7B.4 ASSESSMENT OF THE GROSS U.S. OFFSHORE WIND ENERGY POTENTIAL

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1. INTRODUCTION

Offshore wind resources have the promise to be a significant domestic renewable energy source especially for coastal energy loads with limited access to interstate grid transmission. This potential was recognized in May 2008 when the U.S. Department of Energy (DOE) released a report detailing a deployment scenario by which the United States could achieve 20% of its electric energy supply from wind energy (U.S. Department of Energy 2008). Under this scenario, offshore wind was an essential contributor, providing 54 gigawatts of installed electric capacity to the grid. Many technical and economic challenges must be faced to achieve the deployment levels described in the 20% wind report. The development of a validated offshore wind resource data set is one of the first steps necessary to understand the magnitude of the resource and to plan the distribution and development of future offshore wind power facilities.

DOE and its National Renewable Energy Laboratory (NREL) are working to assess the full potential of the nation's offshore wind energy resources, by producing reports containing updated and validated offshore state wind resource maps and corresponding tables, and developing a national database using Geographic Information System (GIS) techniques. The initial report was published by NREL in June 2010 (Schwartz et al. 2010).

2. OFFSHORE WIND MAPPING

Annual average wind speeds are closely related to the available energy at a particular location. They are categorized in the database by their value at a height of 90 meters (m) above the surface. During the past five years, updated offshore wind mapping projects (Elliott and Schwartz 2006) have been steadily completed. The updated maps provide a better estimate of the offshore wind resource than was previously available.

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At present, updated maps have been completed for the offshore areas off the Atlantic Coast from Maine through Georgia, Texas/Louisiana, and the states bordering the Great Lakes. The updated maps extend from the shoreline to 50 nautical miles (nm) off the coast. Exceptions to the 50 nm distance are the Great Lakes, where the entire lakes were mapped for the offshore resource, and Massachusetts, where the mapped resource did not extend 50 nm from the edge of Nantucket Island and Martha's Vineyard in southeastern Massachusetts. The resource estimates out to 50 nm for the Pacific Coast states and Hawaii are based on data from older mapping projects. The states of Florida, Alabama, and Mississippi did not have any preliminary or final older wind maps available. The lack of tall tower wind measurement data and offshore wind maps for this region made an estimate of the 90 m wind speeds problematic. Therefore, the offshore wind resource for these states was not included in the 2010 report (Schwartz et al. 2010). They will be included in the database once updated offshore maps for these states are complete.

The updated wind resource maps were produced using a physics-based numerical computer model that provided preliminary estimates of the annual average wind resource. The modeling was developed by AWS Truepower (AWST) of Albany, New York, under subcontract to NREL. The horizontal resolution of the model output is 200 m. The preliminary model estimates were validated by NREL, using data from a variety of sources including ocean buoys, marine automated stations, Coast Guard stations and lighthouses, and satellite-derived wind speeds over the ocean, at 10-m height, that were estimated from the "state of the sea", as measured by microwave imaging. The wind measurements from the stations or grid points (in the case of satellite measurements) were extrapolated to 50 m above the surface and compared to the model estimates at the same height. Tall tower data were insufficient to perform a high-quality validation at 90 m height; therefore, the modifications to the preliminary 90 m wind speed model output are based on the 50 m validation results. This adds some uncertainty to the final potential estimates, but should not significantly affect the range of the offshore potential. Final modifications were agreed to after consultations between NREL and AWST. AWST adjusted the model output to reflect the modifications. NREL converted the final data into wind resource maps.

The 90 m average offshore wind speeds were calculated in several ways depending on the available map data. Updated maps had wind speed estimates at the 90-m height. However, Hawaii had older offshore map wind speed values at 70 m and 100 m above the surface. In this case, the 90 m wind speed was calculated through a linear interpolation of the 70 m and 100 m wind speeds. For the states of Washington, and Oregon, where only 50 m wind speed maps were available, the maps for 90 m were calculated using a power law wind speed shear exponent (Elliott et al. 1987) of 0.11. This exponent value was based on the validation experience with other updated offshore wind maps and because other analyses of offshore wind resources in the United States indicate that the shear exponent most often ranges from 0.08 to 0.14. The 90 m speed off the California coast was calculated assuming the speed shear exponent, calculated from the older 50 m and 70 m map data, was also valid for the wind speeds between 70 m and 90 m. For some states, the older map data did not extend to 50 nm from shore. In these cases, the wind speeds that were estimated at the seaward edge of the older map data were extended from the seaward edge to the 50 nm line.

