BLACK & VEATCH

Decarbonising EMEA:

Optimising Offshore Renewables Projects

Contents

Execution certainty is best served by partners able to manage the complex interfaces which define offshore renewables projects.

Offshore Generation is Crucial to Decarbonisation

In the drive to decarbonise offshore generation of electricity has an established role. Fixed offshore wind holds sway currently, but floating wind's potential is starting to be realised. As it matures tidal energy, the most predictable form of renewables, is growing in significance.

As well as generating electricity, offshore energy assets can make a meaningful contribution to the production of green hydrogen, extending the offshore renewables sector's role in meeting carbon reduction goals.

In the Europe, Middle East, Africa (EMEA) region limited and expensive land means many northern and western European countries are looking offshore to maximize their wind power potential, with many gigawatt-scale installations built or under development in Northern European waters. But many other EMEA countries - such as Morocco, Mauritania, Namibia, South Africa, Somalia and Oman - also offer great, as yet untapped, potential for fixed and floating offshore wind.

Floating offshore wind infrastructure, which unlike fixed offshore wind is not restricted to shallow waters, can be developed further out to sea so is able to capture more powerful and reliable winds. The Global Wind Energy Council (GWEC) forecasts that European countries will account for two-thirds of the world's floating wind capacity additions during the second half of this decade.

The importance of sea power

The predictability of ocean currents and tides give marine energy projects a significant advantage in terms of energy security and stability of supply, although the early stage of the industry means that current levelised cost of energy (LCoE) for tidal and wave projects are around four times higher than for solar or wind.

But a forecast fall in LCoE and continued rise in the demand for low-carbon energy, coupled with the reliability and stability of marine energy, means global investment is predicted to triple from US$350 million in 2021 to US$1 billion in 2026; with the European Commission alone targeting at least 1 gigawatt (GW) of installed tidal and wave capacity by 2030. Ocean Energy Europe, a body representing the sector, foresees 100 GW of ocean energy in Europe by 2050.

According to Bloomberg New Energy Finance (BNEF) data the UK leads the world with a tidal and wave energy project pipeline of more than five GW. Ireland, Portugal, Israel, South Africa and France were among other EMEA states in BNEF's analysis of the countries with the largest marine energy project pipelines. Djibouti and Ghana are further EMEA states developing marine energy project pipelines; while Norway's Havkraft has joined a partnership to develop wave energy projects in Oman.

Execution certainty in unforgiving conditions

Be it marine energy or offshore wind, offshore electricity generation's role in decarbonisation strategies across EMEA is only going to grow; and, regardless of technology, all offshore generation projects share the common challenge of needing to succeed in some of the most unforgiving conditions facing any power generation assets.

This means, especially with maturing or nascent floating wind and marine energy systems, that the level of execution certainty will be increased greatly by choosing a partner with not just offshore wind or marine energy technology experience, but one able to augment that with a full understanding of the influence of metocean conditions - such as wave, current and wind - on all aspects of the project lifecycle; and proven experience in the transmission element of offshore power projects. A partner with this spread of expertise and experience will not only be the one best placed to advise on individual aspects of the project but will also successfully manage the complex interfaces between technologies and disciplines that define offshore generation projects.

Site-Specific Metocean Data Means More Accurate LCoE Forecasting

By affecting the ability to undertake both planned maintenance and reactive repairs, metocean conditions have a significant impact on the effective operation and maintenance (O&M) of offshore electricity generation assets. Unless site-specific metocean data has been incorporated in a project's early development, it is possible that the built assets may not be able to consistently achieve the performance forecast – because the ability of metocean conditions to hamper O&M activities has not been accounted for in sufficient detail.

Site-specific O&M optimisation

Consider a notional offshore wind project as an example. A higher wind yield at Location A meant it was considered preferrable over Location B as it offers a higher financial return. However, Location A has a more challenging metocean environment in which to operate than the more benign Location B.

Location A's environment makes maintenance teams' ability to access both surface and subsea assets more difficult as fewer suitable weather windows exist and/or more expensive access methods have to be employed. Unless this was accounted for during project development there is a risk performance forecasts will not be achieved, because equipment cannot be maintained as planned, and timely failure repairs may not be possible or be more costly.

