ENERGY

Wind-Farm-Scale blockage

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Question?

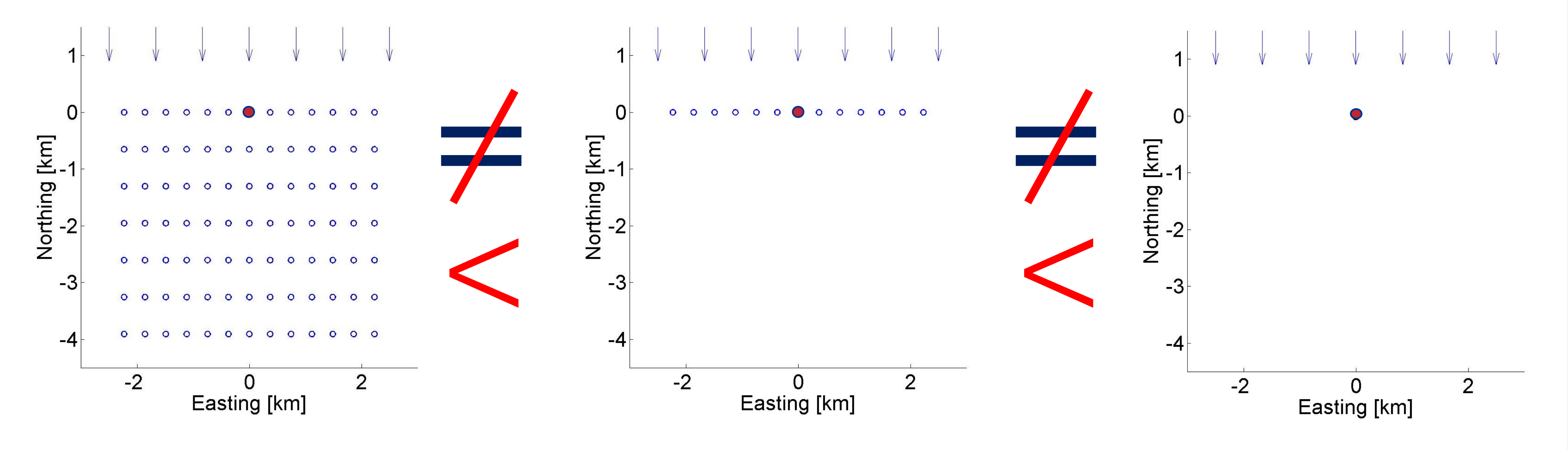
- What is your current approach to quantifying the Wind Farm Blockage Effect?
  - Which type of information is the basis of your current approach?
  - What are the input parameters to the tool?
  - Under which conditions would you not trust your current approach?
  - Has validation with field data been carried out?
- In your view: Which parameters are important (or not important) when quantifying the Wind Farm Blockage Effect *Onshore* in the context of resource assessment? Please give your take on importance (or lack there-of) of at least the following factors:
  - Hub height
  - Stability
  - Turbulence intensity (beyond stability)
  - Terrain
  - Wind rose
  - Layout (e.g. does the blockage differ for two layouts with the same "density of WTGs")

DNV GL’s current approach to wind farm blockage

- Wind farm blockage is considered a fundamental part of DNV GL’s energy assessment methodology since its introduction for Nordic projects in November 2018
- DNV GL also considers it important to consider the impact of blockage effects of power curve measurements (no the focus of this presentation or workshop)

