
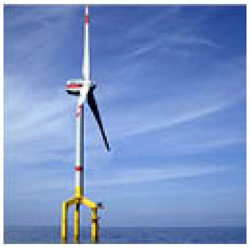


Terminology Guideline for Classifying Offshore Wind Energy Resources

Philipp Beiter and Walt Musial
National Renewable Energy Laboratory

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September 2016

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Editing was provided by Sheri Anstedt and graphics were provided by Stacy Buchanan (NREL).

List of Acronyms

BOEM	Bureau of Ocean Energy Management
DOE	U.S. Department of Energy
EEZ	Exclusive Economic Zone
GCF	gross capacity factor
GW	gigawatt
GWh/yr	gigawatt-hour per year
m	meter(s)
m/s	meters per second
MW/km^2	megawatt per square kilometer
nm	nautical mile
NREL	National Renewable Energy Laboratory
O&G	oil and gas
OCS	Outer Continental Shelf
PIIP	petroleum initially in place
SPE	Society of Petroleum Engineers

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1 Introduction and Background

The purpose of this guideline is to establish a clear and consistent vocabulary for conveying offshore wind resource potential and to interpret this vocabulary in terms that are familiar to the oil and gas (O&G) industry. This involves clarifying and refining existing definitions of offshore wind energy resource classes. Conveying offshore wind resource potential in terms that are familiar to the O&G industry can clarify our understanding of the resource potential across industries and identify areas where these resource comparisons are inappropriate or subject to misinterpretation. The ability to understand similarities and differences in offshore wind and O&G resource classification systems is further motivated by those industries sharing a common regulatory authority, the Bureau of Ocean Energy Management (BOEM). The terminology developed in this guideline represents one of several possible sets of vocabulary that may differ with respect to their purpose, data availability, and comprehensiveness. It was customized to correspond with established offshore wind practices and existing renewable energy industry terminology (e.g., DOE 2013; Brown et al. 2015) while conforming to established fossil resource classification as best as possible. The developers of the guideline recognize the fundamental differences that exist between fossil and renewable energy resources with respect to availability, accessibility, lifetime, and quality. Any quantitative comparison between fossil and renewable energy resources, including offshore wind, is therefore limited. For instance, O&G resources are finite and there may be significant uncertainty associated with the amount of the resource. In contrast, aboveground renewable resources, such as offshore wind, do not generally deplete over time but can vary significantly subhourly, daily, seasonally, and annually. The intent of this guideline is to make these differences transparent.

This guideline also provides methods to quantitatively compare certain offshore wind energy resources to O&G resource classes for specific applications. Finally, this guideline identifies areas where analogies to established O&G terminology may be inappropriate or subject to misinterpretation. Although the offshore wind industry is at a nascent stage in the United States with the first commercial project expected to commence operation in late 2016 offshore Rhode Island (Deepwater Wind 2015), the market potential over the upcoming decades can be expected to grow substantially as a result of declining costs and a unique combination of electrical system benefits. Further, global cost reductions and maturing markets in Europe and Asia provide encouraging signals to prospective U.S. offshore wind developers and investors.

In March 2015, the U.S. Department of Energy (DOE) published *Wind Vision: A New Era for Wind Power in the United States* (DOE 2015). The report examines a detailed, long-term, broad-reaching study scenario for the United States to establish 35% of its electricity from wind energy by 2050, using both land-based and offshore wind. The *Wind Vision* study scenario estimates 86 gigawatts (GW) of offshore wind power capacity in the nation by 2050 and provides a high-level road map of the actions necessary to realize this scenario. The analysis shows that offshore wind could contribute to all regions of the United States, including the North and South Atlantic Ocean, Gulf of Mexico, Great Lakes, and Pacific Ocean (including California, Oregon, Washington, and Hawaii), although varying regional market conditions and technology requirements may dictate a wide range of deployment timelines (Smith, Stehly, and Musial 2015).

