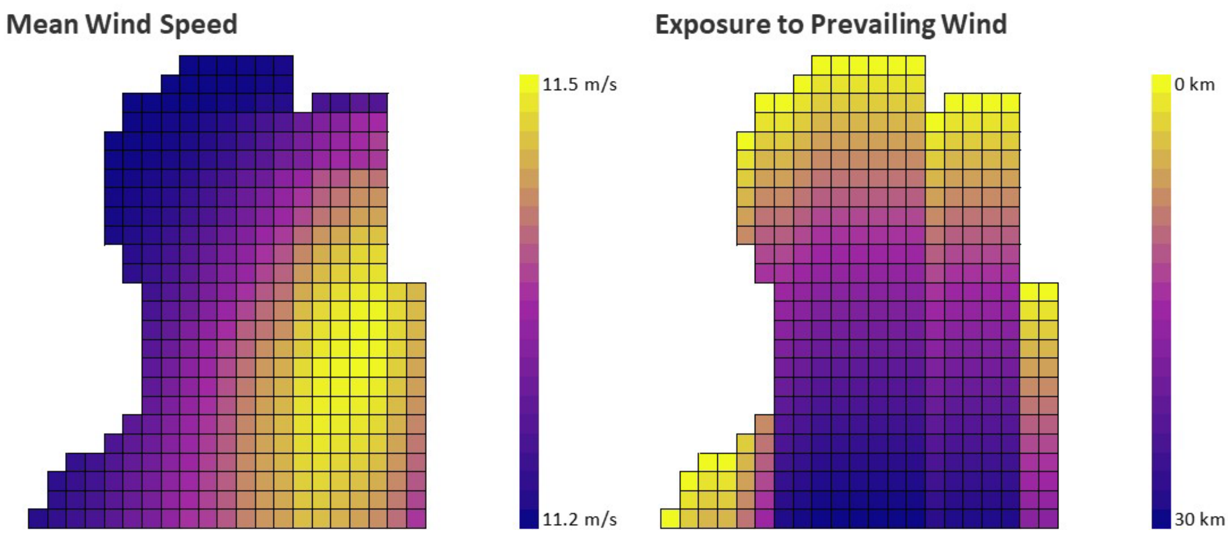

Figure A-1. Mean wind speed at 160 m, 2020–2022, and distance from the northern edge of the WEA

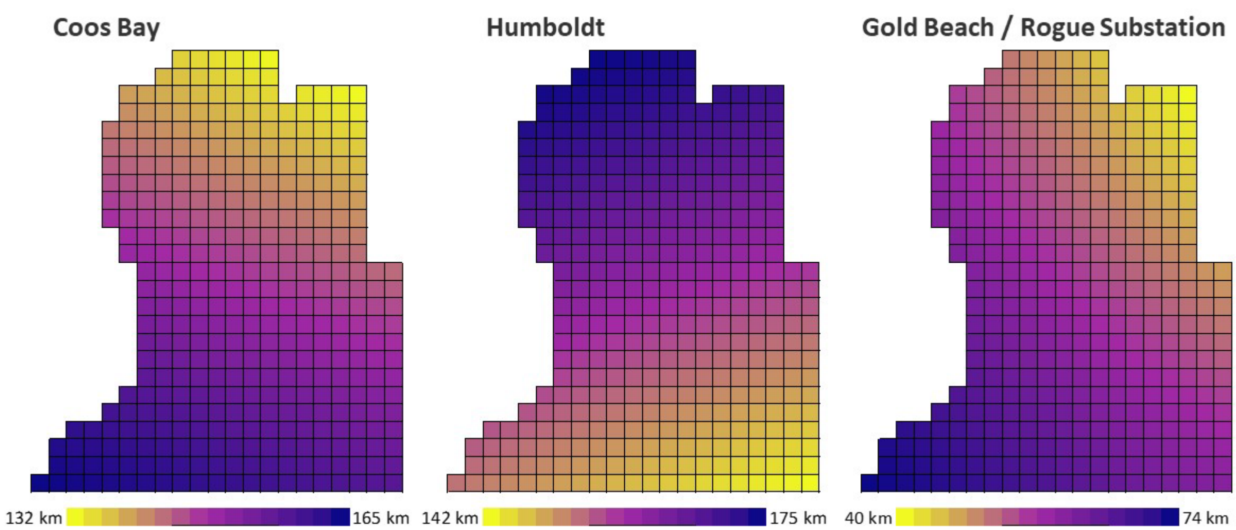

Figure A-2. Distance to ports and the closest point of interconnection to the electric grid

