ENERGY

Wind-Farm-Scale blockage in stable regime

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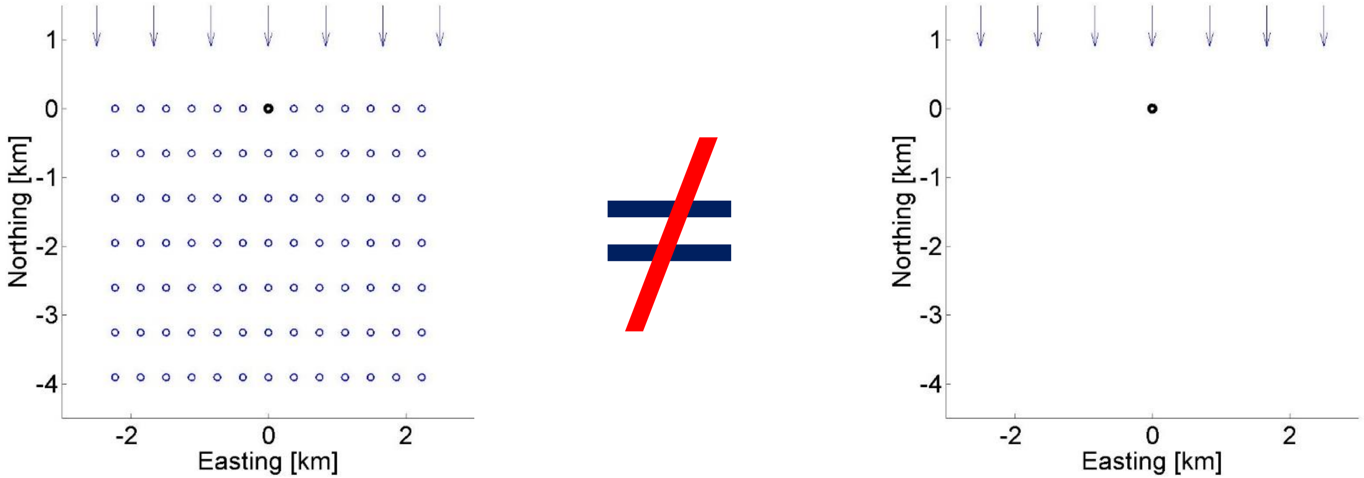
Introduction

- 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

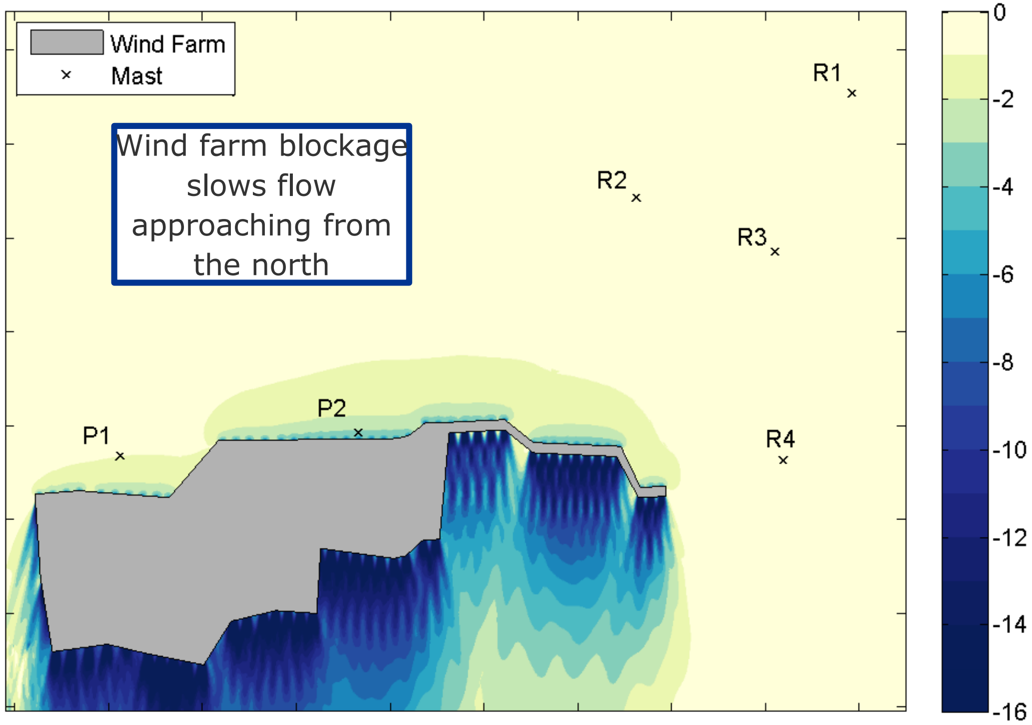
→ Wind-farm-scale blockage. The associated blockage loss* is defined as the difference in power between isolated and array operation for the turbines at the upstream edge of the wind farm.



