MEMO

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Subject:	**Hollandse Kust Noord – Recommended locations for floating LiDAR**
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Introduction

RVO will provide a detailed information package for the Hollandse Kust Noord (HKN) offshore wind farm sites to all participants in the tender for concessions. RVO will order an on-site wind measurement campaign using floating LiDARs. Ecofys WTTS has been asked to compare three options for suitable locations for these floating LiDARs within the HKN zone.

Key criteria

The recommendations for the floating LiDAR positions are based on the following criteria:

- A representative site for a Wind Resource Assessment (WRA) at HKN.
- Undisturbed wind speeds, with minimal wake effects from the two nearby operating wind farms Prinses Amaliawindpark and Offshore wind park Egmond aan Zee (OWEZ).
- The positions should be located outside of any excluded areas defined by RVO, such as safety buffers from subsea cables or pipelines.

RVO asked Ecofys WTTS to explore three options of floating LiDAR location area, considering three objectives of the measurement campaign as defined below:

1. Option 1: Redundancy; Two measurement locations with a maximum separation of 0.5 km between the two areas.
2. Option 2: Wind speed gradient; Two measurement location area that can also be used to calculate the wind speed gradient across the HKN zone.
3. Option 3: Redundancy and wind speed gradient; Combination of the first two objectives.

RVO seeks an advice based on the expected reduction in wind speed uncertainty for each of the objectives. RVO has also asked for a qualitative risk assessment for each option.

1. Representative wind resource assessment

For on-site wind measurements at simple sites, MEASNET guidelines recommend a maximum 10 km distance from the measurement location and all wind turbines[1]. At this distance, the uncertainty in horizontal extrapolation is minimised. A circle with a radius of 10 km would be smaller than the HKN zone, so no location would fully meet this recommendation. However, if this circle is centred over the zone, it would cover about 80% of the planned wind farm area.

The expected wind climate for the HKN wind farm zone will have a stronger gradient perpendicular to the coast, with little change parallel to the coast. This indicates that the optimal locations for the floating LiDARs would be roughly central in the zone, along the axis perpendicular to the coast. This will minimise the overall uncertainty in extrapolation within the HKN wind farm zone.

2. Wake effects

The 120 MW Prinses Amaliawindpark is located in the southern corner of the HKN zone and the 108 MW OWEZ is located in the eastern side of HKN zone. Both operating wind farms along with the HKN wind farm zone are shown in Figure 1.

The floating LiDARs should be located in undisturbed wind, so they must be located at a sufficient distance away from these wind farms. There are few measurements of the extent of wake effects from offshore wind farms. However, there is some general guideline which can be applied. DTU has calculated the downstream effects of large offshore wind farms based on several models.[2] They found that wind speeds are expected to recover to about 98% of their initial value approximately 6-8 km downstream of an offshore wind farm.

Thus, a distance of at least 8 km from the Prinses Amaliawindpark and OWEZ wind farms would allow mostly free-stream wind measurements. An 8 km buffer around the two wind farms is show in Figure 1.

3. Other constraints

RVO has specified that a minimum distance of 500 m was kept from all subsea pipelines and cables exclusion zones, and the floating LiDARs should also be placed outside of helicopter and airplane main routes. These constraints are shown in Figure 1 (the background map is provided by RVO).

[1] MEASNET, November 2009, "Evaluation of Site-Specific Wind Conditions - Version 1"

[2] Risø, October 2007, "Summary report: The shadow effect of large wind farms: measurements, data analysis and modelling" Risø-R-1615(EN)

