Turbine interaction (Wake+Blockage) losses vs layout density

Energy Analytics Wind-France

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0. Introduction

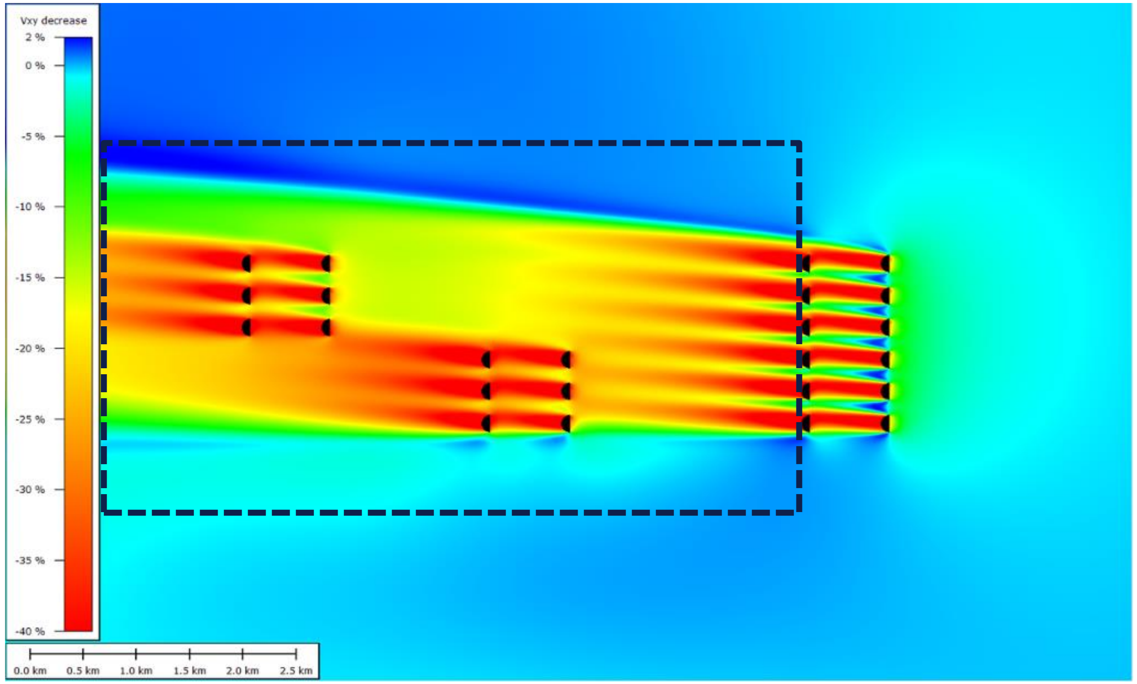
- The French government is currently conducting a wide public debate in order to define the locations and size of the next strategic proposed bidding wind farm areas, as part of the future French offshore tenders of the next 10 years and further, up to 2050. These areas are to allow the installation of at least 45GW of offshore wind power off the French coasts. The DGEC has split these installations among 4 distinct coastlines around France:

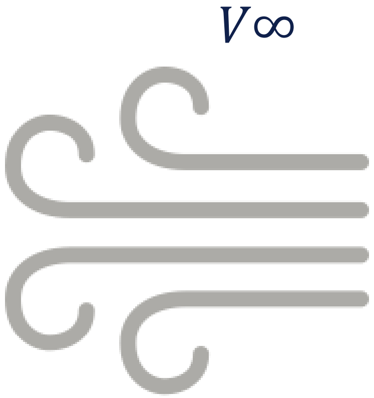
Coastline	Installed/pre-planned Capacity [GW]	Additional capacity planned for 2033 [GW]	Total planned Capacity by 2050 [GW]
MEMN	4.6	7 - 11	12 – 15.5
NAMO	2.2	5.5 - 9	17 - 25
SA	2	1.5 – 4.5	8 - 11
MED	1.6	2 – 3.5	4 – 7.5

- Direction Générale de l’Energie et du Climat (the "Customer") has retained DNV France SARL, part of the DNV Group (“DNV”), to undertake an indicative analysis of the sensitivity of **Turbine Interaction Losses** (Blockage + internal Wakes) to **layout density** (MW/km^2), for densities of 5, 7.5, 10, 12.5 and 15 MW/km^2.
- The wake losses vs density indicative study we present here used a representative wind rose of the Manche Est – Mer du Nord (MEMN) zone.