In 2010, NREL published a report that documented the gross U.S. offshore wind energy resource potential and found an estimated 4,150 GW of gross offshore wind resource potential exists in the coastal and Great Lake regions (Schwartz et al. 2010). This estimate included areas with wind speeds greater than 7 meters per second (m/s) between 0 and 50 nautical miles (nm) from the coastline. It distinguished gross U.S. offshore wind energy resource potential by state, water depth (0–30 meters [m]; 30–60 m; and greater than 60 m), and distance from shore (0–3 nm, 3–12 nm, and 12–50 nm). These depth and distance bands were established by considering technology types (e.g., fixed versus floating) and existing political boundaries. The 50-nm outer boundary was chosen arbitrarily, assuming that the highest priority wind resources were inside that boundary. The resource estimates were based on the nameplate capacity that could be installed with an array power density of 5 megawatts per square kilometer (MW/km^2). At the time of Schwartz's 2010 assessment, this array power density was typical for wind farms being installed in Europe. The gross resource estimate, however, did not assume specific wind turbine technology characteristics and did not attempt to limit the resource potential to account for inevitable exclusions as a result of competing use or environmentally restricted zones. The 4,150-GW gross potential resource estimate provided regulators and planners with assurance that the offshore wind resource in the United States is abundant, but did little to identify or quantify the amount that could practically be developed.

Around the same time that the National Renewable Energy Laboratory (NREL) published estimates for gross offshore wind resource potential, the U.S. Department of the Interior, which was assigned jurisdiction for regulating renewable energy projects on the Outer Continental Shelf, published Code of Federal Regulations Title 30, Part 585—Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf. This code established a framework for licensing and permitting offshore wind projects. The U.S. Department of the Interior delegated its regulatory authority to the Bureau of Ocean Energy Management (BOEM), which, in addition to regulating offshore wind, is responsible for regulating O&G projects on the Outer Continental Shelf. As such, offshore wind and O&G now share a common domain and are regulated by the same agency. These common attributes provide further motivation to enhance understanding of the resource classification systems applied to these two energy sources (Musial et al. 2006).

The terminology developed in this report helped inform an assessment (Musial et al. 2016) to update the Schwartz et al. (2010) offshore wind resource estimates. The resource assessment in Musial et al. (2016) refined the Schwartz et al. (2010) assessment by modifying some key assumptions to reflect current industry knowledge and practice, including the expansion of gross resource areas from 50 nm to 200 nm (the Exclusive Economic Zone [EEZ]), increased reference hub height from 90 m to 100 m, and lowered array power density to 3 MW/km2 from 5 MW/km2. Musial et al. (2016) and Beiter et al. (2016) assess technical and economic potential as defined in Section 3 of this report in terms of gigawatts and gigawatt-hours per year (GWh/yr). These resource assessments are conducted at a high geospatial resolution to capture local and regional variation within the United States. Whether a location is technologically feasible and viable in terms of project economics now and in the future depends on several region-specific factors, including local resource characteristics, cost reduction pathways, market prices and dynamics, and incentive schemes.

This terminology guideline provides a short overview of established fossil resource classifications (Section 2) as well as definitions for offshore wind resource terminology (Section 3). Section 4 includes a discussion of the degree to which analogies between O&G and offshore wind resource classifications are appropriate and identifies caveats in making comparisons. Section 5 illustrates a method of comparing offshore wind electricity that can be generated from commercial leases on the Outer Continental Shelf to the equivalent fossil fuel usage.

2 Fossil Energy Resource

Energy sources can commonly be classified based on a gross resource potential of which only a fraction is available for commercial development under current technological and market conditions. A system to identify different resource categories and classify them based on defined criteria can be helpful for resource planning and risk assessment. Systematic resource classifications established by the O&G industry have been serving as a framework for consistently estimating quantities of petroleum and gas accumulations from reservoirs, properties, and projects (Society of Petroleum Engineers [SPE] 2005). The classification system has been useful for assessing the amount of energy resources available for production at different degrees of geologic certainty and commercial maturity (SPE 2011). International efforts to standardize the definitions of fossil resources began in the 1930s (SPE 2007) and have resulted in a common classification system guideline for petroleum resources, jointly developed by the American Association of Petroleum Geologists, the SPE, and the World Petroleum Council.

Fossil energy is commonly discussed in terms of the general categories of resource, reserves, production, and unrecoverable petroleum or natural gas. Although considerable efforts have been made to standardize O&G resource definitions and classifications, there are several different fossil resource classification schemes applied globally (SPE 2005). Generally, these can be categorized based on the degree of certainty that fossil accumulations exist and by the likelihood that they can be extracted profitably. Figure 1 illustrates the SPE petroleum resource classification framework, which provides general guidelines for the classification of resources and is considered compatible with the 2004 UN Framework Classification for Fossil Energy and Mineral Resources (International Energy Agency 2013). The total amount of petroleum initially in place (PIIP) is classified along two dimensions, project commerciality and maturity, on the vertical axis, and levels of (geologic) uncertainty associated with recoverable volumes on the horizontal axis.

