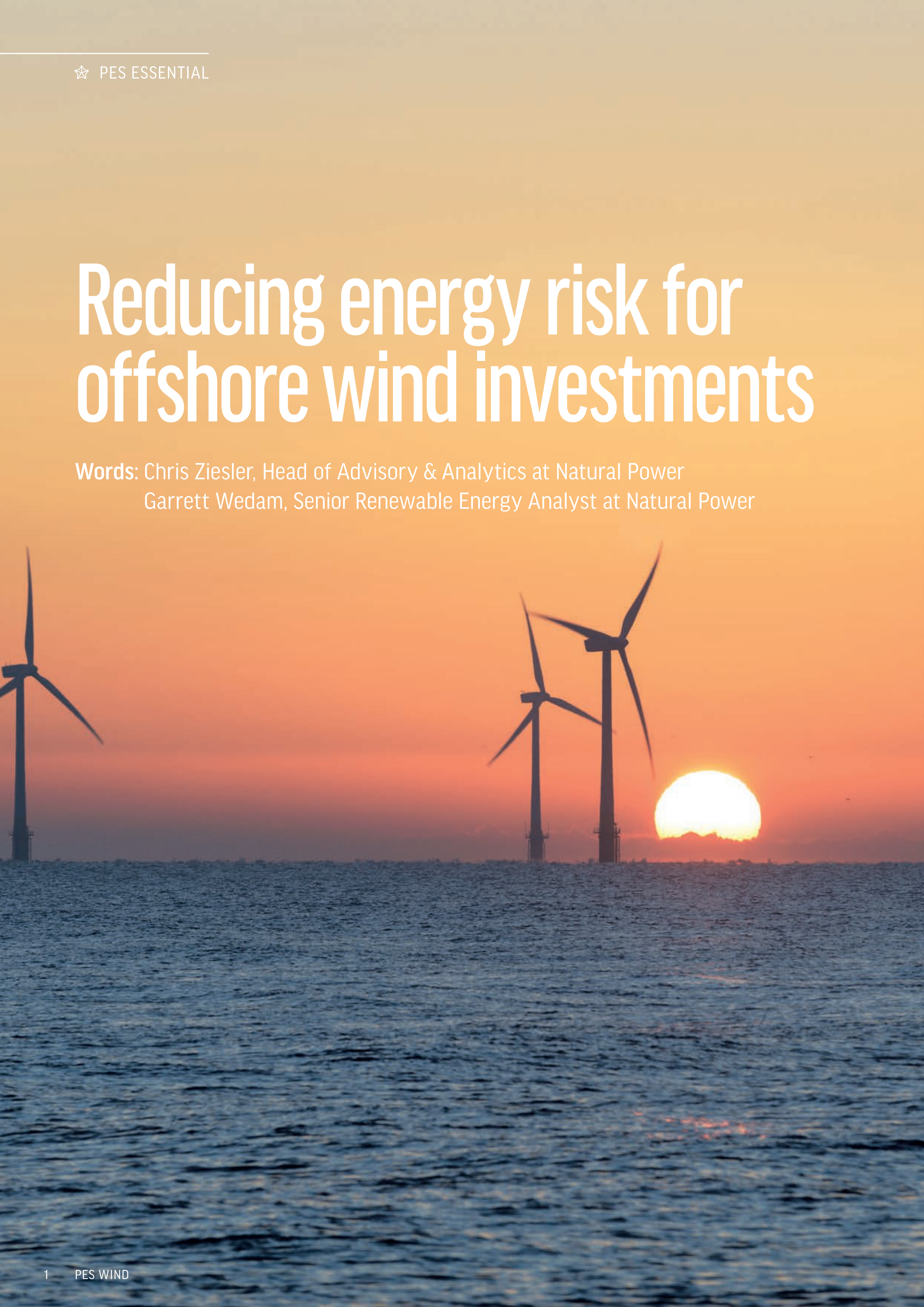

Reducing energy risk for offshore wind investments

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The high prices paid for the Bureau of Ocean Energy Management leases in the recent New York Bight Auction have drawn attention to the high stakes involved in developing offshore wind projects. The highest winning bid was more than a billion dollars for lease area OCS-A 0539 paid by Bight Wind Holdings, a partnership between RWE and National Grid. As soon as the results were announced, industry watchers started to work out how the economics would work to allow the winners to generate profits.

Provisional Winner	Lease Area	Area (Acres)	Winning Bid ($M)	Companies in Partnership
Mid-Atlantic Offshore Wind LLC	OCS-A 0544	43,056	$285.0	CIP
OW Ocean Winds East, LLC	OCS-A 0537	71,522	$765.0	EDPR + Engie
Attentive Energy LLC	OCS-A 0538	84,332	$795.0	EBW + TotalEnergies
Bight Wind Holdings, LLC	OCS-A 0539	125,964	$1,100.0	RWE + National Grid
Atlantic Shores Offshore Wind Bight, LLC	OCS-A 0541	79,351	$780.0	EDF and Shell
Invenergy Wind Offshore LLC	OCS-A 0542	83,976	$645.0	Invenergy + energyRe