1 Project Description: Wake Losses

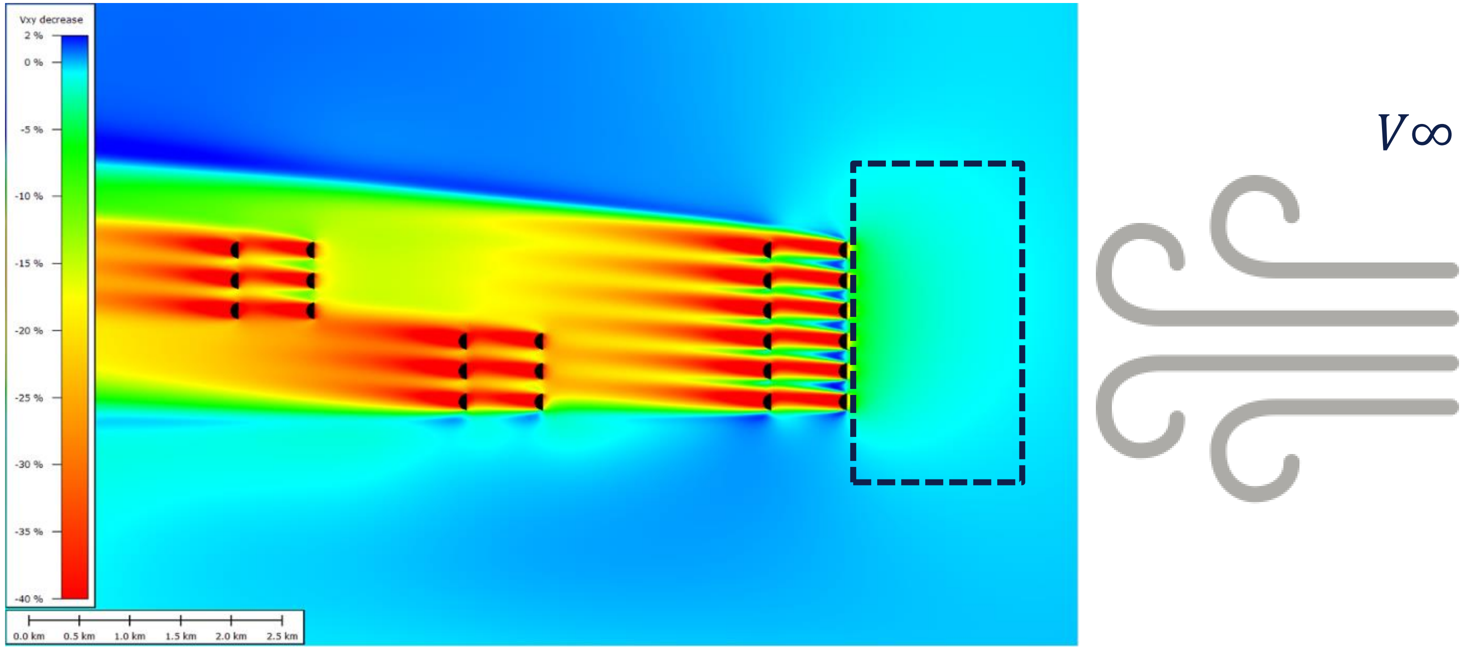
- Freestream wind passing from a turbine creates a deficit of velocity downstream of the turbine.
- Turbines downstream an operating turbine rows reduce their production
- Precise prediction of Wake loss is crucial for an Energy Production Assessment (EPA) of a wind farm





1 Project Description: Blockage losses

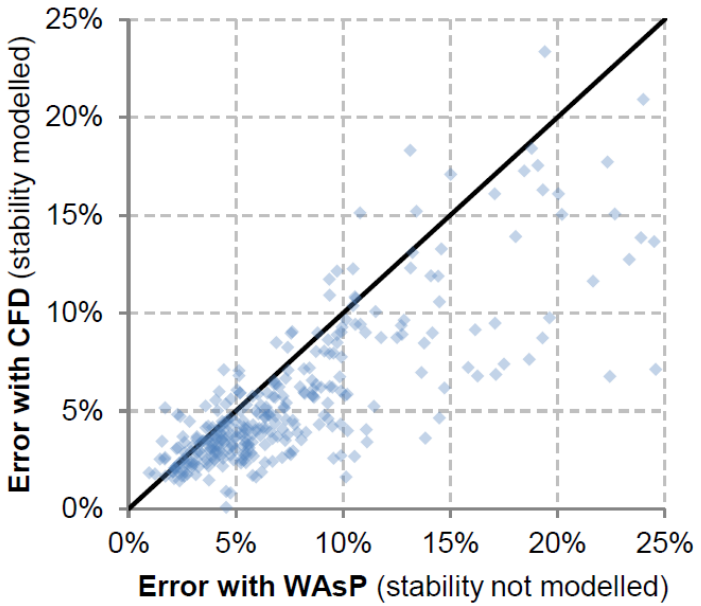
- What is blockage? Wind speeds just upstream of a farm decrease relative to locations farther away
- Turbines experience lower incoming velocity than what we really think
- Parameters like layout density, atmospheric stability and HH/RD ratio play a role in the final blockage loss value
- Precise prediction of Blockage loss is crucial for an Energy Production Assessment of a wind farm

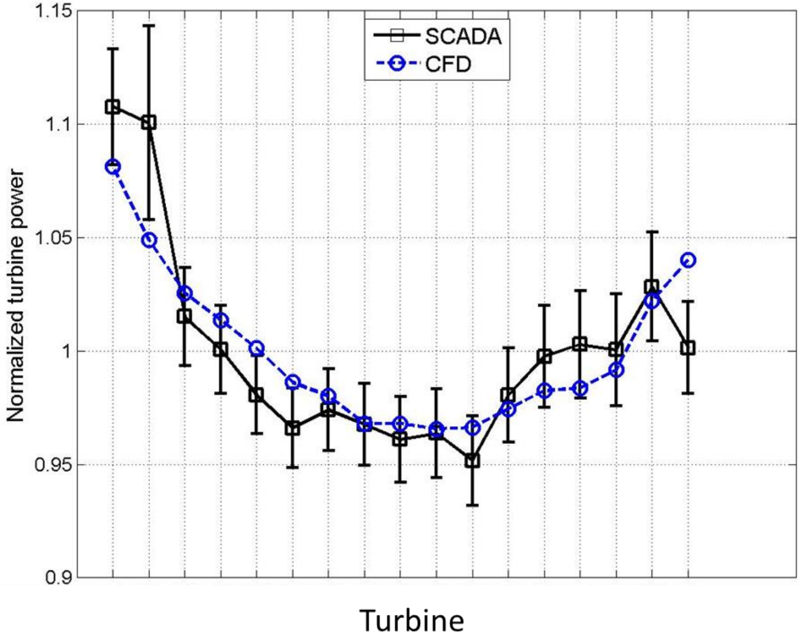


2018 :Bleeg et al. Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production, https://doi.org/10.3390/en11061609, https://www.mdpi.com/1996-1073/11/6/1609

2. Model Description

- RANS k-ε model, modelling Atmospheric Boundary Layer and Free atmosphere up to 17 km.
- Extensively validated against WAsP *
- Extensively validated against mast, SCADA and lidar measurements**





