WIND FARM BLOCKAGE EFFECT

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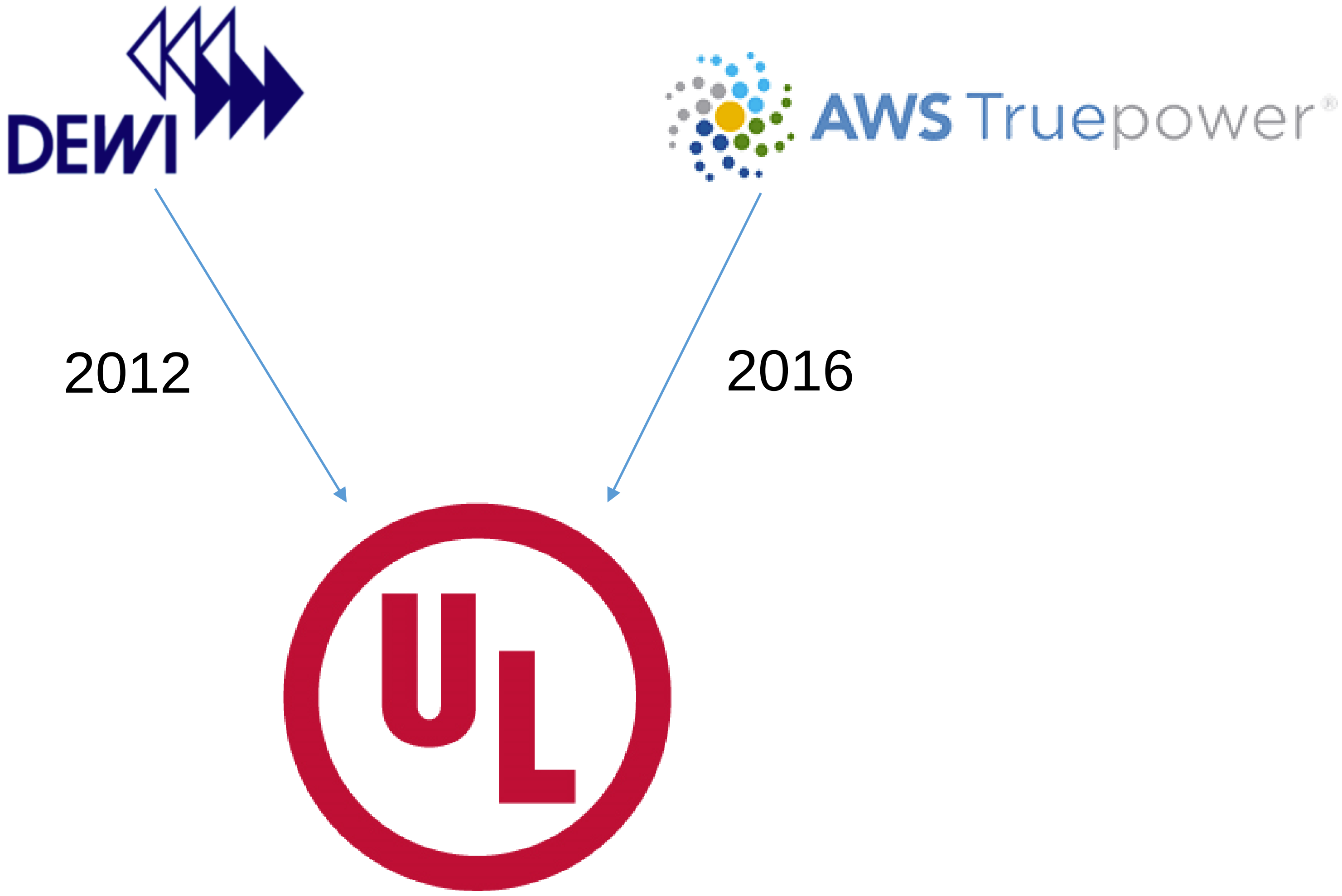
UL Renewables



Global presence

143+
Countries with office locations

500+
Renewable energy experts

Wind Service portfolio overview

● = Advisory, Testing and Inspection Services

● = Certification

Energy Yield Assessment

Work actively in international Committees (IEC, MEASNET and FGW)

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Blockage effect

Recent studies shown this effect is not negligible and increases significantly in magnitude, when a considerable number of wind turbines are operating close to each other.

Impact:
Overestimation in pre-construction studies based on standard wake models, which address only downstream wakes and none upstream effects.

