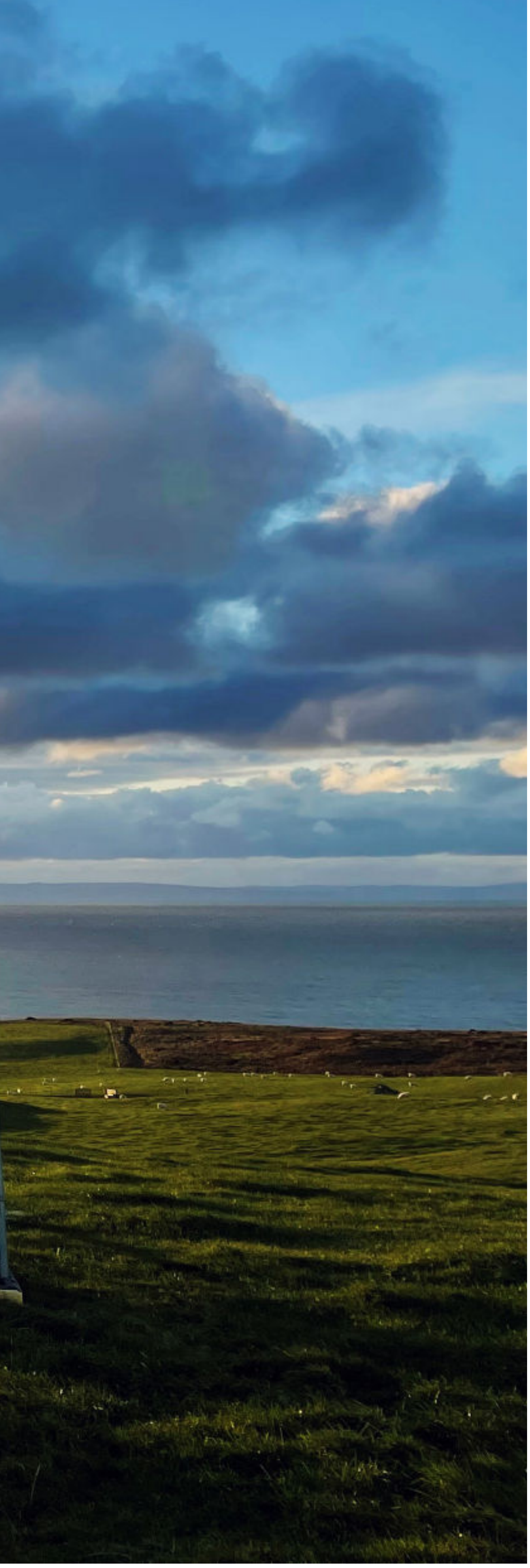
Banking on wind Lidar

In November 2014 we asked the industry 'can we bank on wind Lidar'?[1] Can we use it to provide quantitative data for the annual energy prediction of a wind farm, allowing developers to raise or ratify the necessary finance to progress and construct full-scale developments? Today, in 2022, that question has not only been answered, spoiler alert: it's a 'yes', but the industry is now not just 'banking' on it, it is 'relying' on it. And, by doing so it is managing to reduce wind measurement uncertainty to below that of the met mast and installed cup anemometry. Let's see how we got to that position of finance-grade, more certain wind data from wind Lidars.

1 ZX Lidars (2014): Can the wind industry bank on wind Lidar? Published by Windpower Monthly



Onshore

A decade ago, in October 2012 the ground-based vertical-profiling wind Lidar ZephIR 300 was declared 'bankable' by DNV, known at the time as GL Garrad Hassan. ZephIR 300 was accepted for use in finance-grade wind speed and energy assessments, with either no or limited on-site mast comparisons.

ZephIR 300 was the first commercial wind Lidar system to achieve acceptance at this level and, at least in benign terrain, the industry could begin to bank on Lidar. A pivotal study at the time released by Dutch consultancy Ecofys highlighted further the positive impact of using Lidar within the financial calculations for a project, increasing the Net Present Value by reducing the uncertainty in a project's energy yield[2].