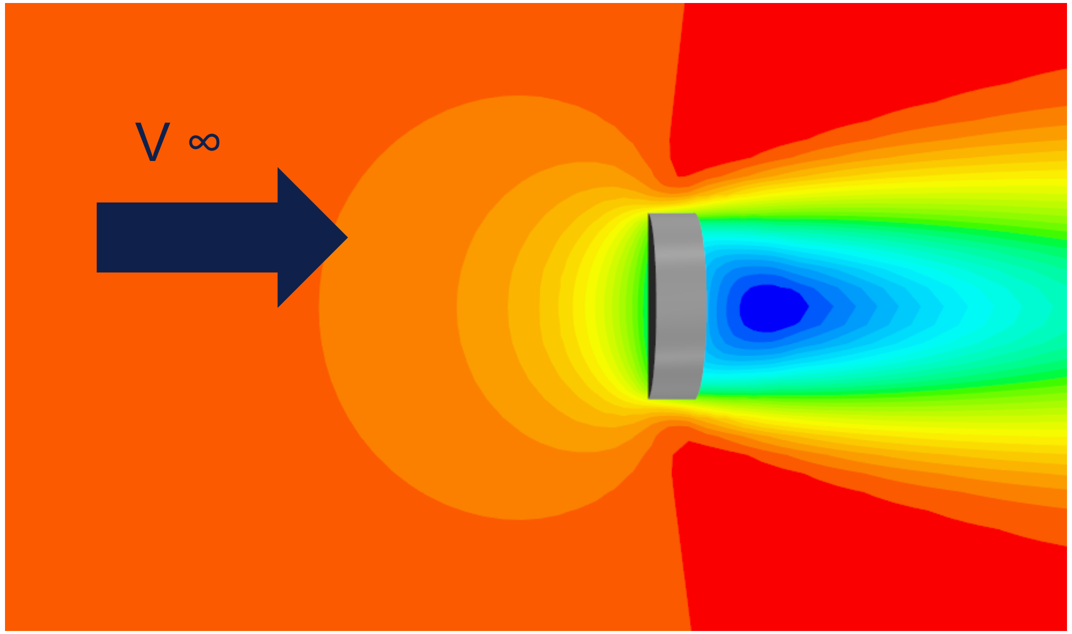
* J.-F.Corbett, Poenariu, Horn, Leask, An extensive validation of CFD Flow Modelling, DEWEK 2015, Bremen

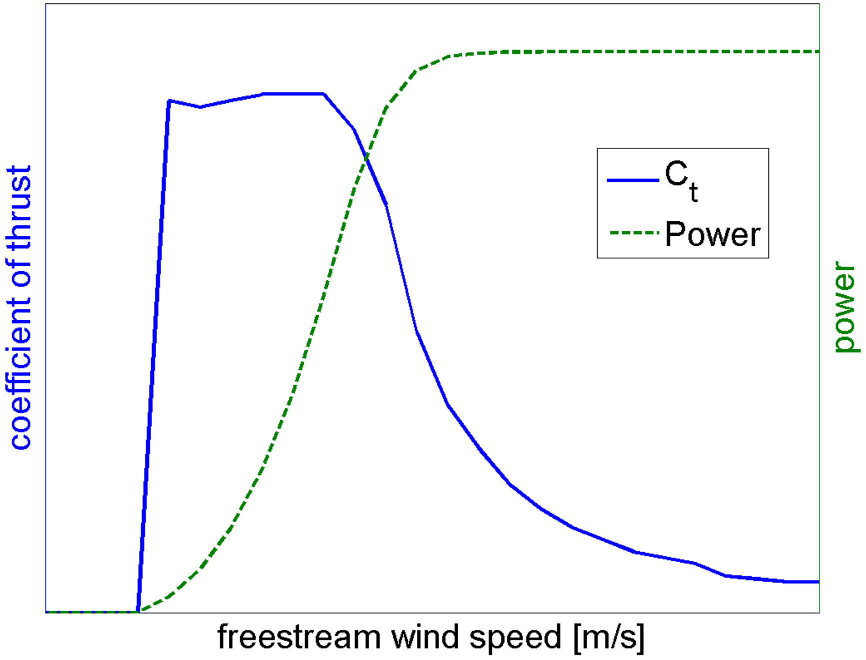
*** **1.**Bleeg, James, et al. "Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production." Energies, vol. 11, no. 6, 2018, p. 1609., doi:10.3390/en11061609*

***2.** Montavon et al., Blockage and cluster-to-cluster interactions from dual scanning lidar measurements, WESC 2023*

2. Representing the wind turbines

- Wind turbines represented with an actuator disk
- Body forces applied based on curves of C_t, power, and rotor speed
- Precursor simulations carried out for single turbine to transform Ct and power curve to be expressed as a function of the mean wind speed at the rotor face
- Subsequent simulations for array derive turbine power and thrust from wind speed at rotor face





3. Assumptions of the study

1. **RANS steady-state** CFD simulations (at incoming velocity of 0, 30, 60, 90,120,150, 180, 210, 240, 270,300, 330 degrees) per layout density, together with **interpolated** directional sectors using an **AI interpolation** model (Neural Network*). It is noted that the CFD-predicted turbine interaction loss factors are sensitive to the number of directions simulated.

2. **Actuator disk model** used to represent the turbines.

3. **Neutral only Boundary Layer (BL)** atmospheric conditions (with stability included in the Free Atmosphere) : Stability conditions in the BL plays an important role regarding the physics of turbine interactions in offshore wind farms, stability in the BL was not accounted for in these simulations.

4. **Symmetric rectangular layout** assumed for symmetry, with aspect ratio 1.66 : A generic study for relative trend results, not a site-specific study.

