



Analysis of Offshore Wind Energy Leasing Areas for the Rhode Island/Massachusetts Wind Energy Area

W. Musial, D. Elliott, J. Fields, Z. Parker,
and G. Scott

Produced under direction of the Bureau of Ocean Energy Management (BOEM) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement M13PG00002 and Task No WFS3.1000.

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Executive Summary

The National Renewable Energy Laboratory (NREL), under an interagency agreement with the Bureau of Ocean Energy Management (BOEM), is providing technical assistance to BOEM on the identification and delineation of offshore leasing areas for offshore wind energy development within the Atlantic Coast Wind Energy Areas (WEAs) established by BOEM in 2012. This report focuses on NREL's evaluation of BOEM's Rhode Island/Massachusetts (RIMA) WEA leasing areas. The objective of the NREL evaluation was to assess the proposed delineation of the two leasing areas and determine if the division is reasonable and technically sound. Additionally, the evaluation aimed to identify any possible technical consequences resulting from the BOEM delineation.

As part of the evaluation, NREL researchers:

1. Performed a limited review of relevant literature and RIMA call nominations
2. Executed a quantitative analysis and comparison of the two proposed leasing areas
3. Conducted interviews with University of Rhode Island (URI) staff involved with the URI Special Area Management Plan (SAMP)
4. Prepared this report summarizing the key findings

NREL also reviewed information from the following sources:

- Rhode Island Coastal Resource Management Council OCEAN SAMP (RI SAMP 2010) and interviews with URI staff
- BOEM Wind Energy Area delineations, as described in the proposed sale notice, and economic considerations used by BOEM to inform the proposed sale notice
- BOEM Call for Information and Nominations for Commercial Leasing for Wind Power on the Outer Continental Shelf (OCS) off of Rhode Island and Massachusetts (referred to throughout this report as the "Call") and responses to the Call

The current RIMA Wind Energy Area delineation is logical in terms of providing two distinct developable leasing areas, based on the criteria that NREL used to evaluate the Rhode Island Wind Energy Area (see [Table ES1](#)). There are two proposed leasing areas: a north leasing area, with 97,498 acres, and a south leasing area, with 67,252 acres. The two areas differ significantly, with varying bathymetry, distance to shore, geotechnical, and wind access attributes. Together, these differing attributes lead to the north leasing area being a more competitive and cost-effective area for near-term commercial development. As such, we would anticipate that the north leasing area may also be more highly valued. Although a full quantitative analysis of all siting criteria was beyond the scope of this report, NREL performed both quantitative and qualitative analyses of the critical technical siting criteria listed in [Table ES1](#).

Table ES1. Evaluation Criteria used to Assess RIMA Wind Energy Areas

Quantitative Evaluation Criteria	Qualitative Evaluation Criteria Considered
Resource area (acres and km ²)	Seabed soil conditions
Development capacity potential (megawatts)	Distance from shore
Bathymetry (m)	Technology challenges
Gross capacity factor (%)	Development timing
Wind resource (meters per second)	Development cost
Wind direction and prevailing conditions	
Wake losses (%)	

[Table ES2](#) provides a comparison of the quantitative metrics for the RIMA Wind Energy Area leasing areas as proposed by BOEM. The north leasing area was larger, shallower, and closer to shore than the south leasing area. The annual average wind resource slightly favors the south leasing area, as indicated by the annual average wind speeds and gross capacity factors (less estimated wake losses) shown in the table. Both areas could provide over 1,000 megawatts (MW) of developable wind area (1,955 MW in the north leasing area and 1,440 MW in the south), based on the NREL 5-MW reference turbine and a nominal 8 rotor diameters (8D x 8D) array spacing (Jonkman et al. 2009, Musial and Ram 2010). Using these criteria, wake losses calculated using the AWS Truepower OpenWind Enterprise tool showed that the north leasing area was more burdened by wake losses than the south leasing area, but external and developer-imposed internal buffers could mitigate these losses.

Assuming that the boundaries of the WEA are fixed, NREL concluded that the BOEM leasing area delineation of north and south was a logical division that provided two leasing areas with natural buffers, but differing attributes.

Table ES2. Rhode Island/Massachusetts BOEM Wind Energy Area Characteristic Comparison
(Source: NREL)

Parameter	North Leasing Area	South Leasing Area
Total area (km ²)	394.6	272.2
Total area (acres)	97,498	67,252
Potential installed capacity (MW)	1,955	1,440
Average annual wind speed (m/s)	9.1	9.2
Average depth (m)	35.7	45.9
Gross capacity factor including wake losses (%)	46.6	47.4
Wake losses (%)	11.3	10.2
Potential annual energy production (AEP) gigawatt-hours (GWh)	7,982	5,985
Assumptions: NREL 5-MW turbine with 8D x 8D array spacing		

Below are the key findings of the NREL analysis and important considerations for policy makers and stakeholders involved in the RIMA offshore wind energy development process.

- The north leasing area is more economically and technically developable because it has shallower bathymetry, is closer to shore, and has a larger area than the south leasing area.
- Assuming that the boundaries of the wind energy area are fixed, the BOEM leasing area delineation of north and south was a logical division, but would not provide equal leasing areas in terms of potential development costs and resource access.
- It may be possible to split the north leasing area into two smaller leasing areas that could provide a nameplate development capacity of up to 500 MW.
- Both leasing areas are capable of supporting at least 1,000 megawatts (MW) of potential installed capacity. The potential installed capacity of the north leasing area is 1,955 MW and the south leasing area is 1,440 MW, based on dense 8D x 8D spacing with no internal buffers.
- The north leasing area can implement current fixed-bottom wind turbine technology in the near term. The south leasing area will be challenged by limits to current experience with fixed-bottom turbine technology with 88% of the resource area at 40-m+ depths and where commercially viable technical solutions have not been fully demonstrated (Musial and Ram 2010).
- The south leasing area may have a later project start of several years than the north leasing area because of increased costs and technical challenges associated with the deeper water in the south leasing area.
- The three islanded aliquots of the north leasing area are more difficult to develop because of their distance from (~10 km) the main lease blocks. The additional revenue from the remote turbines may not outweigh the additional cost of the electrical collection system and other infrastructure required to bridge the distance.
- The ten islanded aliquots in the south leasing area are all in shallower depths that are more comparable to the north leasing area. As a result, these aliquots could be reallocated to the north leasing area to create a more depth-homogeneous project area. This reallocation would add up to 90 MW of capacity to the north leasing area.
- Bathymetry variance within each leasing area may result in natural buffer zones within the WEAs, potentially reducing wake losses and project conflicts. The built-in 20-D external buffer between the north and south leasing areas will also help mitigate waking between the leasing areas (Barthelmie 2010).
- The wind resource is slightly better in the south leasing area, with estimated annual average wind speeds that are approximately 0.1 m/s higher, and with better exposure to predominant southwestern winds. In addition, this leasing area will have smaller potential wake losses. However, this benefit will fully offset higher development costs from deeper water and greater distance to shore.
- Prevailing winds have a strong unidirectional component from the southwest, making it more straightforward to orient the array, a characteristic which could help optimize layout design for both leasing areas.

