Cumulative Induction Zone (Global Blockage) Effect

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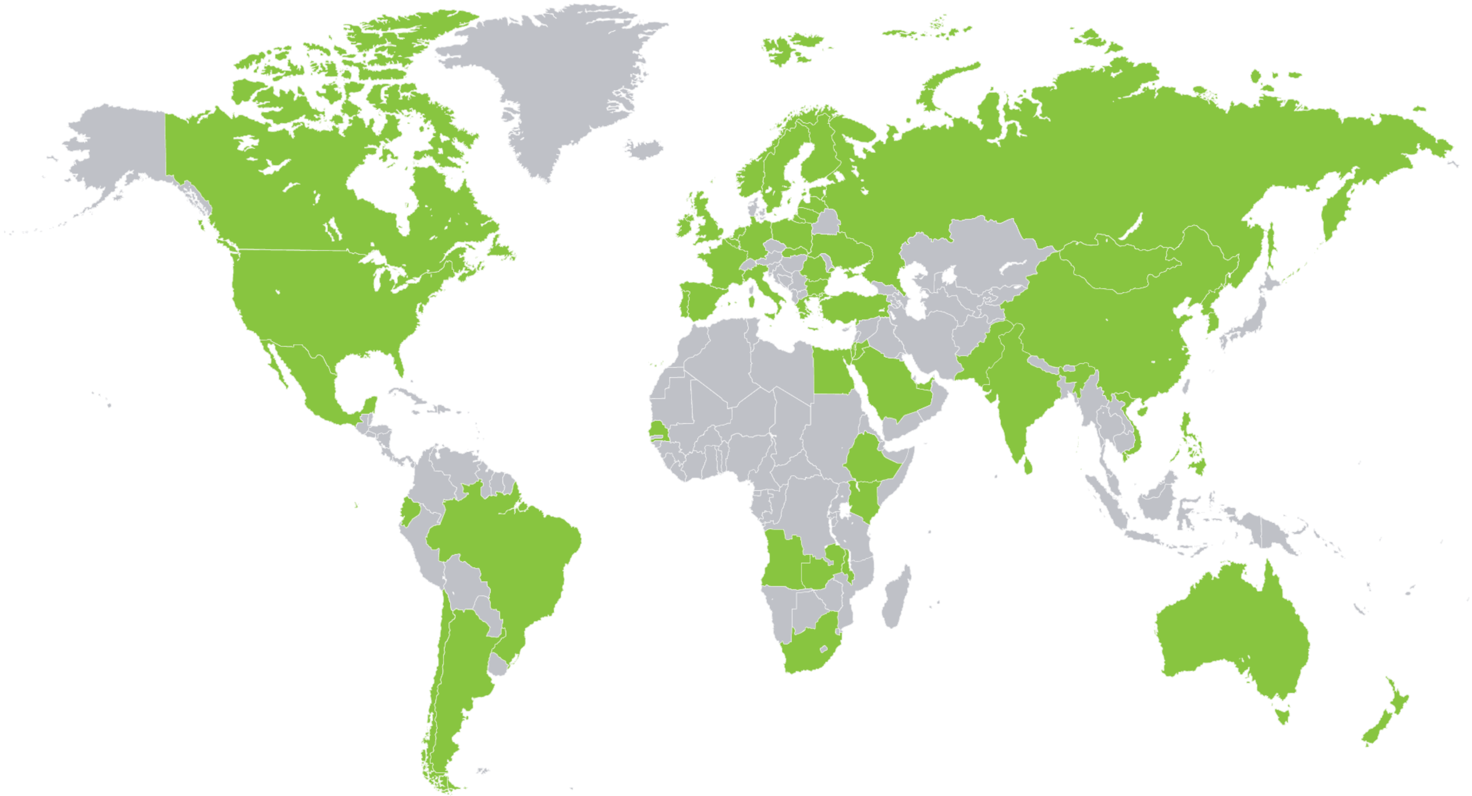
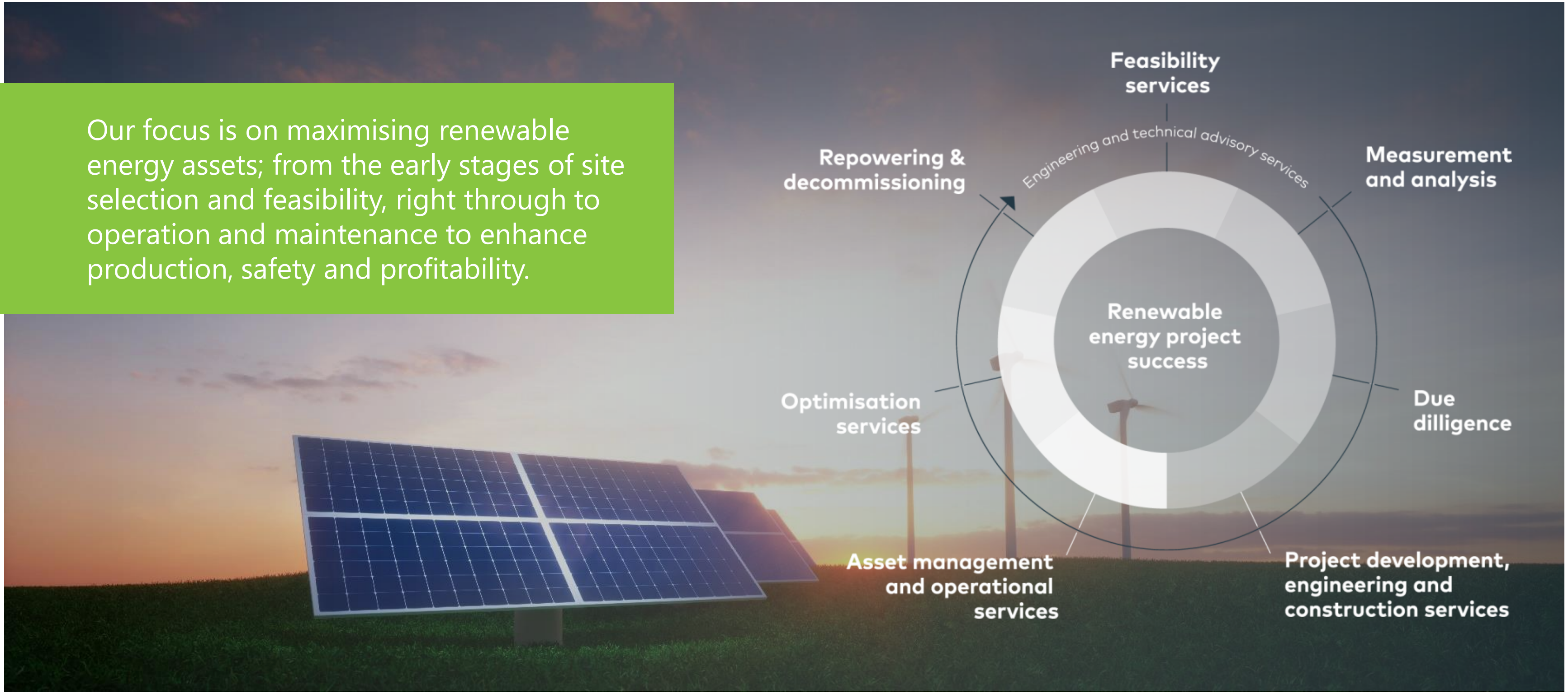
Winterwind, February 2020

