ENERGY

Wind farm blockage onshore

What drives the loss?

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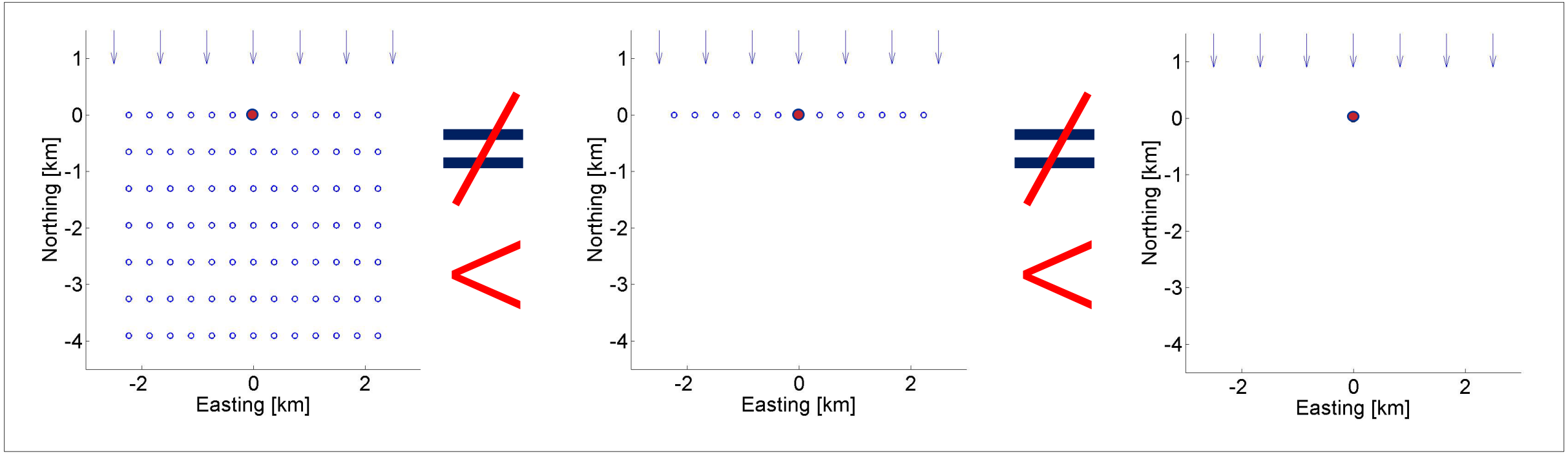
1.What is wind-farm-scale blockage?



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

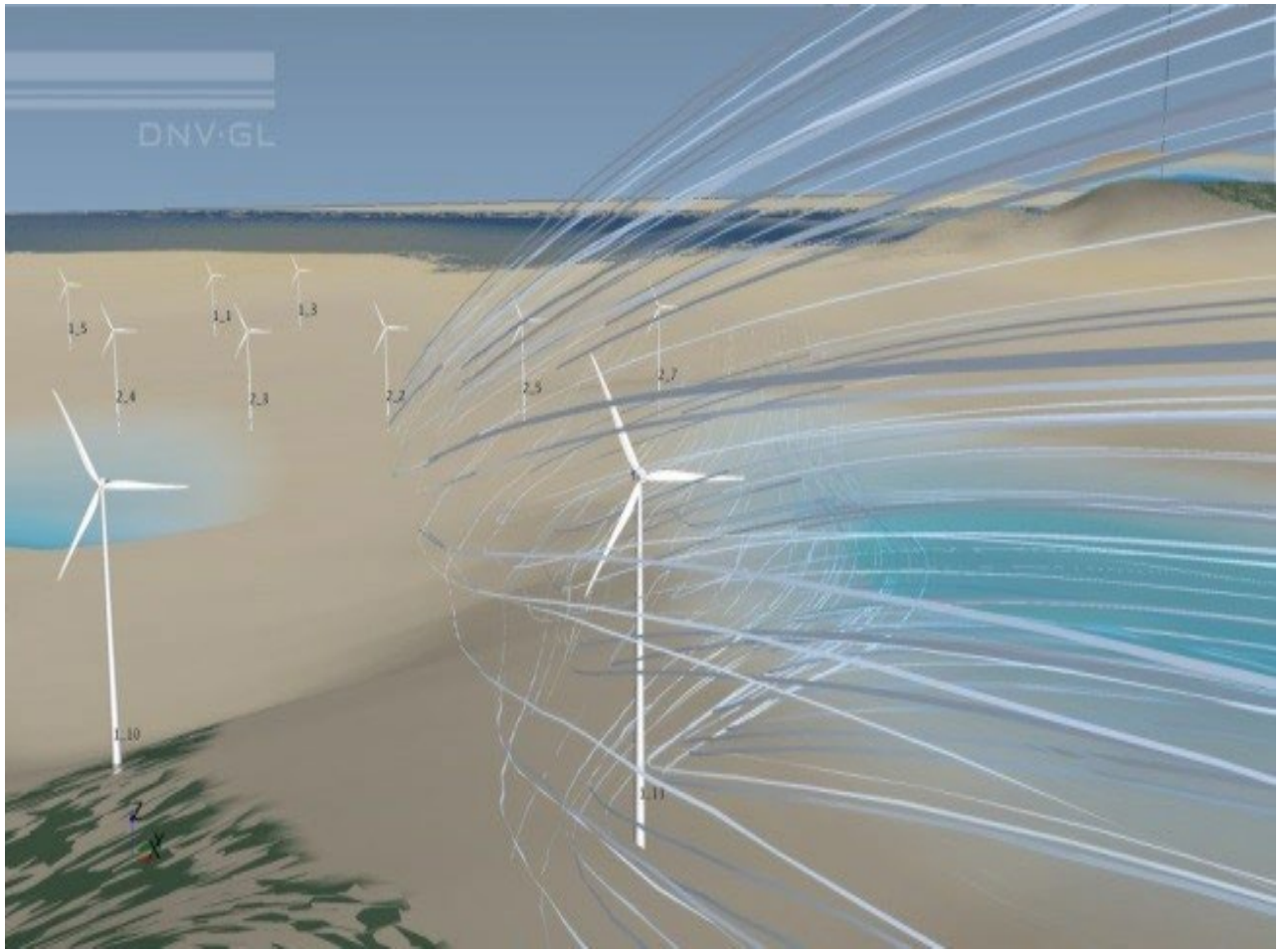
2.How can we calculate blockage?