This was largely because Lidars can measure at the hub height of modern wind turbines, and above, and measurements could be taken at multiple points across a site. Using Lidar within a measurement campaign had been shown to increase Return on Investment, which in itself was becoming key in an increasingly subsidy-free industry.

Wind consultants became aligned in adopting common methodologies for the use of wind Lidar onshore. Global standards converged and in 2017, IEC 61400-12-1 Ed. 2 was released, setting out a scheme to assess the uncertainty of remote sensing devices, resulting in a 'Classification' for every instrument 'type'.

In November 2018, the new generation 'ZX' 300 successfully achieved IEC Classification. DNV reported that environmental conditions should contribute no more than 1.5%, and typically less than 1%, to the standard uncertainty of ZX 300 measurements at heights up to 130m from ground level.

Safety calls

With increased acceptance and standardisation came evidence that Lidar could also be regarded as a safer alternative to installing tall masts. In April 2019, global renewable energy company RES, presented these safety claims at WindEurope's Conference & Exhibition in Bilbao[3]. Based on more than 1,700 met mast installations and almost 300 Remote Sensing Device (RSD) system installations spanning three decades, the evidence concluded more than 2% of these mast system installations had resulted in a Near Miss, or Accident, with the majority identified as a Dangerous Occurrence.

In stark contrast, zero RSD deployments resulted in any safety event. The compelling conclusion from RES being 'Substituting masts with RSDs leads to fewer accidents and near misses'.

Increasingly, we see the change that Lidar can bring to an organisation with respect to safer wind measurements, featuring now within Company Environmental Social & Governance policies and frameworks, demonstrating thorough social responsibility.

In 2017, SSE Generation opted for Permanent Wind Lidars (PWL) (Figure 1) in replacement of Permanent Met Masts (PMM) stating that with ground-based Lidar ZX 300, 'all working at height requirements to perform the statutory inspections of the met mast are removed improving the overall safety standards of the site'.

Considering the cost implications of any site incident, GCube, a specialist provider of insurance services for renewable energy projects, has commented that the cost differential between met masts and RSDs is clearly visible in insurance claims. Speaking to Windpower Monthly in 2018, GCube noted that met masts 'traditionally lost insurers money'.

According to GCube, claims typically range from $12,000 to $140,000, starting with icing and snow damage at the lower end, up to tower collapse due to high winds or construction error. The article stated that accidents can occur when working at height, and met masts are easy targets for vandalism. Waiting for a replacement mast, particularly in remote areas, can mean costly delays.

Offshore, the claims can be significantly higher, going up to €1.5 million ($1.9 million)[4]. GCube continued that, on the other hand, while Remote Sensing Devices aren't without insurance risk they are on the whole 'more straightforward to mitigate for ... and do not translate into substantial losses'. In ZX Lidars experience, <0.1% of the globally installed ZX Lidars fleet have been involved in such a reportable incident.

Complex terrain

As the compelling case for Lidar adoption became not only technical but also one of safety, the industry turned its focus to the use of Lidar in all environments, including 'complex terrain'. From the early days of remote sensing, some Lidar users have had the vision to see the value that these flexible measurements could bring in the understanding of a site's wind characteristics and that while it was never feasible to have multiple masts installed over a complex site, with Lidar you could.

Wind flow which has been disturbed by terrain, forestry or structures is described as 'complex' and can result in an RSD 'seeing' and therefore measuring something different to that of a traditional single point measurement cup anemometer. The cup measures just a single point, whereas the RSD assesses and averages the wind over a scanned area. When the flow is complex there are likely differences in what is being measured and will be evident when the two approaches are compared.

This is similar to the situation where a pair of masts and cups are deployed, for example, 100m or so apart in complex terrain which would also result in differences, because you are indeed measuring something different.

At sites featuring complex terrain there are often challenges associated with access that can cause difficulties in erecting tall masts, making the use of RSDs even more attractive.

2 Holtslag, E. and Ecofys (2013): Improved Bankability, The Ecofys position on Lidar use

3 Stuart, P. and RES (2019): Transforming Data Into Value

4 Jan Dodd 2018, 'Do we still need met masts?', Windpower Monthly, 1st March 2018, Accessed July 2022 <https://www.windpowermonthly.com/article/1458018/need-met-masts>


Figure 1: Permanent Wind Lidar installed with SSE

Conversely, the presence of complex flow requires different procedures for handling RSD data to make it representative of that which would have been measured by a cup anemometer, as discussed above.

