



## Offshore CREYAP Part 2 – preliminary results

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*Publication date:*  
2015

*Document Version*  
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*  
Mortensen, N. G., & Nielsen, M. (2015). Offshore CREYAP Part 2 – preliminary results. Sound/Visual production (digital), European Wind Energy Association (EWEA).

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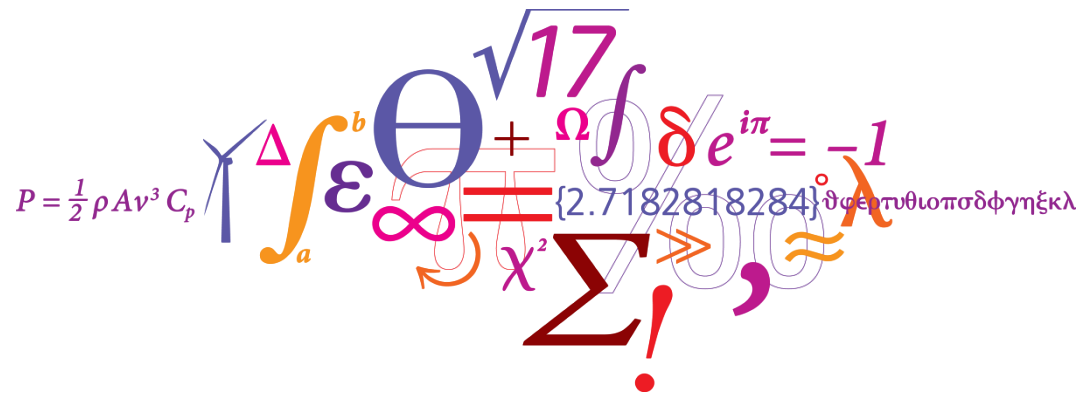
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## Offshore CREYAP Part 2 – preliminary results

Niels G Mortensen & Morten Nielsen



$P = \frac{1}{2} \rho A v^3 C_p$

$\int_a^b \varepsilon \Theta + \Omega \int \delta e^{i\pi} = -1$

$\sqrt{17}$

$\infty$

$\chi^2$

$\Sigma!$

$\approx$

$\lambda$

$\{2.7182818284\}$  δ φ ε ρ τ υ θ ι ο π σ δ φ γ η ξ κ λ

## Acknowledgements

- DONG Energy Wind Power A/S for Barrow data
- Dong Energy, Iberdrola and Crown Estate for Shell Flats wind data and other information.
- 22 teams from 8 countries; thanks for making the comparison and presentation possible!
- EWEA team for arranging the 2015 Offshore CREYAP Part 2, thanks to Tim Robinson et al.

# Comparison of Resource and Energy Yield Assessment Procedures

## EWEA CREYAP concept

- Industry benchmark
- In-house training and R&D
- Identification of R&D issues

## Three issues today

- Long-term adjustment
- Wake modelling
- Modelled vs observed yields

## CREYAP history

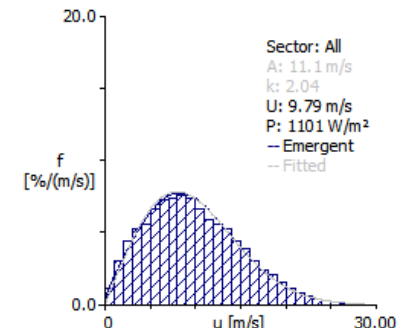
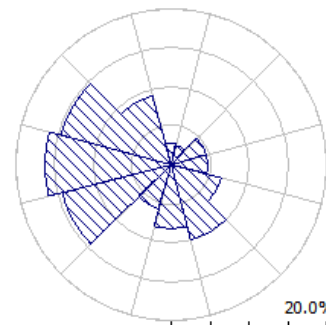
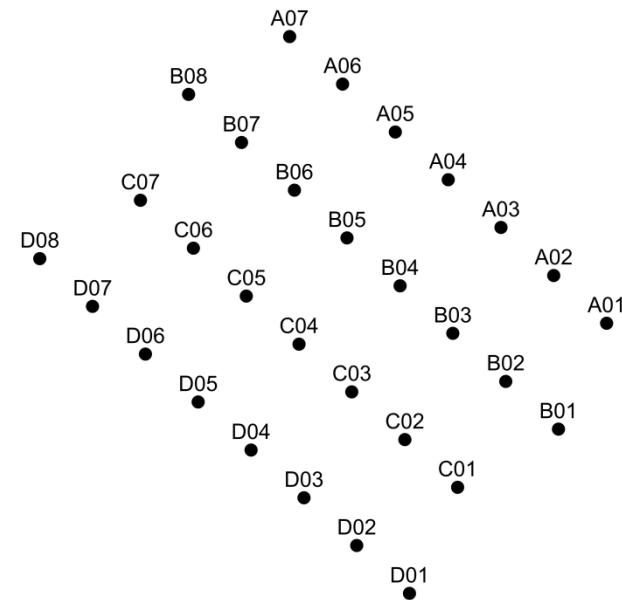
- Onshore Part 1, Bruxelles 2011
  - Scotland, 28 MW, 37 teams
- Onshore Part 2, Dublin 2013
  - Scotland, 29 MW, 60 teams
- Offshore Part 1, Frankfurt 2013
  - Gwynt y Môr, 576 MW, 37 teams
- Offshore Part 2, Copenhagen 2015
  - Barrow, 90 MW, 22 teams