Where we are located



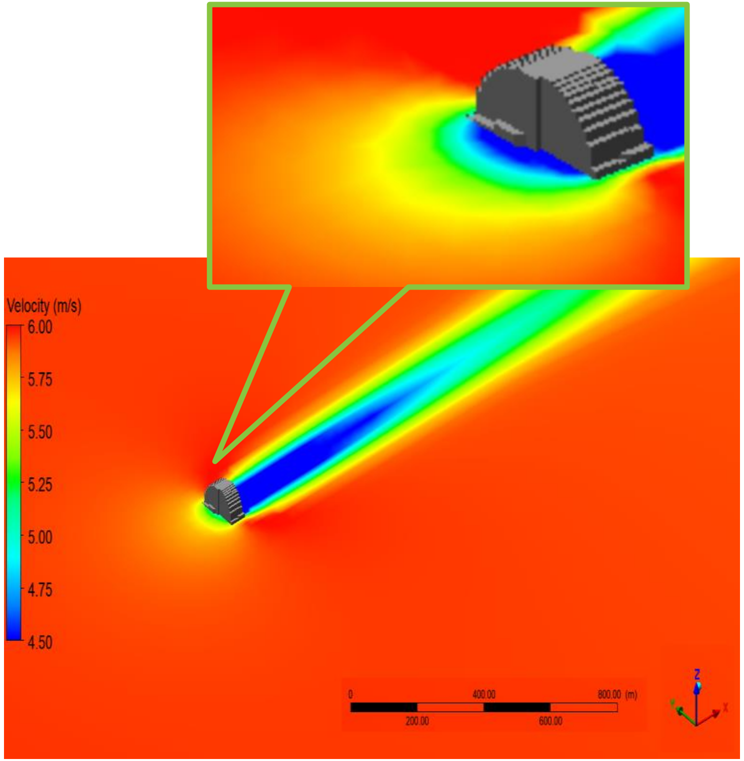
Renewable energy project life cycle

Our focus is on maximising renewable energy assets; from the early stages of site selection and feasibility, right through to operation and maintenance to enhance production, safety and profitability.