There is an argument that the RSD is actually measuring, and better representing, those wind conditions that a turbine will experience in the same location but the industry preference has, until now, always been where possible to use the cup anemometer as the traceable benchmark.

In 2021, independent engineering consultant Deutsche WindGuard and computational wind engineering firm ZephyScience 'unlocked' complex wind sites by combining computational fluid dynamics with ZX 300 wind Lidar onsite wind measurements.

A new 'Complex Flow Solver' (ZX CFS) incorporates results from a high-resolution CFD model, derives conversion factors and applies them to the volume-based wind data sampled by ZX 300 at 50 measurement points per second to achieve equivalent measurements to those of a cup anemometer if it were installed at the same location, as represented in Figure 2.

The design and structure of the service has been described as providing the best available solution for bankable wind resource and energy yield assessment based on stand-alone Lidar in complex terrain. To date, there have been no identifiable limits to the complexity of a site that would render ZX CFS unusable. Further, ZX CFS can act as an effective risk-based approach to minimising uncertainty on site by helping to select the least complex measurement location on a site, prior to deployment of the Lidar.

Verified solutions for operating ZX 300 in complex terrain are also available from DNV, Meteodyn, Natural Power and Windsim. The early work of Ferhat Bingöl is often referenced as tools have been developed to adjust for the variation of the wind around the remote sensor's scan.

Offshore

A matter of cost and time

With dramatically increasing wind turbine hub heights offshore combined with increasing sea depths for new sites, installing met masts offshore became prohibitively expensive at a very early stage in offshore wind development. In a guide published by strategic consultancy BVG Associates on behalf of The Crown Estate, in 2010, estimates were approaching £10m for an offshore hub height met station excluding decommissioning[5].

5 BVG Associates (2010) A Guide to an Offshore Wind Farm Published on behalf of The Crown Estate

More than 10 years later, this figure has more than doubled and is further compounded by the required measurement height increasing to upwards of 150-200 metres. And let us not forget the Health and Safety implications of tall masts offshore. Subject to local consenting policy, the time to complete a met mast installation offshore could easily be in the order of three years following the identification of suitable seabed conditions and, in certain situations, only after favourable geotechnical reports.

This substantial early investment, often at the point of highest risk within the overall project lifecycle, also represented a significant schedule impact to the start of any offshore wind farm

