ENERGY

Assessment wind measurement strategy

Options for Hollandse Kust Zuid - Draft

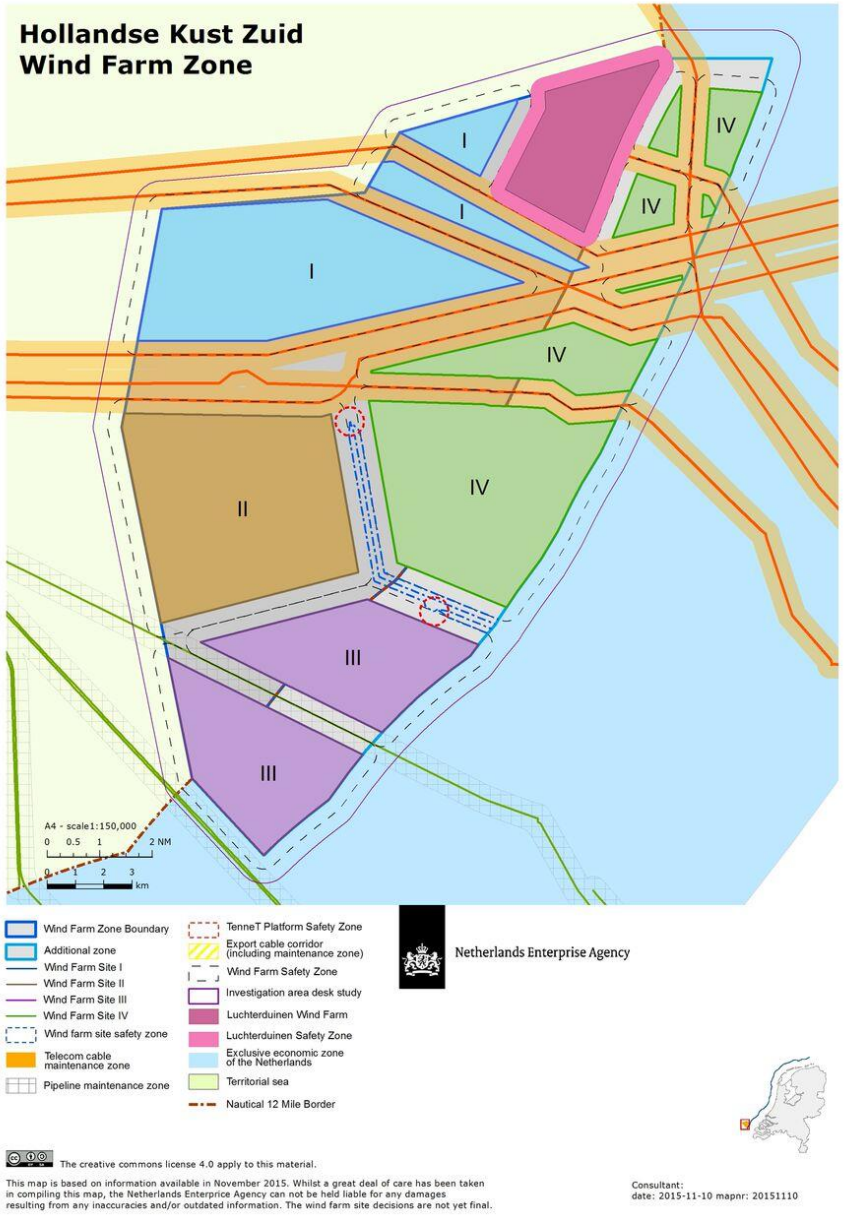
Introduction and assignment

- In December 2014 DNV GL made the following recommendations for wind zone Hollandse Kust Zuid
  - Use publicly available fixed Lidar data from Goeree LE in combination with wind mapping and publicly available historical data;
  - Not to install a floating Lidar in Hollandse Kust Zuid wind farm zone;
  - To consider installation of a fixed Met Mast on site taking into account the additional economic value on the one hand and the extensive preparations needed on the other hand