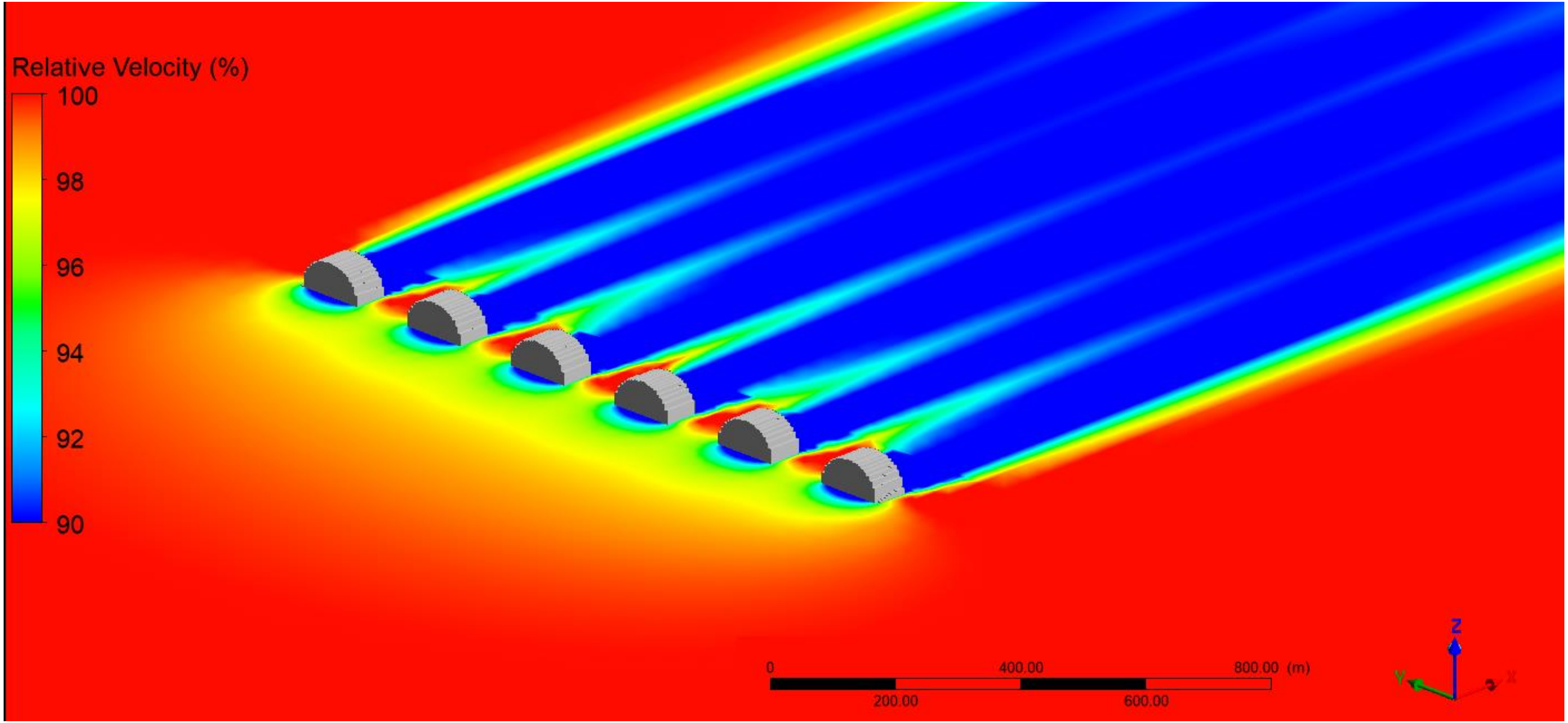


Background

- Single WTG induction zone is a physical manifestation of the WTG structure being placed in the airflow
- Cumulative induction zone (CIZ) refers to interaction between single WTG induction zones (see following slide)
- CIZ has until recently not been considered in energy yield assessment – a source of overprediction
- Wind flow impedance and energy extraction create reduced downstream wind velocity (wake) and reduced upstream/lateral wind velocity (the induction zone)

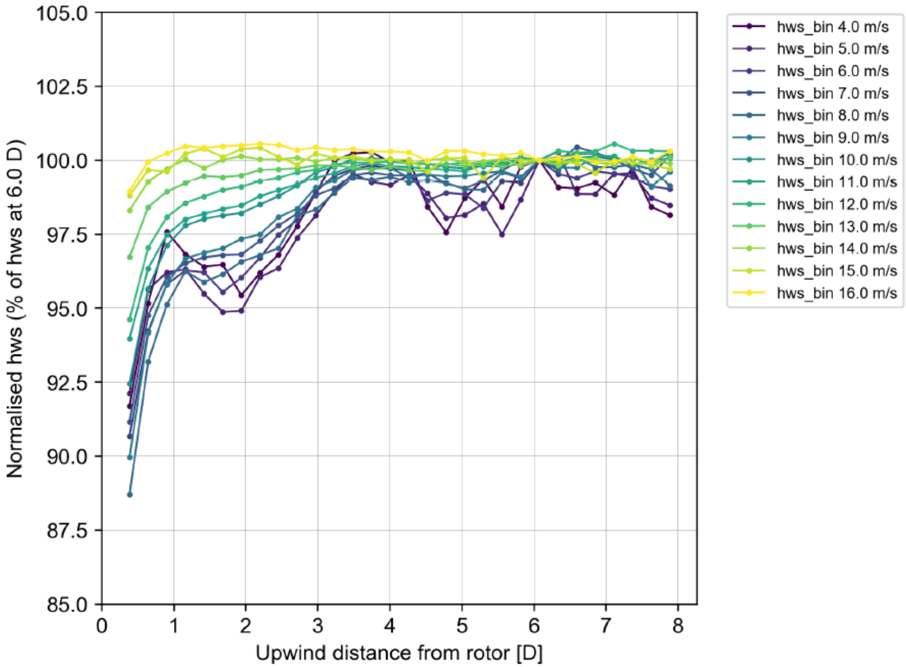


Background – Visualisation of CIZ Effect



Background - Measurements

- Wood first measured and visualised upwind compression zone effects offshore in 2014.
- The long range nacelle-mounted lidar dataset provided measurements of upwind velocity deficits.
- The study was conceived to investigate power performance testing guidelines for upwind freestream wind conditions.