## Summary

- 156 submissions from 27 countries

# Barrow Offshore Wind Farm

- 30 V90 wind turbines (90 MW)
  - Rated power: 3.0 MW
  - Hub height: 75 m MSL
  - Rotor diameter: 90 m
  - 4 staggered rows,  $5.5 \times 8.5 D$
  - Air density:  $1.24 \text{ kg m}^{-3}$
  - SCADA: 2008-02 to 2009-01
  
- Site meteorological masts
  - One 80-m and 50-m mast
  - Wind speed and direction
  - Temperature and pressure
  - Data: 2011-07 to 2012-08
  
- Auxiliary data
  - MERRA reanalysis 1998-2013
  - Topographical data by choice



## Offshore CREYAP II in two parts

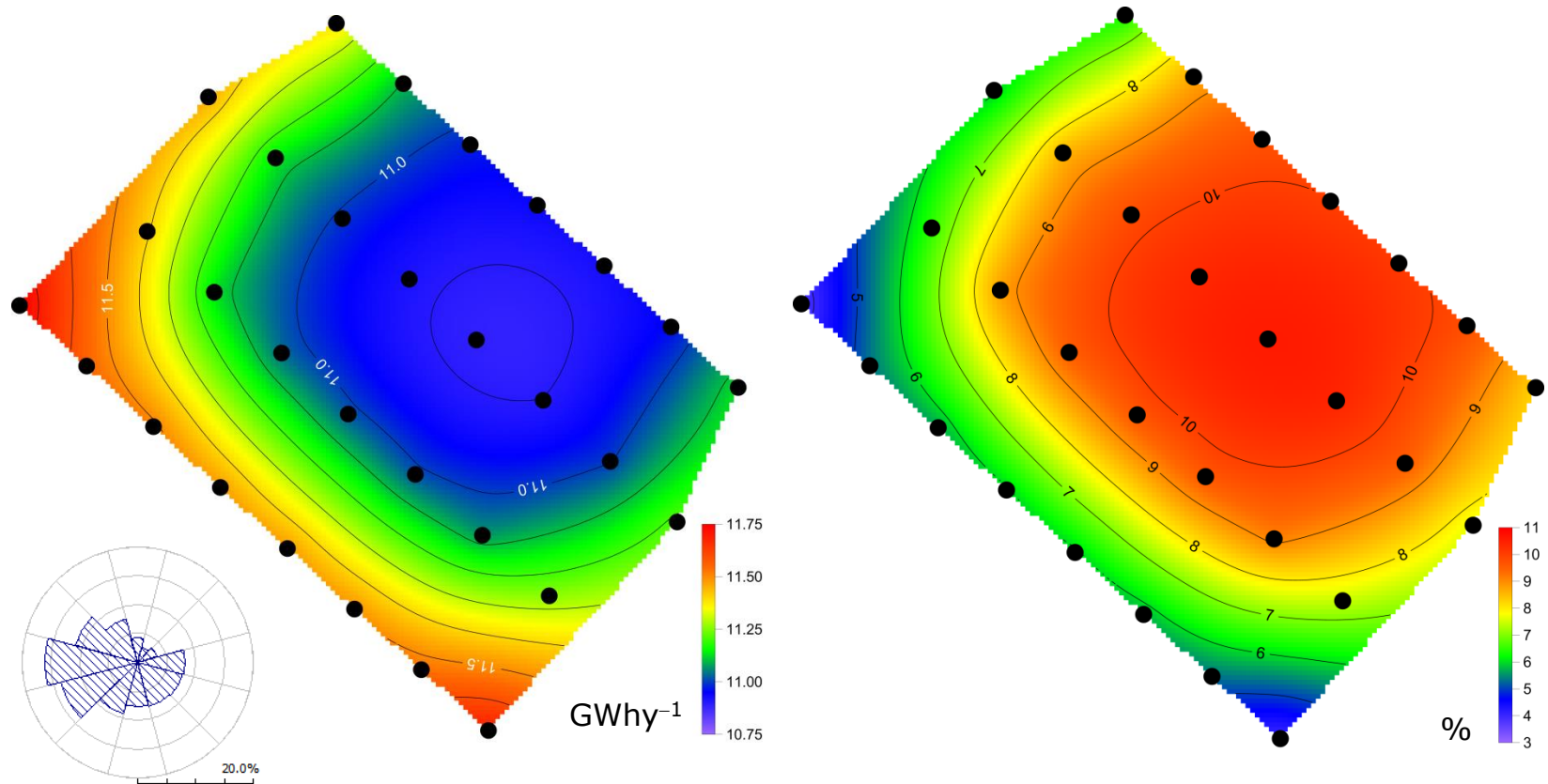
### Long-term comparisons (10 y)