5. **No coastal effects** were included in the study (purely offshore surface)

6. **Generic Power curve** model of 20MW assumed at 160 m Hub height, with a constant total of 100 turbines in each case

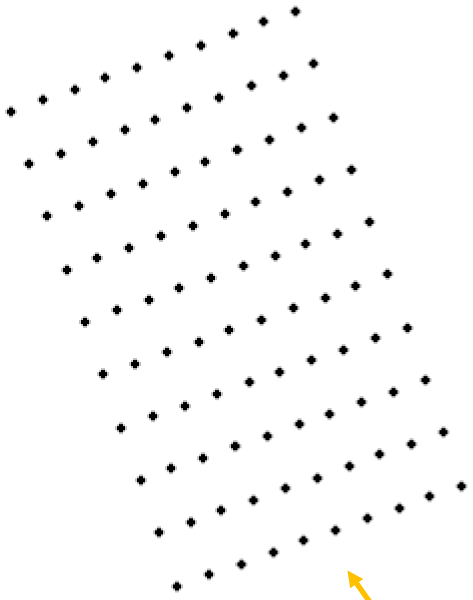
7. Results presented for wind rose representative for point the **MEMN zone**, background wind resource information by **VORTEX****.

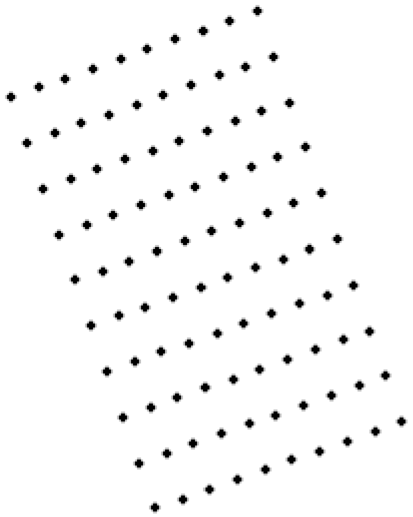
8. Orientation of wind farm in dominant wind rose direction (255 degrees)

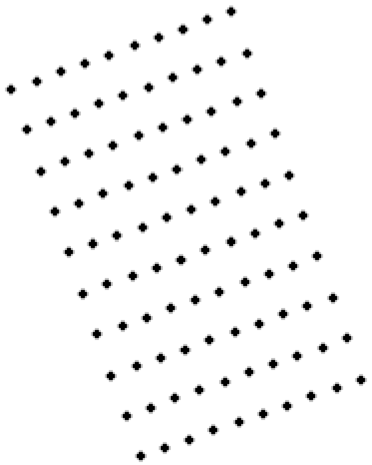
J.Bleeg, A Graph Neural Network Surrogate Model for the Prediction of Turbine Interaction Loss, Journal of Physics:Conference Series ,1618 (2020)

***** www.vortexfdc.com***

3. Layouts



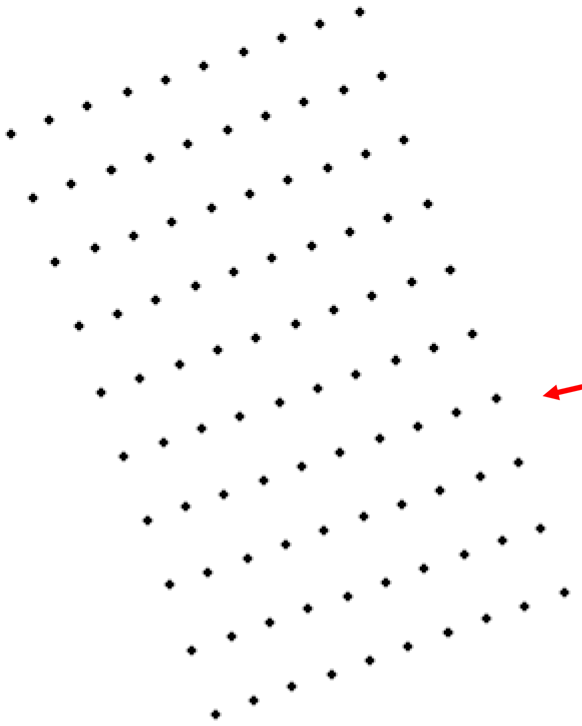


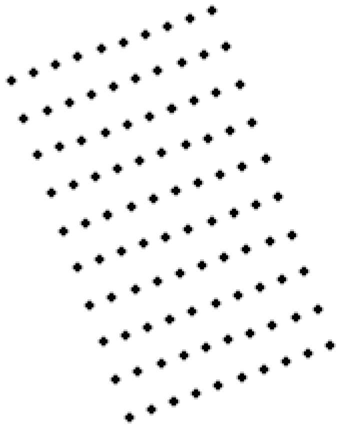


Five Densities studied:

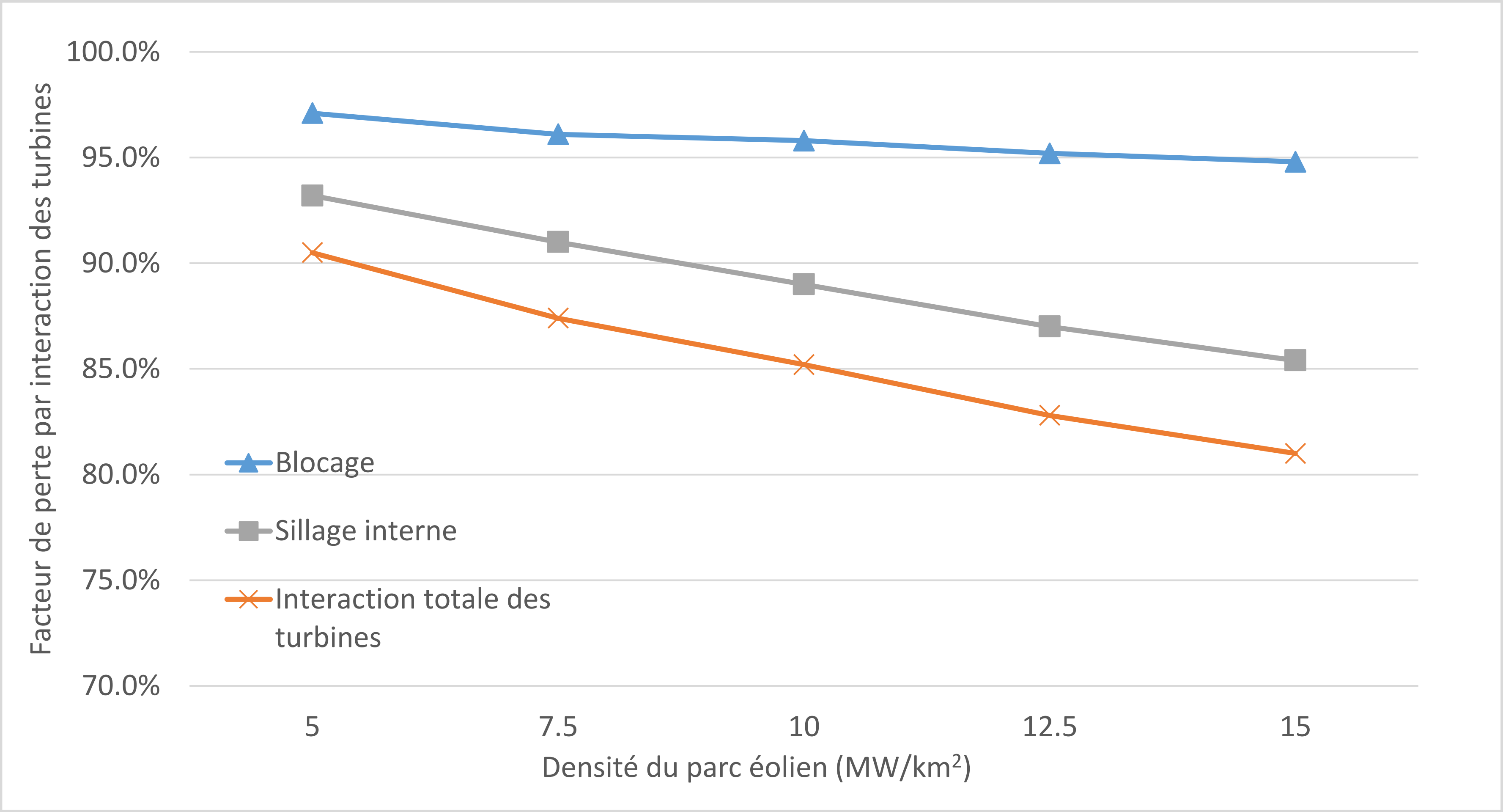
5, 7.5, 10,12.5, **15** MW/ Km2

- Aspect Ratio: 1.66
- Nominal Power: 20MW
- RD: 276
- HH:160
- Number of Turbines: 100



