Impacts of Siting Considerations on Offshore Wind Technical Potential in the United States

Gabriel R. Zuckerman, Anthony Lopez, Travis Williams, Rebecca Green, and Grant Buster

National Renewable Energy Laboratory

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List of Acronyms

AEP	Annual Energy Production
ATB	Annual Technology Baseline
BOEM	Bureau of Ocean Energy Management
CONUS	Contiguous United States
COD	Commercial Operating Date
GW	gigawatt
km	kilometer
m	meter
m/s	Meters per Second
MW	Megawatt
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
OSW	Offshore Wind
reV	Renewable Energy Potential Model
R&D	research and development
SAM	System Advisor Model
TWh	terawatt-hour
W	Watt
WEA	Wind Energy Area
WTK	Wind Integration National Dataset Toolkit

Executive Summary

We estimated the technical potential for the offshore wind (OSW) resource in the United States under two siting regimes to characterize the uncertainty pertaining to the local drivers of siting within a national context. We established Open Access and Limited Access regimes to represent upper and lower bounds on OSW deployment, respectively. These included spatial constraints such as technology depth limits, military use areas, protected areas, existing infrastructure, shipping lanes and more. The same spatial considerations are also considered in the Limited Access regime, but with additional buffers to existing infrastructure as well as a reduced capacity density assumption. Capacity density is the concentration of wind energy development for a given area specified in terms of megawatts (MW) per square kilometer (km^2). In the Open-Access regime we used a 5 MW/km^2 assumption, while in the Limited Access scenario we assumed 3 MW/km^2. This difference reflects our intention for the Open-Access scenario to serve as an upper bound for OSW technical potential, with the Limited-Access scenario as a lower bound. We also applied three technology advancement scenarios to each of the siting regimes. The three technology scenarios (Conservative, Moderate, and Advanced) represent plausible improvements in turbine technology including increased rated power and higher hub heights.

We used the Renewable Energy Potential Model (reV; Maclaurin et al. 2019) to estimate annual energy production (AEP) for the three technology scenarios using the Wind Integration National Dataset Toolkit (see Figure ES-1). We also used reV to apply the two siting regimes to each of the three technology scenarios, resulting in six technical potential estimates (see Table ES-1). The capacity estimates are the same for all the scenarios within the Open- and Limited Access regimes, regardless of turbine technology. The capacity density assumption accounts for the upsizing of turbines, by reducing the numbers of turbines in a given area. However, capacity factors increase as the turbine technology scenarios advanced, resulting in higher AEP (see Table ES-1).

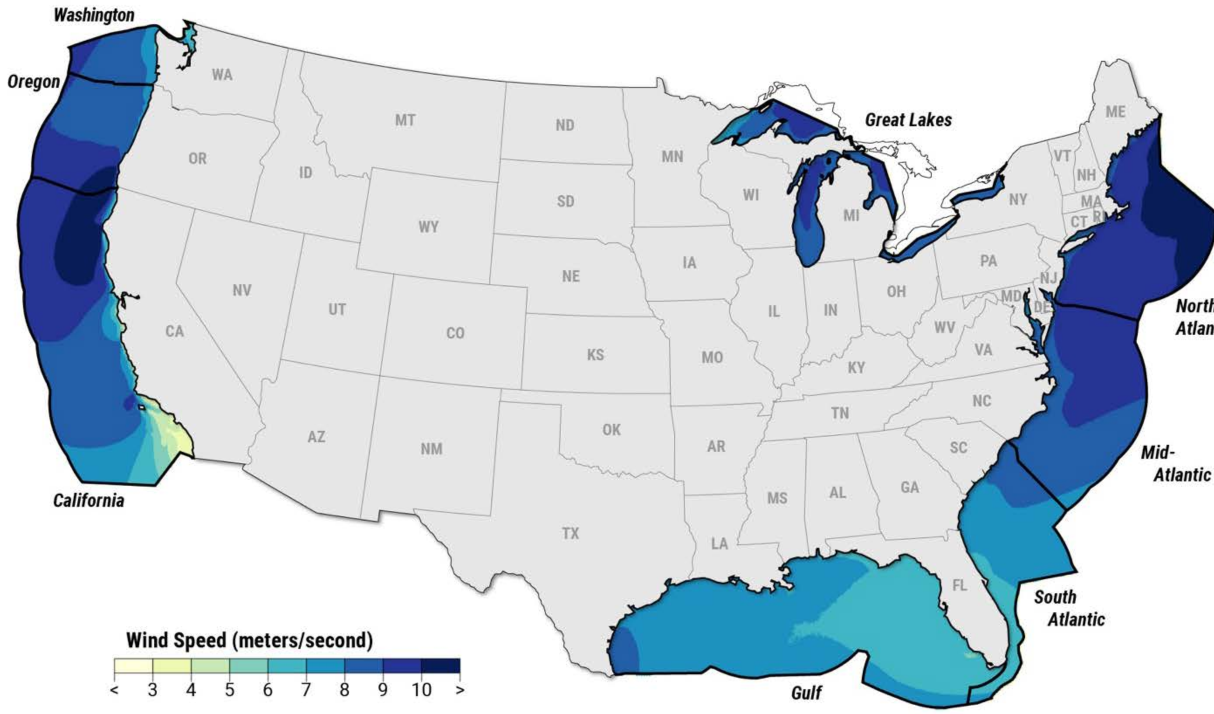

Figure ES-1. Mean windspeed from 2007 to 2013 at 150 m

Source: Wind Integration National Dataset Toolkit

At a national level, we found the contiguous United States (CONUS) has 3,615 GW of OSW technical potential under the Open Access regime, amounting to 11,245 TWh of AEP (see Table ES-1). The resource area for fixed-bottom technology takes up 279,229 km^2 of area, making up 1,396 GW of capacity and 4,301 TWh of AEP. The resource area for floating technology would occupy 443,783 km^2, accounting for 2,319 GW of capacity and 6,944 TWh of AEP. In the Limited Access siting regime, the CONUS OSW drops to 1,665 GW of capacity (46% of the Open Access regime) and 5,164 TWh of AEP (46% of the Open Access regime). Though Alaska and Hawaii are not modeled in this study, including them in the Open Access siting regime, would see the U.S. OSW technical potential rise to 6,657 GW and AEP to 23,562 TWh.

Table ES-1. Technical Potential Estimates for the CONUS

Results are shown for the two siting regimes for each turbine scenario partitioned by fixed and floating turbine technology.

Siting Regime	Turbine Scenario	Turbine Technology	Area (km^2)	Mean Wind Speed (m/s)	Net Capacity Factor (mean)	Capacity (GW)	AEP (TWh)
Open	Conservative	Fixed	279,229	7.87	0.35	1,396	4,301
		Floating	443,783	7.98	0.36	2,219	6,944
Limited	Conservative	Fixed	177,917	7.85	0.35	534	1,626
		Floating	376,862	8.01	0.36	1,131	3,538
Open	Moderate	Fixed	279,229	7.93	0.36	1,396	4,349

Siting Regime	Turbine Scenario	Turbine Technology	Area (km^2)	Mean Wind Speed (m/s)	Net Capacity Factor (mean)	Capacity (GW)	AEP (TWh)
		Floating	443,783	8.03	0.36	2,219	6,997
Limited	Moderate	Fixed	177,917	7.91	0.35	534	1,643
		Floating	376,862	8.06	0.36	1,131	3,565
Open	Advanced	Fixed	279,229	7.98	0.36	1,396	4,377
		Floating	443,783	8.06	0.36	2,219	7,021
Limited	Advanced	Fixed	177,917	7.95	0.36	534	1,652
		Floating	376,862	8.09	0.36	1,131	3,577

[a] Great Lakes Floating is not reported because at the time of the analysis, the most current guidance indicated Floating technology was not feasible in the region due to surface ice issues (Musial et al. 2016). More recent work indicates that floating technology in region is feasible, and therefore should be reflected in future work (Musial et al. 2023).

The 1,300-m depth cutoff reduced the available area by over 50% within CONUS waters in both siting regimes. In the Open Access regime, the depth cutoff accounted for over 70% of the area impacted by siting constraints. Military use areas were the second-largest siting constraint, accounting for over 20% of conflicted area. State waters accounted for 8%, and conservation areas an additional 5%. Given the spatial overlap between siting constraints, the percentage of water area impacted by siting constraints sums to more than 100%. We also found that were the 1,300 m depth limit removed due to technology improvements, significant additional capacity could become available (see Figure ES-2).

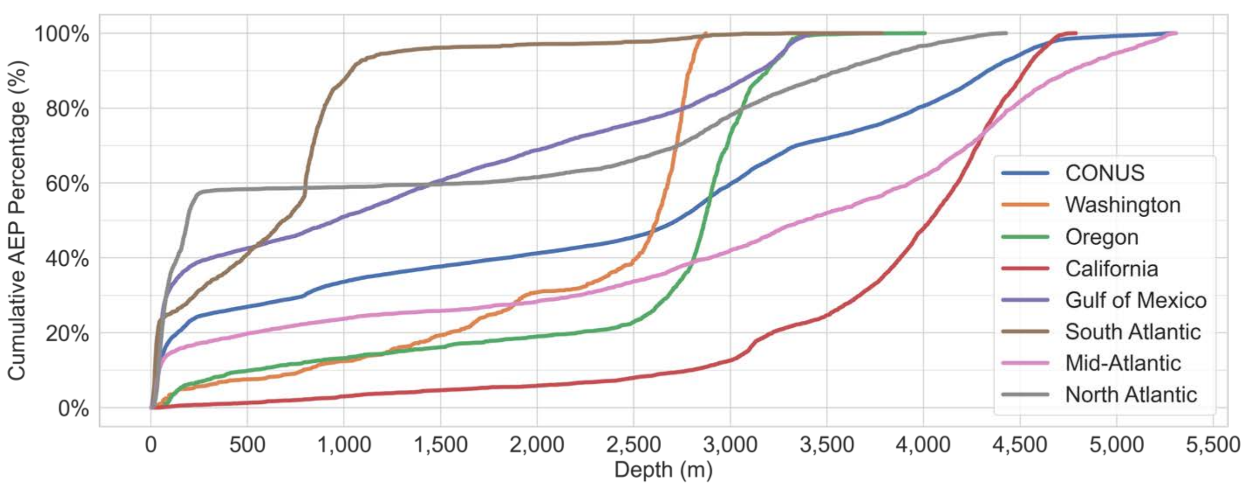

Figure ES-2. Cumulative AEP percentage as function of depth for CONUS and all regions under the Open Access, Conservative technology scenario

This plot includes all exclusions save for the depth cutoff of 1,300 meters in order to show where the cumulative capacity lies in each region relative to depth. This does not show the Great Lakes region.

We also broke results down by region, using the Conservative Technology, Open Access siting regime as the baseline as each region faces siting constraints differently. For example, 97% of California's waters are impacted by siting constraints, with depth and military use the primary constraints (see Figure ES-3). All the existing BOEM planning areas were included in our analysis. In this figure, we show the "individual" areas of each of the siting constraints, as well as the sum of the total constrained area (black) as well as the area with overlapping siting constraints (gray) in the "aggregate" bar. Because some siting constraints overlap, the sum of the total conflicted area (black) is less than the sum of its individual layers. The total overlapping area is shown as well (gray).

