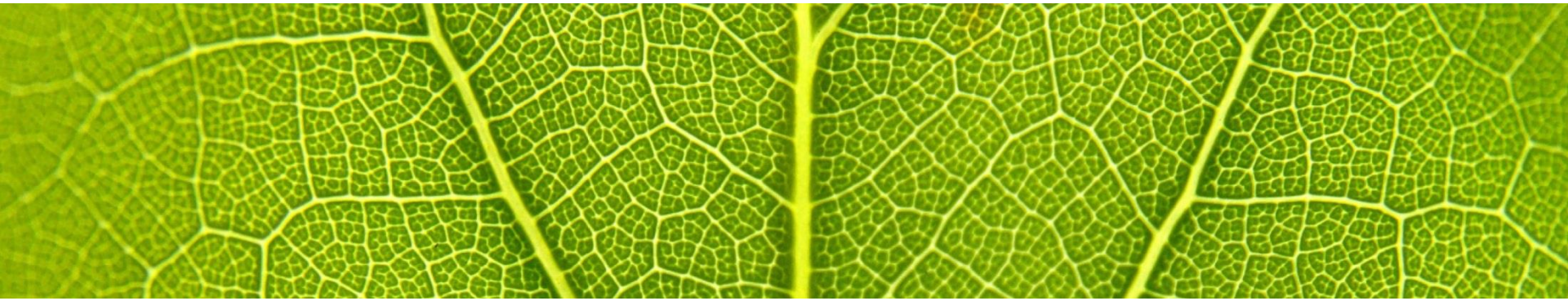
ECOFYS | WIND TURBINE TESTING SERVICES

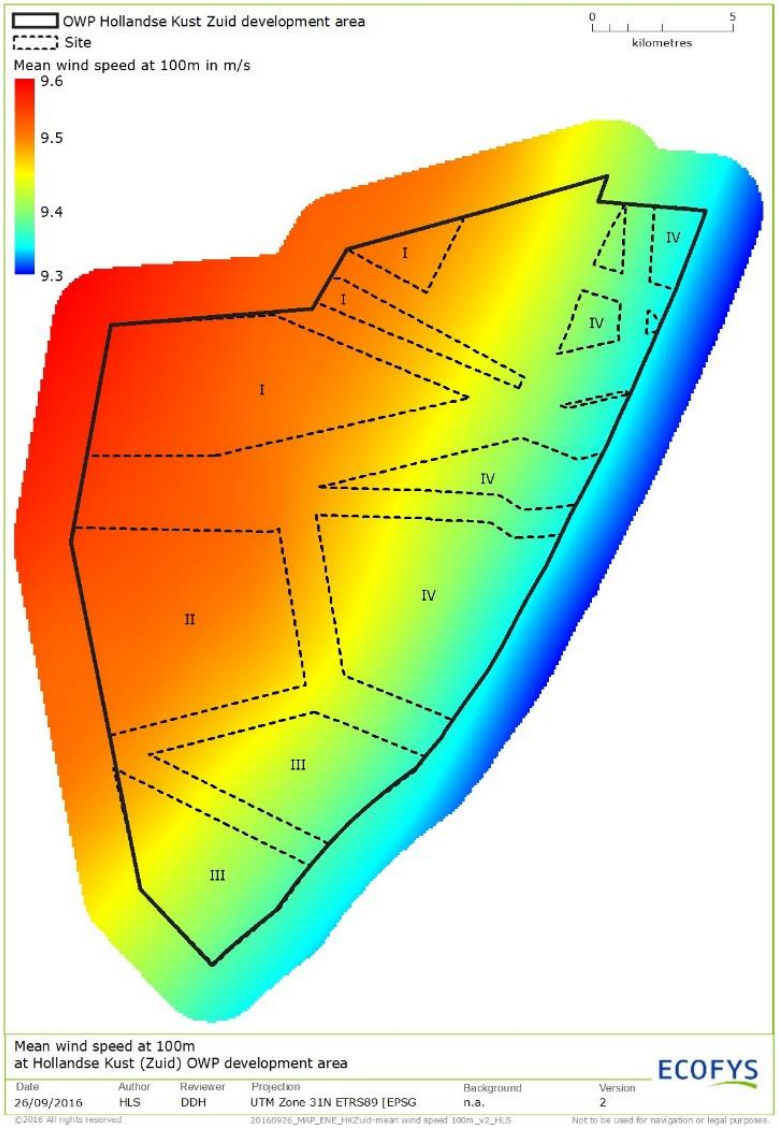


Hollandse Kust (zuid)
Wind resource assessment

17 January 2017

Anthony Crockford

Overview



- Introduction
- Wind measurements
- Mesoscale model
- Calculation of wind climate
- Comparisons
- Conclusions

Introduction

Ecofys WTTS

Ecofys WTTS provides high quality wind measurement services, wind resource & yield prediction assessments and operates remore sensing devices on behalf of its clients, based on its 15-year experience.