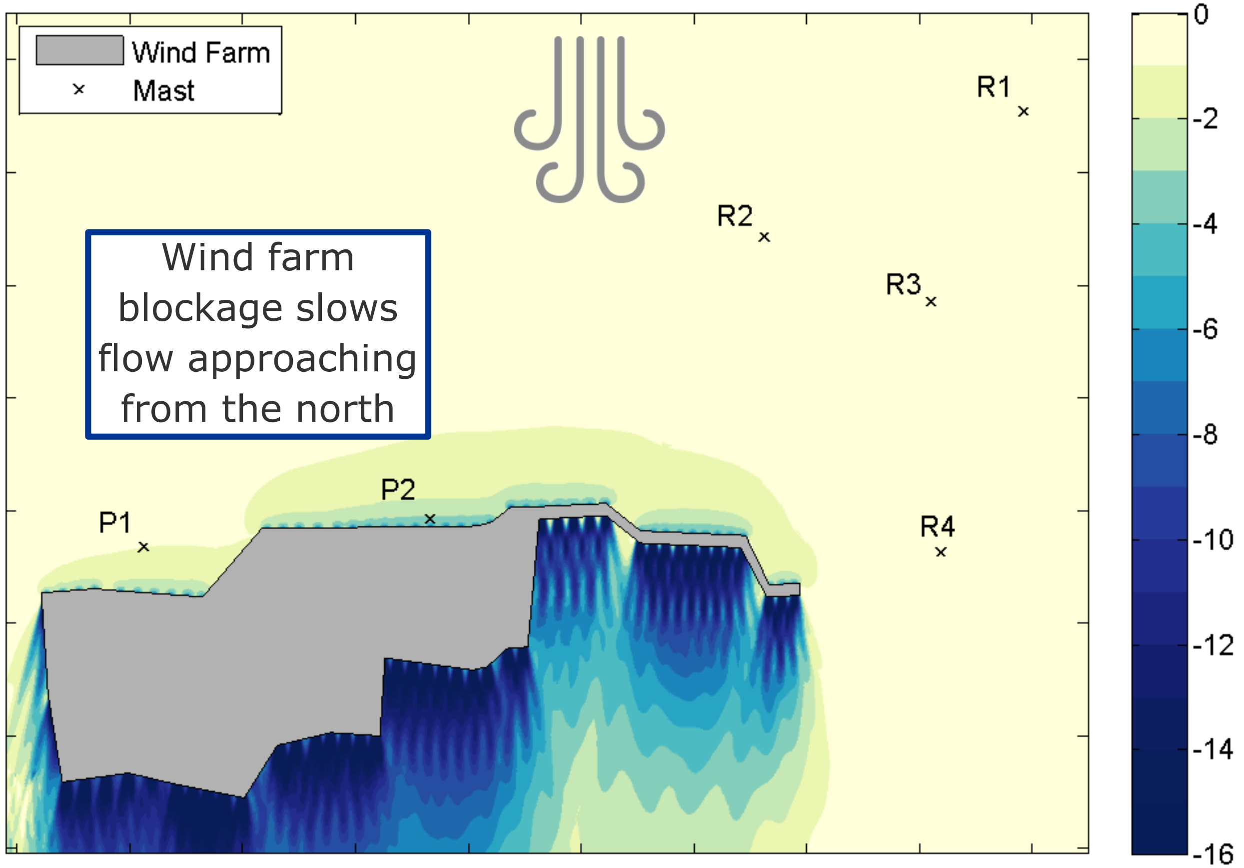
- Traditional approach to modelling turbine interaction is a ‘wakes-only’ approach
  – However: Wind farm exerts drag onto the atmosphere
  – Feedback via pressure field modifies the conditions upstream of the wind farm

Definition of wind farm blockage



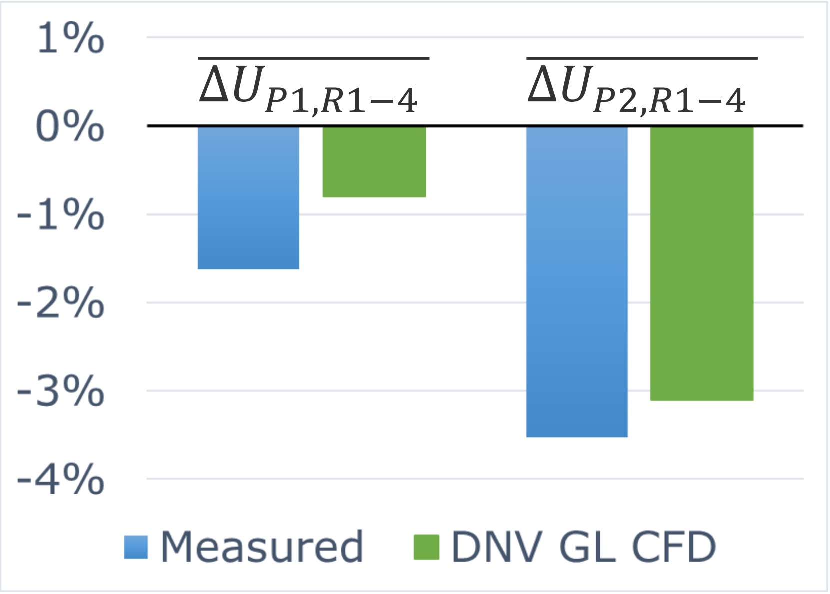
Wind farm scale blockage - difference in power between a turbine operating in isolation when compared to power produced by the same turbine in an array.
This loss is neglected by 'wakes-only' models

