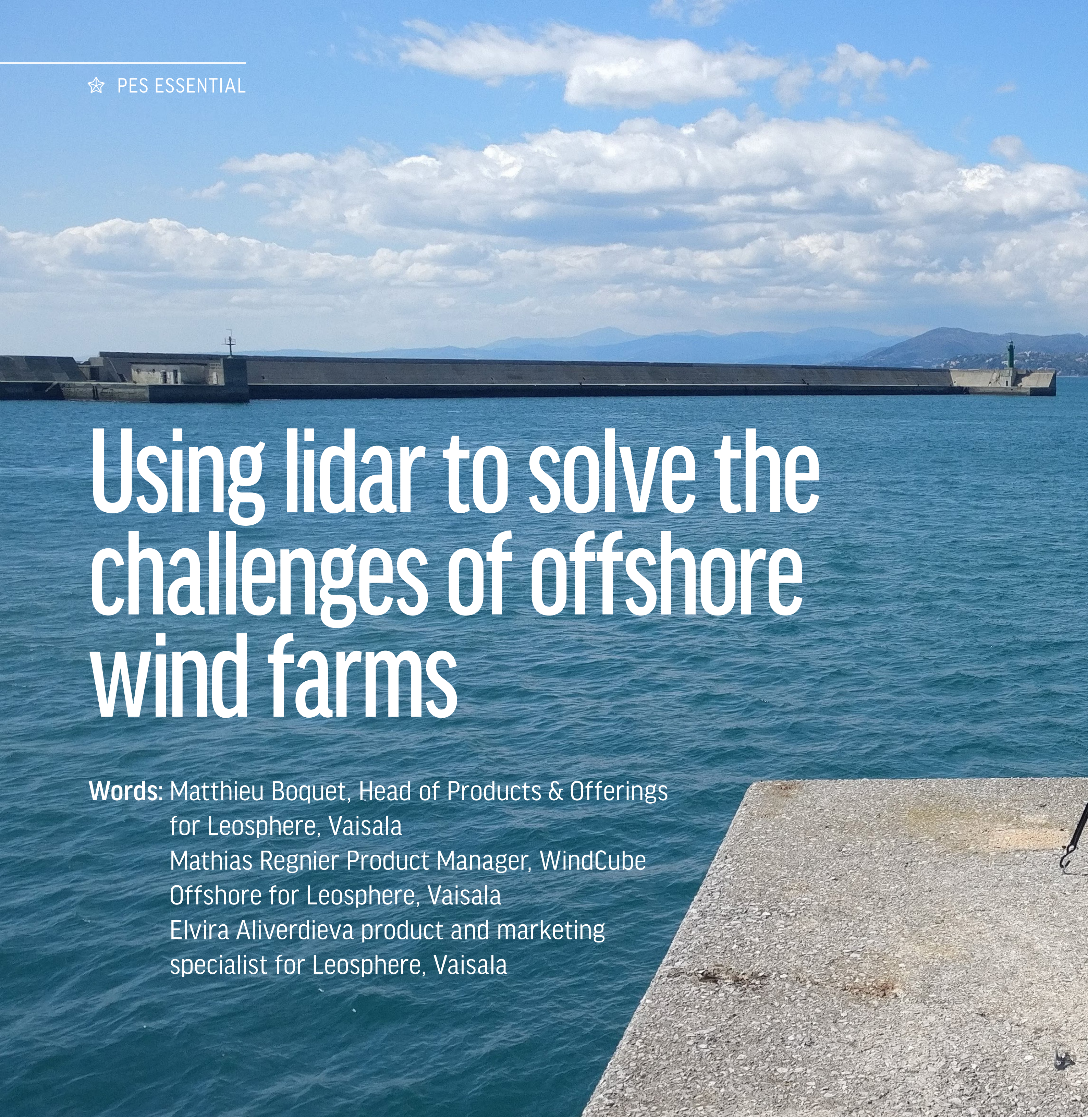

Using lidar to solve the challenges of offshore wind farms

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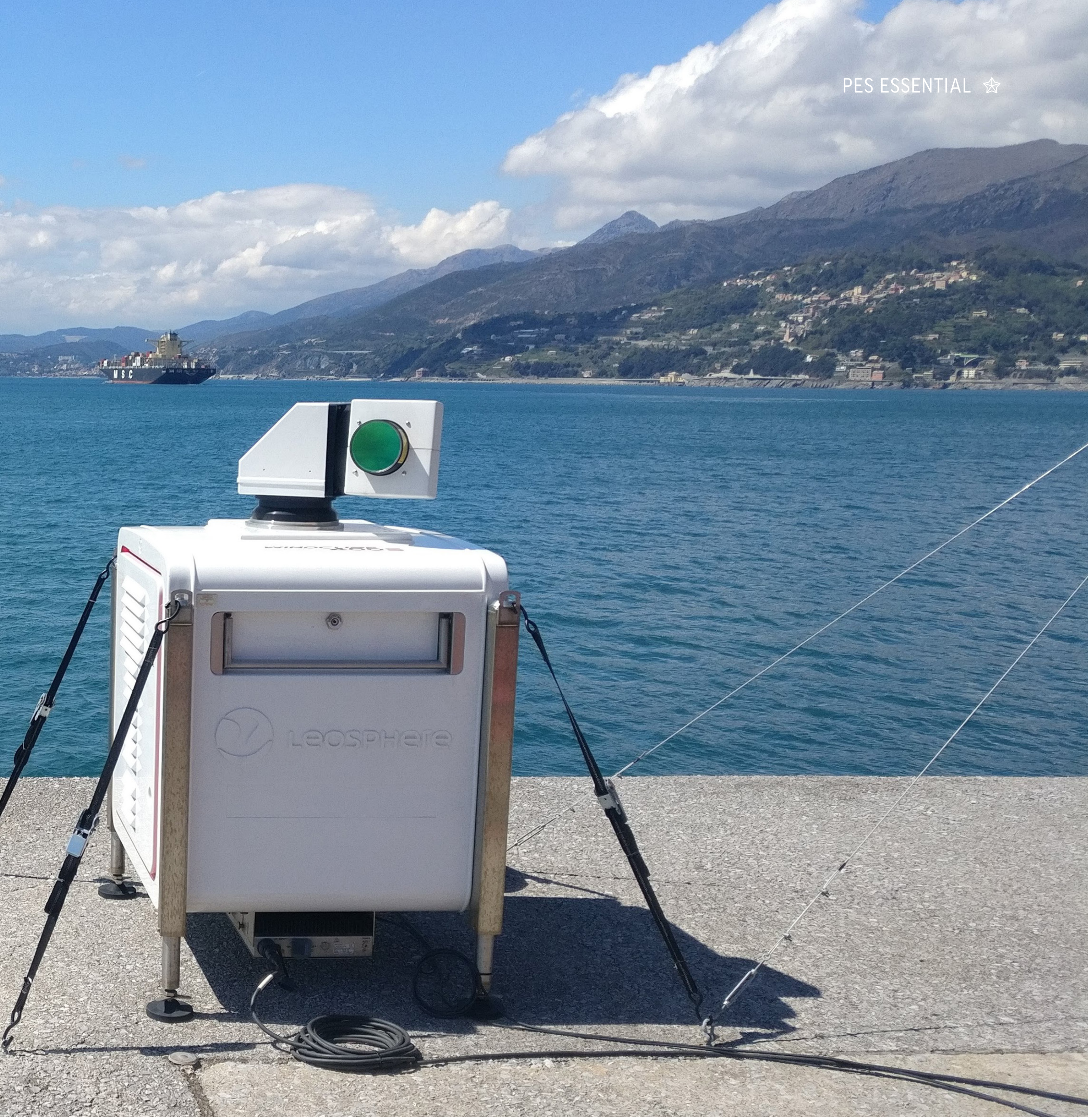
WindCube Scan 400S in Italy. Courtesy of University of Genoa and the ERC Project THUNDERR

As global interest in wind energy continues to grow, an increasing number of projects are looking out to sea, where the vast ocean expanse allows offshore wind farms to cover more area, erect larger turbines and generate more energy.

Offshore wind is expected to constitute 20% of total wind energy installations by 2025. While Europe and Asia are leading the way, the United States is making its own waves in the offshore wind market, with developers planning to implement about nine gigawatts of offshore wind by 2026.

Although offshore wind farms can produce more energy and don't have to deal with the terrain issues and residential opposition some land-based farms face, operating on the open ocean presents its own unique set of challenges.

The traditional measurement towers used to gauge winds for inland farms are difficult, if not impossible, to install and maintain at offshore sites due to the harsher conditions and remote locations. They also may be less accurate for the much larger turbines used at sea, making getting reliable wind characteristic assessments one of the



biggest challenges to maximizing the potential of offshore wind farms. And considering offshore wind farms can cost 10 times as much as their onshore counterparts, getting the most out of the turbines is key.

Enter lidar technology. Light detection and ranging equipment uses pulsed laser light to remotely measure characteristics of the wind flow and data such as wind speed, wind direction, and turbulence. All of this in real time and using technology that is more versatile and adaptable to the various phases and needs of an offshore wind farm.

