Netherlands Enterprise Agency

Webinar Wind Resource Assessment Hollandse Kust (west) Wind Farm Zone

8 October 2020

Joep Bronkhorst

Welcome

- Introduction of the webinar
- Presentation of Wind Resource Assessment by Jochem Vermeir (Tractebel Engie)
- Use chat for anonymous questions to expert team: Andy Oldroyd (Oldbaum), Erik Holtslag (Pondera), Claude Abiven (Tractebel)

Webinar
Hollandse Kust West Wind Resource Assessment

08/10/2020

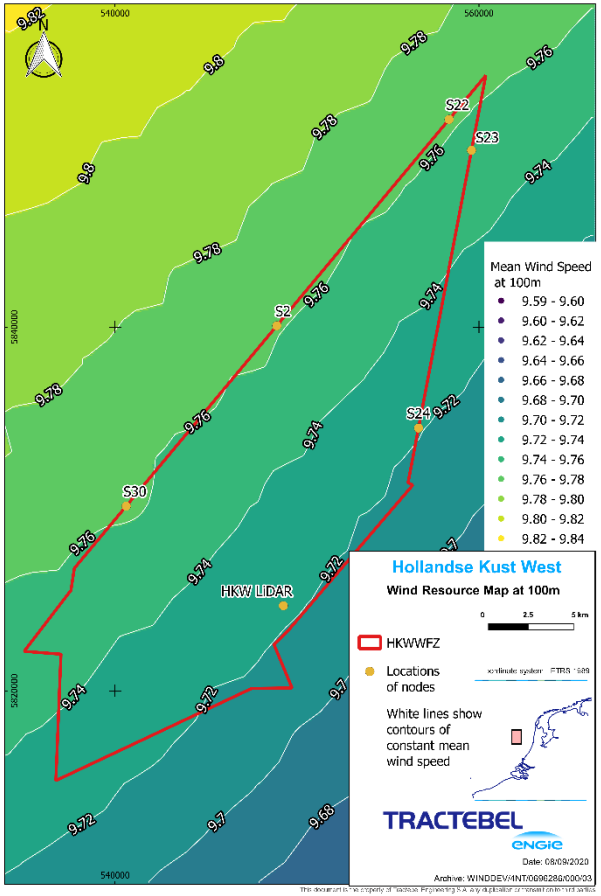
TRACTEBEL

ENGIE

☐ Confidential ☐ Restricted ☐ Public ☐ Internal

Outline

- Introduction
- Wind data collection, selection & analysis
- Data and wind flow modelling
- Wind farm zone wind climate
- Alignment with other studies
- Wake assessment
- Conclusions



Mean wind speed at 100m MSL over the HKWWFZ

01 Introduction

Introduction

- Hollandse Kust (west) Wind Farm Zone (HKWWFZ)
  - — part of Dutch offshore wind 2030 roadmap
  - — distance to shore ~51 km
  - — tender in 2021 with target capacity 2 x 700 MW
- The Netherlands Enterprise Agency (RVO)
  - — selected the Tractebel consortium to perform an independent wind resource assessment (WRA) for HKWWFZ
  - — will publish the certified WRA Report in the course of Q4/2020

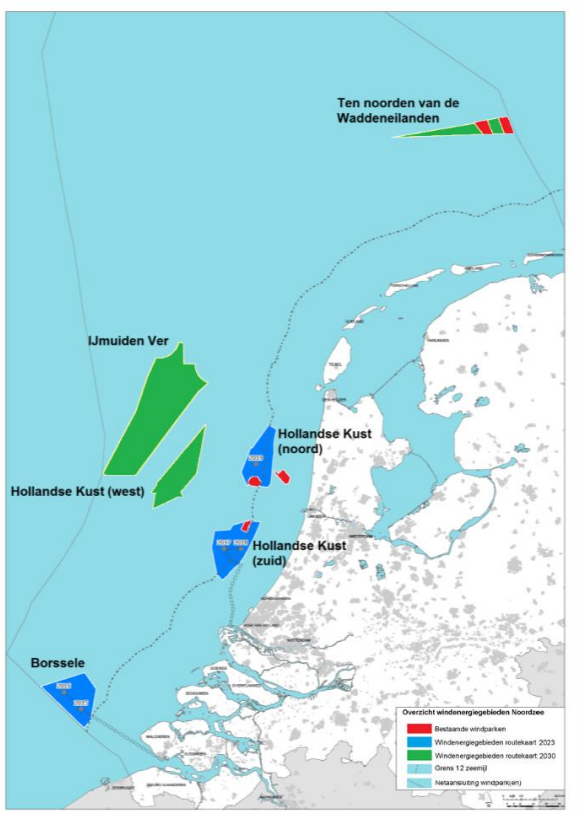
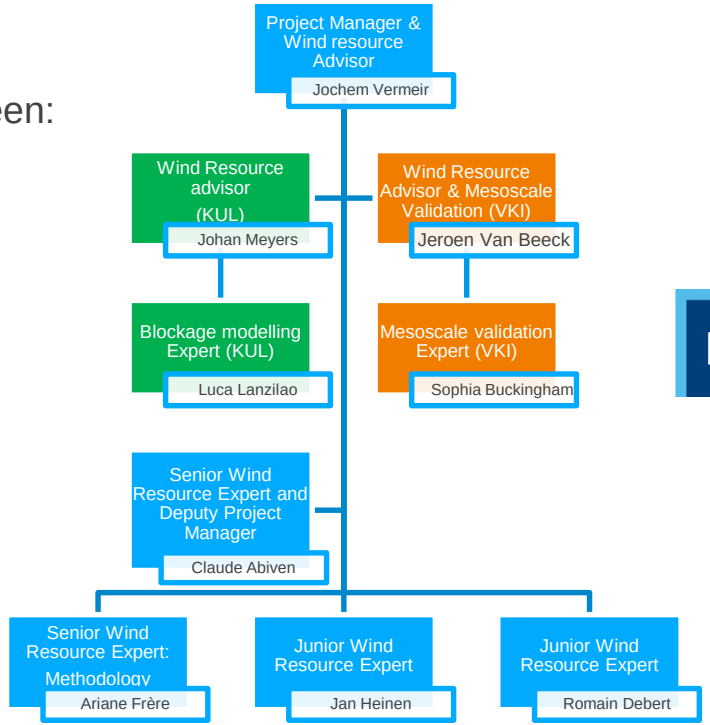