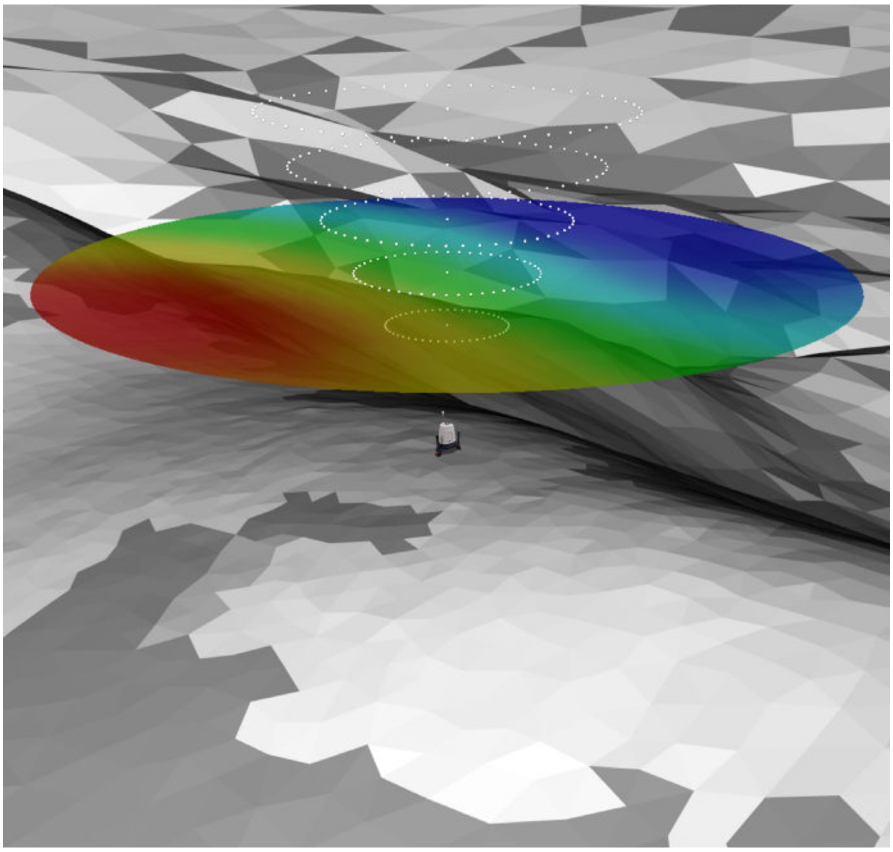


Figure 2: Graphical representation of flow complexity on site being assessed by ZX 300

development. The industry revolutionised itself by accelerating the adoption of Lidar because it had no other choice. It had to bank on Lidar if offshore installation capacity targets were to be given the best chance of being met, and in a timely manner.

In 2005 the first Lidar was deployed offshore on the Beatrice Platform in the North Sea, a ZephIR 150. In 2006, the same Lidar type was deployed in Canadian waters at the NaiKun offshore wind site in British Columbia's Hecate Strait. In 2010 the UK's Robin Rigg Offshore Wind Farm became home to a platform-mounted wind Lidar and in 2014 located in Scottish Waters, Bell Rock Lighthouse once more, metaphorically, lit up the sky, this time with another ZX Lidar for Inch Cape Offshore Wind Farm. NaiKun had demonstrated that a low-cost Lidar platform could technically and feasibly work but only went part of the way to reducing cost and time to water.

In 2010, American offshore wind developer Deepwater Wind demonstrated a first-of-its-kind floating Lidar, again with ZephIR Lidar at the heart, proving that a floating Lidar could work just as well as a platform-mounted Lidar, and with further cost benefits. Just three years later in 2013, a range of 'Floating Lidar Devices' were tested and validated as part of the UK's Carbon Trust Offshore Wind Accelerator (OWA) programme, the Developers involved in this seeing the need to unlock the value of this more flexible and relevant approach. Knowing the time pressures/scale of offshore wind growth, the OWA published a set of recommendations to give the industry the formal framework needed to accelerate the commercial deployment of the technology while standards were being developed[6].

The International Energy Agency (IEA) offered recommendations for using floating Lidar, including wider considerations such as H&S, deployment and moorings[7]. Commercial deployments of floating Lidars were accelerated significantly by the investments made by just a handful of companies and specialists. As a market, the Netherlands certainly helped as it started to conduct the initial wind measurements using floating Lidars before sites were tendered and this continues to this very day.

Today, offshore wind resource assessments are conducted routinely by Floating Lidar Devices against an accepted validation roadmap and a range of technologies are provided by Fugro, AXYS Technologies, EOLOS, RPS, Fraunhofer IWES, Green Rebel Marine (IDS Monitoring), Blue Aspirations and Titan to name but a few. ZX Lidars' systems are standard on all of these devices. There are now literally hundreds of Floating Lidar Devices operational and collecting wind data all around the waters of the world.

By 2019, BVG Associates' original report on offshore wind had been revised and confirmed that 'fixed platform masts are becoming less common as floating Lidar has now reached a higher level of industry acceptance, and the cost advantages of floating Lidar are substantial. A number of offshore wind developers have successfully designed, financed and constructed projects based solely on Lidar data[8]'.

Following a review of market statistics provided by global renewable consultancy Natural Power and BVG Associates, an estimated £150bn of wind development has been financed based on wind data as measured by wind Lidars provided by ZX Lidars in the last 5 years alone[9].

