Establishing floating lidar as the standard for offshore wind resource measurements

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Today, Floating Lidar Systems (FLS) are considered to be the established and de facto standard technology for offshore wind resource assessment measurements in the wind industry. Fraunhofer Institute for Wind Energy Systems IWES has accompanied this development from the beginning, not only as an expert in the development of guidelines and recommendations, but also by providing its own system. The Fraunhofer IWES Wind Lidar Buoy is celebrating its tenth anniversary this year, after the first prototype was tested at the FINO1 meteorological mast in the German North Sea for the first time in 2013.

The planning of offshore wind farms depends to a large extent on knowledge of the prevailing wind conditions at the site in question. This information can be obtained from the available wind atlases and reanalysis datasets, respectively, which are available globally and can often be accessed free of charge. However, only an on-site measurement can provide a calibration and, with this, a traceable uncertainty of the final wind resource estimate and derived expected energy yield.

Meteorological masts equipped with in-situ anemometers have traditionally been used for this measurement task onshore. For offshore, however, it was concluded back in the early 2010s that using masts to measure the wind resource was not cost-efficient. Instead, the use of FLS employing optical remote sensing from a floating buoy-type platform was considered.

The Carbon Trust Offshore Wind Accelerator (OWA) program made a significant contribution to the development of this technology by publishing its 'Roadmap for Commercial Acceptance of Floating LiDAR' in 2013, which was subsequently updated in 2018. Since then, wind farm developers as the end users of the measurement data, and FLS Original Equipment Manufacturers (OEMs) and offshore consultants have followed the recommendations of this roadmap, developing a large body of evidence, experience, and guidance on this basis.

Two Fraunhofer IWES wind lidar buoys during performance verification next to the FINO3 offshore met. mast in the German Bight

The same applies to national authorities which are entrusted with the awarding of offshore sites and the coordinated planning of wind farm projects. These include the Netherlands Enterprise Agency (RVO) and the German Federal Maritime and Hydrographic Agency (BSH), for which FLS has been an integral part of its tenders for wind measurement services for several years now.

Fraunhofer IWES has been contributing to this development since 2009. The first Fraunhofer IWES Wind Lidar Buoy was trialed in the North Sea next to the FINO1 offshore meteorological mast in 2013 and, as such, it shares its 10-year anniversary with the OWA Roadmap.

The first trial of the system was able to confirm that the mean deviations from the mast measurements lie well within the masts' measurement uncertainty range. The movements of the buoy have a negligible influence on the measured mean wind speeds, averaged over 10 minutes, as common in the wind industry, thus an offshore meteorological mast can be replaced by an FLS, with the additional advantage that it is also possible to perform measurements at heights of far above 100 m.

An FLS of a similar type to the one trialed at FINO1 in 2013 was the first to be used in a commercial wind resource measurement campaign in the German Bight at the N-7.2 site. The collected and processed data are now publicly available and have provided valuable information to not just the wind farm developers active in the area, but also the research community. Several further measurement campaigns with FLS in the German Bight and with the Fraunhofer IWES Wind Lidar Buoy in particular have followed. These have served to inform and support offshore wind development continuously not just in the German Bight but also globally.

When the first FLS was developed around 2010, wind lidar was still a relatively new measuring technology in the wind industry. The first international standard mentioning wind lidar in a wind energy-related application was published in 2017. This was the IEC 61400-12-1 for power curve verification allowing ground-based vertical lidar profilers in addition to the traditional meteorological masts.

The development of a technical specification for floating lidar was initiated around 2020; a committee draft of IEC TS 61400-50-4 was distributed in the summer of 2023 and is currently under review. One important point of discussion in the technical specification has been the distinction between unit and type qualification. An instrument qualification cycle specifies how the results of different FLS tests can be interpreted to allow a comprehensive uncertainty quantification for the specific measurement campaign (SMC).

