# MEMO

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| 1.0 | A Crockford | 07.12.2015 | Draft for client review |
| 2.1 | A Crockford | 15.12.2015 | Added P50/P90 analysis |
| 3.0 | A Crockford | 29.02.2016 | Scenarios modified; for distribution at client's discretion |

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| **Subject:** | Estimated uncertainty for various wind measurement strategies including floating LiDAR at the Hollandse Kust Zuid offshore wind farm zone |
| To: | Frank van Erp, RVO |
| CC: | |


**Summary**

RVO has asked Ecofys to estimate the uncertainty reduction for an on-site floating LiDAR campaign at the future Hollandse Kust Zuid offshore wind farm zone. Three scenarios are considered and compared to a base case without on-site measurements. Depending on the scenario, the zone wind resource assessment would likely be based on different primary data sources, considering their relative accuracy, proximity to site and period length. Other complementary data sources would be used to refine calculations and reduce uncertainty.

The uncertainty for a base case scenario is calculated, based on a similar assessment for the Borssele offshore wind farm zone*. The scenarios are presented in the following pages, with a brief explanation of the expected data uses and a breakdown of the estimated uncertainty.

The estimated uncertainty for the different scenarios show that on-site wind measurements with a floating LiDAR can help lower the overall wind climate uncertainty, especially if there is an overlapping period with the LiDARs at LE Goeree and Europlatform. The impact of a reduction in wind speed uncertainty is considered in terms of P90 net energy yield for an example wind farm.


* Ecofys, *Borssele Offshore Wind Farm Zone - Wind Resource Assessment*, 18 September 2015

## Introduction

Several possible data sources that are considered for the wind resource assessment for the Hollandse Kust Zuid offshore wind farms, as indicated in the map in Figure 1:

- Floating LiDAR in the Hollandse Kust Zuid zone (future)
- Floating LiDAR in the Borssele zone
- Meteomast Ijmuiden: LiDAR and 92 m met mast
- LE Goeree: LiDAR and 38 m met mast
- Europlatform: LiDAR (future) and 29 m met mast