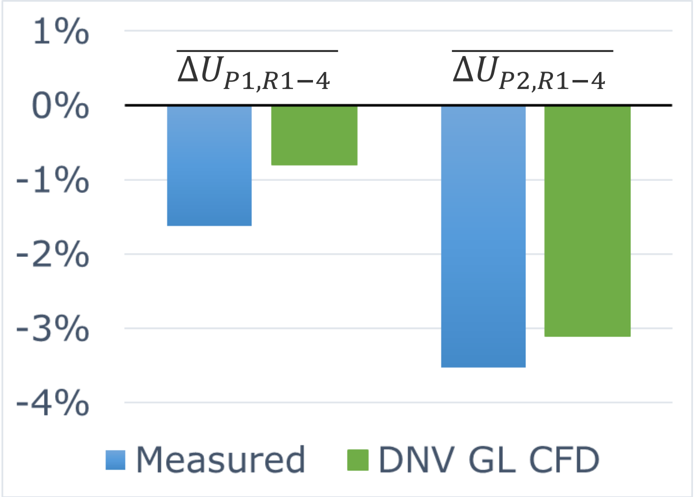
*: shorthand for what is **a neglected loss by 'wakes-only' models.** It's not purely blockage as wakes and blockage are tightly coupled and can not be precisely separated

Blockage validation

From changes in wind speed ratios after commercial operation date between perimeter (P) and reference (R) masts upstream of the wind farm.



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



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

Blockage observed at 18 out of 19 mast pairs from 4 separate wind farm sites

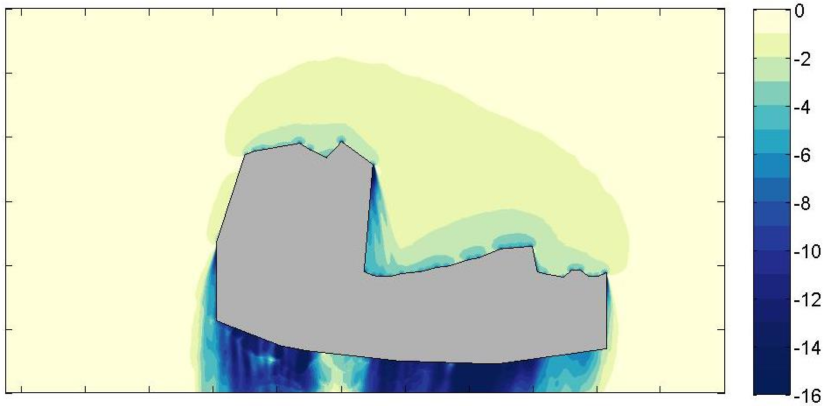
Methodology to evaluate blockage loss factor

- Aim: $E_{Potential} = \eta_{bl}\, \eta_{wake-only}\, E_{Gross}$
  - Loss factor as a correction to wakes-only models

- CFD simulations of elliptic RANS can account for feedback from wind farm onto background flow.
- Two sets of back-to-back CFD simulations:
  - Freestream
  - Wind farm with all turbines in operation (turbines modelled with actuator disk model)