The result is that the slightly higher financial return forecast due to Location A's higher wind yield is eroded by sub-optimal array performance stemming from an inability to ensure the required level of maintenance or significantly increased O&M costs. This may lead to Location B having a more attractive overall whole-Lifecycle cost for the offshore installation.

The same principle applies to marine energy projects. The influence of site-specific metocean conditions on O&M regimes has to be factored into cost forecasts from the outset so they reflect the actual conditions that will be encountered. And these factors will then help identify the optimal location for the best overall whole-lifecycle cost for the generation and transmission assets as well as the optimal O&M strategy.

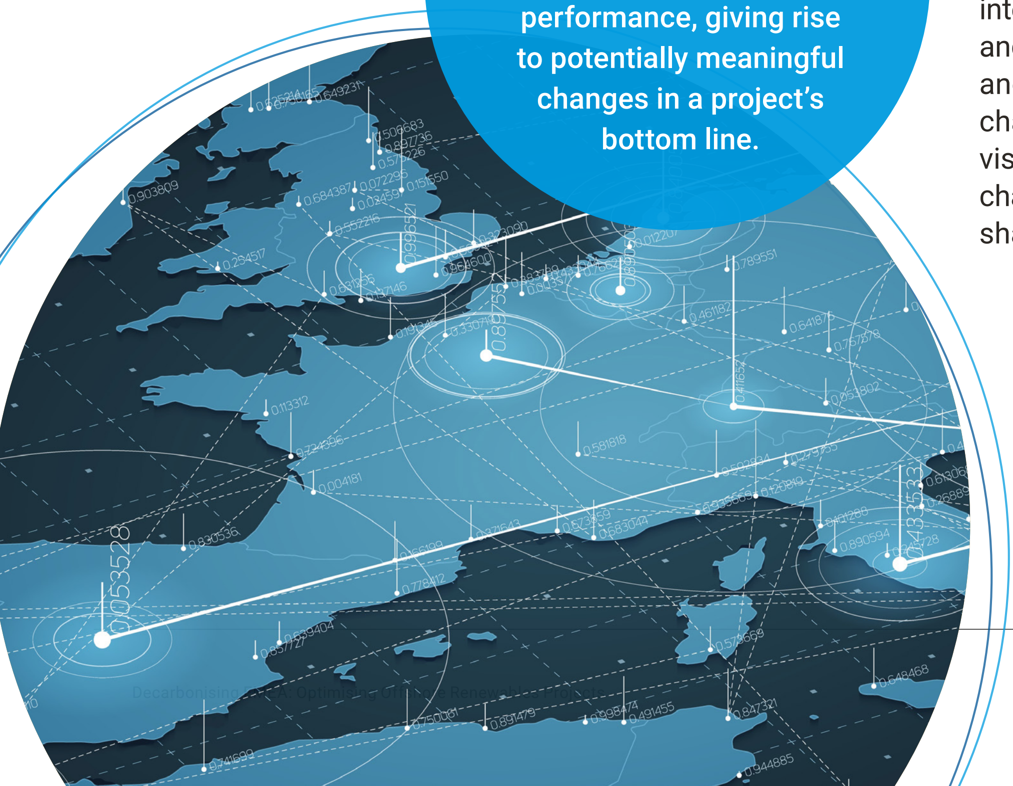
Cut OPEX from the outset

During the development of some offshore wind and marine energy projects, there has been an understandable focus on identifying the location that offers optimal wind or current resources, and swiftly progressing design for that location, thus helping bring the project to faster financial close. Given this initial focus, the project developer may not have fully engaged with O&M experts, particularly with reference to site-specific impacts of metocean conditions on O&M strategies and costs. This approach presents the possibility of 'locking in' substantial amounts of operational expenditure (OPEX) that could potentially be reduced with greater involvement of O&M considerations during early project development.

This is not to suggest developers are unaware of the need to incorporate metocean data in their project planning. But the extent to which such data is accounted for from an O&M perspective, and the detail and sophistication of the data used, varies to a significant degree.

