Technological Advances in Floating LiDAR Reduce Costs and Increase Efficiencies for Offshore Wind Development

How remote monitoring technology is rapidly evolving to lower the cost of finance by reducing uncertainty of atmospheric and met-ocean measurements and improving the overall assessment of a site's wind resource.

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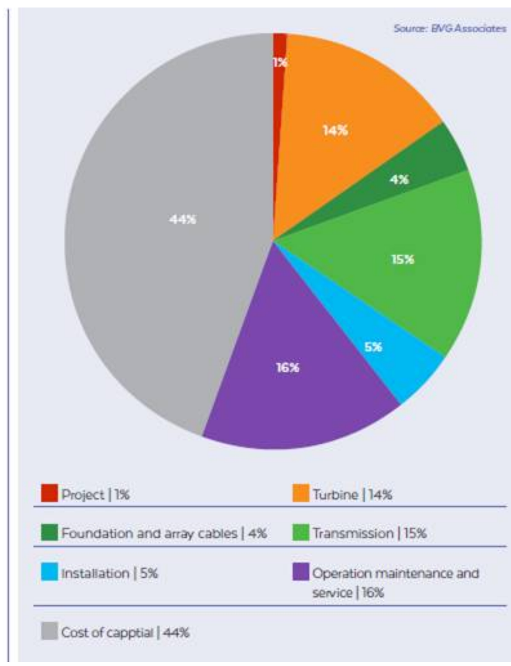
I. Introduction

Offshore wind farms offer a number of advantages as compared to their onshore equivalent, most notably in terms of both the amount and the reliability of the wind resource which can be used to supply significantly more consistent power than onshore farms. Building offshore also offers the ability for farms to scale up considerably in size since they are not as constrained as onshore wind farms with issues such as, proximity to existing populations, noise curtailment, shadow flicker and general NIMBY(not in my backyard)ism.

As offshore wind moves further from shore into deeper waters, with new turbines reaching 8 MW and an unpredictable government support scheme, it's not surprising to see this uncertainty reflected in the cost of finance. Furthermore, since the business model for offshore wind is investment-heavy in the first few years, with 15 years to pay off the investment and five years to make a profit, it can be expected that the capital cost will be significant and that uncertainty reduction will be a top priority of offshore wind project developers. UK based consultancy, BVG Associates, estimates that 44% of the cost of an offshore wind farm comes from the cost of capital[1].



Source: BVG Associates

The calculation of the cost of capital has a direct link to the revenue generating capacity of the site which, in turn, is based on wind resource capacity of the location. When assessing this, bank's engineers typically make an estimate of the power capacity of the location based on in situ measurements. These measurements have two main components:

1. The expected variation of the measurement over the site location; and,
2. The degree of uncertainty inherent in the measurements.

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For wind farms onshore this is a relatively simple matter. The primary tool for data gathering is a meteorological mast, typically around 100m tall, measuring at the future turbine's hub height. Power curve measurements from met masts are governed by an IEC standard, IEC 61400-12-1, and there are many studies that have determined the level of uncertainty that one can reasonably expect to see from an IEC certified meteorological mast. In addition, LiDAR technologies have become increasingly used onshore, in some cases as a primary measurement and other cases to reduce uncertainty of shear profiles and terrain effects at a minimal cost.

For offshore wind farms the measurements must be gathered and assessed differently, and continual technological developments have improved the process and will continue to do so as the techniques progress and mature.

This paper will summarise the work done to date in the field of floating LiDAR, and address the financial implications of the degree of uncertainty in measurement that result from floating LiDAR data as opposed to the state-of-the-art fixed meteorological mast measurements.

II. The Meteorological Mast Challenge

Offshore wind farms suffer from a number of challenges related to collecting primary wind measurements:

1. It is extremely difficult and time consuming to install a 100m met mast offshore. The current cost in Europe to install a mast for a UK round three project is approximately US$15,000,000, and the foundations are typically not robust enough to be used in future as a turbine location,
2. The sensors on an offshore meteorological mast are more susceptible to drift as a result of the hostile marine environment,
3. Offshore servicing of meteorological masts is challenging and therefore the meteorological mast's availability can suffer,
4. The meteorological mast itself is limited in terms of positioning and, unlike onshore, is not moved to different locations on the site,
5. As we move into floating wind farms, the ability to reliably use floating meteorological masts further declines.

As a result, there has been considerable work done to accelerate the commercialisation of floating LiDAR devices in offshore applications to effectively overcome the challenges of offshore measurements without compromising accuracy of the data.