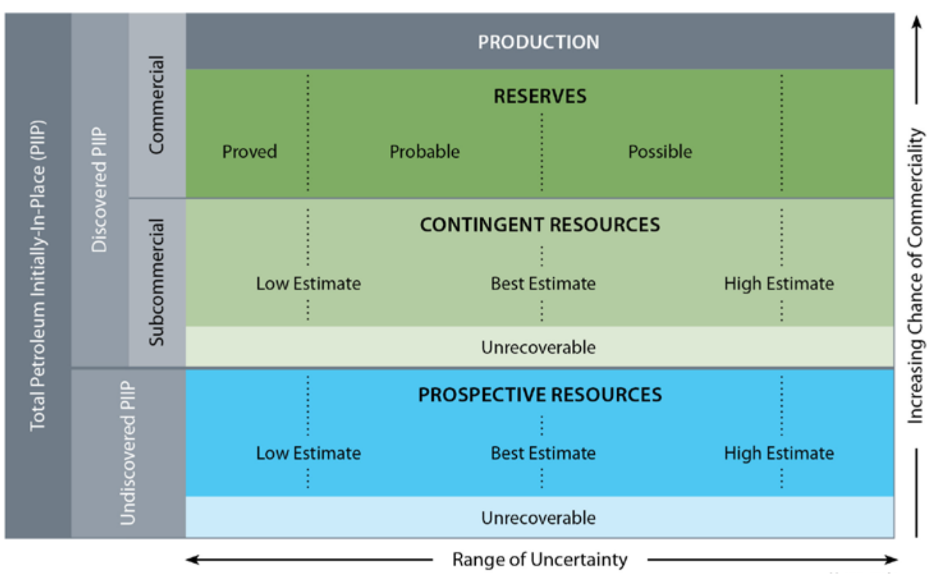

Figure 1. SPE fossil resources classification framework (based on SPE 2011)

In Figure 1, maturity is assessed based on the commercial viability of a project (as shown on the vertical axis). SPE distinguishes between prospective resources, contingent resources, reserves, production, and unrecoverable petroleum. The terms prospective resources refer to potentially recoverable petroleum from undiscovered accumulations. Contingent resources capture the subset of PIIP that is discovered but not considered commercially viable based on current technology, market conditions, and data availability. A portion of both prospective resources and contingent resources can be classified as unrecoverable, which is estimated, at a given date, not to be recoverable by future development projects (SPE 2007). Reserves are defined as those quantities of petroleum that are anticipated to be commercially recovered from known accumulations from a given date forward (SPE 2015). Prospective resources, contingent resources, and reserves are commonly expressed in terms of primary energy units or as a total (e.g., British thermal units, barrels of oil, or cubic feet of natural gas). A separate category, production, includes projects that produce and sell petroleum to markets at the date of evaluation (SPE 2011). Production is defined over a time period, often daily, monthly, or annually (e.g., in terms of barrels per day).

Uncertainty is used as a means to assess the probability of geologic occurrence and recoverability of fossil accumulations. As shown in Figure 1, the categories prospective resource, contingent resource, and reserves can be further disaggregated based on estimated levels of uncertainty associated with fossil occurrence and recoverability. Reserves, comprising the subset of discovered and commercially viable PIIP, can be disaggregated into three subcategories, each with a different probability of recoverability. Proved reserves are estimated volumes of hydrocarbon resource that can be demonstrated through geologic assessments with reasonable certainty[1] (U.S. Energy Information Administration [EIA] 2015a). Other types of reserves, including probable and possible reserves, are estimated volumes with a lower probability of recovery. Reserves estimates will change from year to year as new discoveries are made, existing fields are more thoroughly appraised, existing reserves are produced, and prices and technologies change (EIA 2015a). A recent example of these changes is the increase in reserves of natural gas and oil in the United States corresponding to the development of horizontal drilling and hydraulic fracturing that have made previously unrecoverable resources recoverable. Prospective and contingent resources have subcategories corresponding to the proved, probable, and possible reserves, which are defined by low, best, and high estimates.

[1] Commonly identified as having a probability of recovery of 90% or greater (EIA 2015a).