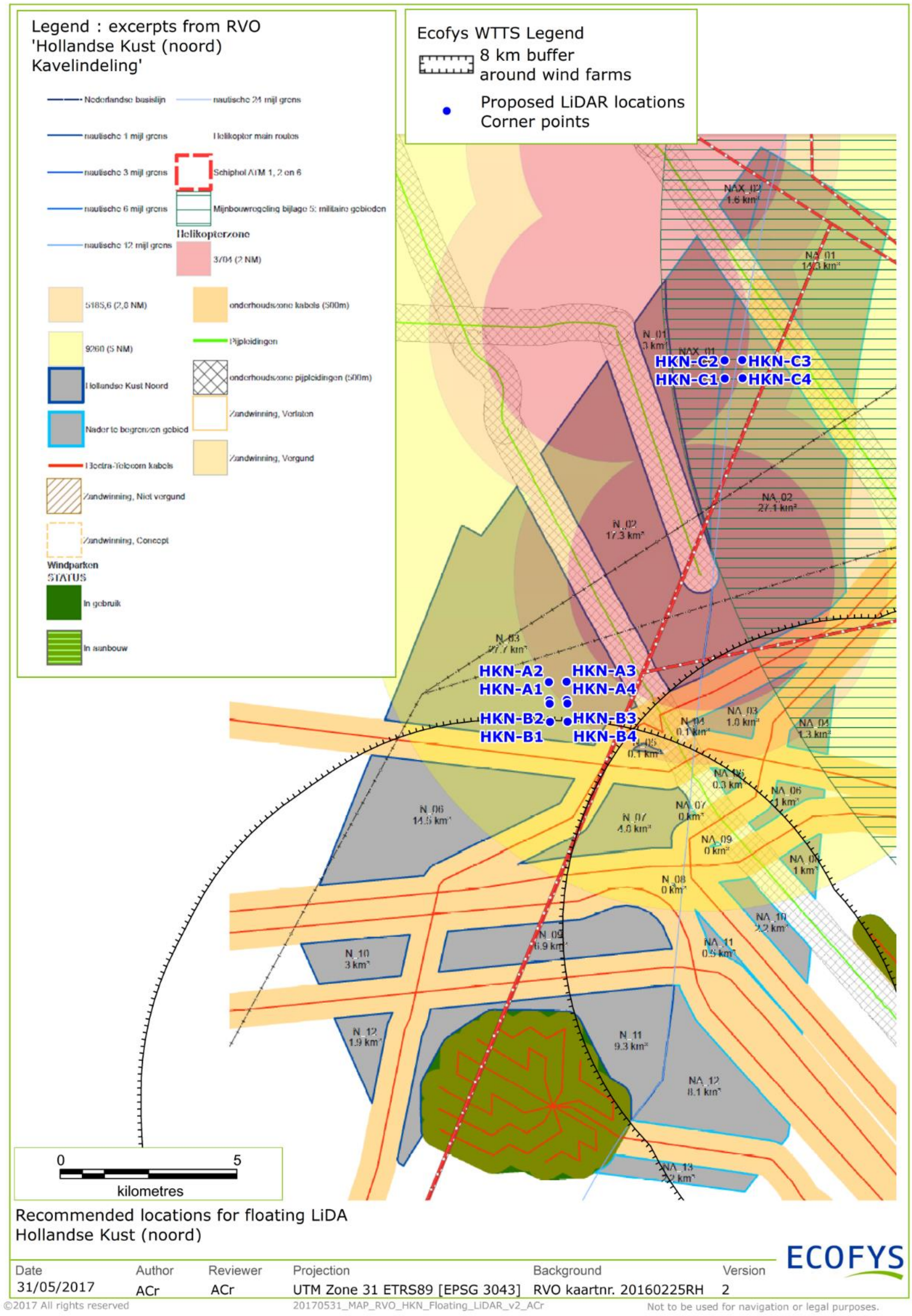

Figure 1: Constraints for Hollandse Kust (noord) with three recommended locations floating LiDAR positions (background map source: RVO)

4. Recommended locations

Three locations are proposed for the floating LiDARs, to meet the three different objectives. The central coordinates for points A and B were provided by RVO, and point C was proposed by Ecofys WTTS. An area was defined around each central point (as a 0.5 km x 0.5 km square) to allow for some flexibility in installation.

Each of the defined areas maintains a distance of at least 8 km from Prinses Amaliawindpark and OWEZ, and is outside any other constrained areas defined by RVO. The locations are also placed away from the airplane routes of Schiphol airport (shown as red dotted lines in Figure 1). Ecofys WTTS believes that the identified locations, shown in Figure 1 and Table 1 is the best balance of all above factors. The approximate distances to the nearest constraints is shown in Table 2.