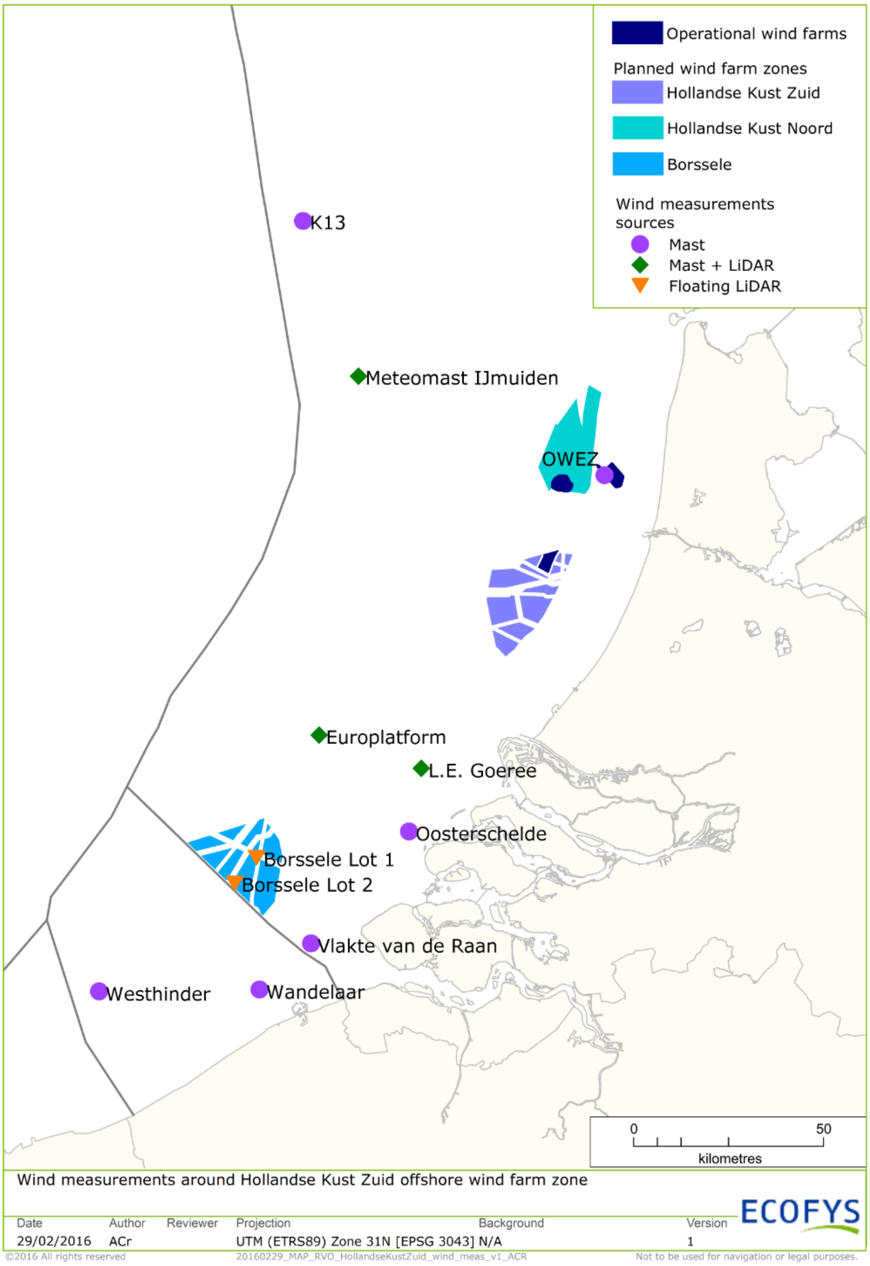


**Figure 1 – Possible measurement datasets surrounding the Hollandse Kust Zuid zone**

Four scenarios are evaluated, based on different dataset assumptions:

- Scenario 0: Base case. No on-site floating LiDAR measurements.
- Scenario 1: 6-month floating LiDAR and existing measurement campaigns
- Scenario 2: 12-month floating LiDAR and existing measurement campaigns
- Scenario 3: 12-month floating LiDAR and extended measurements at LE Goeree and Europlatform

**A note about uncertainty estimates**

It is important to note that the uncertainty estimates presented for each scenario are based on campaigns with a presumed high level of quality and data availability. It is impossible to estimate the impacts of campaigns with reduced quality or availability, since this could affect many different elements of the analysis. Therefore, it is highly recommended that any measurement campaigns are closely monitored with sufficient contingencies to ensure high data availability.

**Scenario 0**

This scenario represents a base case, without any on-site wind measurements and all current campaigns ending by 2016.

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Floating LiDAR Hollandse Kust (HKZ) | | | | | | | |
| Meteomast IJmuiden (MMIJ) | | | | | | | |
| LE Goeree LiDAR (LEG) | | | | | | | |
| Europlatform LIDAR (EUR) | | | | | | | |
| Floating LiDAR in Borssele (BOR) | | | | | | | |

*Likely basis for Hollandse Kust Zuid WRA*

- MMIJ as primary source
- Horizontal extrapolation based on mesoscale models, *validated by* LEG and BOR (overlapping periods)

| Uncertainty in terms of wind speed | | Basis for estimate |
|---|---|---|
| - Instrument accuracy | 2.0% | Thies First Class & MEASNET calibrated |
| - Instrument mounting | 1.5% | Long booms, multiple instruments |
| - Data quality | 0.5% | High availability, redundant anem. |
| - Data processing | 1.0% | Nearly raw; MEASNET party |
| - Vertical extrapolation to hub height | 0.2% | Based on correction to 100 m |
| - Horizontal extrapolation to WTG site | 3.6% | Based on accuracy of mesoscale |
| - Long term representation | 3.0% | 4 years |
| - Other | | |
| **Total [%]** | **5.4%** | |

**Scenario 1**

In this scenario, a floating LiDAR is placed on-site for 6 months. All other campaigns have ended before these on-site measurements.

