Waking up to the magnitude of cluster & far-field wakes: Effects on wind farm AEP

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1. DNV 2. RWE

Intro

The effect of wind farm wakes onto the annual energy production (AEP) is investigated, for two wind farms in the North Sea. The study builds on results presented in [1] and compares the total turbine interaction losses predicted by five models, with a range of fidelity.

Methods

SCADA data from two wind farms is cleaned, processed, & filtered:
1. Amrumbank West (AMK) in Germany, with neighbors (4 yrs)
2. Triton Knoll (TK) in the UK, with neighbors (2.25 yrs)

This delivers a normalized pattern of production (PoP).
PoP at TK is corrected to remove coastal gradients using WRF.

Model validations are carried out for conditions on the plateau of the thrust curve, for a range of sectors.

Models evaluated include:
1. WindFarmer (EVM + LWF 2022 wake settings)
2. RWE VV (EVM + RHB, varying stability by direction)
3. RWE CFD (one set of site average conditions, slightly stable)
4. DNV CFD (combined over two sets of stability conditions)
5. WRF-WFP, default Fitch using a TKE coef. of 0.25 & MYNN PBL

Model accuracy is assessed by comparing model and SCADA normalized PoP, using KPIs such as RMSE, and coefficients from linear correlation of model vs SCADA PoP.

Turbine interaction losses are aggregated with a synthetic wind climate → Hub height WS of 10 m/s and realistic direction dist.

Results

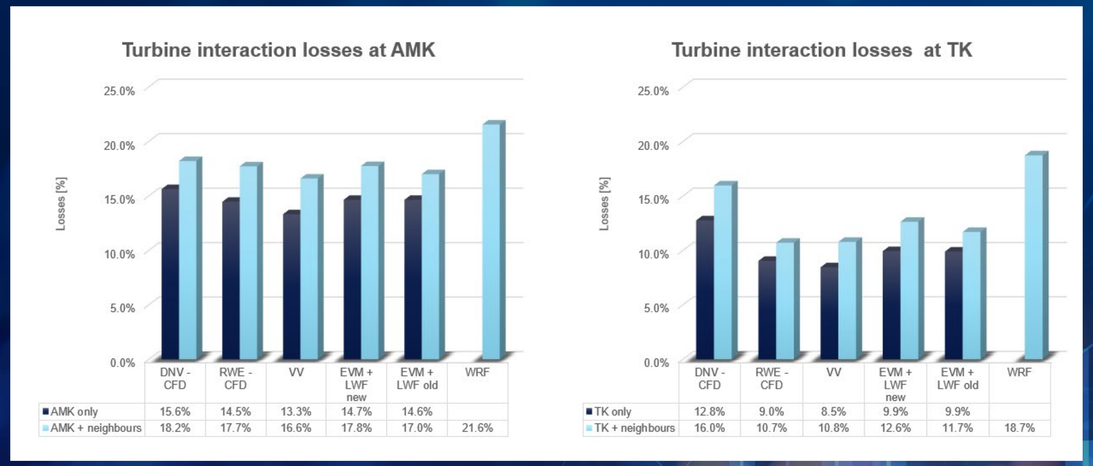
- Normalized PoP best captured by RWE CFD at AMK and DNV CFD @ TK → CFD consistently most performant across both sites.
- WRF performs surprisingly well when modelling the normalized PoP at AMK, a bit less so at TK.
- The impact of the cluster effect is large on the plateau of the thrust curve. Aggregated over the wind climate, the cluster effect shaves off about 3%-4% from the energy yield at AMK and 2%-4% at TK. WRF shows unexpectedly high losses given PoP trends.

Discussion

- At both sites, excluding WRF, the variation in turbine interaction losses between all models are within the uncertainty that would typically be assigned to them. Though somewhat worryingly, the CFD models which agree with the SCADA best also predicts the largest cluster effects.
- WRF delivers consistently larger losses than the other models, likely overpredicted based on [2], indicating a bias between freestream and wind farm power for an isolated turbine, when there should be none.

DNV-RWE collaboration confirms that **far-field wakes can persist over at least 30 km.**

WRF (with Fitch WFP) likely leads to **too low annual energy production** estimates.



