



Summary Analysis of Different Offshore Wind Capacity Density Drivers in Proposed U.S. Projects and Impacts on Progress Towards State and Federal Deployment Targets

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What Is Capacity Density? Why Does It Matter?

$$\text{Capacity Density} = \frac{\text{Project Capacity}}{\text{Area}} \quad \left[\frac{\text{MW}}{\text{km}^2} \right]$$

- Capacity density is crucial for:
 - Resource potential analysis (calculating the U.S. Offshore Wind Pipeline)
 - Strategic planning
 - Supply chain
 - Port infrastructure needs
 - Workforce
 - Emissions.
 - Managing expectations → avoid unnecessary risks.

Why Look at Capacity Density Now?

- More projects in the permitting stage means more available data:
 - Site Assessment Plans (SAPs)
 - Construction and Operation Plans (COPs)
 - Draft Environmental Impact Statements (DEISs)
 - Official Press Releases.
- We get questions about capacity density all the time.

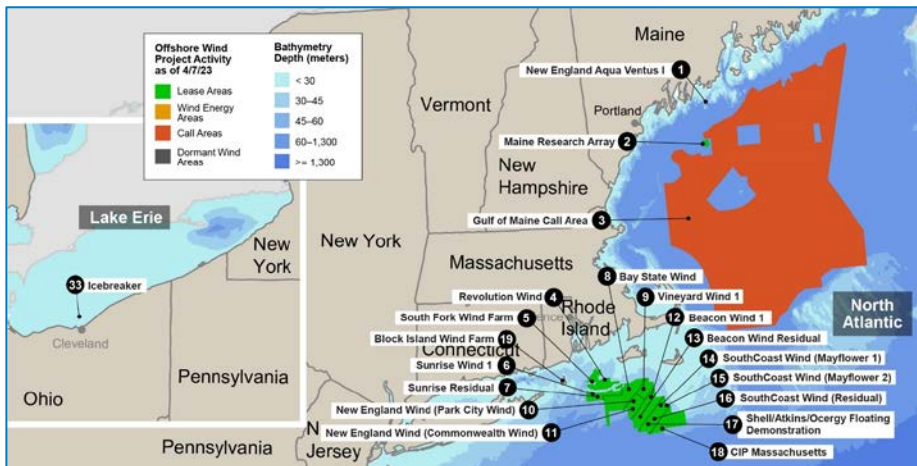


Image from Musial et al. (2023)