Illustration of offshore wind development in the North sea. 2030 target zones appear in green

Introduction – Project setup

- Independent WRA awarded to collaboration between:
  - Tractebel (blue)
    - experience and know-how of WRA up to best practices
  - Scientific Experts
    - Von Karman Institute (Orange)
      - Validation & Expert advice on Mesoscale models
    - KU Leuven (Green)
      - State-of-the-art Wake modelling



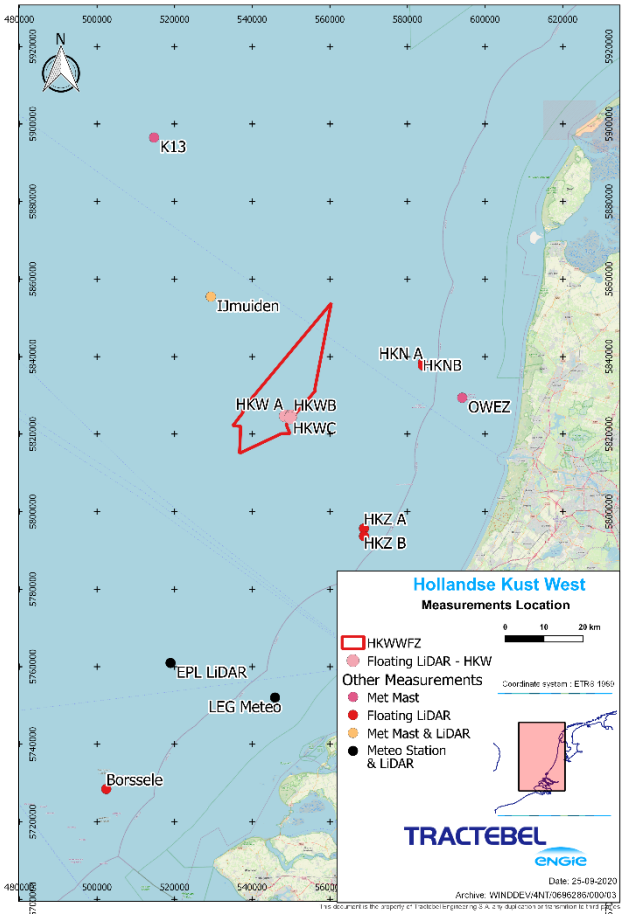
Introduction – Methodology

- Detailed analysis of available wind data
  - Analysis of in-situ data & selection of two additional measurement sources
- Data modelling
  - Prediction of the long-term wind climate across the site for the three main sources
  - Evaluation and selection of appropriate wind flow model(s) for horizontal extrapolation
  - Combination of the 3 long-term datasets using wind flow model & weights minimizing uncertainties
- Estimation of the uncertainties associated with the predicted wind climate
- Alignment of the predicted wind resource with the metocean desk study at pre-defined locations
- Evaluation of potential wake effects within the wind farm and from existing and future neighbouring wind farms

02
Wind data

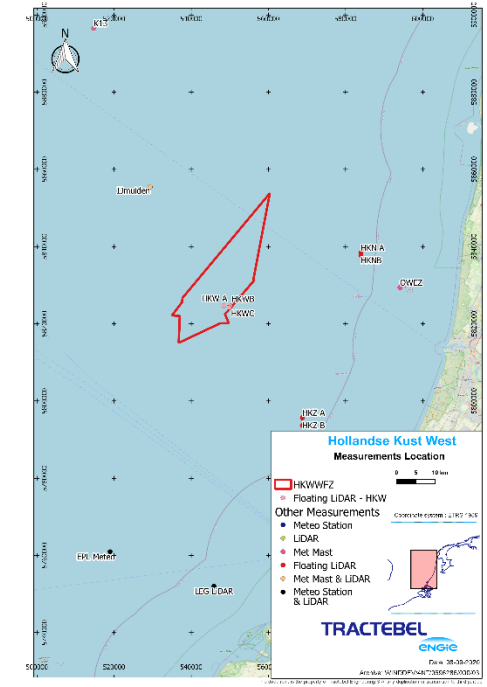
Wind Data - Collection

- Data base
  - — Measured:
    - Offshore meteorological stations
    - Tall offshore met masts
    - Lidar measurements campaigns (Fixed/Floating)
  - — Virtual
    - Reanalysis data
    - Mesoscale data