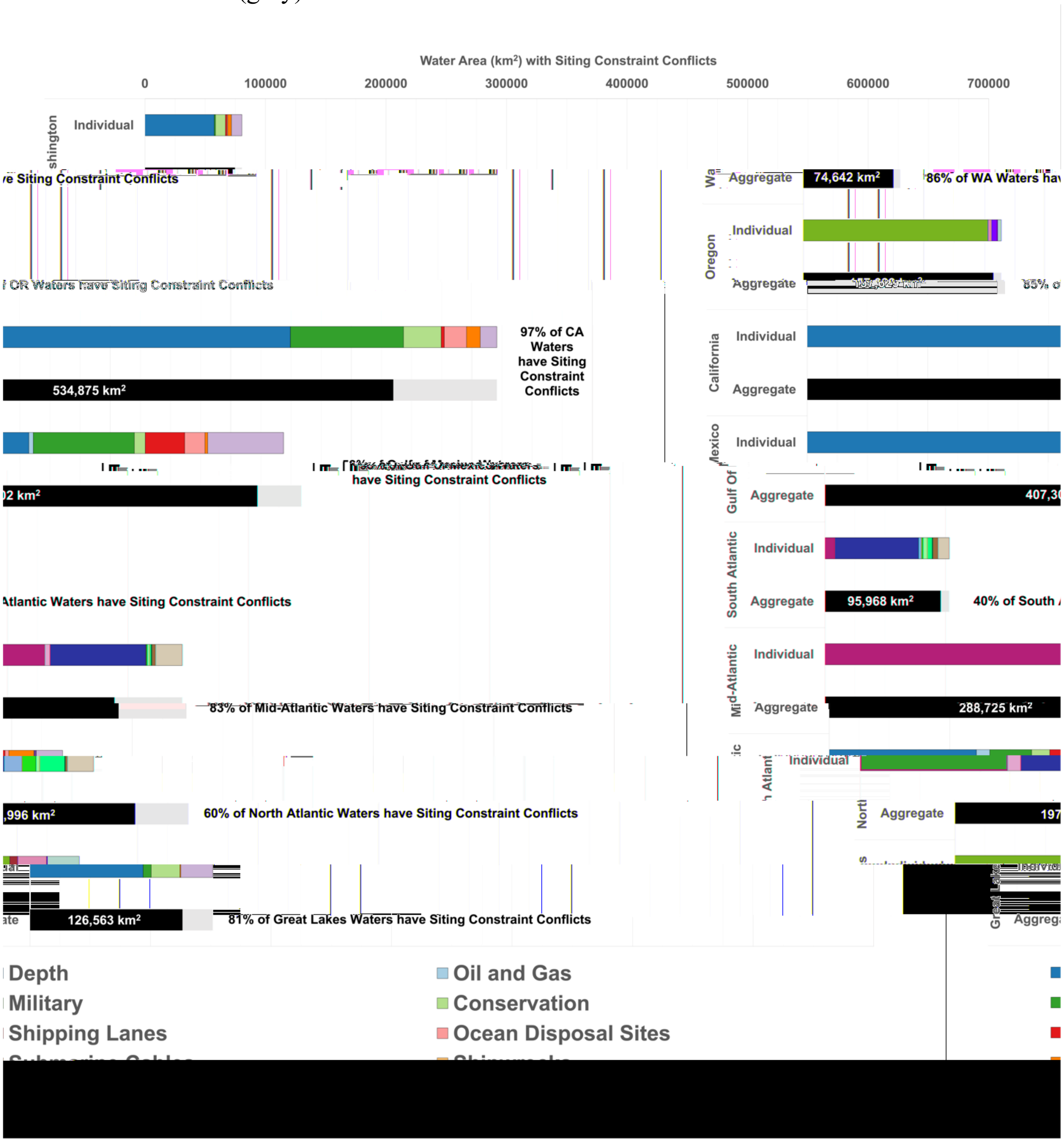

Figure ES-3. Open Access regime siting constraint areas by category

The "Individual" bar plots show the magnitude of each category of siting constraint, whereas the "Aggregate" bar plot shows the total and overlapping area of the siting constraints. Because siting constraints overlap, the total constrained area (in black), is less than the sum of the individual areas. The overlapping area is shown in gray.

With the differential impacts of siting constraints, as well as variations in resource quality, there were significant differences in technical potential between regions (see Table ES-2). On the Pacific Coast, there was almost no fixed-bottom technical potential, although there was high capacity factors for floating technology, especially in Oregon and California. In the Gulf of Mexico, there were low average capacity factors for both fixed and floating, when compared to other regions in the CONUS, but higher capacity factors were present in close to shore areas in the western most portion of the region off Southern Texas. In the Atlantic regions, capacity factors increased in a northwardly direction, with large amounts of available area and the highest average capacity factors in the North Atlantic region.

Table ES-2. Regional Results for the Conservative Technology Scenario, Under the Open Access Siting Regime

Region	Turbine Technology	Available Area (km^2)	Mean Wind Speed (m/s)	Net Capacity Factor (mean)	Capacity (GW)	AEP (TWh)
Washington	Fixed	998	7.19	0.31	4.99	14.81
	Floating	11,049	7.91	0.36	55.3	175.2
Oregon	Fixed	302	8.19	0.37	1.51	4.63
	Floating	28,316	8.77	0.41	141.6	507.7
California	Fixed	699	5.84	0.22	3.5	9.23
	Floating	16,624	7.74	0.34	83.1	316.3
Gulf of Mexico	Fixed	130,906	6.99	0.29	654.5	1,656
	Floating	163,214	7.11	0.30	816.1	2,130
South Atlantic	Fixed	35,404	7.47	0.32	177	506.3
	Floating	110,230	7.39	0.31	551.2	1,523
Mid-Atlantic	Fixed	29,470	8.77	0.42	147.4	545
	Floating	31,151	8.76	0.42	155.8	568.2
North Atlantic	Fixed	49,824	9.44	0.46	249.1	1,011
	Floating	83,198	9.72	0.47	416.0	1,724
Great Lakes[a]	Fixed	29,011	8.33	0.40	158.1	553.3
	Floating	—	—	—	—	—

[a] Great Lakes Floating is not reported because at the time of the analysis, the most current guidance indicated Floating technology was not feasible in the region due to surface ice issues (Musial et al. 2016). More recent work indicates that floating technology in region is feasible, and therefore should be reflected in future work (Musial et al. 2023).

Given the Biden administration's goal of 30 GW of OSW by 2030 it is important to place these results into the context of the current OSW pipeline. NREL's Offshore Wind Market Report: 2023 Edition indicates that over 23 GW of offshore wind projects are in the in the permitting process or further along the pipeline, while there are over 52 GW are in the regulatory pipeline altogether (Musial et al. forthcoming). Most of the current leases are found in the North Atlantic region, given it is the region with the highest average capacity factors. Additional call areas, wind energy areas, and proposed lease sale areas can be found in the Mid-Atlantic, Gulf of Mexico, California, and Oregon waters (Musial et al forthcoming). We found that future floating sites offer the highest capacity factors, although additional floating technology advancements are needed to realize the technical potential.

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1 Introduction

Given the Biden administration's goal of 30 GW of U.S. offshore wind energy (OSW) deployment by 2030, this report is intended to provide updated estimates of the United States OSW resource potential and some of the unique siting challenges it faces (The White House 2021). We developed a suite of spatial siting constraints and considerations to identify the impact on plausible wind technology pathways for both fixed-bottom and floating OSW energy technologies. We applied these siting constraints to estimate available area, potential capacity and annual energy production across the United States.

In this report, we detail the technical potential OSW energy development in U.S. Atlantic waters, Pacific waters (off California, Oregon, and Washington), the Gulf of Mexico, and the Great Lakes under two siting scenarios. Though we did not conduct analysis for Alaska and Hawaii, we incorporated results from previous National Renewable Energy Laboratory (NREL) studies to show results for the 50 U.S. states (Doubrawa et al, 2017; Musial et al, 2016). The analysis in this report builds on published NREL spatial analyses for OSW resource across U.S. offshore regions (e.g., Lopez et al. 2012; Musial et al. 2016).

Our approach follows similar methodologies established in the literature to assess wind potential (Lopez et al. 2012; Lopez et al. 2021). Wind potential is generally defined in four broad categories: geographic (or resource), technical, economic, and finally market potential (see Figure 1; Lopez et al. 2012). Each of which refines the estimates of wind potential by adding spatial, economic, and or cost competitive constraints. Here, we focus on the evaluation of OSW technical potential for United States.

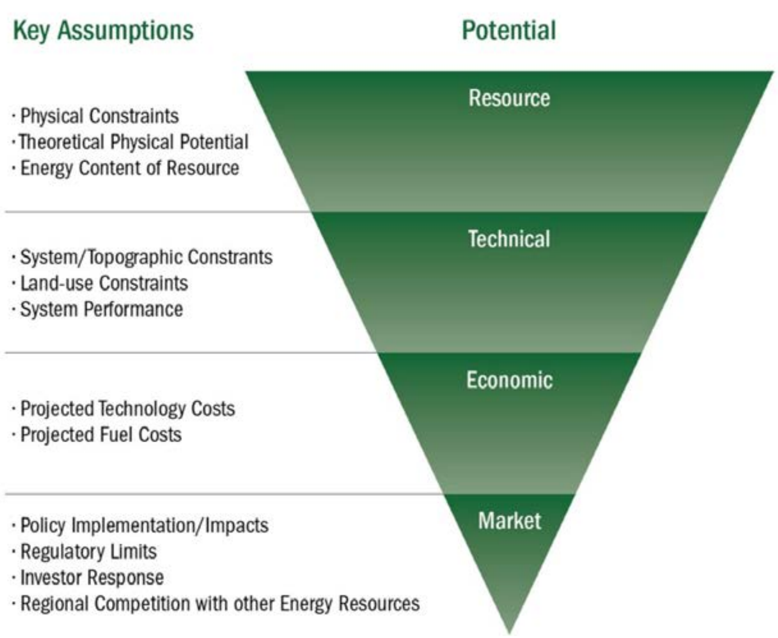

Figure 1. Types of potential assessments

Reproduced from Doris, Lopez and Beckley (2013)

For the study reported here, we updated technology assumptions and spatial siting constraints in order to provide new technical potential estimates. We used three technology scenarios, each representing different levels of plausible turbine technology advancement. Additionally, we developed two levels of siting constraints, with one more limiting than the other. We incorporated spatial data sets such as existing infrastructure, protected areas, military area, shipping lanes and water depth limits for turbine installation into our siting constraints.

The primary metrics of this analysis are national and regional estimates of available area (km^2), capacity (GW), and generation (TWh).[1] We partition the results by geographic region for the Open Access, Conservative technology scenario and discuss key spatial characteristics of the quantity and quality of the OSW resource. We also breakdown the unique siting constraints faced by each region as they can vary significantly. This is a key contribution of the study given that planning and permitting of projects is conducted at the regional level. Lastly, we place our findings into the greater context of the current U.S. OSW pipeline.

[1] The 10.6 km x 10.6 km grid cells containing capacity and capacity factor for the six scenarios created in this analysis are available at https://www.nrel.gov/gis/wind-supply-curves.html.

2 Data and Methodology

This study builds on Lopez et al. (2012) and Musial et al. (2016) and expands their work by incorporating the methods developed in Lopez et al. (2021). We used the Renewable Energy Potential model (reV; Maclaurin et al. 2019), which is an open-source software used for the analysis of technical potential of renewable energy resources such as wind and solar. We used the Wind Integration National Dataset Toolkit (WTK; Draxl et al. 2015; see Figure 2), which is a wind resource data set with 2-km resolution spanning the US exclusive economic zone. The System Advisor Model (SAM; Blair et al. 2018) is integrated into the reV modeling pipeline to efficiently estimate hourly capacity factors based on prespecified technology assumptions. We then use reV to apply flexible, high-resolution geospatial data sets of siting restrictions in order to estimate technical potential.

