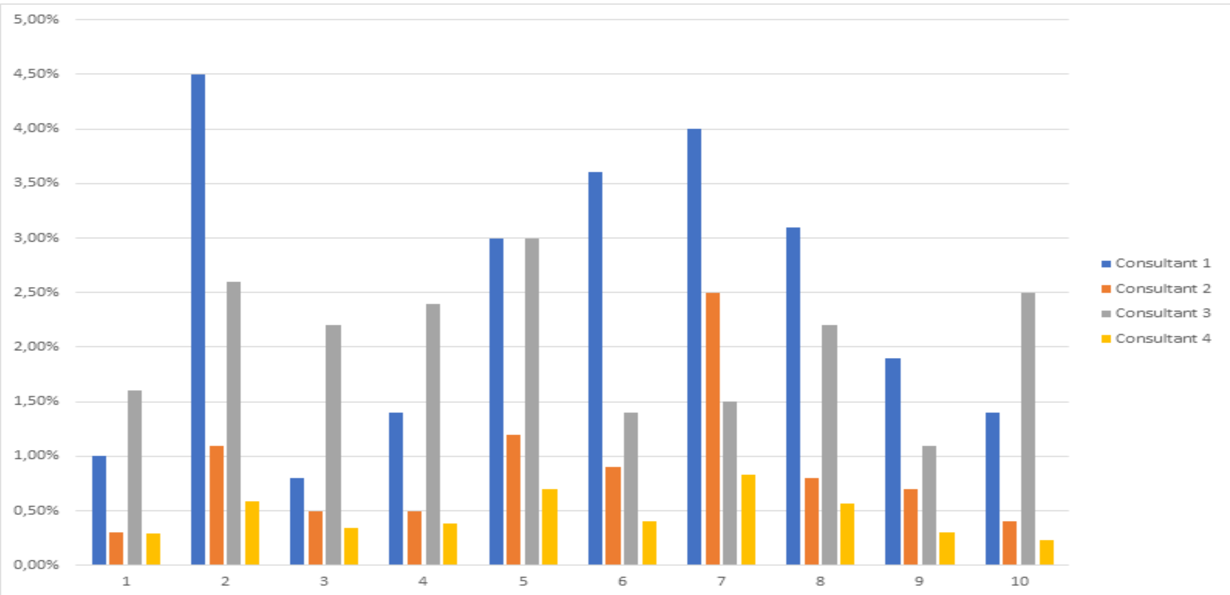
Summary of the workshop regarding the Wind Farm Blockage Effect for onshore wind farms, at WinterWind, February 3rd, 2020

Background

Ørsted issued a press release on October 29th, 2019 containing the following statement: *[…] The blockage effect arises from the wind slowing down as it approaches the wind turbines. There is an individual blockage effect for every turbine position and a global effect for the whole wind farm, which is larger than the sum of the individual effects. Our new wind simulation models show that we have historically underestimated these blockage effects. This finding is also supported by industry consultant DNV GL's recent report on blockage, which indicates that this effect is more broadly underestimated. […]*

The typical onshore wind farm differs from the typical offshore wind farm in a number of ways that may affect the size of the wind farm blockage effect. Such differences may include the number and the size of the installed wind turbines as well as the chosen hub heights, a higher surface roughness onshore, and terrain features within and around the wind farm.

Various models are used in order to estimate production losses that originate from the wind farm blockage effect for onshore wind farms. The below graph shows the wind farm blockage effect as quantified for 10 different wind farms by four different 3rd-party consultants. As seen in the graph the highest and lowest estimates can differ by a factor of 5 of more.



The estimated losses are varying to an extent that is heavily influencing the bankability of wind farm projects during development. Industry players are therefore in need of ensuring a common understanding and definition of what is included when quantifying wind farm blockage effect.

RISE and the Swedish Windpower Association therefore invited to a workshop on the *Wind Farm Blockage Effect for onshore wind farms*. The workshop was held at the Winterwind conference in Åre, Sweden on February 3rd, 2020, from 09:00 to 12:00. Approximately 30 participants representing wind turbine manufacturers, project developers, wind farm owners, 3rd party consultants as well as academia, participated in the workshop.

Summary of the discussions

Welcome Introduction of all participants Blockage effect - Introduction & overview of research

Jan-Åke Dahlberg gave an introduction on the blockage effect and showed some key results from his and Antonio Segalini's recent wind tunnel investigations on wind farm blockage effect: 00_1_56_Dahlberg_Global_blockage_offshore_onshore_reality_or_myth.pdf

Martin de Maré showed some selected results from research regarding blockage: 00_1_57a_de_Mare_Overview_of_Blockage_Research_Pub.pdf

Quantification of blockage by third party consultants

Ivar Rush presented K2 Management's current approach to quantifying the wind farm blockage effect: 00_1_57b_Rush_WinterWind2020_OnshoreBlockage_Pub.pdf .

Dr. Bárbara Jiménez Douglas, presented UL International's current approach to quantifying the wind farm blockage effect: 00_1_57c_Jimenez_Douglas_Wind_Farm_Blockage_Effect_03022020_Pub.pdf .

Morten Lybech Thøgersen presented EMD International's current approach to quantifying the wind farm blockage effect.

Iain Nisbet presented Wood's current approach to quantifying the wind farm blockage effect: 00_1_57d_Nisbet_Cumulative_Induction_Zone_Effect_Pub.pdf .

Till Beckford presented DNV GL's current approach to quantifying the wind farm blockage effect: 00_1_57e_Beckford_Winterwind_Blockage_Workshop_Pub.pdf .

All the above hyperlinks point to the repository at https://windren.se/WW2020/ .