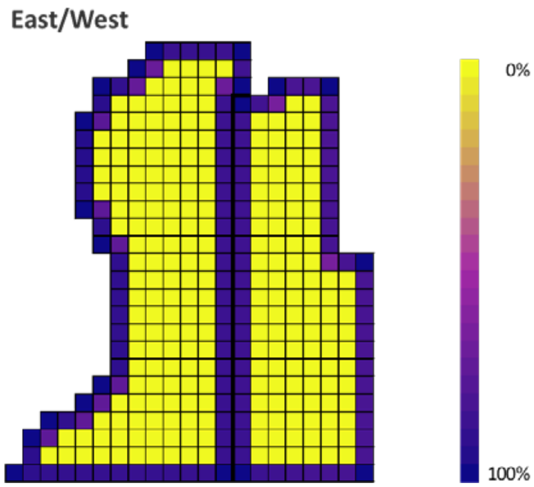

Figure A-3. Percentage of aliquot area infeasible for wind turbine siting based on the semitaut mooring setback assumptions shown in Table 4

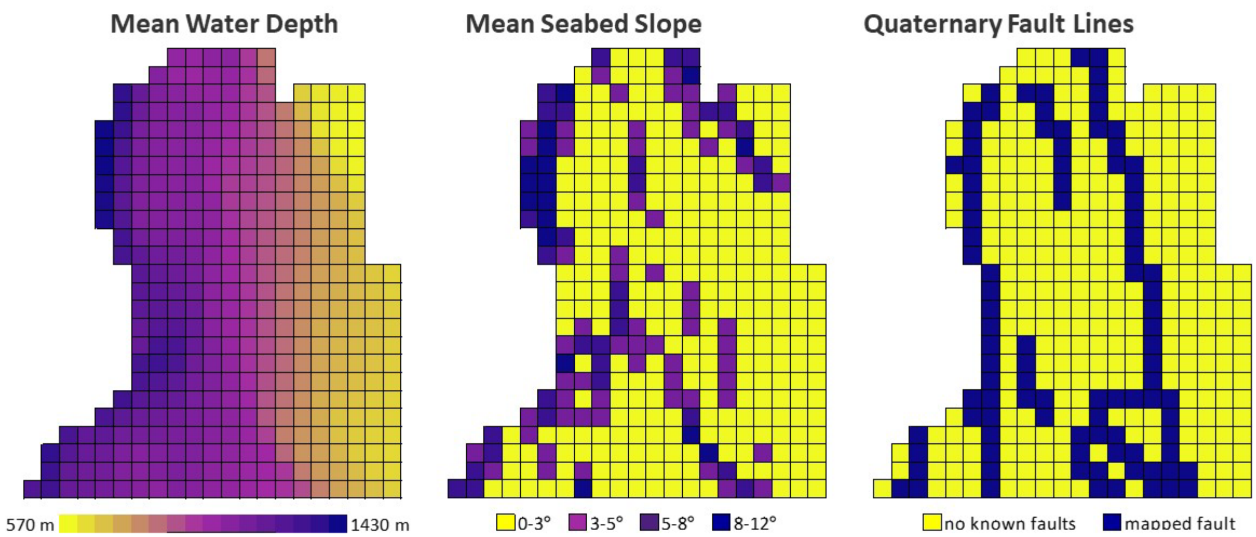

Figure A-4. Bathymetry and seismic faults

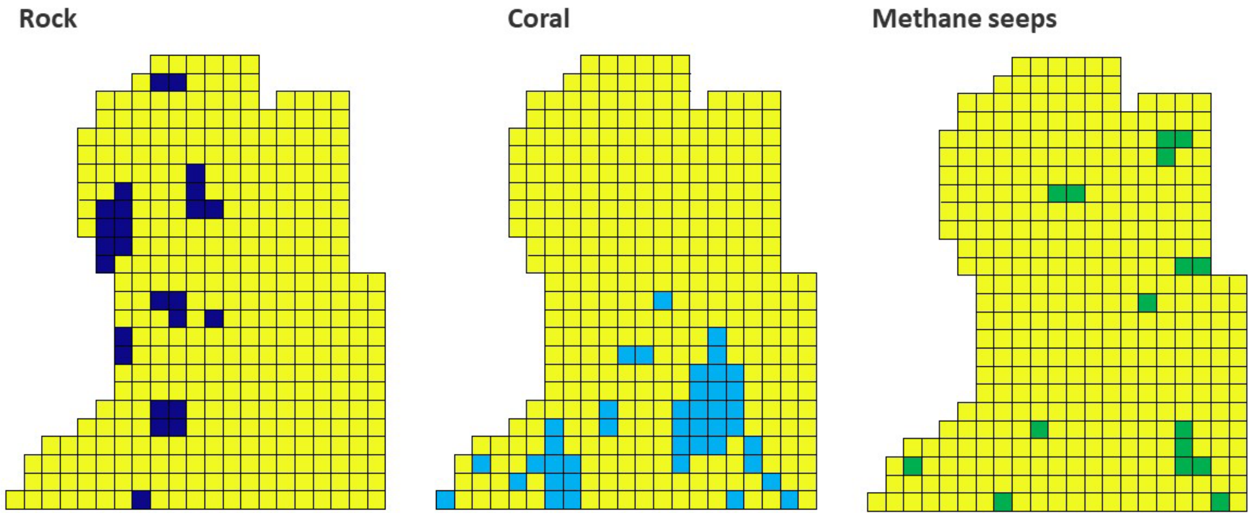

Figure A-5. Aliquots containing the seabed features identified by Merle et al. (2021), Conrad and Rudebusch (2023), and Poti et al. (2020). Dark shading (blue/green) indicates aliquots with rock, coral habitat, or methane seeps.