Since its foundation in 2010, Ecofys WTTS is also the operator of the largest site for wind turbine prototyping testing and certification in Europe, located in Lelystad in the Netherlands.

Ecofys WTTS is a subsidiary of Ecofys, a consultancy company with an international track record of 30 years in the wind energy sector.

Navigant

Ecofys has recently (November 7, 2016) been acquired by Navigant Consulting, Inc. (NYSE: NCI); , a specialized, global professional services firm, with a leading Energy Practice. The firm is headquartered in Chicago, United States, with more than 5,000 employees worldwide.

Introduction

Goals of the study

- RVO commissioned this preliminary independent wind resource assessment for the Hollandse Kust (zuid) Wind Farm Zone and its four sites

- The scope of this study is clearly defined by RVO:

  This **Ecofys WTTS study describes the mean wind climate at 100 m**. The wind shear from OWEZ is also applied to calculate the mean wind speeds at other heights. This information is intended for wind farm modelling, yield assessments and business case calculations for offshore wind farms to be developed in the Hollandse Kust (zuid) wind farm area.

Introduction

Methodology

1. Selection of highest-quality wind measurements

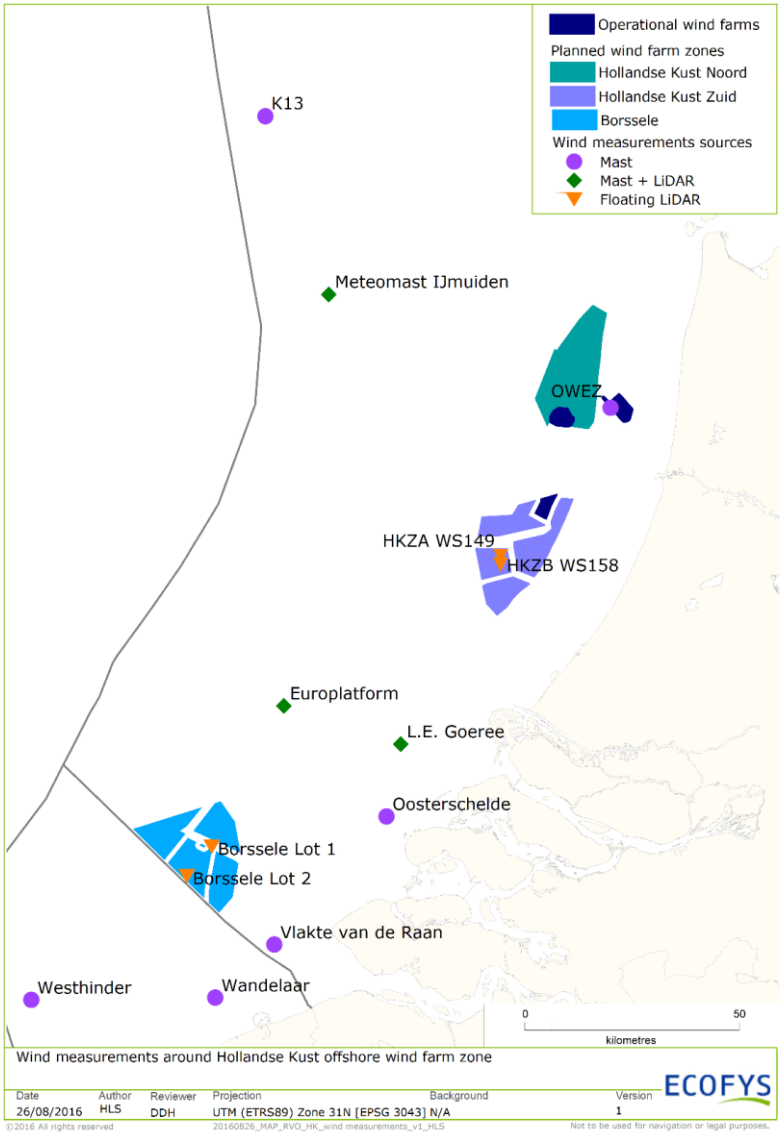
2. Selection and validation of mesoscale model

