Assessment of Offshore Wind Leasing Areas in California

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Contents

1 Objectives, Scope, and Process

2 Findings from Literature and Interviews

3 Mooring System Analysis

4 Lease Area Delineation Options

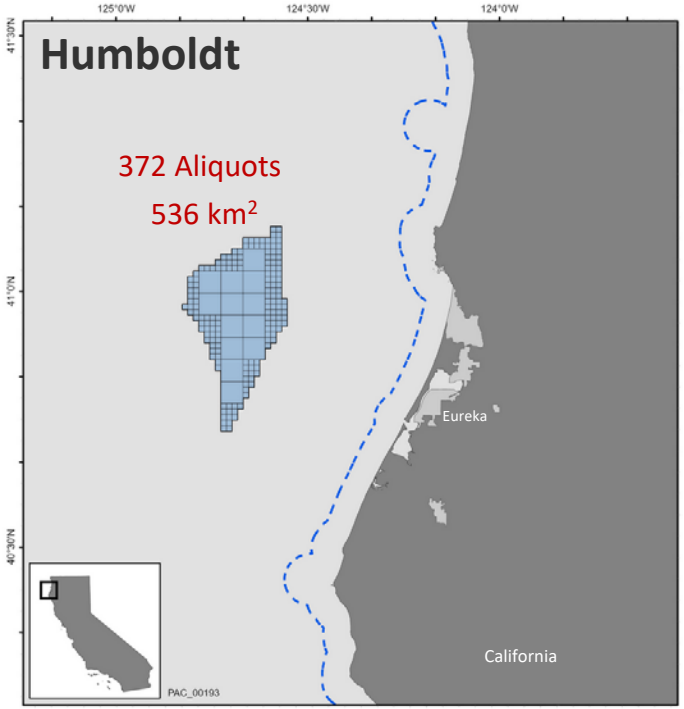
5 Assessment of Generation Potential

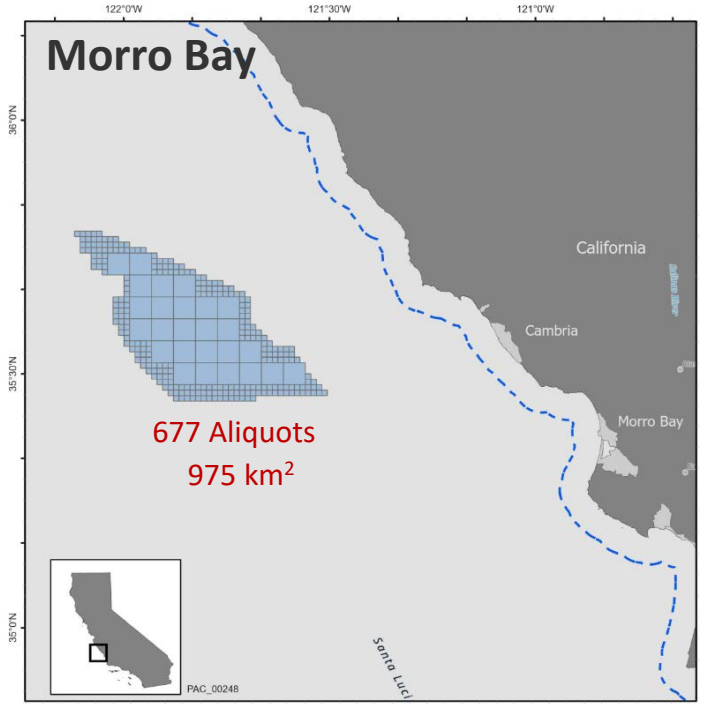
6 Conclusions

Objectives and Scope

- Develop options for delineation of lease areas for offshore wind in Humboldt and Morro Bay Wind Energy Areas (WEAs)
- Lease areas within each WEA should be of approximately **equal value** and capable of supporting at least **1 GW** of energy generating capacity
- Assessment focuses on physical site characteristics and their effects on technology selection and energy generating potential
  - Interaction with the environment and competing uses are not in the scope of this analysis.

California Wind Energy Areas





WEAs are defined in terms of BOEM **aliquots** on the outer continental shelf. Each aliquot is 1.2 km × 1.2 km. 16 aliquots make up a lease block.

Delineation Process

1. Review nominations submitted by wind energy developers in response to California Calls for Information and Nominations (BOEM 2018, 2021)
2. Interview developers who submitted nominations to elicit more information regarding technology selection
3. Review literature and public data repositories
4. Model mooring technologies for floating wind energy systems to estimate required footprint
5. Develop options for dividing each WEA into lease areas
6. Assess generation potential of each lease area using simplified layout assumptions.

Site Characteristics

Findings from nominations, developer interviews, published literature, and public data sets

Key Findings from Nominations and Interviews

- Grid interconnection
  - Lack of transmission capacity is the key barrier to offshore wind development in the Humboldt WEA
  - Potential points of access to high-voltage transmission were identified near Morro Bay WEA
- Platform technology
  - Developers are still analyzing suitability of competing floating designs
  - Spar not suited to California ports; semisubmersible or tension-leg platform (TLP) are feasible
- Turbine size and layout
  - Largest wind turbines commercially available, probably 12–15 MW
  - Layout choices will need to account for wake effects and mooring system footprints
- Port infrastructure
  - Developers will need to identify port facilities with sufficient lead time to implement upgrades or expansions required to support offshore wind
  - Port of Humboldt Bay is well located to support offshore wind in the Humboldt WEA—port facilities and supply chain will need to be developed
  - Port selection for wind energy projects in the Morro Bay WEA could include Hueneme, Long Beach, Los Angeles, or a new location
- Developers' initial assessment of geohazards did not identify any significant barriers to offshore wind.

Example substructure types: (left to right) spar, semisubmersible, tension-leg platform (TLP).

Analysis of Physical Characteristics

Each aliquot was characterized based on the following attributes

Attribute	Range	Description	Source
Wind speed	9.0 – 10.9 m/s	Modeled 20-year mean wind speed at a height of 100 m	Optis et al. 2020*
Exposure to prevailing wind	0 – 30	Distance (number of aliquots) from the front row in the prevailing wind direction	Calculated using wind rose from Optis et al. 2020
Depth	550 – 1,300 m	Mean water depth	National Geophysical Data Center (NGDC) 2003a, 2003b
Seabed gradient	0° – 9°	Mean seabed slope	Calculated from NGDC 2003a, 2003b
Distance to port, point of interconnection (POI)	35 – 355 km	Distance to closest potential ports and points of interconnection	Locations used for this calculation were Eureka (for Humboldt WEA), Port Hueneme and Morro Bay (for Morro Bay WEA)
Hard rock	None / some / predominant	Presence of hard, rocky substrate in the available seafloor data	Cochrane et al. 2022, Goldfinger et al. 2014
Cable	No / yes	Presence of a planned subsea telecommunications cable route	Alcatel Submarine Networks 2021

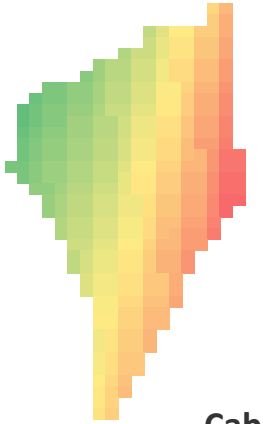
*After this data set was generated, floating lidars were deployed within the Morro Bay and Humboldt WEAs. Comparison of the lidar data with modeled results for the same time period has identified a positive bias in the modeled results. NREL is continuing to investigate the differences between the measured and modeled values.