Appendix B. Wind Plant Layout Maps by Delineation

This appendix presents maps of boundaries and turbine layouts for each delineation and mooring technology type. The turbine spacing is 4 rotor diameters (D) in the east-west direction (X) and 10D in the north-south direction (Y). The map units are meters shown in Universal Transverse Mercator (UTM) zone 10 N.

B.1 Full Wind Energy Area: Semitaut Moorings

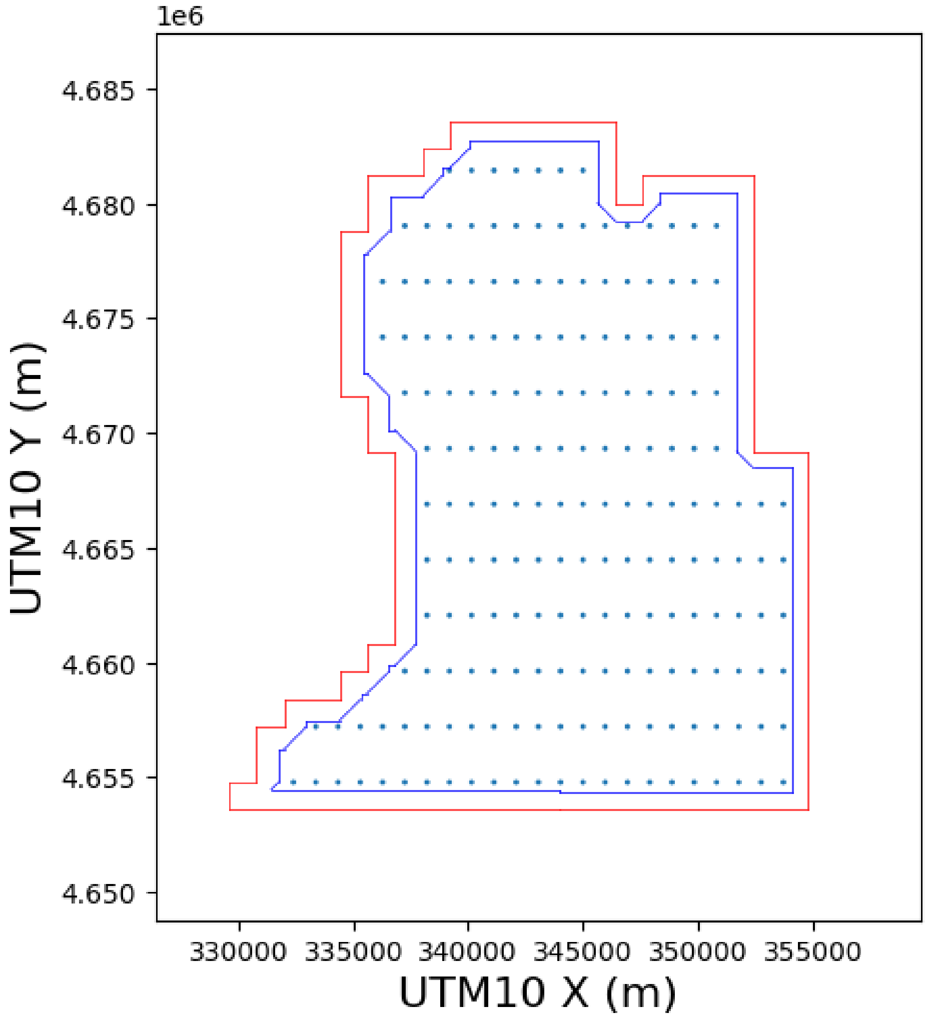

Figure B-1. Map depicting the turbine positions (blue dots) and semitaut mooring technology setback (blue boundary) for the full WEA (red boundary). Note that dot size = 1 rotor diameter. This configuration yields 197 turbine positions spaced 4 and 10 rotor diameters apart along the east-west and north-south directions, respectively.