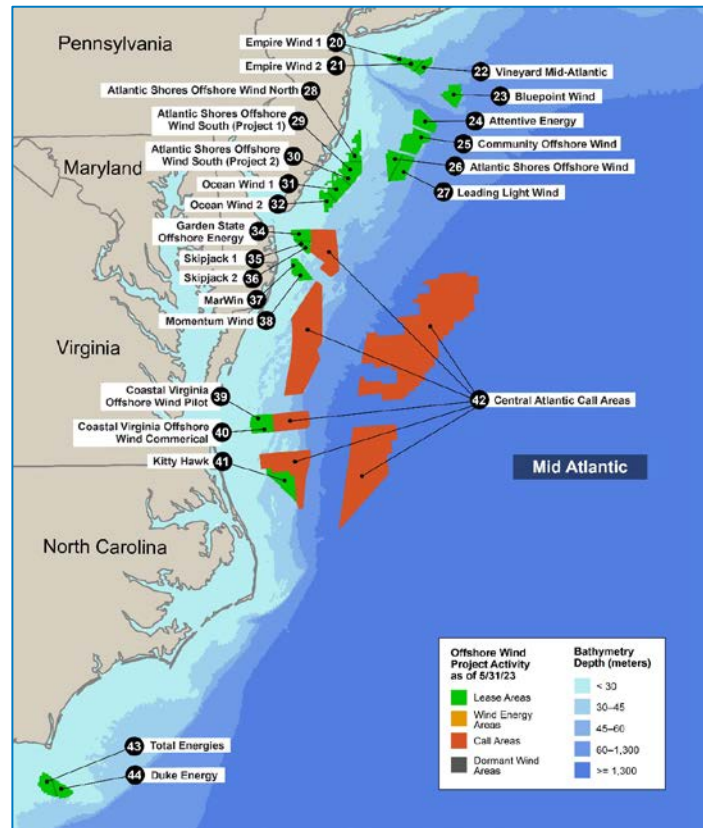
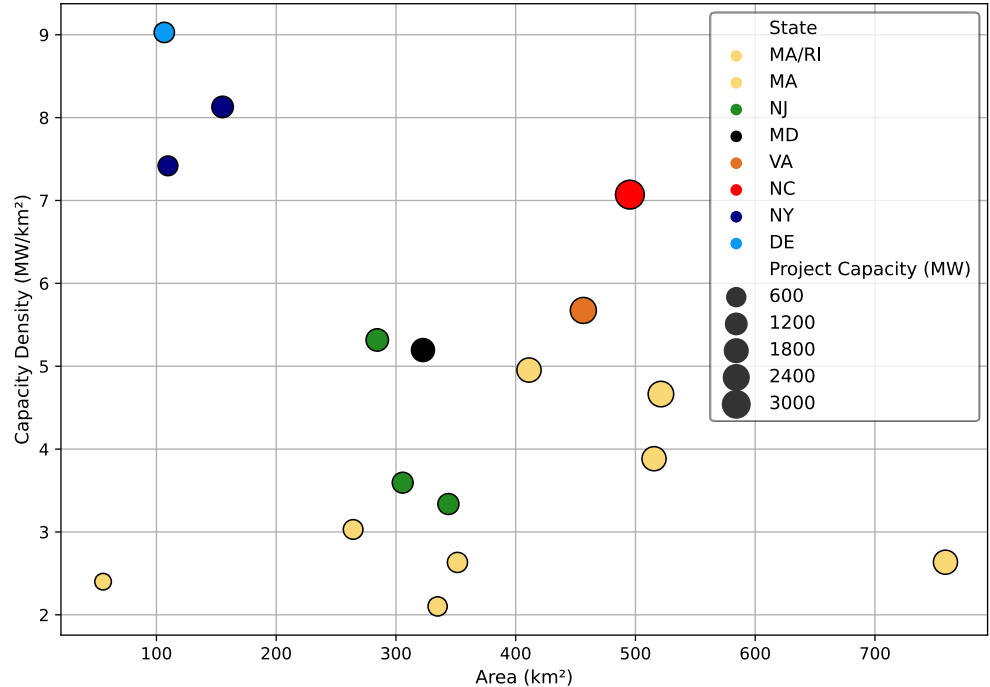


Image from Musial et al. (2023)

Summary Analysis

What Have We Analyzed?

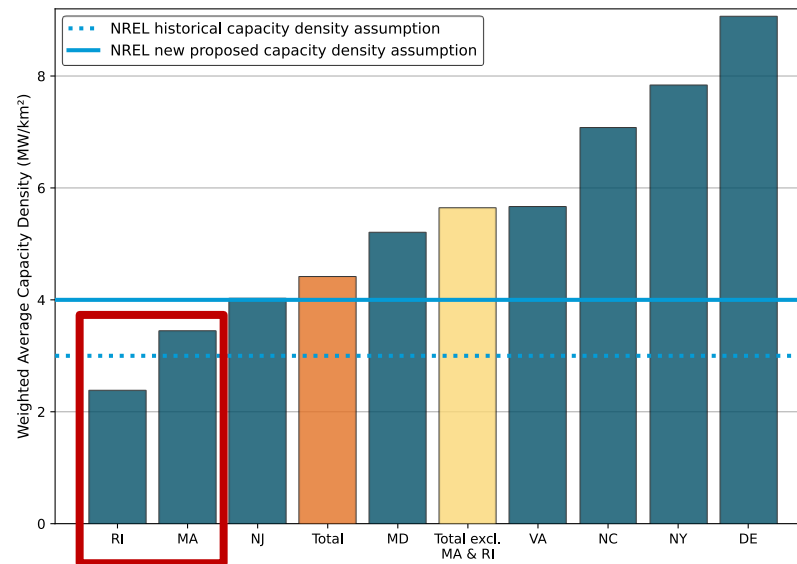
1. Collected project data for 16 projects that:
 - are large-scale
 - have public project documentation (SAPs/COPs/DEISs/Press Releases).
2. Analyzed the data for trends:
 - All are fixed-bottom projects
 - U.S. projects range is 2 to 9 MW/km².
3. Provided a list of the main capacity density drivers.



