Turbines in Hywind Tampen, Norway [own photography]

Technische Universität Braunschweig

Høgskulen på Vestlandet

A wind farm layout optimization including momentum conserving wake superposition and meandering correction

18.01.2024

EERA DeepWind 2024

Session 6A: Wind farm optimization

Daniel Sukhman

Motivation: Model & optimise large offshore wind farms

How can the *AEP* of a farm be predicted and realistically optimised?

- Prediction highly depends on
  - Turbine interactions.
  - Atmospheric phenomena & conditions.
- Computation tool needed for rapid prediction of a farm's annual energy production (AEP).
- Development of own code to include new superposition & meandering model.

Wind Farm Horns Rev 2 [Hasager et al., 2017]

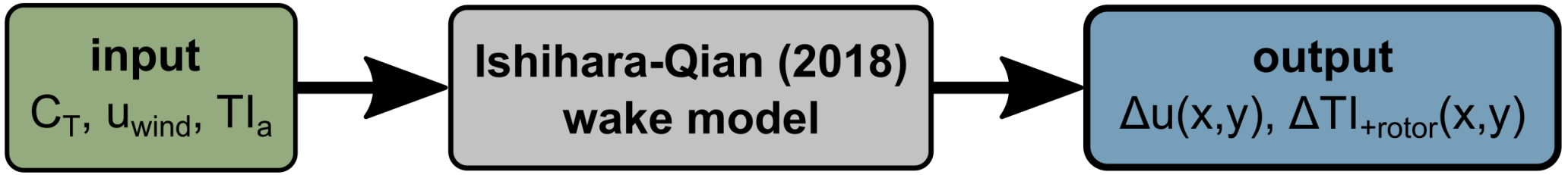
Agenda

1 Methodology

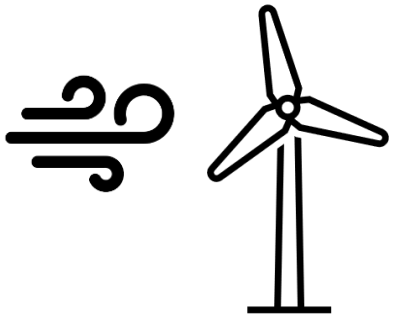
2 Validation

3 Optimization

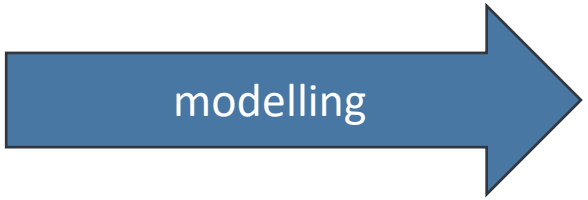
Methodology: Single Wake Model

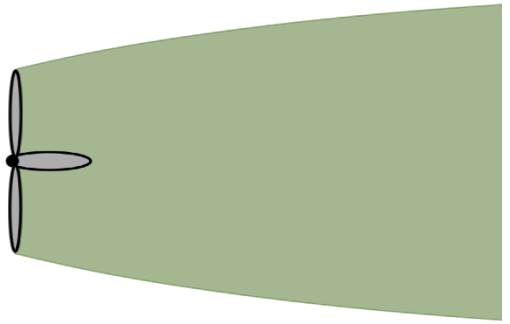


In- and output parameters of the wake model [Qian et al., 2018]