An evidence base is to be used to define an allowed envelope of operating conditions for the FLS; if a unit in a specific campaign exceeds this envelope, uncertainties need to be added to cover the non-existent evidence. It is expected that the more mature a certain technology and type of FLS is, the larger the already available evidence base will be, and, at the same time, there will be a better understanding of the uncertainties that need to be added when exceeding this. A better understanding may again be translated into a less conservative and smaller measurement uncertainty.

The publication of IEC TS 61400-50-4 promises to be the next major milestone in the development and harnessing of floating lidar technology. Fraunhofer IWES has made a significant contribution to this and brings with it experience from both technology development and relevant measurement projects as part of the development of large-scale commercial wind farms.

In addition to technology development and standardisation, a third area is also considered to be particularly important: the combination of on-site measurements and numerical modeling for an optimal offshore wind resource estimate. Within the scope of the publicly funded project 'Digitale Windboje' (Engl. Digital Wind Buoy), Fraunhofer IWES has developed methods that overcome the various limiting factors of real-world measurements, including incomplete technical availability, a relatively short duration of measurement, and limited spatial representativeness, with the help of numerical modeling and other numerical techniques.

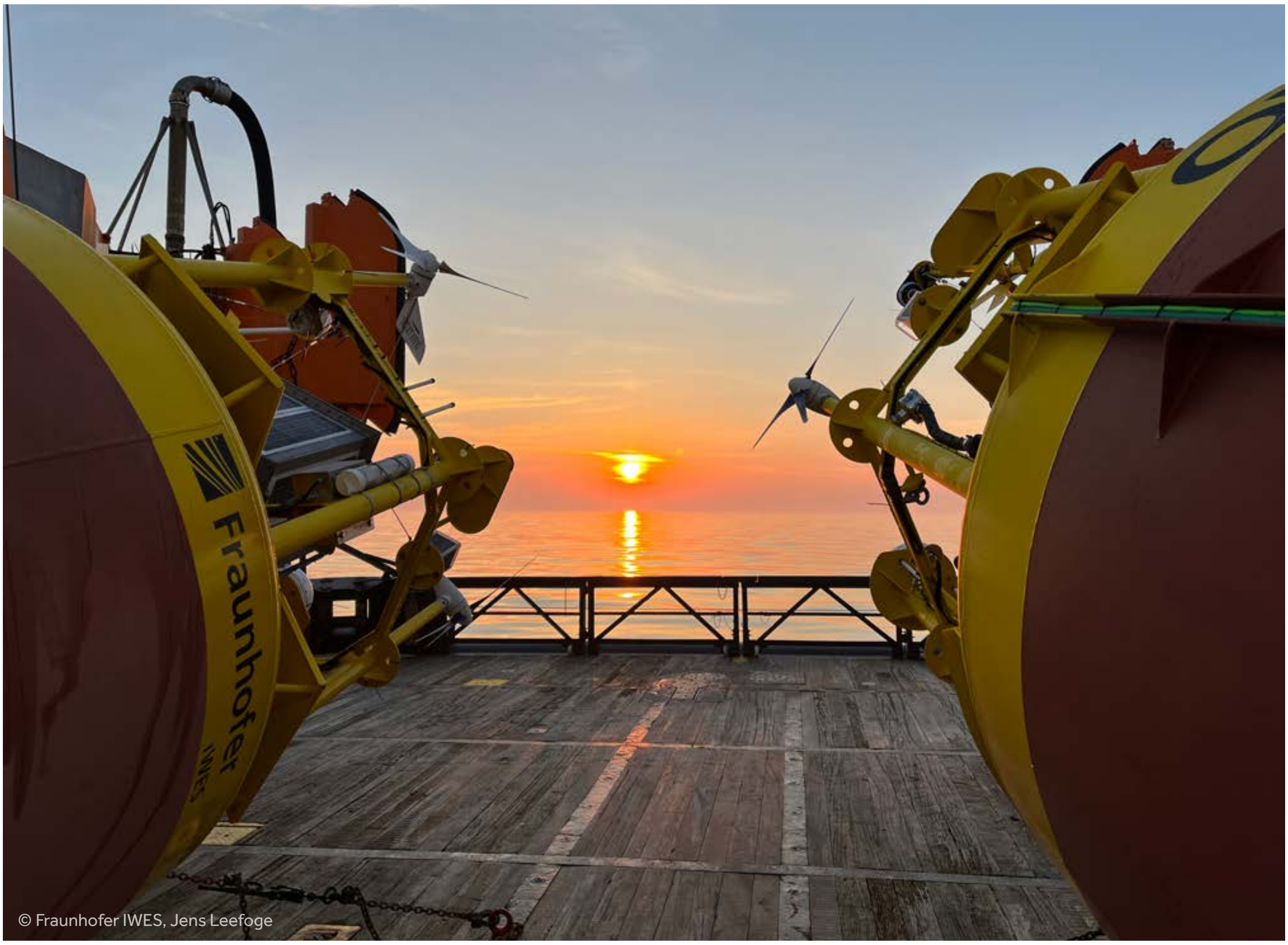
For example, Fraunhofer IWES has investigated how large the data gaps in a measurement can be before there is a significant negative impact on the wind resource estimate. Based on the sites investigated as examples, it became apparent that the criteria required in the 'OWA Roadmap' may be too conservative and that it is possible to compensate for even significantly larger or more frequent failures effectively.