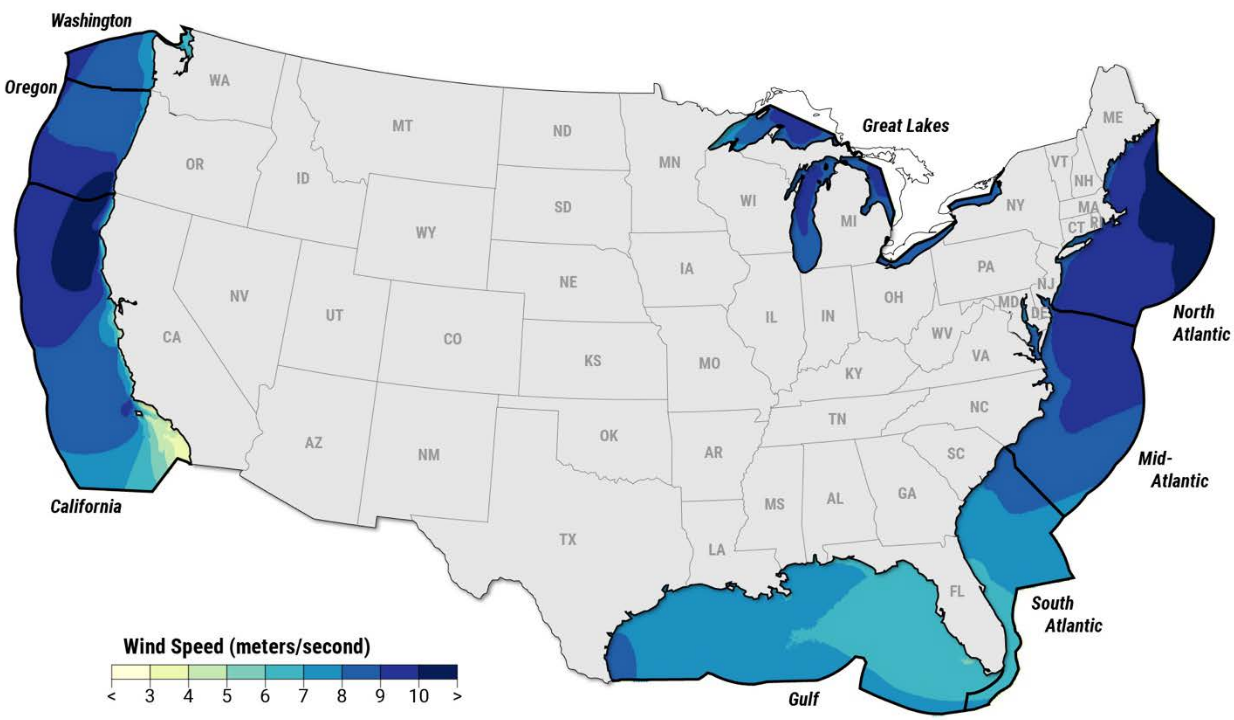

Figure 2. Mean windspeed from 2007 to 2013 at 150 m within the CONUS exclusive economic zone

Source: WTK

2.1 Estimating Generation

We used the reV model to assess three separate turbine technology scenarios across the CONUS exclusive economic zone (EEZ). We drew on the three core scenarios developed in the 2021 Annual Technology Baseline (ATB), a database of turbine designs across a range of R&D advancements (NREL 2021). Each of the turbine scenarios were based on their speculated 2030 design. The Conservative technology case assumes turbine size is consistent with the baseline estimated technology available in 2030. In addition, logistical and manufacturing constraints are those estimated to occur in 2030 and may bound turbine size. The Moderate technology case assumes turbine size continues to increase proportionate with the growth in recent years. Turbine size growth, in this case, is enabled through technology innovation in the turbine, substructure, port and vessel capabilities as well as continued efficiencies in the supply chain. Lastly, the Advanced case assumes turbine size increases as at a higher rate than recent years, a result of technology innovation and fundamental changes to manufacturing, installation, operation, and performance. We assumed a constant loss of 16.7% across all turbine technology scenarios, though this could be improved to incorporate site specific wake losses, and possibly plant layout that are optimized to minimize wake losses. Additional work could also optimize turbines at site specific level similar to Lopez et al (forthcoming). For example, using lower specific turbines in lower wind speed climates (Wiser and Bolinger 2017). Turbine designs are presented in Table 1, and the turbine power curves are shown in Figure 3.

Table 1. Turbine Design and Costs from the Annual Technology Baseline.

	Conservative	Moderate	Advanced
Rating (MW)	12	15	18
Rotor diameter (m)	214	240	263
Hub Height (m)	136	150	161
Specific Power (W/m^2)	334	332	331
Loss Assumption (%)	16.7	16.7	16.7

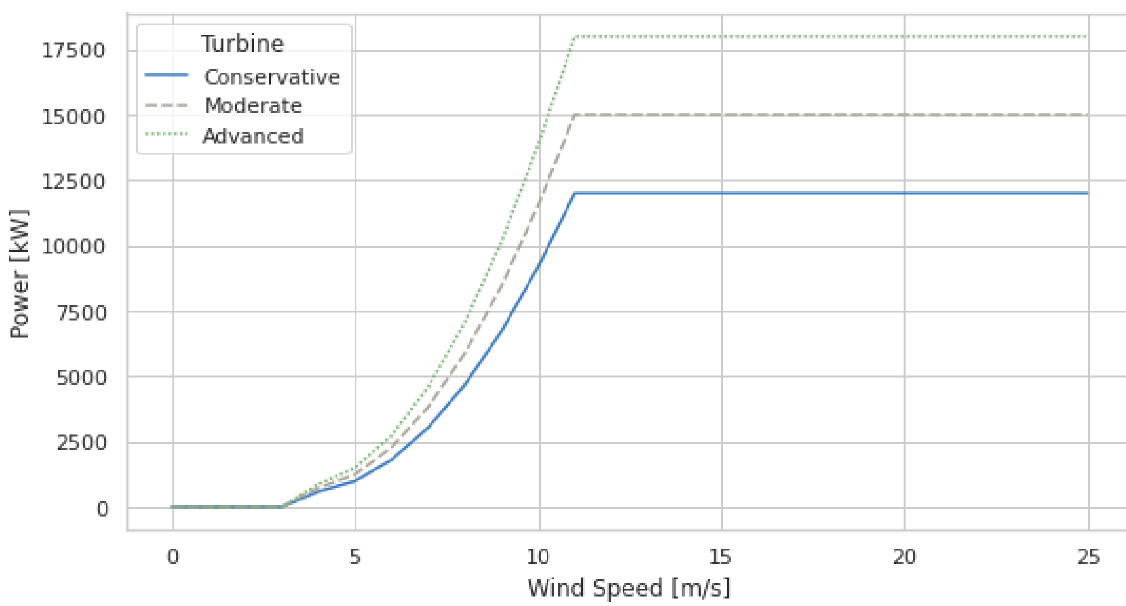

Figure 3. Annual Technology Baseline wind turbine power curves

We assume fixed-bottom substructures would be deployed in waters shallower than 60 m and floating substructures otherwise (Musial et al. 2016). We used the same turbines for floating and fixed-bottom substructures.

2.2 Siting Constraints and Regimes

To capture the significant uncertainty associated with local drivers of siting within a national context, we devised the Open Access and Limited Access siting regimes, or collections of plausible siting restrictions (Lopez et al. 2021). The Open Access siting regime serves as an upper bound to OSW deployment, whereas the Limited Access siting regime is meant to be a lower bound.

The philosophy behind the Open Access siting regime is to capture only known preclusions for wind development (see Figure 4), whereas the Limited Access siting regime attempts to capture additional siting constraints and pressures that may restrict the available resource. For example, in the Limited Access regime we imposed a distance to shore threshold of 32km in order to account for viewshed concerns and minimize their impact (Sullivan et al 2012). While there is no formal distance that is used to determine the distance from shore for lease areas to avoid viewshed impacts, viewshed concerns have proven to be a key driver of local siting and deployment, thus we increased that distance in the Limited Access regime, relative to the Open Access regime (see Table 2).

The Open Access siting regime is a subset of the Limited Access siting regime, meaning some siting constraints are consistent in both siting regimes, though often with increased buffers applied in the Limited Access siting regime (see Table 2). We preclude OSW development in areas where the following are present: oil and gas pipelines and platforms, submarine cables, shipping lanes, conservation areas, military danger zones and restricted areas, U.S. Department of Defense wind exclusions, state waters (see siting constraint rationale in Table 2 for details on Great Lakes), shipwrecks, ocean disposal sites, Atlantic outer continental shelf (OCS) aliquots for both oil and gas and sand resource, as well as at depths greater than 60 m in the Great Lakes (Musial et al. 2016) and depth limit of 1,300 m for the rest of the CONUS (Beiter et al. 2020; see Figure 5).

Given the Open Access siting regime is intended to provide an upper limit of OSW technical potential, we use a capacity density of 5 MW/km^2. The density turbines are within a given area determines the capacity density. Capacity density has a large impact on the total potential and is influenced by many factors and thus varies greatly between projects (Borrmann et al. 2018). 5 MW/km^2 is higher than was used in NREL's previous OSW technical potential estimate (Musial et al. 2016), but lower than empirical capacity densities calculated from existing projects in Europe (Borrmann et al. 2018). For the Limited Access siting regime, we used a capacity density assumption of 3 MW/km^2 from Musial et al. (2016), which is the lowest capacity density seen in empirical data in Europe (Borrmann et al. 2018).

Table 2. Spatial siting constraints restricting prospective OSW development for the Open- and Limited Access Siting Regimes

Siting Constraint	Open Access Siting Regime	Limited Access Siting Regime	Rationale (data source)	Category (Figure 7)
BOEM Wind Lease/Planning Areas	Included	Included	Blocks which have been leased (or are planned to be leased) by a company with intent to build a wind energy facility as of June 2021. Areas are included	-

Siting Constraint	Open Access Siting Regime	Limited Access Siting Regime	Rationale (data source)	Category (Figure 7)
			regardless of spatial overlap with constraints. (BOEM, Renewable Energy GIS Data)	
Oil/gas pipelines	61-m buffer	122-m buffer	Existing infrastructure (Homeland Security Infrastructure Database). The buffer was doubled from Open- to Limited Access to incorporate uncertainty regarding requirement.	Oil and Gas
Oil/gas platforms	250-m buffer	500-m buffer	Existing infrastructure (Homeland Security Infrastructure Database). The buffer was doubled from Open- to Limited Access to incorporate uncertainty regarding requirement.	Oil and Gas
Shipping lanes	Excluded	Excluded	Shipping fairways, lanes, zones defined by BOEM (MarineCadastre)	Shipping Lanes
NOAA charted submarine cables	500-m buffer	1,000-m buffer	Existing infrastructure; Assumed through guidance from NYSERDA 2018 (MarineCadastre). The buffer was doubled from Open- to Limited Access to incorporate uncertainty regarding requirement.	Submarine Cables
Active oil/gas lease areas	Included	Excluded	Active oil/gas leases are included in the open scenario as	Oil and Gas

Siting Constraint	Open Access Siting Regime	Limited Access Siting Regime	Rationale (data source)	Category (Figure 7)
			the lease could theoretically be relinquished. This is unlikely, thus we excluded them in the more limited scenario (MarineCadastre)	
Conservation Areas	Excluded	Excluded	Combination of several categories (marine protected areas, national monuments, national wildlife refuges, and wilderness areas using 30CFR585) as a guide. (MarineCadastre)	Conservation
Danger zones and restricted areas	Excluded	Excluded	Areas defined as restricted due to danger potential, including ship shock boxes, submarine transit lanes, unexploded ordinances (MarineCadastre)	Military
U.S. Department of Defense OSW exclusions	Excluded	Excluded	Defined wind exclusion areas in mission compatibility assessment (MarineCadastre, California State Lands Commission)	Military
State waters	Excluded	Extended 32 kms from shore	Variable by state water extent but typically ≈3–5 nautical miles (5.6-9.3km), but up to 9 nautical miles (16.7km) in some states. BOEM cannot lease state waters as it is a Federal entity. We apply a distance to shore buffer of 3 miles to the Great Lakes, which are entirely state waters.	State Waters