Individual state and regional datasets were combined to form a composite image of the national offshore wind resource, as of January 2011 (Figure 1). A horizontal discontinuity (seam) in the wind resource is present near the border of Oregon and California. The discontinuity results from offshore data that is based on different versions of the numerical model used for the different mapping projects and how the extrapolation software interprets the data on either side of the seam.. The resulting wind speed gradients in that region are not realistic. These seams in the maps and data interpretations will be eliminated as the updated offshore wind resource maps are completed along the Pacific Coast.

3. GIS Database

A GIS database was chosen to house the offshore resource data because all the component datasets have a significant spatial element. Using the same spatial base allows rapid indexing of the different datasets in relationship to each other. The elements in the database include the level of resource (annual average wind speed), water depth, distance from shore, and state administrative areas. The database will be periodically revised to reflect better wind resource estimates and to include updated information from other datasets.

The horizontal resolution of the database grid cells is 100 m by 100 m. The database extends 50 nm from the shoreline and includes major bays and inlets. The primary field is the annual average wind speed at 90 m above the surface, the approximate hub-height of many current-day offshore wind turbines. The annual speeds in the database are binned in 0.25 meters per second (m/s) intervals, with the speed in the database defined as the midpoint of the interval. For example, a grid cell with an annual speed between 7.0 and 7.25 m/s receives a database value of 7.125 m/s. The speeds are binned to represent elements at discrete intervals as required by the database structure. In addition, the database indexes wind resource potential by water depth, in intervals of 10 m, and distance from shore, in increments of 1 nm out to 50 nm. Using the best available offshore state and federal administrative boundaries, provided by the U.S. Department of the Interior's Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), indexing allows the database to be summarized in different ways using these attributes (e.g. resource within 0-5 nm or 0-3 nm of shoreline).

The database is sufficiently flexible to allow the inclusion of new elements such as environmental exclusion areas and shipping lanes/navigation zones, in future versions. The current database quantifies the gross offshore wind resource because identifying appropriate exclusion criteria is a complex issue that will involve multiple stakeholders and negotiations. Exclusions from offshore development are expected to occur on a state or regional basis to assure that local issues are addressed such as was attempted for areas along the Atlantic coast (Dhanju et al. 2008, Applied Technology and Management 2007).

3.1 Bathymetry

In wind resource calculation, bathymetry is important because the water depth affects the type of technology used to develop a given offshore wind resource project (Musial 2007). Current offshore wind turbine technology uses monopoles and gravity foundations in shallow water (0 m to 30 m). In transitional depths (30 m to 60 m), tripods, jackets and truss-type towers will be used. Deep water (> 60 m depth) may require floating structures instead of fixed- bottom foundations, but this technology is currently in an initial stage of development.

The bathymetry data used in the database is categorized into 10 m water depth intervals, with depth calculated relative to the mean water surface height. The majority of the data was acquired from the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) Coastal Relief Model.