- Observed wind climate
- Observed turbulence
- Long-term adjustment
- Reference yield
- Gross yield
- Wake effects
- Net yield P50
- Uncertainty estimates
- Net yield P90
- Per-turbine results
  
- Team characteristics
- Methodology information

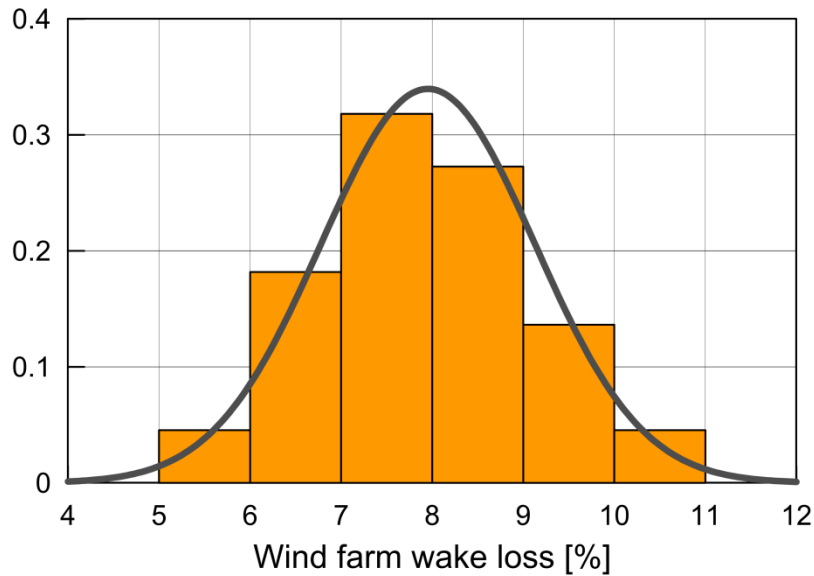
### Predicted vs observed yields (1 y)

- Reference yield
- Potential yield
- Array efficiency
- Net P50 (losses given)
  
- SCADA calculation
  - Sum of WTG power readings
  - Curtailment correction
  - Availability correction to 100%
  - Two independent calculations
  - Checked with sub-station meter

# Estimated turbine mean yield and wake effect (10 y)



# Predicted wind farm wake losses



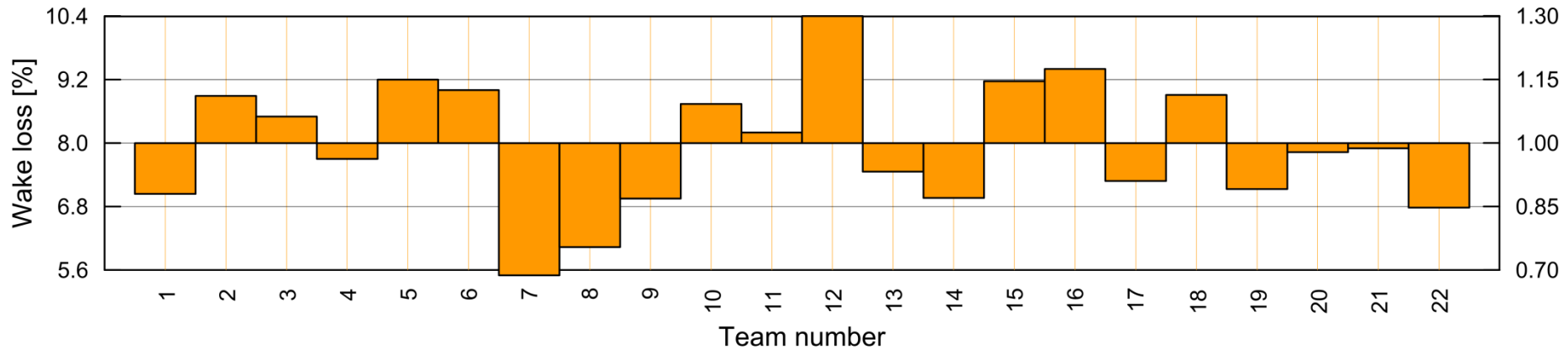
Data points used = 21 (of 22)