Siting Constraint	Open Access Siting Regime	Limited Access Siting Regime	Rationale (data source)	Category (Figure 7)
			We used 32 km as a proxy to minimze the impacts of viewshed concerns (Sullivan et al 2012). (MarineCadastre)	
Shipwrecks	50-m buffer	100-m buffer	BOEM guidance to avoid by using a generalized setback of 50 m (MarineCadastre)	Shipwrecks
Ocean disposal sites	Excluded	Excluded	Active disposal sites to be avoided (MarineCadastre)	Ocean Disposal Sites
Atlantic outer continental shelf aliquots	Excluded	Excluded	Aliquots in the Atlantic Canyons part of the Development and Production oil/gas lease program (MarineCadastre)	Oil and Gas
Great Lakes depth limits	60 m	60 m	At the time of analysis, only fixed-bottom technologies were thought to be viable (Musial et al. 2016); though floating has recently been deemed as a viable option (Musial et al. in review)	Depth
All waters depth limit	Depth exceeding 1,300 m excluded	Depth exceeding 1,300 m excluded	Current depth limit guidance established by BOEM (Beiter et al. 2020; Shields et al. 2021) (Global Gridded Bathymetry Data, derived)	Depth
Atlantic outer continental shelf aliquots with sand resources	Excluded	Excluded	Aliquots on the Atlantic outer continental shelf with sand resources used to mitigate effects from erosion, land loss, and storm damage (Marine Cadastre)	OCS Sand and Gravel Borrow Areas

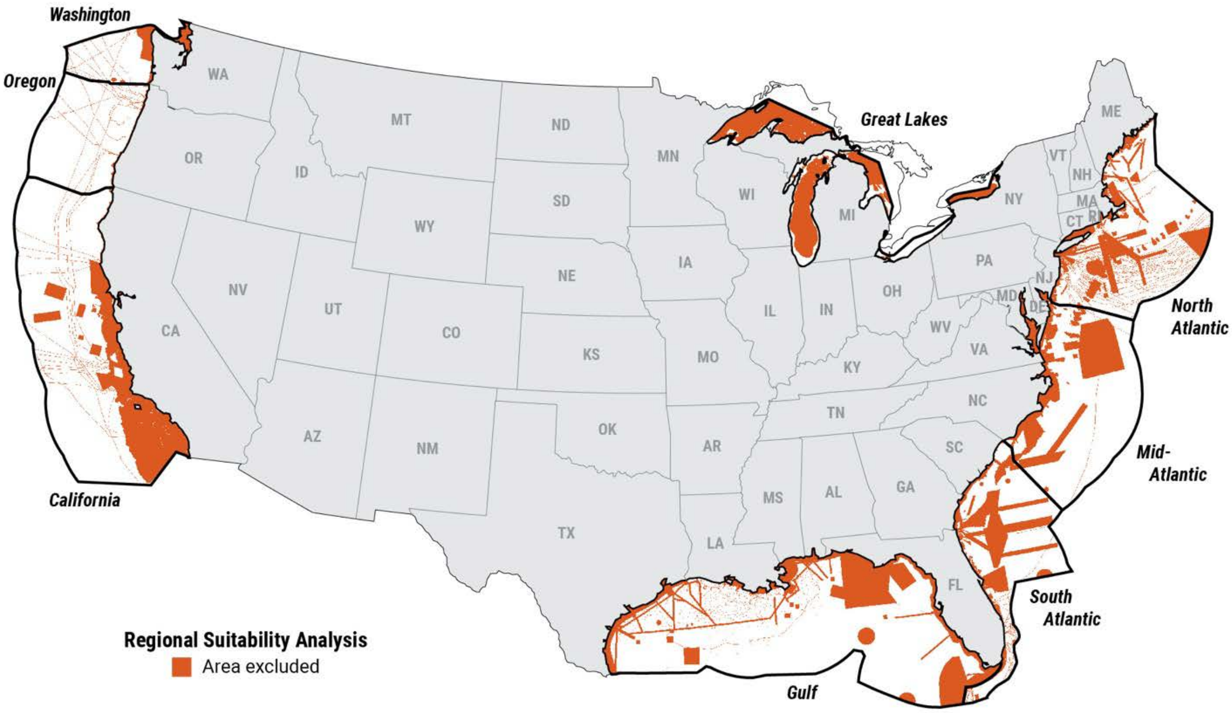

Figure 4. The combined spatial constraints for OSW development under the Open siting regime, not including the 1,300-m depth cutoff but including the 60-m depth cutoff in the Great Lakes

[a] Great Lakes Floating is not reported because at the time of the analysis, the most current guidance indicated Floating technology was not feasible in the region due to surface ice issues (Musial et al. 2016). More recent work indicates that floating technology in region is feasible, and therefore should be reflected in future work (Musial et al. 2023).

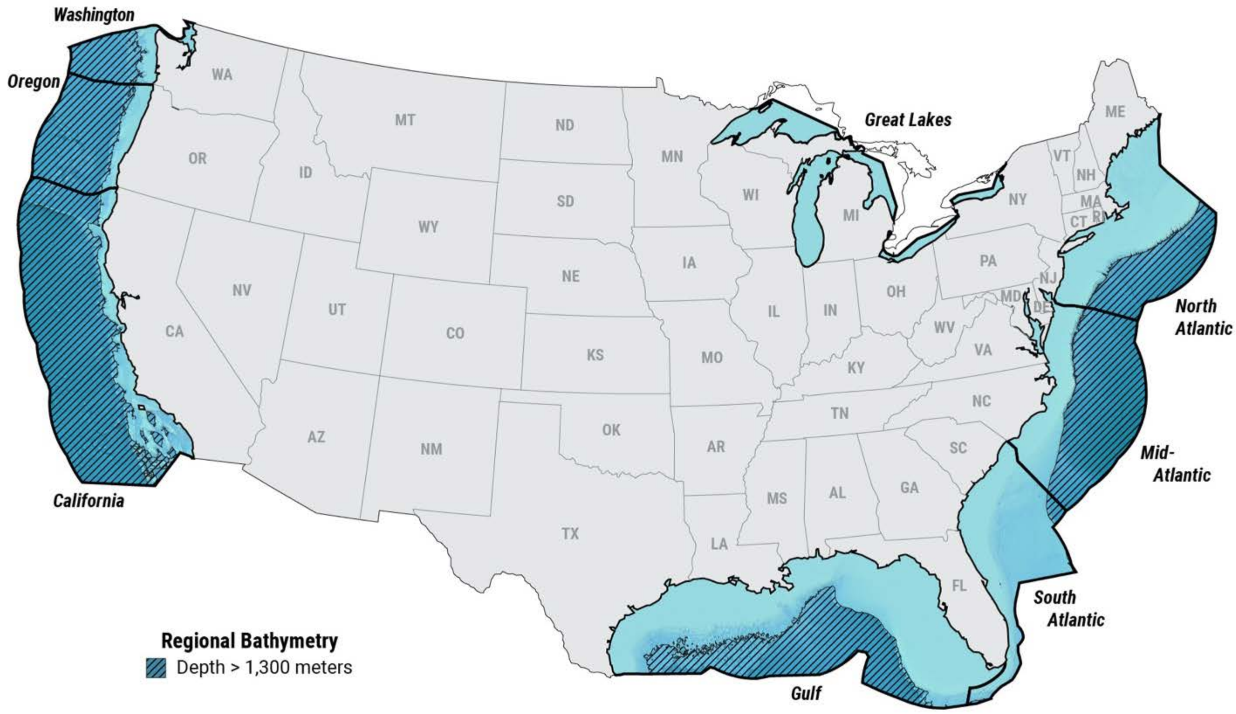

Figure 5. Contiguous United States offshore waters within the EEZ (200 nautical miles from the coastline)

The figure also shows the geographic extent of waters less than 1,300 m in depth.

2.3 Estimating Technical Potential

For each siting regime, we combine the spatial constraints in a single 90-m resolution grid (Figure 4) and apply that grid as a mask, or filter of conflicted areas, to aggregated generation results (see Lopez et al. 2021). The resulting aggregate cells have a 10.62 km x 10.62 km resolution. We apply the siting constraint mask and calculate aggregated generation results based on the remaining area using a weighted average to estimate technical potential.

3 Results

The contiguous United States (CONUS) has 3,615 GW of OSW technical potential under the Open Access siting regime, amounting to 11,245 TWh of AEP (see Table 3). Of this, the resource for fixed-bottom technology takes up 279,229 km^2 of area, making up 1,396 GW of capacity and 4,301 TWh of AEP (see Figure 6). The resource for floating technology occupies 443,783 km^2, accounting for 2,319 GW of capacity and 6,944 TWh of AEP. In the Limited Access siting regime, the CONUS OSW drops to 1,665 GW of capacity (46% of Open Access capacity) and 5,164 TWh of AEP (46% of Open Access AEP). Though Alaska and Hawaii are not modeled in this study, if they are included in the Open Access siting regime, the U.S. OSW technical potential rises to 6,657 GW and AEP to 23,562 TWh (see Table 5).

Figure 6. Fixed and floating available area after considering siting constraints in the Open Access siting regime

Colored pixels indicate available area, though it could be as little as 0.1 km^2.

Though many siting constraints contribute to the reductions in available area, the depth limit of 1,300 m accounts for the largest reduction in resource area, removing over 50% of available area. If considering all resource, without applying a depth limit but adhering to other (Open Access siting regime) siting constraints, the CONUS would have 1.82 million km^2 of developable area, a capacity potential of 9,107 GW and a generation potential of 30,957 TWh. The depth restriction limits the resource to less than 40% of its gross potential within the CONUS exclusive economic zone.

With capacity density constant within each respective siting regime, AEP gains are realized through technology improvements such as larger rotor diameters and higher hub heights combining to increase energy capture. Capacity density determines the capacity regardless of the turbine size, reducing the number of turbines needed to fill a given area with a set capacity. However, the larger turbines capture more energy, meaning AEP will increase within a given area and set capacity as the turbine technology scenarios advance. Annual generation increases 0.9% and 1.3% in the Open Access siting regime, Moderate and Advanced technology scenarios, respectively, when compared to the Conservative technology scenario. The 1.3% increase from the Advanced technology scenario relative to the Conservative scenario represents an increase of 153 TWh of AEP.

Table 3. Technical Potential Estimates for the CONUS

Results are shown for the two siting regimes for each turbine scenario partitioned by fixed and floating turbine technology.

Siting Regime	Turbine Scenario	Turbine Technology	Area (km^2)	Mean Wind Speed (m/s)	Net Capacity Factor (mean)	Capacity (GW)	AEP (TWh)
Open	Conservative	Fixed	279,229	7.87	0.35	1,396	4,301
		Floating	443,783	7.98	0.36	2,219	6,944
Limited	Conservative	Fixed	177,917	7.85	0.35	534	1,626
		Floating	376,862	8.01	0.36	1,131	3,538
Open	Moderate	Fixed	279,229	7.93	0.36	1,396	4,349
		Floating	443,783	8.03	0.36	2,219	6,997
Limited	Moderate	Fixed	177,917	7.91	0.35	534	1,643
		Floating	376,862	8.06	0.36	1,131	3,565
Open	Advanced	Fixed	279,229	7.98	0.36	1,396	4,377
		Floating	443,783	8.06	0.36	2,219	7,021
Limited	Advanced	Fixed	177,917	7.95	0.36	534	1,652
		Floating	376,862	8.09	0.36	1,131	3,577

3.1 Regional Results

Though the national summaries provide critical findings, OSW leasing and development is often thought of through a regional lens.. We partition the CONUS waters into the North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico (Gulf), Great Lakes, and by state in the Pacific, including California, Oregon, and Washington. A map of the regional boundaries can be seen in Figure 6. Each region faces unique challenges based on bathymetric and siting constraints as shown in Figure 7. In Figure 7, we show the areas of the various siting constraint categories (see Table 2) for each region, highlighting the magnitude of each category of constraint in the "Individual" bar plots. The plot also shows the magnitude of the spatial overlap between the siting constraints in the "Aggregate" bar plot, with the total area constrained in black, and the overlapping area in gray. For example, a marine protected area might include a portion of state waters. The areas of each would be displayed in color in the "Individual" bar, while their combined area would be shown in black in the “Aggregate” bar, while the spatial overlap would be displayed in gray, also in the “Aggregate” bar.