  → total turbine interaction loss factor calculated as

  → blockage loss L_{bl} and loss factor η_{bl} calculated as

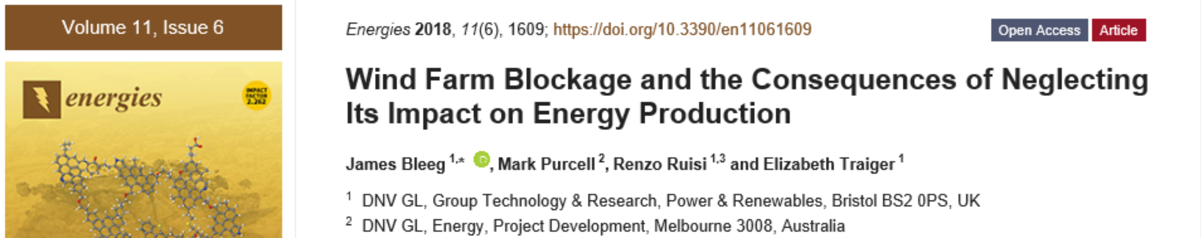


$P_{i,wf}$: power from turbine *i* when whole wind farm is operational

$P_{i,I}$: power from turbine *i* operating in isolation

$$\eta_{total\_turb\_interaction} = \frac{\sum_{All} P_{i,wf}}{\sum_{All} P_{i,I}}$$

$$\eta_{bl} \approx \left(\frac{\sum P_{wf}}{\sum P_I}\right)_{front\ row} \qquad L_{bl} = 1 - \eta_{bl}$$