Further details available for download

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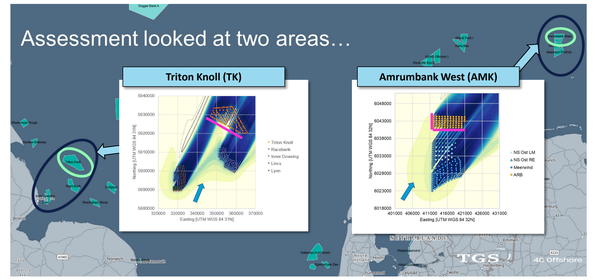
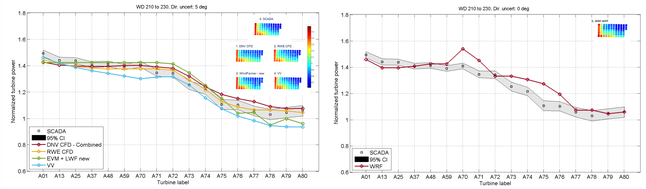
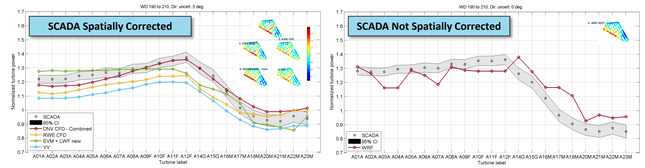
Amrumbank West and Triton Knoll Results



PoP, Models vs SCADA, Amrumbank, WD 210°-230°



PoP, Models vs SCADA, Triton Knoll, WD 190°-210°



RMSE - AMK

sector	DNV CFD - combined	RWE CFD	EVM LWF - new	EVM LWF - old	VV	WRF
190	6.2%	3.8%	7.0%	8.2%	7.3%	10.7%
200	5.2%	3.8%	7.6%	11.0%	4.3%	8.2%
210	5.2%	2.8%	6.0%	8.2%	4.5%	7.9%
220	5.4%	3.0%	5.2%	5.7%	4.1%	6.1%
230	5.6%	3.8%	5.7%	5.7%	3.9%	4.4%
240	6.4%	4.8%	6.6%	6.6%	4.3%	5.2%
250	5.8%	4.9%	6.1%	6.1%	4.8%	6.8%
260	4.9%	3.3%	5.4%	5.5%	4.2%	6.7%
	5.6%	**3.8%**	**6.2%**	**7.1%**	**4.7%**	**7.0%**

→ Lowest RMSE for RWE CFD, consistent across all directions
→ VV showing great promise

RMSE - TK

sector	DNV CFD - combined	RWE CFD	EVM LWF - new	EVM LWF - old	VV	WRF
160	8.6%	8.8%	5.6%	6.8%	7.1%	10.3%
170	6.4%	5.2%	5.9%	6.2%	6.9%	7.6%
180	3.3%	8.5%	9.6%	11.6%	8.8%	6.4%
190	4.0%	8.4%	8.0%	11.9%	8.7%	7.2%
200	3.7%	6.1%	5.4%	6.7%	8.4%	10.2%
210	4.8%	7.4%	6.1%	5.5%	9.2%	7.2%
220	7.5%	8.9%	7.0%	7.4%	11.1%	6.8%
230	8.3%	8.2%	6.4%	6.2%	11.6%	8.9%
240	5.5%	6.1%	5.5%	5.4%	8.9%	8.4%
250	4.8%	6.2%	5.1%	5.1%	8.6%	7.2%
260	4.2%	6.4%	5.0%	5.0%	7.7%	9.9%
	5.6%	**7.3%**	**6.3%**	**7.1%**	**8.8%**	**8.2%**

→ Lowest RMSE on average for DNV CFD
→ Both DNV CFD and EVM LWF reasonably consistent across both wind farms

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References:
[1] C. Rodaway et al, poster presentation, ACP 2023, Austin, https://acp2023rt.eventscribe.net/posters/posterWall.asp.
[2] Vollmer, L..; et al., Wind Energ. Sci., 9, 1689–1693, https://doi.org/10.5194/wes-9-1689-2024, 2024

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