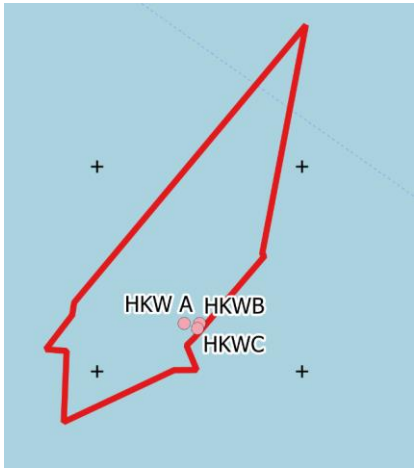


Dutch Offshore Wind measurement campaign

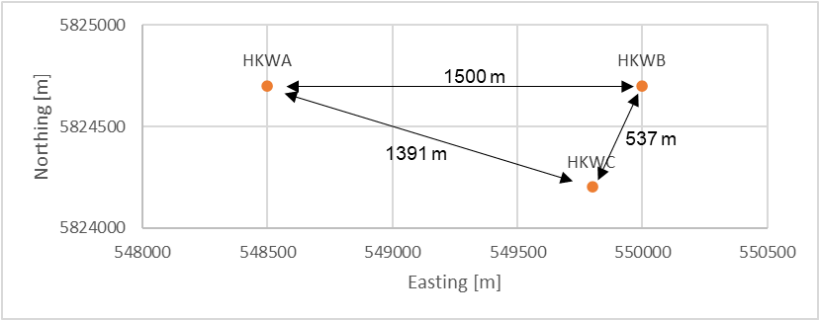
On-site measurements – 3 buoy locations



Locations off the coast of the Netherlands



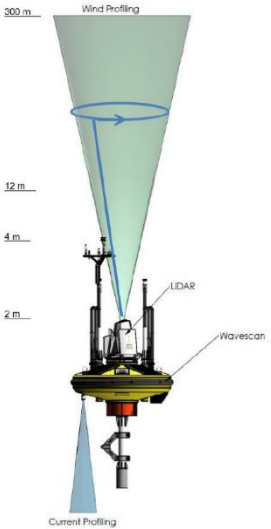
Locations within the HKWWFZ



Locations relative to one another

On-site measurements – Devices

- 3 Seawatch metocean buoys deployed by Fugro
  - — Roadmap Pre-commercial staged FLS (Carbon Trust OWA)
  - — Onshore Lidar verification
  - — Pre-deployment verification for 2 devices at Frøya test site
  - — In-situ verification for device (WS 170)
- Instruments
  - —ZX 300 LiDAR
  - —Ultrasonic wind sensor
  - —Other environmental sensor (Pressure, temperature…)



Illustrations of the LiDAR on its buoy

On-site measurements – Deployment

- The 3 buoys were periodically replaced
- Measurement periods at each one of the 3 locations:

	02/19	03/19	04/19	05/19	06/19	07/19	08/19	09/19	10/19	11/19	12/19	01/20	02/20
HKW A	5/feb			WS187				21/sep	WS188	24/nov		WS187	16/feb
HKW B	10/feb			WS188				19/sep					
HKW C							1/aug	WS170		24/nov	18/dec	WS188	16/feb

Deployment timeline HKW measurement campaigns

On-site measurements – Single dataset

- Data quality-checked
  - —By Fugro
  - —By the RVO expert team
  - —Further filtered by Tractebel (low packets, 180º wind direction shifts, suspicious data,..)
- A single dataset was generated to fulfil the Carbon trust criteria (Stage 2 FLS)
  - —Based on HKWA location (highest availability)
  - —Filled by HKWB and HKWC (excellent correlations between all devices)
    - Both MCP and data substitution approach have been compared
    - Excellent correlation between the different data sets

R^2 (wind speed)	HKWA	HKWB	HKWC
HKWA	-	-	-
HKWB	0.992	-	-
HKWC	0.989	0.993	-

R^2 (direction)	HKWA	HKWB	HKWC
HKWA	-	-	-
HKWB	0.998	-	-
HKWC	0.997	0.999	-

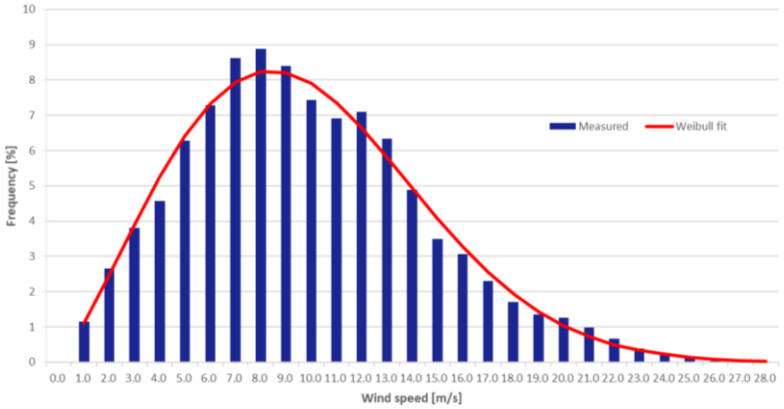
Correlation concurrent wind speed and direction HKW A, B and C