ambient & turbine data



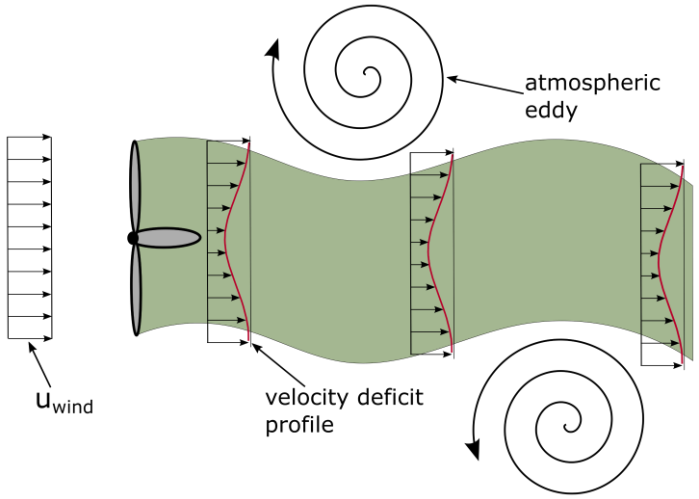


wind speed & turbulence in wake region

Methodology: Wake Meandering Correction

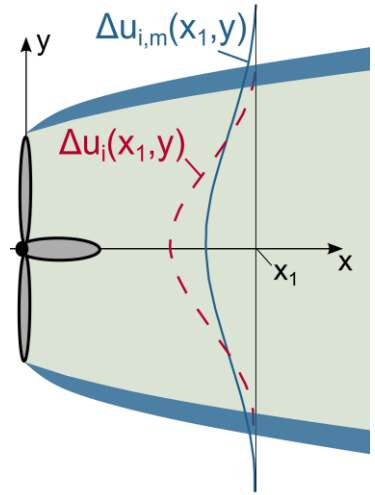
Meandering Correction
Braunbehrens & Segalini (2019)

[Braunbehrens et al., 2019]



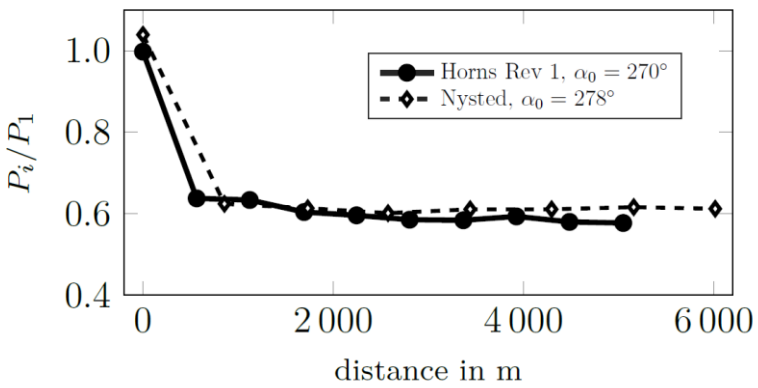
time-dependent motion

correcting

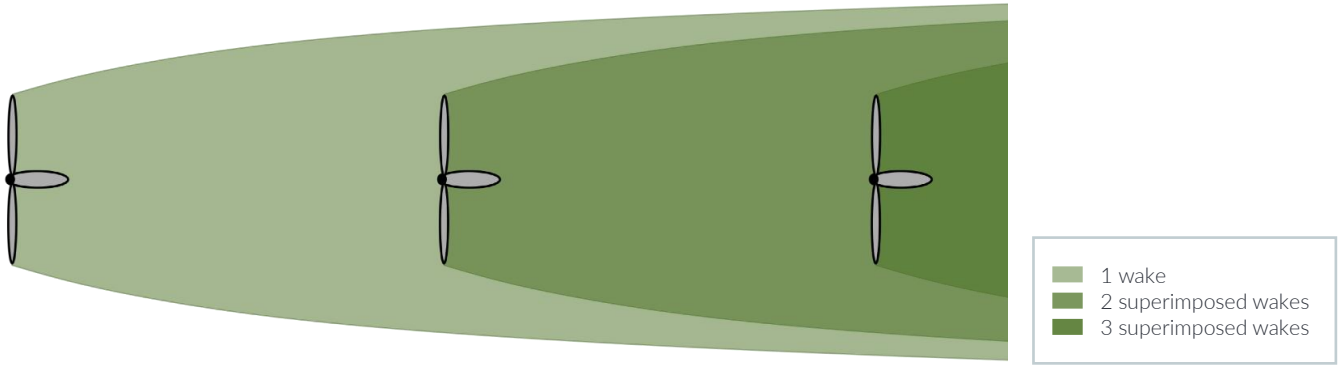


time-averaged for steady-state model

Power losses in a wind farm



Power loss within one turbine row [Barthelmie et al., 2007].