CFD-based Methodology

Ansys CFD Model Development

- Model developed to represent an operational offshore array
- Configured to represent offshore environment

CFD Model Validation

- Upstream velocity deficit profiles modelled and compared to measurements
- Very good level of performance observed

Modelling Multiple Configurations

- Over 100 layout configurations and over 500 flow case simulations
- Sensitivity to model parameters assessed

Parametrised Results

- Parametric wind speed deficit results obtained
- Wind speed deficits converted to energy deficits based on wind distribution and power curve

CIZ Effect Calculation Methodology

Fractional wind velocity reduction for WTG i

$$\delta U^i(d) = \frac{U_s(d) - U_m^i(d)}{U_s(d)}$$

Mean fractional wind velocity reduction (mean of front row WTGs)

$$\Delta U(d) = \left\langle \delta U^i(d) \right\rangle_{i \in FWTG}$$

Reduced wind velocity taken to be

$$\tilde{U}(d) = (1 - \Delta U(d))U(d)$$

Reduced power based on WTG power/thrust

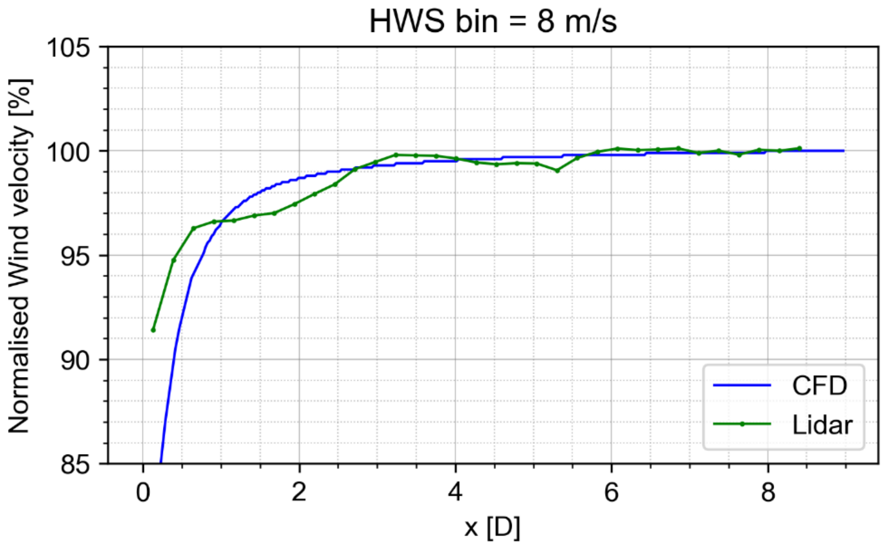
$$\tilde{P}(d) = P(\tilde{U}(d))$$

Fractional energy yield reduction using wind speed distribution

$$\Delta E(d) = \frac{E(U(d)) - \tilde{E}(U(d))}{E(U(d))}$$

CFD Model Validation

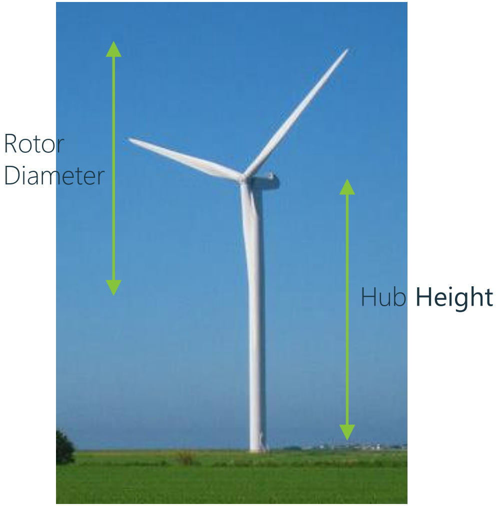
- Measured and modelled upwind velocity profiles compared
- Sensitivity to turbulence model, domain size, surface roughness and atmospheric stability conducted
- Additional validation based on Wood's energy yield assessment database 'bottom up' approach