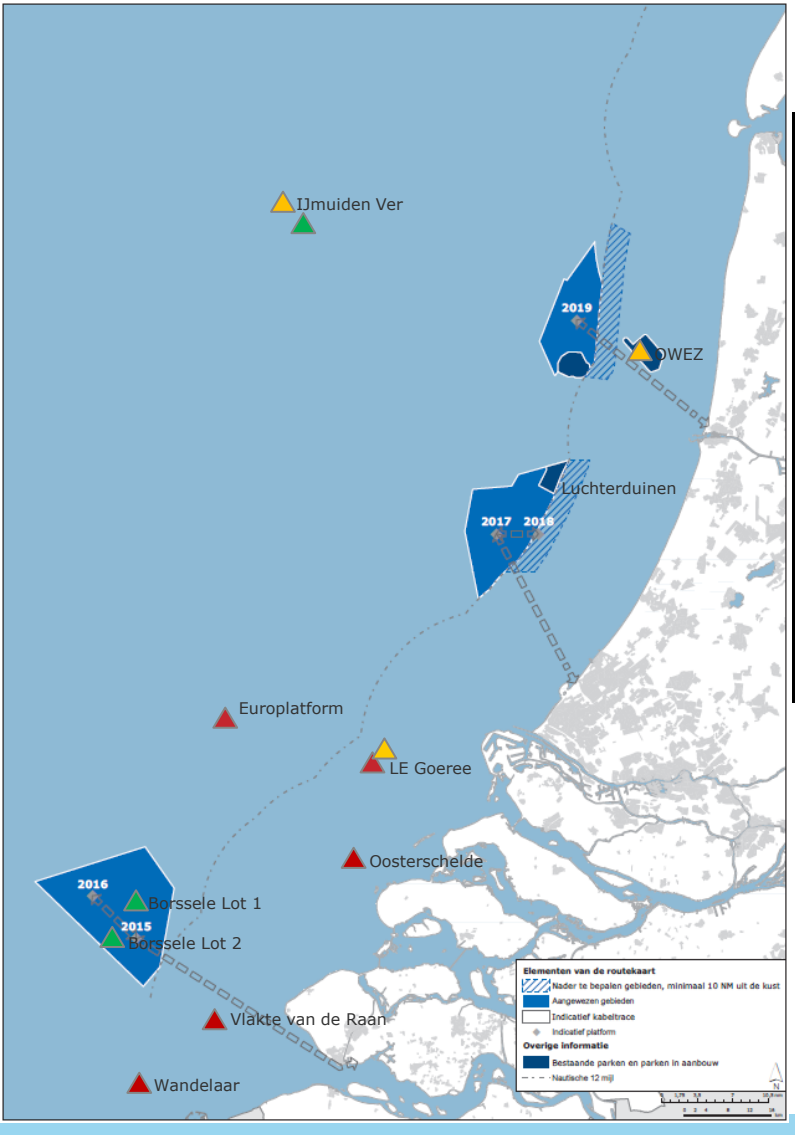
- RvO have asked DNV GL to make an update of the analysis taking into account
  - Developments in floating Lidar technology
  - Status of measurement campaigns in the Dutch North Sea
  - Changes in subsidy tender regime where TenneT is responsible for development of the offshore grid and hence cost for project developers are lower. For the assessment indicative maximum tender levels presented by ECN have been used

Wind zone Hollandse Kust Zuid

- Total planned power 1400 MW
  - 1st 700 MW tender planned Q4 2017
  - 2nd 700 MW tender planned Q4 2018



Overview of existing and planned measurement locations



Time table of measurement campaigns

		2014				2015				2016				2017				2018			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
OWEZ	▲																				
IJMVER	▲	■	■	■	■	■	■	■	■												
IJMVER	▲		■	■	■																
BOR1	▲							■	■	■	◆										
BOR2	▲									■	■	■	◆								
LEG	△					■			■	■	■	■	■								
EPF	△										■	■	■	■							
HKZ 1																	◆				
	▲															■	■				
	▲											■	■	■	■						
HKZ 2																					◆
	▲															■	■	■	■		
	▲																	■	■	■	■