6 Garrad Hassan & Partners, DNV KEMA, Mott MacDonald, ECN, Frazer-Nash Consultancy on behalf of The Carbon Trust (2013) Carbon Trust Offshore Wind Accelerator Roadmap for the Commercial Acceptance of Floating Lidar Technology

7 IEA Wind TCP Annex 32 Work Package 1.5, "State-of-the-Art Report: Recommended Practices for Floating Lidar Systems". Issue 1.0, 2 February 2016. <http://www.ieawindtask32.ifb.uni-stuttgart.de/wp-content/uploads/2016/01/IEAStateOfArtFloatingLIDAR-2Feb2016_v1.0.pdf>

8 BVG Associates (2019) A Guide to an Offshore Wind Farm Published on behalf of The Crown Estate and the Offshore Renewable Energy Catapult

9 ZX Lidars 2021, 'ZX Lidars has provided wind data in support of over £150bn of green energy investment', 11th June 2021, Accessed July 2022 <https://www.zxlidars.com/zx-lidars-has-provided-wind-data-in-support-of-over-150bn-of-green-energy-investment-displacing-245-million-tonnes-of-co2-emissions-globally/>

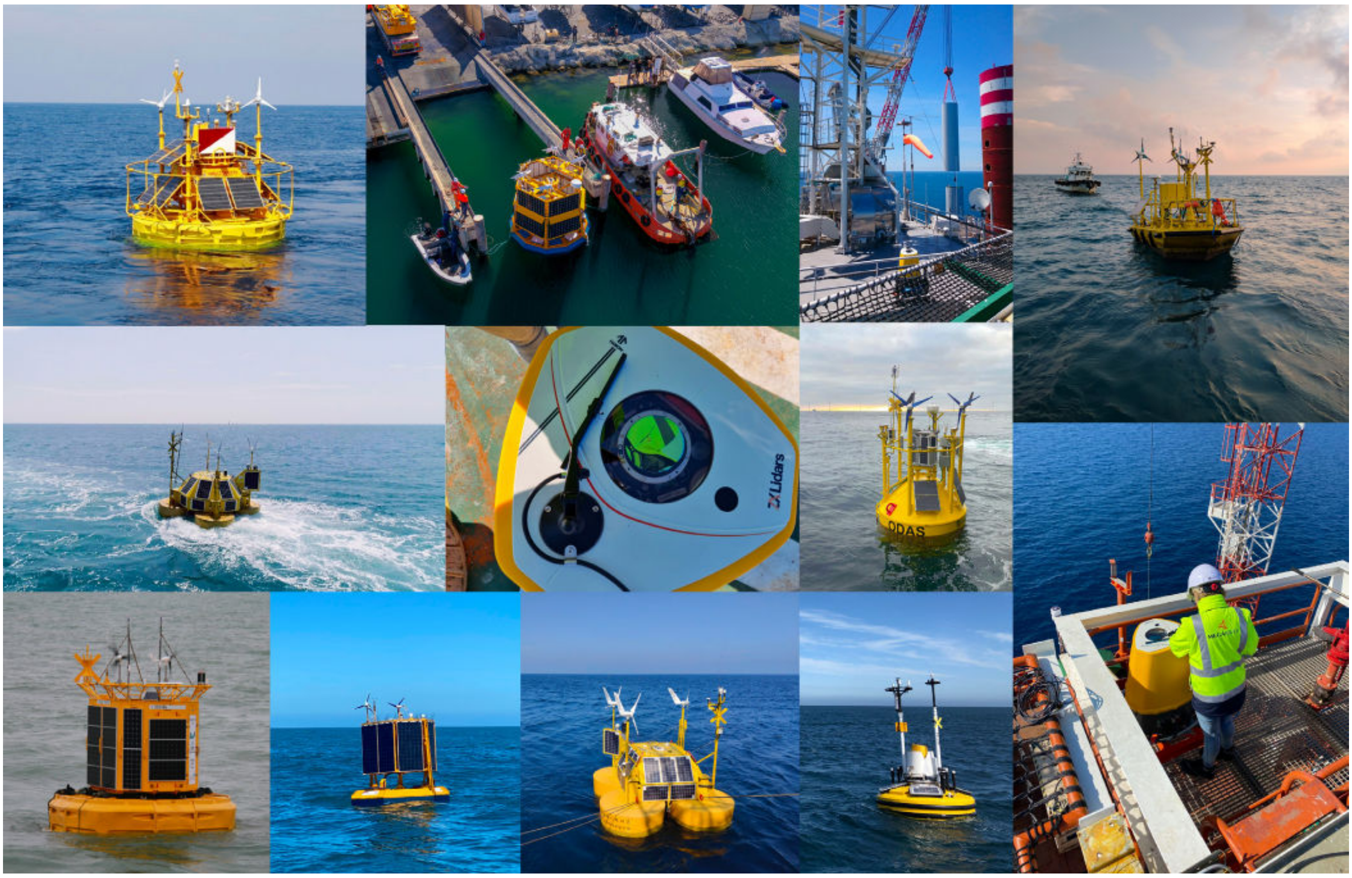


Figure 3: Examples of ZX Lidars' devices installed on floating and fixed platforms offshore

Measurement Heights (m AGL)	10	20	38	45	70	91	105	120	140	160	180	195	200	250	290
Data Availability (%)	99.4	98.9	99.0	98.6	98.1	97.6	96.9	96.2	95.5	94.3	92.9	92.4	91.1	85.8	81.6

Figure 4: Summary of data availability with height across 500 ZX 300 wind Lidar deployments

Examples of Floating Lidar Devices and Offshore Lidars installed on fixed platforms and vessels are shown in Figure 3.

But the offshore industry didn't stop there. As an example, in order to completely eliminate the need for the met mast, Fugro's SEAWATCH Wind Lidar Buoy and EOLOS' FLS200 Floating Lidar Devices achieved the 'Commercial Stage 3' rating within the Carbon Trust's Roadmap for the Commercial Acceptance of Floating Lidar Technology, with other FLDs following the same pathway. In doing so it provides the industry with the opportunity to further 'reduce the overall deployment costs as there may be no requirement for a full floating Lidar system pre-deployment verification' i.e. the need for a met mast verification can be removed.

The offshore wind industry has successfully replaced fixed met masts and cup anemometry-based wind resource assessment with floating Lidar. It had to. The climate change challenges we all face and the commitments being made to achieve the global 2030 wind capacity targets are quite simply huge and as such the Levelised Cost of Energy, and timescales, must be optimised wherever possible. And that starts with wind resource assessment and with floating Lidar; that's the nature of progress.