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

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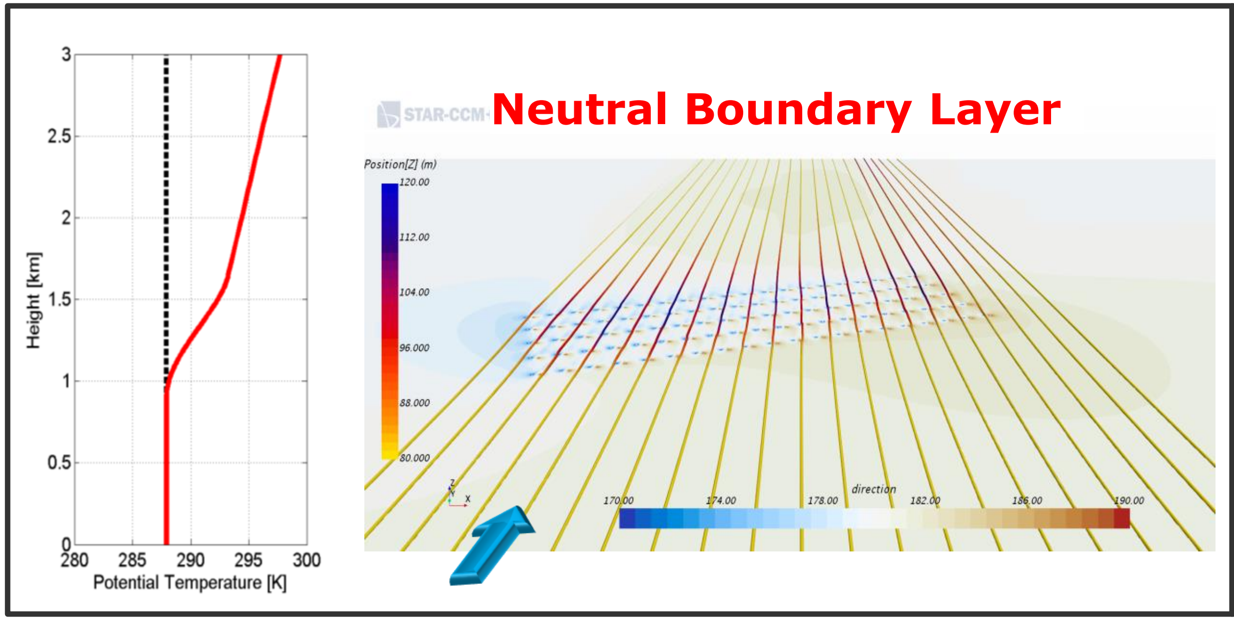
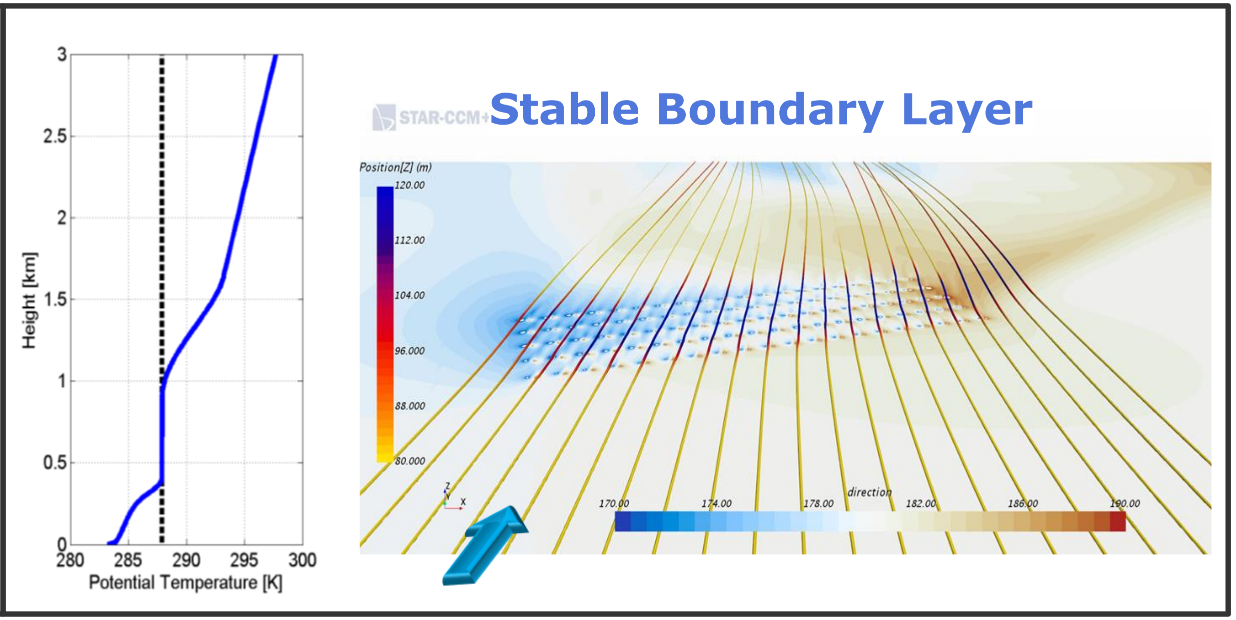
Blockage and cold climate

Cold climate = more stability = stronger blockage

Front raised view of the flow around a 5x20 array (turbine spacing 3D x 5D) in flat terrain conditions. Flow from the south