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Floating LiDAR Hollandse Kust (HKZ) | | | | | | | |
| Meteomast IJmuiden (MMIJ) | | | | | | | |
| LE Goeree LiDAR (LEG) | | | | | | | |
| Europlatform LIDAR (EUR) | | | | | | | |
| Floating LiDAR in Borssele (BOR) | | | | | | | |

*Likely basis for Hollandse Kust Zuid WRA*

- MMIJ as primary source
- Horizontal extrapolation based on mesoscale models, *validated by* LEG and BOR (overlapping periods)
- Site characteristics *validated by* HKZ, but no overlapping periods for comparison with other datasets

| **Uncertainty in terms of wind speed** | | **Basis for estimate** |
|---|---|---|
| - Instrument accuracy | 2.0% | Thies First Class & MEASNET calibrated |
| - Instrument mounting | 1.5% | Long booms, multiple instruments |
| - Data quality | 0.5% | High availability, redundant anem. |
| - Data processing | 1.0% | Nearly raw; MEASNET party |
| - Vertical extrapolation to hub height | 0.2% | Based on correction to 100 m |
| - Horizontal extrapolation to WTG site | **3.0%** | Improved validation of mesoscale |
| - Long term representation | 3.0% | 4 years |
| - Other | | |
| **Total [%]** | **5.1%** | |

**Scenario 2**

In this scenario, a floating LiDAR is placed on-site for a 12-months. All other campaigns have ended before these on-site measurements.

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Floating LiDAR Hollandse Kust (HKZ) | | | | | | | |
| Meteomast IJmuiden (MMIJ) | | | | | | | |
| LE Goeree LiDAR (LEG) | | | | | | | |
| Europlatform LIDAR (EUR) | | | | | | | |
| Floating LiDAR in Borssele (BOR) | | | | | | | |

*Likely basis for Hollandse Kust Zuid WRA*

- HKZ floating LiDAR as primary source
- Long-term correction based on mesoscale models, *validated by* MMIJ, LEG and BOR (overlapping periods)
- No overlapping periods for direct comparison with other datasets

| Uncertainty in terms of wind speed | | Basis for estimate |
|---|---|---|
| - Instrument accuracy | **2.5%** | Floating LiDAR (assumed) |
| - Instrument mounting | **2.5%** | Floating LiDAR (assumes good filters) |
| - Data quality | **1.5%** | Assumes high availability |
| - Data processing | 1.0% | Assumes good traceability |
| - Vertical extrapolation to hub height | **0.0%** | Measurements above hub |
| - Horizontal extrapolation to WTG site | **1.0%** | On-site |
| - Long term representation | **1.5%** | 15 years (after MCP) |
| - Other | **2.0%** | MCP |
| **Total [%]** | **4.8%** | |

**Scenario 3**

A floating LiDAR is placed on-site for 12 months and the LiDAR campaigns at LE Goeree and Europlatform are extended to that period.

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Floating LiDAR Hollandse Kust (HKZ) | | | | | | | |
| Meteomast Ijmuiden (MMIJ) | | | | | | | |
| LE Goeree LiDAR (LEG) | | | | | | | |
| Europlatform (EUR) | | | | | | | |
| Floating LiDAR in Borssele (BOR) | | | | | | | |

*Likely basis for Hollandse Kust Zuid WRA*

- HKZ as primary source
- Horizontal extrapolation based on HKZ, *validated by* EUR, BOR and MMIJ
- Additional comparisons with HKZ, MMIJ and BOR, although no overlapping periods

| Uncertainty in terms of wind speed | | Basis for estimate |
|---|---|---|
| - Instrument accuracy | **2.5%** | Floating LiDAR (assumed) |
| - Instrument mounting | **2.5%** | Floating LiDAR (assumes good filters) |
| - Data quality | **1.5%** | Assumes high availability |
| - Data processing | 1.0% | Assumes good traceability |
| - Vertical extrapolation to hub height | **0.0%** | Measurements above hub |
| - Horizontal extrapolation to WTG site | **0.5%** | On-site + validations to LEG, EUR |
| - Long term representation | **1.5%** | 15 years (after MCP) |
| - Other | **1.7%** | Improved MCP (with validations to LEG, EUR) |
| **Total [%]** | **4.6%** | |

**P90 Comparison**

The impact of the difference in wind speed uncertainty is illustrated for an example 350 MW wind farm, with a P90 net energy yield of 1,300 GWh/y, as shown in the table below. Using the estimated sensitivity in energy yield to a change in wind speed, it is possible to express the wind speed uncertainty in terms of an energy yield uncertainty. All other uncertainty components are estimated, based on typical wind farm design. Each uncertainty is assumed to be independent of the others, so the total uncertainty is calculated as the root-sum-square.