Table 4. Regional Results for the Conservative Technology Scenario, Under the Open Access Siting Regime

Region	Turbine Technology	Available Area (km^2)	Mean Wind Speed (m/s)	Net Capacity Factor (mean)	Capacity (GW)	AEP (TWh)
Washington	Fixed	998	7.19	0.31	4.99	14.81
	Floating	11,049	7.91	0.36	55.3	175.2
Oregon	Fixed	302	8.19	0.37	1.51	4.63
	Floating	28,316	8.77	0.41	141.6	507.7
California	Fixed	699	5.84	0.22	3.5	9.23
	Floating	16,624	7.74	0.34	83.1	316.3
Gulf of Mexico	Fixed	130,906	6.99	0.29	654.5	1,656
	Floating	163,214	7.11	0.30	816.1	2,130
South Atlantic	Fixed	35,404	7.47	0.32	177	506.3
	Floating	110,230	7.39	0.31	551.2	1,523
Mid-Atlantic	Fixed	29,470	8.77	0.42	147.4	545
	Floating	31,151	8.76	0.42	155.8	568.2
North Atlantic	Fixed	49,824	9.44	0.46	249.1	1,011
	Floating	83,198	9.72	0.47	416.0	1,724
Great Lakes[a]	Fixed	29,011	8.33	0.40	158.1	553.3
	Floating	—	—	—	—	—

[a] Great Lakes Floating is not reported because at the time of the analysis, the most current guidance indicated Floating technology was not feasible in the region due to surface ice issues (Musial et al. 2016). More recent work indicates that floating technology in region is feasible, and therefore should be reflected in future work (Musial et al. 2023).

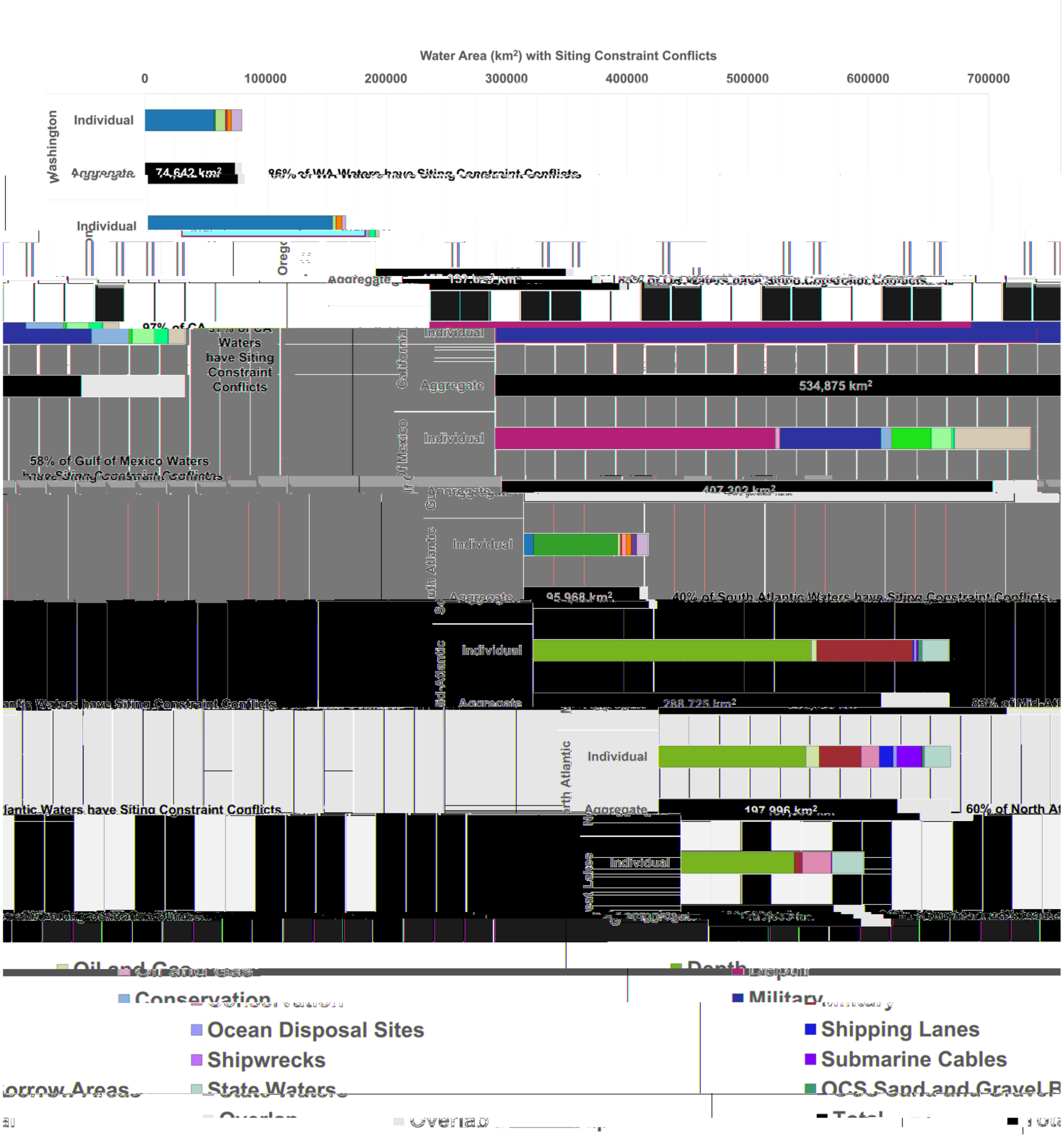

Figure 7. Open Access regime siting constraint areas by category

The “Individual” bar plots show the magnitude of each category of siting constraint, whereas the “Aggregate” bar plot shows the total and overlapping area of the siting constraints. Because siting constraints overlap, the total constrained area (in black), is less than the sum of the individual areas. The overlapping area is shown in gray.

3.1.1 Pacific Regions: Washington, Oregon, and California

On the Pacific coast, the primary limiting factor is the ocean floor topography. A long narrow shelf runs the entire length of the CONUS Pacific coastline and drops off steeply close to shore, precluding much of the western coast's exclusive economic zone from development given our modeling constraints. This significantly limits both the fixed and floating technologies, as nearly all the non-conflicted resource area for both technologies are condensed to within 100 km from shore, despite the exclusive economic zone extending around 370 km from shore (see Figure 6). Figure 8 illustrates this, with boxes colored and labeled by available capacity within a specific distance to shore and mean capacity factor bin. Capacity factor and distance to shore are key characterizations of technical potential, as they represent quality of the resource as well as its accessibility. For example, California has 0.4 GW of fixed-bottom capacity with a capacity factor between 0.27 and 0.3 that is between 0 km and 50 km from shore (under the Open Access scenario). Washington, Oregon, and California have a total of only 10 GW of capacity for fixed-bottom substructures (see Table 4; Figure 8) in the Open Access scenario. The Pacific states have more floating capacity, with 55.3 GW, 141.6 GW, and 83.1 GW in Washington, Oregon, and California, respectively.

Bathymetric constraints restrict over 650,000 km^2 (80%) of the available waters in the Pacific regions, but other siting constraints significantly limit available area as well. Conservation areas, primarily National Marine Sanctuaries off California and Washington, result in an additional 42,500 km^2 of conflicted area, and state waters constrain another 25,000 km^2 across the Pacific region. These siting constraints are not purely additive: the layers overlap, resulting in a total area less the than the sum of the individual layers' area, as shown in Figure 7. California has additional large siting constraints, with military areas (primarily U.S. Department of Defense wind exclusions but also unexploded ordinance, danger zones and restricted areas) removing almost 94,000 km^2, and submarine cables almost 11,500 km^2.

Not only do the Pacific regions see large differences between fixed and floating technical potentials, but in resource quality as well. Floating capacity factors, across all three Pacific regions are, on average, 35% higher than fixed-bottom capacity factors (see Figure 8 and Table 4). This is exemplified in California, where floating capacity factors are over 50% higher on average than fixed-bottom capacity factors. In fact, parts of California have the highest floating capacity factors in CONUS, with over 9 GW above an average of 0.54.

Given fixed and floating turbines are the same, this difference is purely a function of spatial coincidence between resource quality and bathymetry. Capacity factors continue to increase past the 1,300-m depth limit across the Pacific region, with an average of 0.42 meters at depths of 1,300–2,600 m, representing a 13% increase over the current floating domain, and a 53% increase over the current fixed domain.

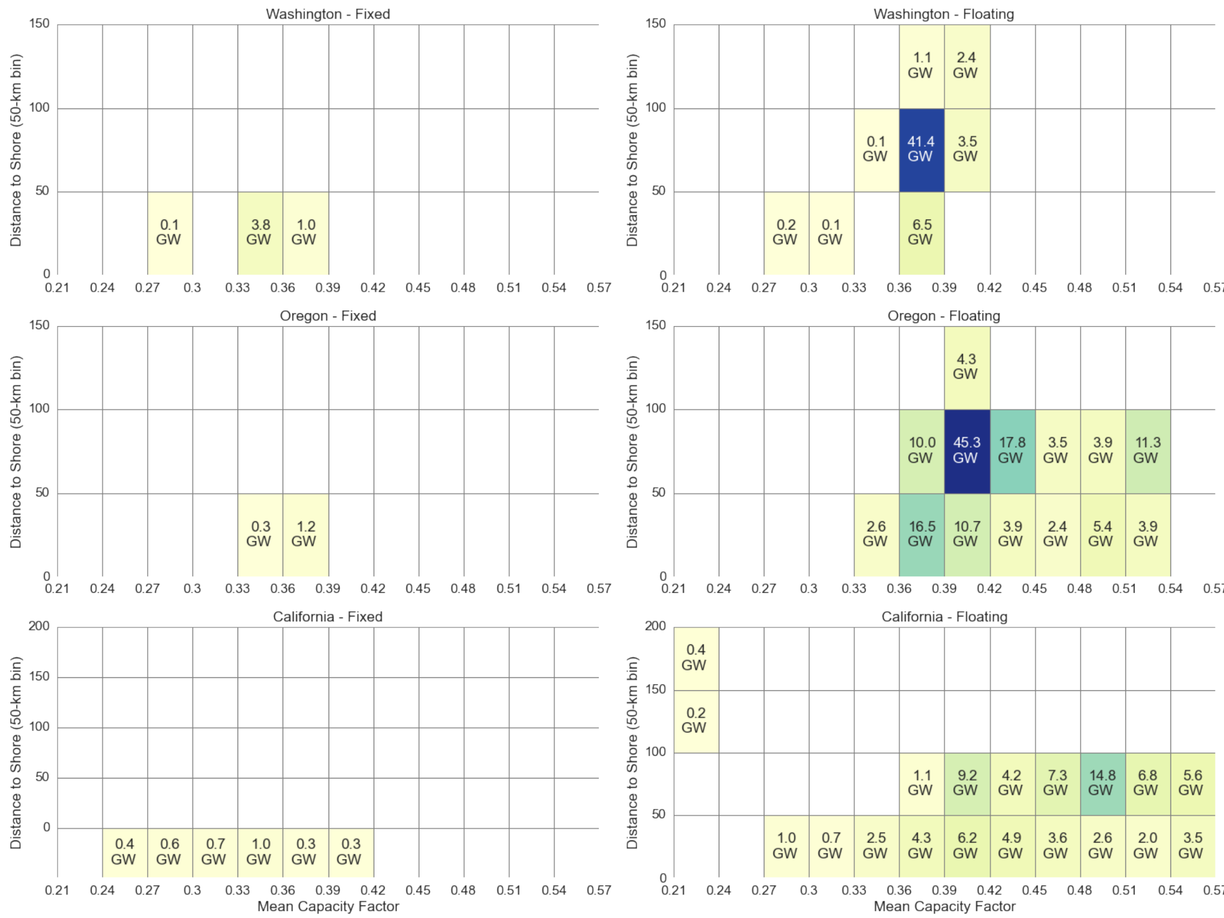

Figure 8. Distribution of technical potential (GW) in Washington, Oregon, and California by distance to shore and mean capacity factor

Darker colors indicate higher capacity. Capacity factor is binned by 0.03 and distance to shore is binned by 50 km. Capacity factors less than 0.21 (roughly equal to 6 m/s wind speed) were removed for this graphic, so it may not reflect total potential. The graphic shows the Open Access siting regime for the Conservative technology fixed and floating turbines.