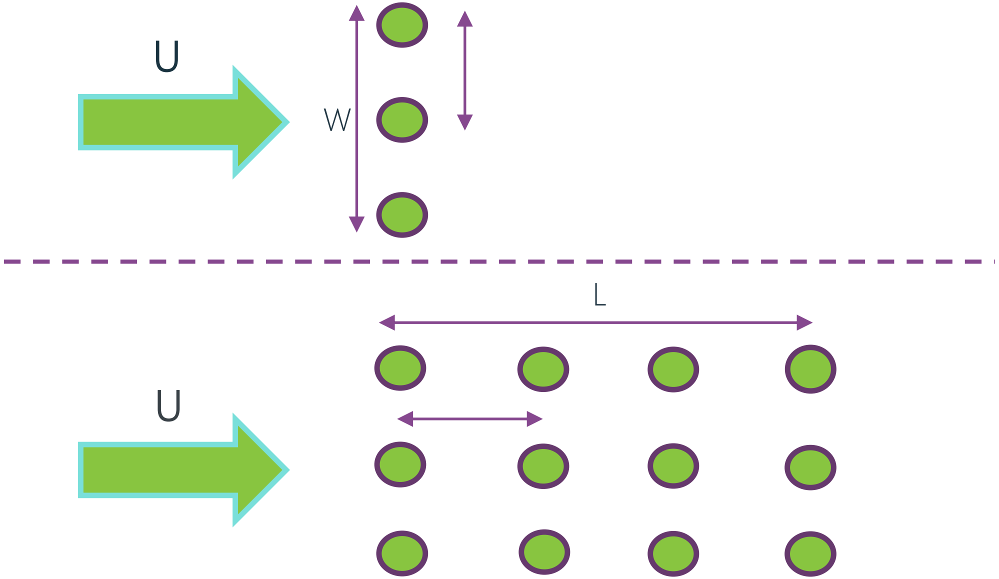
Modelling of Configurations

- Multiple layout configurations modelled to characterise CIZ

Multiple hub height/rotor diameter ratios… 0.6D

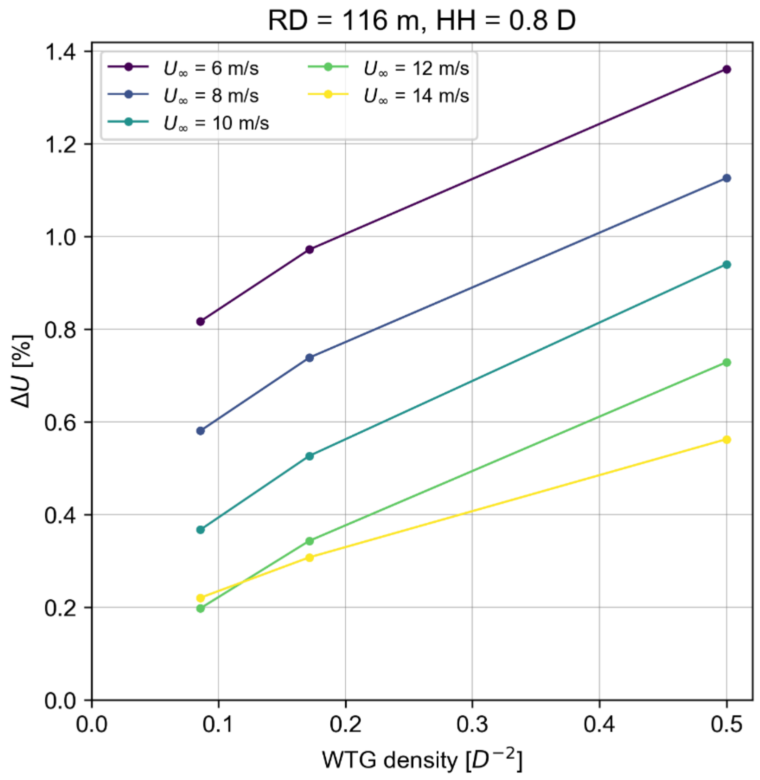


Multiple configurations and spacings (single string to +200 WTG array



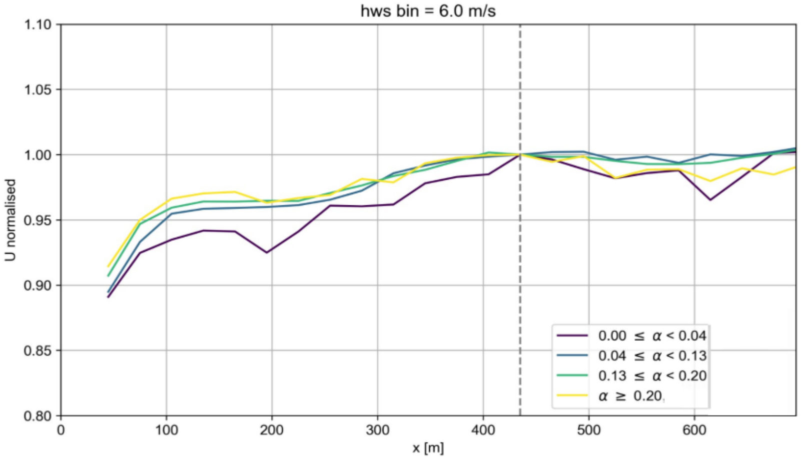
Parametric Results

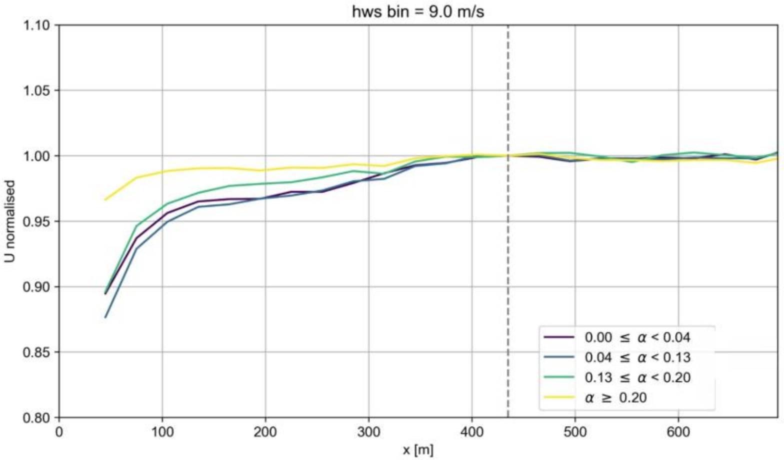
- CIZ shows strong dependence with WTG density
- CIZ shows dependence with hub height/tower height ratio
- CIZ shows dependence on atmospheric stability (modelled), as measurements indicate…



Measured Data – Wind Shear

- Lidar measured velocity deficit binned by wind shear at offshore site
  - Limited but consistent variation observed across all wind speed bins
  - High wind shear associated with stable atmospheric conditions
  - High shear conditions indicate slightly reduced velocity deficit/CIZ effect





CIZ in Energy Yield Assessment

- Wind distribution dependence
  - Sensitivity to wind speed distribution
  - Wind speed to energy gradient (typically higher onshore and at low mean wind speed)
- Example of CIZ effect in terms of wind speed and energy for an onshore Nordic site with different WTG densities

