Is the Power Density of Large Offshore Wind Farms Limited?

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Motivation

Adams and Keith, 2013:

“The results suggest that the maximum energy that can be extracted by turbine arrays at these scales is about 1 W m$^{-2}$.”
Adams and Keith, 2013

Adams and Keith, Are global wind power resource estimates overstated? (2013)

**Method**

- Weather Research & Forecast (WRF) model
- Wind farm parametrisation from Adams 2007 (Turbine drag + TKE)

Simulations over the Great plains in winter/summer 2006

**Power density estimation in function of:**
1) Wind farm size $10^3 - 10^5 \text{ km}^2$
2) Turbine (2 MW turbines) density $0.25 - 16 \text{ km}^{-2}$

**Runs with and without wind farms to predict:**
- Actual power density $P_a$ (wake effects)
- Expected power density $P_e$ (no wake effects)
Adams and Keith, 2013

Comparison between Expected and Actual power density gives:

Limit: \( P_a \sim 1 \text{ W m}^{-2} \)

Horns Rev I \( (20 \text{ km}^2) \) has a measured power density: \( 3.98 \text{ W m}^{-2} \)

This would mean: That the power density of large wind farms is only 25\% of that from regular wind farms
Was the analysis from Adams and Keith 2013 complete?

Does the power density converge to 1 W m\(^{-2}\) for different climates?

**Experiment:** WRF simulation for:
- 3 wind farm parametrisations
- 2 wind farm sizes
- 3 climates

**Wind farm parametrisations:**
- Explicit Wake Parametrisation (Volker et al. 2014)
- WRF-WF scheme (Fitch et al. 2013)
- ROTOR-DRAG scheme: local drag only

**Rectangular Wind farms** (Nominal power density 6.4 W m\(^{-2}\)):
- 2MW X 100
- 2MW X 3.600

**Wind Climates:**
Obtained from 9 idealised case simulations
Results

Dots-size is related to wind farm size
Symbols represent the wind farm parametrisations
Colours indicate the wind climates

- All actual power predictions are larger than $P_a = 1 \text{ W m}^{-2}$
- Clear (almost linear) dependency on the wind climate
- For C2 climate: $3.5 \text{ W m}^{-2}$ (100 Turbines) vs. $2.6 \text{ W m}^{-2}$ (3,600 Turbines)
Conclusion

- The power density modelled with the mesoscale model is in line with observations (3.5 W m\(^{-2}\) for 100 turbines, for the C2 climate (similar to that at HRI))

- The power density is a clear function of the climate
  \[\Rightarrow\] Consequently, the study from Adams and Keith is incomplete

- The power density decreases by around 25\%, for wind farms 36 times larger than HRI