Evidence of wind farm blockage



Colours = % change in hub-height wind speed relative to freestream
Distance between tick marks on axes is 2 km

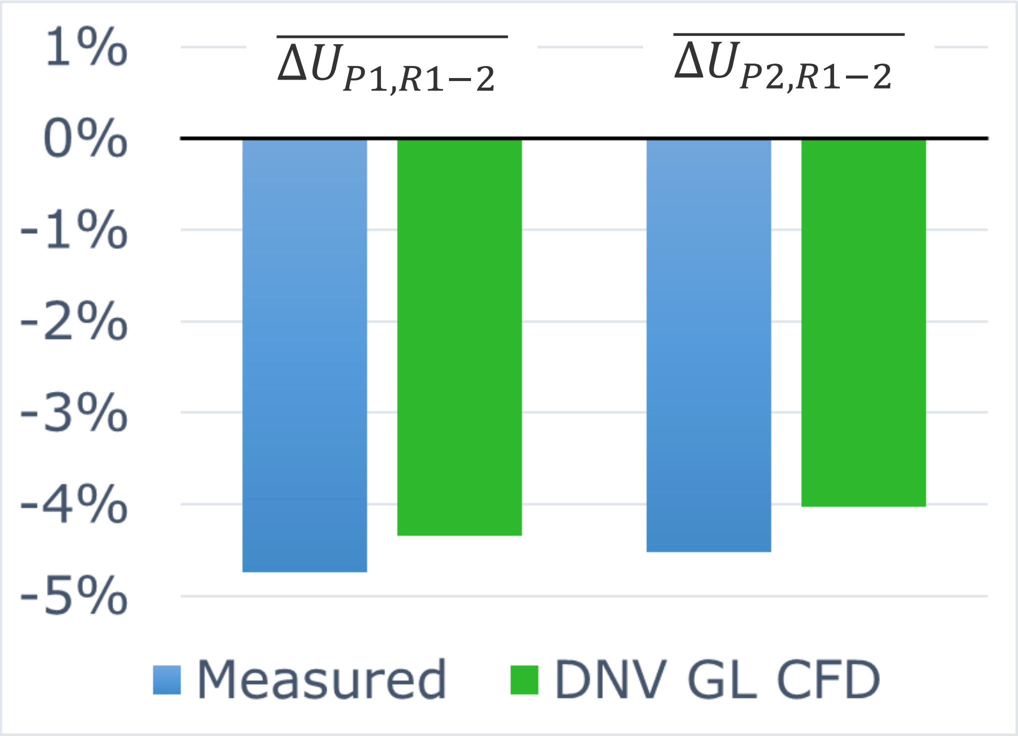
Change in wind speed after commercial operation date (COD) at perimeter mast (P) relative to reference masts (R)



Blockage effects cause upstream wind speed reductions that are more pronounced and far-reaching than commonly assumed in EPAs