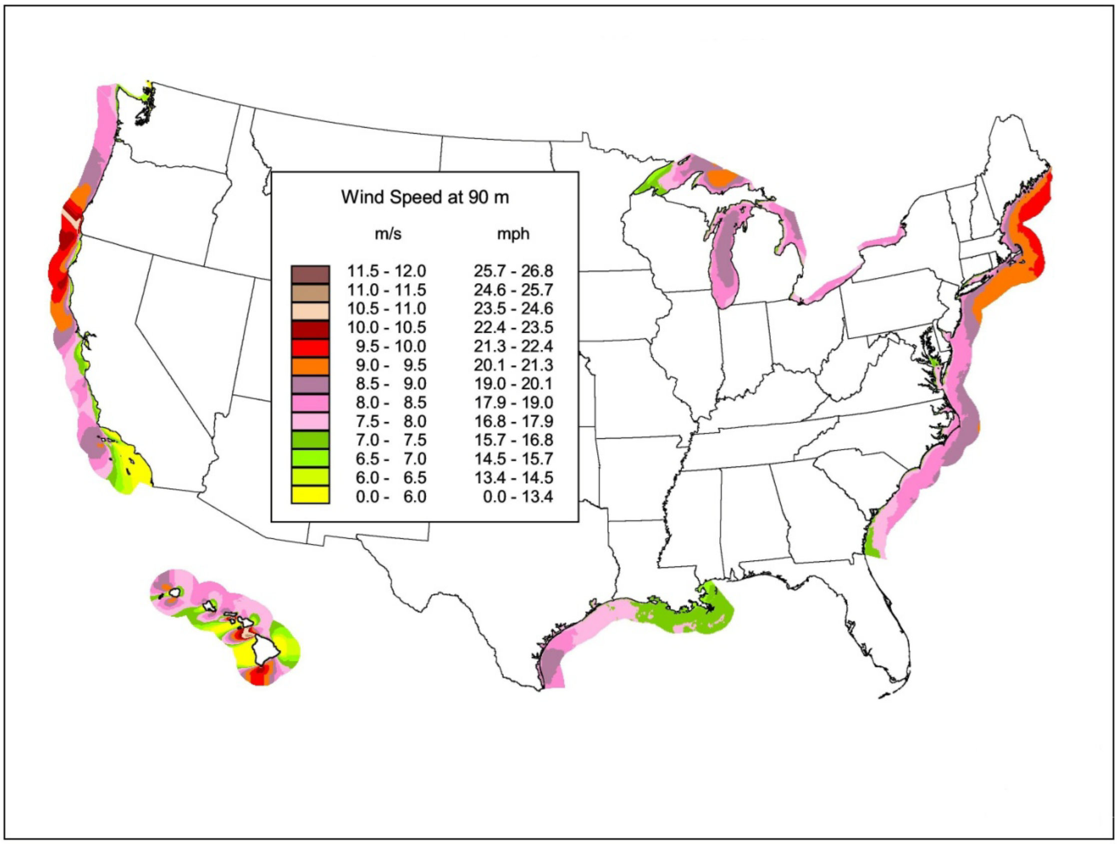

Figure 1. United States offshore wind resource at 90 m above the surface as of January 2011

The bathymetry dataset has a spatial resolution of 90 m. However, Lake Superior and some coastal areas further from shore were not included in the NOAA dataset. For those areas, bathymetry was interpolated from a spatially coarser global NOAA bathymetry dataset.

3.2 Distance from Shore

The distance of a wind project from shore is an indicator of a project's visibility from land, and whether it is located in state or federal jurisdiction. Distance affects the potential cost of development through considerations such as the length of underwater cable needed to connect the offshore wind project to land-based electricity distribution facilities. The database uses nm in its distance calculations. Federal jurisdiction begins 3 nm from the BOEMRE baseline, except for Texas and the Gulf coast of Florida, where it begins at 9 nm. Details on how the baseline of the shoreline was defined can be found in the 2010 report (Schwartz et al. 2010).

Region	GW by Depth (m)			Total
	0–30	30–60	>60	
New England	100.2	136.2	250.4	486.8
Mid-Atlantic	298.1	179.1	92.5	569.7
South Atlantic Bight	134.1	48.8	7.7	190.7
California	4.4	10.5	573.0	587.8
Pacific Northwest	15.1	21.3	305.3	341.7
Great Lakes	176.7	106.4	459.4	742.5
Gulf of Mexico	340.3	120.1	133.3	593.7
Hawaii	2.3	5.5	629.6	637.4
Total	1,071.2	628.0	2,451.1	4,150.3

Table 1. Offshore wind potential by region and by water depth for wind speeds 7.0 m/s and greater

3.3 Administrative Areas

BOEMRE has proposed state boundaries that extend from the state/federal jurisdiction boundary line to the limit of the United States Outer Continental Shelf (OCS). They are based on the United Nations Convention on the Law of the Sea (Federal Register). Landward of the state/federal line, state boundaries are based on legal agreements dating back to the Colonial period. A national dataset of the proposed boundaries is still under development by the BOEMRE and NOAA. For the 2010 report, NREL constructed an offshore administrative boundaries dataset from federal, state, and local government administrative boundary datasets.