3 Offshore Wind Resource

The growing deployment of renewable energy in recent years has motivated the development of a resource vocabulary for renewable energy (e.g., Brown et al. 2015; Arent et al. 2012; United Nations Economic Commission for Europe 2015; Verbruggen et al. 2009; Intergovernmental Panel on Climate Change 2014; Musial et al. 2006). There is no universally accepted set of offshore wind resource definitions in use by the U.S. offshore wind industry today. This guideline presents a proposed set of definitions that can be used by DOE, BOEM, and other government agencies in assessing and evaluating the U.S. offshore wind resource. It represents one of several possible sets of vocabularies that may differ with respect to their purpose, data availability, and comprehensiveness. The offshore wind resource definitions are established here and could, in certain cases and under some general caveats, be described as analogies to the O&G terminology described in Section 2. Section 4 will address in detail the numerous caveats that limit a direct analogy between fossil and offshore wind resource classifications.

Figure 2 shows a possible resource classification for offshore wind, which is based on common renewable energy industry terminology and a classification initially developed in Brown et al. (2015) following a report to Congress on renewable energy resource assessments (DOE 2013). Classification criteria for the different resource classes and analogous terms used in fossil resource classifications are shown in Table 1. The offshore wind resource terminology was customized to correspond with established offshore wind practices while conforming to established fossil resource classifications as best as possible. The definitions were developed to capture resource potential in terms of power (e.g., gigawatts) and energy (e.g., gigawatt-hours per year). In contrast to the distinct SPE fossil resource classes presented in Section 2, the different offshore wind resource classes shown in Figure 2 are subsets of each other. For instance, offshore wind economic potential is the subset of technical potential that may be considered economically viable. The resource classes and classification criteria specified in Table 1 have been applied by the recent Musial et al. (2016) offshore wind resource assessment.

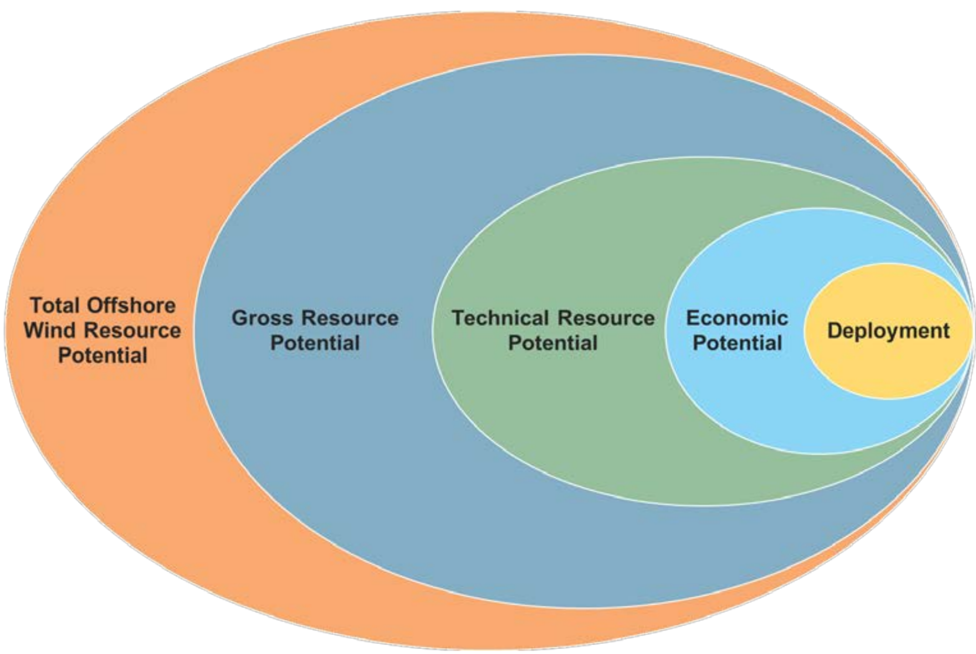

Figure 2. Offshore wind energy resource classification framework

Total offshore wind resource potential represents the entire set of offshore wind resources (recoverable and unrecoverable), regardless of whether the resource can be developed under available technological, land-use, or commercial conditions. Any of the recoverable resource classes displayed to the right of total offshore wind resource potential in Figure 2 are included in this resource class as well as the unrecoverable offshore wind resources, such as upper air wind and high seas wind (>200 nm from shore). Another example that is considered unrecoverable under available conditions for the purpose of this terminology is offshore wind in the Alaska EEZ, where most of the vast energetic resource is remote from load centers. Competing use and environmental exclusions are not considered for this resource category. In contrast to the other resource classes represented in Figure 2, total offshore wind resource potential is not easily quantifiable because of a lack of understanding about the technical feasibility and limitations of unrecoverable resources, of which some are currently in test and pilot development status. Total offshore wind resource potential can be considered analogous to the discovered PIIP identified in fossil resource classifications as it comprises the entire set of recoverable and unrecoverable resources.

