Improved Bankability

The Ecofys position on LiDAR use

Summary

A key goal of a wind measurement campaign is to reduce project uncertainty, as this will improve bankability in terms of better financing terms and reduced project risks. LiDAR is now a mature technology that has been proven to be as accurate as high-quality anemometers. Industry acceptance of LiDAR measurements, as well as our experience with the flexibility of LiDAR deployments, leads Ecofys to recommend LiDAR in the following configurations:

1. LiDAR stand-alone on-site. In simple terrain (flat, few obstacles), a LiDAR can entirely replace a met mast for the wind resource assessment. This is typically recommended if the erection of a met mast is impossible. A stand-alone LiDAR can also be used to characterise a site, for instance evaluating the wind shear around forests.
2. LiDAR next to a relatively short on-site met mast. This can be a cost-effective solution to quantify the wind shear and extrapolate wind speeds to hub height.
3. LiDAR moved around the site, complementing an on-site met mast. This can help to reduce the uncertainty in flow modelling. Several shorter campaigns spread throughout the year (known as seasonal sampling) helps to reduce seasonal effects.

The optimal wind measurement strategy should be assessed on a site-by-site basis. The campaign should aim to reduce the key uncertainties, particularly in vertical and horizontal extrapolation. The costs of additional measurements can be compared to the benefits in terms of reduced equity investment and increased return on investments.

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The need for measurements

Bankable wind farm energy yield calculations require an accurate wind resource assessment based on reliable data, transparent data analysis and a complete uncertainty evaluation, resulting in a level of energy yield that is sufficient for financing the wind farm.

In the Netherlands, many wind farms have been financed with climate-based wind resource assessments (e.g. using KNMI data from 10 m masts). The advantages of this approach are clear: low cost and quick results. However, there is increasing pressure to improve project bankability, largely due reduced credit availability, increased hub heights, larger projects and investments, and reported cases of underperformance of operational wind farms.

The objective of a wind measurement campaign is to reduce project uncertainty. The trade-off for increased data acquisition costs should be improved financing terms and reduced project risks.

A traditional wind measurement campaign consists of a tall met mast with calibrated anemometers. In many cases, LiDAR is now an attractive option to complement or replace the mast. It can accurately measure the wind speed at hub height and across the rotor disk. In addition, a LiDAR can be easily re-deployed around the wind farm site to measure variations in the wind climate. LiDAR also presents logistical advantages over a met mast, as it does not require building permits or extensive groundwork, nor does it attract unwanted attention.

LiDAR wind measurements have been extensively verified against reliable reference anemometers over many sites. As a result, there is now industry consensus that LiDAR is a proven technology for wind resource assessments in simple terrain[*]. In addition to LiDARs verified by Ecofys, this position is supported by several independent reviewers, including DTU Wind Energy [1], Deutsche WindGuard [2], GL Garrad Hassan [3] [4] and ECN [5].

In more complex terrain, site-specific validation of the LiDAR is generally recommended. A limitation to LiDAR campaigns is that turbulence intensity cannot be measured in an appropriate way for comparison with type certification of wind turbines, although there is promising progress in this field.

Several organisations have also prescribed best practice guidelines for LiDAR campaigns:

- The EU project Norsewind provides acceptance criteria for LiDAR verifications [6]
- MEASNET describes informative procedures for LiDAR measurements [7]
- DNV KEMA has guidelines for LiDAR use, including uncertainty metrics [8]
- IEC is preparing procedures for LiDAR measurements [9]

The recommendations are similar:

- A LiDAR measurement campaign targeted at reducing key project uncertainties
- An initial verification of the LiDAR against reference instruments at a similar site
- Inclusion of an on-site met mast, if needed
- Siting of LiDAR to ensure valid results
- Transparent data analysis with a robust estimation of uncertainties

[*] In this paper, we refer specifically to the ZephIR ZP300 and WINDCUBE v2 LiDARs, which are most tested to-date. Other models may attain this status after further verification tests.

LiDAR can help characterise site conditions, including shear in forests allowing for proper wind turbine selection [Project reference: Horb am Neckar, 2012]

Ecofys experience with LiDAR

Based on this industry acceptance, and our own experience with LiDAR campaigns, Ecofys sees a number of ways that LiDAR can enhance a wind measurement campaign:

1. LiDAR stand-alone on-site. In simple terrain (flat, few obstacles), a LiDAR can entirely replace a met mast for the wind resource assessment. This is typically recommended if the erection of a met mast is impossible or too time-consuming.
2. LiDAR next to a relatively short on-site met mast. This can be a cost-effective solution to quantify the wind shear and extrapolate wind speeds to hub height.
3. LiDAR moved around the site, complementing an on-site met mast. This can help to reduce the uncertainty in flow modelling. Several shorter campaigns spread throughout the year (called seasonal sampling) helps to reduce seasonal effects.