Site specific CFD:
Run model with and without the wind farm and calculate the difference
Pro: accounts for "all" details
Con: computationally intensive

Blockage effect estimation tool (BEET):
Empirical model based on CFD results for a range of generic wind farms
Pro: Fast!
Con: may miss some site specific aspects

When is BEET good enough?

When should site specific CFD be used?



3.Study site – Fictitious wind farm in Sweden

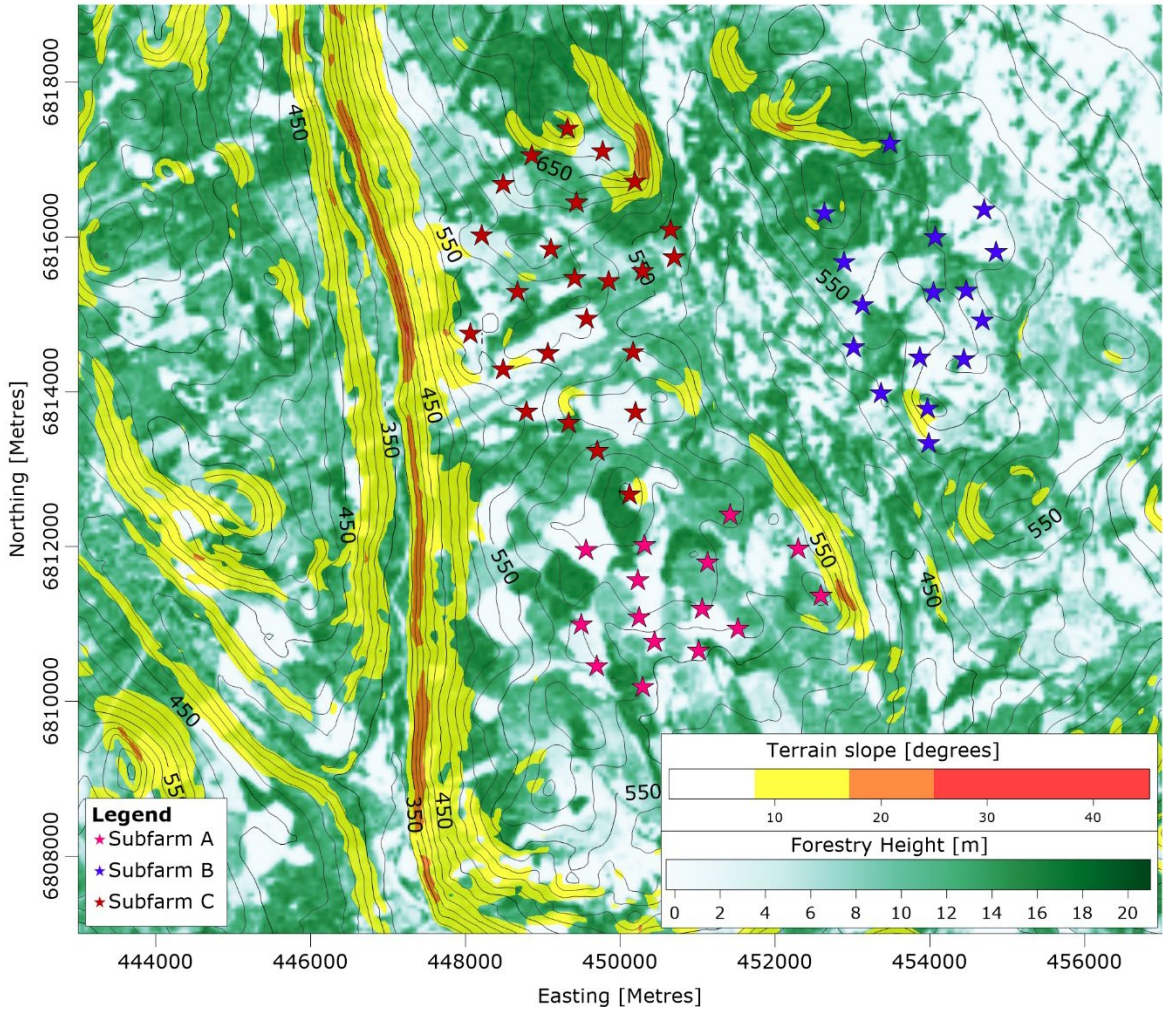
Complex site with 39 turbines arranged in 3 clusters (A,B and C)

Modern wind turbine

- **Rated ~5MW**
- **Hub height of 130 m**
- **Rotor diameter of ~150 m**

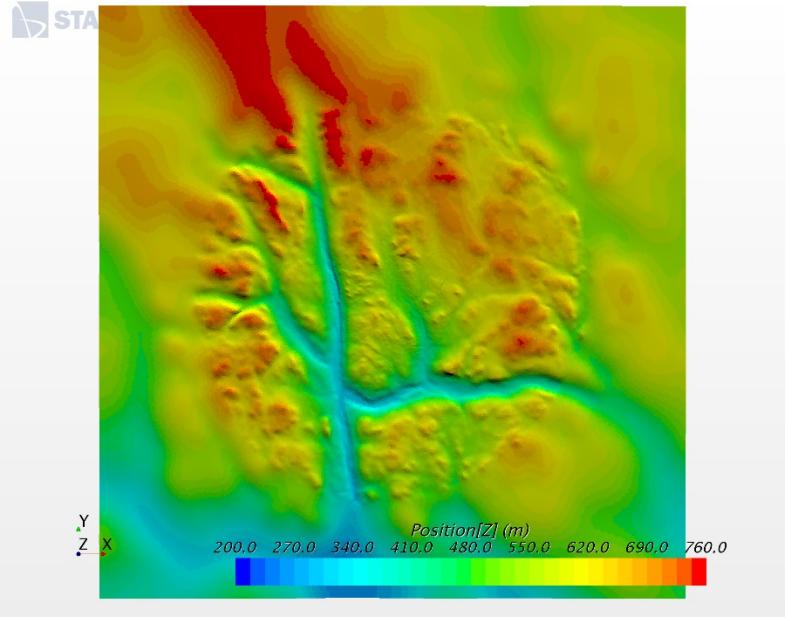
More complex than "typical" Swedish wind farm