Table 1. Offshore Wind Resource Terminology

Resource Class	Classification Criteria		Electricity units	Analogous Fossil Terminology
Total Resource Potential	Entire set of offshore wind resources		N/A	Discovered PIIP
Gross Resource Potential	*Geographic area*	U.S. EEZ (<200 nm from shore)	GW TWh/yr	Contingent resource and reserves
	Technology exclusions	None		
	Array power density	3 MW/km^2		
	Environmental exclusions /competing use	None		
	Turbine performance	Gross capacity factor modeled using Openwind[2] for a generic 6-MW turbine		
	Turbine performance losses	Electrical losses as a function of distance to shore and water depth, availability losses of 4%, wake losses modeled using Openwind, and other losses of 2%		
	Economic viability	None		
Technical Resource Potential	*Geographic area*	U.S. EEZ (<200 nm from shore)	GW TWh/yr	Reserves
	Technology exclusions	Water depths > 1,000 m Wind speeds < 7 m/s Ice regions > 60 m depth		
	Array power density	3 MW/km^2		
	Environmental exclusions /competing use	Percent of total based on likely conflicts (Black & Veatch 2010)		
	Turbine performance	Gross capacity factor modeled using Openwind for a generic 6-MW turbine		
	Turbine performance losses	Electrical losses as a function of distance to shore and water depth, availability losses of 4%, wake losses modeled using Openwind, and other losses of 2%		
	Economic viability	None		
Economic Resource Potential	*Geographic area*	U.S. EEZ (<200 nm from shore)	GW TWh/yr	Proved reserves
	Technology exclusions	Water depths > 1,000 m Wind speeds < 7 m/s Ice regions > 60 m depth		
	Array power density	3 MW/km^2		
	Environmental exclusions/competing use	Percent of total based on likely conflicts (Black & Veatch 2010)		
	Turbine performance	Gross capacity factor modeled using Openwind for a generic 6-MW turbine		

[2] Openwind is a wind project design and optimization software developed by AWS Truepower, LLC, and available at http://www.awsopenwind.org.

	Turbine performance losses	Electrical losses as a function of distance to shore and water depth, availability losses of 4%, wake losses modeled using Openwind, and other losses of 2%		
	Economic viability	Avoided system costs (levelized avoided cost of energy) > offshore wind electricity costs (levelized cost of energy)		
Deployment	Installed capacity Generated electricity		GW TWh/yr	Production

Gross recoverable resource potential is the subset of total resource potential within the boundaries of the U.S. EEZ (200 nm from shore) that can be considered theoretically recoverable without allowing for common technological constraints that exist today. Conflicting use and environmental exclusions are not applied to this resource category. For quantifying gross recoverable resource potential, an array power density of 3 MW/km^2 has been assumed by Musial et al. (2016), which is based on combined array spacing and buffer zones usage that is likely for near-term offshore wind turbine projects in the United States. This is the spacing that might be expected for continuous boundary layer replenishment in very large wind turbine arrays (Musial 2013). Gross recoverable offshore wind resource potential can be considered analogous to the combined set of fossil contingent resource and reserves because it comprises the recoverable portion of both commercial and subcommercial resource, but without being subject to depletion.

Technical resource potential of offshore wind captures the subset of gross recoverable resource potential that can be considered recoverable under available technological and turbine performance conditions while considering land-use and environmental siting constraints. It takes into account technical limits of offshore wind, including system performance and losses, real-world geographic conflicting use and environmental constraints, and turbine spacing criteria. This resource class is quantified in Musial et al. (2016) by considering any available resource at a water depth less than 1,000 m and wind speeds greater than 7 m/s. It also excludes ice regions in the Great Lakes where depths are greater than 60 m, because floating wind technology has not yet been developed to survive fresh water ice floes. Gross capacity factors in Musial et al. (2016) are derived from defined power curves in the year being considered. Losses from wake and grid factors are based on typical project values (e.g., DNV GL 2013; Clifton et al. 2016). Exclusions are considered by defining a percentage reduction of feasible development potential based on likely conflicting use and environmental limits. They are not specifically defined based on exact geography. Technical resource potential corresponds most closely to fossil reserves, as both can be characterized by the prospect of commercial feasibility and depend strongly on available technology at the time of the resource assessment.