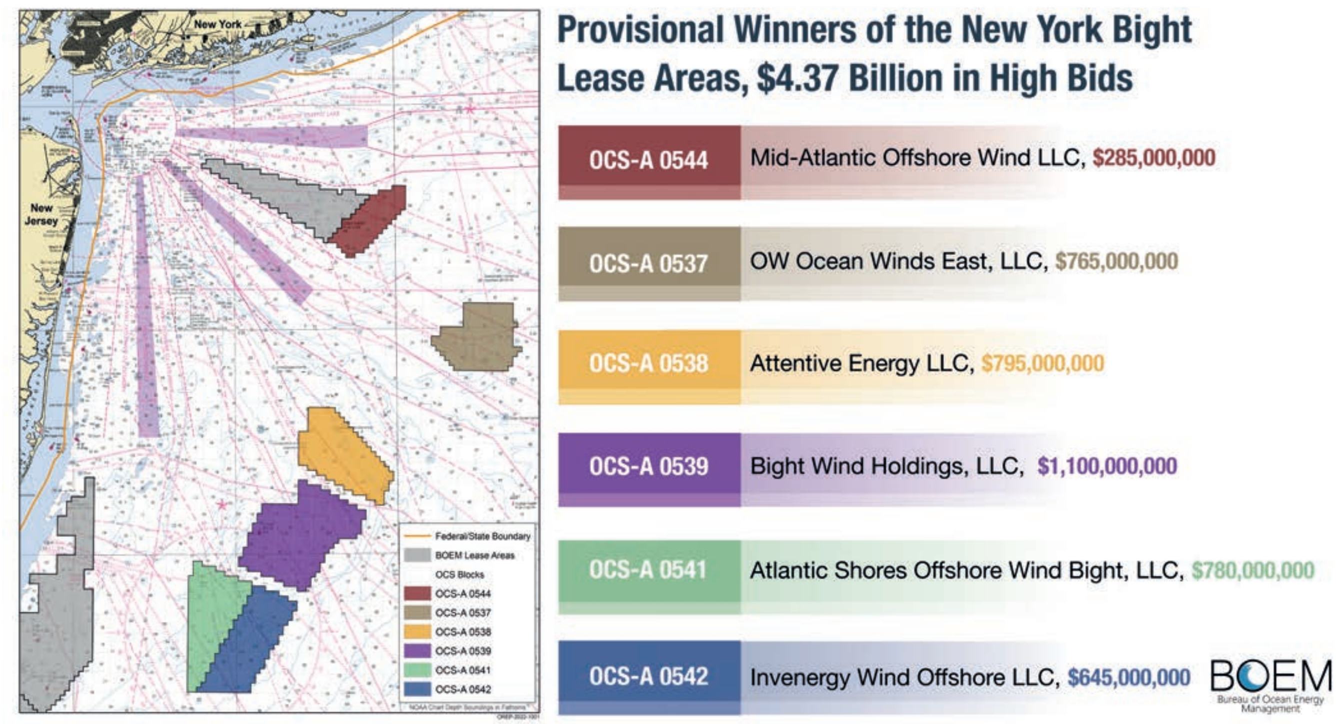
One of the most important parts of the financial equation is the estimate of the energy a farm will produce once built. The revenue from the farm will be directly proportional to this estimate. There are unique challenges to calculating the energy yield of an offshore farm that can make it difficult to arrive at an energy estimate in which the developers can have a high degree of confidence. Reducing the uncertainty of offshore wind resource and energy assessments is a difficult, but essential, task.

Onshore wind energy assessment practices have been developed throughout several decades, but offshore assessments present new challenges that require a different approach. Natural Power has prepared a case study from the New York Bight, to present the recommended approach for assessing an offshore wind energy assessment. The case study is based on work carried out by Natural Power for the New York State Energy Research and development authority (NYSERDA) which is facilitating offshore development in the New York region. Through this undertaking, Natural Power has demonstrated a comprehensive project design and energy assessment process, including turbine selection and layout design for a 1330MW wind farm, comprised of 14MW hypothetical turbines with a 140m hub height.

Measurement campaign

For an onshore wind farm, multiple meteorological masts are used within the project area, but such masts are generally not practicable for offshore projects and are often prohibitively expensive. More usually, remote sensing devices (RSDs), most often floating lidars, are deployed within the project area. These can be combined with near-shore meteorological mast measurements. For this case, Natural Power used a full year of data from the Eolis E05 Zephyr floating lidar, a campaign funded by NYSERDA and managed by DNV[1]. Natural Power also used multiple

1 https://oswbuoysny.resourcepanorama.dnvgl.com/download/f67d14ad-07ab-4652-16d2-08d71f257da1



nearby land-based observational sources to characterize the other regional atmospheric conditions of interest.

Natural Power applied quality control filters to the E05 data, that gave a 94.7% data recovery at the proposed 140m hub height. Natural Power also compared the E05 data to that of E06, a similarly configured floating lidar 80km southwest of the project area, to understand the spatial variability across this region. In addition, a 10-minute WRF-based large eddy simulation (LES) synthetic time was estimated within the project area[2]. This helped inform turbulence intensity (TI) and temperature estimates.