Let's dig a little deeper.

Bigger is better

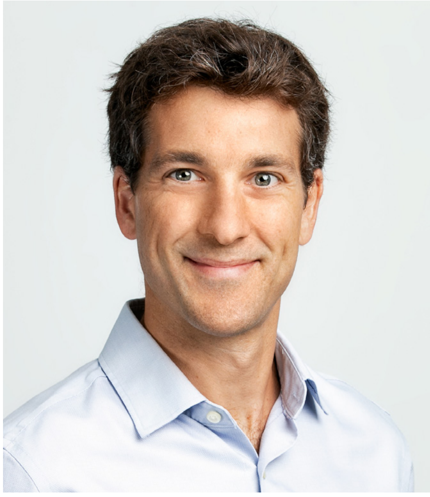
Offshore wind farms have evolved to keep pace with market demands. They cover more expansive areas, are located great distances from the shore and use larger, taller turbines than their land-based counterparts, all of which contribute to increased power generation.

But the scale of operations for an offshore wind farm comes with complications when it comes to accurately assessing wind characteristics as well as obtaining precise wind data at long ranges from the shoreline.

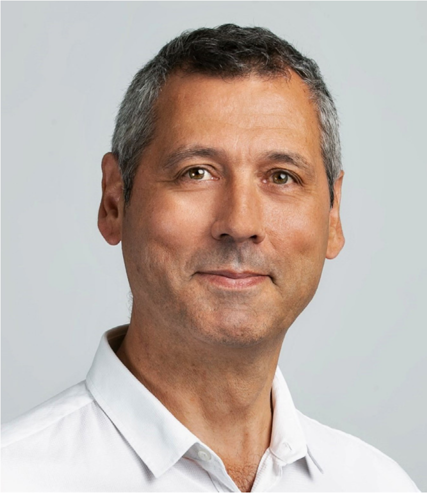
Even if met masts were feasible in offshore conditions, none would be large enough to measure to the full height of the larger turbines without mathematical extrapolation, which leaves room for error.

With bigger turbine capacities and bigger areas of operation, even small errors in data for offshore wind farms can lead to significant economic impacts compared to smaller onshore operations, and even slight inefficiencies can impact a project's success. Taking into mind the costs of offshore wind farms, a difference of decimal points could mean millions of dollars.

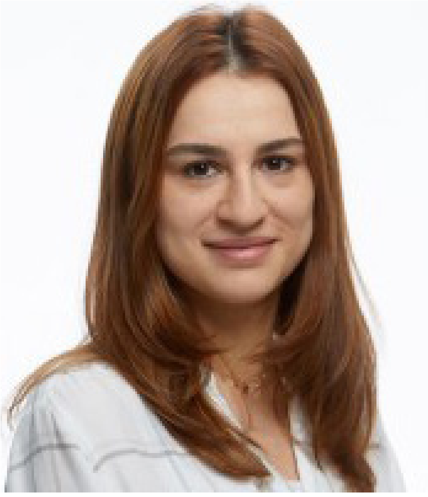
When working on the much larger scale that offshore wind farms require, accurate data during the production forecasting phase and



Matthieu Boquet



Mathias Regnier



Elvira Aliverdieva

monitoring and performance testing once a project is up and running, is crucial. Lidar is able to precisely measure wind characteristics and data up to 300-plus meters in height using vertical profilers, 700 meters in front of turbines with nacelle-mounted lidar and 10-plus kilometers from the shore or from a platform with scanning lidar technology.

Turbine manufacturer Siemens Gamesa in May 2020 announced the launch of what will be the world's largest offshore wind turbine, featuring a 222-meter rotor and 14-megawatt capacity, and for years the company has been using nacelle-mounted lidar in place of met masts to conduct power performance testing.

Versatility and adaptability

Every offshore wind farm is unique and presents its own unique challenges, so versatility is key for developers as a project moves through its various stages, from conception to construction to care.

Lidar is the most comprehensive offshore measurement technology available, with a solution to support every phase of an offshore project, from wind resource assessment and operational power testing to permanent wind monitoring, research and development, and prototype testing.