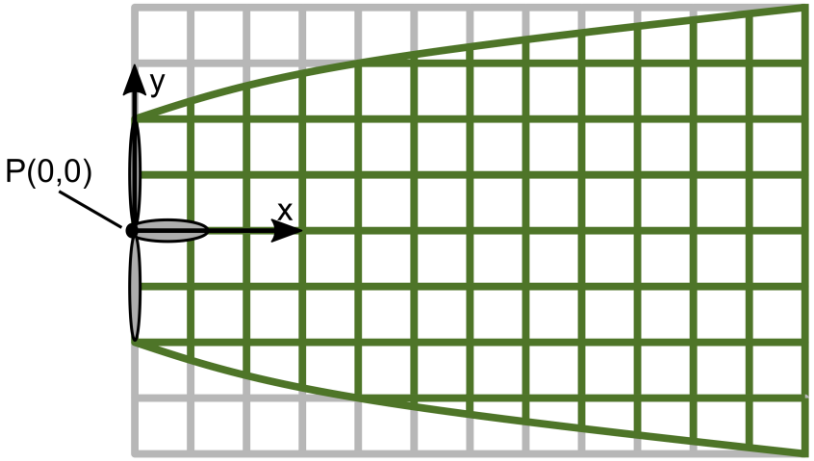
Superimposing wake areas.

So far modelled mainly by mathematically intuitive rules.

Methodology: Wake Superposition

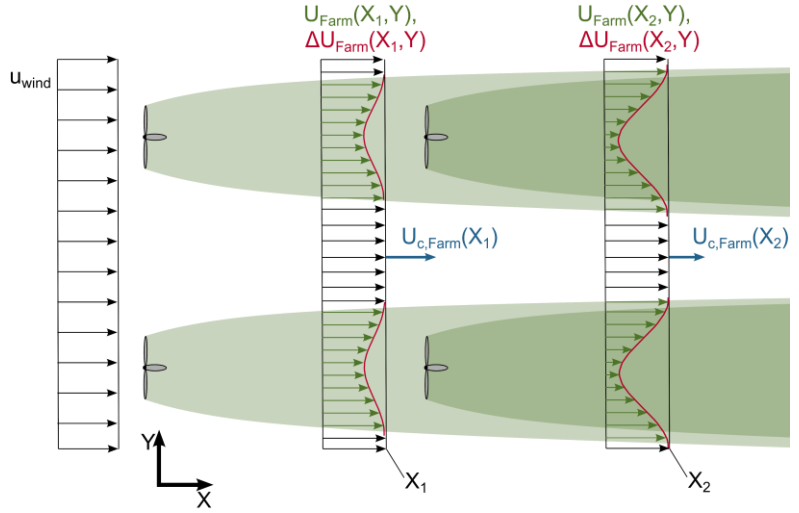
Momentum Conserving
Superposition
Zong & Porté-Agel (2020)

[Zong et al., 2020]