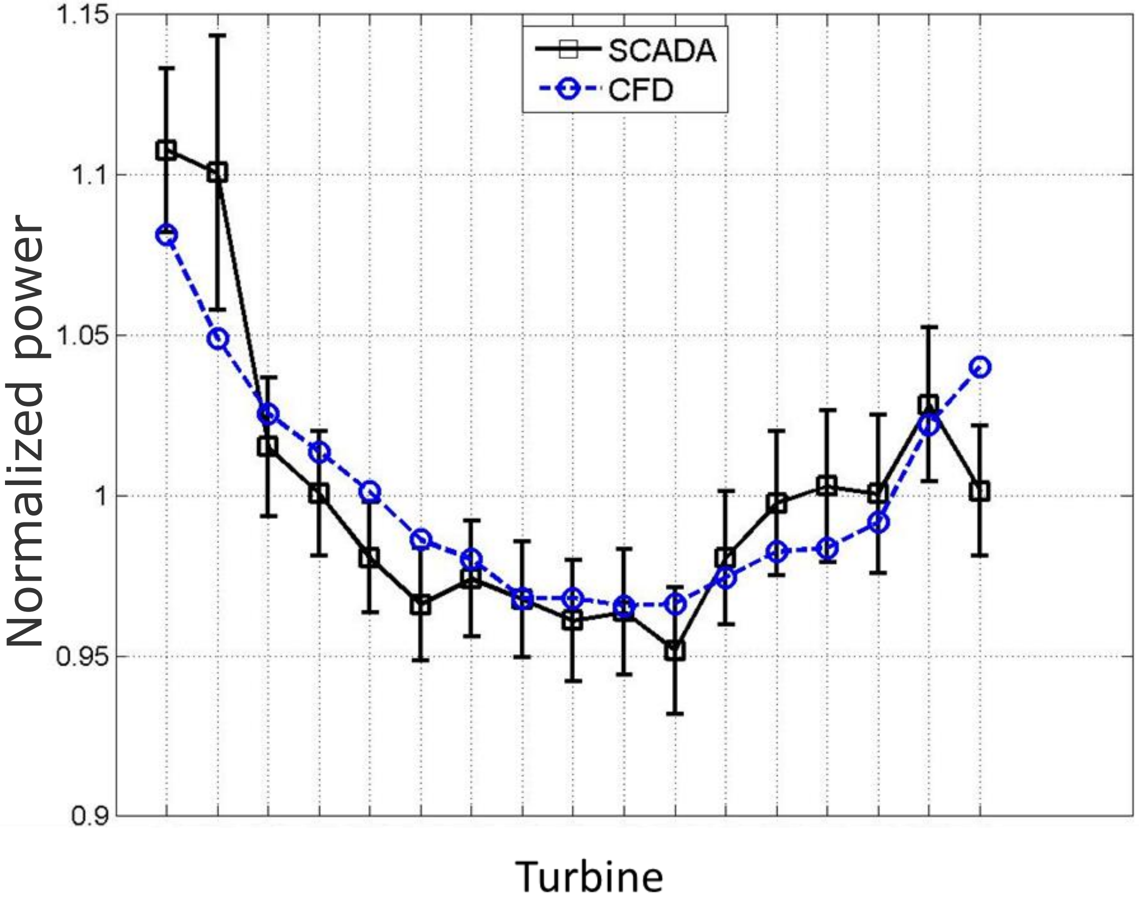
More recent evidence of wind farm blockage

Change in wind speed after COD at perimeter mast (P) relative to reference masts (R), Wind Farm E



22 of 23 mast pairs across 5 wind farms reveal post-COD slowdowns at the perimeter masts