Capacity Densities in Massachusetts and Rhode Island Areas Are Constrained

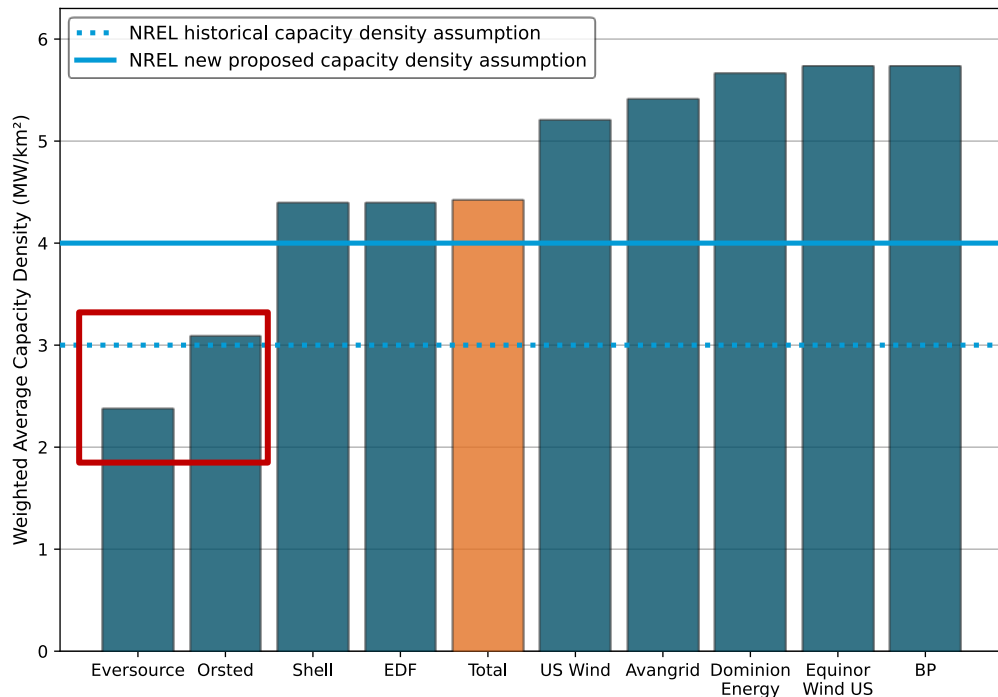
Massachusetts and Rhode Island (MA/RI) areas follow the 1 nautical mile (nm) by 1 nm U.S. Coast Guard recommendations (Coast Guard, DHS 2020)

Project	Lease Area	State	Turbine spacing
New England	OCS-A 0534	MA	1 nm x 1 nm
Bay State Wind	OCS-A 0500	MA	1 nm x 1 nm
SouthCoast Wind	OCS-A 0521	MA	1 nm x 1 nm
Vineyard Wind 1	OCS-A 0501	MA	1 nm x 1 nm
Beacon Wind	OCS-A 0520	MA	1 nm x 1 nm
South Fork Wind	OCS-A 0517	MA/RI	1 nm x 1 nm
Sunrise Wind 1	OCS-A 0487	MA/RI	1 nm x 1 nm
Revolution Wind	OCS-A 0486	MA/RI	1 nm x 1 nm
US Wind	OCS-A 0490	MD	0.77 nm x 1.02 nm
Kitty Hawk	OCS-A 0508	NC	0.76 nm x 1.19 nm
Atlantic Shores South	OCS-A 0499	NJ	1 nm x 0.6 nm
Ocean Wind 1	OCS-A 0498	NJ	1 nm x 0.8 nm
Empire Wind 1	OCS-A 0512	NY	0.71 nm x 0.71 nm
Empire Wind 2	OCS-A 0512	NY	0.71 nm x 0.71 nm
CVOW-C	OCS-A 0483	VA	0.75 nm x 0.93 nm



U.S. Weighted Total Average is 4.42 MW/km²
(5.64 MW/km² excluding MA/RI)

U.S. Industry Norms Without Constrained Spacing Are Greater Than 4 MW/km²



100 % of Eversource's offshore wind portfolio will take place in MA or RI lease areas.
55 % of Orsted's portfolio will take place in MA or RI lease areas.