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1 Project Background

Since 2009, the U.S. Department of the Interior’s Bureau of Ocean Energy Management (BOEM) has been working to create and collaborate with intergovernmental task forces to identify the most appropriate areas for commercial wind energy leasing on the Outer Continental Shelf (OCS) off the Atlantic Coast. To date, BOEM has identified six Wind Energy Areas (WEAs) on the OCS that are appropriate for commercial offshore wind energy development, with the goal of minimizing conflicts with existing uses and the environment. BOEM is currently considering issuing leases for five WEAs through a competitive process: 1) Virginia, 2) Rhode Island/Massachusetts, 3) New Jersey, 4) Maryland, and 5) Massachusetts. Except for Virginia, BOEM intends to offer more than one lease within each WEA. WEAs that have multiple leasing areas (all but Virginia) within their boundaries require analysis; using engineering tools and available WEA site characteristics to ensure that the leasing areas are appropriately divided.

1.1 Rhode Island/Massachusetts WEA and Leasing Areas

The National Renewable Energy Laboratory (NREL), under an interagency agreement with BOEM, is providing technical assistance to identify and delineate offshore leasing areas for wind energy development within the Atlantic Coast WEAs. The work being performed by NREL for each WEA depends on the specific area requirements, available information provided by BOEM, and a predetermined scope of work. This report focuses on NREL’s evaluation of BOEM’s Rhode Island/Massachusetts leasing area delineation. Background information and the scope of work for the Rhode Island/Massachusetts WEA are provided below.

BOEM has been working with the Rhode Island and Massachusetts Renewable Energy Task Force since 2009 to identify the most appropriate areas for offshore leasing in Rhode Island and Massachusetts. In July 2010, the two states signed a memorandum of understanding establishing the area of mutual interest on the OCS for joint coordination and collaboration of offshore wind energy development. Working with the joint task force, BOEM refined the area of mutual interest and published a Call for Information and Nominations for Commercial Leasing for Wind Power on the OCS off of Rhode Island and Massachusetts (referred to in this document as the “Call”) in the Federal Register in August 2011. In response to the Call, BOEM received eight nominations of interest wishing to obtain a commercial lease for offshore wind energy development. The Bureau then refined the area further and announced the identification of the Rhode Island/Massachusetts Wind Energy Area (RIMA WEA) in February 2012. BOEM intends to hold a lease sale for the RIMA WEA in 2013, with plans to issue leases corresponding to the entire WEA. The Bureau initially proposed to delineate the RIMA WEA into two leasing areas—north and south—for the lease sale. The north leasing area comprises 97,498 acres and the south leasing area comprises 67,252 acres, as shown in [Figure 1](#).

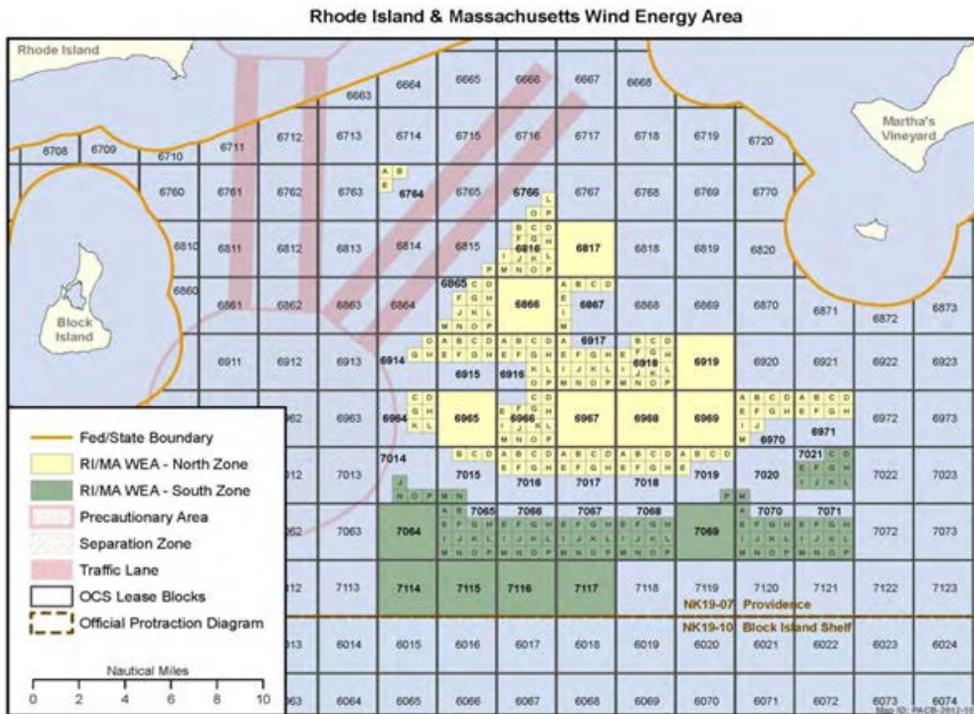


Figure 1. Proposed lease areas for RIMA WEA (north and south leasing areas)
(Source: BOEM)

1.2 Summary of Proposed Task Work

BOEM has proposed that the RIMA WEA be delineated into a north leasing area and a south leasing area, and provided NREL with these leasing area delineation coordinates for review. NREL assessed BOEM’s recommendation and the proposed sale notice, as well as the economic information that informed the proposed sale notice. NREL evaluated the proposed delineation on the basis of several technical criteria, including (but not limited to) total energy production capacity, wake losses, and water depth. This technical report summarizes the findings of the NREL analysis and identifies any potential technical consequences resulting from BOEM’s leasing area delineation.

BOEM also provided NREL with the eight nominations submitted in response to BOEM’s Federal Register Notices for use in NREL’s evaluation of the RIMA WEA leasing area delineation. These nominations, in many instances, included detailed project information such as siting constraints, project layout specifications, turbine type and size, foundation type, project capacity, development schedule, interconnect points, and various cost indices. NREL determined which (if any) of the provided information should be considered in the development of the leasing area identification and delineation methodology. As part of that process, NREL researchers considered factors such as meteorological information and potential wake effects between leasing areas.

2 Literature Review

During this project, NREL researchers reviewed the following technical documents and communications:

- Rhode Island Coastal Resource Management Council OCEAN SAMP (RI SAMP 2010) and interviews with University of Rhode Island (URI) staff.
- BOEM Wind Energy Area delineations, as described in the proposed sale notice, and economic considerations used by BOEM to inform the proposed sale notice.
- BOEM Call for Information and Nominations for Commercial Leasing for Wind Power on the OCS off of Rhode Island and Massachusetts (the “Call”) and responses to the Call.

2.1 Rhode Island Coastal Resource Management Council SAMP

The Rhode Island Special Area Management Plan (SAMP) document contains large amounts of technical detail on the proposed offshore wind areas including wind resource, bathymetry, geotechnical, marine transport and shipping, recreation and tourism, fisheries, and environmental considerations. In addition, the document highlights several key issues for offshore wind energy development, but most of those issues could not be evaluated for this analysis. For example, the SAMP report discusses the presence of glacial moraine in the soils, with higher levels found in the south leasing area. This presence could limit the type of turbine foundation that can be used in these areas. However, the report did not provide enough data on where these soils are present and how much area is affected, so it was not possible to make a strong case for modifying the leasing area on this criterion alone.