The wind Lidar proof book

In 2022, the largest body of evidence, traceable to an IEC compliant met mast, of any Remote Sensing Device was released by ZX Lidars at WindEurope's Annual Event, Bilbao[10]. The evidence summarised 500 individual ZX 300 ground-based vertically-profiling Lidar unit Performance Verifications undertaken at the UK Remote Sensing Test Site. Based on a sample of Lidar deployments between 2017 and 2021, horizontal wind speeds, directions and turbulence intensity comparisons to the mast and installed cup anemometry were conducted.

The study also aimed to evaluate the performance of Lidars having undergone purely a Factory calibration in order to remove the reliance on any met mast-based comparison. The results show that 'out-of-the-box' Lidar performance demonstrated very high availability across all heights measured (Figure 4), very high accuracy when compared to an IEC compliant met mast (Figure 5) and a robust, consistent measure of Turbulence Intensity (Figure 6).

The results clearly demonstrated the reliability and repeatability of ZX Lidars' standard Lidar calibration and quality control process. It can be stated that the generated Key Performance Indicator values are also well within the industry best practice criteria. The consistency of the results highlights an opportunity for the industry that met masts could be excluded from the Lidar verification process for ZX 300, since limited additional value is gained within this stage of the process.

The timescale required for a met mast validation is dependent on weather conditions and so introduces a potentially unnecessary and significant uncertainty in project planning as the internal calibration process will fulfil the most rigorous expectations of the wind energy industry. Removing the use of met masts in the verification of calibration process for Lidars offers an opportunity to further reduce the through-life cost of Lidar.

A further validation, the highest height Lidar / mast public validation known on record, was released in 2021 from the 213-metre research meteorological mast at the Cabauw Experimental Site for Atmospheric Research (CESAR), Netherlands. Covering a two-year campaign, comparative accuracy between a ZX 300 Lidar and the met mast was demonstrated to be 0.99 to 1.00, and an R2 greater than 0.995 was achieved. System uptime of 99.4 % and quality-controlled data availability of 96.8 % - 98.4 % was also demonstrated[11].