- Capacity densities for **existing European projects** range from 2 to 19 MW/km².
- **Planning recommendations in Europe** range from 4.90 to 5.90 MW/km². (Borrmann et al. 2018, Müller et al. 2017, Hundleby and Freeman 2017)
- Both **Orsted and Eversource** have a considerable percentage of their portfolio in MA/RI lease areas.
- **Taking out Orsted and Eversource**, weighted average **capacity densities by developer in the United States** generally range from 4 to 6 MW/km².

Main Capacity Density Drivers

Area Utilization Drivers

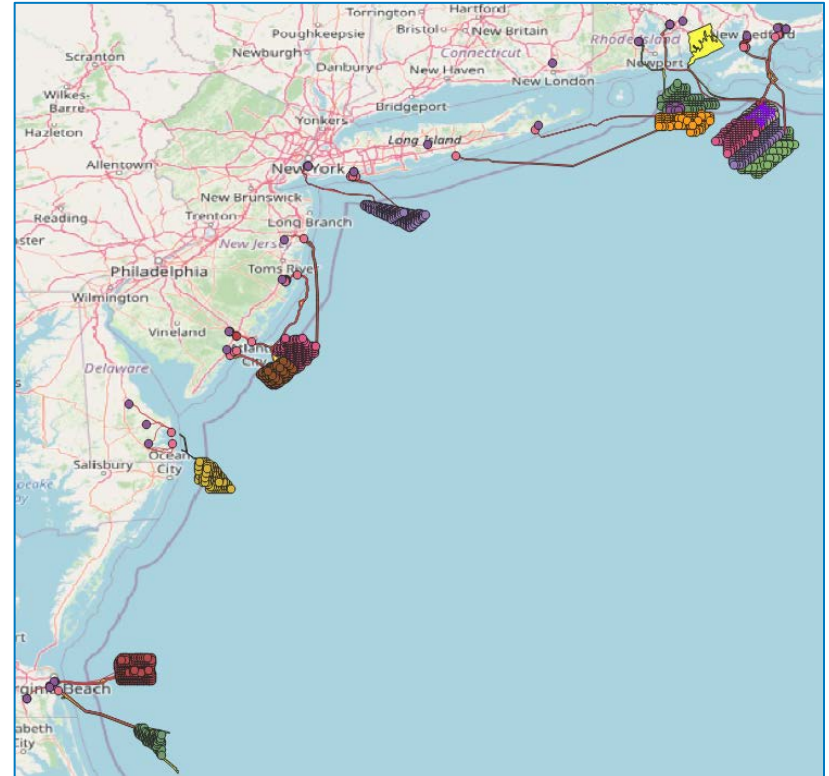
- Unfeasible turbine positions
- Lease area geometry
- Stakeholder considerations
- Area lost from anchor placement in floating systems.

Physical Project Design Drivers

- Turbine rating
- Turbine spacing
- Adjacent wind farms.

Economic and Policy Factors

- Offtake agreements
- Prescribed turbine spacing
- Lease area price
- State renewable energy policy.



GIS data from Bureau of Ocean Energy
Management (BOEM) 2023

Summary Analysis

- Based on limited available data (16 U.S. fixed-bottom projects), capacity densities range from 2 to 9 MW/km².
- There are many factors that influence capacity density.
- The U.S. Weighted Total Average is 4.42 MW/km² (5.64 MW/km² excluding MA/RI).
- The findings to this date may:
 - help make more accurate assessments of the U.S. Offshore Wind Pipeline
 - provide a better understanding of the factors that influence area utilization and capacity density for future strategic planning.

Impacts on Progress Towards State and Federal Deployment Targets

How Many Square Kilometers Do We Need to Reach Offshore Wind Goals?