3. Calculation of on-site wind climate
   a) Vertical extrapolation
   b) Long-term correction
   c) Horizontal extrapolation

4. Comparison to other site studies

5. Validation of key results and trends

Wind measurements



Primary wind measurements

> 116 m OWEZ met mast

Secondary met masts

> 92 m Meteomast IJmuiden
> 29 m Europlatform
> 38 m Lichteiland Goeree

Secondary LiDARs

> HKZB floating LiDAR
> Borssele Lot-1 floating LiDAR
> Meteomast IJmuiden
> Europlatform
> Lichteiland Goeree

Wind measurements

	OWEZ
Measurement type	116 m offshore mast
Location [Latitude, longitude: ETRS89]	52°36'22.89" N / 4°23'22.68" E
Distance from coast	15 km
Measurement period	07/2005 - 06/2006 (1.0 year)
Measurement interval	10-minute
Documentation	Mast design and data manual [6] Data filtering manual [7]
Traceable instruments	MEASNET calibrated anemometers; other instruments also calibrated; regular maintenance by Mierij Meteo
Availability of valid data	85.7% at 116 m and 95.7% at 70 m

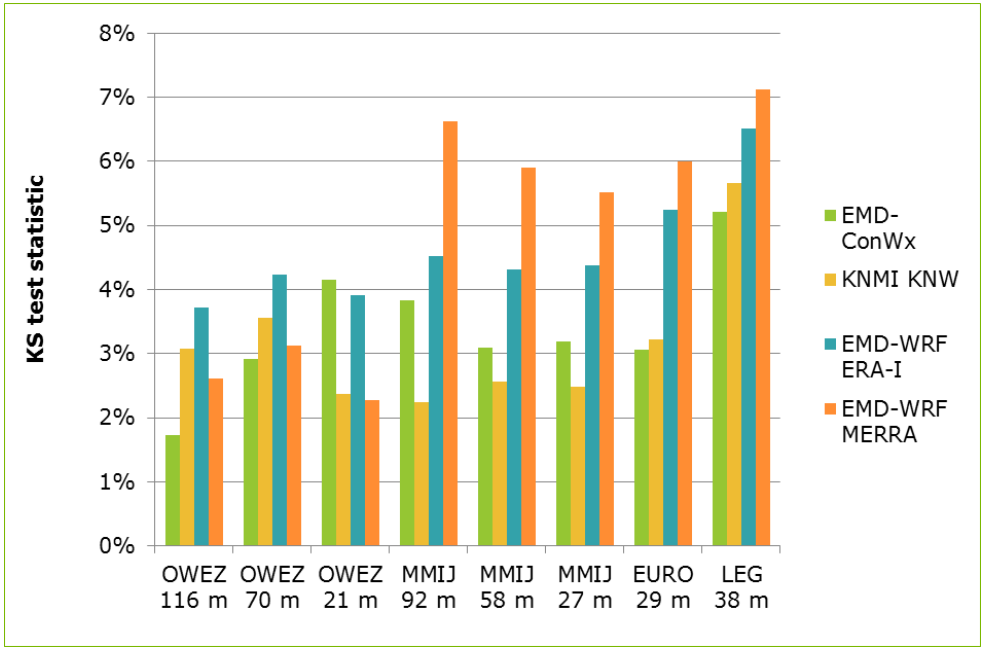
Source: Noordzeewind

Mesoscale model

> Validated 4 mesoscale models:

1. EMD-ConWx
2. KNMI KNW
3. EMD-WRF (ERA-I)
4. EMD-WRF (MERRA)

> Against 4 met masts
(total 8 measurement heights)



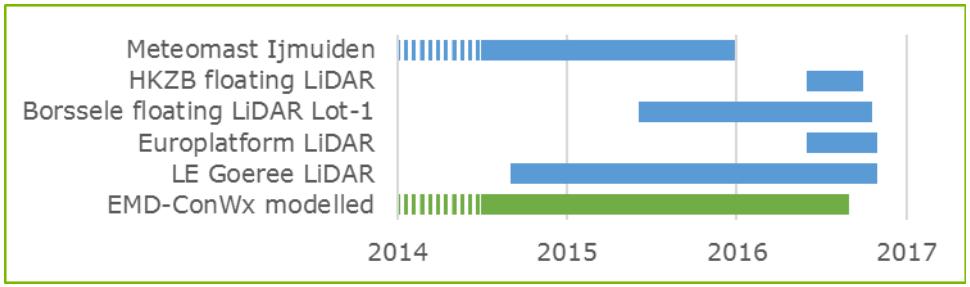
Conclusions:

> EMD-ConWx and KNMI KNW represent reasonably well the wind speeds at the four measurement locations

> EMD-ConWx selected, due to longer available dataset (up to Aug 2016)

Mesoscale model

> EMD-ConWx model further validated by comparing the horizontal gradient between different locations, based on concurrent measurements at the same measurement height



Conclusion:

> The comparisons show differences within ±1% between the measured and modelled horizontal gradient, with a maximum absolute difference of 1.7%.

Calculation of wind climate

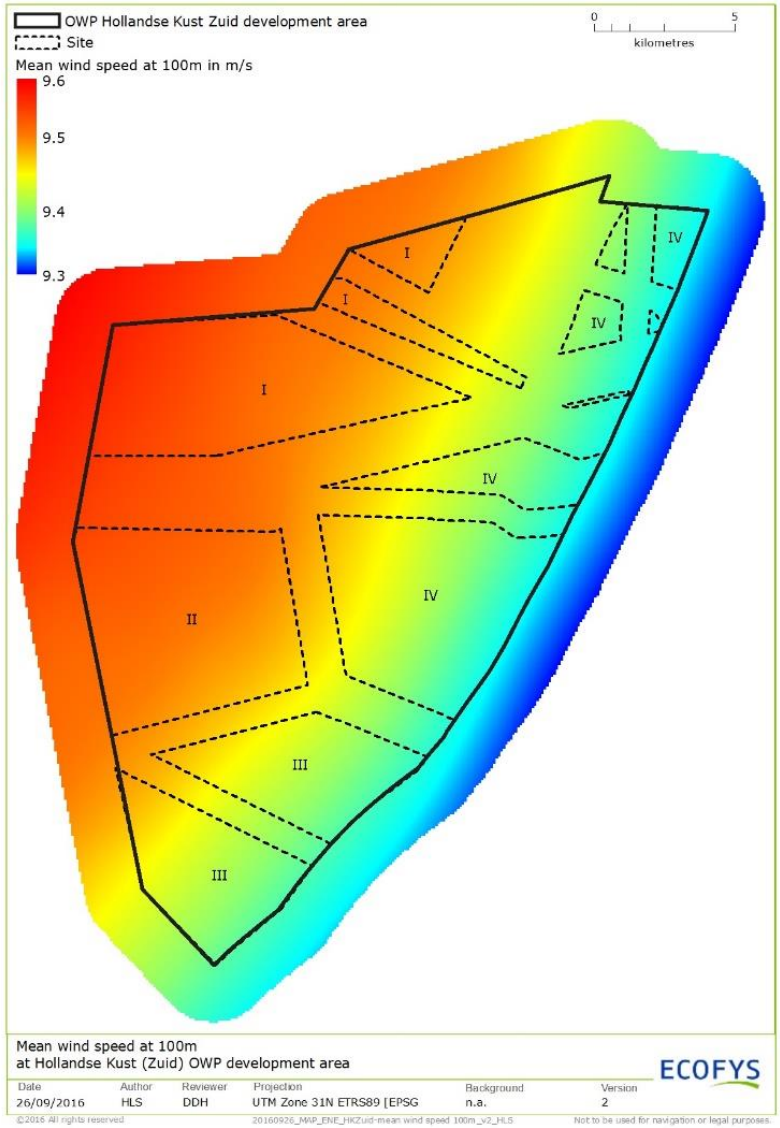
> Primary source: 1 year of OWEZ wind measurements at 70 m

1. Extrapolation from measurement height to 100 m, based on average measured shear profile

2. Long-term correction and extension from 1 years of measurements to a 16-year period (2000-2016), based on MCP with EMD-ConWx model data

3. Extrapolation from the measurement location to the Hollandse Kust (zuid) zone, based on horizontal gradient in EMD-ConWx model data