ZX 300 is probably the world's most validated ground-based Lidar. ZX Lidars have been deployed more than 10,000 times in over 90 countries globally.

Wind turbine OEMs collaborate to expand industry acceptance of Lidar

Another indicator of maturity of any sensor is the recognition and inclusion of that sensor either as standalone hardware, or within a process, by the dominant Original Equipment Manufacturer (OEM) within the sector. Within the wind energy industry, that OEM is the wind turbine manufacturer and the Lidar is 'just another' trusted, proven and accepted sensor. The turbine manufacturers within the wind industry respond to industry (developer) demand and innovate to both compete but also to advance the industry as a whole.

Following the release of the already mentioned IEC 61400-12-1 Ed. 2, wind turbine and service provider Siemens Gamesa Renewable Energy (SGRE) approved the use of nacelle-based wind Lidar ZX TM for the purpose of 'Power Performance Testing' on Siemens Gamesa wind turbines, the very method by which wind turbine performance is verified as a function of the wind speed. In 2022 SGRE went one further and unveiled ZX Lidars technology on the company's 14MW flagship offshore wind turbine.

The nacelle Lidar, ZX TM, gives the turbine a 'whole rotor vision' upgrade allowing for a fully IEC compliant power curve measurement to be undertaken without a met mast. Measurements across the whole rotor unlock additional value throughout the lifetime of the turbine, optimising customer assets offshore based on the wind conditions observed on site. This now standard Lidar option is fully-approved and validated by SGRE.

At WindEurope's Technology Workshop 2022 in Brussels, designer, manufacturer, installer and service-provider of wind turbines, Vestas, released research of a novel methodology for using measurements solely from the ground-based vertical-profiling wind Lidars, such as ZX 300, as a way towards Lidar-only turbine suitability assessments.

The methodology aims to derive met mast equivalent load responses that would likely be observed from measurements from a hypothetical met mast, at a Lidar location where only Lidar data are available. This is achieved through a 'Bandpass Adjusted Turbulence' (BAT) for the Turbulence Intensity (TI) whereby the turbulence spectra from the Lidar measurements is then transformed through a pre-defined model. In this research, the variation of TI driven loads between met mast and a collocated Lidar was found to be 6% for the sites tested and this reduces to 1.5-2.0% with BAT transformation. Vestas states that the industry is going towards a higher adoption rate of RSD for new project development, which increases the relevance of solving this industry-wide challenge. This methodology is being actively researched and discussed in the Site Suitability Sub-group of the Consortium For Advancing Remote Sensing (CFARS) [12].

10 Mate-Toth, R. & ZX Lidars (2022) Wind Lidar Performance Verification Repeatability Study

11 Knoop, S., Bosveld, F. C., de Haij, M. J., and Apituley, A.: A 2-year intercomparison of continuous-wave focusing wind Lidar and tall mast wind measurements at Cabauw, Atmos. Meas. Tech., 14, 2219–2235, https://doi.org/10.5194/amt-14-2219-2021, 2021

12 Chattopadhyay, S and Vestas (2022) Lidar-only load response comparison: a way towards Lidar-only turbine suitability assessments

Measurement Height (m)	Gradient	Gradient Std (%)	RMSE (m/s)	R^2	R Std (%)
91	1.000	0.800	0.23	0.991	0.018
70	1.000	0.600	0.19	0.993	0.015
45	1.003	0.600	0.16	0.994	0.013
20	1.000	0.500	0.16	0.992	0.013

Figure 5: Summary of wind speed correlations of 500 ZX 300 wind Lidars with an IEC compliant met mast

Measurement Height (m)	Gradient	Gradient Std (%)	RMSE (%)	R^2	R^2 Std (%)
91	0.983	0.041	1.9	0.809	0.056
70	0.976	0.032	1.9	0.839	0.049
45	1.001	0.023	1.8	0.855	0.045
20	1.061	0.02	2.2	0.811	0.06

Figure 6: Summary of turbulence intensity correlations of 500 ZX 300 wind Lidars win an IEC compliant met mast

Wind Industry 2.0 begins: the world without met masts

As a Lidar OEM, of course it's easy to say 'just use Lidar' and this article is a summary of the industry position on Lidar use as it stands today. But, as mentioned above, within any industry it is the responsibility of OEMs, and in this case the Lidar OEMs, to respond to industry demand, and to innovate.