3.1.2 Gulf of Mexico

The Gulf of Mexico region is the largest of all the CONUS regions, and with that, sees the highest available area and capacity out of any region. However, the region has over 400,000 km^2 of conflicted area in the Open Access scenario. Over half of that can be attributed the 1,300-m depth cutoff, which restricts over 230,000 km^2 of area, or over 1,150 GW in the using the Conservative technology, Open Access scenario capacity density assumption of 5 MW/km^2 (or over 690 GW in the Limited Access regime). Other significant conflicts include military areas (nearly 84,000 km^2), state waters (nearly 63,000 km^2), and shipping lanes (nearly 32,000 km^2). Military conflict areas are made up of danger zones and restricted areas primarily, but also ship shock boxes and unexploded ordinance. Siting constraints due to oil and gas infrastructure are present, but not at the scale of other regions; only 3,700 km^2 is conflicted.

Although the region has the highest capacity and AEP out of any region, the Gulf has some of the lowest average capacity factors in the CONUS (second to California). Despite the low capacity factors, the wind resource distribution is such that there is accessible high quality resource: nearly 90 GW of fixed-bottom capacity within 50 km from shore, 7.5 GW of which are in the highest-two capacity factor bins for the region (0.39–0.45; see Figure 9). Most of the floating capacity (>90%) is more than 100 km from shore, and nearly 40% is more than 200 km from shore. Unlike in the Pacific regions, capacity factors in the Gulf of Mexico do not increase with depth, as the average capacity factor between 1,300 and 2,600 m is also 0.3. Instead windspeeds and capacity factors tend to increase westwardly.

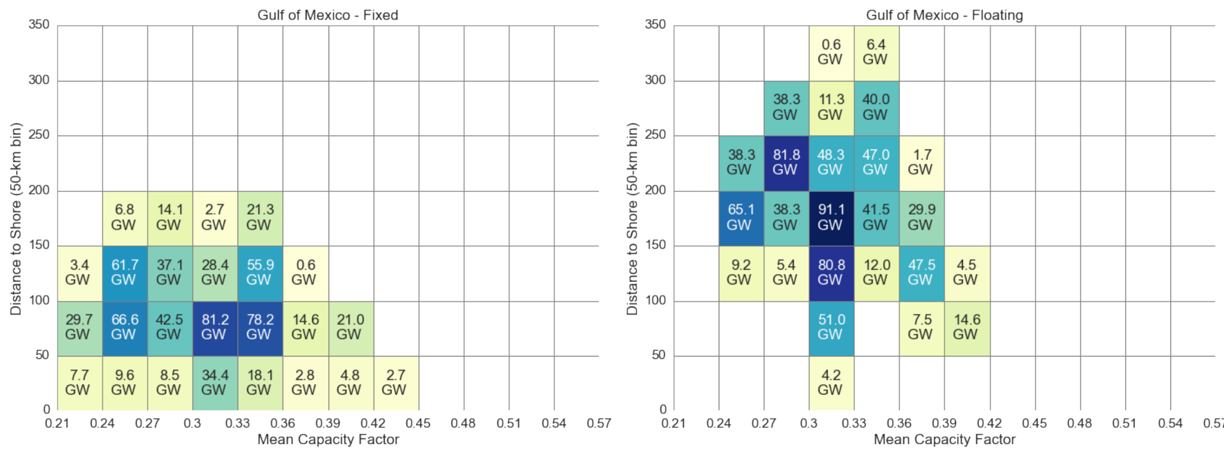

Figure 9. Distribution of technical potential (GW) in the Gulf of Mexico by distance to shore and mean capacity factor

Darker colors indicate higher capacity. Capacity factor is binned by 0.03 and distance to shore is binned by 50 km. Capacity factors less than 0.21 (roughly equal to 6 m/s wind speed) were removed for this graphic, so it may not reflect total potential. The graphic shows the Open Access siting regime for the Conservative technology fixed and floating turbines.

3.1.3 South Atlantic

Unlike other regions, the South Atlantic's largest conflicted areas are military related, as opposed to bathymetry. The South Atlantic has roughly 8,200 km^2 of area (or less than 41 GW of capacity, using the capacity density assumption for the Conservative Technology, Open Access scenario) in waters deeper than 1,300 m (see Figure 7). There are 778 GW in water less than 1,300 m deep, 75% of which is in floating depth zone. Military conflicts such as U.S. Department of Defense wind exclusions, danger zones and restricted area, submarine transit routes, unexploded ordinance areas, and ship shock boxes comprise most of the conflicted area (nearly 70,000 km^2). State waters (9,400 km^2), sand and gravel borrow areas (nearly 4,500 km^2), submarine cables (≈4,100 km^2), and ocean disposal sites (≈3,700 km^2) make up the rest of the conflicted area in the region. The south Atlantic region also has the lowest proportion of waters in conflicted areas under the Open Access scenario across all CONUS regions, with only 40% of its waters conflicting with siting constraints.

Fixed-bottom technology makes up only 25% of the available capacity and generation potential in the South Atlantic region but have higher average capacity factors than floating technology (see Figure 10). Fixed-bottom technology is also generally closer to shore, with 22.5 GW in the highest capacity factor bin for the region (0.39 – 0.42) and within 100 km from shore. Floating technology has nearly 42 GW in that same capacify factor range, although all further than 100 km from shore.

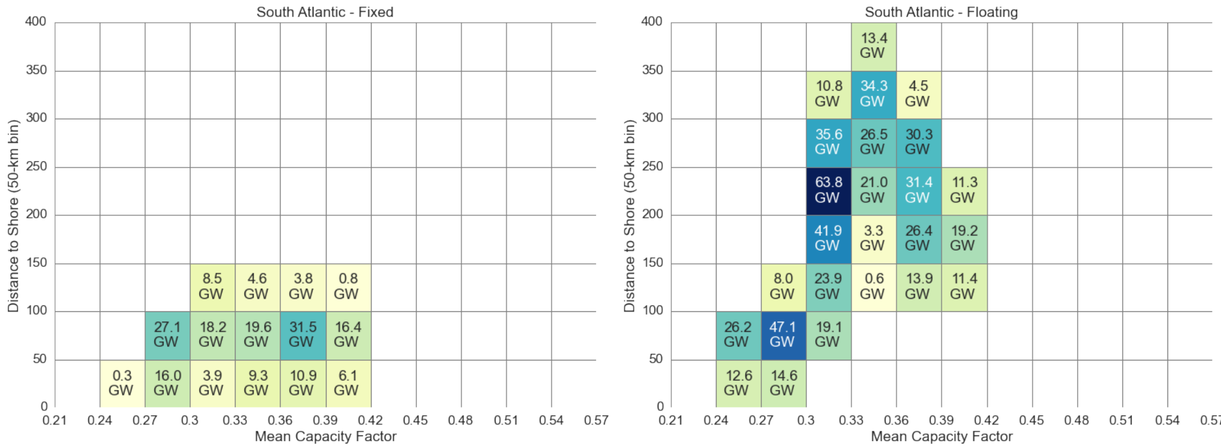

Figure 10. Distribution of technical potential (GW) in South Atlantic by distance to shore and mean capacity factor

Darker colors indicate higher capacity. Capacity factor is binned by 0.03 and distance to shore is binned by 50 km. Capacity factors less than 0.21 (roughly equal to 6 m/s wind speed) were removed for this graphic, so it may not reflect total potential. The graphic shows the Open Access siting regime for the Conservative technology fixed and floating turbines.

3.1.4 Mid-Atlantic

The Mid-Atlantic, like most other regions, loses most of its available area to waters deeper than 1,300 m. Nearly 82% of its available area (nearly 290,000 km^2; or 1,450 GW of capacity in the Open Access regime), is lost due to the depth cutoff (see Figure 7). Military uses are the second most significant siting constraint conflict in the area, and area primarily made up of ship shock boxes, submarine transit routes, and U.S. Department of Defense designations, as well as danger zones, and unexploded ordinance, limits available area by nearly 80,000 km^2. State waters also result in a significant amount of conflicted area (over 22,000 km^2).

Technical potential is comparable for fixed-bottom and floating technologies in the Mid-Atlantic region, and the two technologies have similar capacity factors there. However, fixed-bottom technology has the advantage of being closer to shore, with nearly 29 GW in the top two capacity factor bins (0.42–0.48) and within 50 km from shore (see Figure 11). Within 100 km from shore, the Mid-Atlantic region has nearly 116 GW of capacity with capacity factors above 0.42. The Mid-Atlantic region, like the Gulf of Mexico, does not see average capacity factor increases in water with depths of 1,300–2,600 m.

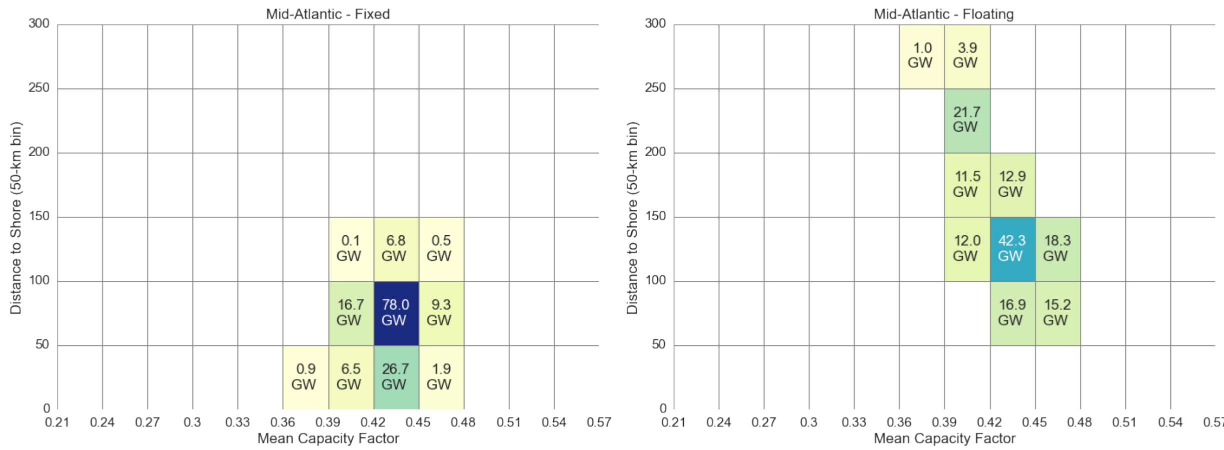

Figure 11. Distribution of technical potential (GW) in the Mid-Atlantic by distance to shore and mean capacity factor

Darker colors indicate higher capacity. Capacity factor is binned by 0.03 and distance to shore is binned by 50 km. Capacity factors less than 0.21 (roughly equal to 6 m/s wind speed) were removed for this graphic, so it may not reflect total potential. The graphic shows the Open Access siting regime for the Conservative technology fixed and floating turbines.