State Planning Goals (Mandated State Procurements by Year for the East Coast)

State	Target (GW)	Year
ME	0.156	2030
RI	1.43	2030
CT	2	2030
MD	8.5	2031
VA	5.2	2034
LA	5	2035
MA	5.6	2035
NY	9	2035
NC	8	2040
NJ	11	2040
NY	20	2050
MA	23	2050

State Planning Goals (Mandated State Procurements by Year for the West Coast)

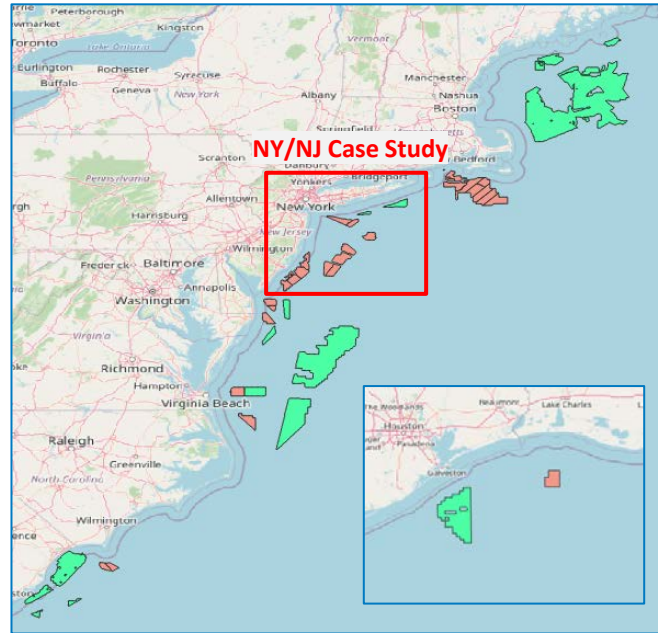
State	Target (GW)	Year
OR	3	2030
CA	25	2045

Federal Goal

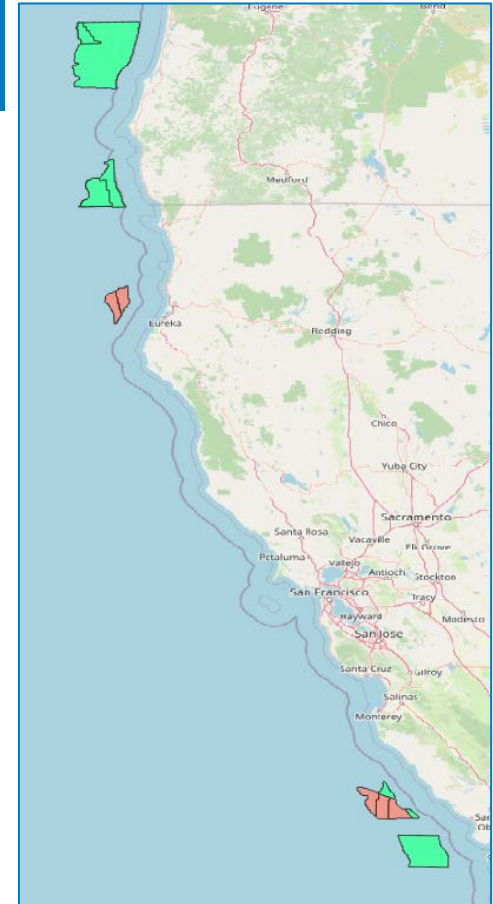
Target (GW)	Year
30	2030

Source: Musial et al. 2023

Planning Areas and Wind Lease Areas as of Oct 24, 2023



GIS data from BOEM 2023



GIS data from BOEM 2023

New York/New Jersey Case Study

NY/NJ Projects with a published COP

Lease	Project Name	Auction Date	State	Area (km ²)	Project Capacity (MW)	Capacity Density (MW/km ²)	Estimated COD	Time from Auction to COD (years)
OCS-A 0498	Ocean Wind 1	3/1/2016	NJ	306	1,100	3.60	3/1/2025	9
OCS-A 0499	Atlantic Shores	3/1/2016	NJ	414	2,400	5.80	3/1/2028	12
OCS-A 0512	Empire Wind	4/1/2017	NY	321	2,076	6.46	4/1/2027	10

NY/NJ Lease Areas without a published COP

Lease	Auction Date	State	Area (km ²)
OCS-A 0532	3/1/2016	NJ	344
OCS-A 0549	3/1/2016	NJ	329
OCS-A 0537	5/1/2022	NY/NJ	289
OCS-A 0538	5/1/2022	NY/NJ	341
OCS-A 0539	5/1/2022	NY/NJ	510
OCS-A 0541	5/1/2022	NY/NJ	321
OCS-A 0542	5/1/2022	NY/NJ	340
OCS-A 0544	5/1/2022	NY/NJ	174