Production variation along a leading string of turbines, Wind Farm F



All results correspond to below rated conditions

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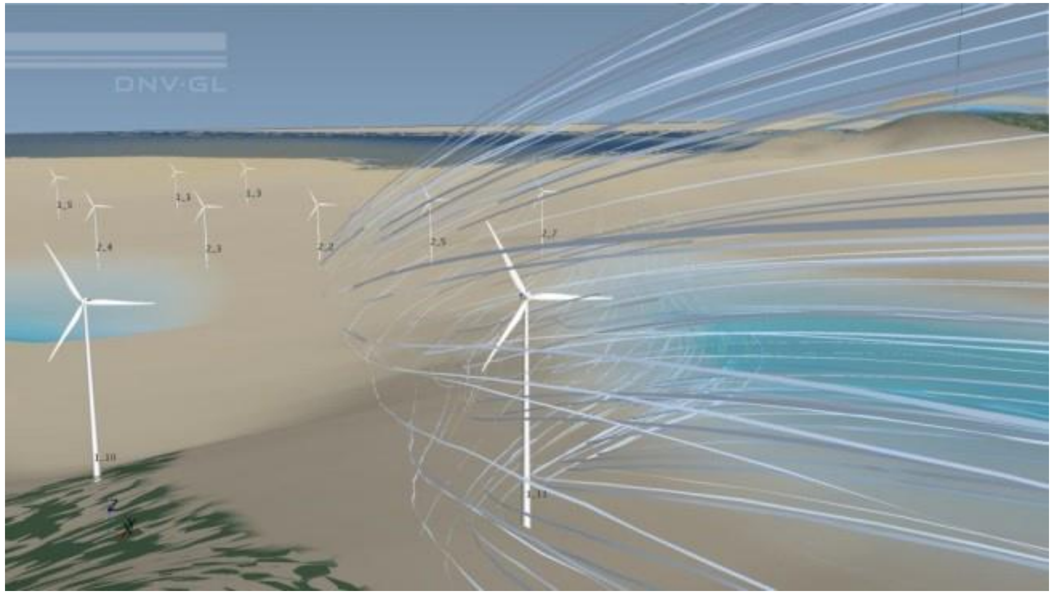
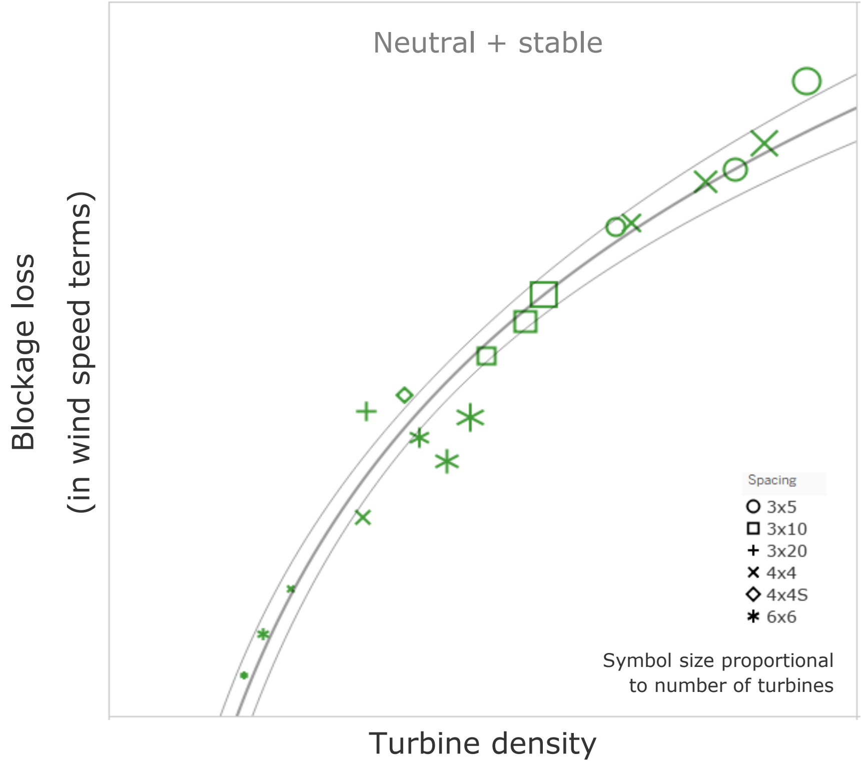
Blockage loss calculation – How?

- Site specific CFD:
  - Pro: accounts for all details on site, terrain, forestry, stability, wake interactions),
  - Con: slow
- Blockage effect estimation tool (BEET), derived from CFD on range of generic wind farm layout
  - Pro: Fast!
  - Con: may miss some of the site specific aspects (e.g. simplified stability set up)



BEET input parameters:
- **Site layout**
- **Turbine configuration (hub height, power curve, rotor diameter)**
- **Site wind speed frequency distribution**
- **Site expected stability**