Adopting modelling capable of accurately incorporating site-specific metocean data into an assessment of the effect of O&M costs and downtime on a project's LCoE will assist with the development of a more informed long-term projection of a site's profitability, aiding in site selection, in addition to helping optimise O&M strategies for specific site conditions.

Minor changes in offshore asset design and location can cascade into significant effects on cost and performance, giving rise to potentially meaningful changes in a project's bottom line.



Accurate LCoE Calculation

The modelling sophistication required to accurately calculate a project's LCoE is possible by pooling data sets not typically analysed together, and processing them using algorithms configured to inform data-driven O&M planning for site-specific conditions. Such data sets can include site-specific metocean data analysed alongside equipment failure rates, original equipment manufacturer (OEM) maintenance schedules and generation asset power curves. The result is a greater level of O&M optimisation because of the sophistication of the site-specific, rather than generic, data being analysed. This includes the ability to schedule predictive maintenance during times of lower energy generation, thereby maximising energy-based availability.

This level of sophistication is important because metocean data are very complex and often highly interdependent. Minor changes in offshore asset design and location can cascade into significant effects on cost and performance, giving rise to potentially meaningful changes in a project's bottom line. A tool which gives visibility and insights into the consequences of such changes will help enable more fully informed decisions shaping the project from the outset.

Real-World Challenges

Once offshore operations commence understanding actual on-site metocean conditions, as opposed to what is predicted, can greatly assist in operational planning. Since weather and current predictions do not necessarily match up with the on-site conditions operations are sometimes aborted as a result of unsuitable metocean conditions. Having real-time on site metocean data feeds can prove invaluable in allowing detailed operational planning.

Incorporating more complete and accurate metocean data brings a new level of sophistication to the O&M element of the development of an offshore generation project. This can help reduce the risk of performance modelling, and hence forecasts, being affected by an insufficient understanding of the ways in which metocean conditions can influence developers' ability to ensure an asset can consistently deliver the performance upon which the business case is built.

In addition, using sophisticated metocean data creates opportunities to further optimise O&M strategies and develop fuller, more accurate projections for the O&M element of a project's costs and yield.

Marine Energy CV Highlights

Orbital Marine Power

Black & Veatch was appointed to support the development of Orbital's world-leading tidal turbine. The project's main aim was to identify and de-risk innovations capable of accelerating cost reductions for tidal stream energy. Black & Veatch's scope:

- Techno-economic LCoE analysis on existing and future turbines
- O&M strategy in the tidal sector
- Anchor design optimisation
- Array configuration optimisation
- Site development support
- Metocean data assessment

Click for more details

MeyGen

The first multi-megawatt tidal array, MeyGen is a 6 MW demonstration array, comprised of four 1.5 MW tidal turbines. Black & Veatch's scope:

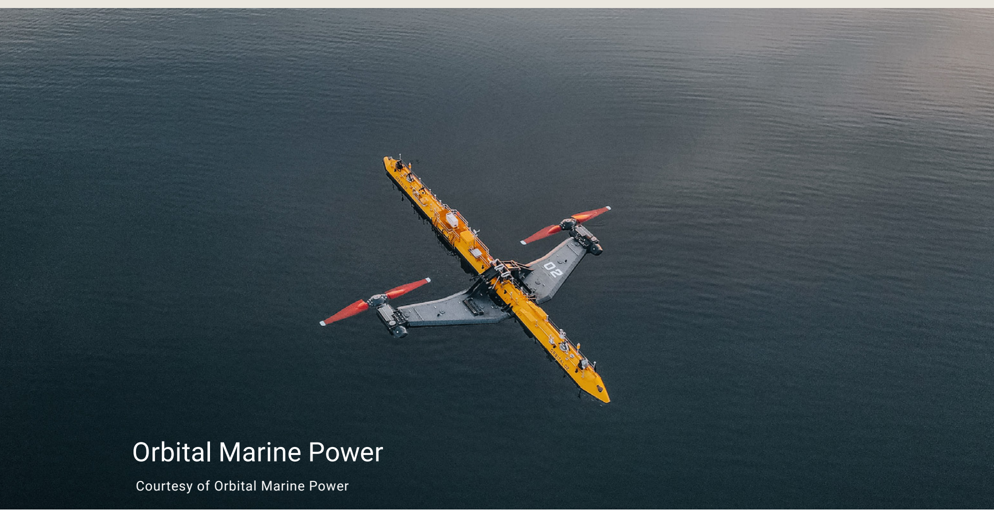
- Phase 1A - Funders' Technical Advisor
- Phase 1B - Design and manage procurement process