Flexibility of approach is key to informing offshore resource, particularly in early-stage development. Multiple sources of modeled and measured resource data must be evaluated and integrated in an uncertainty-based manner to estimate site conditions.

Long-term adjustment

All available long-term and synthetic reference sources should be considered. Natural Power found reasonable correlations with nearby ERA5 and MERRA-2 reanalysis grid points, as well as downscaled ERA5, MERRA-2, and CFSR[3]. Fair correlations were found with NOAA buoy 44025[4]. If a buoy is used as a primary wind measurement source, sea conditions should be taken into account. Instruments will be sheltered when in a trough between high waves.

Many different approaches to long term adjustment can be undertaken for offshore projects. We recommend using a measure-correlate-predict (MCP) approach if shorter duration on-site measurements are available, with the skill of the MCP used to guide the final selected approach. It is important to consider not only the accuracy or potential bias of the long-term speed but the directional and wind speed frequency distribution estimate too. Given the atmospheric stability that may occur over water, it is important to consider the way in which shear may play into correlations with any land-based references.

In this case study project, the downscaled ERA5 data was selected to adjust the E05 observed speeds based on favorable period of record overlap, coefficients of determination, as well as favorable preservation of the observed wind speed and direction frequency distributions. A long-term 140m wind speed of 10.0m/s was estimated at the E05 location.

Vertical wind shear

The offshore environment presents unique shear conditions, largely driven by the temperature gradients experienced over water. This can lead to a non-uniform shear profile, which can lead to significant over-prediction of energy production if shear relaxation with height is not sufficiently captured. As such, modeled shear parameters such as WRF-based LES series may help inform risk of reduced energy content above observational heights.

In this case, Natural Power found a mean annualized shear exponent of 0.10 at the site, typical of offshore shear. But more interesting, and arguably more important to the project, was the wide range of shear values observed. Both negative shear and higher shear exponents such as those greater than 0.25 were not uncommon. Variability in shear is important to note for any turbine suitability investigation or turbine performance related loss estimates where rotor equivalent wind speed estimation may be of importance to capture for these purposes.

Spatial modeling

Natural Power used the VORTEX FARM[5] flow model, which downscales wind data from the WRF large scale climate model to various resolutions from a few kilometers down to 100m. As expected for the region and for offshore sites in general, there is a relatively modest gradient in wind resource across the site, with speeds ranging from just under 9.8 up to 10.0m/s. As the industry moves into very large, multi-GW, multi-phase projects across large spatial areas, it becomes important to understand both the applications and limitations of various modeling resources, including the trade-offs of higher resolution, which may be necessary at a coastline, with larger model domain sizes.

2 https://vortexfdc.com/wind-turbulent-time-series/

3 https://vortexfdc.com/wind-speed-time-series/

4 https://www.ndbc.noaa.gov/station_page.php?station=44025

5 https://vortexfdc.com/high-resolution-wind-resource-maps/

Turbine technology and layout

We created a hypothetical 14MW turbine with a 238m rotor diameter and 140m hub height based on contemporary offshore turbines. Other aspects of our hypothetical turbine that are typical of the offshore market include a high wind de-rate rather than fixed cut-out so that high wind hysteresis losses are minimized.

For the case study layout, we chose a 1x1 km spacing as a base case typical of an offshore array to balance collection system cost with wake losses. Any real layout optimization process would also consider more refined optimization of net production or levelized cost of energy (LCoE). With actual offshore projects those preferences will need to be balanced by other layout constraints, such as fishing grounds, seafloor features, department of defence and other shipping lane requirements.

Energy and wake modeling

For our energy yield calculations, we employed multiple commercial energy calculation models as well as several wake model configurations with various settings that are used across the industry.

Wake models and wake model configurations can be a contentious topic across the industry. There are many viewpoints, as with flow modeling. But for this exercise, we used a range of values from wake models, an ensemble approach, to provide an idea of a reasonable wake loss. We also included farm-level blockage calculations. This resulted in a wake and turbine interaction loss ranging from 7.7% to 9.7%. It is important to scrutinize the wake model(s) and their inputs because wake loss estimates factor into decisions early in the planning process i.e: proposed layout arrangement, but also are often an important factor at financing.

Energy results, losses and uncertainties

For the case study project, Natural Power applied default offshore secondary losses, resulting in a total of a 21.7% annual loss with a 47% net capacity factor, which is fairly typical for offshore regions with good wind resource similar to this location.

Natural Power also went through an uncertainty scheme with some conservative assumptions and determined a 10-year energy uncertainty of 7.2%.

Conclusions

The opportunities for developing offshore wind farms continues to grow rapidly. Much of that growth will be in emerging global markets that have a wide variety of different atmospheric and ocean conditions. Accurate energy yield assessments are essential to support building successful wind farms.

The whole approach of energy assessment, from the measurement campaign design, to assessing the suitability of the turbine technology, to modeling long-term wind climate needs to be appropriate for working in the offshore environment. If this is done correctly the wind industry will succeed in building the large, profitable offshore wind farms that we need to help combat climate change.

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