Sensitivities 1 – density, stability, HH/RD ratio

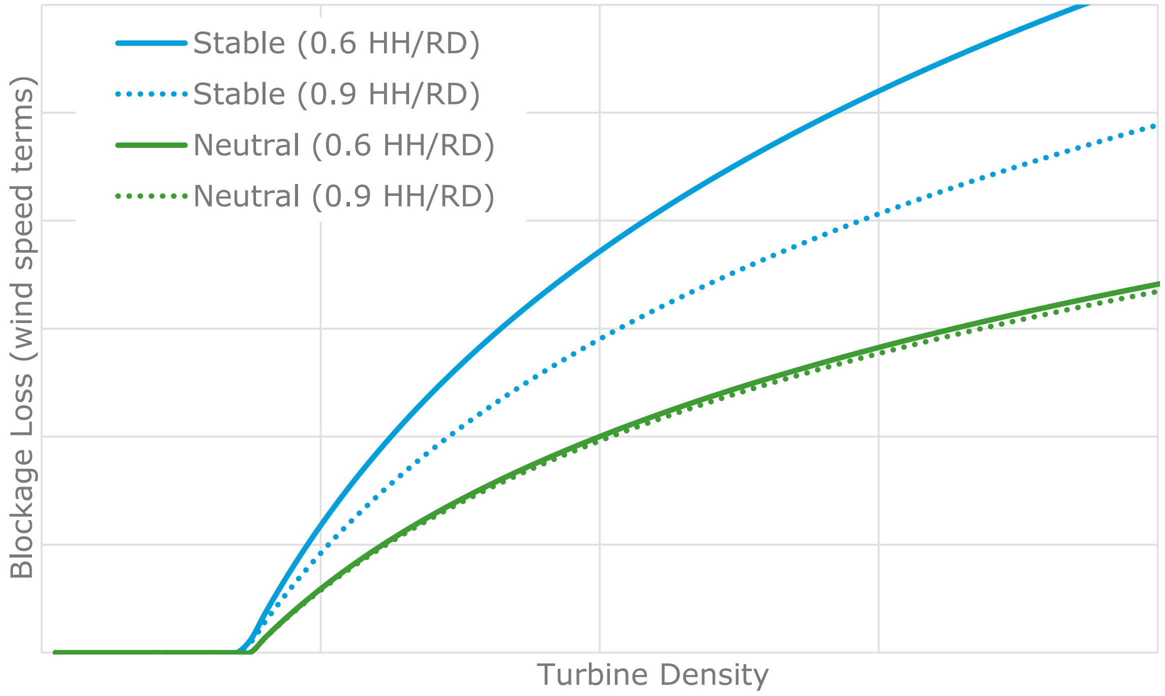


Strong sensitivity to turbine density.

Range of blockage loss seen so far in our analyses: 0 – 5%

*Stronger blockage loss in **stable** than **neutral** stability conditions.*

In stable conditions, strong sensitivity to hub-height-to-rotor-diameter ratio HH/RD.

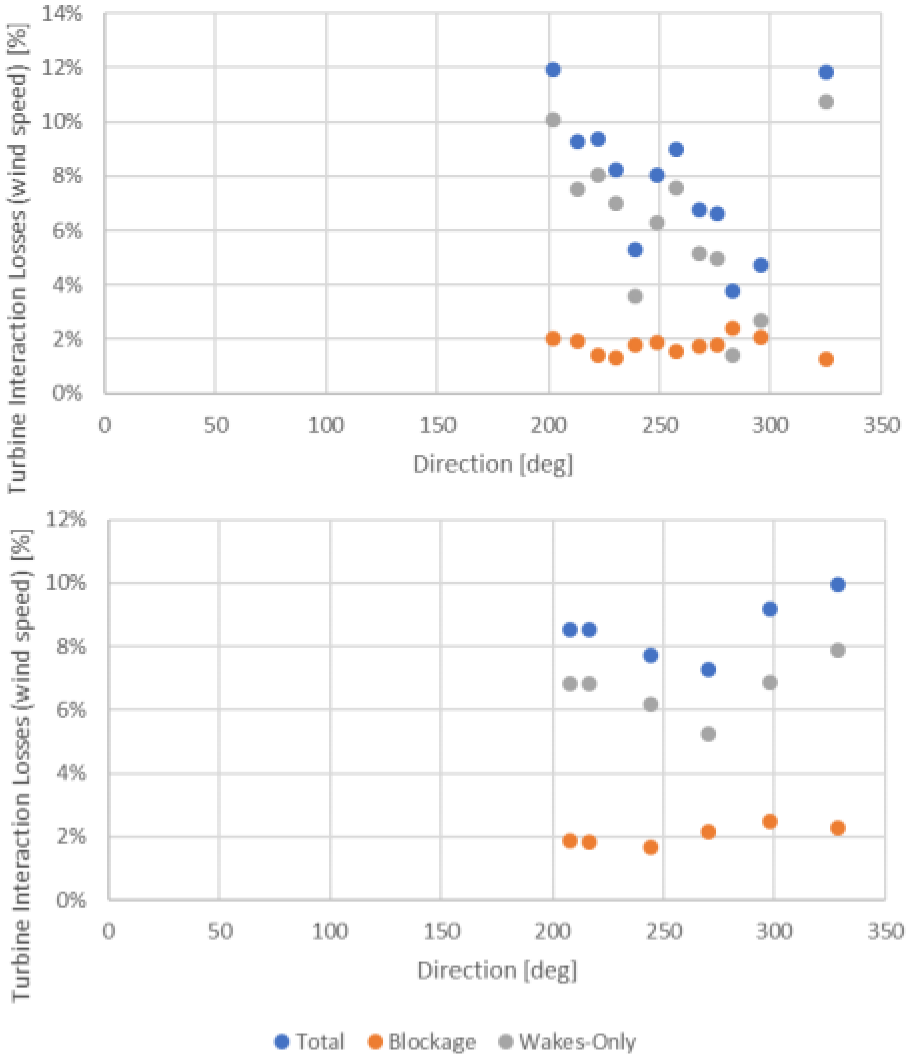


Sensitivities 2 – layout shape and wind rose?