Turbine base elevation	Fictitious	"Typical"
Range [m]	212	60-130
Std.Dev [m]	38	15-30



3.Study site – Simulation setup

Terrain

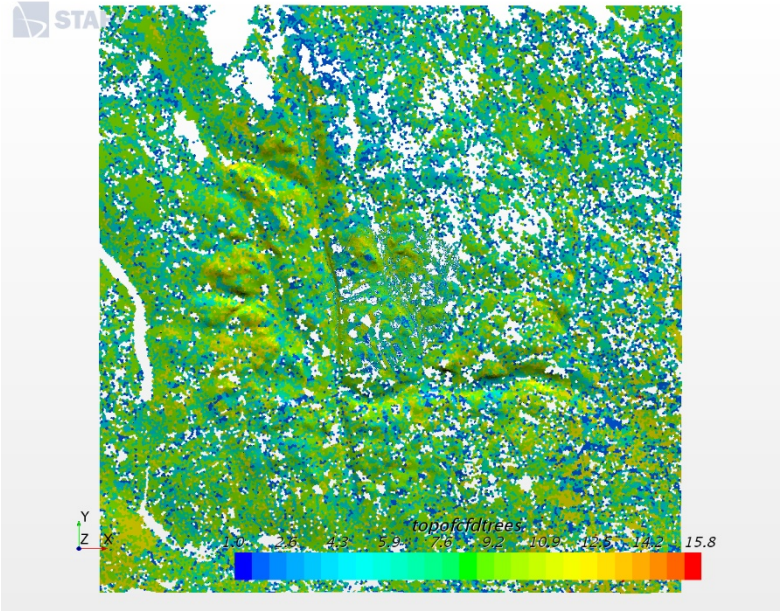


Variations:

T0: Flat

T1: Real terrain

Tree heights



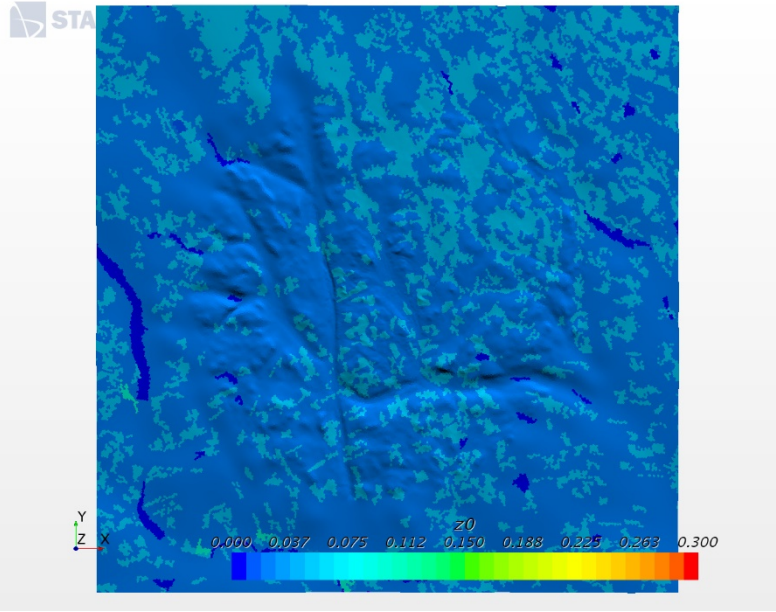
Variations:

F0: No forestry

F1: Canopy height = Representative height

F2: Canopy height = Representative +40%

Roughness



Variations:

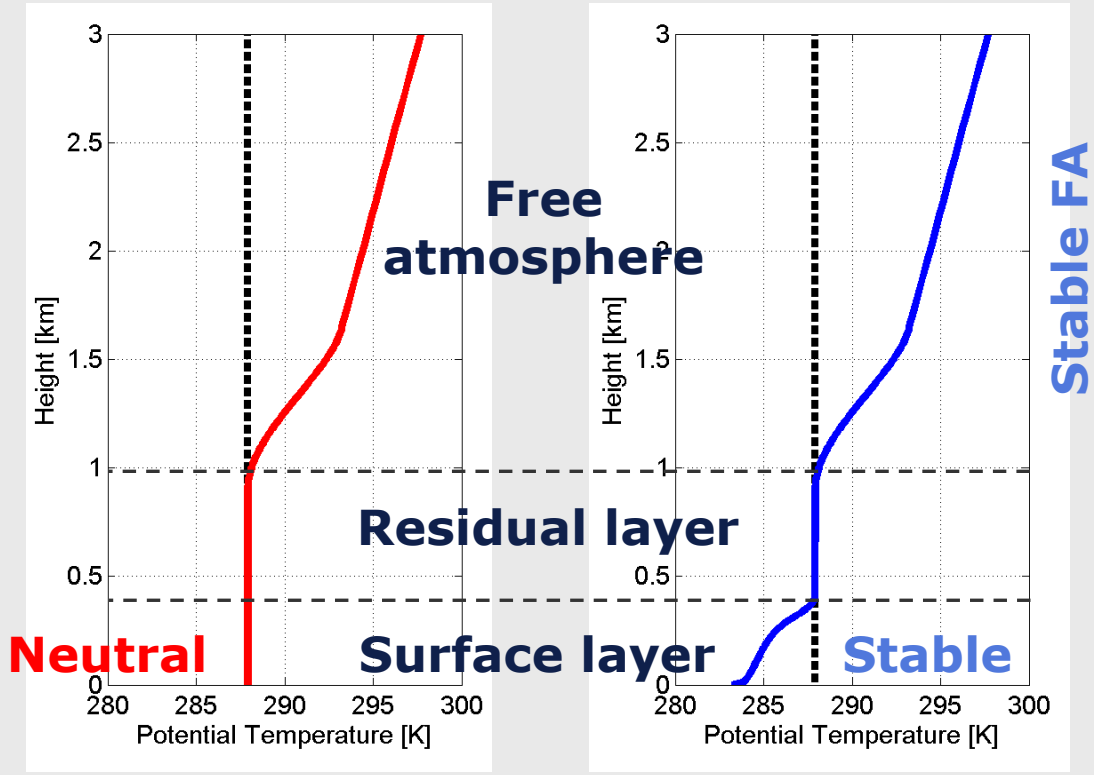
R1: Site roughness

R2: Site roughness + additional towns

R3-R6: constant roughness from z0 = 0.0002, 0.002m, 0.02m, 0.2m

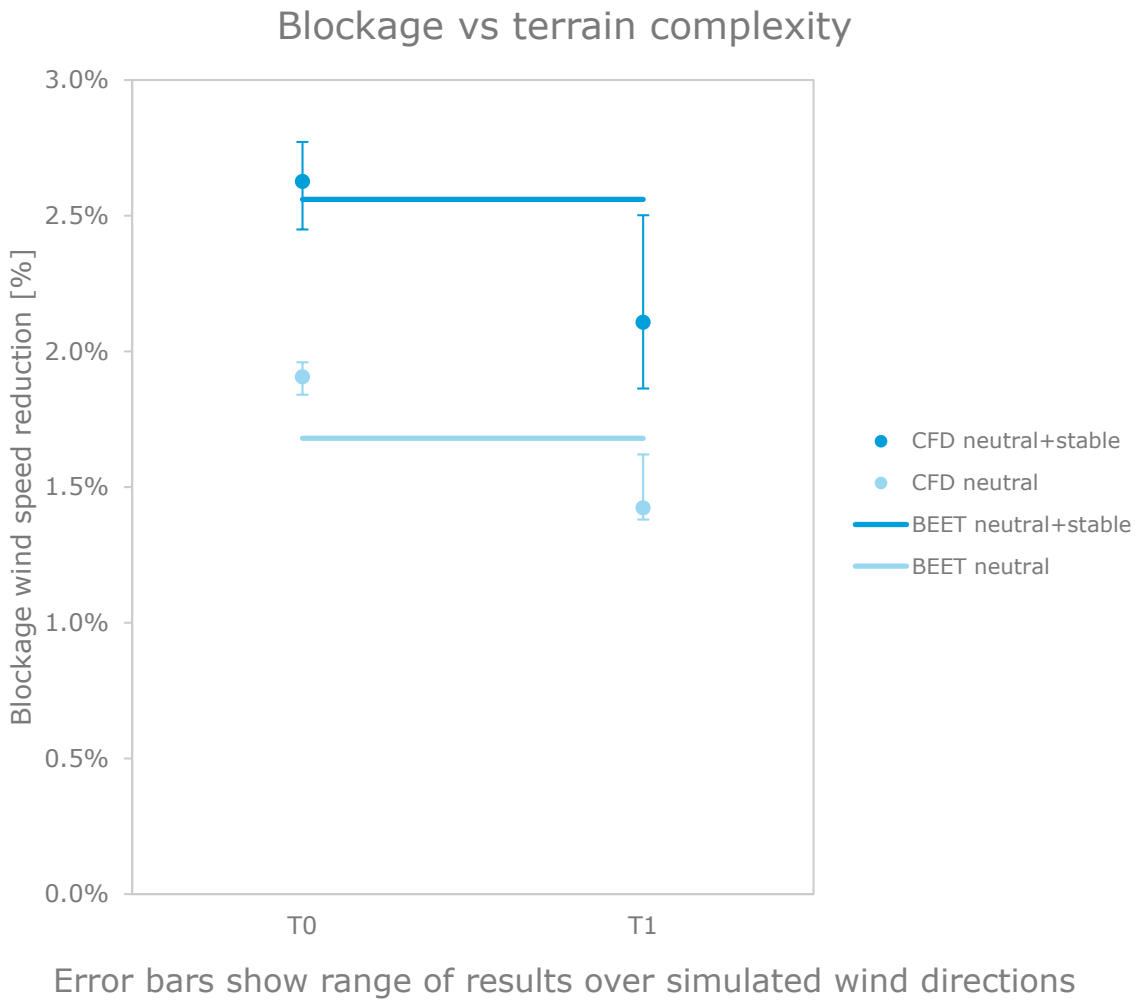
3.Study site – Simulation setup 2

- Westerly directions (30 degree sector), between 4-9 directions simulated
- Both neutral and stable surface stability
- Site simulated with boundary layer height of ~1000m.



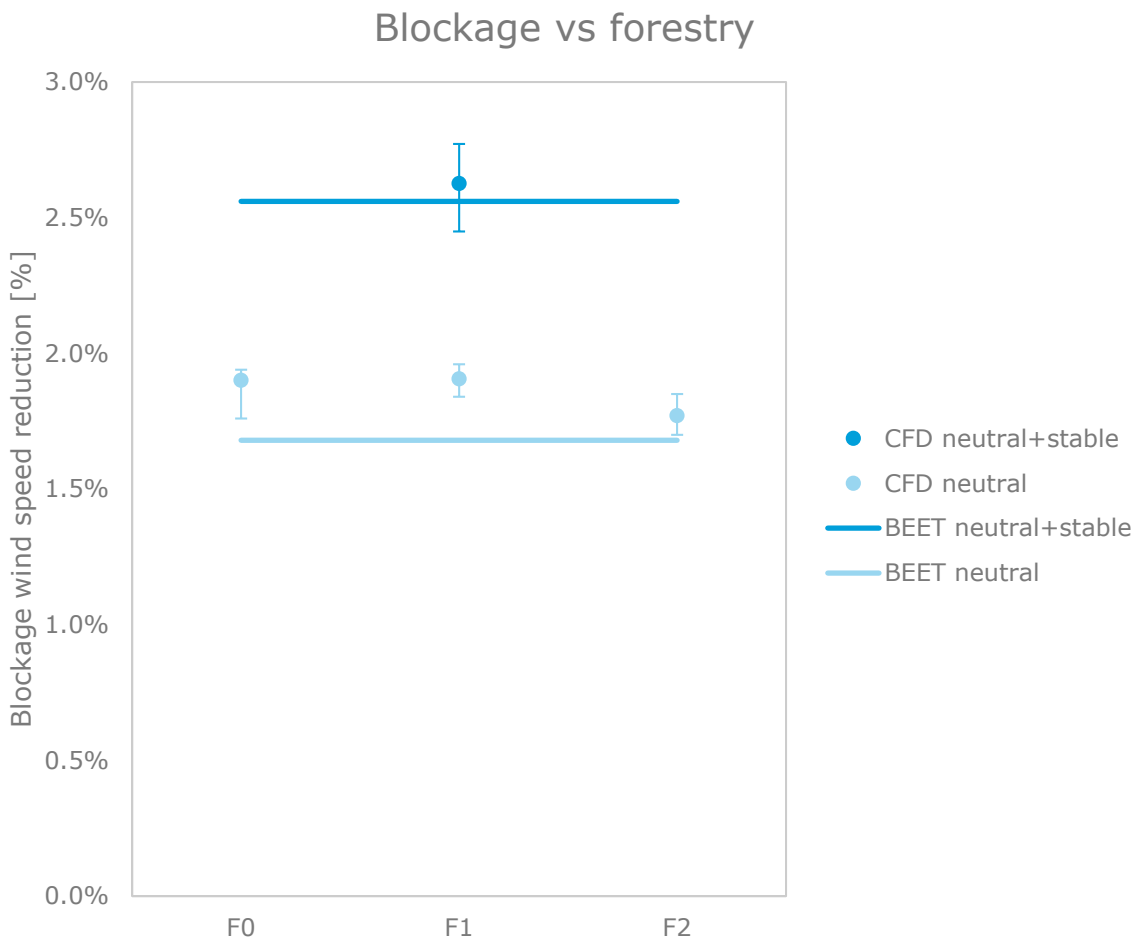
3.Sensitivity of blockage loss to terrain configuration