Physical Characteristics—Humboldt

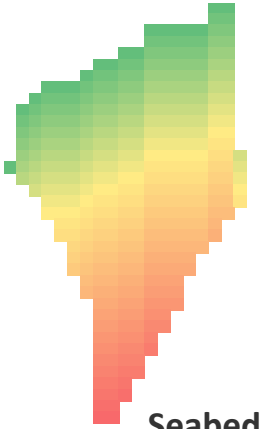
More favorable

Less favorable

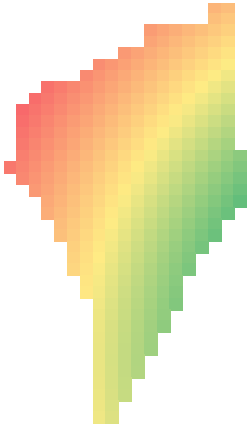
Wind speed



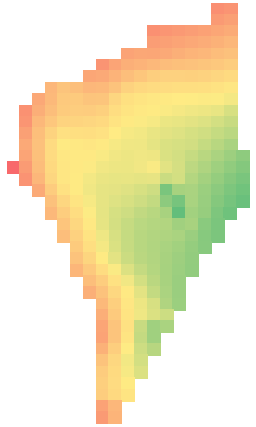
Exposure to prevailing wind



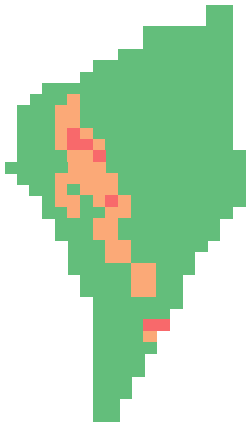
Port/POI distance



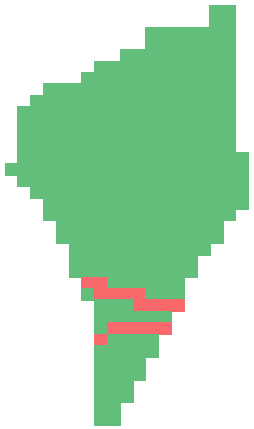
Water depth



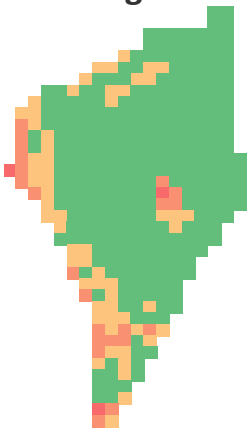
Hard rock

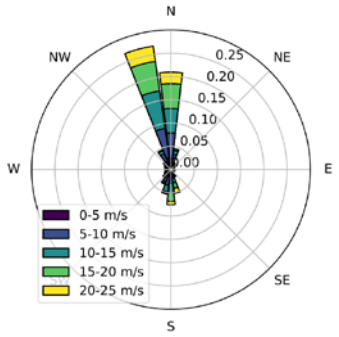


Cable



Seabed gradient





Wind rose at 150 m

*Color scales extend from minimum to maximum for each attribute within each WEA and are not comparable between Humboldt and Morro Bay or between attributes.

Physical Characteristics—Morro Bay

More favorable

Less favorable

Wind speed

Exposure to prevailing wind

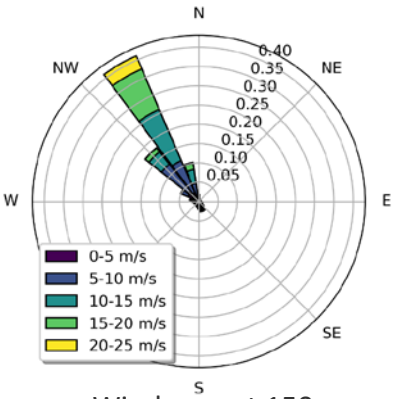
Port distance

POI distance

Water depth

Seabed gradient

Cable



Wind rose at 150 m

*Color scales extend from minimum to maximum for each attribute within each WEA and are not comparable between Humboldt and Morro Bay or between attributes.

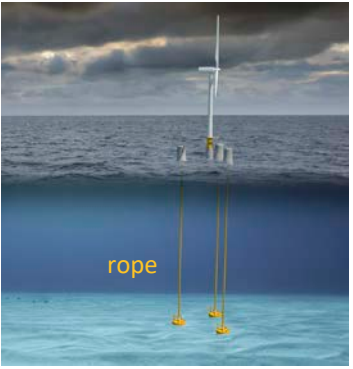
Mooring System Analysis

Mooring Configurations

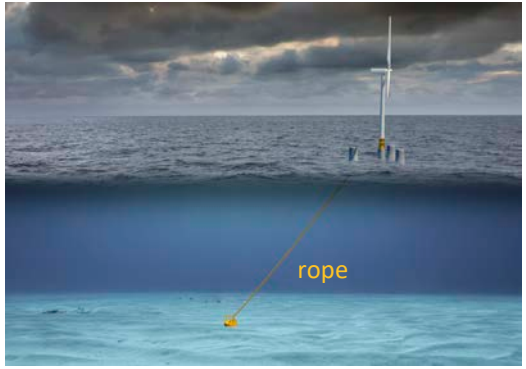
- Floating wind turbines are connected to the seabed via mooring lines and anchors
- Anchors must be placed within the boundaries of the seabed lease, which limits where turbines can be located
- Our analysis considers space requirements for four different mooring configurations: TLP, taut, semi-taut, and catenary moorings.