4. OFFSHORE WIND POTENTIAL

The offshore wind potential is expressed either as gigawatts (GW) or megawatts (MW) of potential installed capacity. The potential installed capacity was calculated using a uniform factor of 5 MW per square kilometer (km^2) of offshore area with annual average wind speeds greater than 7.0 m/s at 90 m above the surface. This speed was chosen as the lower boundary for wind potential calculations because current economic factors make development nonviable in areas with less than 7.0 m/s average wind speed. This delineation may be adjusted in future versions of the database, as warranted. Examinations of the offshore wind resource distribution show an abundant wind resource pool, with wind resources greater than 7.0 m/s, located in many offshore areas of the country.

Tables in the 2010 report show the gross wind potential by wind speed, water depth, and distance from shore for the individual states and the country as a whole. It is important to note that the wind potential estimates do not exclude areas due to environmental and other ocean-use factors. The current offshore potential for the contiguous United States is estimated to be 4150 GW. Any uncertainty in the resource estimates will significantly decrease as updated maps are completed. Table 1 (above) shows the wind potential by water depth for different regions of the United States. An example of the wind potential for the state of Maine is shown in Table 2.

5. FUTURE WORK

The data base is designed to be iterative with its elements subject to modification and change. The offshore wind resource is anticipated to undergo notable change as new updated resource maps are completed. The Pacific Coast, Hawaii, and the states of Florida, Alabama, and Mississippi are the next regions that are needed to be mapped. The database will be modified to include the new information from these regions upon completion of the maps. The database eventually will contain the wind resource for all 50 states.

Incorporation of environmental exclusions and ocean-use factors impacting offshore wind development will likely be included in future editions of the database. These exclusions could include many factors including shipping lanes, marine habitat areas, submerged obstacles, military areas, and ocean-bottom topography. In addition, the database may be expanded to include other important characteristics such as wave power density, extreme wind and wave events, ocean currents, and a number of other parameters important to the design of offshore wind turbines. Wave power resource estimates are the first type of water power data likely to be included in future versions of the database.

6. ACKNOWLEDGMENTS

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	Distance from Shore (nm)								
	0 - 3			3 - 12			12 - 50		
Depth Category	Shallow (0 - 30 m)	Transitional (30 - 60m)	Deep (> 60m)	Shallow (0 - 30 m)	Transitional (30 - 60m)	Deep (> 60m)	Shallow (0 - 30 m)	Transitional (30 - 60m)	Deep (> 60m)
90 m Wind Speed Interval (m/s)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)	Area km^2 (MW)
7.0 - 7.5	787 *(3,935)*	91 *(456)*	12 *(59)*	8 *(39)*	5 *(24)*	4 *(18)*	0 *(0)*	0 *(0)*	0 *(0)*
7.5 - 8.0	797 *(3,986)*	285 *(1,427)*	19 *(97)*	7 *(33)*	20 *(98)*	14 *(70)*	0 *(0)*	0 *(0)*	0 *(0)*
8.0 - 8.5	777 *(3,885)*	441 *(2,204)*	74 *(371)*	63 *(317)*	386 *(1,928)*	235 *(1,173)*	0 *(0)*	0 *(0)*	0 *(0)*
8.5 - 9.0	513 *(2,567)*	614 *(3,070)*	158 *(788)*	18 *(91)*	219 *(1,095)*	1,402 *(7,010)*	0 *(0)*	0 *(0)*	407 *(2,034)*
9.0 - 9.5	142 *(711)*	390 *(1,950)*	309 *(1,546)*	26 *(129)*	469 *(2,345)*	3,504 *(17,520)*	0 *(0)*	58 *(289)*	3,531 *(17,655)*
9.5 - 10.0	6 *(28)*	25 *(124)*	42 *(211)*	1 *(5)*	38 *(191)*	1,460 *(7,299)*	0 *(0)*	7 *(37)*	13,906 *(69,528)*
>10.0	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	0 *(0)*	42 *(208)*	0 *(0)*	0 *(0)*	0 *(0)*
Total >7.0	3,022 *(15,111)*	1,846 *(9,231)*	615 *(3,073)*	123 *(615)*	1,136 *(5,682)*	6,659 *(33,297)*	0 *(0)*	65 *(326)*	17,843 *(89,217)*

Table 2. Offshore wind potential for the state of Maine.

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