The economic potential of offshore wind captures the subset of technical potential that is likely economically viable. Economic potential may be defined in several ways depending on the purpose of the analysis and data availability (see Brown et al. 2015). For the purpose of this analysis and similar to Brown et al. (2015) and Namovicz (2013), it is defined as the available supply of a renewable energy project at a given site where the project's revenue requirements (as can be proxied by levelized costs of energy) are equal to or below the expected revenues at that location (as can be proxied by levelized avoided cost estimates). Economic potential as it is defined for the purpose of this analysis is moderately analogous to fossil proved reserves under a set of limitations. Proved reserves are characterized by (1) commercial status, and (2) a determination of their (geologic) recoverability with reasonable certainty. Offshore wind economic potential shares a high chance for commercial status and economic viability with proved reserves. It also has in common relatively low levels of uncertainty. However, the nature of uncertainty is fundamentally different from proved reserves because offshore wind does not face the same uncertainty with respect to resource recoverability. Although offshore wind deployment involves considerable risks associated with each project phase (e.g., uncertainty related to wind speed assessments, installation, and operation), the underlying resource assessments (primarily wind speeds and technical feasibility) are believed to be generally more deterministic than fossil projects facing widely varying degrees of geologic uncertainty. Economic potential can vary significantly depending on the specific economic and market factors considered. One way to quantify economic potential would be to rely on a site-specific comparison of available revenue (levelized avoided cost estimates) and required revenue (levelized costs of energy) as suggested in Namovicz (2013). However, depending on the purpose of the economic potential assessment and data availability, a range of additional market or economic factors may be considered. Among these factors are local incentive schemes, market barriers, competition among different technologies, electricity exports and imports, elasticity of demand, market failure, the social cost of carbon, and forms of strategic market behavior and monopoly power. For instance, a local or state incentive for offshore wind may increase the revenues available to an offshore wind project in a specific region and its competitiveness. Market and economic factors can change the economic potential of offshore wind considerably and potentially within a relatively short timeframe. By comparison, options to increase the technical potential of offshore wind are likely conducted over a longer timeframe.[3]

Lastly, deployment is the amount of energy expected to be captured through market deployment of offshore wind turbines and is analogous to the category production used in fossil resource classifications. It can be determined by the nameplate gigawatt capacity of the commissioned offshore wind installations (e.g., Smith, Stehly, and Musial 2015) and by the quantity of electric energy delivered.

[3] In a long-term perspective, research and development activities can be expected to increase offshore technical potential considerably.

4 Caveats

An analogy between fossil and offshore wind resource classification systems has a number of caveats that should be considered when making comparisons between offshore wind and O&G resources.

4.1 Depletion Versus Renewable

Fossil resources can be depleted, whereas offshore wind resources are inexhaustible.[4] Fossil resources are commonly expressed in units corresponding to their physical state of occurrence. They may occur as a liquid or in a gaseous or solid state. Petroleum is commonly measured in barrels, natural gas in cubic feet, and coal in pounds or short tons. The composition, quality, and heat content of these fossil resources vary by type, which must be considered when converting one type of fossil fuel to the equivalent amount of another (Whitney et al. 2010). In contrast to renewable energy resources and corresponding to their finite characteristic, fossil resource classes are usually denoted as a total finite sum without considering any temporal dimension (e.g., per year). An exception to that convention is fossil production (commonly in terms of barrels per day or barrels per year, for example). If the rate of future fossil extraction was known, fossil resource classes beyond production could be expressed with a temporal dimension. However, for distinguishing fossil from renewable energy resource potential, the primary difference is that the rate of fossil extraction eventually diminishes to zero as long as its demand continues.