Legenda:

Fixed met mast ▲

Floating Lidar ▲

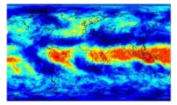
Fixed Lidar △

Tender date ◆

Options for Hollandse Kust Zuid

- In December 2014 DNV GL made recommendations for wind zone Hollandse Kust Zuid
  - Use publicly available fixed Lidar data from Goeree LE in combination with wind mapping and publicly available historical data; A fixed Lidar was installed, but there have been issues with data recovery
  - To support installation of a fixed Lidar at Europlatform by ECN to give more insight in the horizontal gradient of the wind speed off the Dutch coast. This has been in planning for at least 18 months, but so far no Lidar has been installed;
  - Taking into account the development stage by the end of 2014, it was not considered necessary to invest in a floating Lidar at Hollandse Kust Zuid. This was due to the fact that no improvement in uncertainty was to be expected as most floating Lidar were just entering pre-commercial stage.
  - To consider installation of a fixed Met Mast on site taking into account the additional economic value on the one hand and the extensive preparations needed on the other hand. Since then one year has passed, and it is at least doubtful whether installation of a fixed mast would be feasible before the tender for Hollandse Kust Zuid will be launched early 2018;
- In the methodology used, there is an important role for mesoscale (weather-based) wind speed and wind direction data. These data are either available from commercial companies, and from (semi-)public National Met Offices. These models are still under development, it is therefore considered wise to consider investment in such models.

Measurement techniques

					
		Fixed met mast	**Fixed Lidar**	**Floating Lidar**	**Reanalysis data** **MERRA/ERA/Harmony**
Measurement principle		Traditional cup anemometers	Lidar anemometry	Lidar anemometry with/out motion compenstation	Virtual weather model data
Maturity		Baseline	Baseline	Pre-commercial	Standard product, but under continuous development
Accuracy		2%	2-4%	4-7% (pre-commercial) 2-4% commercial	10% absolute error Calibration with meas. required
Implementation requirements		Permit to build and operate (RWS)	Power supply Agreement platform operator	Permit to build and operate (RWS)	Regular updates of data should be made in order to facilitate MCP methods
Mobilization time		2 years (including tender, design and installation)	Dependent on agreement with platform operator Limited construction period	6 months including • Tendering • Notification coastguard	None
Costs	1st yr	10000 kEUR	200 kEUR	1000 kEUR	100 kEUR improve model
	Add year	250 kEUR/a	100 kEUR/a	500 kEUR/a	10 kEUR/a commercial data

Present status floating Lidar equipment (November 2015) Floating Lidar systems

Experience with floating Lidars

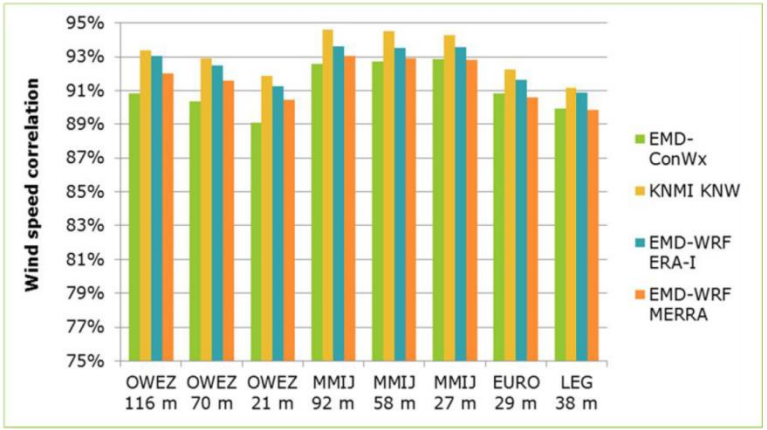
- At present Floating Lidars have been used in 11 commercial projects
- Duration of the campaigns ranges from 6 to 24 months
- Validation campaigns were conducted. Several devices (see right) have reached the criteria for pre-commercial stage
- As far as known to DNV GL no greenfield projects have obtained financing based solely on FLD data. However in April 2015 Dong Energy obtained green light for Burbo Bank extension relying on FLD data only
- So far there is limited knowledge on "real" campaign FLD measurement uncertainty. More information will become available soon. Until then DNV GL can only refer to the OWA roadmap (next slide)