B.2 Full Wind Energy Area: Tension-Leg Platform Moorings

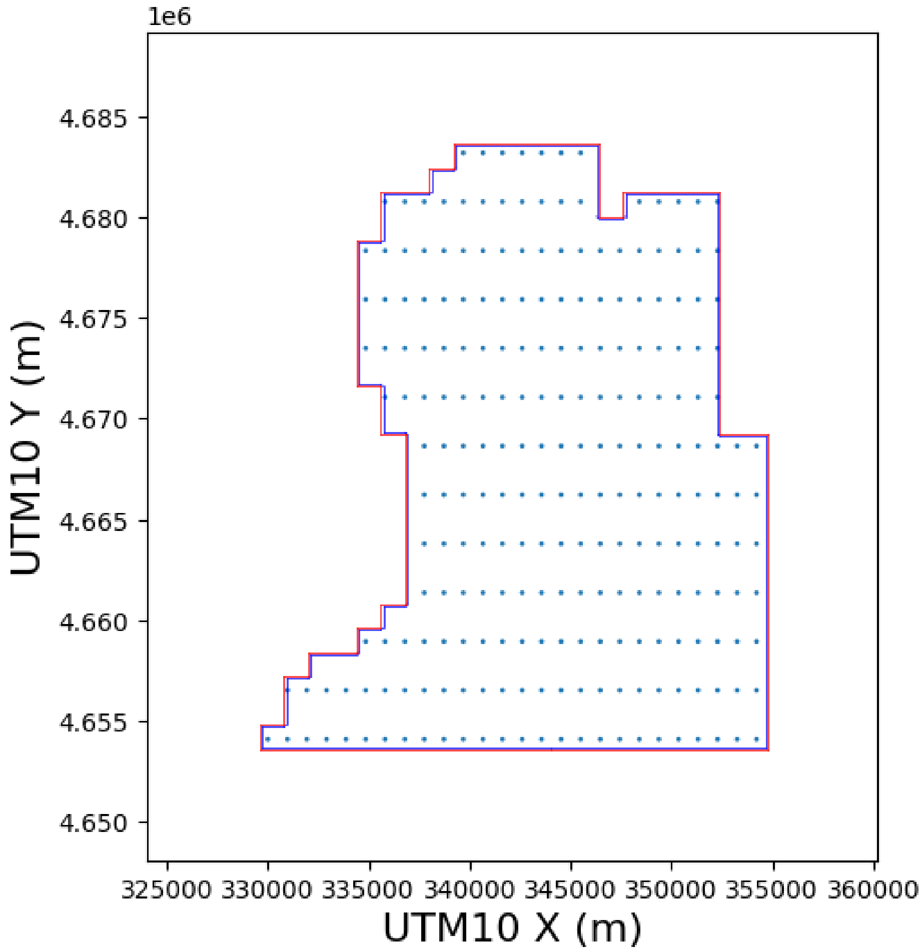

Figure B-2. Map depicting the turbine positions (blue dots) and TLP mooring technology setback (blue boundary) for the full WEA (red boundary). Note that dot size = 1 rotor diameter. The UTM zone is 10 N. This configuration yields 242 turbine positions spaced 4 and 10 rotor diameters apart along the east-west and north-south directions, respectively.