Three deployment scenarios

1. Conservative

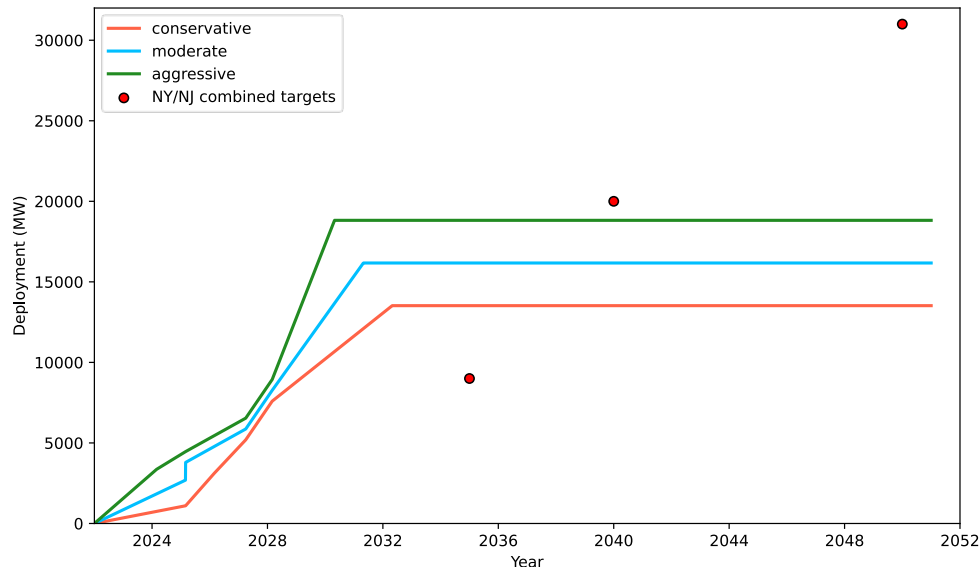
- 3 MW/km²
- 10 years from auction to COD.

2. Moderate

- 4 MW/km²
- 9 years from auction to COD.

3. Aggressive

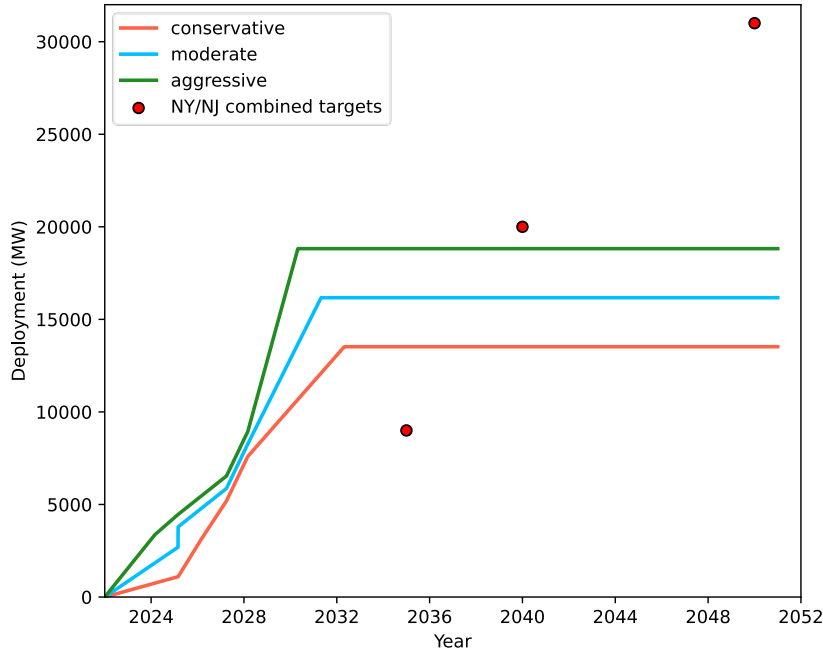
- 5 MW/km²
- 8 years from auction to COD.



Preliminary – Do not cite or quote

Conclusions

Area Required to be Leased to Meet New Jersey and New York Combined Targets



New York has 96 km² and 357 km² available on planning areas.