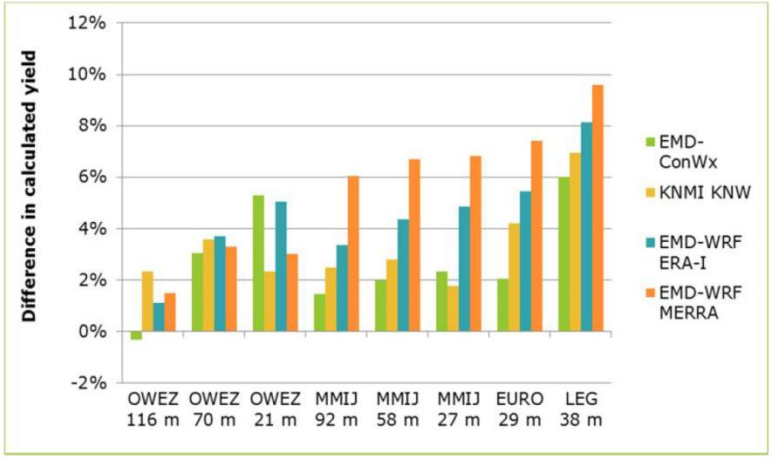
Floating Lidar systems

System	Lidar	Platform	Status
Flidar, AXYS	Windcube v2 (Leosphere)	Surface Buoy	Pre-commercial
Wind sentinel, AXYS	Vindicator (OADS); ZephIR	Surface Buoy	Stage 2 to be achieved Q1-2016
FORECAST, Babcock	ZephIR	Spar Buoy	Pre-commercial
SeaZephIR, SeaRoc	ZephIR	TLP	Unknown
Seawatch Wind Lidar Buoy, Fugro	ZephIR	Surface Buoy	Pre-commercial
Eolos	ZephIR	Surface Buoy	Pre-commercial ?

Meso-scale modelling

- Several meso-scale models exist that can be used to extrapolate wind fields for the North Sea
- Ecofys' validation shows that the KNMI North Sea Windatlas has high correlation with measured wind speeds and energy generation
- KNMI have requested funding for:
  - Model updates
  - Site modelling to carry out MCP-extrapolation using site measurements
  - Help desk function
- Commercial parties have indicated that
  - there is added value to make available public meso-scale data from a reliable source
  - MCP services could be offered as commercial services by tender or contract