Mean wake loss = 8.0%

Standard deviation = 1.2%

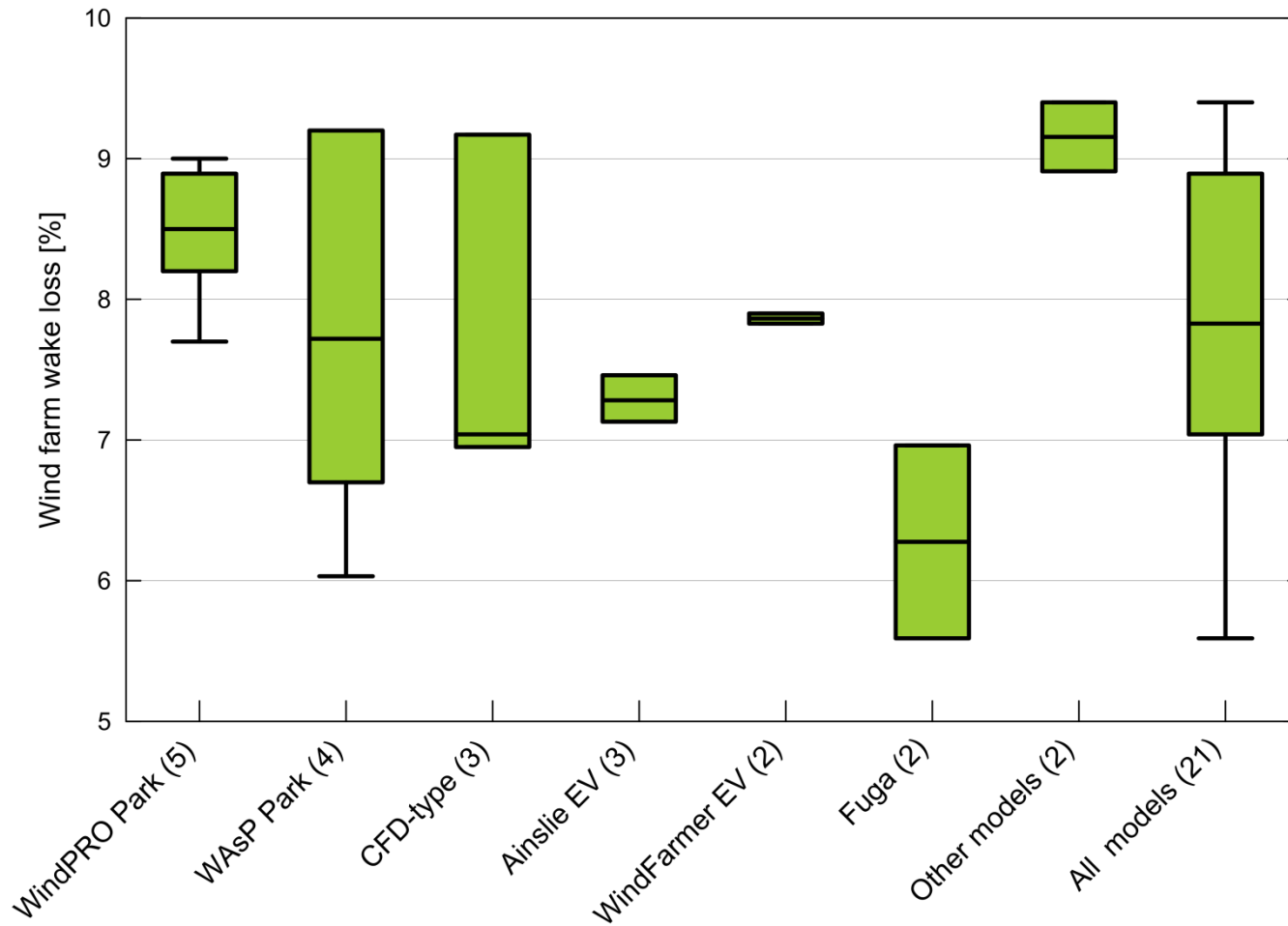
Coefficient of variation = 15%