III. Floating LiDAR Devices

The first two technological challenges floating LiDAR device manufacturers needed to overcome were: motion and power.

1) Motion: LiDARs typically take between 4.5 and 10 seconds to gather wind speed and direction data across all of their range gate heights (commonly between 6 and 10 programmable heights). The heave, pitch, roll, and yaw motion of a floating platform can induce error into this data.

Device manufacturers can take two main routes to address motion. The first is to create a platform which dampens the motion of the LiDAR by absorbing the sea's energy. These platforms are typically either a spar buoy or a tension leg buoy. While these platforms do offer the necessary stability, they can be expensive and quite difficult to redeploy.

The second option is a smaller buoy, typically between 3m to 6m, which includes either mechanical motion damping or algorithmic motion compensation or a combination of both. It is this style of device that is becoming increasingly common, with five systems that have seen operation in the US, seven in Europe and one in Taiwan. While these systems are increasingly able to address the motion issue, they face long term deployment issues as a result of the second main challenge, which is power.

2) Power: LiDARs require a consistent power draw of between 45W and 100W, which can be difficult to achieve on an autonomous buoy at sea. All device manufacturers address this challenge using renewable energy power systems, such as solar panels and wind turbines. One manufacturer developed and deployed a floating LiDAR device with an integrated diesel generator, which resulted in a cumulative deployment time of over two years. The floating LiDAR supply chain is continually pushing the limits of the reliability and new technologies are constantly being investigated, such as methanol fuel cells and wave energy converters.

Floating LiDAR devices demonstrated quite early on that they are capable of long-term deployments which provide high data availability, (in many cases higher than that of the state-of-the-art meteorological mast). Organizations such as, Fishermen's Energy, Grand Valley State University, and the US Navy started to see the potential in the technology at this point, but to make a breakthrough in the offshore wind industry it was necessary to also demonstrate data accuracy.

IV. The Carbon Trust Offshore Wind Accelerator roadmap for the commercial acceptance of floating LIDAR technology[2]

The Offshore Wind Accelerator has a technical working group consisting of nine offshore wind developers[3] dedicated to reducing the cost of measuring wind resource and wake effects. In 2011, the group identified the meteorological mast as a challenge for the industry and decided to research this problem further. Their first project was to create a technology roadmap which would help to assess the business case for this technology in a way that they could explain in terms of impact to the bottom line. Together with DNV-GL and the Carbon Trust, the technical working group conducted a study on the benefits that floating LiDAR could have to the offshore industry when it was able to both partially and fully replace a meteorological mast for primary wind speed measurements. Ultimately, this evolved into a three-stage roadmap very similar to that developed by DNV-GL for the onshore use of remote sensing, such as LiDAR.

In 2012, the Carbon Trust launched a validation campaign hosted by RWE at their Gwynt Y Môr site, which contained an IEC meteorological mast. Before the campaign started they worked again with DNV-GL and a variety of key industry stakeholders (e.g., other bank's engineers, universities, floating LiDAR manufacturers, etc.) to develop a set of key performance indicators (KPIs) which could be used to assess the floating LiDAR's accuracy as compared to a meteorological mast.

In November 2013, the Carbon Trust published their Roadmap for commercial acceptance of floating LiDAR which has become an industry standard for both proving the accuracy of a system and completing pre-validations of systems ready to be used on commercial deployments.

V. Floating LiDAR Bankability

Onshore, the acceptance of LiDAR for bankability purposes was effectively completed in late 2012 when the leading sensors on the market completed the DNV-GL (formerly GL Garrad Hassan) parallel technology roadmap for the use of onshore LiDAR. While LiDARs had previously been used for financing purposes, those were typically limited to uncertainty reduction in shear profiles or horizontal wind variation rather than as a primary wind speed measurement. DNV-GL's roadmap provided clear guidelines for the use of LiDAR systems collecting primary wind data going forward that provided a consistent and ultimately widely accepted standard.

The Carbon Trust Offshore Wind Accelerator Roadmap, seeks to achieve an analogous result for floating LiDAR being used to collect primary wind data. Key features include:

- Explanation of the three stages a floating LiDAR device needs to move through to reach full commercialisation
- Explanation of the KPIs that need to be met in order to consider a validation against a meteorological mast successful
- Explanation of the duration and wind speed bins needed to be filled for a floating LiDAR validation to move a system from Stage 1 to Stage 2 on the roadmap

As a result of this work, offshore wind resource assessment engineers and their financial partners now have clear standards against which they can evaluate floating LiDARs prior to making a commitment to deploy such systems on their wind farm lease.