Table 1: Proposed locations for HKN floating LiDARs (corner points of 0.5 km x 0.5 km area surrounding central points)

Corner point	Easting (UTM ETRS89 zone 31N)	Northing (UTM ETRS89 zone 31N)
HKN-A1	583,696	5,838,120
HKN-A2	583,696	5,838,620
HKN-A3	584,196	5,838,620
HKN-A4	584,196	5,838,120
HKN-B1	583,708	5,837,523
HKN-B2	583,708	5,838,023
HKN-B3	584,208	5,838,023
HKN-B4	584,208	5,837,523
HKN-C1	588,785	5,846,882
HKN-C2	588,785	5,847,382
HKN-C3	589,285	5,847,382
HKN-C4	589,285	5,846,882

Table 2: Approximate distances for suggested LiDAR locations from nearest constraints

Corner point	Distance from cables	Distance from pipelines	Distance from helicopter routes	Distance from neighbouring windfarm
HKN-A1	1.5 km	2.6 km	2.1 km	8.6 km
HKN-A2	2.1 km	2.4 km	2.3 km	9.1 km
HKN-A3	2.2 km	1.9 km	1.9 km	9.1 km
HKN-A4	1.6 km	2.2 km	1.7 km	8.6 km
HKN-B1	1.0 km	2.9 km	2.0 km	8.0 km
HKN-B2	1.5 km	2.6 km	2.1 km	8.5 km
HKN-B3	1.6 km	2.2 km	1.7 km	8.5 km
HKN-B4	1.1 km	2.5 km	1.4 km	8.0 km
HKN-C1	7.2 km	1.9 km	2.4 km	15.5 km
HKN-C2	7.6 km	1.6 km	2.8 km	16.0 km
HKN-C3	7.5 km	1.2 km	2.6 km	16.0 km
HKN-C4	7.0 km	1.5 km	2.2 km	15.5 km

Option 1: Redundancy

For Option 1, the recommended location of the two areas (A & B) is roughly in the central of HKN zone. The recommended locations are the most representative for the WRA of the HKN wind farm zone.

Option 2: Wind speed gradient

For Option 2, one area (A) is roughly at the central of HKN wind farm zone and the second area (C) is towards the north of the HKN wind farm zone. The minimum distance between these two areas is around 9.4 km. The recommended location of area A is the most representative location for WRA of the HKN wind farm zone, and area B is located such that it serves the wind speed gradient purpose along with representativeness of the wind climate of north of HKN wind farm zone.

While a larger gradient is anticipated perpendicular to the coast, Ecofys WTTS judges that there is relatively little space east-west within the zone to measure this gradient, without placing the buoys at the extreme edges, which would reduce the representativity of the primary dataset. Thus, Ecofys WTTS proposes to place the second buoy further north, to evaluate the gradient parallel to the shoreline, even though this gradient is expected to be small. This northern location also increase the number of wind turbines within 10 km of one of the LiDAR locations to about 90% of potential locations within the zone (see Section 1).

Option 3: Redundancy and wind speed gradient

For Option 3, all three areas would be used. The first two areas (A & B) are roughly in the centre of HKN zone and they are placed at the most representative location for the WRA of the HKN wind farm zone. The third area (C) is at the north of the HKN wind farm zone and it serves the wind speed gradient purpose along with representativeness of the wind climate of north of HKN wind farm zone.

Ecofys WTTS considers that the third LiDAR (area C) could be on-site for a shorter period than the other two. A parallel measurement campaign of about 3-6 months should be sufficient to quantify the gradient within reasonable uncertainty levels.

5. Uncertainty

To better understand the benefits of each option, Ecofys WTTS have estimated the total measurement uncertainties. For these estimates, it has been assumed that each LiDAR is operationally available for the full period that it is on-site. The uncertainty breakdowns in Table 3 show similar uncertainty levels for all options and slightly lower for Option 3.