Increasing Anchor Footprint

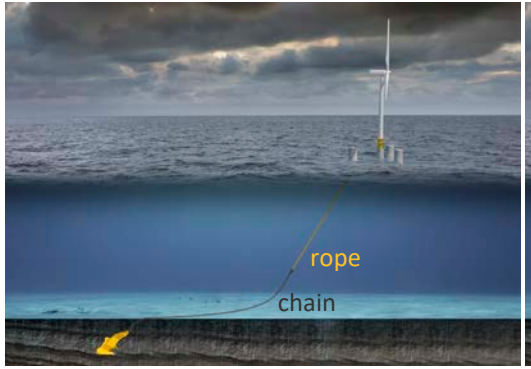
TLP



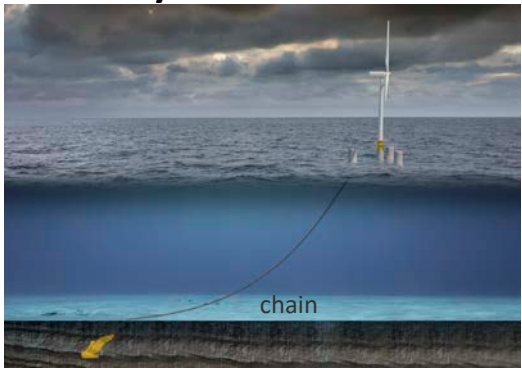
Taut



Semi-taut

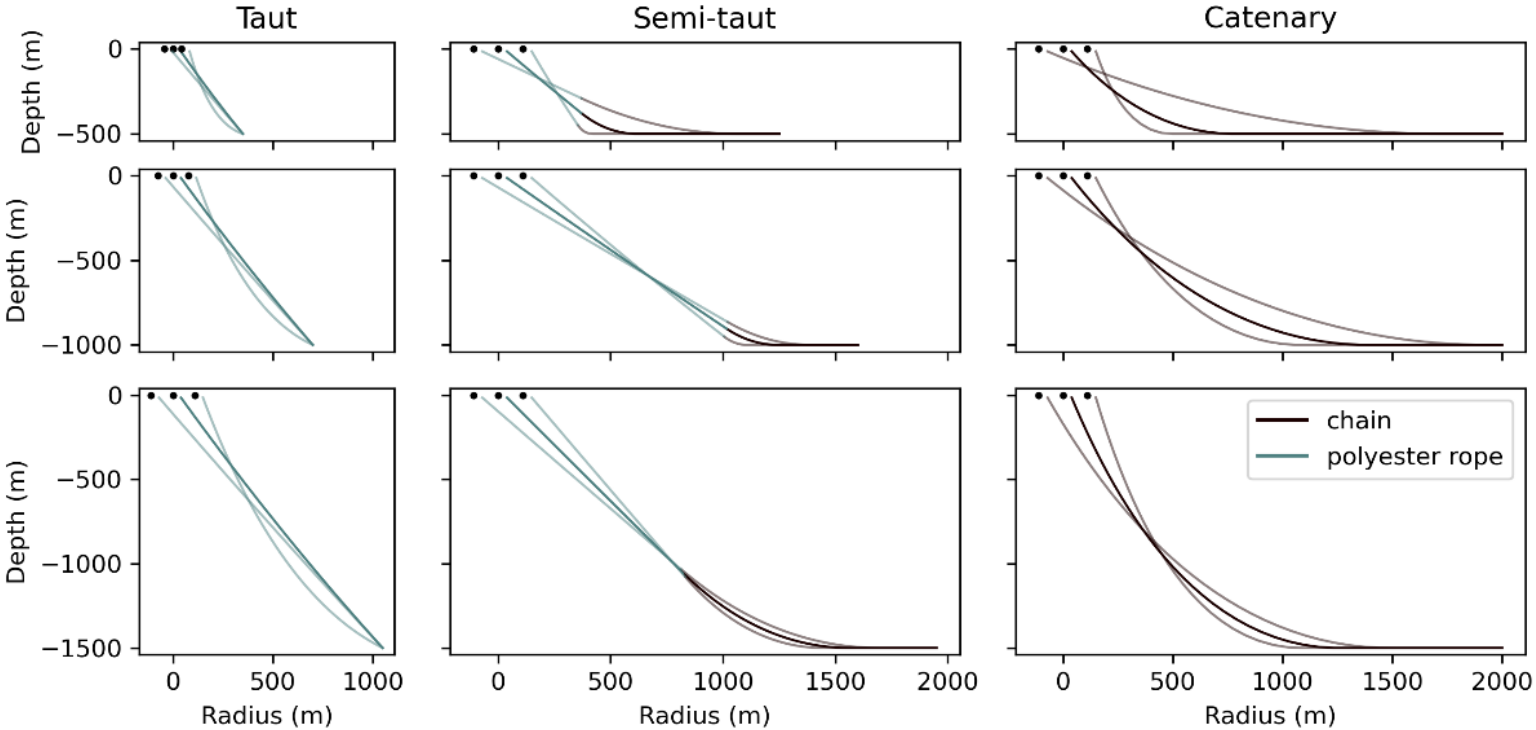


Catenary



Mooring Footprint

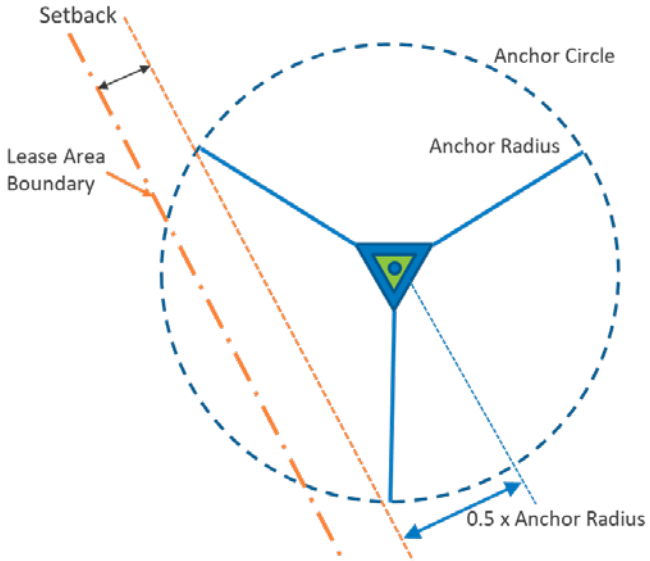
- Different mooring configurations modeled with MoorPy (Hall et al. 2021)
- In the plots below, darker lines indicate the undisplaced mooring line profiles and lighter lines indicate extreme displaced states
- Horizontal extent of mooring system varies with water depth (except for vertical moorings used for TLPs).



Lease Area Boundary Distances

- Mooring system footprints impose significant limits on potential nameplate capacity within lease areas, depending on the mooring configuration
- Based on analysis using MoorPy, this study assumes these minimum distances between a wind turbine and the lease area boundary

Mooring Type	Minimum Turbine-to-Boundary Distance*
TLP	100 m
Taut (55° incline)	0.35 × water depth
Semi-taut	0.35 × water depth + 500 m
Catenary	1,100 m



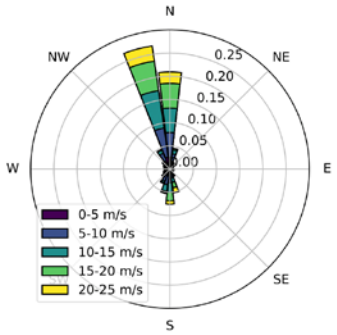
Lease Area Set-Back Assumptions for Three Moorings in Most Favorable Orientation

* Representative distances based on assumptions used for this study; distances may be larger or smaller for future installed systems depending on design specifications.