| | **Scen 0 (Base case)** | **Scen 1 (6 mon HKZ floating LiDAR)** | **Scen 2 (1y HKZ floating LiDAR)** | **Scen 3 (1y HKZ + LEG & EUR)** |
|---|---|---|---|---|
| Total uncertainty in wind speed [%] | 5.4% | 5.1% | 4.8% | 4.6% |
| Sensitivity (% increase in energy yield / % increase in wind speed) | 1.6 | 1.6 | 1.6 | 1.6 |
| Uncertainty in wind speed, expressed in terms of energy yield | 8.7% | 8.1% | 7.7% | 7.4% |
| | | | | |
| Uncertainty in energy | | | | |
| - Power curve | 5.0% | 5.0% | 5.0% | 5.0% |
| - Metering | | | | |
| - Long term correction | | | | |
| - Other | | | | |
| Uncertainty in losses | | | | |
| - Wake effects | 4.0% | 4.0% | 4.0% | 4.0% |
| - Non-availability | 2.0% | 2.0% | 2.0% | 2.0% |
| - Electrical | 0.5% | 0.5% | 0.5% | 0.5% |
| - Environmental | | | | |
| - Turbine Performance | | | | |
| - Curtailment | | | | |
| - Air Density | | | | |
| - Other | | | | |
| **Total uncertainty** | **11.0%** | **10.5%** | **10.2%** | **10.0%** |
| | | | | |
| P50 net energy yield (350 MW) [GWh/y] | 1300 | 1300 | 1300 | 1300 |
| Full load hours - P50 | 3714 | 3714 | 3714 | 3714 |
| **Net energy yield (P90 long-term) [GWh/y]** | **1117** | **1125** | **1130** | **1134** |
| Full load hours - P90 (long-term) | 3192 | 3214 | 3228 | 3239 |
| P90/P50 Ratio [long-term] | 85.9% | 86.5% | 86.9% | 87.2% |
| Net energy yield (P90 1 year) [GWh/y] | 1057 | 1063 | 1067 | 1069 |
| Full load hours - P90 (1 year) | 3021 | 3037 | 3048 | 3056 |

A previous case study by Ecofys and BMO Offshore examined the relationship between wind climate uncertainty and financial returns. An improvement in the P90/P50 ratio is assumed to facilitate an increase in debt leverage, which would improve the project's internal rate of return (IRR). The analysis considered a simplified financial model, as the full impacts will depend on market conditions and a full evaluation of the risk profile of the project, including a range of factors such as contracting risks, supply chain risk, weather risk and regulatory risks. Considering these limitations, the study found that a 1% reduction in energy yield uncertainty could increase the project's internal rate of return (IRR) by approximately 1%, which was roughly equivalent to a 0.9% reduction in capital costs (CAPEX)[*].

The study results can provide a rough indication of the potential CAPEX reduction for a 1400 MW offshore wind farm. The indicative CAPEX reduction is shown below for each scenario, for a range of assumed CAPEX (€ 2-3 M / MW). This analysis is **indicative only**, since the previous study considered a detailed analysis of a different wind farm configuration, it was not investigated whether the results scale with more or less uncertainty reduction, and the results have not been updated for the Hollandse Kust Zuid zone.

The previous study also identified a number of other benefits from on-site measurements, including improved wind farm layouts and better support structure design, both of which could further reduce the wind farm CAPEX, although these impacts are not considered in the indicative CAPEX reductions below.

| | **Scen 0 (Base case)** | **Scen 1 (6 mon HKZ floating LiDAR)** | **Scen 2 (1y HKZ floating LiDAR)** | **Scen 3 (1y HKZ + LEG & EUR)** |
|---|---|---|---|---|
| Total uncertainty | 11.0% | 10.5% | 10.2% | 10.0% |
| Uncertainty reduction compared to Base case | - | 0.5% | 0.8% | 1.0% |
| | | | | |
| **Indicative** CAPEX reduction for 1400 MW wind farm @ €2-3 M / MW (Total CAPEX = €2,800-4,200 M) | - | €10 M to €20 M | €20 M to €30 M | €30 M to €40 M |

**Considering the indicative nature of this analysis, Ecofys strongly recommends that any conclusions are validated with experts in wind farm finance, such as banks or project developers.**

[*] Ummels B, Hulscher G, Crockford A, Coelingh J, *Offshore Wind Project Risks: Experience, Assessment And Reduction*, EWEA Offshore 2011, Amsterdam, Netherlands