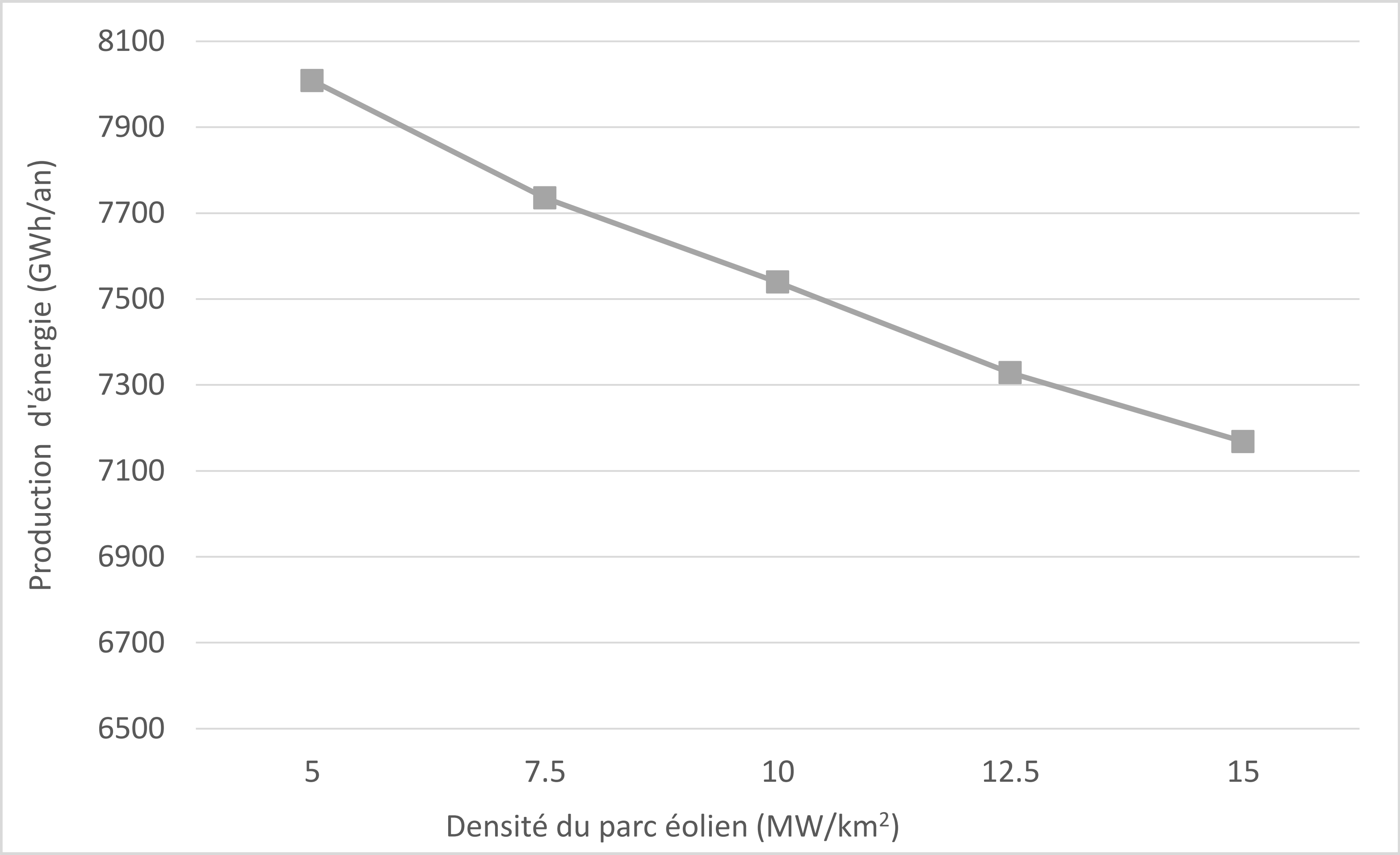


4.1 Turbine Interaction Results: Wakes and blockage



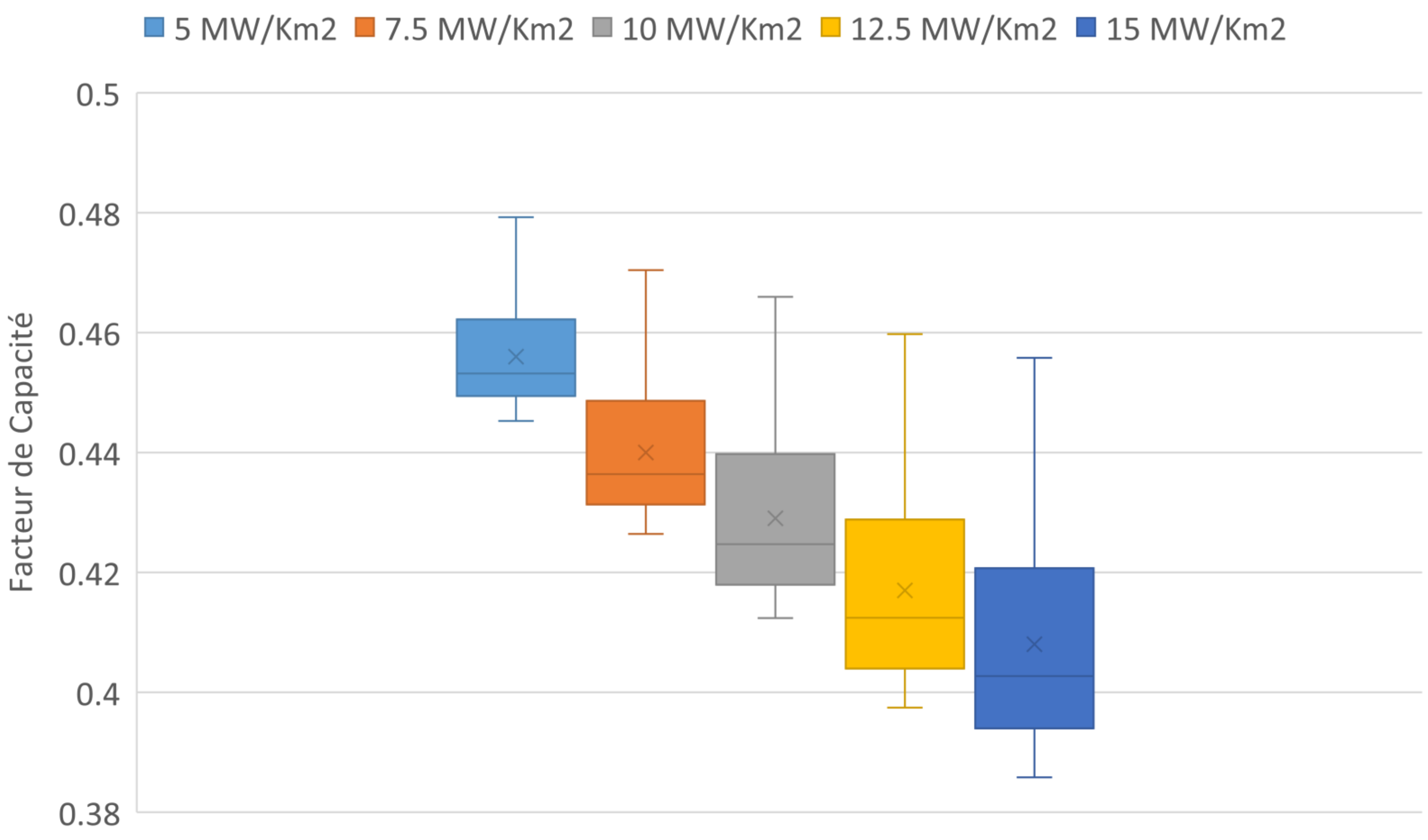
**based on assumptions presented in slide 8*