The costs of a LiDAR measurement campaign are structured differently than that of a met mast, leading to different campaign designs. Installation is one of the largest costs for a mast, so it usually makes sense to leave it at a single location for a long period. For a LiDAR, the largest cost component is equipment hire. Thus, it can be preferable to deploy a LiDAR in shorter campaigns to take advantage of its flexibility to characterise more positions within a project site.

In addition to assessing the wind speeds at a site, the measurement campaign can also characterise other site conditions. For instance, a LiDAR can help evaluate the wind shear around forests. If turbulence intensity may be a critical factor in the selection of wind turbine class, we highly recommend a mast on-site, as LiDAR alone cannot yet measure this with sufficient confidence.

Reduction in uncertainty

A recent detailed examination of the uncertainty of a WINDCUBE v2 LiDAR, according to the latest draft of the IEC standard 61400-12-1 (ed 2) [9], found a total standard uncertainty in wind speed measurements in the range of 2-3% for simple terrain [10]. This is equivalent to the accuracy of a high-quality mechanical anemometer (including mounting and mast effects).

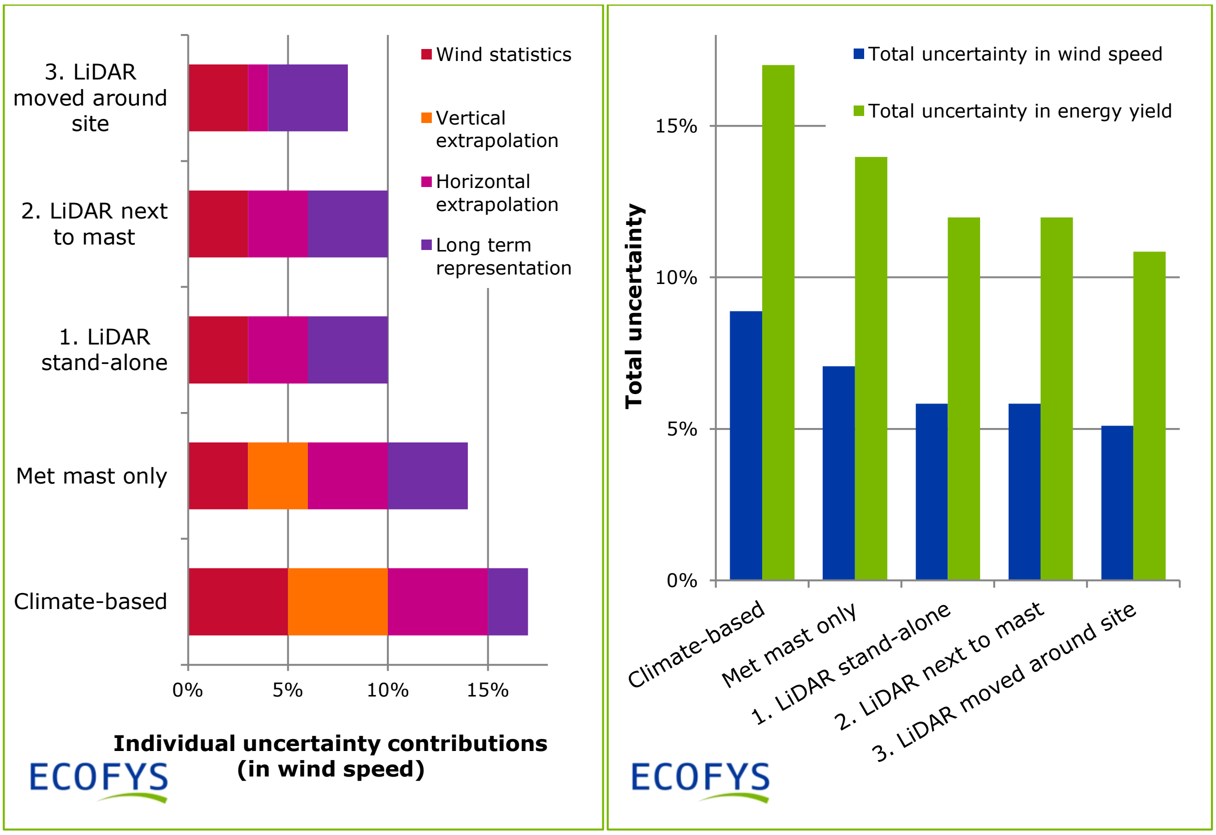
Considering that the LiDAR can measure directly at hub height, there is reduced uncertainty in the vertical extrapolation, if compared to a typical met mast at $^2/_3$ hub height [7].