Calculation of wind climate



9.5 ± 0.5 m/s at 100 m

at zone centre

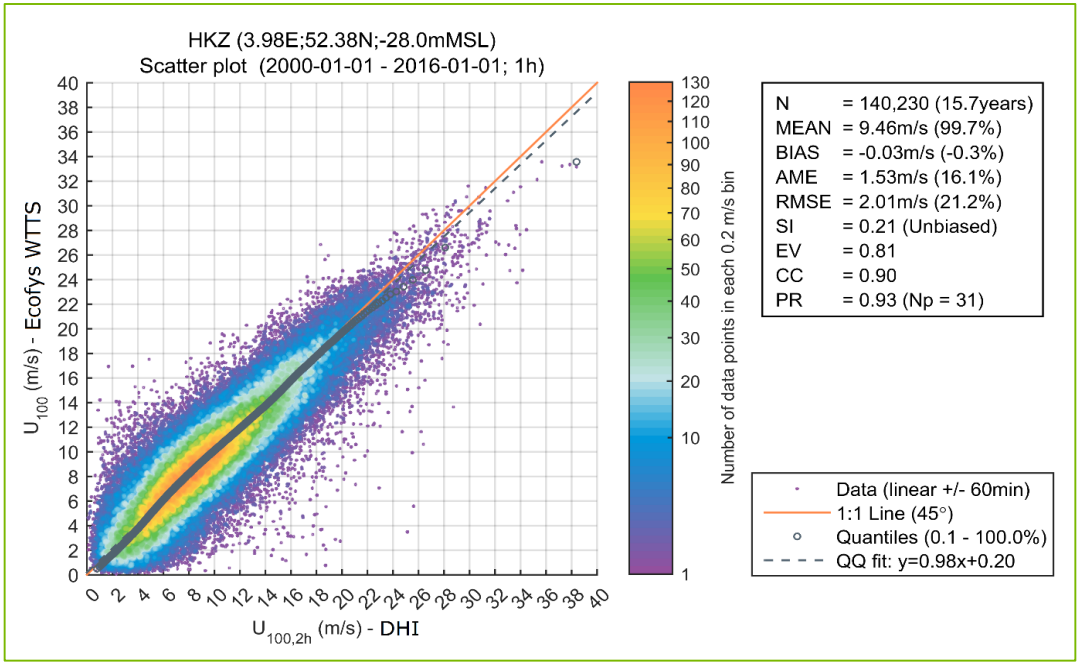
Uncertainty description	HKZ
- Instrument accuracy	2.0%
- Instrument mounting	2.5%
- Data quality	0.5%
- Data processing	1.0%
- Vertical extrapolation	0.3%
- Horizontal extrapolation	1.0%
- Long term representation	1.5%
- MCP	0.7%
- Mesoscale model distribution	3.1%
Total	**5.0%**

Comparison

- RVO has also commissioned DHI to perform metocean desk study for the Hollandse Kust (zuid) offshore wind farm zone, with a different scope:

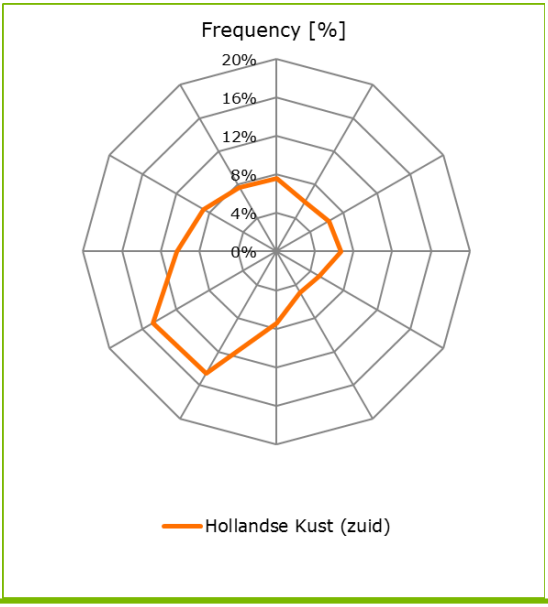
  The DHI report and metocean database describe the **normal and extreme wind conditions**. This includes turbulence intensity, extreme wind speeds and wind shear. This information is intended for wind farm design