Range = 5.5 to 10.4%

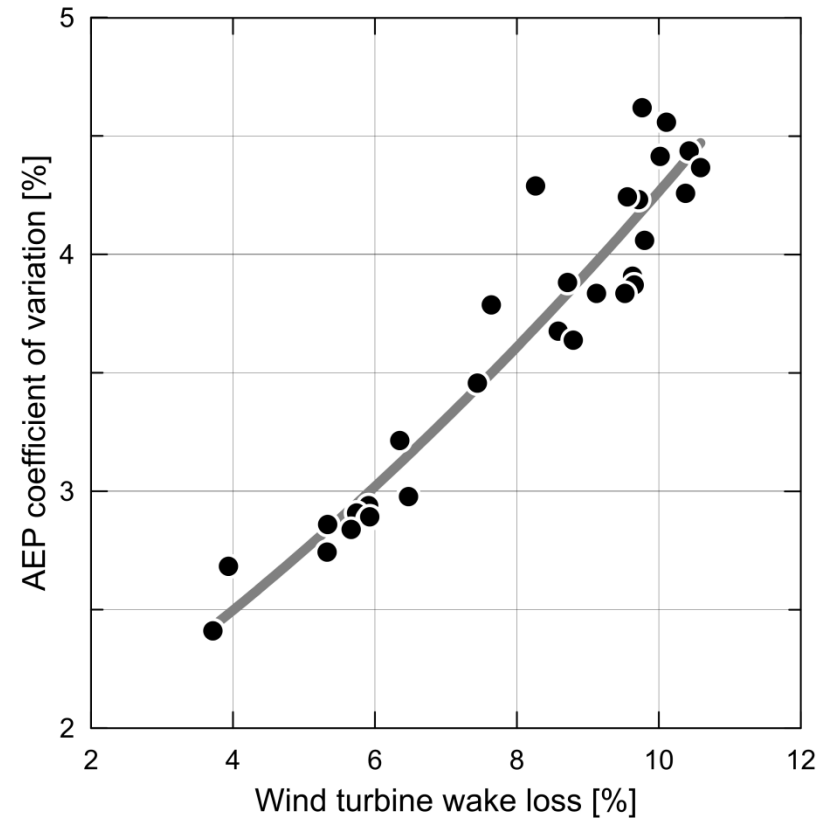
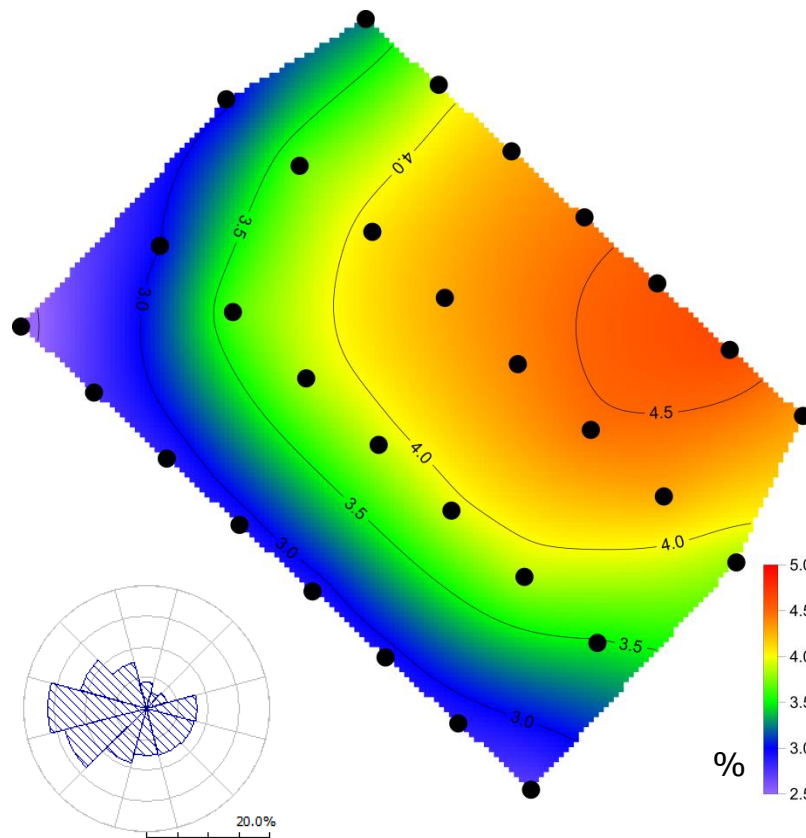