Click for more details

SBS International

Feasibility study of tidal energy arrays to support the client in attaining a power purchase agreement with the local distribution network operator. Black & Veatch's scope:

- Site selection based on: Resource potential, technical aspects, environmental aspects, socio-economic factors, financial
- Development of site-specific outline tidal stream turbine specification



Orbital Marine Power
Courtesy of Orbital Marine Power

Courtesy of Orbital Marine Power

MeyGen
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Transmission Infrastructure: Successful Stakeholder Engagement as Vital as Technical Expertise

The transmission element of offshore renewables projects presents many challenges and mitigations common to both marine and wind projects.

Identification of a subsea cable routing that will satisfy the necessary planning and consenting permissions must be given appropriate consideration and resource allocation in a project's formative phase. Early engagement with permitting bodies can help mitigate much of the consenting, programme and cost risk.

The value of developing a full understanding of subsea cable routing conditions is often overlooked; but detailed seabed analysis during early design will help account for the risk presented by common factors such as rock, unexploded ordnance ship-wreck and mobile sediments. Accurate seabed geotechnical analysis and cable routing will also help minimise installation delays and unexpected costs. In addition, early-phase seabed analysis aids specification of the correct cable type for the conditions, and appropriate subsea cable protection measures, both elements are vital in ensuring reliable operation of the transmission system in the long-term.

Making Landfall Successful

Landfall infrastructure poses some unique challenges. Assessing site suitability requires an understanding of metocean conditions, and ground conditions in the intertidal zone; the latter may give rise to the high cost of site investigations offshore. Establishing whether a trenchless crossing will be necessary is another important element of early planning, as is ensuring suitable access for installation, both of these factors will inform the scope of the site investigations. Additionally, to be consentable the landfall solution needs to give sufficient consideration to third-party use of the landfall site.

Planning and Consenting

Acknowledging the importance of planning and consenting permissions is also essential to the successful delivery of a projects' onshore infrastructure. The landfall site, onshore cable routing, substation and grid connection all require locations and characteristics that meet the requirements necessary to secure planning and consenting permissions.

A major factor in achieving planning permission and consenting is the ability to create an integrated, onshore infrastructure design capable of meeting the challenges of local engineering constraints, but also the diverse requirements of a wide group of stakeholders - typically including environmental regulators and authorities, utilities, the relevant transport authority, drainage boards, local authorities, third-party asset owners and landowners.

The Value Of Stakeholder Engagement

Designing cost efficient onshore assets that meet the requirements of the project, planning authorities and – by extension local community - requires a partner with demonstrable expertise in combining the technical requirements of the project and value engineering with effective local stakeholder engagement.

Experience proves that regular contact with stakeholders is key. Consulting with stakeholders and providing clear, concise information; understanding their concerns and requirements - and where feasible modifying designs if necessary – is key to attaining permissions and consents.

Onshore infrastructure designs that successfully achieve planning permission and consents incorporate some or all of these attributes:

- Cable routing along field boundaries minimising any sterilised land during construction
- Siting of joint bays, and site access bellmouths to minimise disruption and land sterilisation
- Utilising and upgrading existing farm tracks
- Minimising loss of hedgerows and trees
- Avoidance of cable routing through Special Protection Areas (SPAs) avoiding where possible any ecologically sensitive areas
- Utilising and upgrading existing land drainage
- Utilising land parcels which are commercially less valuable to landowners
- Trenchless crossing of key assets and infrastructure
- Provision of permanent easement rights and accesses for affected landowners
- Siting of temporary compounds to minimise traffic volume on local roads

Grid Connection

A partner with proven stakeholder engagement, as well as technical ability, is also essential to the grid connection element of offshore renewables projects, because at this point projects interface with live, critical infrastructure.