Workshop on

- Definitions of the blockage effect
- Influencing parameters
- Validation possibilities
- Way forward

Definitions of the blockage effect

As was highlighted in the overview of research, Feszty et al (2016) showed that a reduction in the incoming wind speed due to blockage doesn't necessarily lead to a reduction in the produced power. For this reason, it was argued in the workshop that it is preferable to base a wind farm blockage effect quantification on the power produced by the wind turbines, and not on the incoming wind speed.

Bleeg et al (2018) described how the wind industry has a history of quantifying wind turbine wakes by comparing the production of waked wind turbines to the production of the un-waked front row wind turbines. In this "wake-only" approach, the front row wind turbines are assumed to produce the same amount of power as a wind turbine operating in isolation would produce. If the wind farm influences the production of the front row wind turbine, the wake-only paradigm will propagate this bias to the waked wind turbines. In the paper, the following steps were proposed for arriving at a wind farm blockage correction:

1. For the un-waked wind turbines set $P_{WO} = P_I$. Here P_I denotes what a wind turbine would have produced if the rest of the wind farm was not present.
2. For wind turbines in wake of other wind turbines set $P_{WO} = P \cdot \left(\frac{\sum P_{WO}}{\sum P}\right)_{unwaked\ waking\ WTGs}$
   As indicated only front row wind turbines that wake downstream wind turbines, are included when calculating the factor on right hand side.
3. A wind farm blockage correction, for a particular wind speed and wind direction, is now defined as $\frac{\sum P}{\sum P_{WO}}$.

The most popular terms to use for the above metric were:

- *Wind-farm-scale Blockage*
- *Wind farm Blockage*

while the following terms garnered only limited backing by the workshop participants:

- *Wind farm Upstream Interaction,*
- *CIZE (Cumulative induction Zone Effect)*
- *Global Blockage.*

Comments in the workshop:

- *How does this definition interact with power performance measurements/definitions for the front turbines? Is there a risk of double counting?*
- *Ideally wake and blockage (or downstream and upstream turbine interaction effects) should be treated in unison since it is challenging to separate the two effects in a stringent way.*

Influencing parameters

There was limited time in the workshop to discuss the parameters believed to influence the wind farm blockage effect one-by-one in detail. Here is therefore a list of parameters mentioned by the presenters and participants during the workshop:

- Boundary layer height
    - Mentioned as potentially important in the presentation from UL.
- Hub height (in relation to rotor diameter)
    - Important factor according to the presentations from DNV and Wood.
- Installed capacity and number of wind turbines
    - Important factor according to the presentation from UL.
    - Limited influence according to the presentation from DNV.
- Number of rows in the main wind direction
    - Experiments in presentation by Jan-Åke Dahlberg indicated that the amount of wind farm blockage leveled out after approximately 5 wind turbine rows.
    - Important factor according to the presentation from UL.
- Stability of the boundary layer
    - Important factor according to presentations from DNV and Wood
    - See also e.g. Allaerts and Meyers (2017)
- Stratification of the free atmosphere above the boundary layer
    - Important factor according to Wu and Porté-Agel (2017)
- Terrain complexity
    - Important factor according to the presentations from DNV and UL.
- Turbulence intensity and surface roughness
    - Experiments in presentation by Jan-Åke Dalbergs indicated increasing wind farm blockage effect with turbulence intensity.
    - Important factor according to the presentation from UL.
    - Low importance according to the presentation from DNV.
- Wake losses
    - Used by several 3rd party consultants as input to the wind farm blockage quantification.
- Wind rose and layout shape
    - Important factor according to the presentation from UL.
    - Low importance, unless extremely directional wind rose and layout, according to the presentation from DNV.
- Wind turbine density
    - Important factor according to the presentations from DNV and Wood.
    - Important factor also according to presentation by Jan-Åke Dahlbergs where the following definition of turbine density was used $\frac{S_x S_y}{D^2}$, where S_x and S_y are the turbine spacings in the grid layout, and D is the rotor diameter. There was no discussion in the workshop for how turbine density is defined for non-grid layouts.
- Wind turbine thrust-curve and wind speed distribution
    - Important factor according to the presentation from DNV.

Validation possibilities and the way forward

The workshop concluded with a very short discussion regarding validation possibilities and the way forward. The main take-aways were:

- More research is needed in order to shed light on the quantity of the wind farm blockage effect in different situations, as well as which parameters needs to be taken into account when quantifying of the wind farm blockage effect in practical situations.
- The industry would benefit from collaboration around the production of reference LES results that can be used for development and validation of computationally less demanding models.

Comments in the workshop:

- *Inspiration may be taken from the comparisons between wind tunnel results and LES calculations organized by NTNU in a series of blind test workshops.*

Wrap-up of discussion

The organizers very much encourage initiatives addressing the issues discussed in the workshop.

References

Allaerts, D., & Meyers, J. (2017). *Gravity Waves and Wind-Farm Efficiency in Neutral and Stable Conditions*. Boundary-Layer Meteorology, 166(2), 269–299. https://doi.org/10.1007/s10546-017-0307-5

Bleeg, J., Purcell, M., Ruisi, R., & Traiger, E. (2018). *Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production*. Energies, 11(6), 1609. https://doi.org/10.3390/en11061609

Feszty, D., McTavish, S., Bodnya, I., & Jee, D. (2016). *"Synthetic shroud" concept for wind turbine performance optimization*. 14th International Energy Conversion Engineering Conference. https://doi.org/10.2514/6.2016-4820

Wu, K., & Porté-Agel, F. (2017). *Flow Adjustment Inside and Around Large Finite-Size Wind Farms*. Energies, 10(12), 2164. https://doi.org/10.3390/en10122164