On-site measurements – Short-term wind climate

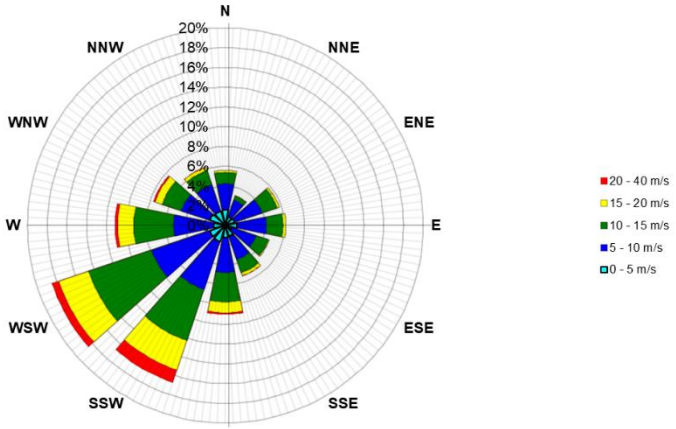
- Average wind speed = 9.81 m/s at 100m MSL

Measurement	Height [m MSL]	Considered period	Statistical mean wind speed [m/s]	Availability [%]
HKW	100	11/02/19 – 10/02/20	9.81	94.5

- Average wind shear = 0.08



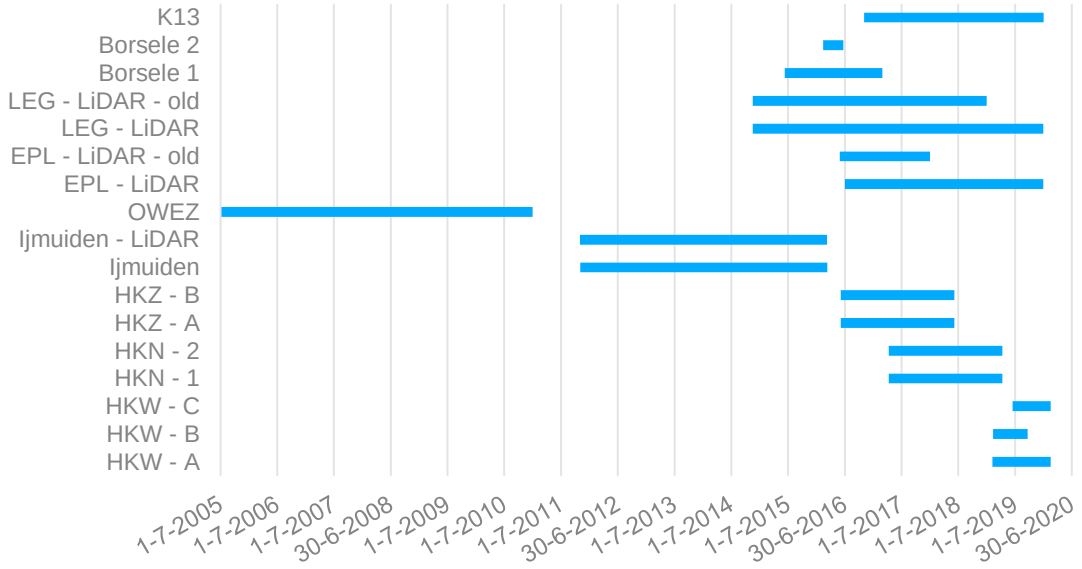
Wind histogram & Weibull distribution



Wind rose

Other wind data – Overview

- 2 additional main sources to reduce uncertainty
- Screening of all known wind data available in the site's vicinity
  - —HKN LiDARs
  - —HKZ LiDARs
  - —Ijmuiden met mast/LiDAR (MMIJ)
  - —OWEZ met mast
  - —K13a LiDAR
  - —EPL mast/LiDAR
  - —LEG mast/LiDAR



Deployment other wind measurement campaigns

Other wind data – Main sources selection

- Methodology
  - Objective: To find the combination of measurement sources leading to the lowest uncertainty
  - Each dataset was assigned uncertainties
    - Instrument type
    - Horizontal extrapolation to HKW
    - ...
  - The overall uncertainty of HKW measurements + 2 additional sources was computed
    - For all possible combinations
    - Taking into account dependent and independent uncertainties (ref. IEC 61400-12-2)
- OWEZ + Ijmuiden met masts were selected
  - OWEZ was preferred as the 3rd source for its location compared to HKW and Ijmuiden

Combined Uncertainties [%]	HKN	HKZ	MMIJ	K13	LEG (Lidar)	EPL (Lidar)	OWEZ
HKN		3.32	2.26	3.05	3.15	3.05	2.59
HKZ			2.26	3.05	3.15	3.05	2.59
MMIJ				2.17	2.24	2.17	2.23
K13					2.99	2.89	2.44
LEG (Lidar)						2.99	2.54
EPL (Lidar)							2.44
OWEZ							

Combined uncertainties for combinations of 2 additional sources of measurements

Wind data – Questions

- Any questions from the webinar participants?