Options for
Lease Area Delineation

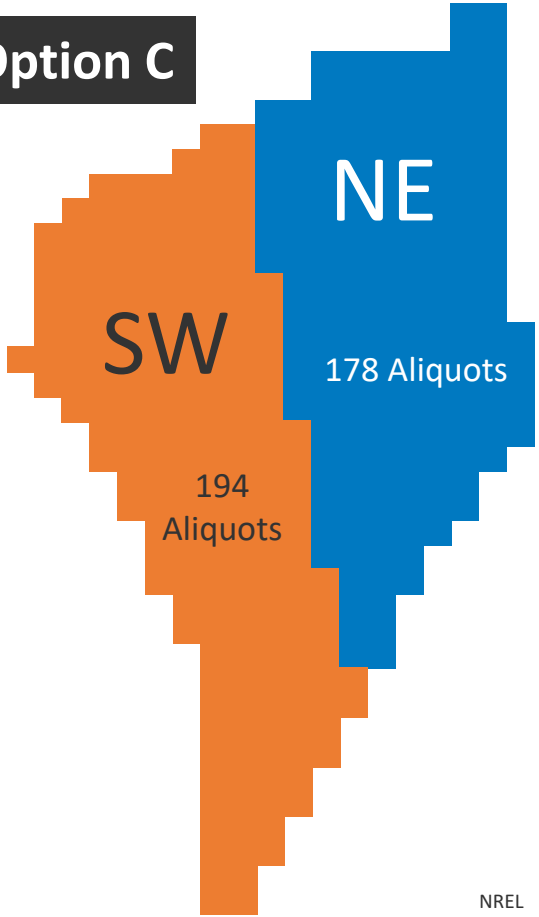
Humboldt Delineation Options

Option B



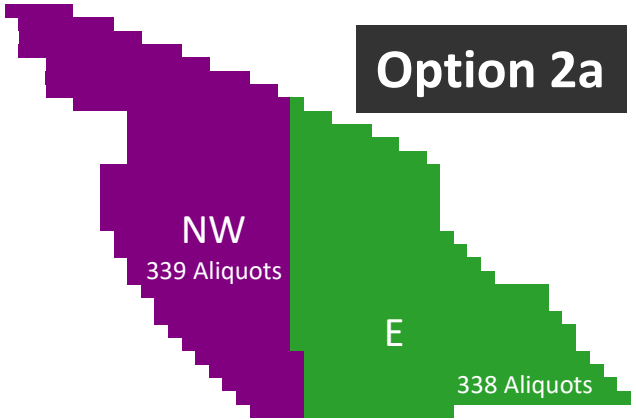
prevailing
wind direction

Option C

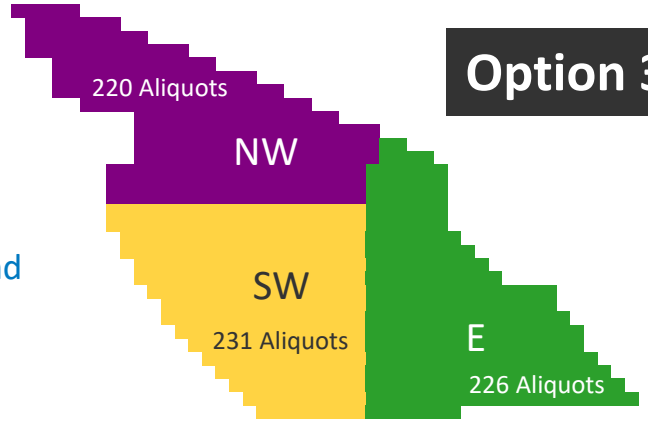


Morro Bay Delineation Options

Option 2a

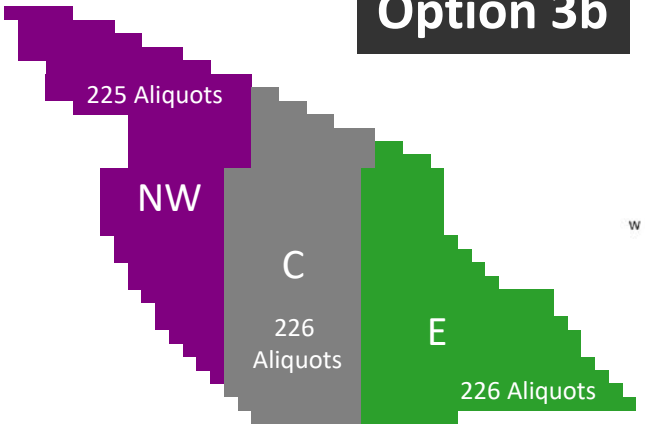


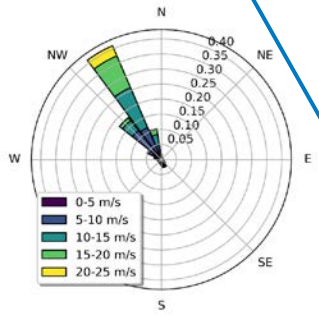
Option 3a



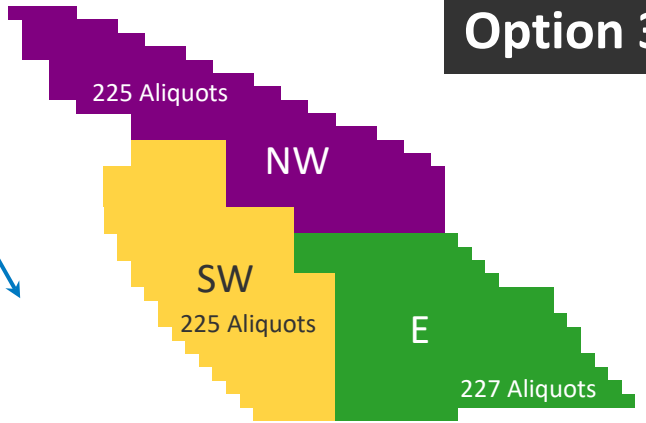
prevailing wind direction

Option 3b





Option 3c



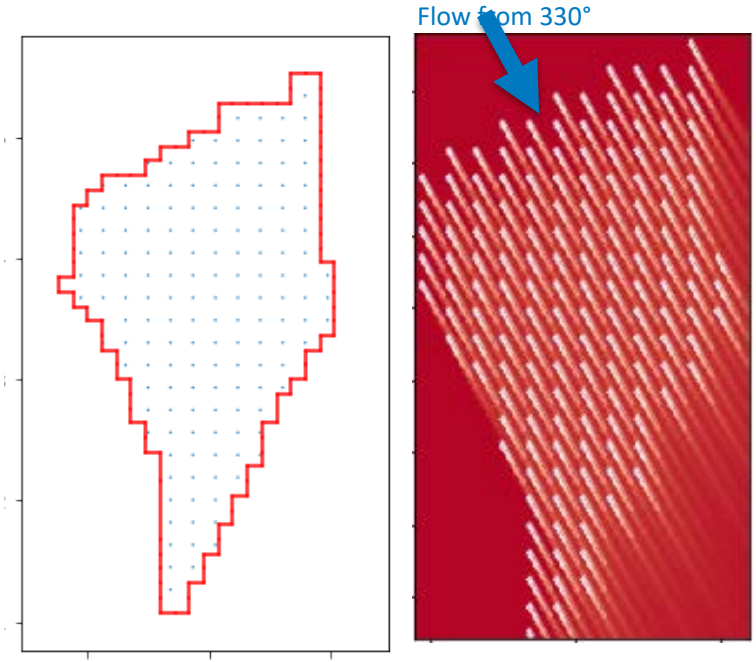
Assessment of Generation Potential

Electricity Generation Potential

- The amount of energy generated by a wind power plant depends on the wind resource and on plant layout choices, including the size, number, and location of turbines
- Array density (turbine spacing) has a large impact on lease area generating capacity
- Analysis used two turbine spacings with 15-MW, 240-m rotor diameter (D) reference turbines:
  - 1 nautical mile × 1 nautical mile (array density 4.4 MW/km^2)
  - 4D × 10D (array density 6.5 MW/km^2)
- Wake loss analysis illustrates how lease areas in each delineation option may be affected by neighboring wind plants.

Methodology

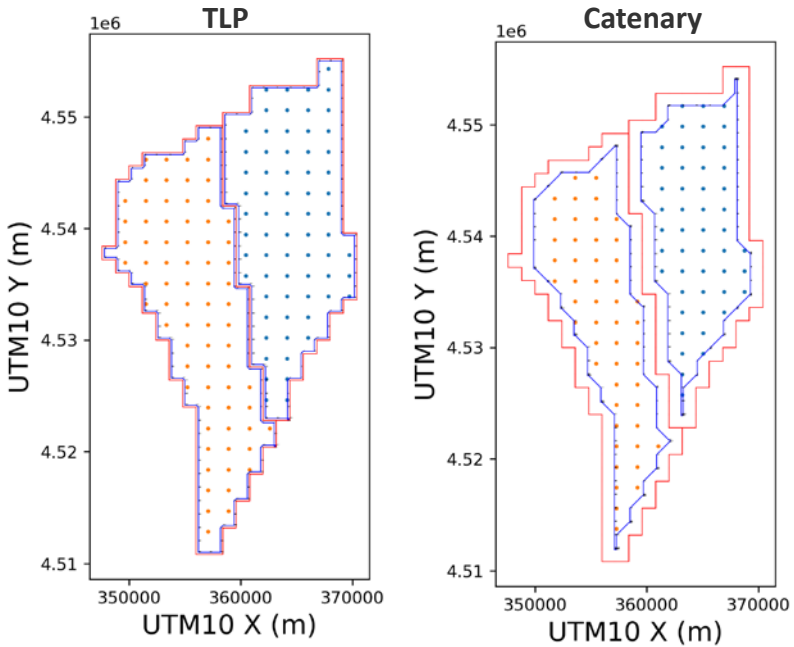
Visualizing Wakes for Humboldt



- Annual energy production calculated with FLORIS, NREL's steady-state wake modeling toolbox
- IEA Wind 15-MW reference turbine (Gaertner et al. 2020)
- Two turbine spacings:
  - Uniform 1 nautical mile × 1 nautical mile
  - 4D × 10D (rotor diameter D = 240 m)
- Utilized wind resource from centroid of each WEA (Optis et al. CA20 data set)
- TurbOPark wake model describes wake recovery over longer distances (Nygaard et al. 2020).