B.3 East-West Delineation: Semitaut Moorings

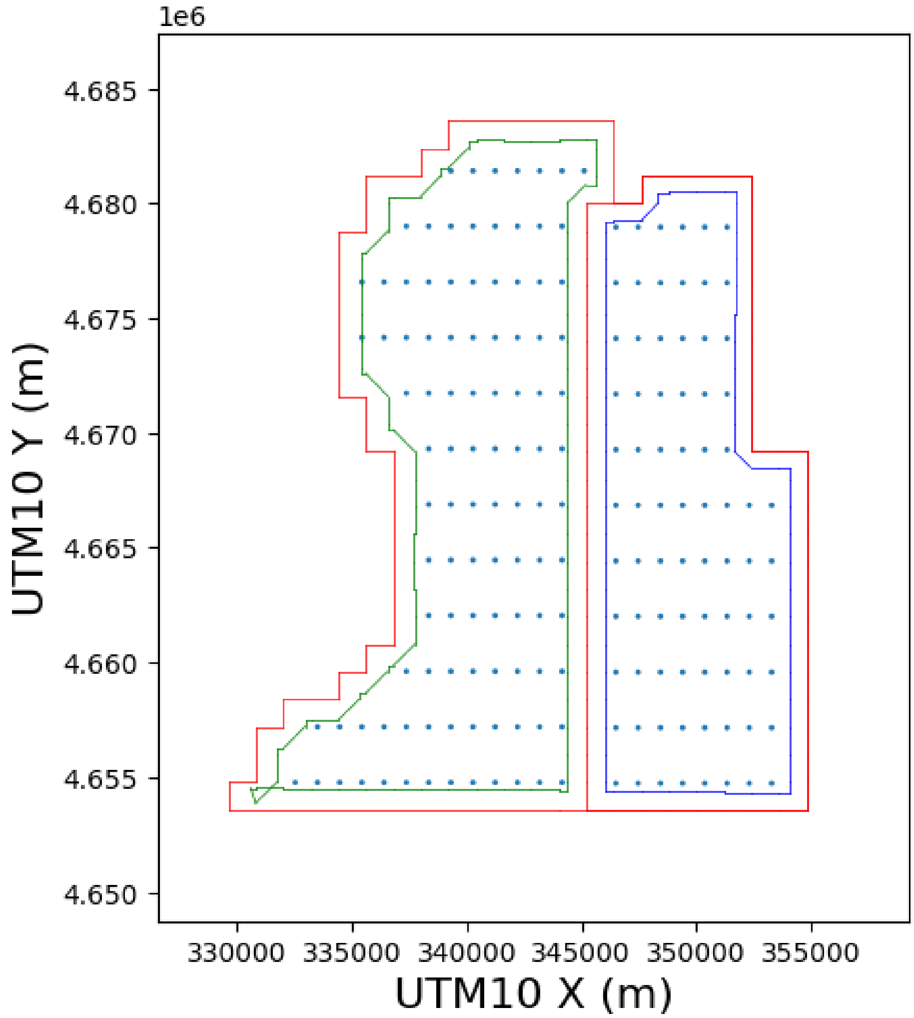

Figure B-3. Map depicting the turbine positions (blue dots) and semitaut mooring technology setback (green boundary = west, blue boundary = east) for the east-west delineation (red boundary). Note that dot size = 1 rotor diameter. The UTM zone is 10 N. This configuration yields 182 turbine positions (78 in east, 108 in west) spaced 4 and 10 rotor diameters apart along the east-west and north-south directions, respectively.

B.4 East-West Delineation: Tension-Leg Platform Moorings

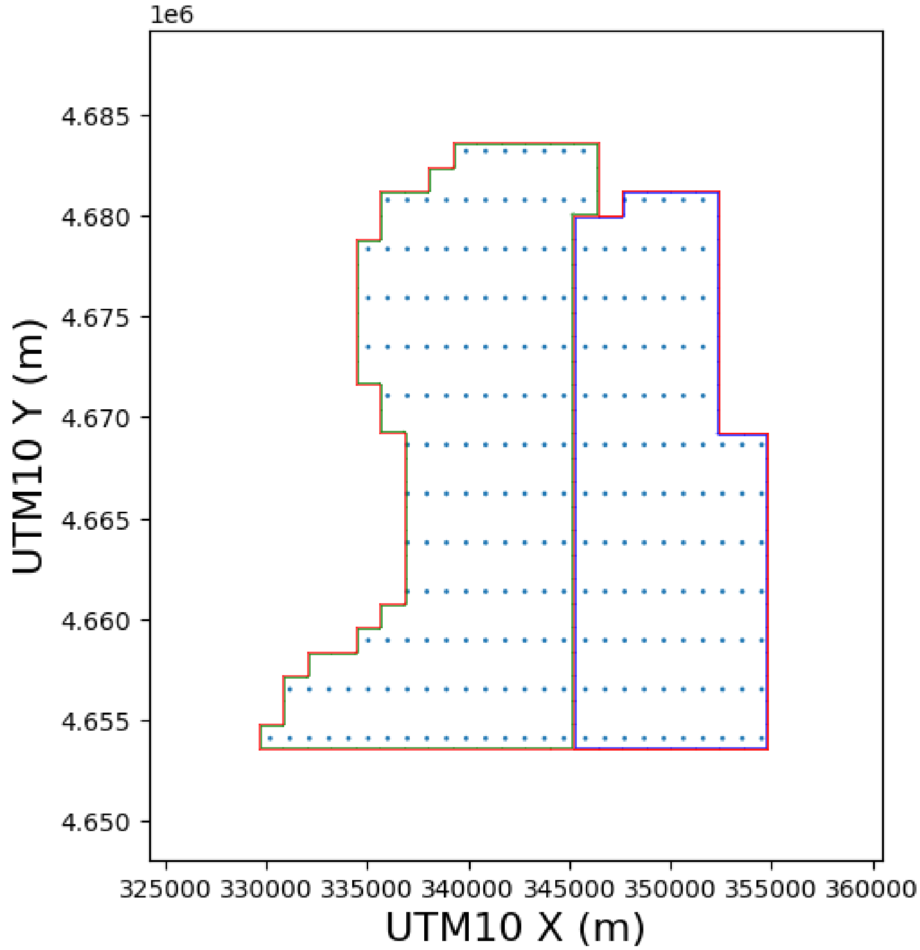

Figure B-4. Map depicting the turbine positions (blue dots) and TLP mooring technology setback (green boundary = west, blue boundary = east) for the east-west delineation (red boundary). Note that dot size = 1 rotor diameter. The UTM zone is 10 N. This configuration yields 242 turbine positions (103 in east, 139 in west) spaced 4 and 10 rotor diameters apart along the east-west and north-south directions, respectively.