03

Data & Wind Modelling

Data modelling - Long-term correction

- Methods
  - —Linear regression, Matrix correction, Neural networks
- Long-term reference datasets
  - —ERA5, MERRA2, CFSRv2, LEG met mast
- ERA5 and Neural networks were selected
  - —Highest R^2 values for diurnal, monthly and time series fit

Site Measurement	Height [m MSL]	Short-term period	Short-term mean wind speed [m/s]	Long-term period	Long-term mean wind speed [m/s]
HKW	100	11/02/2019 – 10/02/2020	9.81	31/10/1999 – 31/10/2019	9.55
MMIJ	100	01/11/2011 - 09/03/2016	10.36	31/10/1999 – 31/10/2019	9.91
OWEZ	100	01/07/2005 – 30/06/2006	9.02	31/10/1999 – 31/10/2019	9.49

Short and long-term wind speeds from the 3 main data sources

Wind modelling – Mesoscale model selection

- Mesoscale model required in order to:
  - Extrapolate other measurements than HKW LiDARs to HKW
  - Extrapolate from HKW LiDAR to the HKW Wind Farm Zone
- Available models:
  - KNW
  - DOWA
  - NEWA
  - 3Tier-ERA5
  - EMD-WRF-ERA5
  - Ensemble

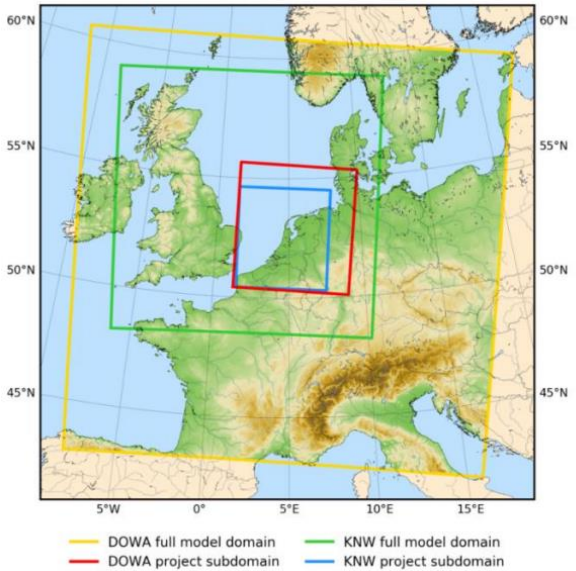


Illustration of the extents of the HARMONIE domain for the DOWA (yellow) vs. the KNW (green) atlas

Wind modelling – Mesoscale model Validation

- Available models were compared
  - — Against measurements (8 sites) available in the North Sea
  - — Derivation of specific KPI's for its use
  - — Weights per station based on its individual uncertainty

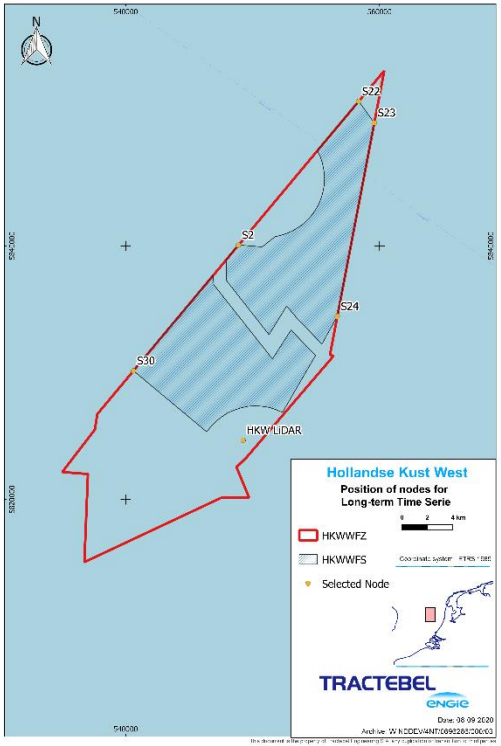
Measured parameter	Metric	Mesoscale model					
		KNW	DOWA	NEWA	3TIER-ERA5	EMD-WRF-ERA5	Ensemble
Average wind speed	Bias Vave - Average Bias [m/s]	0.008	0.008	0.006	0.017	0.008	0.008
	Correlation [r]	0.87	0.88	0.80	0.90	0.88	0.90
Average wind direction	Bias D ave - Average Bias [º]	1	1	1	1	1	1
	Correlation [r]	0.86	0.87	0.82	0.86	0.87	0.88
Energy rose	Bias f ave [º]	5	6	7	6	7	6

  - —DOWA was chosen (ensemble results in a negligible difference on the wind climate)

Wind Farm Zone wind climate – Site nodes

- Computation
  - —MMIJ and OWEZ long-term series were extrapolated to HKW using DOWA
  - —The 3 long-term series at HKW were weight-averaged
    - Weights were derived from associated uncertainties
- Time series were extrapolated to site nodes using DOWA

Site node	Height [m MSL]	Long-term mean wind speed [m/s]
HKW	100	9.72
S2	100	9.76
S22	100	9.76
S23	100	9.75
S24	100	9.72
S30	100	9.77



Site node locations

Please note that the contours of the Wind Farm Sites within the HKWWFZ are preliminary only and no rights can be derived from it.

Data & Wind Modelling - Questions

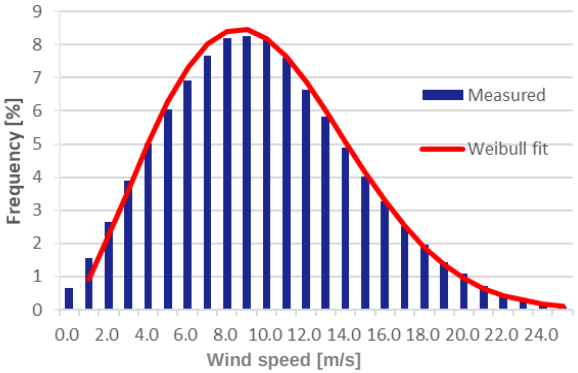
- Any questions from the webinar participants?