Example Layouts and Nameplate Capacities

Humboldt—1 NM x 1 NM Option C

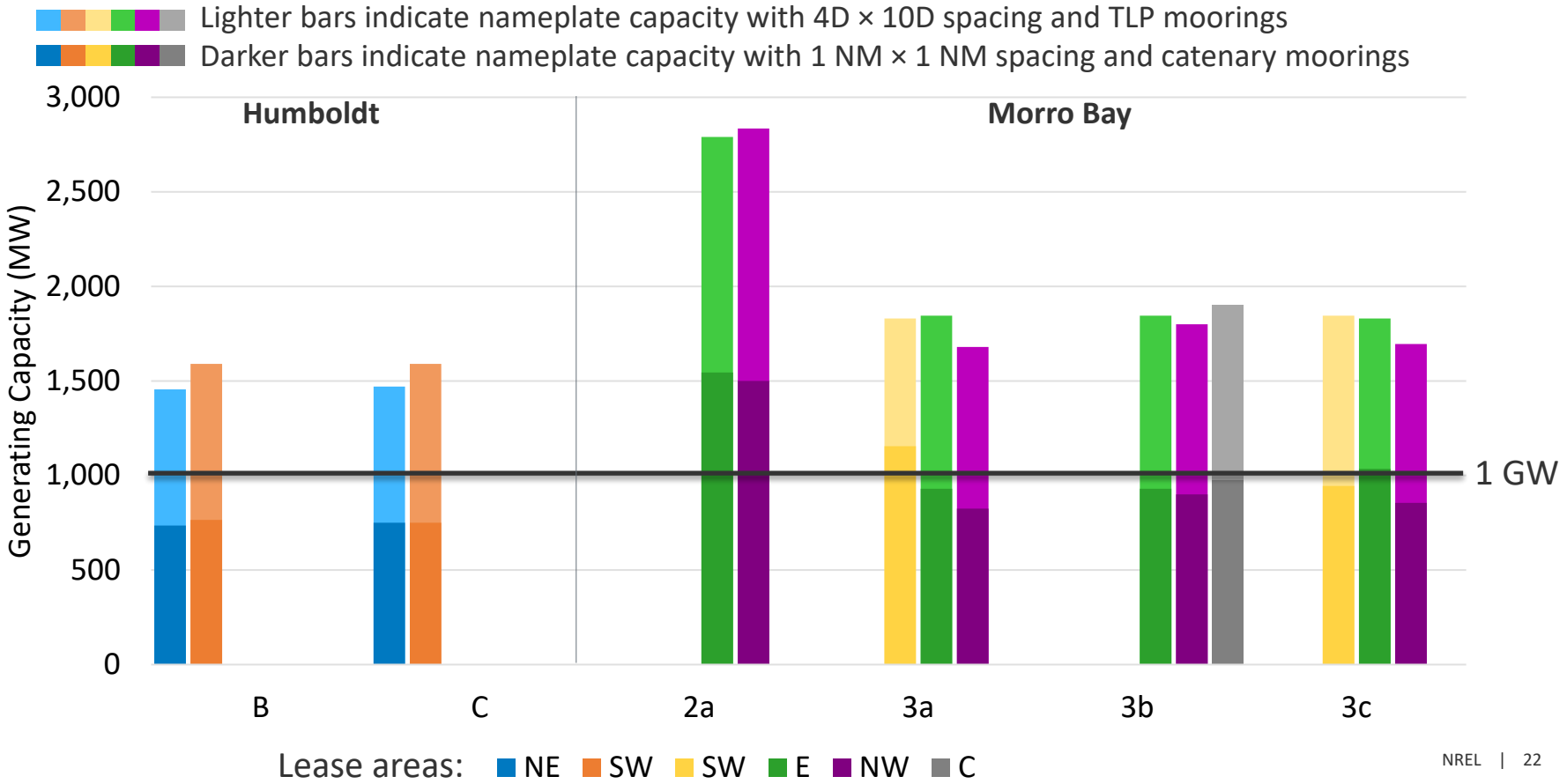


Nameplate Capacities of Example Layouts

	Humboldt Option C	Morro Bay Option 3b
4D × 10D TLP	3,060 MW	5,550 MW
5.5 MW/km^2	2,948 MW	5,363 MW
4D × 10D Catenary	2,190 MW	4,290 MW
1 NM × 1 NM TLP	2,130 MW	3,855 MW
3 MW/km^2	1,608 MW	2,925 MW
1 NM × 1 NM Catenary	1,500 MW	2,805 MW

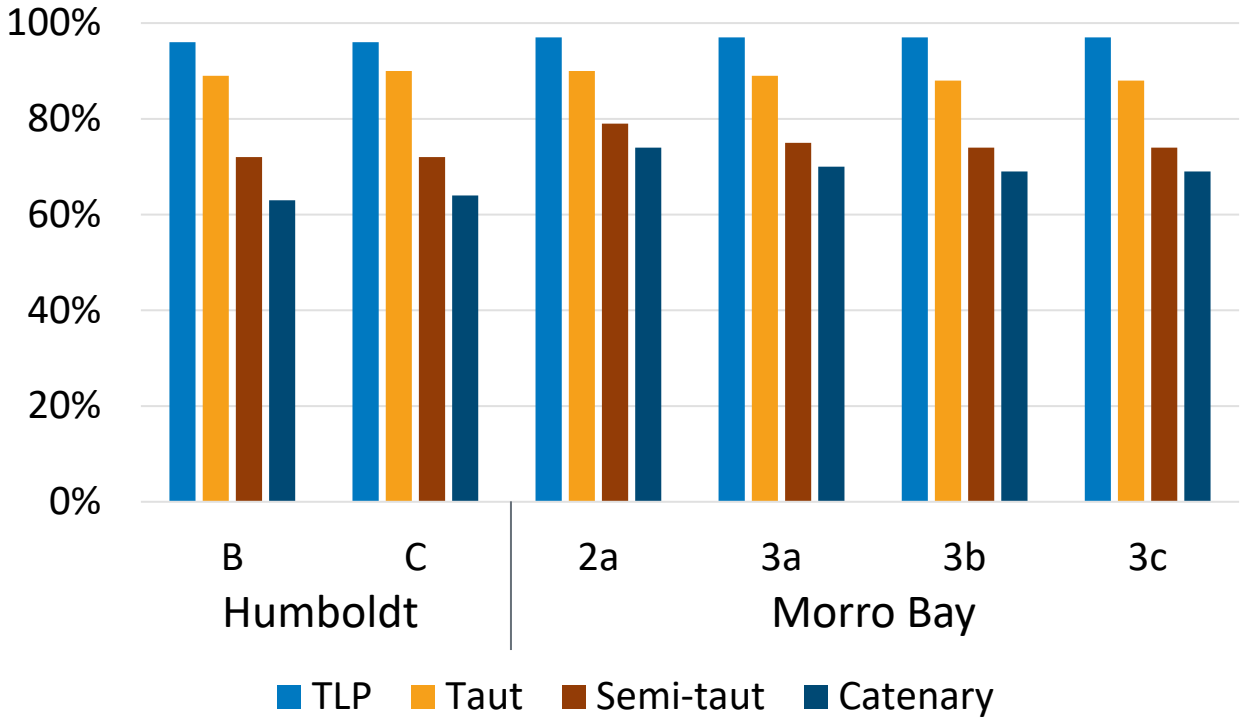
Capacity densities:
3 MW/km^2 has been used to estimate resource potential over large regions