B.5 North-South Delineation: Semitaut Moorings

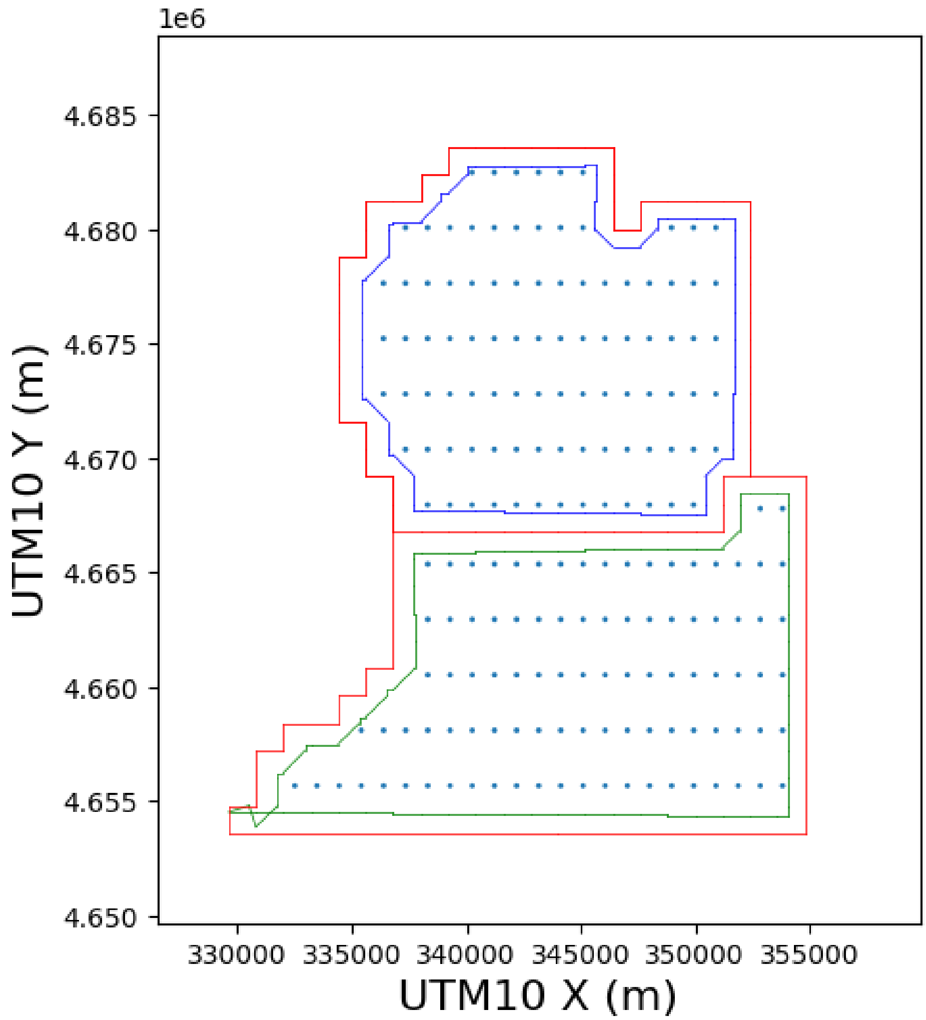

Figure B-5. Map depicting the turbine positions (blue dots) and semitaut mooring technology setback (green boundary = south, blue boundary = north) for the east-west delineation (red boundary). Note that dot size = 1 rotor diameter. The UTM zone is 10 N. This configuration yields 190 turbine positions (94 in north, 96 in south) spaced 4 and 10 rotor diameters apart along the east-west and north-south directions, respectively.