04

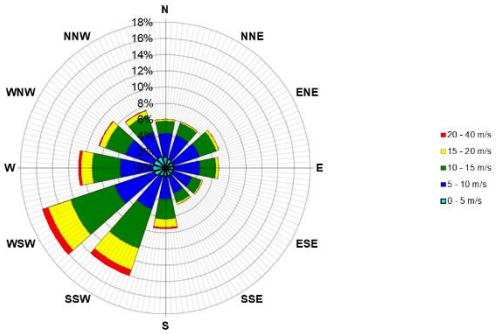
Wind Farm Zone wind climate

Wind Farm Zone wind climate

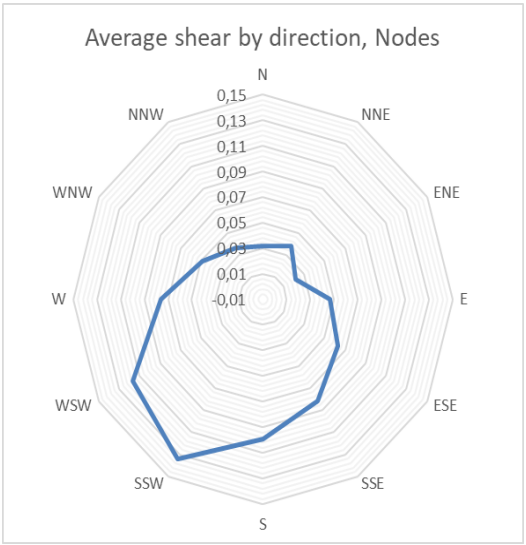
- Average wind speed at 100 m MSL HKW LiDAR node
  - —Statistical = 9.72 m/s
  - —Weibull = 9.80 m/s (A = 11.11 m/s & k = 2.283)



Weibull fit at the HKW LiDAR site node



Wind rose at the HKW LiDAR site node



Directional shear at HKW LiDAR site node

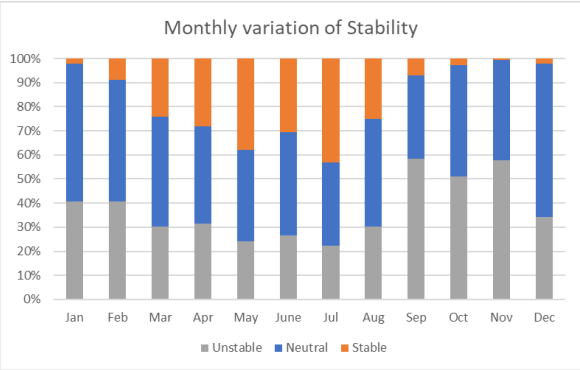
Wind Farm Zone wind climate - Stability

- Stability conditions based on ERA5 (HKW Location)
  - Compared with linked shear conditions at a representative site (Ijmuiden)

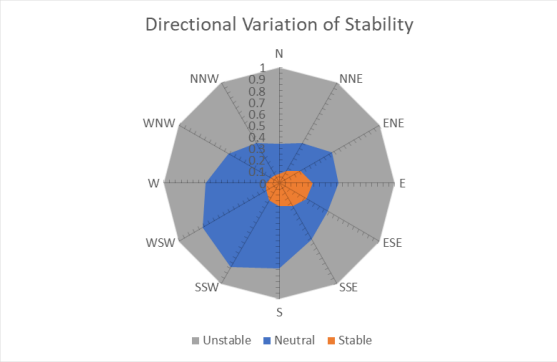
A Comparison of the UK Offshore Wind Resource from the Marine Data Exchange. Peter, Argyle, et al. Hamburg: Windeurope Summit, 2016.

MOL	1/L < -0.005	-0.005 < 1/L < 0.005	1/L > 0.005
Stability Class	Unstable	Neutral	Stable
Weight (%)	37.3%	45.0%	17.7%

Classification of stability based on the 1/L value



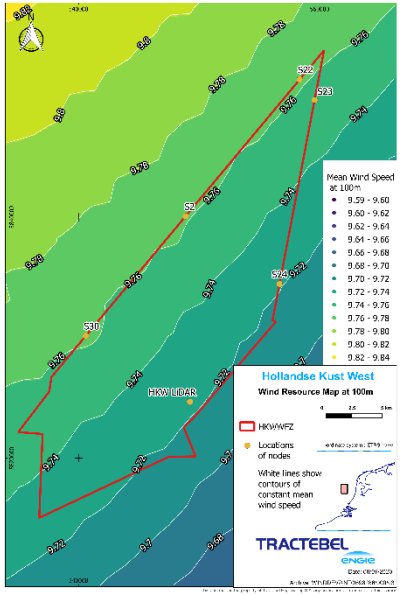
Monthly variation of stability at the Ijmuiden met mast location