5.5 MW/km^2 is a typical density observed within European offshore wind plants (Deutsche WindGuard, 2018).

Lease Area Nameplate Capacity



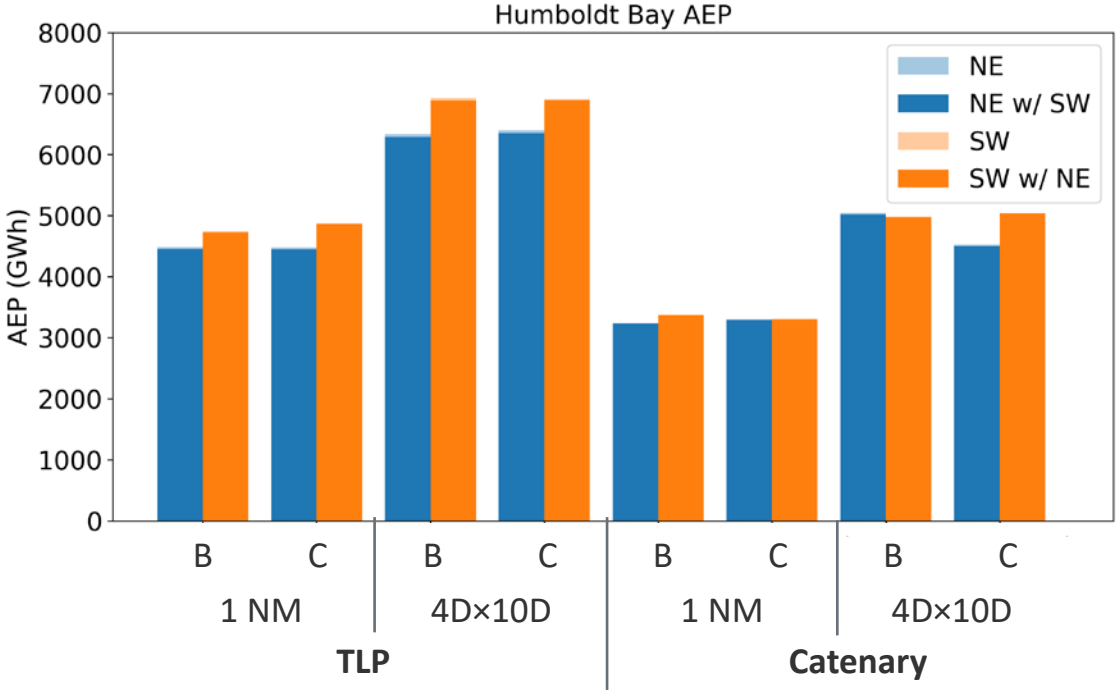
Impact of Mooring Type on Lease Area Capacity

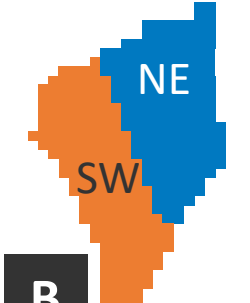
Percentage of total Wind Energy Area available for wind turbine placement within lease areas under different mooring technology setback assumptions for delineation options in Humboldt and Morro Bay.