Although it is desirable to have as few measurement failures as possible, this knowledge can help to develop FLS and the associated recommendations in the most effective way, allowing lower availability where this does not affect the final result.

To assess the spatial representativeness, Fraunhofer IWES investigated how the measurements can be linked to wake modeling so that the wake effects of neighbouring wind farms present at the measurement site can be extracted and the measurement data can be used for future layout planning as effectively as possible. In addition to the quality and level of detail of the model, the characteristics of the selected measurement location within the future wind farm area used have an influence on the accuracy of the final results. That is why this approach can also be used to optimise this location in advance.

The results of the 'Digitale Windboje' R&D project have already been published and are set to be published again in the coming months. The project was funded by the German Federal Ministry of Economic Affairs and Climate Action (BMWK; project term: 2020-23).

One question that both guidelines, the OWA Roadmap and the IEC 61400-50-4 Committee Draft (CD), have so far left unanswered is the extent to which FLS can be used for turbulence measurements. When discussing turbulence, the wind industry typically means explicitly the parameter Turbulence Intensity (TI).



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Floating lidar systems (FLS) awaiting offshore deployment

FLS has revolutionised offshore wind resource assessments and will soon no longer be a de facto standard technology, but fully specified in international standards.

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Fraunhofer IWES wind lidar buoy during final factory acceptance

This is defined as the ratio between the standard deviation of second-scale fluctuations within a 10-minute interval and the mean wind speed value within that interval.

Measured TI is an integral part of a site assessment study and supplies information to the metocean database for wind turbine design and load simulations and verification in particular. The extent to which lidar measurements can generally be trusted to provide TI values is currently a subject of discussion in the wind community. In particular, the larger measurement volume, but also a deviating type of sampling in the second range, compared to the typical mast sensors considered as a reference here, provide for deviations that cannot be easily corrected or calibrated.

The motion effects which impact a Floating Lidar measurement give rise to further, additional deviations. At the same time, TI measurements are becoming increasingly important, especially offshore, as not only the expected loads but also the characteristics of wind farm effects including both inner-farm and long-distance wakes depend on the prevailing turbulence conditions at the site.

The accurate and precise modeling of these, based on the prevailing conditions assessed during the site assessment, is of the utmost importance for predicting future large-scale energy yields reliably. Whether FLS will be able to contribute to this challenge remains an open question. The acceptance of FLS for TI measurements does not only depend on the technology itself, but in particular on the specifications and requirements of the future standards for TI measurements. In any case, Fraunhofer IWES can conclude that FLS has revolutionised offshore wind resource assessments and will soon no longer be a de facto standard technology, but fully specified in international standards.

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