B.6 North-South Delineation: Tension-Leg Platform

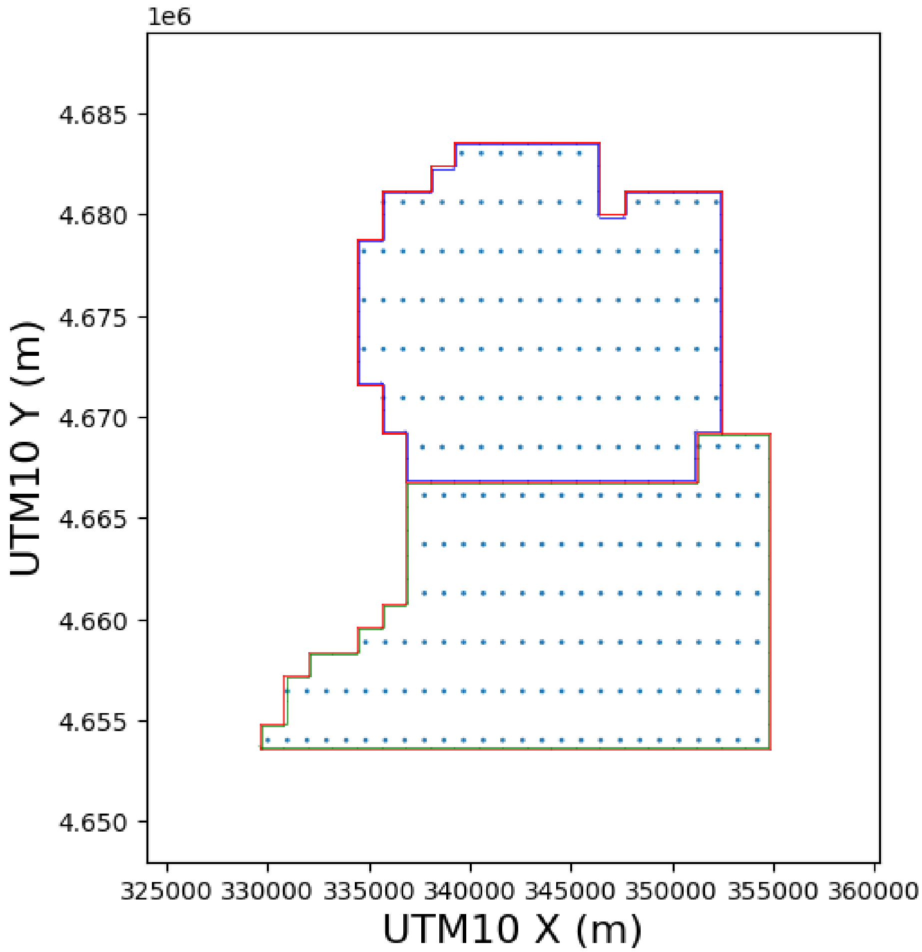

Figure B-6. Map depicting the turbine positions (blue dots) and TLP mooring technology setback (green boundary = south, blue boundary = north) for the east-west delineation (red boundary). Note that dot size = 1 rotor diameter. The UTM zone is 10 N. This configuration yields 242 turbine positions (112 in north, 130 in south) spaced 4 and 10 rotor diameters apart along the east-west and north-south directions, respectively.

Appendix C. Wake Analysis Results

This section includes detailed breakdowns of the wake analysis by wake model in a tabular format.

C.1 Wake Analysis—Cumulative-Curl Model

Table C-1 summarizes the results obtained with the cumulative-curl model.

Table C-1. Cumulative-Curl Wake Analysis Results

Area	Mooring Type	No. WTGs	Capacity (GW)	Gross AEP (TWh)	GCF (%)	AEP With Wakes (TWh)	Wake Loss (%)	Total Losses (%)	NCF (%)	Net AEP (TWh)
Full WEA	TLP	242	3.63	19.89	61.8%	17.94	9.8%	20.0%	49.5%	15.92
Full WEA	Semitaut	197	2.96	16.19	61.8%	14.67	9.4%	19.6%	49.7%	13.02
East alone	TLP	103	1.55	8.47	61.8%	7.75	8.4%	18.7%	50.2%	6.88
West alone	TLP	139	2.09	11.43	61.8%	10.44	8.6%	18.9%	50.1%	9.27
East alone	Semitaut	78	1.17	6.41	61.8%	5.91	7.8%	18.2%	50.6%	5.25
West alone	Semitaut	104	1.56	8.55	61.8%	7.88	7.8%	18.2%	50.6%	6.99
North alone	TLP	112	1.68	9.21	61.8%	8.51	7.5%	17.9%	50.7%	7.56
South alone	TLP	130	1.95	10.69	61.8%	9.92	7.2%	17.6%	50.9%	8.80
North alone	Semitaut	94	1.41	7.73	61.8%	7.16	7.3%	17.8%	50.8%	6.35
South alone	Semitaut	96	1.44	7.89	61.8%	7.38	6.4%	16.9%	51.3%	6.55
East w/west	TLP	103	1.55	8.47	61.8%	7.56	10.7%	20.7%	49.0%	6.71
West w/east	TLP	139	2.09	11.43	61.8%	10.38	9.2%	19.4%	49.8%	9.21
East w/west	Semitaut	78	1.17	6.41	61.8%	5.80	9.5%	19.7%	49.7%	5.15
West w/east	Semitaut	104	1.56	8.55	61.8%	7.84	8.2%	18.6%	50.3%	6.96
North w/south	TLP	112	1.68	9.21	61.8%	8.35	9.3%	19.5%	49.8%	7.41
South w/north	TLP	130	1.95	10.69	61.8%	9.59	10.3%	20.4%	49.2%	8.51
North w/south	Semitaut	94	1.41	7.73	61.8%	7.04	8.9%	19.1%	50.0%	6.25
South w/north	Semitaut	96	1.44	7.89	61.8%	7.14	9.5%	19.7%	49.6%	6.34

Wake Analysis—Gauss-Curl Hybrid Model

Table C-2 summarizes the results obtained with the Gauss-curl hybrid model.