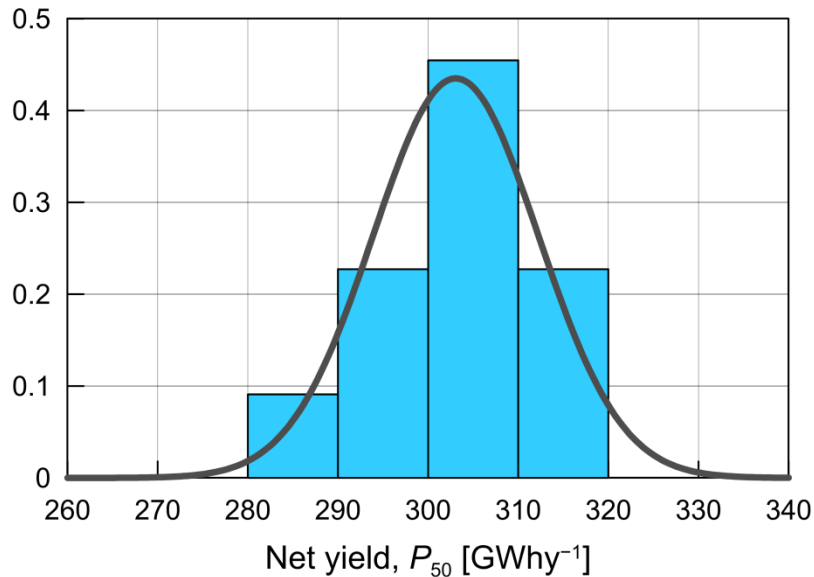
# Comparison of wake models



# Estimated turbine yields – coefficient of variation



# Net energy yield of wind farm, $P_{50}$



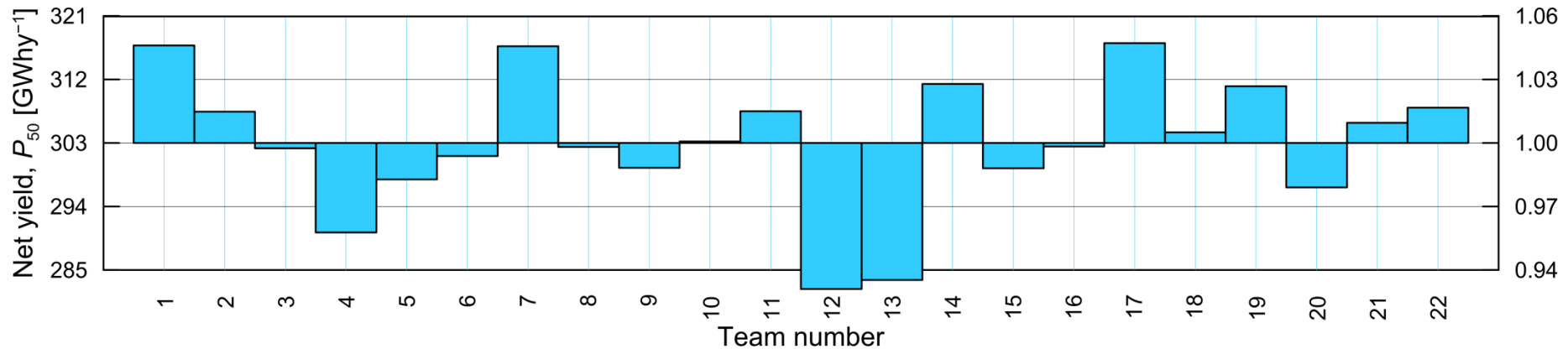
Data points used = 22 (of 22)