Target	Conservative	Moderate	Aggressive
9 GW by 2035	No area required to be leased	No area required to be leased	No area required to be leased
20 GW by 2040	6.5 GW by 2040 2,160 km ² by 2030	3.8 GW by 2040 960 km ² by 2031	1.2 GW by 2040 240 km ² by 2032
31 GW by 2050	17.5 GW by 2050 5,830 km ² by 2040	14.8 GW by 2050 3,710 km ² by 2041	12.2 GW by 2050 2,440 km ² by 2042

Assuming a capacity density of 5 MW/km², it is likely that at least 1 240-km² lease area would be required to meet the 20-GW by 2040 target.

Assuming a capacity density of 5 MW/km², it is likely that at least 7 360-km² lease areas would be required to meet the 31 GW by 2050 target.

Preliminary – Do not cite or quote

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Thanks!

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Supplemental Slides

Projects Data

Project	Lease Area Name	State	Area (acres)	Area (km ²)	Project Capacity (MW)	Capacity Density (MW/km ²)	Phase(s) Name(s)	Commercial Operation Date (COD)	Developer	Lease Area Price (2022\$)
Revolution Wind	OCS-A 0486	MA/RI	82,732	335	704	2.10	Revolution Wind	2026	Orsted/Eversource	1,634,784
South Fork Wind	OCS-A 0517	MA/RI	13,700	55	132	2.40	South Fork Wind	2024	Orsted/Eversource	268,397
Sunrise Wind 1	OCS-A 0487	MA/RI	86,823	351	924	2.63	Sunrise Wind 1	2026	Orsted/Eversource	1,903,181
Bay State Wind	OCS-A 0500	MA	187,523	759	2,000	2.64	Bay State Wind	TBD	Orsted	341,474
Vineyard Wind 1	OCS-A 0501	MA	65,296	264	800	3.03	Vineyard Wind 1	2024	Avangrid	71,341
Ocean Wind 2	OCS-A 0532	NJ	84,955	344	1,148	3.34	Ocean Wind 2	2028	Orsted	558,174
Ocean Wind 1	OCS-A 0498	NJ	75,525	306	1,100	3.59	Ocean Wind 1	2025	Orsted	496,516
SouthCoast Wind	OCS-A 0521	MA	127,388	516	2,004	3.88	SouthCoast Wind 1, SouthCoast Wind 2, Residual	2028, 2029, TBD	Shell/EDF	154,525,000
Beacon Wind	OCS-A 0520	MA	128,811	521	2,430	4.66	Beacon Wind 1, Residual	2029, TBD	Equinor Wind US/BP	154,525,000
New England	OCS-A 0534	MA	101,590	411	2,036	4.95	Park City Wind, Commonwealth Wind	2027	Avangrid	110,995
US Wind	OCS-A 0490	MD	79,707	323	1,678	5.20	MarWin, Momentum Wind, Future Development	2025, 2028, TBD	US Wind	10,553,535
Atlantic Shores South 1	OCS-A 0499	NJ	70,277	284	1,510	5.32	Atlantic Shores South 1	2027	Shell/EDF	1,205,011
CVOW-C	OCS-A 0483	VA	112,799	456	2,587	5.67	CVOW-C	2026	Dominion Energy	1,971,276
Kitty Hawk	OCS-A 0508	NC	122,405	495	3,500	7.07	Kitty Hawk North 1, Kitty Hawk North 2, Kitty Hawk North 3	TBD	Avangrid	10,592,835
Empire Wind 1	OCS-A 0512	NY	27,095	110	816	7.42	Empire Wind 1	2026	Equinor Wind US/BP	20,121,649
Empire Wind 2	OCS-A 0512	NY	38,363	155	1,260	8.13	Empire Wind 2	2027	Equinor Wind US/BP	28,489,641
Skipjack	OCS-A 0519	DE	26,332	107	966	9.03	Skipjack 1, Skipjack 2	2026, 2027	Orsted	-

Notes: Pilot projects are not included in this assessment. We select the WDA stated in the COP/DEIS/SAP for Sunrise Wind 1, Empire Wind 1, and Empire Wind 2. Under a conservative approach, we select the project 1 area plus the project 1 and 2 overlap area available for use for Atlantic Shores South 1. For the lease areas that were partitioned into separated lease areas after being auctioned, we distribute the original lease area price proportionally to the area (km²) of each of the new partitioned areas.