Successfully connecting the assets to an existing network requires a robust and buildable design solution that accounts for the specific technical requirements of the applicable network owner/operator, sensitivities of a working substation and existing services and infrastructure. The structural and electrical solution needs to meet the requirements of the project, the party responsible for the substation, and the grid operator.

Transmission CV highlights

Erebus Offshore Floating Wind

Floating wind installation in the Celtic Sea, with an agreement for up to 100 MW installed capacity, developed by Blue Gem Wind. Black & Veatch's scope:

- FEED of onshore civil infrastructure:
- Civil and electrical design for onshore substation
- Routing of onshore cabling from landfall to onshore substation
- Routing of onshore cabling from onshore substation to point of connection
- Trenchless crossing of critical features
- Open-cut trench for onshore cable and buried chambers
- Constructability review including temporary working areas and transportation reviews

Morlais Tidal Energy Demonstration Zone

Developed by Menter Môn, the Morlais Demonstration Zone project in Anglesey aims to provide a consented offshore renewable energy technology demonstration zone with communal electrical infrastructure for several developers to install and operate their energy devices/ arrays. Black & Veatch's scope:

- Preliminary design of the onshore components to support the production of the Environmental Statement and Transport and Works Act Order application:
- Landfall and grid connection substations - location and layout design
- Routing of 132 kV onshore cable circuit
- Open-cut trench for onshore cable and buried chambers
- Landfall solutions
- Constructability review including temporary working areas

Click for more details

Valorous Offshore Wind Farm

The 300 MW Valorous Offshore Floating Wind Farm is being developed by Blue Gem Wind in the Celtic Sea. Black & Veatch's scope was the conceptual development of the onshore cable route, onshore substation and grid connection arrangement.

Pembrokeshire Demonstration Zone

Project provides site for testing multiple wave and floating wind energy arrays of up to 180 MW. Black & Veatch's scope:

- Site characterisation: Resource, metocean, geotechnical, geophysical
- Infrastructure design
- Grid connection
- Updating scoping review report and submitting to stakeholders

Hydrogen Production a Viable Alternative to Electricity

Green hydrogen can be used as zero-carbon fuel, feedstock and energy carrier, and as a method of energy storage. As a result, green hydrogen is a cornerstone of decarbonisation strategies across EMEA. Producing green hydrogen with electricity generated by offshore assets represents a significant opportunity for owners and developers of offshore energy installations, and can offer a commercially attractive alternative where grid connections and local demand for electricity is limited, and grid curtailment can be an issue.

Producing green hydrogen using marine energy is currently at the demonstration stage, having been achieved at the European Marine Energy Centre, in Orkney, Scotland; with transmission lines bringing the electricity to the on-shore electrolyser. There is also interest in ocean current energy: combining turbines in large-scale in ocean currents with offshore electrolysis technology; using tankers or pipelines to bring the hydrogen ashore.

Producing green hydrogen using offshore wind electricity, is also becoming a reality. In ScotWind - Crown Estate Scotland's January 2022 auction of offshore wind seabed development rights - successful bidders included the Total, GIG and RIDG 2 GW West of Orkney wind farm, which is set to power the Flotta Hydrogen Hub on Orkney. There was also a green hydrogen component to BP and EnBW's successful 2.9 GW project bid.

As well as projects using offshore wind to power onshore electrolysers, the North Sea is also home to pilot schemes investigating the feasibility of undertaking electrolysis at source – at the offshore windfarm.

Offshore Electrolysis

The PosHYdon pilot project will see electricity generated by offshore wind powering an electrolyser housed on Neptune Energy's Q13a oil and gas platform. Alongside RWE, Neptune is also a partner in the H2opZee demonstration project, which aims to build 300-500 MW of offshore wind powered electrolysers in the North Sea by 2030.

While these projects use separate wind arrays and electrolyser assets, Siemens Gamesa and Siemens Energy are developing an integrated turbine and electrolyser system capable of directly producing green hydrogen. Full-scale offshore demonstration is expected by 2026.