Directional variation of stability at the Ijmuiden met mast location

Wind Farm Zone wind climate - Uncertainties

Uncertainty category	#	Sub category	Effect on	Dependance	Value (in σ)		
					HKW	MMIJ	OWEZ
1. Site measurement	1a	Instrument accuracy	wind speed	Instrument	2.56%	2.0%	2.0%
	1b	Instrument mounting	wind speed	Instrument	0.5%	1.0%	2.5%
	1c	Data quality and metadata	wind speed	Independent	1.0%	0.5%	1.5%
	1d	Data Processing	wind speed	Processor	1.0%	1.0%	1.0%
2. Historic wind resource	2a	Representativeness	wind speed	Independent	1.0%	0.6%	1.0%
	2b	Reference Site (MCP)	wind speed	Reference Dataset	2.4%	1.9%	2.8%
3. Vertical extrapolation	3a	Extrapolation to 100m	wind speed	Independent	0.0%	0.8%	1.5%
4. Future wind variability	4a	Interannual variability (20 years uncertainty)	wind speed	Dependent	0.8%	0.7%	0.9%
5. Spatial variation	5a	Horizontal extrapolation to HKWWFZ	wind speed	Dependent	0.0%	0.5%	0.5%
	5b	Horizontal extrapolation within HKWWFZ	wind speed	Dependent	0.5%	0.5%	0.5%
Combined Uncertainty			**wind speed**		**3.24%**		



Mean wind speed at 100m MSL over the HKWWFZ

Wind Farm Zone wind climate - Questions

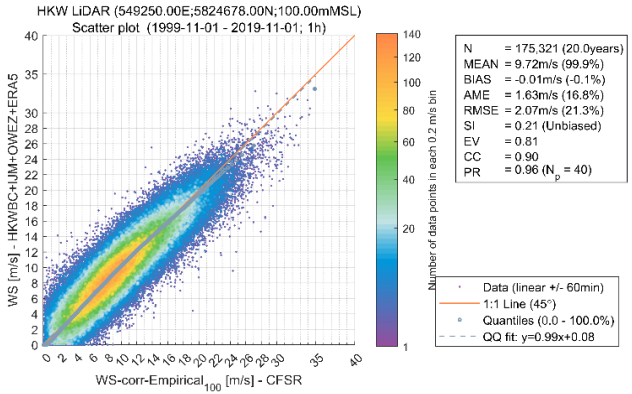
- Any questions from the webinar participants?

05

Alignment with other studies

Comparisons with other studies – Metocean study

- Alignment with Metocean study performed by DHI
- Deviations at site nodes between -0.01 and 0.11m/s



Tractebel vs. DHI's long-term wind speeds at the HKW LiDAR node location

Parameters Node	HKW LiDAR	S30	S2	S22	S23	S24
Height [mMSL]	100	100	100	100	100	100
Mean wind speed Tractebel [m/s]	9.72	9.76	9.76	9.76	9.75	9.72
Mean wind speed DHI [m/s]*	9.73	9.73	9.73	9.73	9.71	9.61
Bias [m/s]	-0.01	0.03	0.03	0.05	0.04	0.11

Summary of the mean wind speeds at the 6 nodes Tractebel vs. DHI

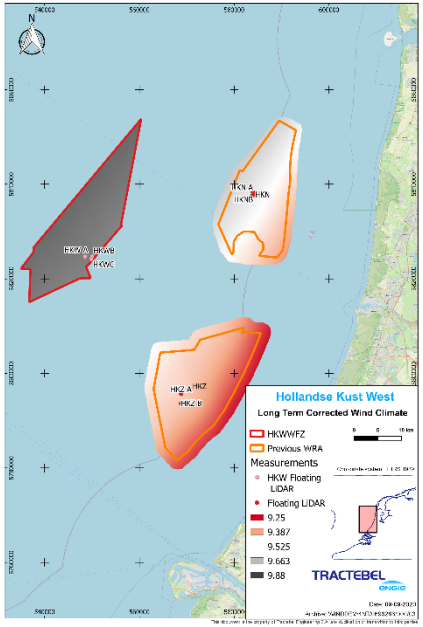
* Discrete extracts from the CFSR original grid

Comparisons with previous studies - WRAs

- Comparisons

Study	Max gradient between nodes	Long-term mean wind speed [m/s]
HKW (Tractebel)	0.05 %/km	9.72
HKN (Oldbaum)	0.14 %/km	9.56
HKZ (Ecofys)	0.21 %/km	9.44

- Differences are in line with expectations
  - HKW is located further offshore
    - Stronger winds
    - More uniform wind flow



Wind speed maps computed for HKW, HKN and HKZ

Statement of Compliance

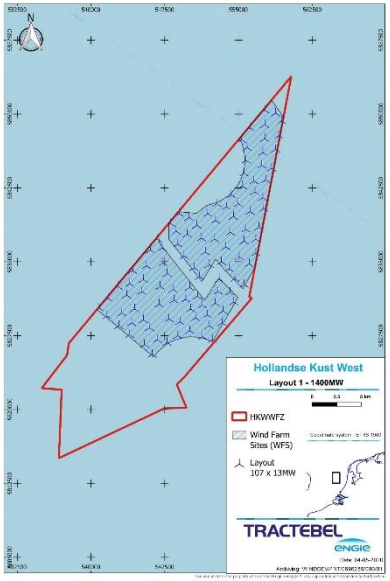
- Review by certification body DNV GL
  - Ensure quality, accuracy, detail to serve as WRA
- Statement of Compliance with
  - DNV-GL-SE-0190:2015-12
  - IEC 61400-1
  - IEC 61400-3
- Statement of Compliance will be published together with WRA report