- BEET simulations conducted with regular arrays
  - BEET assumes exact positioning of turbines is not a strong driver of blockage – it is the density that is important

- Assumption tested with CFD simulations, indicating little sensitivity to wind direction or layout shape (with constant density)

- Two real wind farms in Sweden simulated over a range of directions
  - Wake effects show significant variation between directions
  - Blockage effects show little variation between directions



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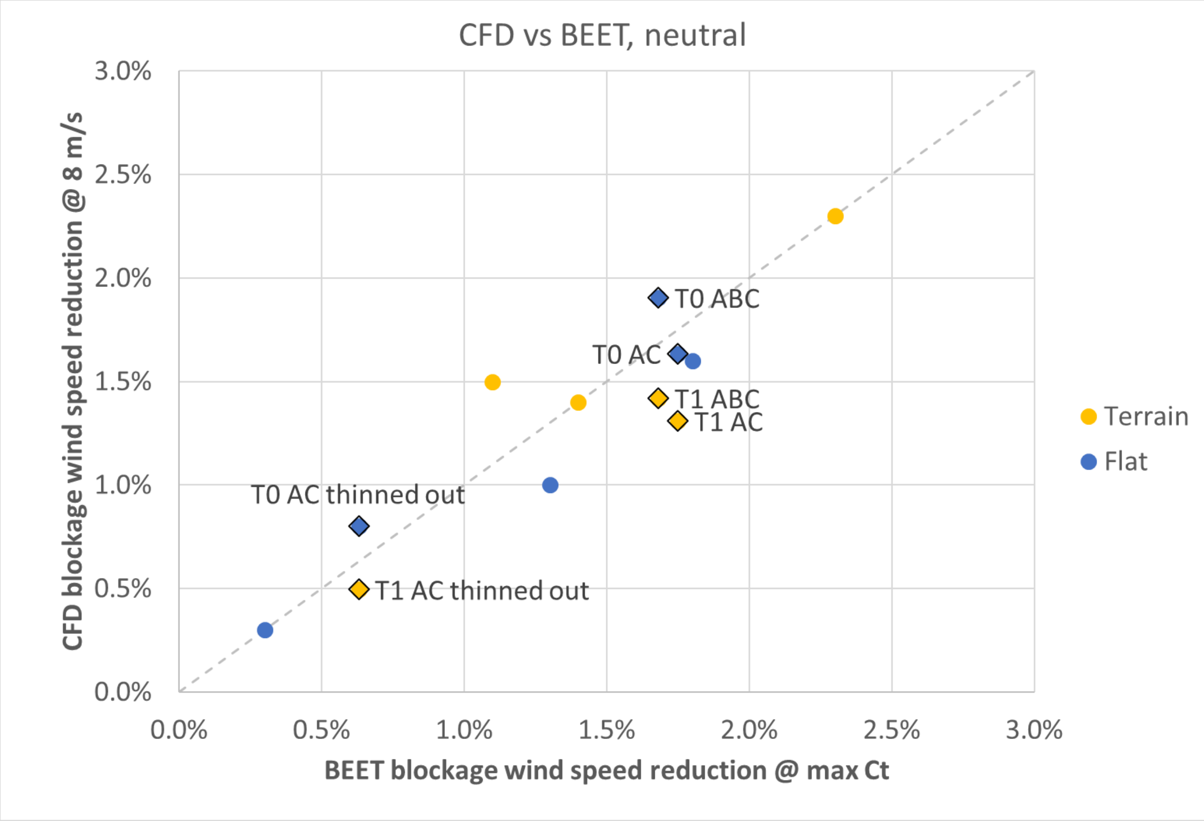
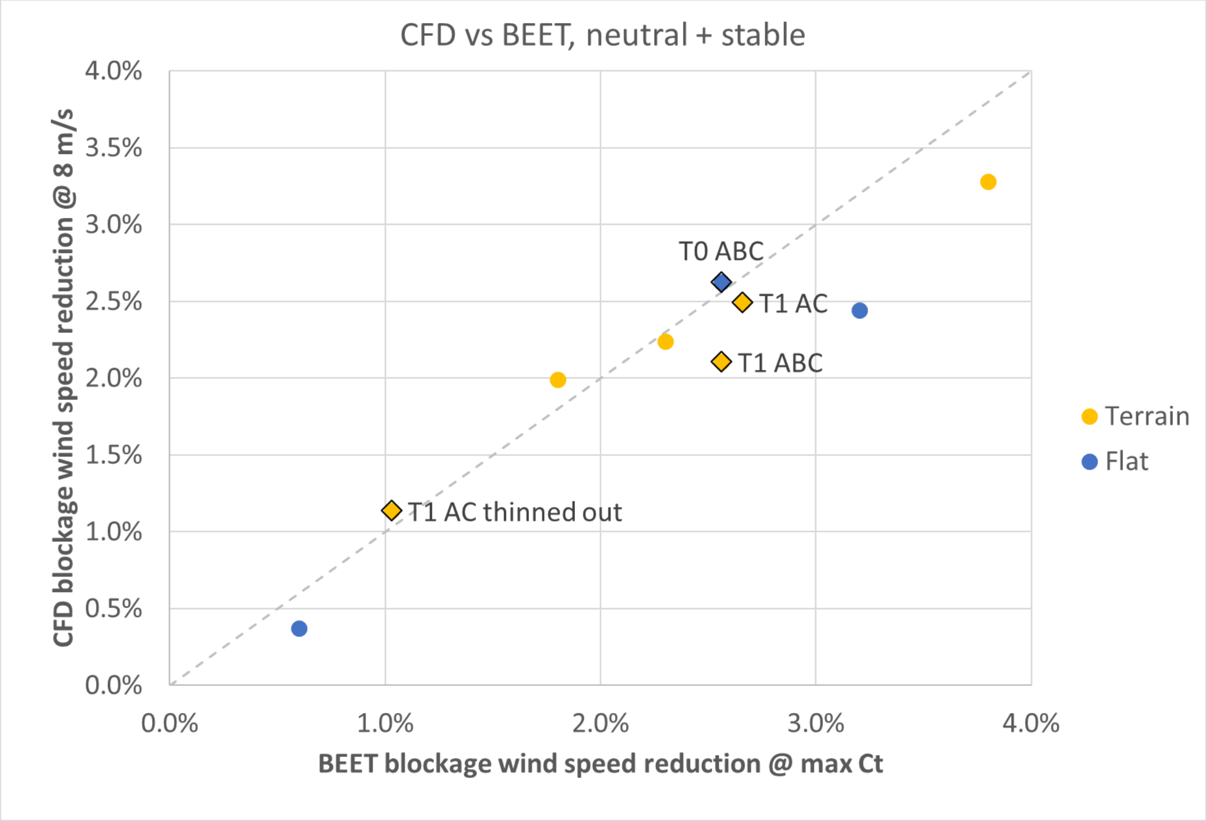
BEET vs Site specific CFD