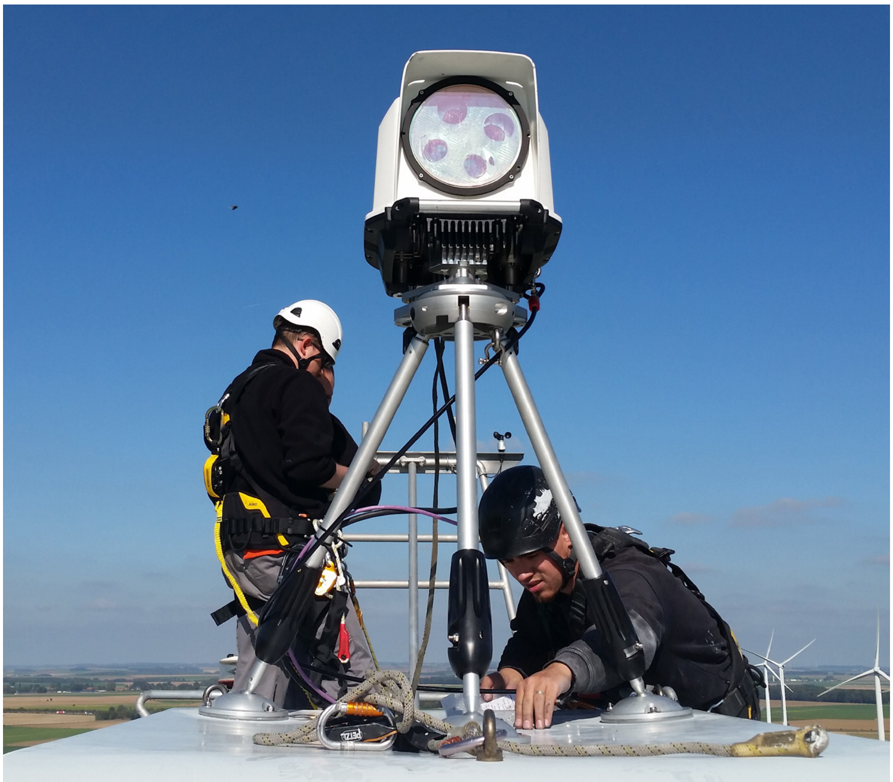
Before a wind farm can ever begin harnessing energy, a lot of work goes into figuring out exactly how to design and layout the turbines using the most accurate data possible. As an example, the WindCube suite of lidar solutions can help with this important first step in a number of different ways.

WindCube Offshore vertical profiling lidar is mountable on existing platforms, such as oil rigs, sub-stations, islands or lighthouses. In situations where there is no platform or the platform is too far away from the shoreline, the WindCube Offshore can be integrated on a vessel or buoy (Floating Lidar System). This lidar provides direct wind assessment and reduces uncertainty to support the feasibility and bankability of the wind farm project. It is marinized to match the offshore harsh conditions, providing a versatile solution to assess proposed offshore wind farms at almost any location.

WindCube Scan scanning lidar can be mounted on a fixed platform or placed onshore at the coastline. It allows for full, 3D spatial mapping of the wind field affecting multiple real or potential turbines. With a range of more than 10 km and up to 19 km, scanning lidar can provide wind data of an offshore site from the shoreline, where it is much easier and more cost-effective to operate and maintain. A single WindCube Scan provides rich data from one strategic vantage point, while the WindCube Scan Dual Lidar Ready offering provides an even more comprehensive picture of the wind resource profiles. Today it is considered one of the key innovations to reduce the cost of offshore wind energy.

In addition, different lidar technologies can be mixed and matched to provide developers and operators with the most comprehensive site data possible to reduce uncertainty.

When a proposed wind farm location becomes reality, lidar can still play a key role. Vertical profiling lidars can be used during craning and mounting operations to help



WindCube nacelle ENGIE

ensure accurate placement and installation. In addition, scanning lidar enables users in the construction or commissioning phases to conduct power performance testing (PPT) of multiple turbines with just one lidar unit. Nacelle-mounted lidar is also commonly used to perform PPT and continuous monitoring of active wind farms, which is key to verifying performance or validating repairs and upgrades. It also troubleshooting and identifying underperformance since it is quick and affordable to deploy and provides reliable data in real time.

During manufacturing and prototyping stages, lidar can be used as a testing aid that can lead to better design decisions and improve manufacturers' understanding of operational performance. Plus, lidar data can be used to reduce fatigue and extreme loads on critical components, increasing the lifespan of a turbine design.

Unlike met masts, lidar requires little to no permitting, can be erected in less time and with less manpower than traditional measurement towers, and can be moved from site to site or repurposed depending on needs.

Operational continuity

Offshore wind farms operate in harsh environments far from maintenance resources. Fixing a problem at an inland wind farm might require someone to simply drive out to the site. Maintenance at an offshore wind farm, on the other hand, requires a boat and waiting for the right weather in order to even access the turbines.