Just as the offshore sector innovated with the use and acceptance of Floating Lidar it is ZX Lidars' view that the information shared in this article represents an opportunity for the entire wind industry to operate in an increasingly Lidar-only capacity, measuring the wind remotely, measuring the wind speed at light speed, measuring a more representative vertical area across an entire wind site, and always measuring as safely as is possible. The only real remaining step that currently requires a met mast in a Lidar's world, is where a mast is used to 'verify' the Lidars performance either at a test site, or occasionally in the field.

If we consider the innovative step in the offshore sector, the OWA Roadmap highlights a risk-based approach to assess the need for a met mast verification as discussed above. The capability of a particular Lidar type and the specific deployment conditions are separately and individually assessed. If we compare this to onshore, the capability of a particular Lidar type has been demonstrated through the IEC Classification combined with the proof books associated with that particular Lidar type, accuracy and reliability are confirmed.

Regarding the deployment conditions, offshore this includes the moorings, buoyancy, possible gimbal and software specific to floating Lidars and the overall system's dynamic response to the differing sea states. Onshore, the deployment conditions are far more favourable and can be easily defined.

Excluding any environmental sensitivities for which any uncertainties are already managed through thorough application of a particular Lidar's IEC Classification, the remaining differences that could affect the Lidar are relating to the complexity of flow across the site. As discussed above there already exist verified solutions for mitigating the effects of complex flow, pre- or post-deployment.

At the European Wind Energy Association (EWEA) Resource Assessment Workshop 2015, the Danish Technical University's (DTU) Department of Wind Energy presented on the topic of 'Why are Lidars cups so uncertain', which summarised that the 'reference uncertainty' when performing Lidar calibrations against cup anemometers 'is entirely due to the cup', noting the cup calibration (from the wind tunnel), classification (operational uncertainty) and mounting are the key causes. Variation within Lidar calibration results was also cited as probably being due to the cup.

By applying 'good metrology and modern technology' such as Lidar itself, which is 'inherently very accurate' can 'considerably reduce all three' of the uncertainties associated with the calibration process of comparing Lidars and cups[13].

This article therefore concludes that with the acceptance of consultants, the introduction of standards, the requirements for verifying performance, the involvement of wind turbine OEMs and the appropriate treatment of data dependent on conditions, there is a pathway for the use of Lidar-only wind measurements for every project, anywhere in the world, onshore and offshore. In doing so, it removes the built-in cup uncertainty that currently exists for any Lidar verified against the mast / cup. The Lidar becomes the 'truth', and the answer would be a more certain one.

The industry is banking on wind Lidar

This is less of a question and more of a statement because the industry really is banking on wind Lidar. It has to. According to GWEC the global wind industry grew by nearly 9% cumulatively in 2021 which itself was a year when the industry year-on-year increase in installations was 53%[14]. And yet for the world to meet the Net Zero pathway set out by IRENA in their 2050 roadmap, installations need to grow fourfold by 2030[15].

Urgent action is in the hands of policymakers now to both scale up wind power and do so at the necessary pace. And we the industry must look at the entire supply chain and at all technologies, including Lidar, so it may be deployed in a way that helps us to scale and to scale quickly.

Lidar is presented here as being a safer, faster, cheaper and better way of conducting wind measurements, the very cornerstone of wind farm development, with far-reaching and ever-expanding benefits throughout a wind farm lifecycle onshore and offshore. That much is clear. But rather than talking about banking on Lidar, and 'managing down' the uncertainties associated with wind measurements, perhaps the more fundamental question is about what world future we want to bank on, so that we may act accordingly.

www.zxlidars.com

13 Courtney, M and DTU (2015) Why are Lidars cups so uncertain?

14 GWEC (2022) Global Wind Report 2022

15 IRENA (2019) Global energy transformation: A roadmap to 2050 (2019 edition)