http://projects.knmi.nl/knw/

Ecofys Borssele Wind Resource Assessment

Recent developments in measuring campaigns

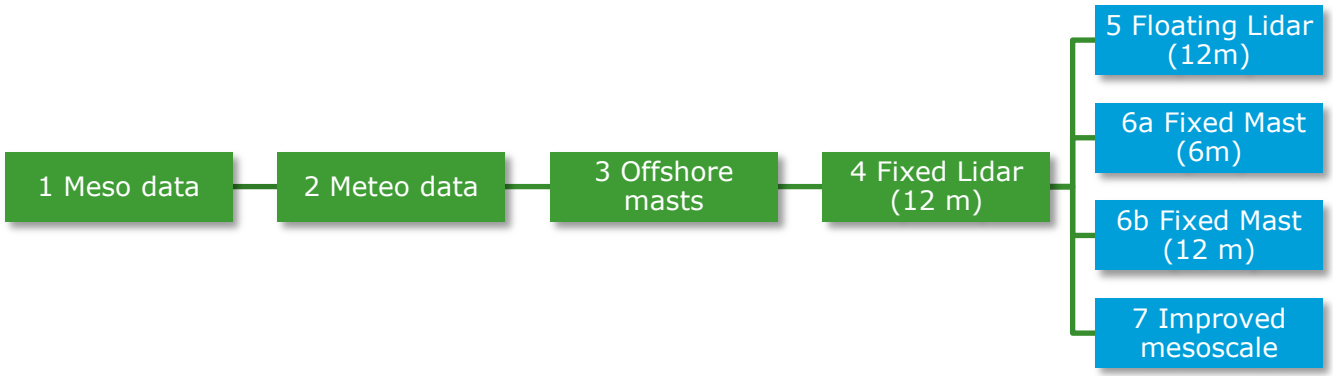
Measurement set	Type	Remarks
IJmuiden Ver	Fixed Mast	IJmuiden Ver Met Mast will be discontinued.
OWEZ	Fixed Mast	No plans to reestablish OWEZ measurements because measurements are too disturbed by upstream measurements.
LE Goeree	Essential Met Station Fixed Lidar installation	Since October 2014, ECN operates a fixed Lidar. Due to data storage problems 5 months (10-4 to 28-9) are missing. It is being investigated whether the data can be recovered. It is intended to install a second fixed Lidar in the near future.
Europlatform	Essential Met Station Fixed Lidar negotiated	ECN has continued to develop plans to deploy a fixed Lidar at EPF. With RWS an agreement has been reached for operations and transport.
Borssele 1	Floating Lidar	Since June 2015 a floating Lidar has been deployed and measurements have been provided to RvO. ECN has been assigned for data management and quality control Except for June 2015, no data has been released yet.
Borssele 2	Floating Lidar	A second floating Lidar has been deployed near the Belgian border, in order to monitor the influence of Belgian wind farms on the Borssele site.
Ijmuiden Ver	Floating Lidar	As part of the FLOW program a floating Lidar was deployed during part of 2014. IJmuiden Ver measurements have been used to validate the instrument

Summary of OWA roadmap

Maturity Stage	Prerequisites	Possible Applications	Limitations	Indicative measurement uncertainty
Baseline	➢ LiDAR type considered as "proven technology" in onshore wind industry.	**Scenario A** Fixed met mast supplemented by one or more FLD deployments	➢ FLD data used only in a relative sense to support wind flow modelling used to estimate horizontal and vertical variation in wind resource across site	N / A (uncertainty assessment driven by primary met mast measurements, possibly reduced by use of FLD)
Pre-commercial	➢ As above, plus: ➢ Pilot validation trial for FLD type completed success-fully including independent scrutiny and confirmation of Acceptance Criteria	**Scenario B** Single FLD deployment	➢ 2-Phase FLD Unit Validation required: ➢ Metocean conditions during campaign must be demonstrated to be within the Unit Validation and Type Validation. ➢ Independent wind data source (regional measurements or modelling) and / or high level of industry experience of wind resource in region required to cross-check results.	4-7%
		Scenario D Fixed met mast supplemented by one or more FLD deployments	➢ 2-Phase FLD Unit Validation required. Phase 2 can be carried out on target site	N / A (uncertainty assessment driven by primary met mast measurements, possibly reduced by use of FLD)
Commercial	➢ As above, plus: ➢ Good operational experience and accuracy achieved across a number of pre-commercial deployments. ➢ Residual environmental sensitivities well understood and documented.	**Scenario E** Single FLD deployment	➢ Scenario B and C Limitations recommended for lowest uncertainty, although not essential.	2-4%
		Scenario G Fixed met mast supplemented by one or more FLD deployments	➢ 2-Phase FLD Unit Validation recommended for lowest uncertainty, but not essential. Phase 2 can be carried out on target site.	2-4%

