Measuring, analysing and acting for a better world with lidar

Around the globe, lidar is becoming the modern standard for wind measurement campaigns. With new wind energy projects being built rapidly, the need for accurate and reliable wind measurement data has never been greater. As organizations use lidar data and integrate remote sensing technology into every stage of wind energy development campaigns, it is important to understand the industry's evolution, new challenges and opportunities, and how lidar innovations are accelerating wind energy worldwide.

The world's installed wind generation capacity, onshore and offshore, has increased 98-fold over the past two decades. There are many drivers of this growth, including investments in wind energy research and development, supportive policies pursuing net-zero goals, falling costs of technologies, and exploding end-user demand for renewable energy. Precise on-site wind measurements from lidar reduce project uncertainty and increase value for investors and developers.

Today, wind energy experts continue to discover incredible and innovative ways to leverage these remarkably versatile lidar solutions, to propel wind energy into the future.

Existing wind energy industry trends and challenges

One fundamental trend is the growth of wind turbine hub heights and rotor diameters, particularly for offshore wind farms. This shift is expected to continue, as more countries invest in offshore wind farms, and turbine vendors compete for market share. Accurate measurements at higher heights are vitally important.

For decades, meteorological masts, or met masts, outfitted with mechanical anemometers have been the standard measurement technology. But for today's tallest turbines, with hub heights between 100m and 200m, and blades sweeping above 200m, met masts are expensive and difficult to deploy and maintain. This is especially true in offshore campaigns, where installation requires sea-bed foundations, and construction in dangerous offshore conditions. Less expensive and safer, buoy mounted lidar has rapidly replaced offshore met masts and has become the new standard measurement equipment for offshore development. This change was driven by the Carbon Trust's Offshore Wind Accelerator.

Given the current wind energy trends and challenges, lidar usage and acceptance have evolved to the point where the technology has become a standard instrument for reliable wind measurement throughout all phases of a wind development.

Advancing lidar verification capability with 200m met masts

Accurately assessing a site and selecting the best solution for the measurement campaign is essential to build a profitable and reliable wind farm.

Before lidar devices are deployed in a measurement campaign, they are tested following the requirements of current IEC guidelines. To assist organizations with lidar verification in compliance with IEC 61400-50-2, Pavana GmbH, a German wind energy service company, has erected a 200m measurement mast, providing lidar verification services 200m above ground.

These pre-campaign verifications provide the basis for reliable and bankable wind resource measurements. Measuring the accuracy of lidar measurements up to 200m creates traceable uncertainties for the wind measurement campaign and validates the

functionality and consistency of lidar devices before deployment. This process quantifies financial risk via traceable measurement uncertainty estimates, following international standards.

Investments in dedicated lidar verification facilities demonstrate industry confidence that lidar is becoming the modern standard for wind measurement campaigns.

How high-res simulations provide insight into lidar accuracy

An inherent element of lidar measurement accuracy is atmospheric variability.

To assess how atmospheric characteristics affect the performance of lidars, Professor Julie Lundquist and PhD candidate Rachel Robey of the University of Colorado used large-eddy simulations with dozens of virtual lidars in the simulation domain. High-resolution atmospheric simulations provide a controlled environment to quantify the accuracy of measurements using the entire 3D flow field, examining sensitivities to atmospheric factors such as stability, wind shear, and turbulence.

Comparing the virtual lidar measurements with the known, simulated wind profiles enabled Lundquist and Robey to quantify the differences between the lidar retrievals and the reference truth. Virtual measurements were collected throughout the simulation domain, collecting hundreds of thousands of samples. This large sample size enables statistical quantification of the differences between the virtual lidar and the ground truth. Understanding error-driving mechanisms helps assess how new or different measurement approaches might improve lidar measurement accuracy.

The research showed that time averaging significantly reduces measurement uncertainties, and that combining lidar scalar averages and vector averages, the WindCube's hybrid wind field reconstruction, effectively reduces biases between lidar-measured wind speeds and the true wind speed.

The evolving IEC 15-2 standard

Adding to the discussion, the International Electrotechnical Commission (IEC) has progressed on its path towards the new IEC 61400-15-2 standard. This standard is expected to significantly improve the acceptance and use of lidars for WRA as stand-alone measurement devices.

Encompassing all aspects of the assessment of the wind resource and energy yield for wind farms, the IEC 61400-15-2 describes key methodologies, defines energy losses and estimates uncertainties for each piece of energy yield assessment.

The standard covers major wind and energy uncertainty categories, with three to six key subcategories for each, including measurement uncertainty, horizontal extrapolation, vertical extrapolation, and historical variability.

There are categories for specific energy losses, such as turbine wakes, blade icing, and curtailment. For each category, guidance is provided on methodologies, which circumstances to use them, and how to estimate the uncertainties associated with each subcomponent. There is also guidance on credible value ranges, documentation for traceability and informative annexes to help promote best practices. The standard provides a Microsoft Excel workbook to input and propagate the uncertainties to the final estimates of wind farm output. Finally, the standard will describe a Digital Exchange Format for data and metadata, enabling seamless collaboration between project stakeholders.

Even for methodologies not explicitly described in the standard, there will be

guidance on documenting and validating new techniques and applying them while still complying with the standard framework. The intent of the IEC 61400-15-2 standard is not to be prescriptive, limiting wind energy players to specific uncertainties, but rather to enable innovation where new techniques have gained acceptance. The ability to adapt and incorporate innovative new techniques is a key enabler of industry growth.

Indeed, there are links between today's lidar innovations and the standard.

The WindCube's hybrid wind field reconstruction directly reduces measurement uncertainty, one of many components quantified in the standard. High-quality, turnkey, third-party validation campaigns, like those from Pavana are an integral part of campaign planning and workflows. Digital Exchange Formats help streamline workflows and ensure data integrity and traceability of measurement data. The growing network of field engineers and validation partners worldwide, all following the same standards and best practices help enable the use of lidar for all aspects of wind energy development and wind farm operations.

Accelerating wind energy success

With the necessary standards to guide wind energy decision-makers, the industry can confidently leverage lidar, share knowledge and work to implement lidar into most wind energy measurement processes. Increased acceptance of lidar technology facilitates the escalating use of lidar in all phases of a wind project. With lidar, the future of wind energy appears limitless.

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Focusing on WindCube™ for wind energy applications, Andrew has worked in R&D for various products at Vaisala, including the Triton sodar, the X- and C-band weather radars, and wind energy forecasting technology.

A 15-year wind energy veteran, Andrew has vast experience in earlier sodar solutions as well as today's modern lidar technologies. He has also served in various industry groups, including the American Meteorological Society's Renewable Energy Committee, the Consortium for the Advancement of Remote Sensing, and the IEC 61400-15, among others.

He has a bachelor's degree in physics from Tufts University and a Master's in applied physics from Columbia University.