- **Site specific CFD for flat terrain (T0), site roughness and forestry conditions leads to a prediction slightly above that from BEET**
- **Site specific CFD for real terrain (T1), site roughness and forestry conditions leads to a prediction slightly below that from BEET**
- **At fictitious complex site in Sweden, CFD predicts ~0.5% lower blockage than BEET**



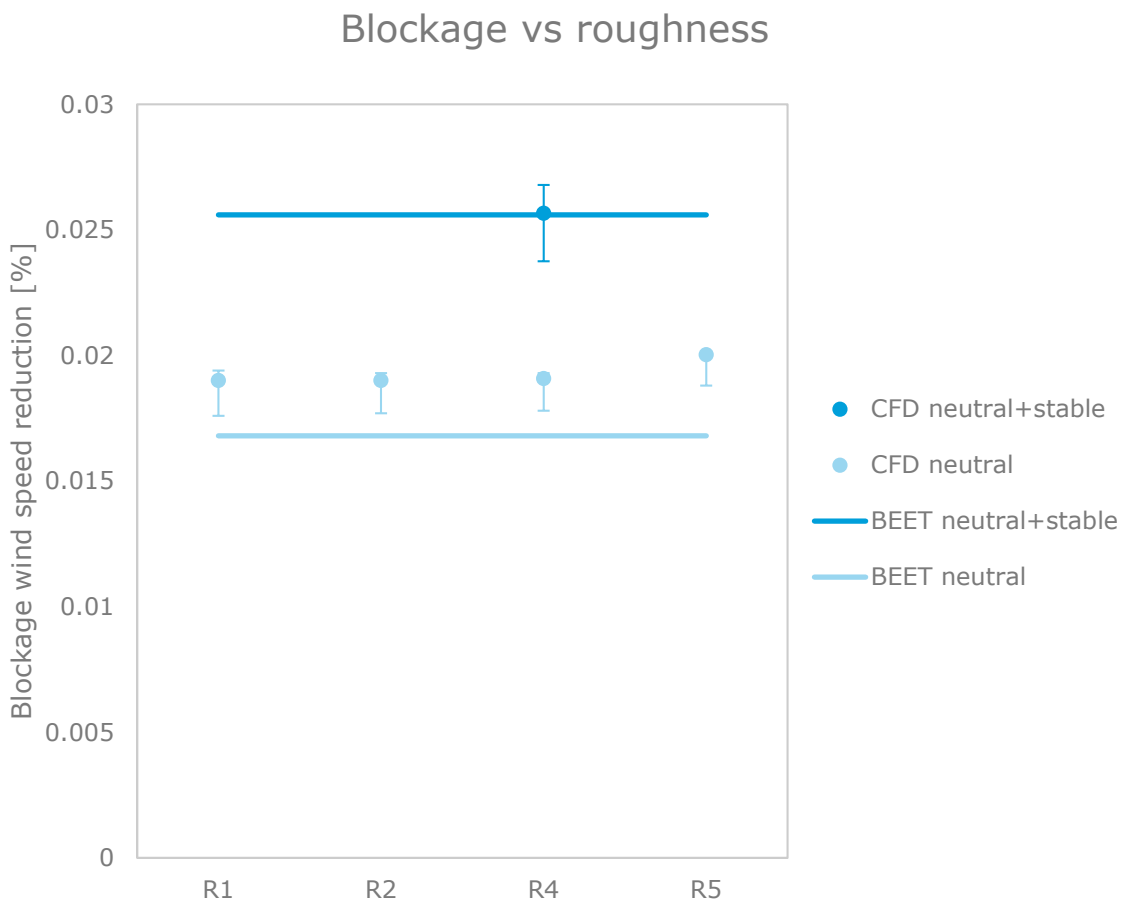
3.Sensitivity of blockage loss to forestry configuration

- The sensitivity of the blockage loss to the forestry cover was tested with neutral surface stability conditions
- F0: no forestry, F1: representative tree height, F2: tree height +40%
- Very little sensitivity observed for the blockage loss (blockage far less sensitive to changes in forestry than to stability conditions)
- Wake losses though are sensitive to the choice of forestry scenario! (not shown)