The original SAMP document contains information for the area bounded by the coordinates shown in [Figure 2](#). This SAMP area is significantly larger than the current proposed RIMA WEA shown in [Figure 1](#).

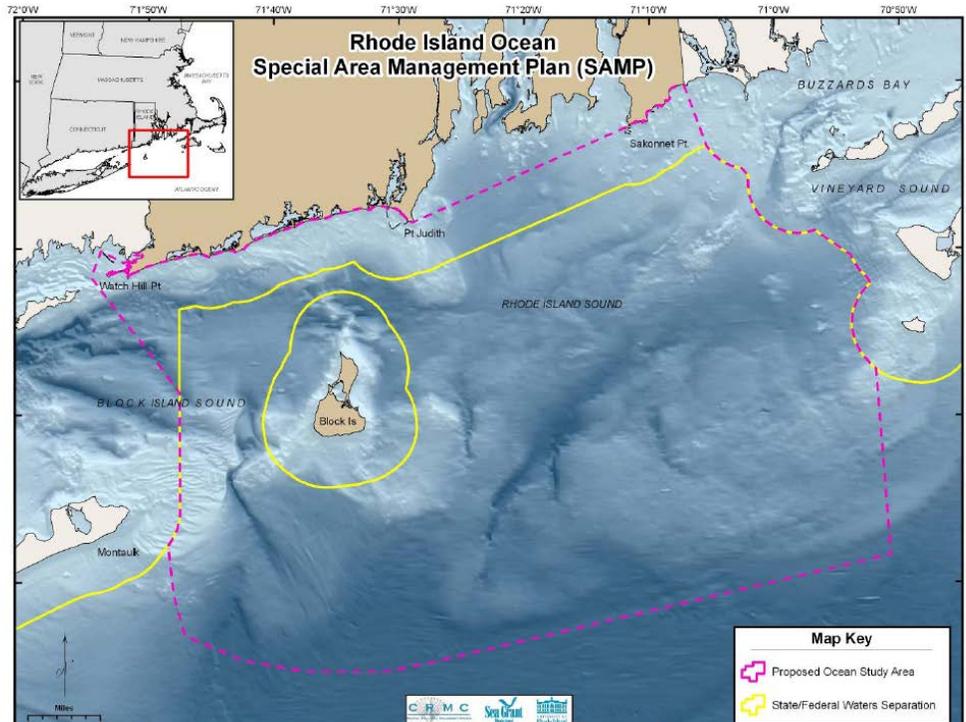


Figure 2. Rhode Island SAMP study area
 (North: 41.497420°; South: 40.912180°; West: -71.907426°; East: -70.848987°)
 (Source: RI SAMP 2010)

2.2 BOEM WEA Delineations

The current WEA under consideration, shown in [Figure 1](#), evolved significantly over time as input was received by BOEM from various stakeholder groups and as a result of the SAMP process. NREL used the final north and south leasing areas shown in [Figure 1](#) for RIMA WEA to perform the analysis in this report. It should be noted that the leasing areas are not equal in terms of area, depth, and distance to shore, and most likely will be valued differently by offshore wind developers. However, assuming that the boundaries of the WEA are fixed, the BOEM proposed delineation offers two distinct leasing areas, each with advantages and disadvantages that are separated by external buffer zones.

NREL was not asked to evaluate alternative delineation methods as part of this report, but a qualitative NREL assessment suggests that an additional delineation, from north to south, through the north leasing area could create two approximately equal leasing areas in terms of area, potential power production, and bathymetry. This alternative would subdivide the shallower north leasing area into two areas with approximately equal near-term development potential, but with a developable capacity only up to 500 megawatts (MW) per leasing area.

2.3 Evaluation of RIMA Call Notice Responses

NREL was provided with confidential access to the eight industry responses to the Call. These nominations served to provide insight into the commercial sector considerations for offshore development and wind energy leasing area delineation.

The Call responses addressed the following topics as part of their RIMA development recommendations:

- Wind resource
- Bathymetry and geotechnical attributes
- Marine transport and shipping
- Recreation and tourism
- Fisheries and commercial interests
- Environmental factors.

Key findings from NREL’s review of the nominations are shown in [Table 1](#). Because of confidentiality requirements, the project data from the industry responses were reduced to statistical averages, and maximum and minimum values and area compared to the nominal values determined from the NREL analysis.

Table 1. Summary of Nomination Statistics from the BOEM Rhode Island/Massachusetts Wind Energy Area Call (Source: NREL)

	Average	Maximum	Minimum	NREL Values
Project nameplate capacity (MW)	1,038	2,000	501	3,395
Turbine nameplate capacity (MW)	4.76 (Model is 5 MW)	7	3	5
Avg wind resource (meters per second) at 90 meters (m)	9.1	9.6	8.4	9.2
Proposed project area (km ²)	482	750	262	667
Array spacing (rotor diameters)	12D x 12D	15D x 15D	9D x 9D	8D x 8D
Array power density (MW/km ²)	2.2	1.4	3.9	4.9
Number of turbines	209	334	140	679
Notes:				
1. NREL used the RIMA WEA (8/8/12) for its analysis, which differs from the WEA considered by developers during the call for nominations.				
2. Array power density computation assumes 126-m NREL reference turbine dimensions and nameplate power capacity.				

Note that NREL’s assessment used conservatively high turbine array density (5 MW/km² and 8D x 8D turbine spacing) that is consistent with the gross resource estimations carried out in 2010 (Schwartz et al. 2010), but may not reflect current best practices. This differs from the nominal proposed offshore wind projects for the RIMA WEA. However, NREL wanted to remain consistent with past analysis and used a high density array to induce enhanced wake effects for the purposes of this investigation. Array densities proposed by developers ranged from 1.4 to 3.9 MW/ km². This turbine spacing tends to reflect an industry trend toward more cautious siting practices to avoid large wake losses. This trend can be contrasted against early wind projects like the 80 turbine Horns Rev project in Denmark, which used higher array power densities (6.4 MW/ km² and 7D x 7D turbine spacing). Although Horns Rev is not the highest density offshore array, its performance is well-documented with array losses over 10% (Hansen et al. 2012).

During the nomination evaluation, some prospective developers expressed concerns about the economic and technical viability of development in deeper water [40 or more meters (m)], that is prevalent in the south leasing area. These findings are generally consistent with typical offshore project proposals, industry experience, and NREL's prior experience, and did not significantly influence the conclusions of this report or the NREL evaluation of the proposed BOEM delineation of the RIMA WEA.

3 NREL Methodology

NREL's technical assessment of the leasing area delineation included the use of input data from a variety of sources to model and compare key parameters such as maximum development capacity, wind speed, wind direction, and wake losses. To model these parameters, gridded layouts representative of maximum turbine deployment were created and evaluated with the OpenWind Enterprise tool developed by AWS Truepower.