4.2 Undiscovered Versus Discovered

Fossil resources can be classified as undiscovered because statistical analysis from past exploration data supports the assumption that some reservoirs are likely to exist even though their geographical locations have not yet been identified. In contrast, offshore wind potential resources are assumed to be present at all elevations and geographic regions over the entire planet. Although most of these resources are unrecoverable with current technology (e.g., upper atmosphere winds above 500 m), they are not assumed to be undiscovered. They are above ground and can be measured, modeled, and observed with existing tools if desired. More appropriately, they should be considered unrecoverable. Aside from the surface winds near available grid connection points, most of these resources have not been assessed and their characteristics remain highly theoretical. However, as technology advances, certain unrecoverable offshore wind potential may be reclassified as gross recoverable potential, and new assessments may quantify these new resource domains.

4.3 Uncertainty

A fossil resource can be classified by uncertainty as a metric to estimate potentially recoverable volumes of accumulation based on the anticipated difficulty of extraction and confidence in the accuracy of reservoir size estimates. Offshore wind faces uncertainty related to project development (uncertainty related to wind speed assessments, installation, and operation) but does not share the same degree of ambiguity with respect to the recoverability of its resource because generally more is known about a prospective wind site before development begins. Some uncertainty in offshore wind exists because of the confidence placed on the accuracy of various

[4] Except for the possibility of nonstationary climate variations.

meteorological models that estimate the wind characteristics needed to predict energy output (e.g., annual average wind speed). However, with experience, and as better measurements, models, and observational tools are developed, the uncertainty in offshore wind estimates can be expected to decrease over time.

4.4 Resource Quality

Offshore wind and fossil resources differ in their ability to serve market and electricity system needs. For instance, electricity from offshore wind is variable and cannot be transported or stored as easily as fossil fuels. However, fossil commodity prices and extraction costs tend to fluctuate considerably over time, whereas offshore wind projects can be expected to have relatively stable production costs during their lifetime.

4.5 Unit Conversion

Fossil resources are commonly reported in terms of primary energy units and as a total (e.g., British thermal units, barrels of oil, cubic feet of natural gas, tons of coal), whereas offshore wind is commonly reported in electricity units and on a temporal basis (megawatt-hours per year or kilowatt-hours per year). These units cannot be compared directly because electricity can be considered a higher quality energy state than primary energy commodities, such as barrels of oil. Yet, offshore wind electricity units can be converted to primary energy units to make them comparable if the conversion efficiencies are taken into account. EIA (2015c) suggests a set of assumptions that allow a conversion from energy produced by oil (barrels), gas (cubic feet), or coal (tons) into megawatt-hours, the units that wind-generated electricity is commonly reported in. The EIA estimates are provided in Table 2.

Table 2. EIA Conversions for Various Fossil Fuels Used to Generate Electricity (EIA 2015c)

	Fuel Needed to Generate 1 Megawatt-Hour (MWh)	Megawatt-Hours Generated Per Unit of Fuel	Heat Rate Assumptions (British thermal unit/MWh)
Coal	0.52 short tons	1.904 MWh per ton	10,089,000
Natural Gas	10.10 Mcf	.099 MWh per Mcf	10,354,000
Oil	1.75 barrels (73.5 gallons)	.570 MWh per barrel	10,334,000

1 Mcf = 1,000 cubic feet of natural gas
** 1 ton = 2,000 pounds
*** 1 barrel of oil = 42 gallons (U.S.)

These conversions assume that the fuel is used in a thermal power plant to generate electricity. In principle, a similar method could be used to compare fuels that are consumed in vehicles using internal combustion engines with electric vehicles.

5 Wind Energy Area Comparison

As of October 2015, BOEM issued nine commercial offshore wind leases on the Outer Continental Shelf with a total area of 3,416 km^2, as summarized in Table 3. Although an accurate estimate of the total offshore wind capacity that will ultimately be installed is difficult to make, these lease areas provide a valid way to illustrate the method of comparing offshore wind electricity generated in megawatt-hours to an equivalent fossil fuel usage to generate the same amount of electricity. The commercial lease areas shown in Table 3 generally represent the most advanced offshore wind energy projects in the early development pipeline for the United States (Smith, Stehly, and Musial 2015).