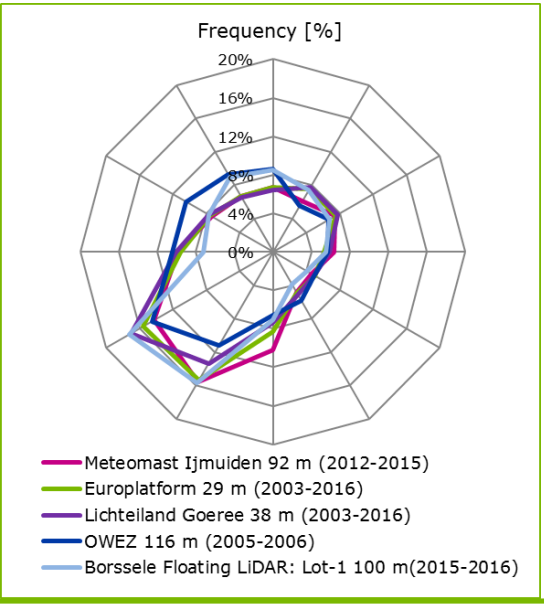
- Both reports found a **mean wind speed at 100 m of 9.5 m/s**, with excellent correlation between the time series and similar trends. The use of results from both studies is dictated by the separate scope of the two reports



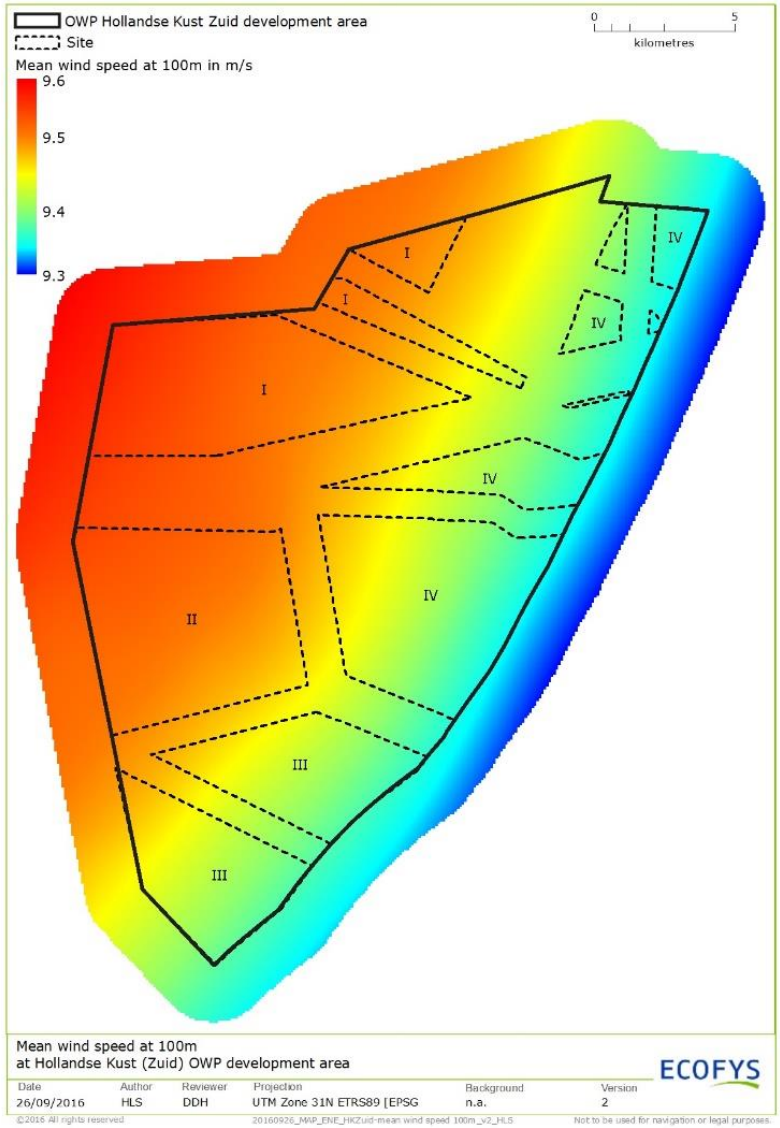
Validation of key results

- Detailed analyses of the calculated wind climate were carried out across the modelled heights, showing good comparisons of the analysed trends with measurements at other offshore sites in the Dutch North Sea
  - Mean wind speed
  - Wind shear
  - Diurnal variation
  - Monthly variation
  - Inter-annual variation
  - Frequency distribution
  - Weibull parameters
  - Wind rose
  - Temp., pres., humid.
  - Air density
  - Wake effects
- See report for details





Conclusions



9.5 ± 0.5 m/s at 100 m

at zone centre

- Report published online
  - Extensively reviwed by RVO, Blix, ECN & DHI
  - Certified by DNV GL
- Other deliverables available online
  - Calculated wind speed & direction time series at zone centre & 4 site centres
  - GIS layer

- Further questions?

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