Blockage effect: Recent studies

- *SgurrEnergy* (Asimakopoulos et al., 2014): Upwind "compression zone" extending 2.5-3.5 RD in front of an offshore wind farm arranged in 3 downwind rows. Reduction in wind speed compared to free stream was reported to be **1%-3%.**
- *DNV* (Bleeg et al., 2018): Estimation around **2%** wind speed deficit at an upwind distance similar to distance between rows, in a wind farm array with 7 turbine rows. This studies also shows that "wind-farm-scale blocking" has a much bigger magnitude of the "turbine-scale blocking".
- *AWST Backcast 2018* (Ziesler et al., 2018a): Tendency of the mean bias (between pre and post construction studies) to become increasingly negative with larger plant size (above 50MW). Plants less than 50 MW in size appear to show little or no bias; above 50 MW, the bias increases with the farm size. WRF simulation confirmed the increasing effect as increasing the number of turbine rows of the wind farm.
- *Natural Power* (Spalding, AWEA, 2019): Blockage loss is primarily depent on the array geometry and wind rose. They estimate blockage losses range form **0.3% to 1.5%** at most projects.
- *ProPlanEn* (Wolfgang, WindEurope, 2019): Hub height, rotor diameter and ground clearance dependency of the wake effects.

Blockage effect: UL approach

- Blockage effect in function of the plant size (installed power) and the number of rows.
- Approach based on recent backcast studies comparing with WRF modeling.

Table 1: Summary of the 2008, 2012 and 2018 Backcast Study Datasets

Parameter	2008	2012	2018
Wind Plants	11	24	61
Total Plant Operational Years	45	106	253
Average Operational Years Per Plant	4.1	4.4	5.1
Range of Operational Years per Plant	1 to 7	1 to 11	1 to 10
Average Plant Capacity (MW)	74	82	83
Range Plant Capacity (MW)	10 to 160	10 to 210	5 to 239

Blockage effect: UL approach-Calculation

Total Blockage Loss (TBL) is calculated with the following formula, which was derived from WRF simulations:

$$TBL = Min(Bf \ * Wtot, 3.0\%) * Mf$$

Where

- $Wtot$ is the total wake loss (internal + external wakes)

- Bf *is the blockage factor, which depend on the wind farm installed power P:*

$$Bf = Min\left(\frac{(P - Pmin)}{(Pmax - Pmin)}.Fmax, Fmax\right)$$

  Being $Pmin$ = 50 MW, $Pmax$ = 200 MW and $Fmax$ = 37%

- The product ($Bf \ * Wtot$) is called the “blockage loss”. Maximum Blockage loss is 3% .
- Mf is the *modification factor* which depends on the number of turbine rows in the main wind direction. Estimated from WRF modeling work done to quantify the effect of the number of rows in the prevailing wind direction on the blockage loss.

Blockage effect: UL approach-Calculation

- Variation of the blockage factor and the modification factor, as a function of the plant size (installed power) and the number of rows respectively.
- Blockage effect starts to have an impact for wind farms bigger than 50 MW with more than 1 row of turbines in the main wind direction.