Source: Carbon Trust Offshore Wind Accelerator

Overview of scenarios



- For Hollandse Kust Zuid the following data are assumed to be available in the base case:
  - State of the Art mesoscale wind resource data
  - Climatological data from KNMI essential meteo stations (LE Goeree, Europlatform)
  - Wind speed data sets from fixed meteo masts (IJmuiden Ver, OWEZ)
  - Fixed Lidar wind speed data from fixed Lidar measurements on LE Goeree, potentially complemented with measurements from EPF
- Additional measurement scenarios have been assessed:
  - Floating Lidar measurement at HKZ
  - Fixed Mast measurement at HKZ (6 months and 12 months)
  - Improved mesoscale modelling

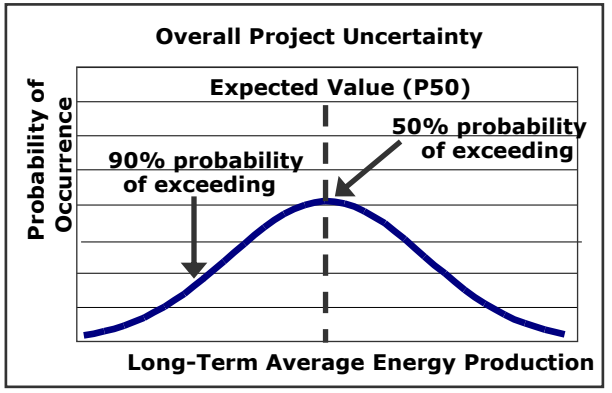
Possible scenarios

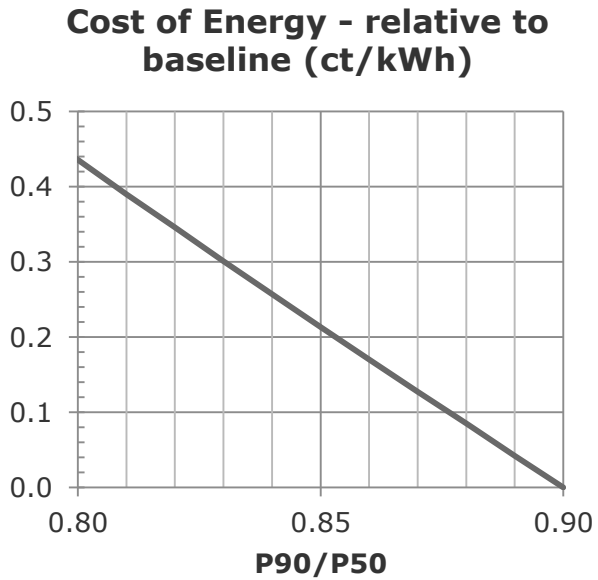
		Hollandse Kust Zuid 1	Hollandse Kust Zuid 2
Base line (1-4)	Existing met data (LEG, EPF ,OWEZ, IJmuiden) Mesoscale models Fixed Lidar LEG, EPF (1 year)		
5	Floating Lidar on location	1 year	1 year
6a, 6b	Fixed mast on location	6 months	1 year
7	Improved mesoscale modeling		

- Met data and/or mesoscale models alone are not "bankable" (too high uncertainty)
- Combination of all available data (met data, mesoscale models, offshore met masts) is bankable and defined as reference
- Fixed Lidar measurements by ECN at LE Goeree included in baseline
- All scenarios are used with wind mapping using available models and historical data
- IJmuiden Ver measurements have been continued in 2015
- All benefits and costs are relative to baseline

Uncertainty and Finance

- Energy yield uncertainty is a driver for financing costs
- P90 is regarded as a good measure for "certain" revenue stream
- Banks require DSCR of 1.3 at P90,
  - free cash flow = 1.3 x debt service
- Weighted Average Cost of Capital (WACC):
  - WACC = Y * RoE + (1-Y) * interest
- Lower uncertainty → Lower WACC