3.Sensitivity of blockage loss to roughness configuration

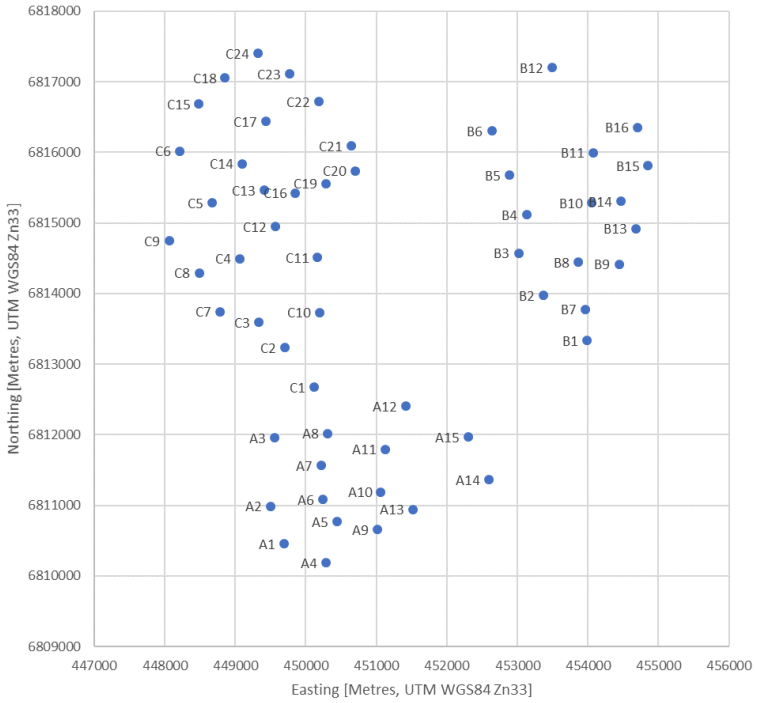
- The sensitivity of the blockage loss to the roughness cover was tested with neutral surface stability conditions
- R1: actual site roughness, R2: as R1 + additional rough patches for towns, R4: z0 = 0.02m, R5: z0=0.2m
- R3 omitted because small roughness of 0.0002m leads to surface layer thinner than tip of rotor (i.e. rotor operates partly in residual layer)
- Blockage loss far less sensitive to changes in roughness than to stability conditions



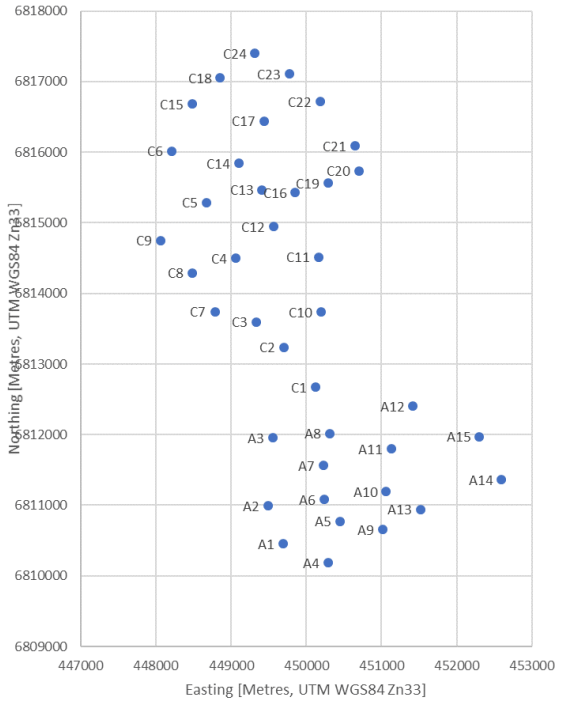
Error bars show range of results over simulated wind directions