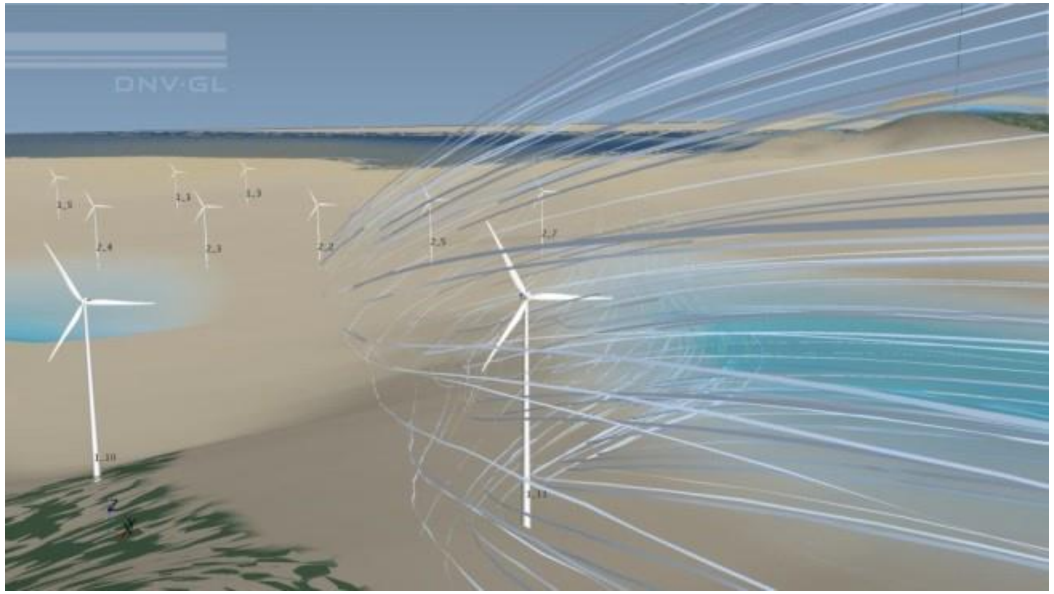


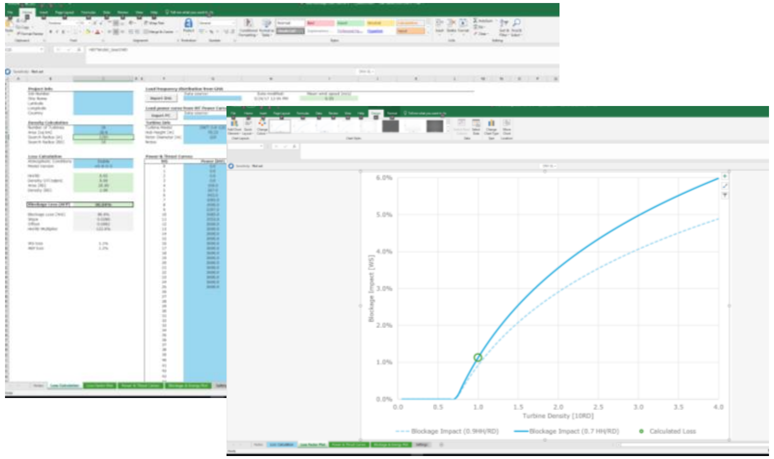
Horizontal plane at hub height coloured with wind direction: blue → flow deflection in anti-clockwise direction, red → flow deflection in clockwise direction
Streamline originating from hub height upstream of the wind farm. Colours on streamlines show local elevation.

Blockage loss calculation

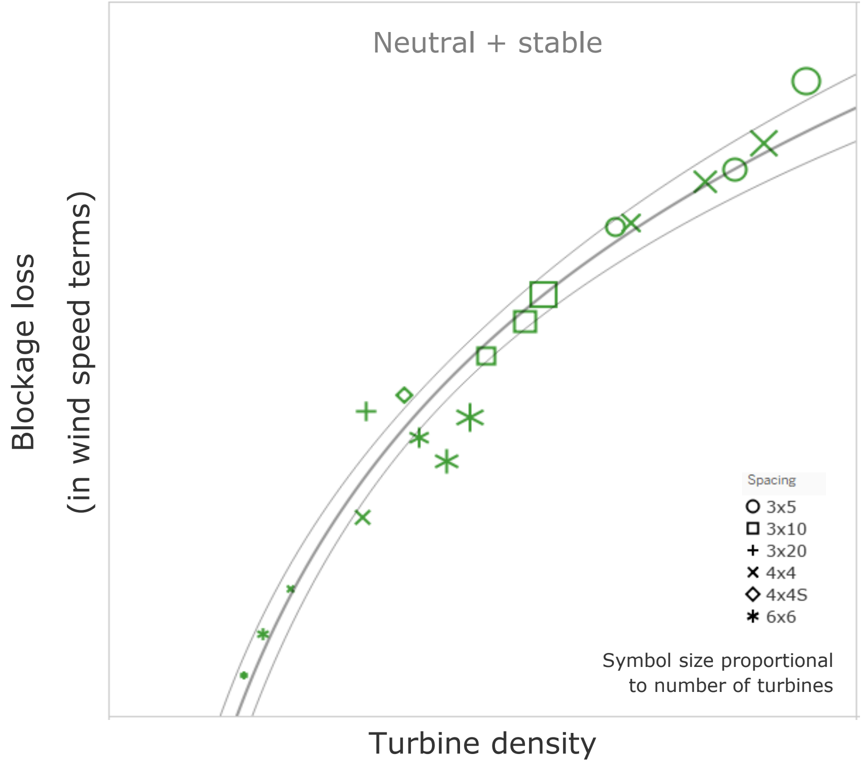
- Site specific CFD:
  - Pro: accounts for all details on site, terrain, forestry, stability, wake interactions),
  - Con: slow