4.1 Turbine Interaction Results: Indicative energy Production



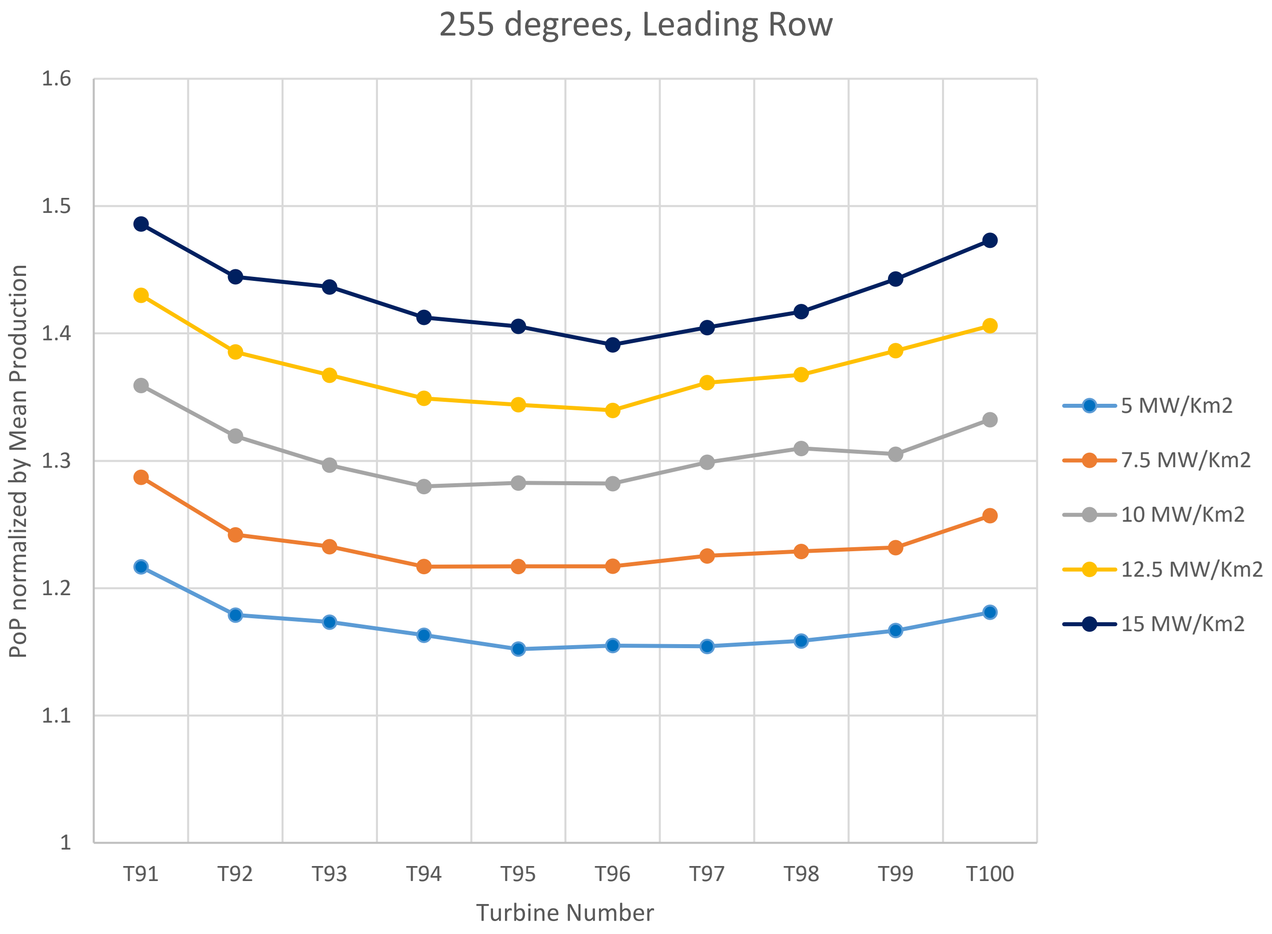
**based on assumptions presented in slide 8*