Mean net yield = 303 GWhy<sup>-1</sup>

Standard deviation = 9.4 GWhy<sup>-1</sup>

Coefficient of variation = 3.1%

Range = 282 to 317 GWhy<sup>-1</sup>

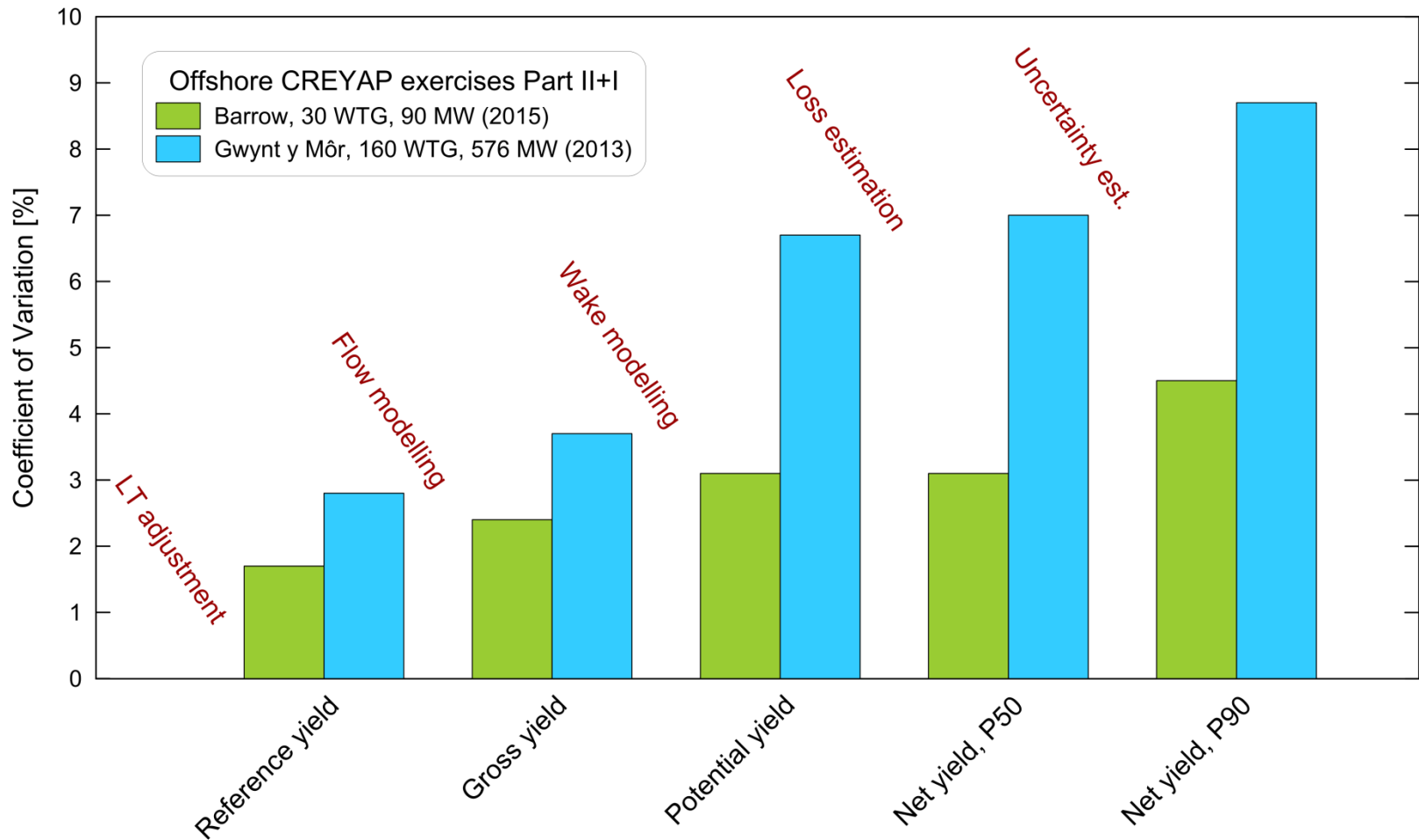


## Wind farm key figures – 10-year estimates

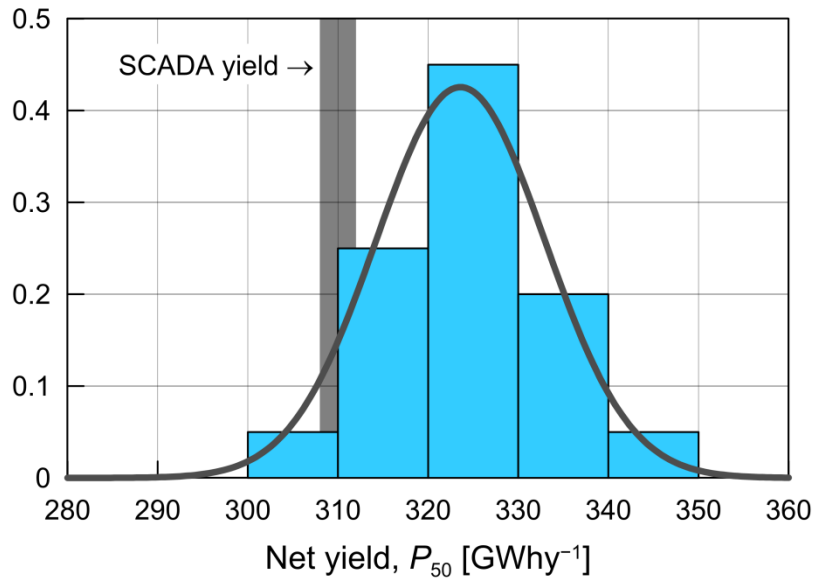
Barrow (10 y)		Mean	$\sigma$	CV*	Min	Max
Gross yield	GWh	366	8.9	2.4	338	377
Wake loss	%	8.0	1.2	15.1	5.5	10.4
Potential yield	GWh	334	10.3	3.1	311	350
Technical losses	%	9.3	0.1	1.0	9.2	9.6
Net yield $P_{50}$	GWh	303	9.4	3.1	282	317
Uncertainty	%	9.7	2.3	23.4	6.1	13.7
Net yield $P_{90}$	GWh	267	12.1	4.4	245	282

\* Coefficient of Variation in per cent.

# Spread for different steps in the prediction process



# Comparison of predicted to observed $P_{50}$



Data points used = 20 (of 22)

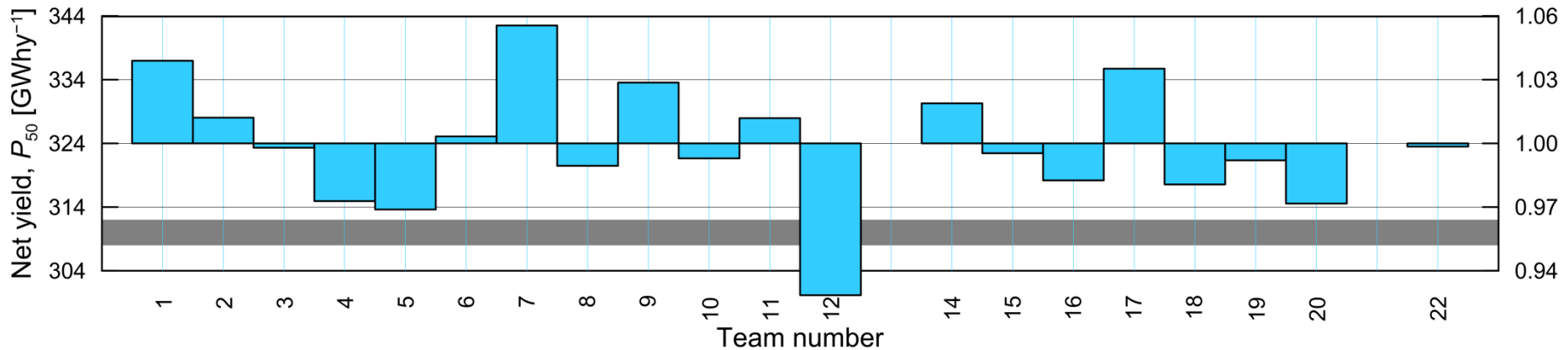
Mean predicted  $P_{50}$  = 324 GWhy<sup>-1</sup>

Standard deviation = 9.6 GWhy<sup>-1</sup>

Coefficient of variation = 3.0%


Range = 300 to 343 GWhy<sup>-1</sup>

Prediction bias = +4%



## Summary and conclusions

- Long-term adjustment (applied twice)
  - Average effect = 5.7%, spread = 1.2%
- Wake modelling
  - Average wind farm wake effect = 8%, spread = 15%
  - Wake modelling spread increases with depth into wind farm
- Modelled vs observed 1-y yields
  - Estimated = 104% of observed, spread = 3%
  - Measured yield has an uncertainty too
- CREYAP results seem to improve over time
  - No or fewer outliers in present study
  - Loss and uncertainty calculations improved
- Outlook for future
  - Comprehensive results at EWEA Resource Assessment (June 2015)
  - High-quality wind farm data in high demand for future studies!

A photograph of an offshore wind farm at sunset. The sky is a gradient of blue and orange, and the sea is dark blue. Several wind turbines are visible, with the largest one in the foreground on the left. The text is overlaid on the right side of the image.

*Thank you for your attention!  
More results to be presented at  
EWEA Resource Assessment in  
Helsinki, 2-3 June 2015*