In addition, it is possible to reduce the uncertainty in horizontal extrapolation (flow modelling) by deploying the LiDAR around the wind farm site.

In order to demonstrate the potential reduction in uncertainty, we have compared different campaign strategies for a representative inland Dutch site with flat terrain and nearby forests and towns.

- Climate-based assessment. No LiDAR or on-site met mast.
- On-site met mast for one year, 2/3 hub height. No LiDAR.

1. LiDAR stand-alone on-site, single position.
2. On-site met mast for one year, $^2/_3$ hub height. LiDAR next to mast for 3 months.
3. On-site met mast for one year, $^2/_3$ hub height. LiDAR at 4 sites (seasonal sampling).



Uncertainty for a representative Dutch inland site, comparing different measurement strategies.
Notes: Total uncertainty is calculated as root-sum-square of individual uncertainty contributions. Total uncertainties shown in blue are in terms of wind speed. Total uncertainties shown in green are in terms of energy yield (and also include uncertainties in power curve and losses).

LiDAR can complement a met mast campaign, allowing for a shorter mast with better understanding of extrapolation to hub height [Project reference: Delfzijl Noord, 2011]

Benefits to the bottom line

As stated earlier, the goal of a wind measurement campaign is to reduce project uncertainty, with the purpose of improving financing conditions and lowering project risks. The value of a given uncertainty reduction can be quantified in terms of improved leverage (less equity investment) and increased rate of return. This added value can be compared to the costs of a measurement campaign in order to evaluate the optimal return on investment.

For the same representative Dutch inland site, we have compared the cost-benefit of the different measurement campaign strategies. These calculations are based on the Ecofys Cash Flow model, for a 20 MW wind farm in the Netherlands with typical project finance conditions. It is assumed that the P_{50} annual energy yield remains the same for all scenarios. All other assumptions and costs used are described in more detail in Appendix B.

The advantage of a well-designed wind measurement campaign is clear: reduced uncertainty leading to a lower equity investment and improved IRR. Similar studies of the cost-benefit of LiDAR have been published recently by DNV KEMA [11], Sgurr [12] and DEWI/Leosphere [13].

Example cost-benefit analysis for a representative Dutch inland site, comparing different measurement strategies

Cost-benefit analysis	**Reference: Climate-based**	**Met mast only**	**1. LiDAR stand-alone**	**2. LiDAR next to mast**	**3. LiDAR moved around site**
Approximate measurement costs [k€]	5	35	95	65	120
Uncertainty in energy yield [%]	17.0%	14.0%	12.0%	12.0%	10.8%
P_{90} / P_{50} ratio	78%	82%	85%	85%	86%
Leverage [%]	80%	82%	83%	83%	84%
Equity investment [k€]	5,400	4,800	4,400	4,400	4,200
Return on Equity [%]	9.7%	11.8%	13.4%	13.4%	14.5%
Increase in Net Present Value [k€] compared to reference case	-	700	1,100	1,100	1,300

Post-construction energy assessments

Wind measurements can also play an important role after the construction of the wind farm, either in a post-construction energy assessment (e.g. for re-financing or sale) or in performance assessment. If a wind farm seems to be under-performing, it is often insufficient to use nacelle anemometers to analyse the wind speed.

The wind turbine warranty will typically require a hub height met mast to justify power curve claims, although this may change with the introduction of LiDAR in the next edition of the IEC standard 61400-12-1 [9]. In the meantime, a short-term LiDAR campaign is a cost-effective means to verify wind turbine performance, possibly justifying met mast costs if a legal challenge is warranted.

Other uses for LiDAR

An improved power curve measurement method is now being implemented [9] that considers the "equivalent wind speed" across the whole rotor disk. This will mean that wind resource assessments for future wind turbines will go up to the upper tip-height, further justifying LiDAR measurements.

LiDAR will soon be part of the IEC standard for power curve measurements
[Project reference: ZephIR ZP300 Verifications at Test Site Lelystad, 2013]

In addition to reducing the uncertainty in an onshore wind resource assessment or quantifying site conditions such as shear, LiDAR has a number of other promising uses. For instance, LiDAR is now being tested on floating platforms offshore. This would lead to a greatly reduced investment in measurements and allow characterisation of the variation across large sites. Also, nacelle-based LiDAR is being developed to improve wind turbine performance.