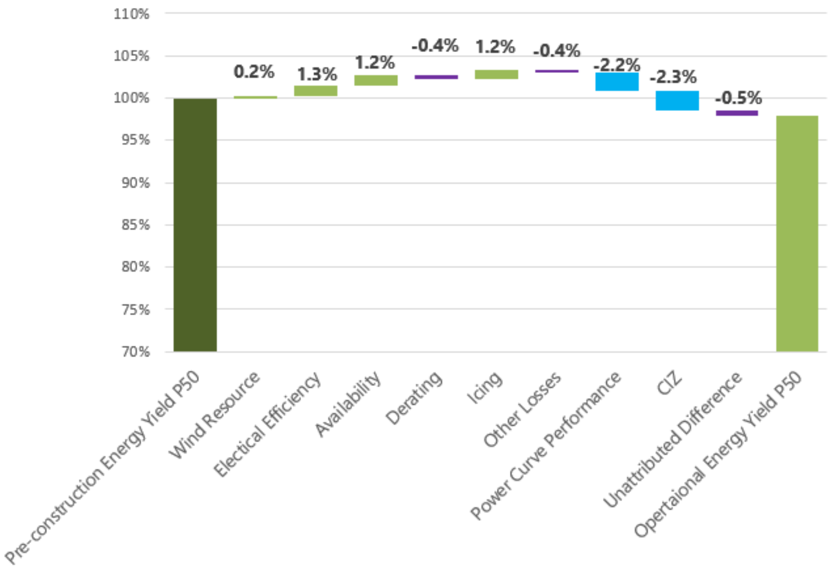
D (m)	ΔU (%)			ΔE (%)		
	4 D × 6 D	7 D × 10 D	10 D × 14 D	4 D × 6 D	7 D × 10 D	10 D × 14 D
116	1.26	0.89	0.76	3.06	2.04	1.64

- CIZ losses in terms of energy are typically in range of 0.5 to 4.0% with lower end of range being relevant offshore

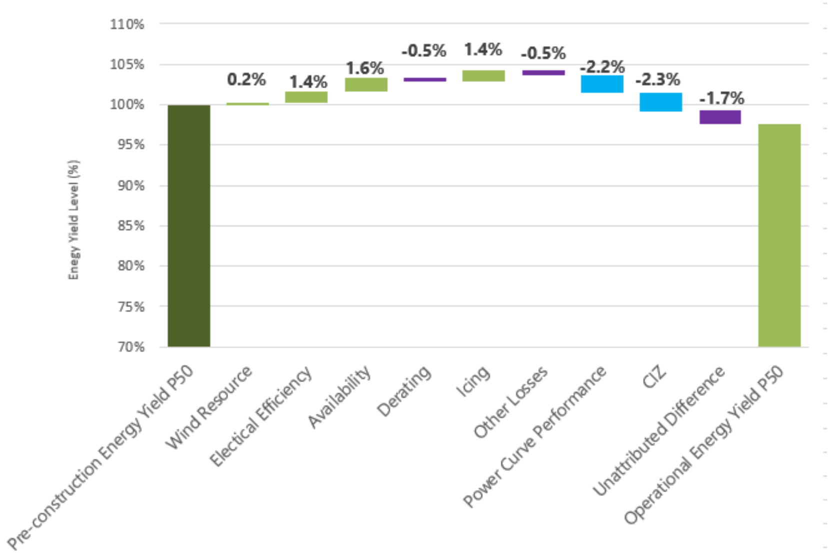
'Bottom Up' Validation

- Reconciliation from two recent Nordic pre-construction/operational assessments

Site 1



Site 2



Wood's CIZ Solutions

- Development of tool for commercial applications
  - Commercial tool development is ongoing
  - Tool used by Wood in energy yield assessment (layout, power and thrust curves, wind distribution, atmospheric stability characteristics)
  - Experience and refinement expected to be incorporated in later releases

- Site specific Ansys CFD wind flow modelling
  - Precise layout considered, irregular arrays
  - Refined parametrisation of CFD model to onsite conditions
  - Array/wind distribution specific flow cases

Limitations and Further Work

- Atmospheric stability
  - Improved understanding and site specific integration
  - Typically lack of suitable onsite measurements
- Terrain complexity
  - Investigation of onshore terrain environments
- Roughness complexity
  - Investigation of onshore roughness environments
- Validation and collaboration
  - Consideration of additional sites in CFD validation
  - Collaboration with site operators in operational phase
  - Measurement campaigns focused on assessing CIZ effect
  - Continued ‘bottom up’ validation from energy yield assessment experience

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