Table 3: Wind speed uncertainty estimation

Uncertainty component	Option 1	Option 2	Option 3	Remarks
-Instrument accuracy	3.3%	3.3%	3.3%	Wind speed uncertainty[3] taken from similar floating LiDAR
-Instrument mounting	0.5%	0.5%	0.5%	Assumption
- Data quality	0.9%	1.0%	0.9%	Assuming high data availability; slight reduction for redundant systems
- Data processing	1.0%	1.0%	1.0%	Assuming good traceability
- Vertical extrapolation to hub height	0.0%	0.0%	0.0%	Hub height measurements
- Horizontal extrapolation to WTG site	1.0%	0.25%	0.25%	With / without gradient measurement
- Long term representation	1.5%	1.5%	1.5%	Long term correction using 15 year of long term data
- Other	3.5%	3.5%	3.5%	MCP method uncertainty, including distribution
Total uncertainty in wind speed, in terms of wind speed [%]	**5.3%**	**5.3%**	**5.2%**	
Sensitivity (% increase in energy yield / % increase in wind speed)	1.6	1.6	1.6	
Uncertainty in wind speed, expressed in terms of energy yield [%]	**8.5%**	**8.4%**	**8.4%**	

[3] Ecofys WTTS, 2016, Uncertainty Assessment Fugro OCEANOR SEAWATCH Wind LiDAR Buoy at RWE Meteomast IJmuiden 11.04.2014 – 27.10.2014. http://offshorewind.rvo.nl/file/download/45051422

A previous study by Ecofys WTTS for RVO for the Hollandse Kust (zuid) wind farm zone[4] considered the indicative effect of an uncertainty reduction on wind farm CAPEX. With reference to a case study presented at EWEA Offshore 2011[5], a reduction of 1% in the wind climate uncertainty (in terms of energy yield) was found to lead to an indicative cost reduction of 0.9% CAPEX.

Amongst the options considered in the table above, the biggest difference in wind speed uncertainty is 0.14%, which would lead to a cost reduction of €2-3M for a 700 MW wind farm, using the same assumptions as for the Hollandse Kust (zuid) study. As in that earlier study, it is noted that these conclusions are **indicative only** and Ecofys WTTS strongly recommends that any conclusions are validated with experts in wind farm finance, such as banks or project developers.

6. Qualitative Risk Assessment

One of the primary risks for a wind resource assessment is low data availability, particularly a data gap which may induce a seasonal bias to the measurements. Considering this risk, there is an advantage to the two options which include redundant measurements at the same location (Option 1 and 3). In case a LiDAR has any error, the redundant LiDAR would likely still record wind measurements and there would be no data gap.

In the event of a data gap from one LiDAR in Option 2, it may be possible for the second LiDAR dataset to be used to reconstruct the wind speeds, depending on the cause of the data gap and the relationship between the two datasets. However, the uncertainty in this reconstruction would be higher than for co-located LiDARs.

7. Conclusion

RVO asked Ecofys WTTS to explore three options of floating LiDAR location area, based on their defined objectives. Ecofys WTTS performed indicative uncertainty assessments and qualitative risk assessments for each objective.

Ecofys WTTS conclusions for each objective are as below:

1) Option 1: It serves the purpose of redundancy of a central location, but it is not able to measure the wind speed gradient across the HKN windfarm zone. This option minimises risk for data availability, but has slightly higher uncertainty in the wind speed gradient across the site.

2) Option 2: It serves the purpose for wind speed gradient, but has slightly reduced redundancy. The uncertainty in wind speed is slightly lower than Option 1, although the risks of data gaps are slightly higher.

[4] Ecofys WTTS, 2016, Estimated uncertainty for various wind measurement strategies including floating LiDAR at the Hollandse Kust Zuid offshore wind farm zone, ref: 20160224_MEM_RVO_HKZ floating LiDAR uncertainty_v3

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

3) Option 3: It serves both purposes: wind speed gradient and redundancy of the central location. This results in the lowest uncertainty and lowest risks of the three considered options.

To ensure the lowest uncertainty, with lowest risk, Ecofys WTTS would recommend that the option 3 is the best measurement strategy. It should be noted that the relative difference between options is small and this assessment has not included the associated costs.