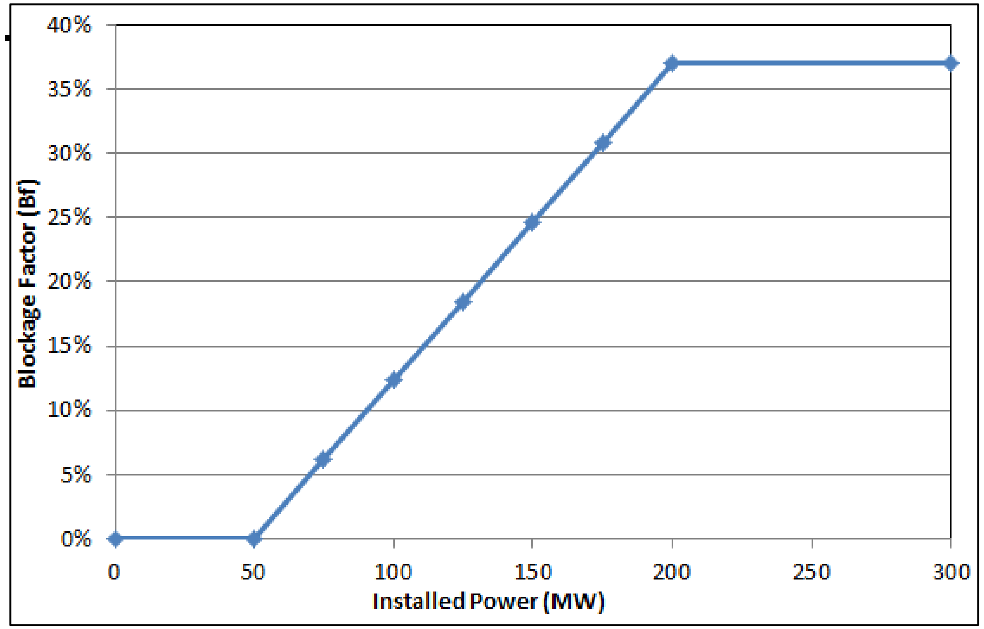

Figure 1 – Blockage Factor as a function of the wind farm installed power

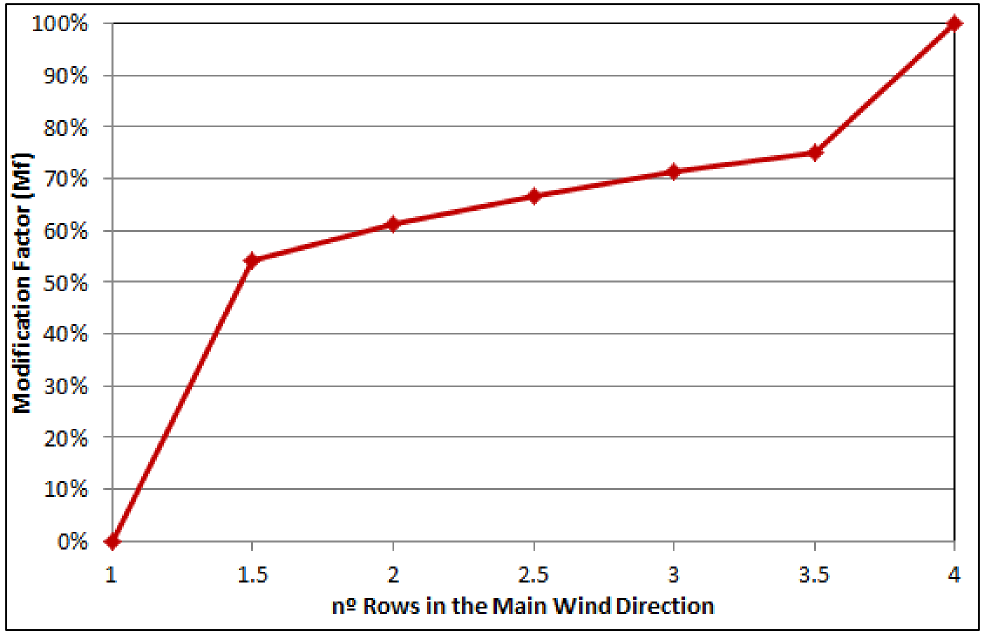

Figure 2 – Modification Factor as a function of the nº of row in the main wind direction

Blockage effect: UL approach-Calculation

EXAMPLE:

P= 175 MW

Wake loss= 6.7%

Wind farm with two rows

Bf= 30.8%

Blockage loss=6.7%*30.8%= 2.07% **Maximum 3%**

Mf= 61.2%

Total Blockage Loss (TBL)=2.07%*61.2%= 1.26%

Wake loss including blockage= 6.7%+1.26%=**7.96%**

The Total Blockage Loss (TBL) is directly summed to the wake loss

Blockage effect: UL approach-Calculation

Summary

- The blockage loss varies from 0% to 3%.
- It depends on the plant capacity and the number of rows.
- No blockage loss, when plant capacity is below 50 MW or there is a single row.

Important to define the “block” of wind turbines (including the neighboring wind farms)

Blockage effect: Parameters and effects

<u>Which effects should be considered under "Blockage"?</u>

<u>Wind Resource Assessment Group (WRAG) meeting, 08102019</u>.

Blockage brief by Wolfang Schlez, ProPlaNen.

1. Single turbine induction zone (blockage).
2. Wind farm induction zone (blockage).
3. Wake-ground interaction in a wind farm (blockage, ground clearance, hub height/rotor diameter, stubby turbines and ground effect).
4. Wake-wake interaction in a wind farm (blockage, turbine density, close spacing, deep array losses and large wind farm effect).
5. Mesoscale blockage, impact on the atmospheric flow (blockage and mesoscale impact).

Blockage effect: Parameters and effects

Which parameters are important?

1. Wind rose
2. Installed capacity
3. Layout
4. Terrain
5. Turbulence intensity

Height boundary layer???

Future Steps

- Actual collaboration with the University of British Columbia to run detailed LES of a large number of different turbine layout configurations in order to attempt to derive a simple model of the combined induction effect from multiple wind turbines.
- Future work is planned to include:
  - How to combine induction and array loss into one model
  - The effect of the terrain complexity on induction effects

THANK YOU!!!