3.1.5 North Atlantic

The North Atlantic sees the most variation in siting constraint conflicts, losing significant area due to military use, conservation areas, submarine cables, ocean disposal sites, shipping lanes, oil and gas, and state waters, in addition to bathymetric constraints. The bathymetry in the region limits available area by about 120,000 km^2 (or approximately 600 GW in the Open Access regime), making it the largest conflict in the region. Military use is the next largest siting constraint conflict in the region (nearly 35,000 km^2), followed by state waters (22,000 km^2), submarine cables (21,000 km^2), conservation areas (15,00 km^2), shipping lanes (11,500 km^2), and oil and gas (11,000 km^2). The military conflicts are made up primarily of U.S. Department of Defense designations, as well as submarine transit routes. The conservation areas consist of National Marine Monuments and a National Marine Sanctuary. The oil and gas conflicted areas are entirely made up of Aliquots in the Atlantic Canyons, which are part of the Development and Production oil/gas lease program.

The North Atlantic regions has the highest average capacity factors across all the CONUS regions, with a fixed-bottom average of 0.46 and a floating average of 0.47. The region sees high capacity factors for fixed-bottom technology close to shore with almost 16 GW of capacity within 50 km from shore and above a 0.48 capacity factor. No other region has fixed-bottom capacity with as high of capacity factors. The region also has over 52 GW of floating capacity above a 0.48 capacity factor within 100 km from shore. Only Oregon and California have comparable capacity factors within 100 km of shore, though neither has as much capacity as the North Atlantic.

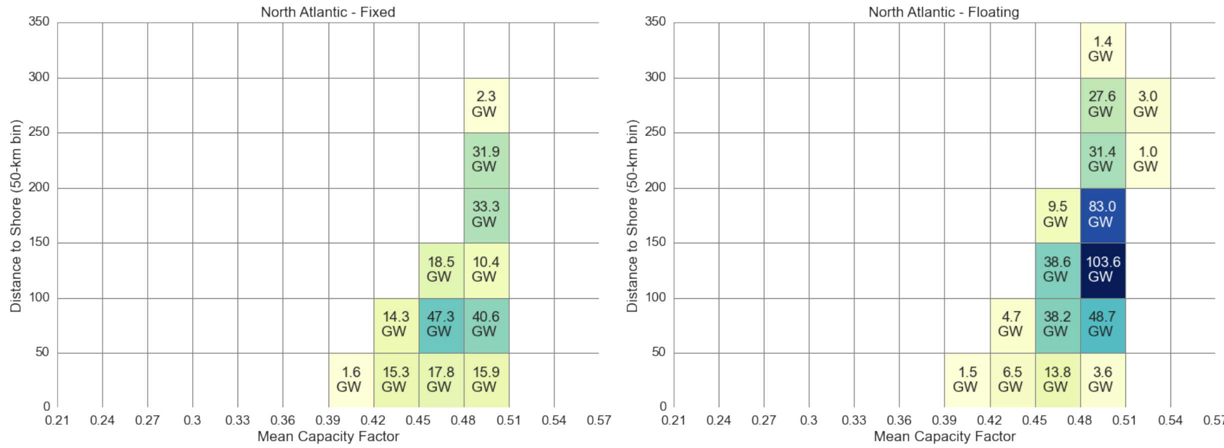

Figure 12. Distribution of technical potential (GW) in the North Atlantic by distance to shore and mean capacity factor

Darker colors indicate higher capacity. Capacity factor is binned by 0.03 and distance to shore is binned by 50 km. Capacity factors less than 0.21 (roughly equal to 6 m/s wind speed) were removed for this graphic, so it may not reflect total potential. The graphic shows the Open Access siting regime for the Conservative technology fixed and floating turbines.

3.1.6 Great Lakes

This study only assessed fixed-bottom technology for the Great Lakes region, limiting available area by almost 94,000 km^2. The three-mile distance to shore buffer (in place of the state waters siting constraint, as the Great Lakes region is all state waters) limits area by 26,500 km^2, with conservation areas (almost 24,000 km^2) and military areas (nearly 7,000 km^2) making up the rest of the significant siting constraint conflicts.

Even though over 80% of the region's waters area is limited due to only including fixed bottom technology, significant capacity is still available. The region has nearly 40 GW of fixed-bottom capacity with capacity factors above 0.42 within 50 km from shore, more than any other region besides the North Atlantic. We did not include floating technology in the region because, at the time of the analysis, the most current guidance indicated the technology was not feasible in the region due to surface ice issues (Musial et al. 2016). More recent work indicates that floating technology in region is feasible, and therefore should be reflected in future work (Musial et al. 2023).

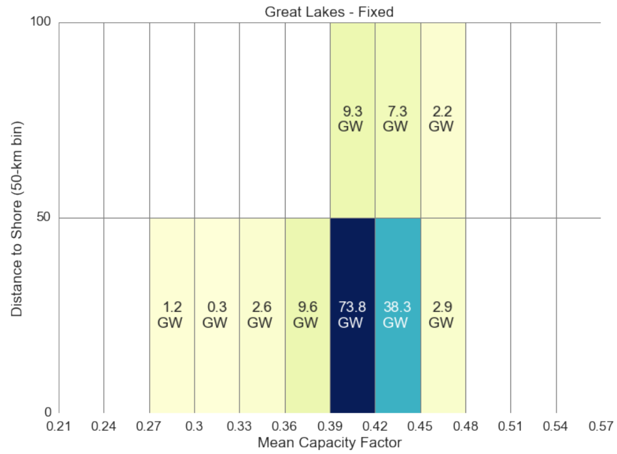

Figure 13. Distribution of technical potential (GW) in the Great Lakes by distance to shore and mean capacity factor

Darker colors indicate higher capacity. Capacity factor is binned by 0.03 and distance to shore is binned by 50 km. Capacity factors less than 0.21 (roughly equal to 6 m/s wind speed) were removed for this graphic, so it may not reflect total potential. The graphic shows the Open Access siting regime for the Conservative technology fixed turbine.

3.1.7 Alaska and Hawaii

Though we did not assess technical potential in this study, we compiled comparable technical potential data from Alaska and Hawaii from previous NREL studies. Alaska has significant technical potential due to its large size and northerly, high wind climate (Doubrawa et al. 2017). Alaska has nearly 1,000,000 km^2 of available area, which is more than the entire available area of the CONUS regions under the Open Access scenario (see Table 5). The AEP from Alaska is slightly greater than the entire CONUS region's AEP as well.

Hawaii also offers high technical potential, especially from floating technology (Musial et al. 2016). Over 20,000 km^2 are available area in Hawaii, which is more than either California or Washington. Similar to the other regions in the Pacific, 90% of Hawaii's available area in water deeper than 60 m. Given this, AEP in Hawaii is significantly higher for floating technologies, though capacity factors are similar in waters shallower and deeper than 60 meters. Though we used 1,000 m as the depth cutoff for Alaska and Hawaii due to data availability, both regions would see significant gains in available area were the depth limit extended.

Table 5. Technical Potential Results for Alaska and Hawaii from Previous NREL Studies

State	Siting Assumptions	Turbine Technology	Area (km^2)	Capacity (GW)	AEP (TWh)	Source
Alaska	3 MW/km^2; 1,000-m depth cutoff	Fixed	478,527	1,436	5,728	Doubrawa et al. (2017)
		Floating	512,882	1,539	6,360	
Hawaii	3 MW/km^2; 1,000-m depth cutoff	Fixed	2,459	7.4	23.32	Musial et al. (2016)
		Floating	19,771	59.3	206.1	

4 Summary and Conclusions

4.1 Key Takeaways

Despite significant area impacted by siting constraints, namely depth restrictions, we found that the United States still has over 720,000 km^2 available area in the Open Access siting regime. Of the available capacity, under the Open Access, Conservative Technology scenario, 38.4% (1,479 GW) is fixed, and 61.6% (2,373 GW) is floating. A similar proportion of AEP, 38% (4,548 TWh), comes from fixed technology with 62% (7,427 TWh) from floating. The depth cutoff of 1,300 m (60 m in the Great Lakes region) restricted over 50% of the total CONUS waters. It accounted for over 70% of the total area with siting constraint conflicts in the Open Access siting regime, though it overlaps with other constraints. Military related siting constraints were the second largest area category, accounting for over 20% of area removed to due siting constraints in the Open Access regime (includes overlapping area). Additional, unexamined, siting constraints such as fishing activity, seasonal protected habitats, and conflicts due to avian or marine mammal migration, exist and should be considered in regional studies that assess local siting constraints.

In the Limited Access siting regime, there was 554,437 km^2 available area with 1,665 GW capacity (46% of the Open Access regime). Of that, 32% of available capacity is fixed (629 GW), with 31.4% (1,915 TWh) of AEP. Floating area makes up the other 68% (1,335) of capacity, and 68.6% (4,179 TWh) of AEP. Though the additional siting constraints in this regime account for the loss of almost 170,000 km^2 of additional area compared to the Open Access scenario, the lower capacity density plays a large role reduced technical potential, decreasing capacity by a further 40% relative to what it would have been under the Open Access regime. The variation in capacity density assumptions between the siting regimes could be considered contrary to a goal of maximal energy production, as in more area constrained locations, capacity densities ought to be higher. However, given the intent to bound technical potential with the Open and Limited Access regimes, we feel the choices of capacity density are justified.

Available capacity and resource quality varied regionally across the United States. On the Pacific coast, the Washington, Oregon and California resources were limited to primarily floating technology, with pockets of high resource quality, despite lower average capacity factor values. The Gulf of Mexico region has the most available area of all CONUS regions with its highest capacity factor locations being close to shore fixed-bottom sites. The Atlantic regions have higher average capacity factors, with values increasing northwardly. The North Atlantic region has the highest average capacity factors for both fixed and floating technologies. Unlike the other CONUS regions, much of the Atlantic regions' capacity lies far from shore due to the spatial distribution of siting constraint conflicts. The Great Lakes region was limited to just fixed-bottom technology, in this study, but has relatively high capacity factors within 50 km from shore. Though we did not assess the technical potential of Alaska and Hawaii in this study, we found Alaska has more available area and higher AEP the entire CONUS, and Hawaii has high floating capacity factors.

Under the Open Access siting regime, the Conservative technology scenario had an estimated AEP within the entire CONUS region of 11,245 TWh. Under the moderate technology scenario, the CONUS AEP rises to 11,346 TWh and the advance technology assumption AEP rises to

11,398 TWh, representing a 0.9% and 1.3% increase relative to the Conservative technology scenario, respectively. These gains are largely due to increased hub heights and rotors diameters in the improved technology scenarios. Though these gains may seem modest, a 1.3% increase in production amounts to an additional 153 TWh, which is nearly 4% of the 2021 annual US electricity usage (EIA 2022). Under the advanced technology scenario, the CONUS AEP is almost three times that of the 2021 U.S. electricity consumption (EIA 2022). However, under the Open Access, Conservative technology scenario, with the depth limit of 1,300 meters removed, CONUS could see an AEP as high as 30,957 TWh, or 5 times that of the 2021 U.S. electricity consumption (EIA 2022).

Indeed, for most regions, as well as CONUS, to reach 50% of their gross resource potential, the depth limit would have to be extended past 2,500 m (see Figure 14). Given the technological limitations associated with deep water floating substructures, there are other ways to increase AEP. One way is optimizing turbines to fit regional wind climate, such as using lower specific power machines in areas with lower wind speeds (Wiser and Bolinger 2017). With location specific turbine optimization (Lopez et al. forthcoming), it may be possible to shift larger proportions of cumulative AEP to shallower waters, where there are fewer depth related technological constraints (see Figure 14).