Table 3. Summary of Energy Potential from Offshore Wind Energy Leases and Equivalent Annual Fossil Fuel

State	Existing Lease Areas	Lease Issue Date	Lessee	Area (km^2)	Potential Capacity in Megawatts (MW) 3 MW/km^2	Annual Energy (40% Net Capacity Factor) (Megawatt-hours [MWh])	Annual Barrels of Oil Equivalent (.570 MWh/ Barrel)	Annual Mcf Natural Gas Equivalent (.099 MWh per 1,000 cubic feet)	Annual Tons of Coal Equivalent (1.904 MWh/ton)
Massachusetts	OCS-A 0478	10/6/10	Energy Management Inc.	119	357	1,250,928	2,194,611	12,635,636	657,000
Delaware	OCS-A 0482	11/16/12	Bluewater Wind	418	1,254	4,394,016	7,708,800	44,384,000	2,307,782
Rhode Island/ Massachusetts	OCS-A 0486 (North)	7/31/13	Deepwater Wind	395	1,185	4,152,240	7,284,632	41,941,818	2,180,798
Rhode Island/ Massachusetts	OCS-A 0487 (South)	7/31/13	Deepwater Wind	272	816	2,859,264	5,016,253	28,881,455	1,501,714
Virginia	OCS-A 0483	9/4/13	Dominion Virginia Power	456	1,368	4,793,472	8,409,600	48,418,909	2,517,580
Maryland	OCS-A 0489 (North)	8/19/14	U.S. Wind	132	396	1,387,584	2,434,358	14,016,000	728,773
Maryland	OCS-A 0490 (South)	8/19/14	U.S. Wind	190	570	1,997,280	3,504,000	20,174,545	1,048,992
Massachusetts	OCS-A 0500	1/29/15	DONG Energy Massachusetts	759	2,277	7,978,608	13,997,558	80,592,000	4,190,445
Massachusetts	OCS-A 0501	1/29/15	OffshoreMW	675	2,025	7,095,600	12,448,421	71,672,727	3,726,681
Total				**3,416**	**10,248**	**35,908,992**	**62,998,233**	**362,717,090**	**18,859,765**

In Table 3, the total nameplate offshore wind capacity that could be installed on the existing lease areas is estimated by simply applying a standard array power density assumption of 3 MW/km^2 to the total area. The array power density of 3 MW/km^2 is conservative when compared to typical turbine array densities used in European wind farms, in which the average is around 6 MW/km^2 (Musial 2013). Still, 3 MW/km^2 is closer to the values proposed to BOEM by U.S. developers for lease areas and could become less conservative if further easements and setbacks are imposed on developers (Musial 2013). This assumption yields a total aggregate capacity for all nine lease areas of 10,248 MW. This capacity was converted to annual energy by assuming an average net capacity factor of 40% for all sites, yielding an annual electric generating potential for all lease areas of almost 36 million MWh. Using the conversions in Table 2, this amount of electricity can be equated to about 63 million barrels of oil per year, or about 12% of the current oil production in the Gulf of Mexico (EIA 2015b). Alternatively, it would take approximately 363 billion cubic feet of natural gas per year to generate this amount of electricity, or nearly 19 million tons of coal per year. It is also important to note, first, that this level of generation can theoretically be sustained indefinitely for offshore wind resources, whereas typical fossil fuel production is limited by the size of the reservoir or reserve and is eventually depleted. Also, the nine lease areas represent a fraction of the 86 GW of offshore deployment modeled under the *Wind Vision* (DOE 2015). According to the *Wind Vision*, almost 530 million barrels of oil, 3,000 billion cubic feet of natural gas, or 160 million tons of coal per year would be required to match 86 GW of offshore wind capacity, approximately corresponding to the crude oil production in the Gulf of Mexico in 2015 (EIA 2015b).

6 Conclusions

This guideline establishes a clear and consistent vocabulary for conveying offshore wind resource potential and interprets this vocabulary in terms that are familiar to the O&G industry. A more precise method of defining and classifying the different offshore wind resources can be helpful in assessing the resource and economic potential of this industry and its contribution to meet future U.S. electricity demand. The analogies established between the offshore wind resource terminology and O&G resource classifications can help leverage synergies between these two industries and inform BOEM (as the joint regulator) and other stakeholders to assess resource potential comprehensively. Offshore wind has been classified into the following categories: resource potential, gross recoverable resource, technical potential, economic potential, and deployment. Possible ways to quantify these resource classes were covered in Section 3. As discussed in Section 4, a direct comparison between offshore wind and fossil resource classifications is limited for a number of reasons. Most importantly, the offshore wind resource is inexhaustible and cannot be depleted. Also, offshore wind cannot appropriately be classified as undiscovered, even for remote winds without grid access. Further analysis can help inform DOE's offshore wind strategy by refining these resource classes with respect to specific market conditions and addressing the complexity of accurately quantifying the developable economic resource.

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