Table C-2. Gauss-Curl-Hybrid Wake Analysis Results

Area	Mooring Type	No. WTGs	Capacity (GW)	Gross AEP (TWh)	GCF (%)	AEP With Wakes (TWh)	Wake Loss (%)	Total Losses (%)	NCF (%)	Net AEP (TWh)
Full WEA	TLP	242	3.63	19.89	61.8%	18.79	5.6%	16.2%	51.8%	16.67
Full WEA	Semitaut	197	2.96	16.19	61.8%	15.31	5.5%	16.1%	51.9%	13.59
East alone	TLP	103	1.55	8.47	61.8%	8.03	5.2%	15.9%	52.0%	7.12
West alone	TLP	139	2.09	11.43	61.8%	10.84	5.2%	15.8%	52.0%	9.62
East alone	Semitaut	78	1.17	6.41	61.8%	6.09	5.0%	15.7%	52.1%	5.41
West alone	Semitaut	104	1.56	8.55	61.8%	8.13	4.9%	15.6%	52.2%	7.22
North alone	TLP	112	1.68	9.21	61.8%	8.74	5.1%	15.8%	52.1%	7.76
South alone	TLP	130	1.95	10.69	61.8%	10.16	4.9%	15.6%	52.2%	9.02
North alone	Semitaut	94	1.41	7.73	61.8%	7.34	5.0%	15.7%	52.1%	6.51
South alone	Semitaut	96	1.44	7.89	61.8%	7.53	4.6%	15.3%	52.3%	6.68
East w/west	TLP	103	1.55	8.47	61.8%	7.97	5.9%	16.5%	51.6%	7.07
West w/east	TLP	139	2.09	11.43	61.8%	10.82	5.3%	16.0%	51.9%	9.60
East w/west	Semitaut	78	1.17	6.41	61.8%	6.06	5.5%	16.1%	51.9%	5.38
West w/east	Semitaut	104	1.56	8.55	61.8%	8.12	5.0%	15.7%	52.1%	7.21
North w/south	TLP	112	1.68	9.21	61.8%	8.70	5.5%	16.1%	51.8%	7.72
South w/north	TLP	130	1.95	10.69	61.8%	10.09	5.6%	16.2%	51.8%	8.95
North w/south	Semitaut	94	1.41	7.73	61.8%	7.31	5.4%	16.1%	51.9%	6.49
South w/north	Semitaut	96	1.44	7.89	61.8%	7.47	5.4%	16.0%	51.9%	6.63

C.2 Wake Analysis—TurbOPark Model

Table C-3 summarizes the results obtained with the TurbOPark model.

Table C-3. TurbOPark Wake Analysis Results

Area	Mooring Type	No. WTGs	Capacity (GW)	Gross AEP (TWh)	GCF (%)	AEP With Wakes (TWh)	Wake Loss (%)	Total Losses (%)	NCF (%)	Net AEP (TWh)
Full WEA	TLP	242	3.63	19.89	61.8%	17.27	13.2%	23.0%	47.6%	15.33
Full WEA	Semitaut	197	2.96	16.19	61.8%	14.17	12.5%	22.4%	48.0%	12.57
East alone	TLP	103	1.55	8.47	61.8%	7.51	11.3%	21.3%	48.7%	6.67
West alone	TLP	139	2.09	11.43	61.8%	10.10	11.6%	21.6%	48.5%	8.96
East alone	Semitaut	78	1.17	6.41	61.8%	5.74	10.4%	20.5%	49.2%	5.10
West alone	Semitaut	104	1.56	8.55	61.8%	7.65	10.6%	20.6%	49.1%	6.79
North alone	TLP	112	1.68	9.21	61.8%	8.34	9.4%	19.6%	49.7%	7.40
South alone	TLP	130	1.95	10.69	61.8%	9.73	8.9%	19.2%	50.0%	8.64
North alone	Semitaut	94	1.41	7.73	61.8%	7.02	9.2%	19.4%	49.8%	6.23
South alone	Semitaut	96	1.44	7.89	61.8%	7.28	7.8%	18.1%	50.6%	6.46
East w/west	TLP	103	1.55	8.47	61.8%	7.26	14.2%	23.9%	47.0%	6.44
West w/east	TLP	139	2.09	11.43	61.8%	10.01	12.4%	22.2%	48.1%	8.89
East w/west	Semitaut	78	1.17	6.41	61.8%	5.59	12.9%	22.7%	47.8%	4.96
West w/east	Semitaut	104	1.56	8.55	61.8%	7.59	11.2%	21.2%	48.7%	6.74
North w/south	TLP	112	1.68	9.21	61.8%	8.10	12.0%	21.9%	48.3%	7.19
South w/north	TLP	130	1.95	10.69	61.8%	9.22	13.8%	23.5%	47.3%	8.18
North w/south	Semitaut	94	1.41	7.73	61.8%	6.83	11.6%	21.6%	48.5%	6.06
South w/north	Semitaut	96	1.44	7.89	61.8%	6.86	13.0%	22.8%	47.7%	6.09