4.2 Turbine Interaction Results: Indicative capacity factor variation per turbine

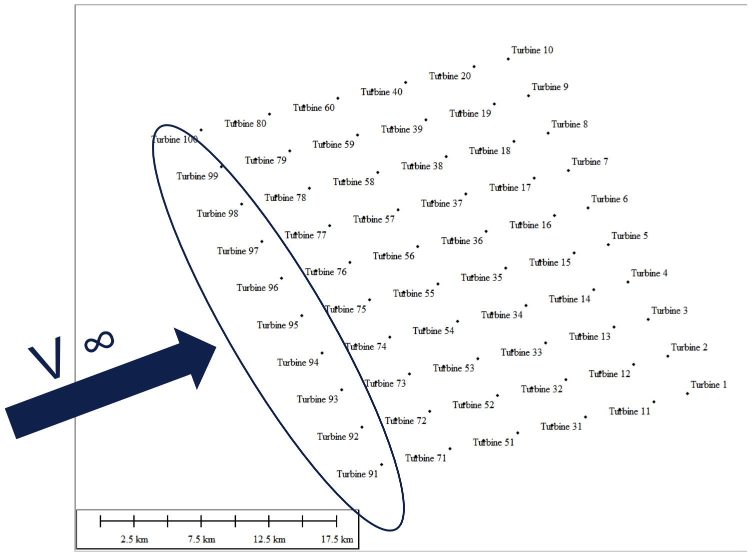


**based on assumptions presented in slide 8*

4.2 Results per Turbine **per direction**: Leading Row



**results based on assumptions presented in slide 8*



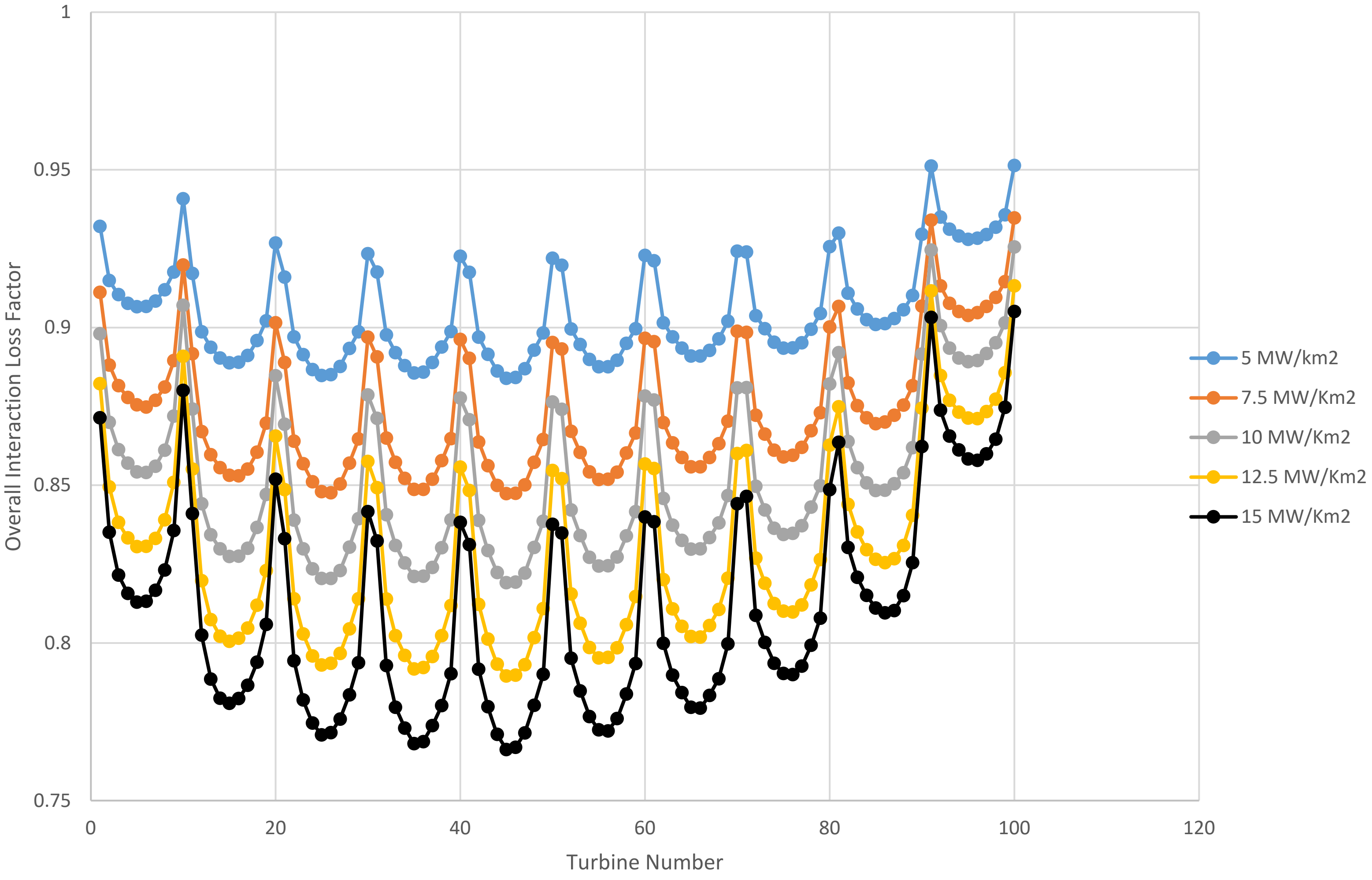
$$PoP = Pattern\ of\ Production$$

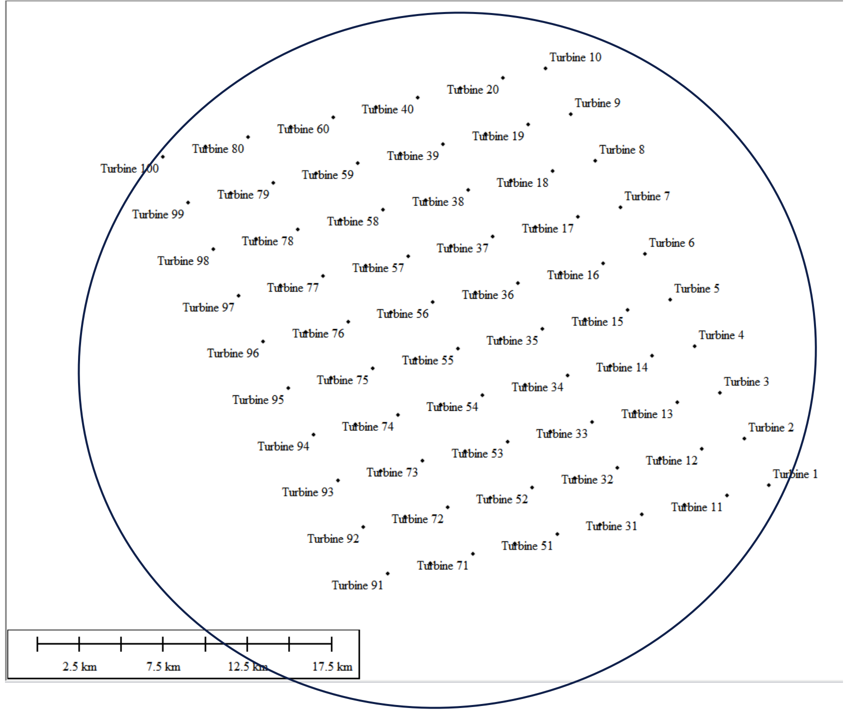
$$PoP = \frac{Individual\ Turbine\ Energy}{Total\ Wind\ Farm\ Energy}$$

$$Mean\ Production = \frac{\sum(Individual\ Turbine\ Energy)}{\#\ Turbines}$$

DNV

4.2 Results per Turbine all directions





** Results based on assumptions presented in slide 8*

DNV

Overall results (matrix)

Case number	**1**	**2**	**3**	**4**	**5**
Density (MW/Km2)	**5**	**7.5**	**10**	**12.5**	**15**
Blockage Loss Factor	97.1%	96.1%	95.8%	95.2%	94.8%
Turbine interaction Loss Factor (TIL)	90.5%	87.4%	85.2%	82.8%	81.0%
Wakes-only Loss Factor	93.2%	91.0%	89.0%	87.0%	85.4%
Area km2	400	267	200	160	133
Indicative Capacity Factor (%)	46%	44%	43%	42%	41%

Final conclusions

- From the total turbine interaction losses (wakes and blockage), wake losses are the most sensitive to the turbine layout density
- From 5 MW/k$m^2$2 to 15 MW/Km^2, the total turbine interaction difference is in the order of 10%
- Site-Specific studies using high fidelity modes are needed to specify with precision the turbine interaction losses in the final layout scenarios, turbine models and atmospheric conditions.

Thank you for your attention

Energy Analytics-Wind, France

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