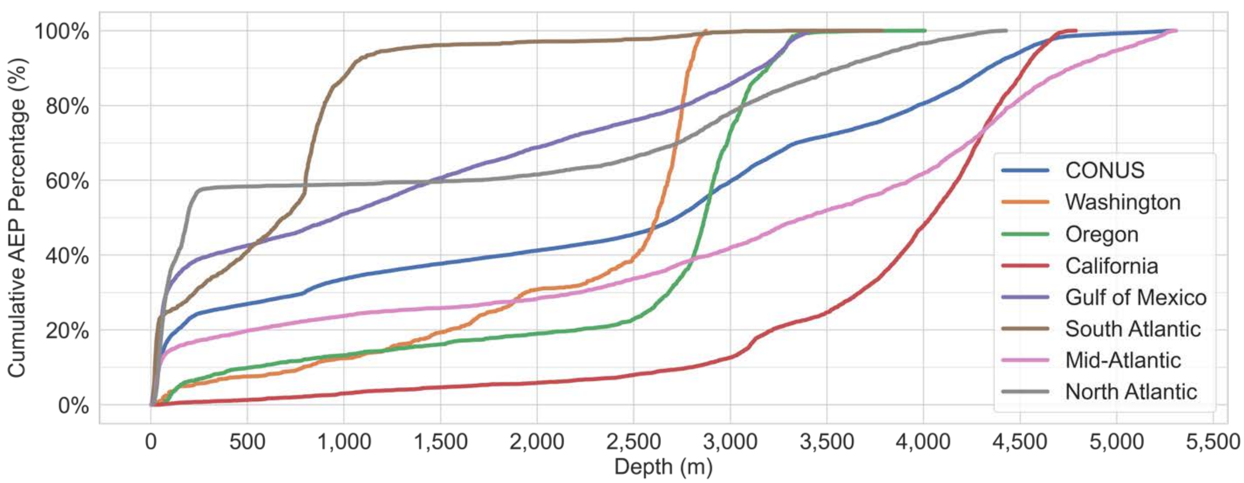

Figure 14. Cumulative AEP percentage as function of depth for CONUS and all regions under the Open Access, Conservative technology scenario

This plot includes all exclusions save for the depth cutoff of 1,300 meters in order to show where the cumulative capacity lies in each region relative to depth. This does not show the Great Lakes region.

4.2 Outlook for the US OSW Pipeline

To reach the Biden administration's 30 GW by 2030 goal, additional deployment may be needed. The areas in Table 6 represent the most likely locations for future deployment, and timeline-dependent, could bring the U.S. OSW deployment to 30 GW by 2030. Given the locations of the call areas, floating technology will become far more prevalent as the technology matures. As mentioned earlier, the key factor for floating technology is the depth limit. In recent modeling work, it has been increasing over years: Musial et al. (2016) assumed a 1,000-m depth limit, where more recent studies such as Beiter et al. (2020), Shields et al. (2021) and Duffy et al. (2022) used a 1,300-m depth limit. The three Mid-Atlantic floating draft WEAs are all in waters deeper than 1,300 m, indicating BOEM believes the depth limit will increase. Floating technology development is critical for accessing the two-thirds of CONUS water area deeper than 60 m, as well as the higher capacity factors that are often be found in deeper waters (see Figure 15). However, moving to deeper water could also lead to additional siting constraints not identified in this report.

Table 6. Summary of BOEM Call Areas, WEAs and proposed lease sale areas as of June 2023

Sources for geographic locations include BOEM (2022), Musial et al. (forthcoming), Shields et al. (2021), BOEM (2023a, 2023b). Area, capacity, and capacity factor results are from this report unless otherwise stated.

Region	Name	Type	Technology	Area (km^2)	Open Access Capacity (5 MW/km^2; GW)	Conservative Technology Average Capacity Factor
Oregon	Brookings	Call Area	Floating	1,160	5,797	0.50
Oregon	Coos Bay	Call Area	Floating	3,533	17,666	0.42
Gulf of Mexico	OCS-G 37334	Proposed Lease Sale Area	Fixed	415	2,075	0.33
Gulf of Mexico	OCS-G 37335	Proposed Lease Sale Area	Fixed	415	2,074	0.33
Gulf of Mexico	OCS-G 37336	Proposed Lease Sale Area	Fixed	392	1,959	0.33
South Atlantic	Charleston	Call Area	Fixed	144	720	0.37
South Atlantic	Winyah	Call Area	Fixed	141	705	0.38
South Atlantic	Cape Romain	Call Area	Fixed	629	3,147	0.37
South Atlantic	Grand Strand	Call Area	Fixed	2,451	12,703	0.38
Mid-Atlantic	Central Atlantic WEA A	Draft WEA Primary Area	Fixed	186	929	0.43
Mid-Atlantic	Central Atlantic WEA B1	Draft WEA Primary Area	Fixed	89	447	0.43

Region	Name	Type	Technology	Area (km^2)	Open Access Capacity (5 MW/km^2; GW)	Conservative Technology Average Capacity Factor
Mid-Atlantic	Central Atlantic WEA B2	Draft WEA Primary Area	Fixed	830	4,150	0.43
Mid-Atlantic	Central Atlantic WEA C	Draft WEA Primary Area	Fixed	485.67	2,428	0.43
Mid-Atlantic	Central Atlantic WEA D	Draft WEA Primary Area	Fixed	742	3,733	0.43
Mid-Atlantic	Central Atlantic WEA E1	Draft WEA Primary Area	Floating	1,904	9,520	0.45
Mid-Atlantic	Central Atlantic WEA E2	Draft WEA Primary Area	Floating	1,392	6,958	0.44
Mid-Atlantic	Central Atlantic WEA F	Draft WEA Primary Area	Floating	170	850	0.44
Hawaii/ Alaska	Oahu North	Call Area	Floating	609 (from Shields et al. 2021)	3,045	0.52 (from Shields et al. 2021)
Hawaii/ Alaska	Oahu South	Call Area	Floating	1,289 (from Shields et al. 2021)	6,445	0.49 (from Shields et al. 2021)
North Atlantic	Gulf of Maine	Call Area	Floating	39,677	198,385	0.48

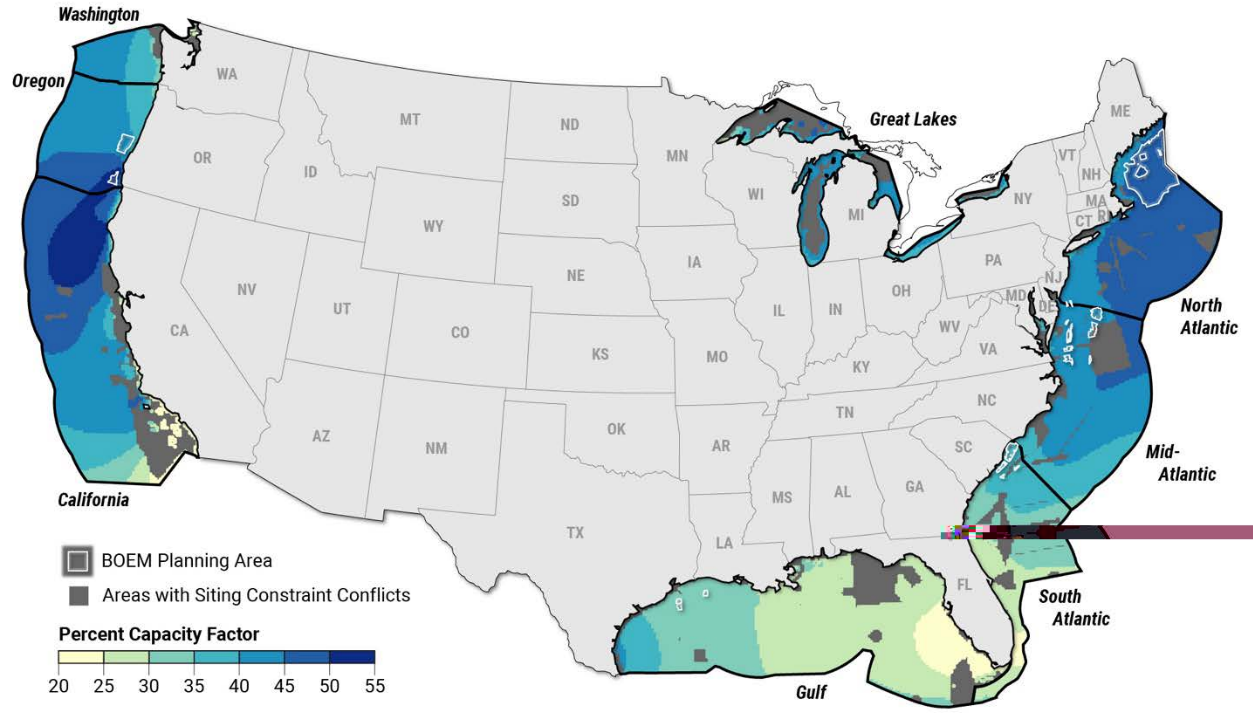

Figure 15. Average capacity factors under the Open Access, Conservative Technology Scenario

This map shows capacity factors considering all siting constraints except for the depth limitation of 1,300 meters (but still including the 60-meter limit in the Great Lakes). Capacity factors below 0.2 (roughly equal to 6 m/s wind speed) are stylized like those between 0.2 and 0.25 for clarity. It also includes the BOEM Call Areas, WEAs, and proposed lease sale areas from Table 6, but does not show current leases.

Though we did not discuss costs, they play a key role in determining actual deployment location within available area. Determining the most cost-effective locations depends on many things, including site-specific physical characteristics, as well as the establishment of supply chains. Additionally, building turbines that can stand up to extreme weather events will be key in some regions (Duffy et al. 2022). Future NREL studies are assessing both the supply chains and site-specific costs.

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Appendix

A.1 Siting Constraint Conflict Area by Type

Table A-1. Summary of Regional Area and Siting Constraint Conflicts under the Open Access, Conservative Technology Scenario

Because of overlaps between the siting constraint conflicts, columns sum to more than the total area with siting constraint conflicts. All values are in km^2.

	Washington	Oregon	California	Gulf of Mexico	South Atlantic	Mid-Atlantic	North Atlantic	Great Lakes
Total Region Area	**86,690**	**186,247**	**552,198**	**701,422**	**241,601**	**349,346**	**331,018**	**155,574**
Available Area	**12,047**	**28,618**	**17,324**	**294,120**	**145,634**	**60,621**	**133,022**	**29,011**
Area with Depth Siting Constraint Conflicts	57,487	153,038	449,396	232,444	8,154	230,870	122,138	93,903
Area with Oil and Gas Siting Constraint Conflicts	3	2	65	3,713	3	4,434	11,114	2
Area with Military use Siting Constraint Conflicts	1,016	91	93,853	83,813	69,506	79,556	34,703	6,703
Area with Conservation Siting Constraint Conflicts	8,235	3,034	31,268	9,033	2,521	370	15,040	23,771
Area with Shipping Lanes Siting Constraint Conflicts	1,160	0	2,558	32,730	1,109	700	11,437	0
Area with Ocean Disposal Sites Siting Constraint Conflicts	642	149	18,488	16,851	3,719	1,999	3,193	0
Area with Submarine Cable Siting Constraint Conflicts	3,172	4,775	11,364	2,283	4,106	1,461	20,810	733
Area with Shipwreck Siting Constraint Conflicts	0	0	0	0	0	0	0	2
Area with State Waters Siting Constraint Conflicts	8,657	3,085	13,755	62,937	9,400	22,252	21,814	26,515
Area with OCS Sand and Gravel Borrow Areas Siting Constraint Conflicts	0	0	0	0	4,489	3,311	1,982	0
Total Area with Siting Constraint Conflicts	**74,642**	**157,629**	**534,875**	**407,302**	**95,968**	**288,725**	**197,996**	**126,563**