Floating wind infrastructure offers the potential for greater predictability, and volumes, of green hydrogen production. The Dylan project is piloting a combination of electrolysis, desalination and hydrogen production on a floating wind platform being developed in the Celtic Sea.

Offshore green hydrogen projects are first-of-a-kind in terms of both technology combinations and location. Successfully utilising offshore wind, or marine energy, for the production of green hydrogen requires the expertise in - and integration of – a diverse range of technologies and disciplines. Ideally developers and owners need a partner with not just offshore wind or marine energy technology experience, but one able

to augment that with – for example – knowing how a full understanding of using site-specific metocean data can deliver more accurate LCoE forecasting.

The most effective support for a project's business goals will come from organisations able to couple these disciplines with similarly comprehensive expertise in the fields of hydrogen electrolysis, desalination, marine structures and marine power transmission and, crucially, how to make all of these elements work in concert in a hostile marine environment.

While helping organisations develop green hydrogen projects, many first of a kind, Black & Veatch has identified six core considerations that require close attention in a project's earliest stages, in order to ensure a successful outcome. Click here to read our core considerations.

Green Hydrogen CV Highlights

Fixed and floating wind/green hydrogen LCoE/LCoH modelling – client confidential

Black & Veatch undertook the LCoE and levelised cost of hydrogen (LCoH) analysis of a 985 MW offshore wind and green hydrogen production project in Ireland. The initial phase comprised 67 wind turbines - 58 fixed and nine floating; a 484 MW capacity electrolyser plant and ammonia production facility.

Click for more details

Mercury Renewables

Mercury Renewables is developing one of Ireland's first co-located onshore wind farm and hydrogen electrolysis plants. A 78 MW wind farm will power an electrolyser plant generating green hydrogen. Black & Veatch's scope has included feasibility studies, conceptual design, permitting support and cost estimation.

Click for more details

Advanced Clean Energy Storage hub, ACES-Delta

The world's largest industrial green hydrogen production and storage hub, converting more than 220 MW/d of renewable energy into 100 tons of green hydrogen, stored in salt caverns. Black & Veatch's Scope:

- Turnkey EPC
- Full facility, switchyard through connection to caverns
- Full wrap of critical equipment

Click for more details

Digitalisation Key To Reaching Offshore Wind's Potential

Digitalisation is necessary to achieve the capacity targets anticipated for offshore wind. To do this we need to move from met masts to lidar as the primary source of wind data. Wind is a time-varying three-dimensional vector field. We can no longer rely on simplifying this as a "wind speed" of the sort acquired by met masts.

Managing complexity

With lidar we gain detailed insights into phenomena such as wakes and complex shear which can have a significant effect on the bottom line of a wind project throughout the asset's lifecycle, from demonstrating project bankability pre-construction right through to optimised O&M. As offshore turbines and arrays get bigger, the impacts of these phenomena are becoming more important.

Engineering approximations of wind conditions tend to assume that wind gradually increases with height. In the North Sea complex, intermittent - and crucially - unanticipated wind shear phenomena associated with variations in atmospheric stability have been directly observed using lidar.