06

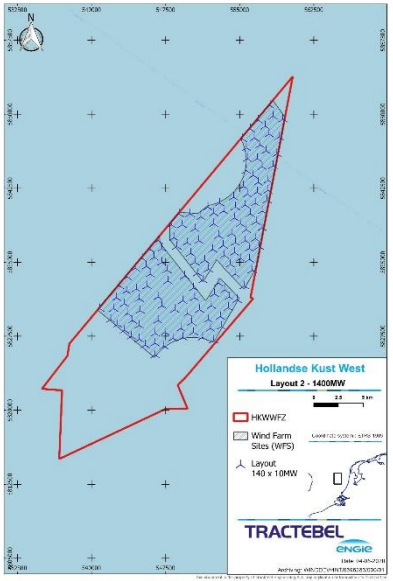
Wake assessment

Wake assessment – Turbine layouts

- Provide high-level assessment to identify expected attention points
- Based on the wind climate: 1.4 GW optimized layouts
  - Layout 1 using 13MW turbines
  - Layout 2 using 10MW turbines
- Approach
  - Industry standard model
    - Internal wake effects
  - State-of-the-art model
    - Impact of (far) wind farm clusters
    - Self-induced AEP loss due to blockage



Layout 1, 13MW turbines



Layout 2, 10MW turbines

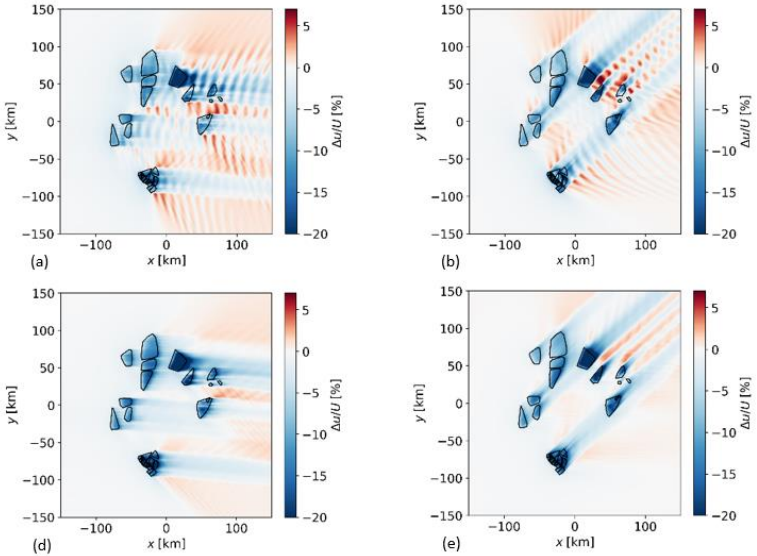
Please note that the contours of the Wind Farm Sites within the HKWWFZ are preliminary only and no rights can be derived from it.

Wake assessment – Industry-standard models

- Park1, Park2
  - —Turbulence intensity measurements from Ijmuiden were used to compute wake decay constants
- Eddy-viscosity
  - —Turbulence intensity measurements from Ijmuiden were used as an input
- Park2 stability weighted
  - —ERA5 was used to compute stability classes
  - —Stability classes were associated with Turbulence intensity from Ijmuiden
  - —Outputs for the several stability class were weighted based on the occurrence of each stability class

Wake assessment – Three-layer model

- Developed by the group of Johan Meyers at KU Leuven
- Fast engineering model based on insights from LES simulations
  - —Incorporates gravity-waves feedback
  - —Gaussian-wake merging model for internal wakes
  - —“Blockage” modelled as an interaction with the boundary layer
  - —Able to model long-distance wake effects
  - —Stability-dependent



Reduction in wind speed due to operating wind farms, for very stable and stable conditions (top to bottom) for Westerly and South-Westerly winds (left to right)

Wake assessment – Combined estimate

- Internal wake losses

	Average of all models	Min of all models	Max of all models
13MW layout	9.2%	6.0%	11.8%
10MW layout	9.4%	5.7%	12.2%

- Internal + external wakes + “blockage”

	Average of all models	Min of all models	Max of all models
13MW layout	18.5%	15.3%	21.1%
10MW layout	18.6%	14.9%	21.4%

- Wide gap between wake models
  - It is recommended for readers to satisfy themselves of the influence of neighbouring wind farms

Wake assessment - Questions

- Any questions from the webinar participants?

07
Conclusions

Conclusions

- Mean long-term wind speed at the HKW site centre at 100 m MSL: **9.72 +/- 0.31 m/s**
  - — High Wind resource compared to previous projects
- Confidence in the wind resource assessment enhanced by:
  - —The alignment with the Metocean study
  - —Previous studies
  - —DNV-GL's certification
- Significant estimated Wake/blockage losses, but associated with a large uncertainty
  - — Neighbouring WF need specific attention
- Any questions from the audience?

Thank you for your attention!

- Contact: Jochem.vermeir@tractebel.engie.com

Netherlands Enterprise Agency

Closing the webinar

Please fill in the questionnaire

This webinar, the powerpoint presentation and the list with questions & answers will be made available on: https://offshorewind.rvo.nl

Thank you for participating in this webinar

All webinars about the Hollandse Kust (west) Wind Farm Zone can be found on https://offshorewind.rvo.nl