See also: Assessment Wind Measurement Program North Sea - DNV GL

Hollandse Kust Zuid

	Baseline	Floating Lidar (12 months)	Met mast (6 months)	Met mast (12 months)
P90/P50	88.3%	87.7%	88,9%	89,0%
Cost of Energy (ct/kWh) *)	11.77	11.80	11.75	11.74
Additional revenues	0	0	21.0	23.6
Cost (MEUR)	0	1.0	10.3	10.6
Financial benefit over 15 years compared to baseline (MEUR)	0	-1.0	10.7	13.0

- Hollandse Kust Zuid mainly benefits from installation of fixed Lidar (already in the basecase)
- There is no apparent additional value of the installation of a floating Lidar on site compared to the baseline.
- Hollandse Kust Zuid could benefit from a fixed Met Mast in case an optimistic planning for deployment is used, but this option is highly theoretical because the risks of delay are very large, which would quickly take away the benefits

*) cost of energy only includes investment in wind farms. Cost for grid are excluded from calculations. (Source: ECN)

Sensitivity analysis and discussion

- The cost benefit analysis presented in the previous slide is based on the assumptions that financiers are willing to give higher debt/equity ratios if wind resource data become more accurate.
- In the base case already a high P90/P50 ratio has been obtained. Although it has been shown that there are financial benefits to install a ***fixed met mast***, this depends significantly on the assumptions. Assuming that a fixed met mast could be built in 18 months (including tendering, design, manufacturing, permitting and deployment), it is unlikely that more than 6 months of data could be collected. According to DNV GL this does not justify the time and financial investment in relation to the real risks of delays, which would make the benefits disappear.
- **Fixed Lidar** at EPF has been discussed for a long time. This is considered a cost effective option, that would serve to give insight into the horizontal gradient of the wind speed, while at the same time offering some redundancy to other measurement equipment
- At present ***floating Lidars*** are still in pre-commercial stage, but in rapid pace experience is gained with using Floating Lidars. Potential bidders have indicated that a floating Lidar at site gives additional comfort, because no vertical or horizontal extrapolation would be required. This could come at an acceptable cost.
- **Mesoscale wind maps** have rapidly developed over the latest years and have become an important tool to make Energy Production Assessments. The KNMI North Sea Wind Atlas has proven to correlate well with wind measurements; improvements in Energy Production Assessments are still possible. DNV GL would advise to make available wind fields in the public domain. Energy Production Assessments could be left to commercial companies, that have plenty of experience with this.

Conclusions and recommendations

		HKZ 1	HKZ 2
Baseline	Existing met data (LEG, EPF ,OWEZ, IJmuiden) Mesoscale models (MERRA, ERA, Harmonie) Fixed Lidar LEG, EPF	++	++
5	Floating Lidar on location	0/+	0/+
6a, 6b	Fixed mast on location	--	-
7	Improved mesoscale modelling	+	+

Recommendations

- Install EPF fixed Lidar for at least one year
  (spatial information of the land/sea transition zone, and redundancy for other measurement systems)
- Consider to install a floating Lidar at Zuid-Hollandse Kust in order to provide extra comfort to bidders at relatively low cost.
- Do not build a fixed met mast, because design, permitting and deployment risks are considered too high
- Consider to fund further development of KNMI North Sea Wind Atlas, but leave detailed Energy Production Assessments and wind correlations to commercial companies.

DNV GL Distribution:

☒ Unrestricted distribution (internal and external)

☐ Unrestricted distribution within DNV GL Group

☐ Unrestricted distribution within DNV GL contracting party

☐ No distribution (confidential)

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2015-12-07	First issue	Hans Cleijne	Detlef Stein	Jillis Raadschelders
1	2016-03-31	Public version	Hans Cleijne	Patrick Schwenk	Jillis Raadschelders

Hans Cleijne
hans.cleijne@dnvgle.com
+31 26 356 6393

www.dnvgl.com

SAFER, SMARTER, GREENER