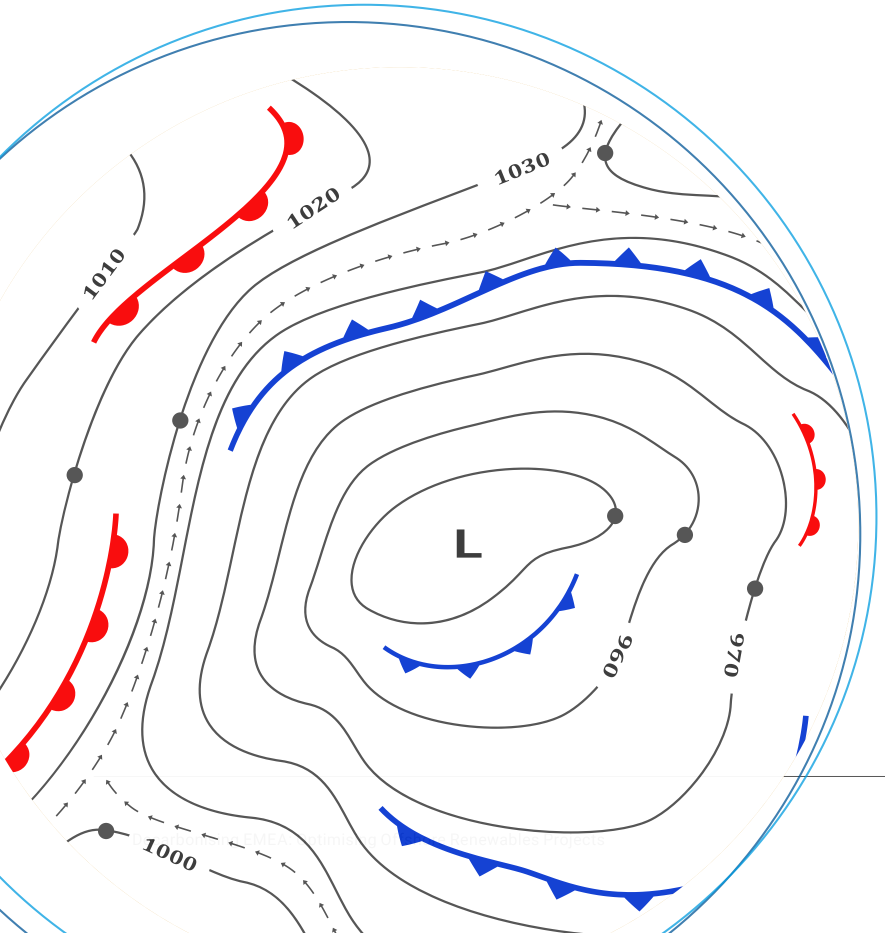
These phenomena impose mechanical loads on the turbine blades that propagate through the rotor nacelle assembly and drive train. Thanks to lidar data we now understand some of the loads that had been observed on offshore wind farms which were previously unexplained.

Lidar has also helped reveal the importance of atmospheric stability on wake propagation. Wake losses downwind of a wind turbine have been seen to increase at night, compared to day-time operations, because more stable night-time atmospheres meant that wakes propagated further.

Reducing uncertainty

The benefits of lidar lie in grappling with the inherent complexity of the problems we are trying to solve as we seek to develop profitable offshore wind farms. By helping manage complexity, digitising the wind using lidar reduces uncertainty and increases confidence in offshore wind project outcomes by allowing this inherent complexity to be accommodated in our models and calculations.

Lidar data can be combined with mid-fidelity wake models for validation, and to support wind farm control methods.



Using a met mast leaves gaps in the information upon which a project is based which are filled with assumptions. Lidar helps close these gaps and reduce the possibility of surprises later in the project lifecycle when adverse wind conditions - that could have been predicted and mitigated with a properly designed and executed lidar measurement campaign prior to construction – come to light through unforeseen consequences in terms of component failure and unscheduled downtime.

Component or structural failures that could have been proactively mitigated during design or construction, or accommodated into a properly informed O&M strategy, become instead the subject of reactive remedial work, which is rarely the most cost-effective approach to operations and maintenance.

This issue is especially pertinent to offshore wind assets where inspection, repair and maintenance represent a significant programme cost and consideration. Unless site-specific wind data has been incorporated into a project's early development, it is possible that the built assets may not be able to consistently achieve the performance forecast.

Floating lidar systems are the primary source of offshore wind data where there are no other opportunities to install equipment to acquire site data, for example, when undertaking the pre-construction wind surveys to support wind resource assessment and energy yield estimation.

Ultimately this all feeds into greater confidence in the quality of LCoE analysis which enhances bankability for developers and gives owners and operators greater confidence when evaluating energy production - and ultimately – profitability.

Offshore wind CV highlights

Marine Power Systems (MPS)

MPS appointed Black & Veatch to undertake a LCoE analysis and to support the design and optimisation of their Pelaflex floating wind platform and megawatt-scale demonstrator development.