3.Sensitivity of blockage loss to layout

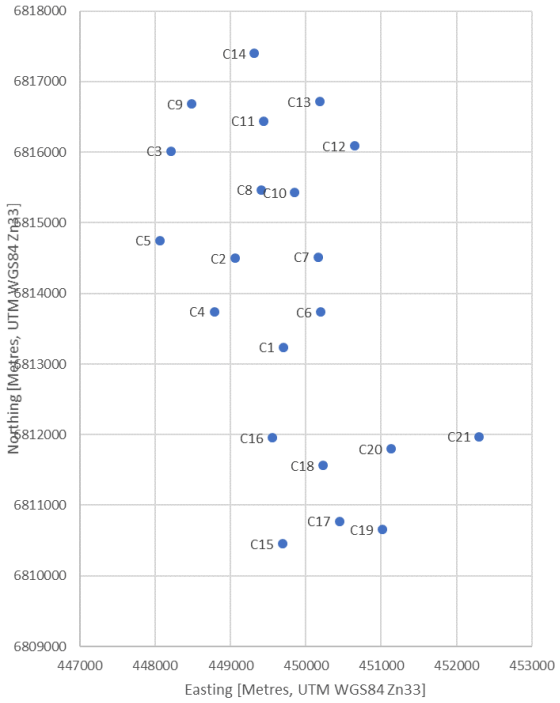
ABC



AC



AC thinned out

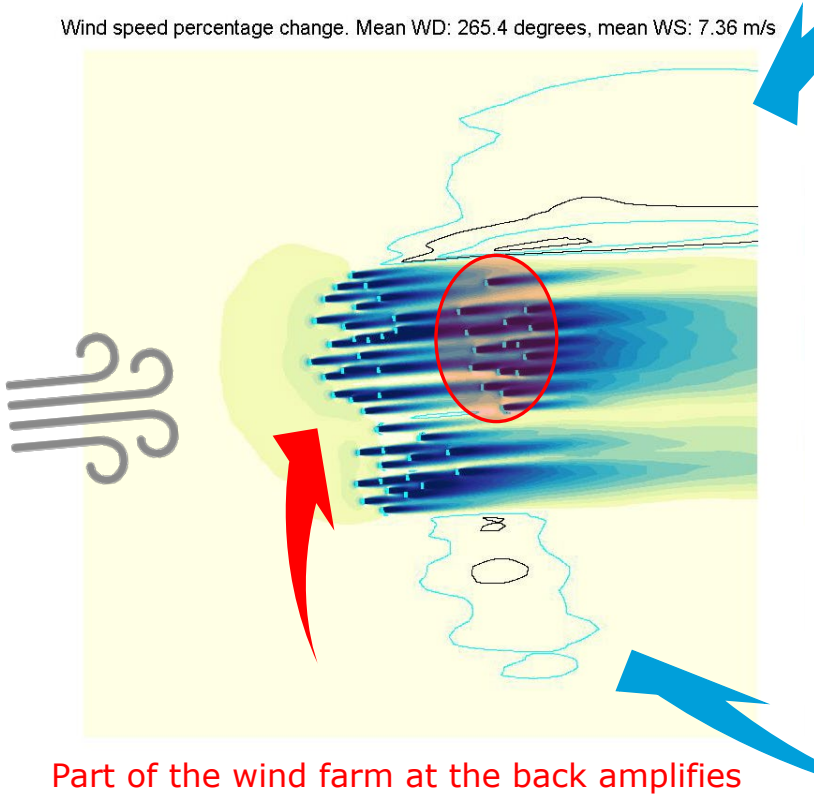


Base elevation	ABC	AC	AC thinned out
Range [m]	212	189	189
RMS [m]	38	38	40

3.Sensitivity of blockage loss to layout

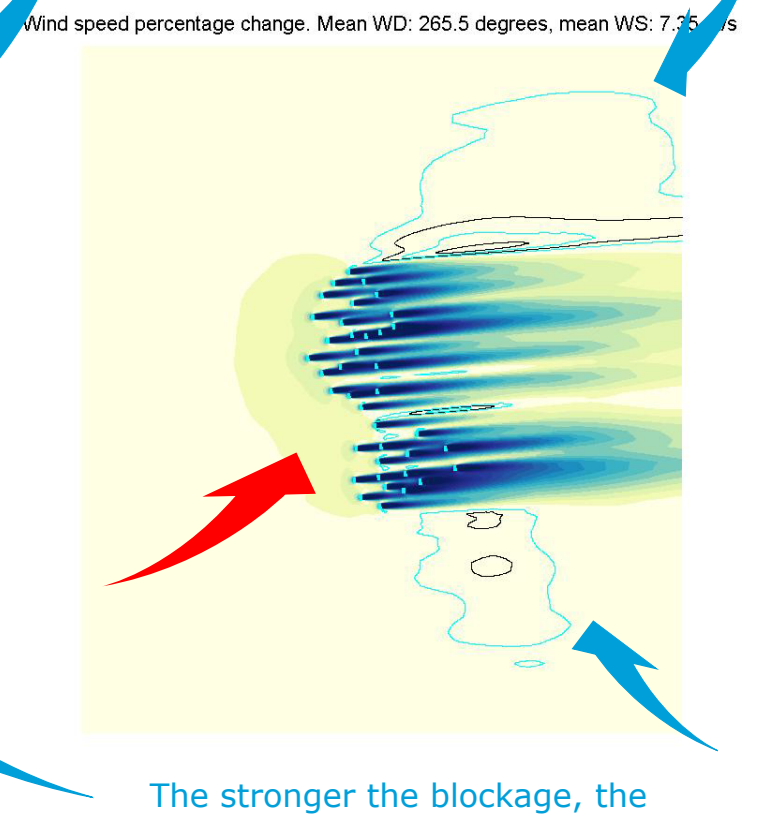
3 cases simulated with same conditions – flat terrain, real forestry and roughness, neutral stability

ABC



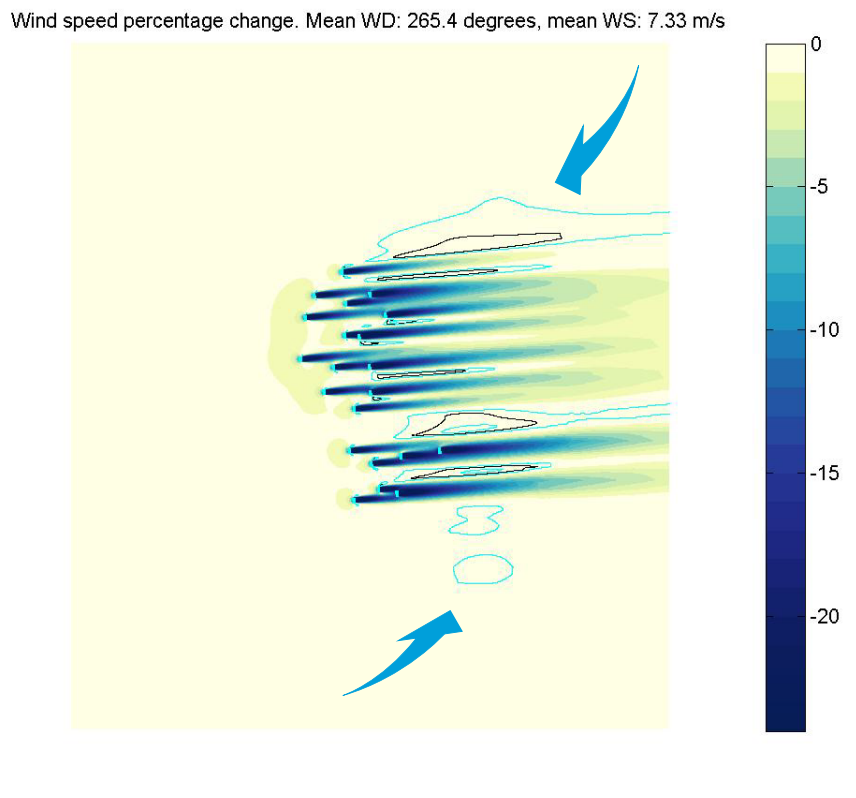
Part of the wind farm at the back amplifies the blockage upstream of the whole layout (despite the gap in-between)

AC



The stronger the blockage, the stronger the speed-up round the side (isolines indicate speed-up)