3.1 Evaluation and Use of SAMP and Nominations Information

NREL evaluated both the SAMP and industry nominations, as described in [Section 2](#). These evaluations were used to guide the analysis, along with NREL's own expertise, available data, and numerical models. Note the following important caveats about these documents:

- The SAMP analysis is useful in informing the current WEA; however, the SAMP analysis area is much larger than the current WEA established by BOEM in February 2012. Therefore, the conclusions drawn from SAMP are broader and may be less applicable to the WEA in its current configuration.
- The current WEA established in February 2012 is also smaller than the area referenced in the Call, released in August 2011. Therefore, broader conclusions drawn from the nominations may also have diminished applicability to the WEA in its current configuration.

NREL researchers utilized the available information to guide our analysis and ensure that the analysis included all potential scenarios from the developers. Specifically, researchers focused on the wind resource, array spacing, and nominated areas to inform the analysis. NREL is unable to present additional specifics from the Call documents because of their proprietary nature; however, many of the documents included perceptions on economic drivers, which generally agreed with the conclusions provided in this document.

3.2 Characterization of Wind Resource and Wake Effects

To evaluate the wind resource across the RIMA WEA, NREL researchers used time-series-modeled wind data from AWS Truepower. Researchers also determined the wind speed gradient across the WEA and the directional distribution. Wake losses were evaluated using the Deep Array Fast Eddy-Viscosity Wake Model (DAWM Fast Eddy-Viscosity) in OpenWind Enterprise (see [Section 3.3.2](#)) and the gross capacity factor was determined for each leasing area by accounting for only the losses that were caused by wake effects.

3.3 OpenWind Enterprise Tool

The OpenWind Enterprise tool is a wind energy facility design tool created by AWS Truepower (validated in 2010) and licensed to NREL (AWS Truepower 2010). The tool can be used for layout design, flow modeling, wake modeling, and energy assessment; and it was selected for its interoperability with geographic information system (GIS) data as well as its ability to model deep array wake effects. OpenWind Enterprise is intended for commercial applications. The following paragraphs describe the primary OpenWind components.

3.3.1 WindMap Flow Model

The WindMap flow model within OpenWind is based on the NOABL code (Phillips 1979) and solves the conservation of mass equation to generate a three-dimensional wind flow map. The model accounts for moderate changes in terrain and surface roughness when used in conjunction with measured time series meteorological data.

3.3.2 Wake Model

Wind turbine wake modeling is an emerging science and carries a relatively high uncertainty. Uncertainties include measurement uncertainty, the effect of wake meandering, and even fundamentals such as the correct choice of free-stream wind speed profile (Barthelmie et al. 2005). As a result, it is difficult to make an accurate comparison of the different wake models that are currently available. Wake models and scientific approaches are evolving rapidly. More computationally intensive research methods that are used to calculate wakes are currently applied in research laboratories that are not yet practical for commercial use (e.g., large-eddy simulations) (Churchfield et al. 2012). Even though these methods may produce more accurate results, they are still under development and are computationally too expensive to be used for wind energy evaluations like the one conducted for this report. As of the writing of this report, the OpenWind DAWM model is one of the most widely used and accepted tools in industry. NREL's prior experience (mostly land-based) indicates that the OpenWind DAWM model performs better than other models currently available.

The DAWM Fast-Eddy Viscosity within OpenWind (AWS Truepower 2010) is a combination of the open-source standard Eddy-Viscosity (EV) model and a roughness effect associated with each turbine.

3.3.3 Layout Design

The gridded turbine layer function within OpenWind was used to create maximum capacity layouts to fill the WEA zones. An assumption of $8D \times 8D$ (rotor diameter) turbine spacing was used by NREL as the reference spacing for the analysis, based on an assumed 5-MW/km^2 resource capacity, when calculating the global gross offshore wind resource potential of the OCS (Musial and Ram 2010). As noted in [Section 2](#), potential RIMA developers prefer larger array spacing. Square or triangular tiling is used with manually adjusted bearing, obliquity, and offset to obtain the maximum number of turbines.

3.3.4 Energy Assessment

The energy capture function in OpenWind sums the energy produced by the turbines using 72 direction sectors and 71 wind speed steps. It calculates and stores the energy yield, capacity factor, and wake losses associated with each turbine. Losses other than those caused by the wake effect can be accounted for by directly entering assumptions or calculating from other layers.

4 Results and Conclusions

4.1 Summary of Results

The comparison of the north and south leasing areas of the Rhode Island/Massachusetts (RIMA) Wind Energy Area (WEA) shows important differences between the two leasing areas in terms of potential development challenges and cost. Generally, researchers from the National Renewable Energy Laboratory (NREL) found that the north leasing area, as delineated by the Bureau of Ocean Energy Management, had more favorable characteristics with respect to maximum potential project size and ease of development, considering the criteria listed in [Table 2](#).

Overall, the south leasing area had more favorable access to the southwesterly winds and would have a better wind resource and lower wake losses. However, the better wind and unobstructed exposure in the south leasing area is unlikely to offset the increased costs and technical challenges of its deeper water.

Table 2. Evaluation Criteria used to Assess RIMA Wind Energy Areas

Quantitative Evaluation Criteria	Qualitative Evaluation Criteria Considered
Resource area (acres and km ²)	Seabed soil conditions
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Bathymetry (m)	Technology challenges
Gross capacity factor (%)	Development timing
Wind resource (m/s)	Development cost
Wind direction and prevailing conditions	
Wake losses (%)	

[Table 3](#) provides a comparison of the quantitative metrics for the RIMA Wind Energy Area leasing areas as proposed by BOEM. The north leasing area is larger, shallower, and closer to shore than the south leasing area. The annual average wind resource slightly favors the south leasing area, as indicated by the annual average wind speeds and gross capacity factors (less estimated wake losses) shown in the table. Both areas could provide over 1,000 megawatts (MW) of developable wind area (1,955 MW in the north leasing area and 1,440 MW in the south) based on the NREL 5-MW reference turbine and nominal 8 rotor diameters (8D x 8D) array spacing (Jonkman et al. 2009, Musial and Ram 2010). Using these criteria, the wake loss analysis that was calculated using the AWS Truepower OpenWind Enterprise tool showed that the north leasing area was more burdened by wake losses than the south leasing area, but natural and developer-imposed internal buffer zones could mitigate these losses.

Assuming that the boundaries of the WEA are fixed, NREL concluded that the BOEM leasing area delineation of north and south was a logical division that provided two leasing areas with external buffers, but differing attributes.