Since accessing a wind farm location can be expensive, risky and time-consuming, operational continuity is key to a project's success or failure.

Lidar systems are comprehensive and easy to deploy and repurpose throughout the life cycle of an offshore wind farm project and can adapt with a project or developer as needs change.

Lidar has also proven capable of providing 5-10 minutes of advanced notice for approaching wind disruptions and storms,

WindCube offshore solution matrix

	Wind resource assessment/Pre-construction				Construction/commissioning	
	Green field	Platform available	Nearshore situation (or close to island, lighthouse etc.)	Farm extension (Impact of existing farms)	Craning (Optimization of ship operations)	PPT - Contractual Power Curve
Floating Lidar Systems (including on vessels/ships/floating drones)	■					
Vertical profiler lidar		■	■			
Nacelle-mounted lidar						■
Long-range scanning lidar			■	■		

	Post-construction/ Operations		Post-construction/Research					
	Permanent wind monitoring (Off grid compensation)	PPT - During Operations	Blocking effect (Understand wind farm layout impacting wind ahead)	Wake losses studies (Understand production losses intra-farm)	Wind farm wake effect (Impact of existing wind farm on neighbors and extenstion)	Turbine control (Costs reduction, AEP increase)	Wind farm control (Increase of farm production globally)	Short-term forcasting (Monitor upcoming wind minutes in advance)
Floating Lidar Systems (including on vessels/ships/floating drones)								
Vertical profiler lidar	■							
Nacelle-mounted lidar		■				■		
Long-range scanning lidar			■	■	■		■	■

which can allow developers to act and protect turbines from undue strains.

Companies looking to build and operate offshore wind farms must research the lidar manufacturer's warranty and service offerings, including ongoing training and its global support infrastructure and service centers.

A big part of operational continuity is also trusting the solution has been validated and certified to reliably work, and that the solution is backed by a reputable company. WindCube Lidar technology is validated and accepted by the world's leading independent experts and research institutes, including DNV, DTU Wind Energy, UL, Deutsche WindGuard, NREL and AIST, and the equipment meets the latest international verification standards and is compliant with IEC standards.

Harnessing the power of the wind

Offshore farms are more expensive to start up than inland ones, and there are challenges and risks to starting one. But it appears the future of wind power lies beyond our shores. Lidar can save time and money while also providing the type of accurate data needed to maximize the economic impact of an offshore wind farm.

www.vaisala.com/en/wind-lidars/wind-energy

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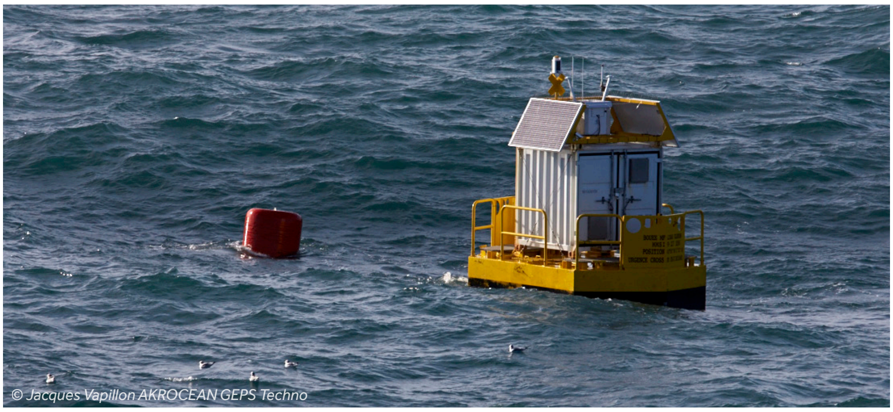

WindCube Buoy offshore

About Leosphere, a Vaisala company

Leosphere is the iconic and trusted gold standard in wind lidar and its WindCube product suite offers innovative, reliable, powerful and turn-key solutions that are key to harnessing the power of the wind on any offshore wind farm.

Bio

Matthieu Boquet is Head of Products & Offerings for Leosphere, a Vaisala company. In this role, he drives Leosphere's WindCube® lidar offerings to meet the industry's high-level expectations while helping customers continually generate value from their lidars.

Mathias Regnier is the Product Manager for the WindCube Offshore lidar at Leosphere, a Vaisala company. As such, he continually evaluates customer needs in order to develop lidar product strategies and solutions for the booming offshore wind market.

Elvira Aliverdieva is a product and marketing specialist for Leosphere, a Vaisala company. She participates in the evolution of the company's onshore and offshore wind product strategy, with a primary focus on the booming offshore market.