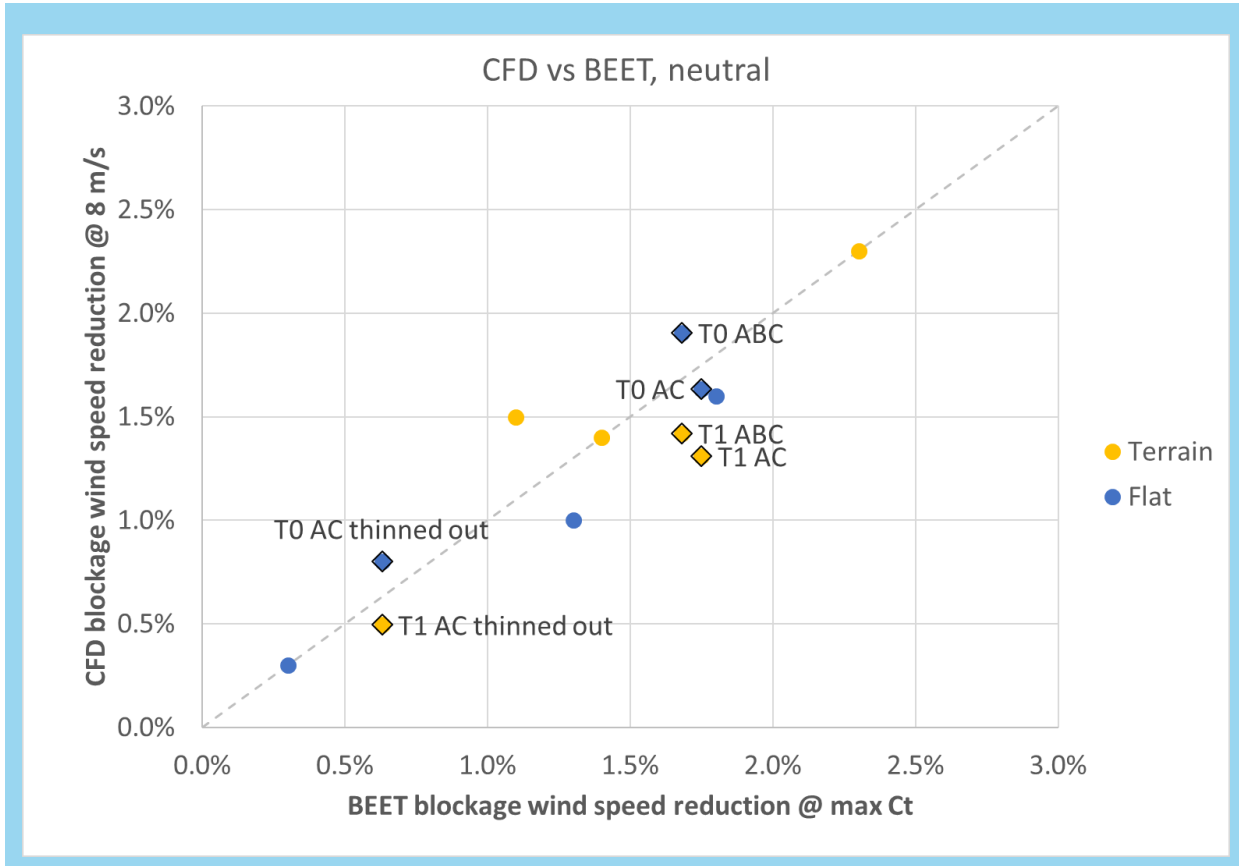
AC thinned out

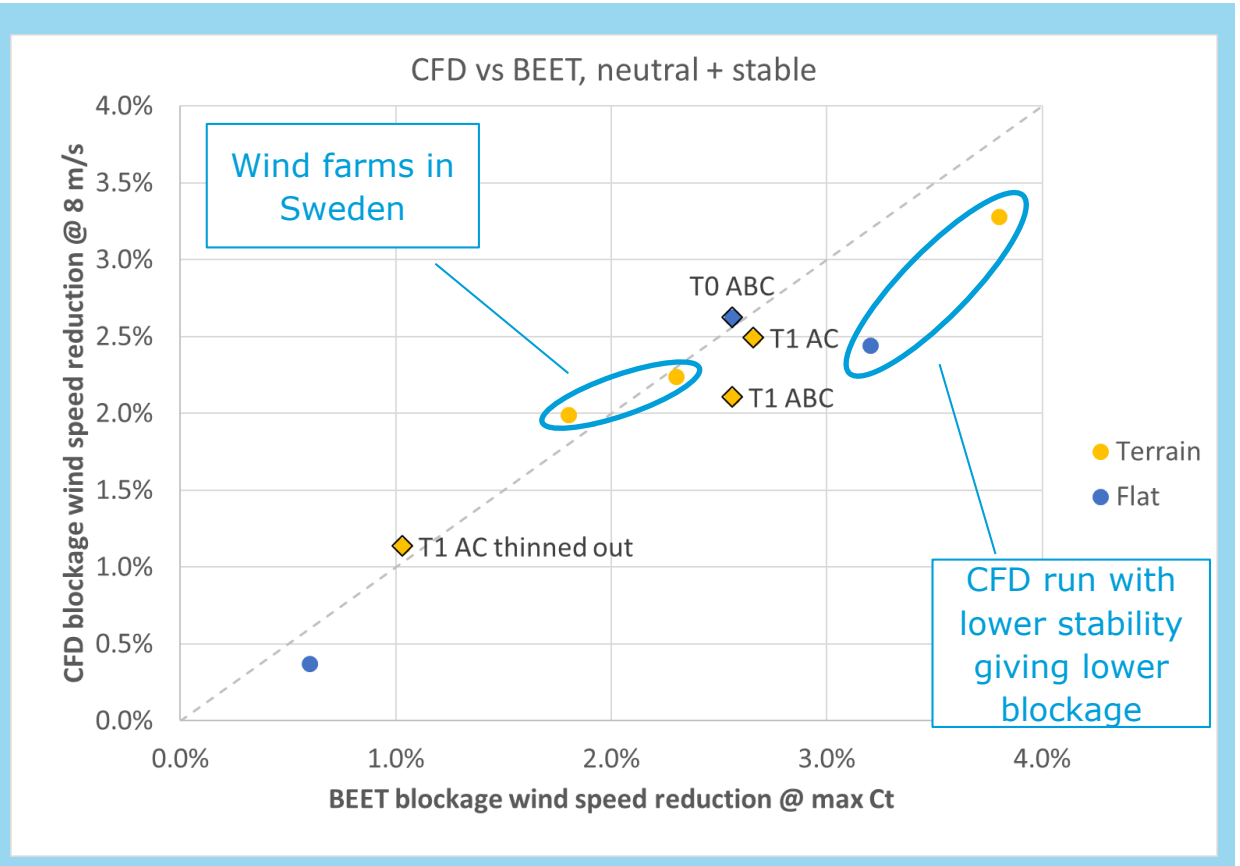


Low density (AC thinned out) shows barely any blockage

4.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





5.Conclusions

- **Blockage effects as calculated by CFD can be well approximated by DNV GL's Blockage Effect Estimation Tool (BEET)**
  - **Includes sites with irregular layouts, varying terrain, forestry and varying roughness**
- **Forestry and roughness are found to have limited impact on blockage**
- **Terrain at complex sites can be important and may reduce the blockage effect**
  - **Flat and moderately complex sites well approximated by BEET**
  - **For complex sites, site-specific CFD can be used to define more accurate loss and reduce uncertainty**

Thank you for listening

Further reading: Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production
https://www.mdpi.com/1996-1073/11/6/1609

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