Table 3. Rhode Island/Massachusetts BOEM Wind Energy Area Characteristic Comparison
(Source: NREL)

Parameter	North Leasing Area	South Leasing Area
Total area (km ²)	394.6	272.2
Total area (acres)	97,498	67,252
Potential installed capacity (MW)	1,955	1,440
Average annual wind speed (m/s)	9.1	9.2
Average depth (m)	35.7	45.9
Gross capacity factor including wake losses (%)	46.6	47.4
Wake losses (%)	11.3	10.2
Potential annual energy production (AEP) gigawatt-hours (GWh)	7,982	5,985
Assumptions: NREL 5-MW turbine with 8D x 8D array spacing		

4.2 Leasing Area Development Capacity

The development capacity of the two leasing areas was evaluated by creating layouts that maximized the developable area of the leasing zones using the NREL 5-MW reference turbine (Jonkman et al. 2009) with 8D x 8D spacing. In creating these layouts, no additional buffer zones were added other than the external buffer (~20D) between the two leasing areas was applied. The potential nameplate capacity in megawatts, as a function of depth, was also analyzed and compared. For this analysis, it was assumed that all areas were developed, regardless of potential technology challenges in the deeper aliquot portions. As shown in [Figure 3](#), the entire WEA was filled with 5-MW turbines in a gridded array to maximize the 8D x 8D turbine density for the OpenWind analysis. This allowed the researchers to make a determination of the upper bound for development potential and wake losses.

We discovered that both areas could support large-scale offshore wind project development with over 1,000 MW of developable wind area. The north leasing area has a greater maximum capacity with 1,955 MW, representing about 58% of the total capacity of the WEA, than the south leasing area, which has 1,440 MW, representing about 42% of the WEA.

Some additional observations by NREL that may affect development capacity are as follows:

- The three islanded aliquots of the north leasing area may be more difficult to develop due to their distance (~10 km) to the main lease blocks. The additional revenue from the turbines may not outweigh the additional cost of the electrical collection system and other infrastructure required to bridge the distance.
- The 10 islanded aliquots in the south leasing area are all in shallower depths and therefore more comparable to the north leasing area. These aliquots could be reallocated to the north leasing area to create a more depth-homogeneous project area. This reallocation would add up to 90 MW of capacity to the north leasing area.

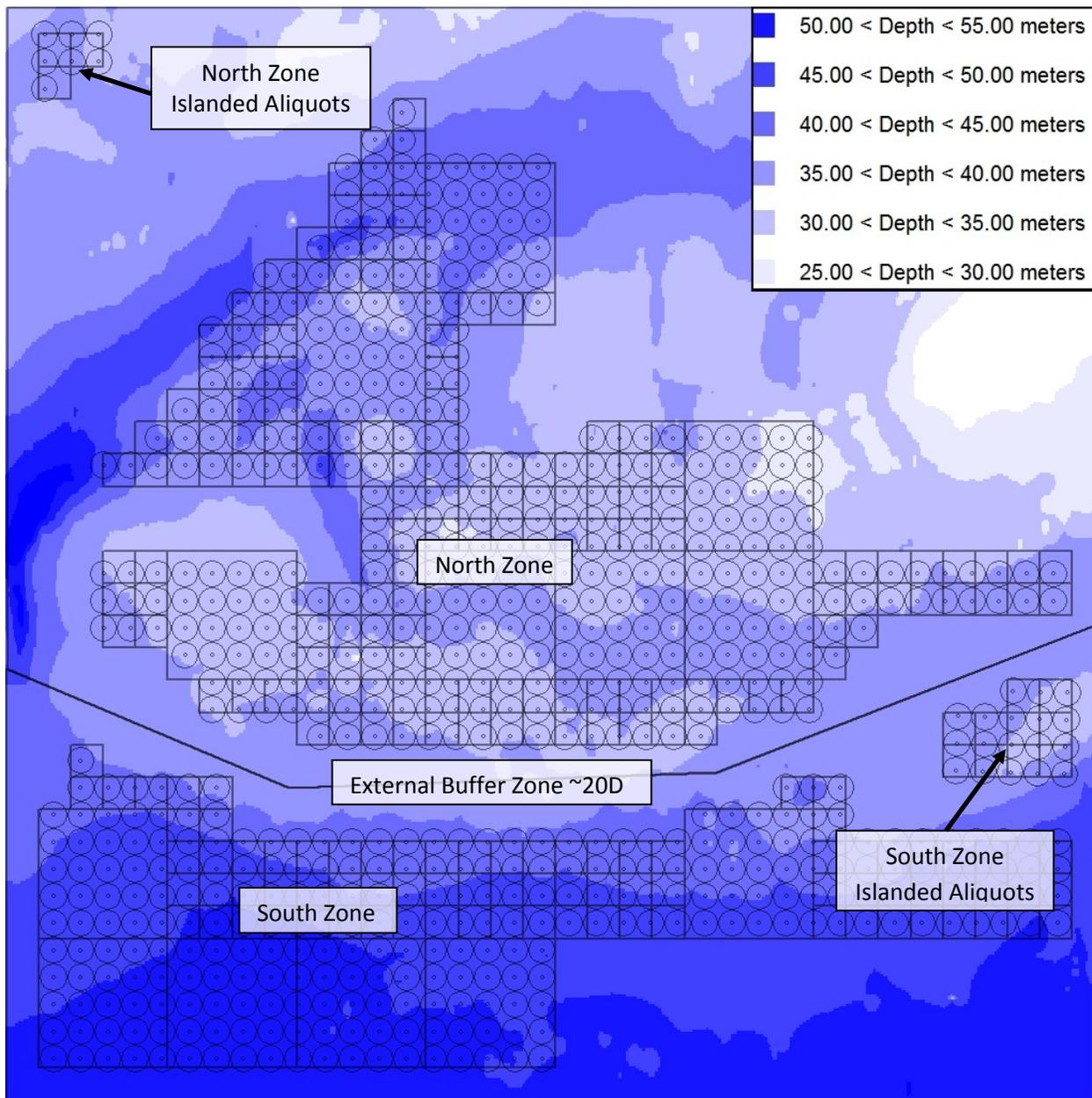


Figure 3. Turbine 8D x 8D layout and depth map for the north and south leasing areas
(Source: NREL)