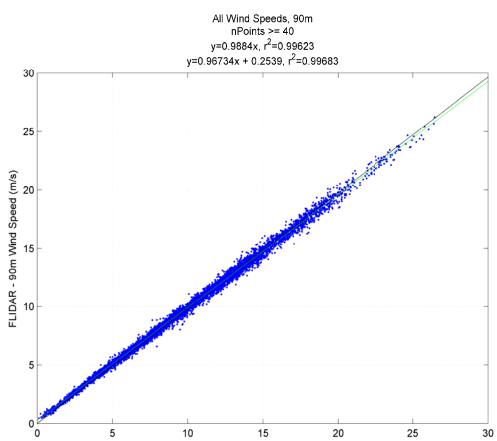
VI. Validation Studies to Date

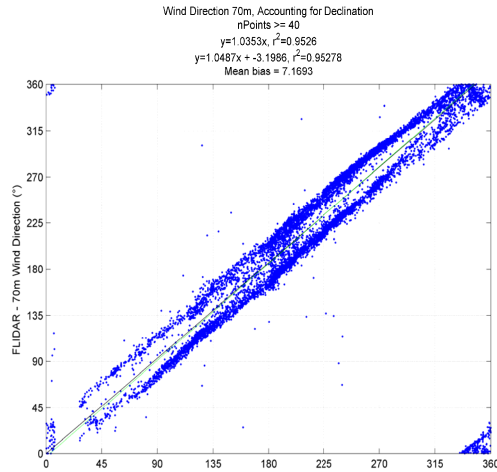
At time of writing there have been two formal published studies along with a number of studies that have yet to be publicly shared. This section will outline the results of the published studies and, for the first time, detail the results of one of the unpublished studies.

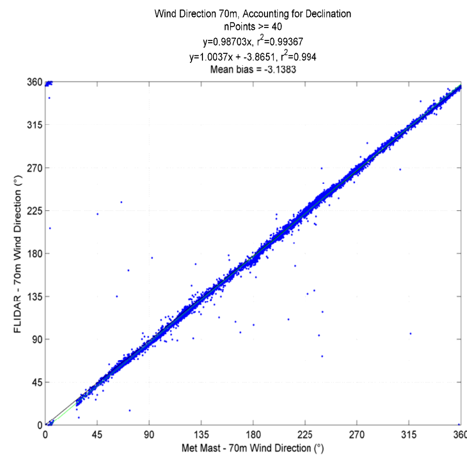
A. Published Studies

FLiDAR and Babcock reached their Stage 2 certification as part of the Carbon Trust’s Offshore Wind Accelerator validation project. This validation was performed against the Gwynt Y Môr meteorological mast. Detailed results have been presented at various offshore wind conferences. Wind speed and direction data from the campaigns are shown in the graphs below.

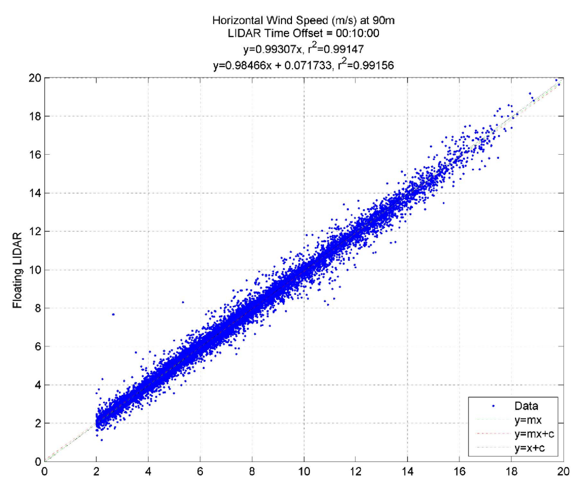
FLiDAR Data[4]:

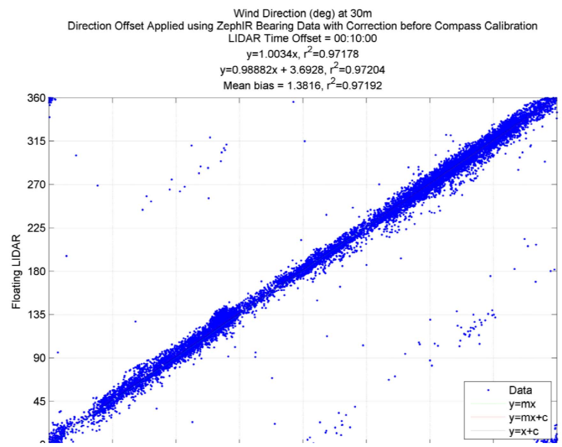






Babcock Data[5]:





B. Unpublished Studies

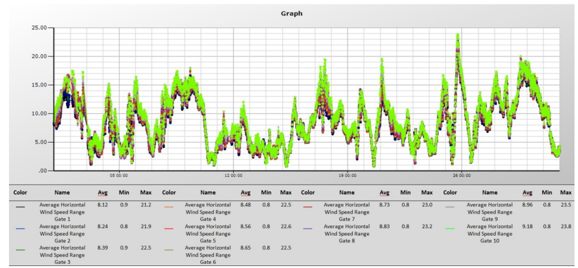
a) AXYS Blyth Deployment

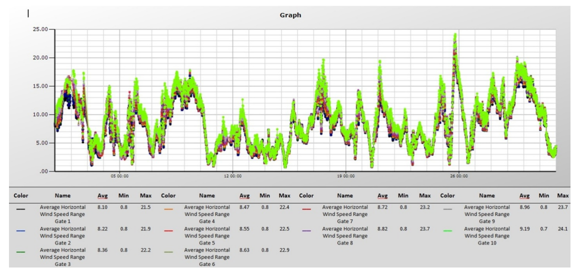
In March 2015, AXYS Technologies deployed two WindSentinel floating LiDAR devices each equipped with two LiDARs three miles off the coast of Blyth, Northumberland for a one-month validation and research study at the ORE Catapult's National Renewable Energy Centre. Final results are being validated at time of writing and will be shown in the presentation version of this paper to be presented at the Oceans MTS/IEEE Conference October 2015.

b) NORCOWE OBLEX-F1

AXYS Technologies joined the Norwegian Centre for Offshore Wind Energy (NORCOWE) FINO1 measurement campaign by contributing a WindSentinel floating LiDAR device for a period of approximately six months. The WindSentinel buoy, configured with two LiDARs, was deployed in June 2015 and data is being compared to other high-quality meteorological and oceanographic data being collected at the site. Average wind speed data from July 2015 is shown in the graphs below.

Average Wind Speed from LiDAR 1 and LiDAR 2





VII. Floating LiDAR and the Degree of Uncertainty in Financing Offshore Wind Farms

As can be seen from the studies listed above, floating LiDAR devices have now reached a clear milestone on the route to market acceptance with studies clearly supporting the accuracy of the technology. This acceptance has been demonstrated by the market; to date, floating LiDAR devices have been selected by at least eight projects for wind resource assessment to support the financing of their offshore wind farms, with systems either deployed or set to be deployed during 2015.

The question that now needs to be addressed relates to the relative degree of uncertainty between a floating LiDAR and its impact on the cost of financing. This area has been covered by Babcock as a result of the study noted previously.

Babcock based their work on the use of IEC61400-12-1 annex L, which can be used to assess the impact of environmental effects on accuracy. Annex L measures environmental parameters and their effect on accuracy classified as a function of each parameter. Once key environmental parameters are established, the overall accuracy class is determined based on those parameters. This, in turn, assists with the definition of uncertainty for the system by assessing random noise and other relevant factors. The following tables[6] show the result of the Annex L assessment and the variable parameters that had no relevant impact on observed accuracy.

Annex L Assessment Results - Accuracy

	Mean Value	Standard Deviation	Slope, m	Sensitivity m*std	r^2	r*sens	Variable Range	m*range	Relevance
Wind Direction (°)	196.681	103.429	0.002	0.224	0.004	0.014	180.000	0.389	Not Relevant
Turbulence Intensity (-)	0.076	0.044	-0.777	-0.034	0.000	-0.001	0.210	-0.163	Not Relevant
Shear Exponent (-)	0.081	0.170	-2.873	-0.489	0.004	-0.029	1.200	-3.448	Not Relevant
Air Temperature (℃)	14.578	2.525	0.055	0.140	0.001	0.004	40.000	2.211	Not Relevant
Max Wave Height (m)	0.934	0.605	-0.122	-0.074	0.000	-0.001	3.670	-0.448	Not Relevant
Peak Wave Period (s)	3.947	1.312	0.009	0.012	0.000	0.000	11.610	0.110	Not Relevant
Peak Wave Direction (°)	214.302	116.473	0.002	0.238	0.005	0.017	180.000	0.367	Not Relevant
Wave Directional Spreading (°)	32.018	10.959	0.023	0.249	0.001	0.008	180.000	4.087	Not Relevant
Wave Zero Crossing (s)	3.090	0.508	0.327	0.166	0.001	0.006	3.165	1.034	Not Relevant
Significant Wave Height (m)	0.584	0.367	0.310	0.114	0.001	0.003	2.070	0.641	Not Relevant
Sea Temperature (℃)	14.822	2.083	0.062	0.129	0.001	0.005	40.000	2.485	Not Relevant