Comparison for real wind farms not in the data set onto which BEET was fitted - includes irregular layouts and terrain





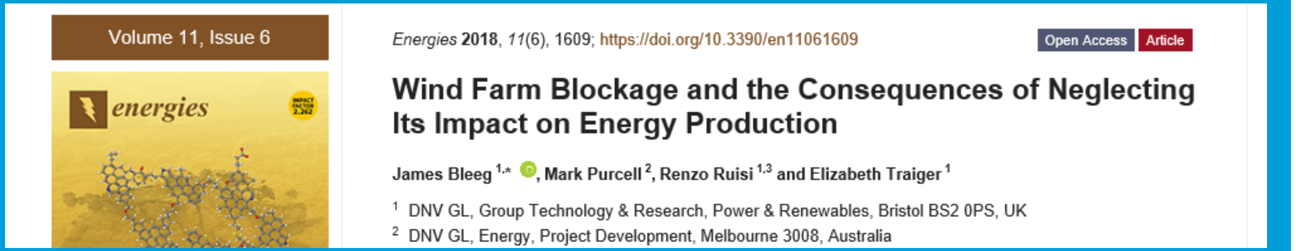
Current understanding of key influencing parameters for wind farm blockage

High	Medium	Low
• Wind farm density • Atmospheric stability	• Wind speed distribution • Power/Thrust curve • Hub height and rotor diameter • *Terrain complexity*	• *Layout shape (unless extremely directional wind rose)* • *Wind rose (unless extremely directional layout)* • *Turbulence intensity*

Considered by both BEET and CFD

Considered by CFD only (note: non-exhaustive list)

Thanks for listening



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Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production

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