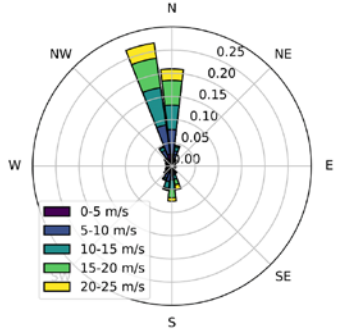


Humboldt Annual Energy Production (AEP)

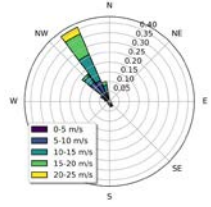
Southwest lease areas are slightly larger than northeast areas and give higher AEP for most layout and technology combinations. In Humboldt, the neighboring wind project has such a small effect on AEP that the increases in AEP for a solitary project are not visible in the graph (e.g., difference between NE and NE w/SW is <1%).

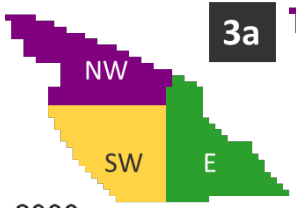


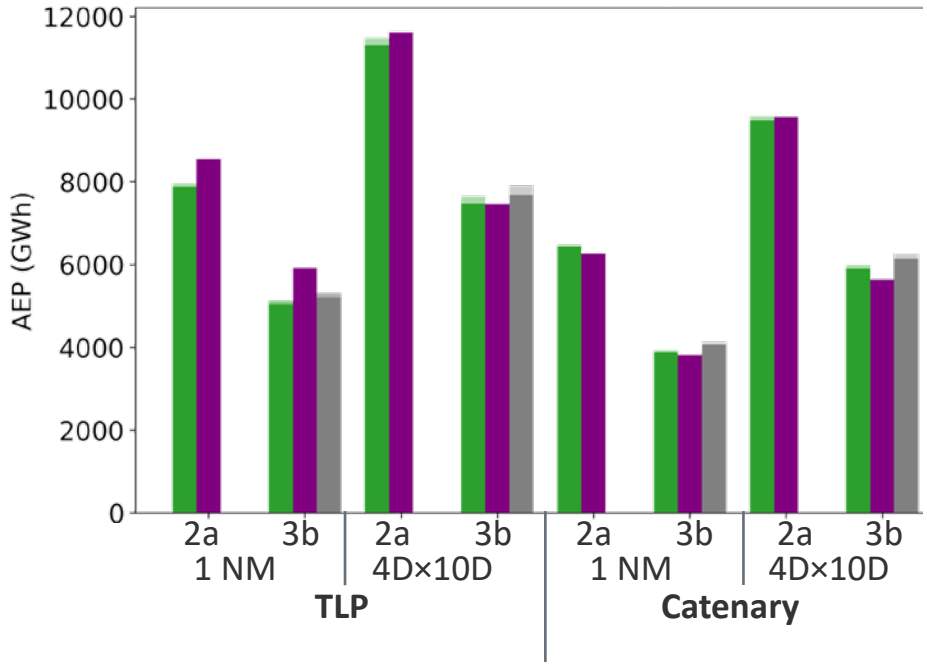


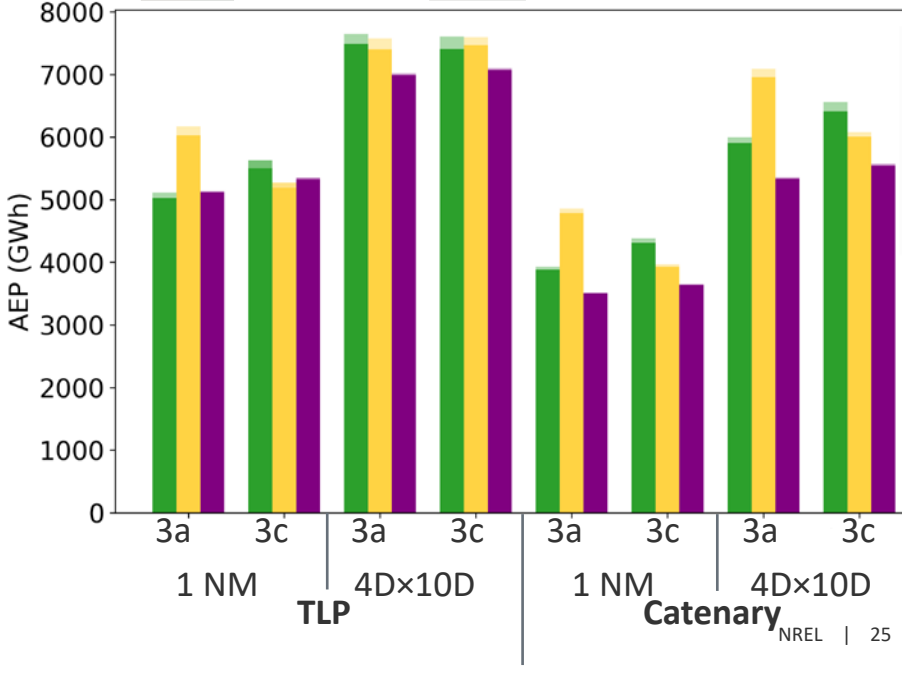


Morro Bay AEP



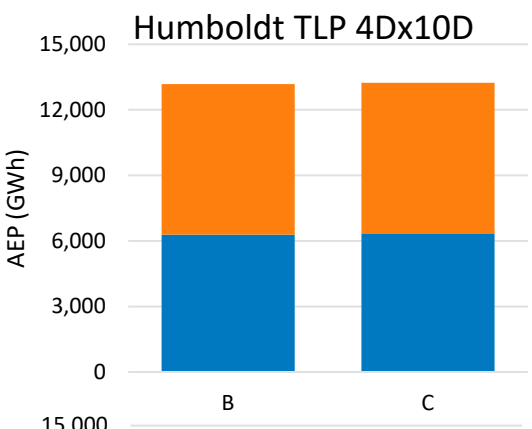


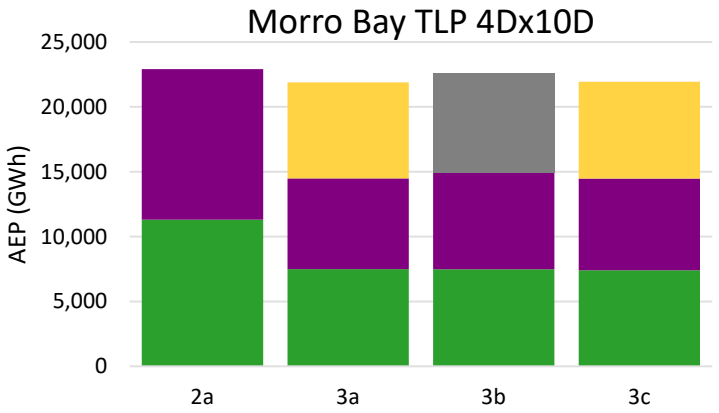


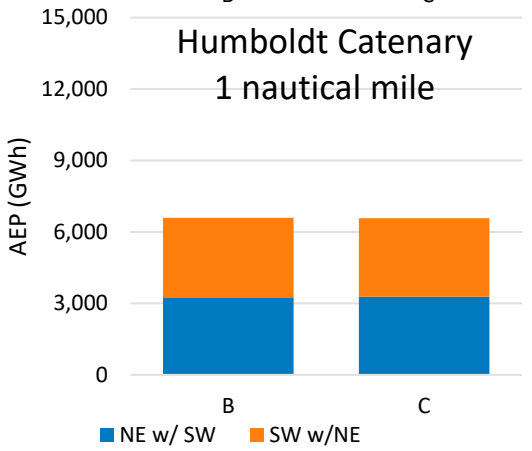


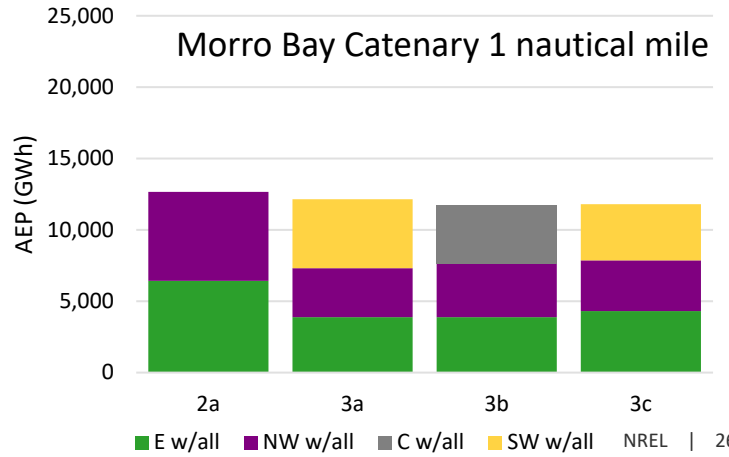
Full WEA AEPs

Comparison of the upper and lower bounds of the modeled AEP shows minimal differences between the delineation options.









Upper bound = TLP 4D×10D

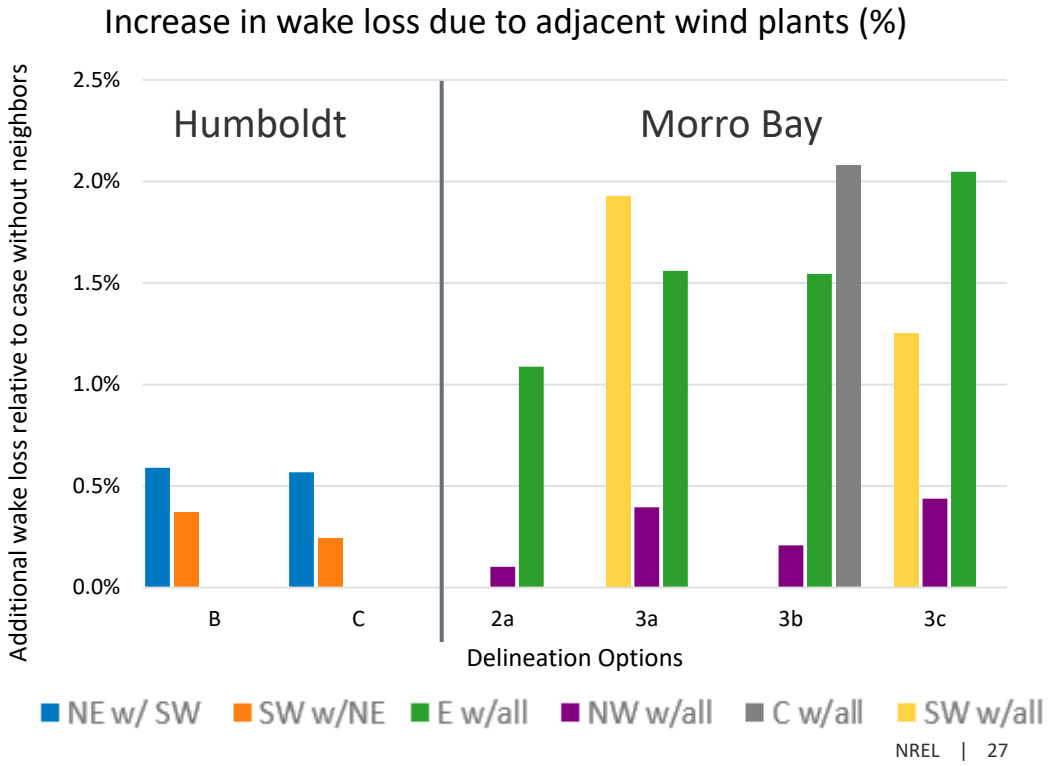
Lower bound = Catenary 1 NM

Inter-Array Wake Loss

- Wake losses are higher for TLP cases because there are more turbines within each area
- Considering all mooring and layout options, northwest areas are least impacted by neighbors.

Wake loss (%) by mooring technology and plant layout

	Humboldt	Morro Bay
TLP 4D × 10D	6.9	8.7
Catenary 4D × 10D	6.4	8.3
TLP 1 nm × 1 nm	6.0	6.8
Catenary 1 nm × 1 nm	5.5	6.1



Conclusions

Summary

- For all delineation options, each lease area has a generating potential of **approximately 1 GW**, depending on turbine layout and mooring footprint
- Delineation strategy was to balance advantages from site characteristics, wind direction, and access to infrastructure to create lease areas of **equal value**
- Lease area generating capacity estimates are highly sensitive to the **choice of mooring technology**
- **Inter-array wake effects** were a key parameter considered in the delineation of the California WEAs
- **Geohazards** were identified within the WEA boundaries, but most developers indicated these could be mitigated
- Access to **transmission and ports** is essential and will impact the value of the lease areas.

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