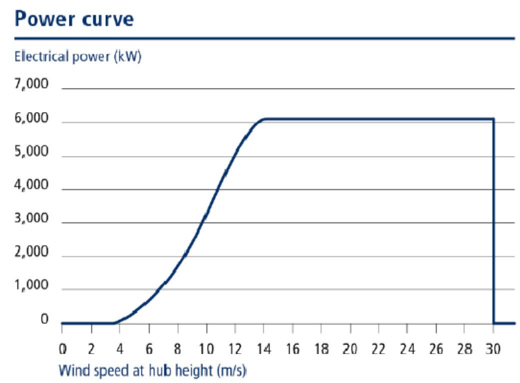
The next table translates these results into an assessment of their impact on the uncertainty of measurement:

Mean Anemometer Speed in bin	Mean Floating LIDAR Speed in bin	Number of Data sets	$V_{floating\ LIDAR}$ max	$V_{floating\ LIDAR}$ min	$V_{floating\ LIDAR}$ std	$V_{floating\ LIDAR}$ std/sqrt(n)	Mean Deviation	$V_{metmast}$ Uncertainty	Floating LIDAR Mounting Uncertainty	$V_{floating\ LIDAR}$ Combined Uncertainty
ms^{-1}	ms^{-1}	-	ms^{-1}	ms^{-1}			%	%	%	%
4.143	4.135	328	4.249	4.001	0.281	0.015	0.203	2.464	0.5	2.522
4.509	4.500	771	4.749	4.250	0.247	0.009	0.229	2.322	0.5	2.387
4.992	4.996	832	5.249	4.750	0.238	0.008	0.210	2.167	0.5	2.234
5.495	5.492	730	5.749	5.253	0.255	0.009	0.216	2.035	0.5	2.107
6.014	6.001	765	6.248	5.750	0.225	0.008	0.195	1.922	0.5	1.995
6.501	6.500	791	6.749	6.250	0.243	0.009	0.193	1.832	0.5	1.909
7.000	6.993	742	7.248	6.750	0.207	0.008	0.175	1.753	0.5	1.831
7.492	7.487	598	7.749	7.251	0.280	0.011	0.192	1.685	0.5	1.768
7.985	7.993	524	8.248	7.750	0.239	0.010	0.197	1.625	0.5	1.712
8.492	8.505	531	8.748	8.252	0.271	0.012	0.211	1.572	0.5	1.663
8.986	8.994	451	9.248	8.750	0.242	0.011	0.197	1.525	0.5	1.617
9.478	9.499	387	9.749	9.250	0.231	0.012	0.200	1.483	0.5	1.578
9.986	9.996	320	10.249	9.753	0.218	0.012	0.195	1.444	0.5	1.541
10.506	10.497	251	10.747	10.252	0.203	0.013	0.190	1.409	0.5	1.507
10.992	11.003	256	11.249	10.750	0.153	0.010	0.156	1.378	0.5	1.474
11.482	11.504	298	11.747	11.250	0.166	0.010	0.154	1.350	0.5	1.448
11.994	11.999	250	12.241	11.752	0.198	0.013	0.183	1.323	0.5	1.427
12.499	12.490	231	12.747	12.251	0.296	0.019	0.229	1.299	0.5	1.411
12.999	12.998	208	13.246	12.752	0.236	0.016	0.225	1.277	0.5	1.390
13.492	13.509	177	13.748	13.252	0.194	0.015	0.199	1.257	0.5	1.367
13.997	13.993	130	14.247	13.752	0.222	0.019	0.216	1.237	0.5	1.352
14.494	14.483	100	14.740	14.255	0.231	0.023	0.239	1.220	0.5	1.340
14.997	14.989	82	15.247	14.754	0.291	0.032	0.282	1.203	0.5	1.333
15.465	15.482	42	15.738	15.258	0.283	0.044	0.246	1.188	0.5	1.313
15.875	15.833	13	15.977	15.750	0.496	0.138	0.588	1.176	0.5	1.414