4.3 Bathymetry

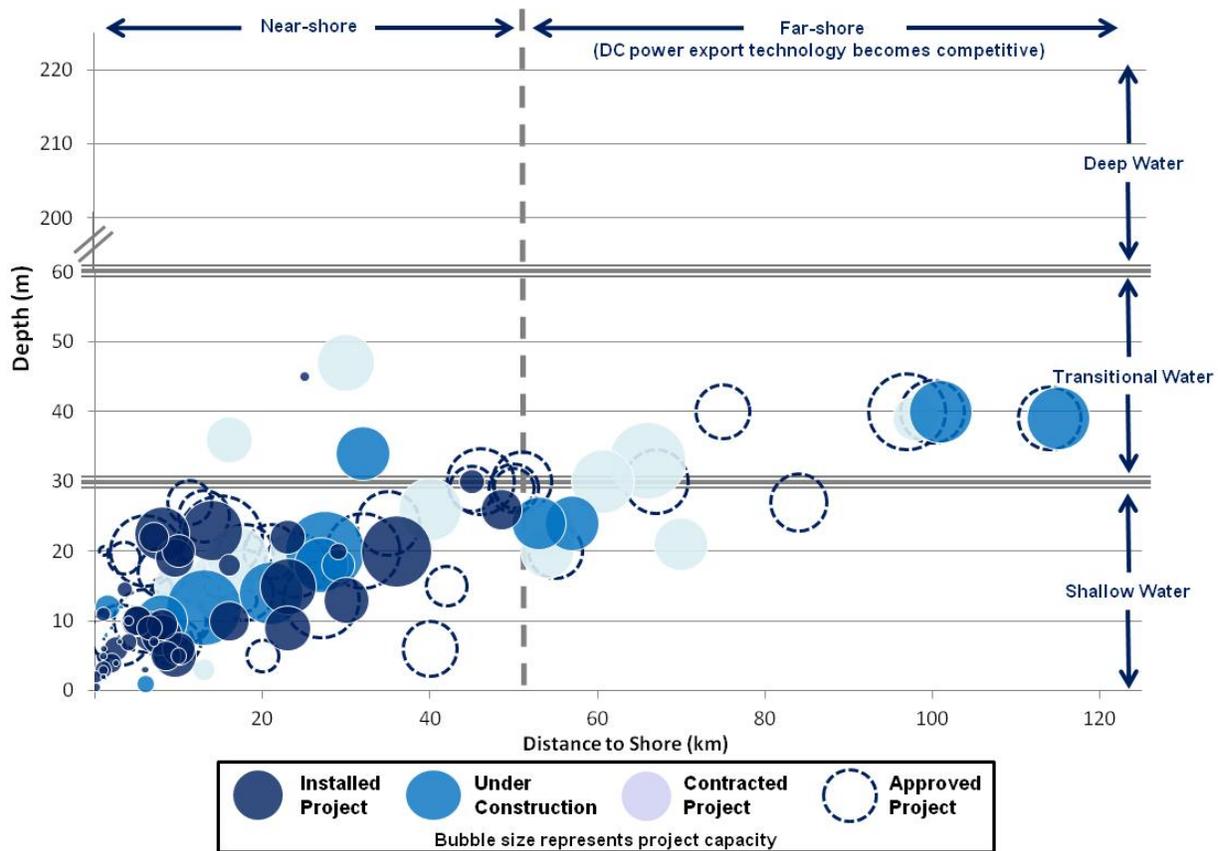
Water depth is a significant driver in the cost of offshore wind and was a primary criterion that was used by NREL to evaluate the BOEM delineation of the RIMA Wind Energy Area. [Table 4](#) shows the maximum deployment capacity that can be supported by the two proposed leasing areas by depth. The analysis shows (quantitatively) that the south leasing area is significantly deeper.

Table 4. Potential Installed Wind Capacity by Leasing Area and Depth (Source: NREL)

Depth Range	North Leasing Area		South Leasing Area		Total Wind Energy Area	
	Capacity [Megawatts (MW)]	Turbines	Capacity (MW)	Turbines	Capacity (MW)	Turbines
25–30 meters (m)	45	9	0	0	45	9
30–35 m	990	198	55	11	1,045	209
35–40 m	685	137	110	22	795	159
40–45 m	220	44	400	80	620	124
45–50 m	15	3	590	118	605	121
50–55 m	0	0	285	57	285	57
Total	1,955	391	1,440	288	3,395	679

The north leasing area corresponds to an average water depth of about 35 meters (m), with significant capacity in waters below this depth. However, 96% of the capacity of the south leasing area corresponds to a depth of greater than 35 m, with 88% above 40 m in depth.

The greater overall depth of the south leasing area represents a significantly higher cost of development (with an estimated 20%–40% increased substructure cost) and would require technology that has not yet been demonstrated on a large scale in European wind facilities. [Figure 4](#) shows the current projects installed, under construction, contracted, or approved in Europe as a function of water depth and distance from shore.



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Figure 4. Current offshore wind projects in Europe (installed, under construction, contracted and approved) as a function of water depth and distance to shore
(Source: NREL)

Figure 4 shows that most of the technology for support structures has not been deployed beyond the 40-m depth. A large part of this is due to the fact that shallow waters are more abundant in the North Sea and European offshore wind developers have not yet had to venture into deeper waters.

Figure 5 shows that approximately half the cost of offshore wind projects is related to balance of station (BOS). BOS is defined as the balance of equipment on a wind project that is not the turbine, namely foundations and support structures, installation costs, substations, and the electrical collection system. Therefore, some of the biggest cost drivers for offshore wind projects are factors affecting BOS.

Deeper waters would increase the amount of steel required for a given support structure and could limit the feasibility of some support structure options. The depth of the waters in the RIMA WEA, particularly for the south leasing area, could also limit vessel options and increase the cost of the vessels needed by dictating more specialized capabilities. As such, NREL anticipates that the south leasing area may have a later project start of several years compared to the north leasing area because of increased costs and technical challenges that are a consequence of deeper water.

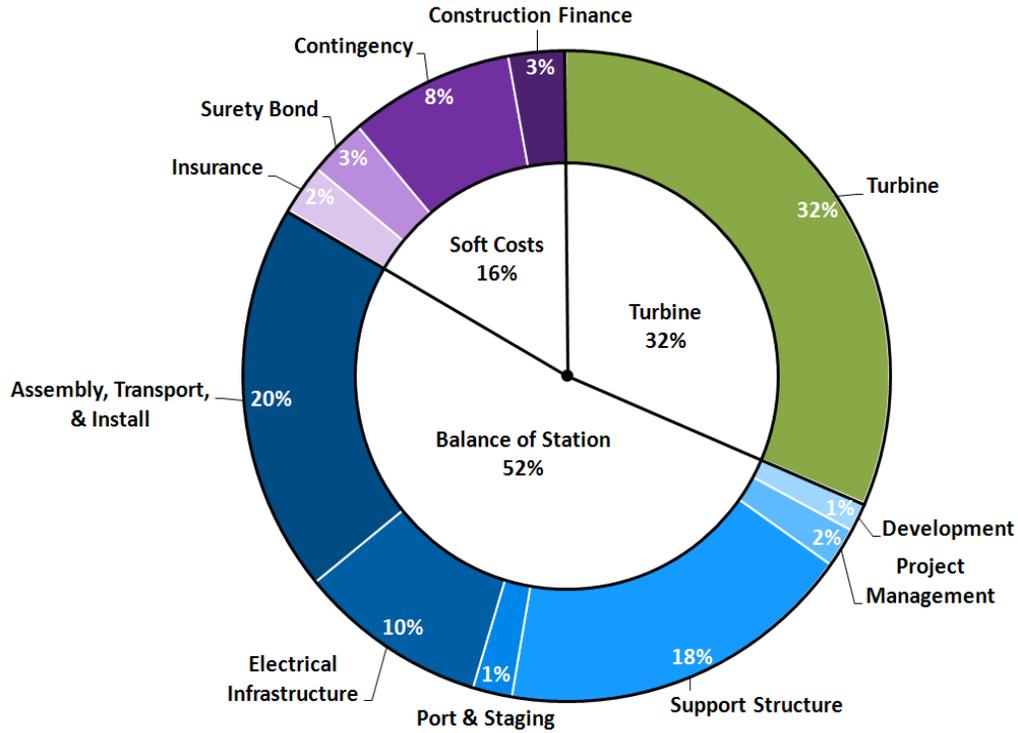


Figure 5. Offshore wind project development cost breakdown
(Source: NREL)

Figure 6 shows a trend of rising cost as water depth increases (Maples 2012). Although this figure only extends to a depth of 30 m, this preliminary analysis led researchers to conclude that the model would likely show a cost trend that continues to rise, and perhaps rise more steeply at greater depths.