Click for more details

Offshore Wind Feasibility Study – Client Confidential

Black & Veatch supported the pre-feasibility and programme management of a proposed 50 MW floating wind farm in Mediterranean waters. Black & Veatch's scope:

- Project and programme management
- Floating platform, environmental and commercial study review
- Production of a project implementation plan
- Development of combined pre-feasibility study

Offshore Wind Performance Upgrade Study – Client Confidential

For a utility scale UK offshore wind farm Black & Veatch delivered an assessment of the production enhancement potential of different asset upgrade scenarios.

Setting Standards To Reduce Risk

Floating wind and marine energy are maturing technologies, which need to be built, operated, and maintained in unforgiving conditions – all factors that increase risk. As the G+ Floating Offshore Wind Hazard Identification report noted there are gaps in industry guidance for constructing and operating floating offshore wind projects, including the risk of novel technology being deployed in markets with no offshore experience nor regulatory frameworks.

This risk profile means there is significant value in working with partners who are helping develop the standards, and thus fully understand the risks and mitigations, that are being created to nurture the sector's long-term viability. Black & Veatch's Marine Energy & Offshore Engineering Services team has a wealth of such expertise.

Claire Cohen, Head of Marine Energy, Black & Veatch EMEA, is co-convenor for the International Electrotechnical Commission (IEC) Technical Specification 62600-201 Tidal Energy Resource Characterisation.

CohenC@bv.com

Andrew Jones, Head of Offshore Engineering & Civil Discipline Lead, Black & Veatch EMEA, was nominated UK Expert and contributing author for the IEC Technical Specification 62600-2:2016 Design Requirements for Marine Energy Systems. He is also a member of the IEC TC 114 Maintenance Team 62600-2.

JonesAL@bv.com

Peter Clive, Principal Wind Energy Consultant, Black & Veatch EMEA, is project leader for IEC PT 61400-50-4, writing the technical specification providing normative guidance for the use of floating lidar systems. In addition, Peter is a member of Lloyd's Register Offshore Technical Committee and sits on various other IEC wind power committees.

CliveP@bv.com

Let’s Talk

While fixed offshore wind is a mature technology, marine energy and floating wind – both in the ascendency – are developing technologies; as is producing green hydrogen with power generated offshore. By definition all of these technologies are built, operated and maintained in challenging conditions.

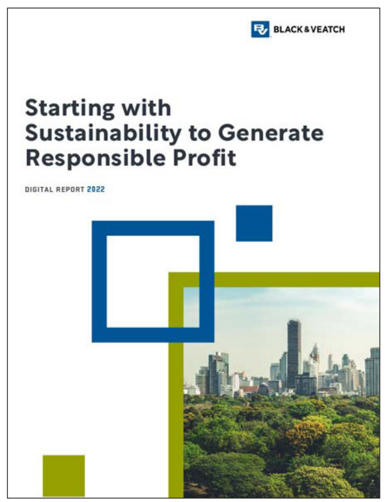
To succeed, and minimise risk, projects to generate electricity offshore need partners expert in the established technologies as well as helping nurture the developing ones to commercial viability. The most complete support, in addition, needs to be technology agnostic; and based on proven experience in the transmission as well as generation of electricity offshore.

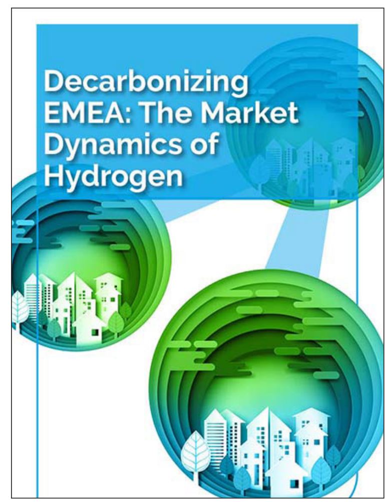
Finally, execution certainty is best served by partners with demonstrable experience of adding value at every point in the project lifecycle, and managing the complex interfaces between the differing disciplines and systems offshore energy projects encompass. Let’s talk and see how we can help you and your project.

Learn more about Black & Veatch at bv.com

At Black & Veatch, our mission is to build a world of difference through innovation in sustainable infrastructure. We help organizations integrate a range of technologies to cost-effectively achieve resilience, sustainability, and growth.

Read Our Other eBooks to Stay Ahead of the Net-Zero Curve





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