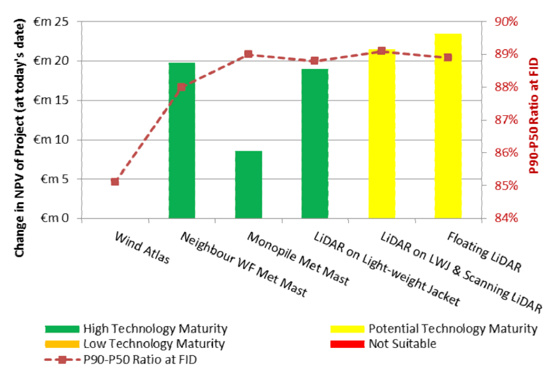
The conclusion drawn by the Babcock team is that their study suggests that the overall uncertainty demonstrated by their floating LiDAR device is comparable to traditional anemometry.

This conclusion can then be used to illustrate the financial impact of this degree of uncertainty by showing its impact on Annual Energy Production (AEP). If we assume a 600 MW wind farm, composed of 100 X 6MW wind turbines with wind measurements grouped into 0.5 m/s bins, this degree of uncertainty equates to a variance of 250 kW over the slope of the power curve. If we assume that 5% of measurements are incorrectly binned by a 1% degree of inaccuracy and a US$155 MWh price, this equates to an annual variance of US$1,550,000 in power production which can be either positive or negative.

Power Curve Table from Babcock Study[7]



DONG Energy, the world's largest offshore wind developer, have taken this degree of uncertainty and used it to map the impact of this level of uncertainty compared to the level of uncertainty of other technologies. Their rating is based on the impact of the degree of uncertainty on the Net Present Value of a project as it relates to the P90-P50 ratio at time of Final Investment Decision (FID). As can be seen from the table below[8], the floating LiDAR device is considered to be comparable to the monopile foundation meteorological mast, the current market leading measurement tool.



This work was undertaken using data from a single LiDAR deployed on the Babcock study. Work has yet to be undertaken using data from a floating LiDAR device equipped with two LiDARs, however it is likely that redundancy in data samples from two identical sensors will work to reduce the degree of uncertainty further, while enhancing the device's reliability.

VIII. Conclusion

The cost of capital is the single biggest factor in the construction of an offshore wind farm. The application of floating LiDAR technology has given developers a powerful tool to reduce the degree of uncertainty in their resource measurements, resulting in a reduction in the cost of capital and increasing the efficiency of offshore wind farm development. New developments in the technology, such as the introduction of dual-LiDAR systems and fuel cell power supplies, will further enhance the capacity of these systems to deliver reliable, accurate data on demand.

REFERENCES

[1] BVG Associates report *Offshore Wind: Delivering More for Less, An Independent Analysis Commissioned by Statkraft UK.* July 2015 http://statkraft.com/globalassets/4-statkraft-uk/offshore_wind_more_for_less_pages.pdf

[2] http://www.carbontrust.com/resources/reports/technology/owa-roadmap-for-commercial-acceptance-of-floating-lidar-technologies

[3] DONG Energy, EON, Mainstream Renewable Power, RWE, Scottish Power Renewables, SSE, Statoil, Statkraft and Vattenfall

[4] Results and Findings of a Floating LiDAR Trial in the Irish Sea, November 21, 2013. Authors: Neil Adams, Frazer-Nash Consultancy & Detlef Stein, GL Garrad Hassan. http://www.flidar.com/wp-content/uploads/2014/05/OWA-FLiDAR-presentation.pdf

[5] OWA floating LiDAR campaign: Babcock trial at Gwynt Y Mor, March 11, 2015. Author: Megan Smith http://www.carbontrust.com/media/640173/owa-floating-lidar-campaign-babcock-trial-ewea-2015.pdf

[6] *Floating LiDARs True Impact on LCoE*, Author: Chris McConville, Babcock International http://offlinehbpl.hbpl.co.uk/NewsAttachments/OPW/Chris_McConville.pdf

[7] *Floating LiDARs True Impact on LCoE*, Author: Chris McConville, Babcock International http://offlinehbpl.hbpl.co.uk/NewsAttachments/OPW/Chris_McConville.pdf

[8] *Wind Measurement Campaigns: and how do they Create Value?* Authors: Fergal Darcy and Andrew Henderson, DONG Energy http://www.ewea.org/offshore2013/conference/proceedings/Posters/PO_208_EWEAOffshorepresentation2013.pdf