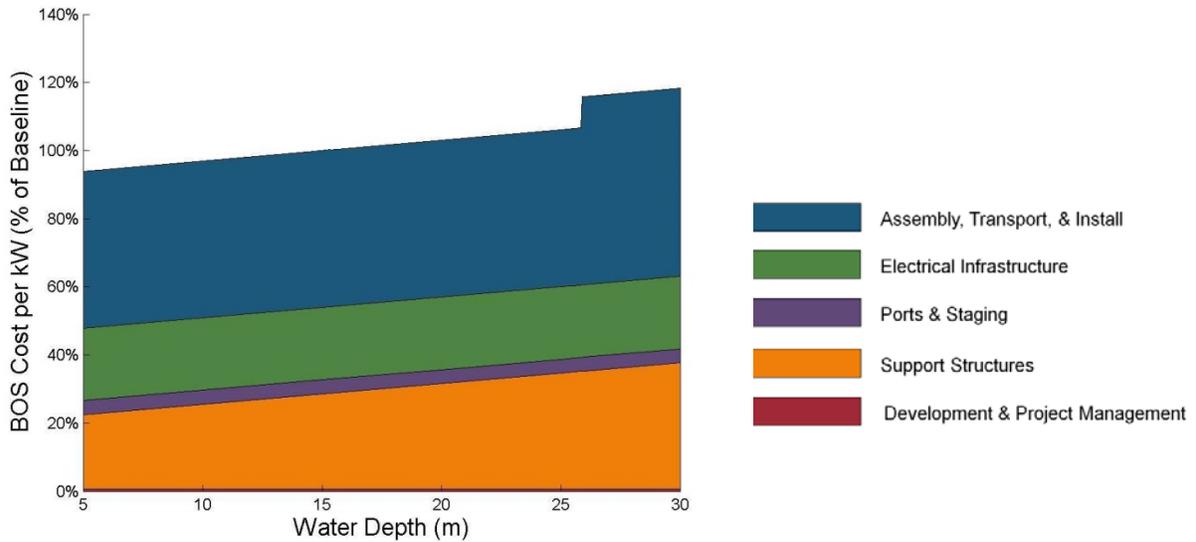


Figure 6. BOS development cost by depth
(Source: Maples 2012)

4.4 Wind Resource

The RIMA WEA wind resource is dominated by strong southwest winds, with an annual average wind speed shown in [Figure 7](#) (approximately 9.1 m/s in the north leasing area compared to 9.2 m/s in the south, both at 90 m hub height). The southeast has slightly higher winds than in the northwest. The wind speed gradient across the entire RIMA WEA is small and only about 0.2 m/s. The prevailing winds, shown by the wind rose in the center of [Figure 7](#), and in more detail in [Figure 8](#), come from a well-defined prevailing southwest component.

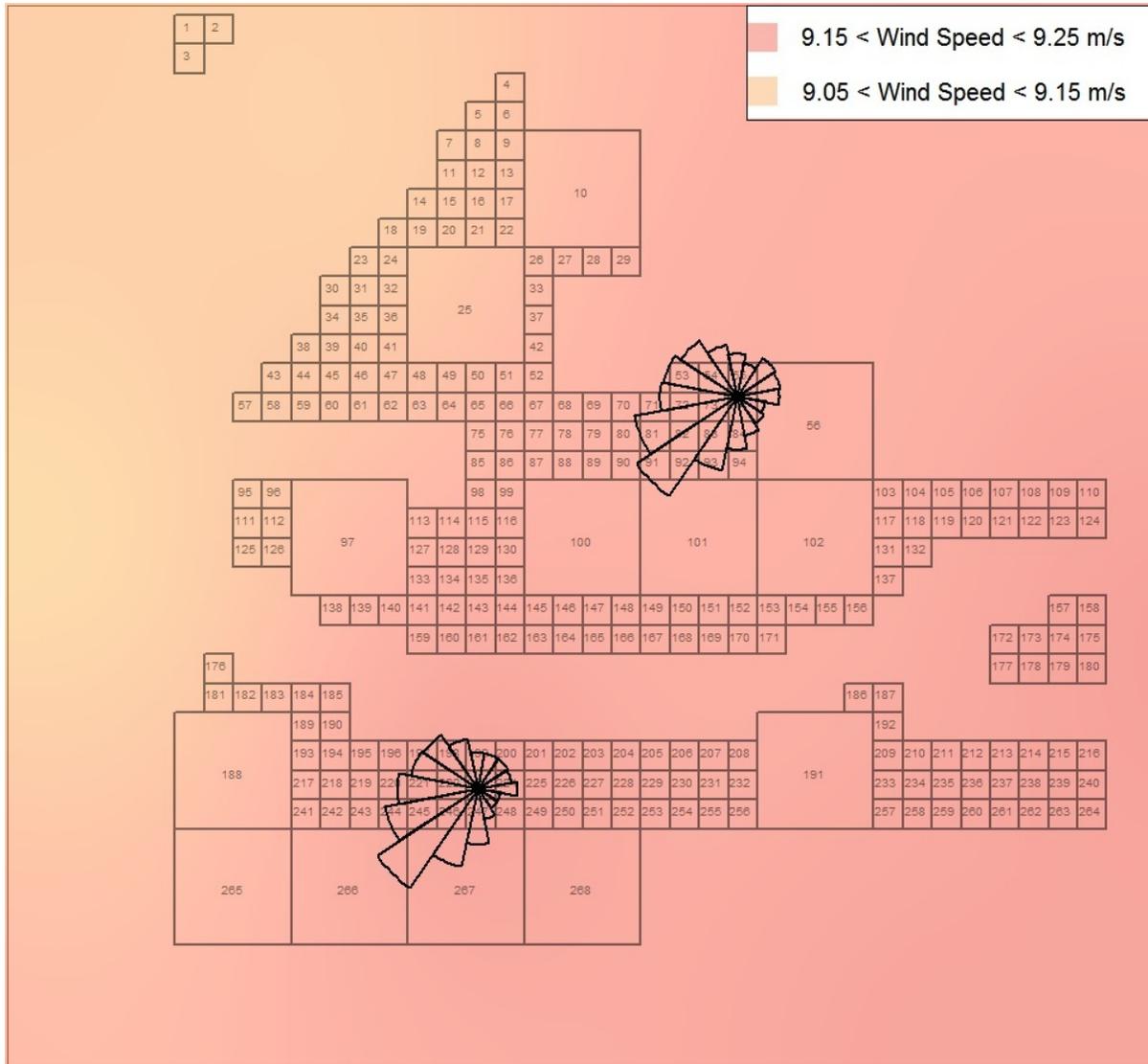


Figure 7. RIMA WEA showing the annual average wind speed in 0.1 meters per second (m/s) increments and wind roses for each leasing area
(Source: NREL)

4.5 Gross Capacity Factor and Wake Effects

[Figure 8](#) shows a wind rose of the annual wind distribution for the RIMA WEA. The prevailing wind comes from the southwest direction. Therefore, there is potential for the north leasing area to experience greater wake effects from a fully developed south leasing area. These interarray effects would be greatest among the north leasing area turbines that are placed adjacent to the external buffer dividing the two leasing areas, although the OpenWind model predicts that the overall wake losses will differ by just over 1% between the two leasing areas. Generally, the strong unidirectional component from the southwest prevailing winds may make array orientation more straightforward, which could help developers optimize layout design for both leasing areas.