Conclusions

A wind measurement campaign aims to reduce project uncertainty, in order to improve bankability in terms of better financing terms and reduced project risks. LiDAR is now a mature technology and there is industry acceptance of LiDAR measurements in bankable wind resource assessment, provided the campaign is well designed. Our experience with the accuracy and flexibility of LiDAR deployments leads Ecofys to recommend LiDAR for specific purposes.

The optimal wind measurement strategy should be assessed on a site-by-site basis. The campaign should aim to reduce the key uncertainties, particularly in vertical and horizontal extrapolation. The costs of additional measurements can be compared to the benefits in terms of reduced equity investment and increased return on investments.

Key References

[1] Lindelöw-Marsden, P., 2009, 'UpWind D1. Uncertainties in wind assessment with LIDAR', Risø-R-1681(EN)

[2] Albers, A. W. Janssen, J. Mander, 2010, 'How to gain acceptance for LiDAR measurements', DEWEK10

[3] Tindal, A., 2012, 'GL GH Position Statement on the ZephIR Remote Sensing Device', 111593-UKBR-T-01.

[4] Tindal, A., 2012, 'GL GH Position Statement on the WINDCUBE Remote Sensing Device', 111593-UKBR-T-02.

[5] Oostrum, H., 2012, 'Preliminary evaluation of the MMIJM Natural Power ZephIR LiDAR operational comparison', ECN-WIND-2012-183.

[6] Kindler, D., Courtney, M., Oldroyd, A., 2009, 'Testing and calibration of various LiDAR remote sensing devices for a 2 year offshore wind measurement campaign', EWEC 2009.

[7] MEASNET, 2009, 'Evaluation of site-specific wind conditions - version 1', Annex C.

[8] Det Norske Veritas, 2011, 'Recommended practice - Use of remote sensing for wind energy assessments', DNV-RP-J101

[9] IEC, 2012, 'Committee Draft - Power performance measurements of electricity producing wind turbines', IEC 61400-12-1 Ed. 2 (88/422/CD)

[10] Albers, A., Franke, K., Wagner, R., Courtney, M., Boquet, M., 2012, 'Ground-based remote sensor uncertainty - a case study for a wind lidar', EWEA 2012.

[11] Briggs, K., Day, B., Sutton, M., 2012, 'Increasing wind project value through LiDAR measurements: a Return on Investment study', EWEA 2012

[12] Mina, G., Iliffe, M., 2012, 'Quantifying the financial benefits of LiDAR', EWEA 2012

[13] Boquet, M. Görner, K., Mönnich, K., 2012, 'Wind measurement strategies to optimize LiDAR Return on Investment', EWEA 2012.

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Appendix – Representative Dutch inland site

The measurement campaigns have been compared for an example site in the Netherlands. The table below outlines the main assumptions regarding the different scenarios, as well as the financial parameters used to calculate the project cash flow.

	Reference: Climate-based	Met mast only	1. LiDAR stand-alone	2. LiDAR next to mast	3. LiDAR moved around site
Uncertainties					
- Wind statistics	5%	3%	3%	3%	3%
- Vertical extrapolation to hub height	5%	3%	0%	0%	0%
- Horizontal extrapolation to WTG site	5%	4%	3%	3%	1%
- Long term representation	2%	4%	4%	4%	4%
Total uncertainty in terms of wind speed	8.9%	7.1%	5.8%	5.8%	5.1%
Sensitivity (% increase in energy yield / % increase in wind speed)	1.8				
Uncertainty in wind speed, in terms of energy yield	16%	13%	10%	10%	9%
- Energy Calculation	5%	5%	5%	5%	5%
- Losses	3%	3%	3%	3%	3%
Total uncertainty in terms of energy yield	**17.0%**	**14.0%**	**12.0%**	**12.0%**	**10.8%**
P_{90}/P_{50} Ratio	78%	82%	85%	85%	86%
Wind farm	20 MW (10 x 2 MW)				
Wind speed [m/s]	6.8				
Hub height [m]	100				
P_{50} net full load hours	2,500				
Wind farm CAPEX [k€/MW]	1,340				
Equity term	20 years				
Equity interest	12%				
Debt term	15 years				
Debt interest	5.5%				
Debt repayment structure	Annuity				
Support mechanism	SDE 90€/MWh @ 2200 flh; 50€/MWh grey				
Inflation	2%				
Corporate tax	25%				
Limitation	Average DSCR > 1.2 for P_{90} Minimum annual DSCR > 1.06 for P_{90}				