- Blockage effect estimation tool (BEET), derived from CFD on range of generic wind farm layout
  - Pro:
    - Fast!
    - Compared and agreeing reasonably well so far with site specific CFD for real sites (varying terrain and forestry, irregular arrays)
  - Con: may miss some of the site specific aspects (e.g. simplified stability set up)





Sensitivities

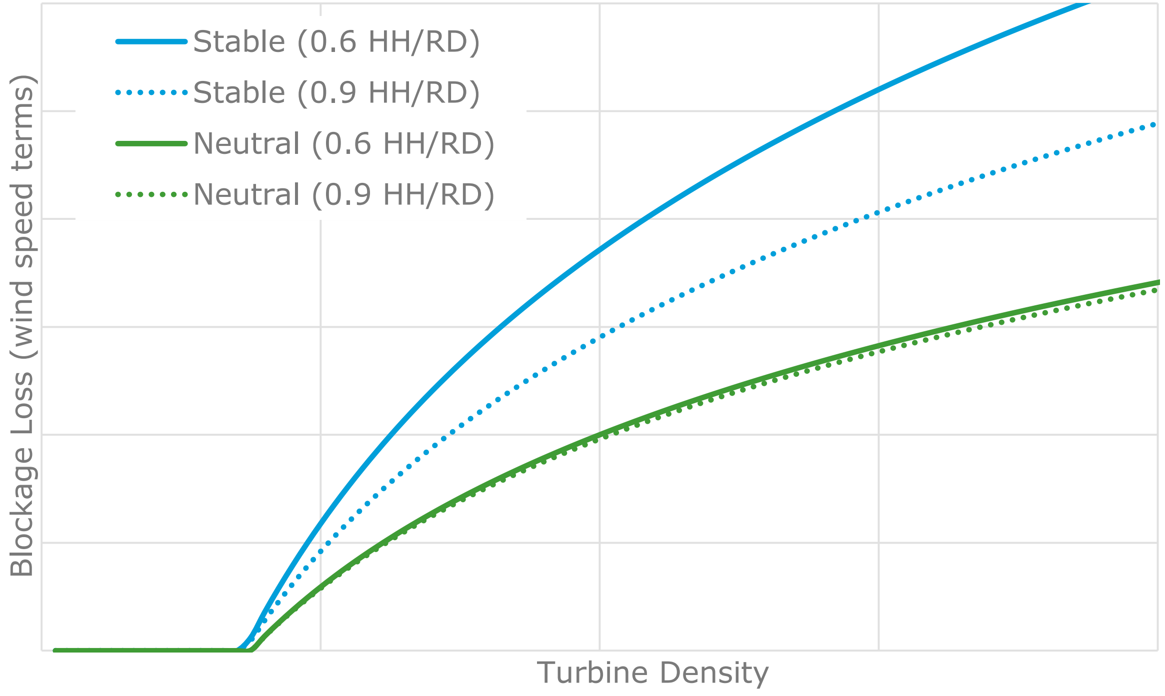


Strong sensitivity to turbine density.

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.



Conclusions

Wind-farm-scale blockage affects all wind farms, large and small. Blockage magnitude increases with:

- Turbine density
- Rotor diameter (for a given hub height)
- Stable conditions

Predominance of stable surface stability conditions in cold climates

→wind-farm-scale blockage should be included in EPA for realistic assessment.

Thanks for listening

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