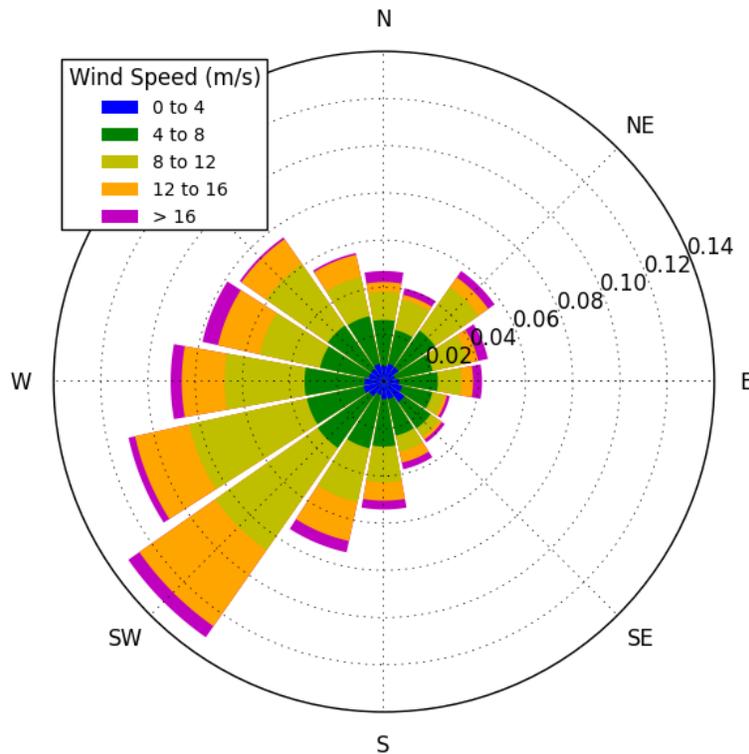


Figure 8. RIMA WEA annual average wind rose showing strong prevailing winds from the southwest (Source: NREL)

[Table 5](#) provides an assessment of average wake losses predicted by OpenWind for both leasing areas assuming that they are fully developed and using 8D x 8D spacing. All stated capacity factors include wake losses but do not account for other losses such as electrical transmission losses.

Table 5. Capacity Factor (Less Wake Losses) and Wake Losses by Leasing Area
(Source: NREL)

Parameter	North Leasing Area	South Leasing Area
Capacity factor	46.6%	47.4%
Wake loss	11.3%	10.2%

Developer imposed increases in array spacing and internal buffer zones may reduce wake losses considerably. Also, variations in bathymetry within both leasing areas may inhibit uniform grid spacing in which could provide internal buffer zones within the WEAs, having the benefit of potentially reducing wake losses and project conflicts. The built-in 20-D external buffer between the north and south leasing areas will also help mitigate waking between the leasing areas (Barthelmie 2010).

4.6 Qualitative Evaluation Criteria

Several qualitative criteria were considered in this evaluation including seabed conditions, distance from shore, development cost and timing, and technology challenges.

Concerns regarding seabed soil conditions have been raised in the Special Area Management Plan and by the University of Rhode Island. Glacial moraine substrates that may prevail in some areas could be unsuitable for certain foundation types, thereby further impacting development costs, especially in the south leasing area. If certain foundation types (e.g., pile-driven substructures) are eliminated because of unsuitable soil conditions, the impact on development cost could be significant, but not enough is known at this time to draw this conclusion.

The south leasing area is significantly further from the shore than the north leasing area, which would also contribute to increased development costs. Distance from shore would increase costs by lengthening travel time for vessels moving to and from the wind facility as well as by increasing the overall length of the export cable. NREL does not have data to quantify the effect of distance from shore for this analysis, but the impact on cost is not expected to be as significant as water depth.

[Section 4.3](#) concludes that water depth will be a major cost driver in the development cost and timing of the RIMA WEA. Some analysis is provided that supports this conclusion, but a full quantitative analysis is beyond the scope of this report.

4.7 Key Findings

Below are the key findings of the NREL analysis and important considerations for policy makers and stakeholders involved in the RIMA offshore wind energy development process.

- The north leasing area is more economically and technically developable because it has shallower bathymetry, is closer to shore, and has a larger area than the south leasing area.

- Assuming that the boundaries of the wind energy area are fixed, the BOEM leasing area delineation of north and south was a logical division, but would not provide equal leasing areas in terms of potential development costs and resource access.
- It may be possible to split the north leasing area into two smaller leasing areas that could provide a nameplate development capacity of up to 500 MW.
- Both leasing areas are capable of supporting at least 1,000 megawatts (MW) of potential installed capacity. The potential installed capacity of the north leasing area is 1,955 MW and the south leasing area is 1,440 MW, based on dense 8D x 8D spacing with no internal buffers.
- The north leasing area can implement current fixed-bottom wind turbine technology in the near term. The south leasing area will be challenged by limits to current experience with fixed-bottom turbine technology with 88% of the resource area at 40-m+ depths and where commercially viable technical solutions have not been fully demonstrated (Musial and Ram 2010).
- The south leasing area may have a later project start of several years than the north leasing area because of increased costs and technical challenges associated with the deeper water in the south leasing area.
- The three islanded aliquots of the north leasing area are more difficult to develop because of their distance from (~10 km) the main lease blocks. The additional revenue from the remote turbines may not outweigh the additional cost of the electrical collection system and other infrastructure required to bridge the distance.
- The ten islanded aliquots in the south leasing area are all in shallower depths that are more comparable to the north leasing area. As a result, these aliquots could be reallocated to the north leasing area to create a more depth-homogeneous project area. This reallocation would add approximately 90 MW of capacity to the north leasing area.
- Bathymetry variance within each leasing area may result in external buffer zones within the WEAs, potentially reducing wake losses and project conflicts. The built-in 20-D external buffer between the north and south leasing areas will also help mitigate waking between the leasing areas (Barthelmie 2010).
- The wind resource is slightly better in the south leasing area, with estimated annual average wind speeds that are approximately 0.1 m/s higher, and with better exposure to predominant southwestern winds. In addition, this leasing area will have smaller potential wake losses. However, this benefit will fully offset higher development costs from deeper water and greater distance to shore.
- Prevailing winds have a strong unidirectional component from the southwest, making it more straightforward to orient the array, a characteristic which could help optimize layout design for both leasing areas.

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