information on single wake

wake mixing



superimposed result in a wind farm

Overview

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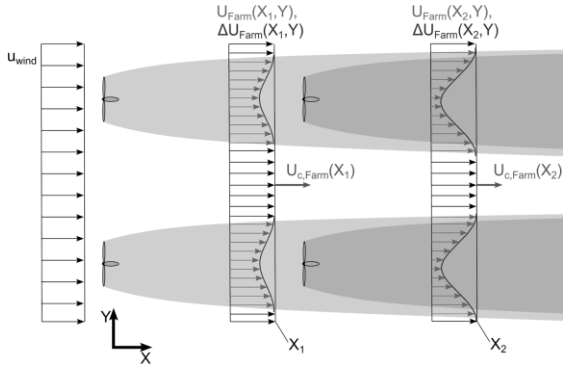
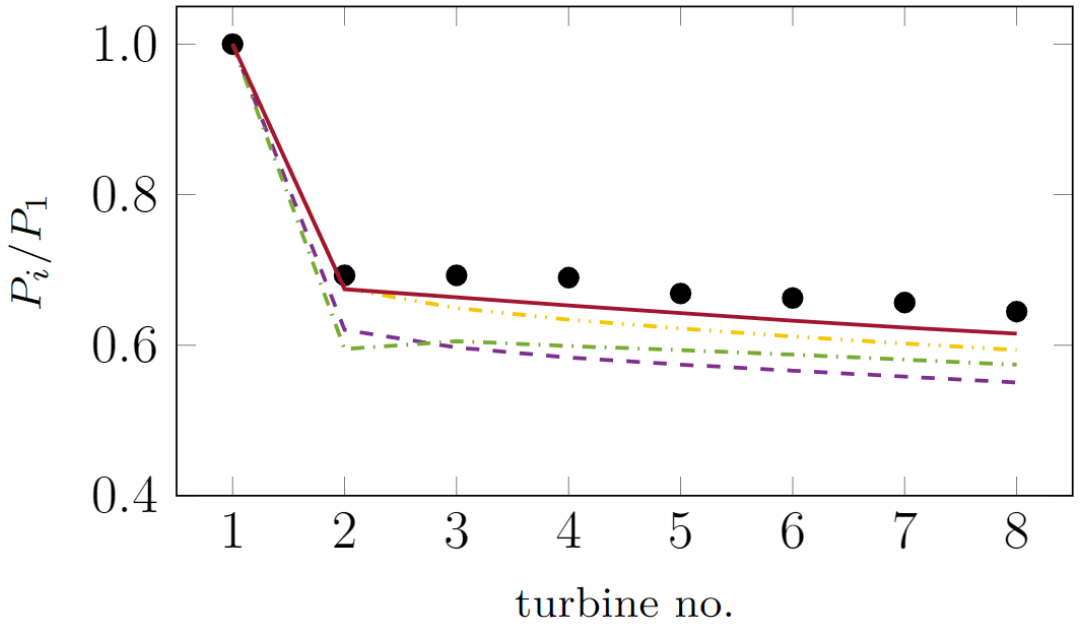
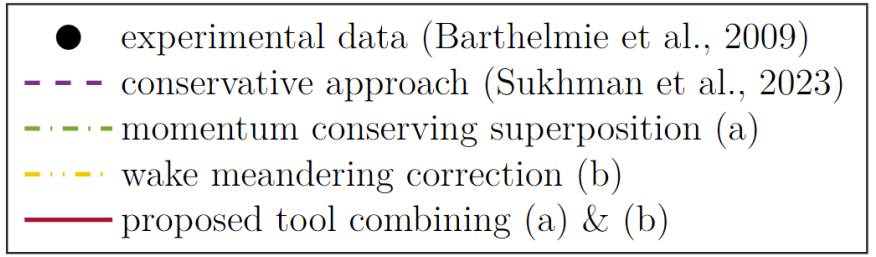


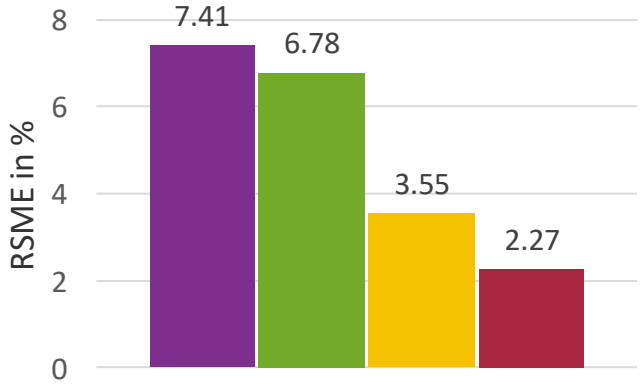
Validation



Modelled and measured power within one turbine row.



Proposed tool outperforms conservative approach.



RSME with respect to experimental data (Barthelmie et al., 2009).

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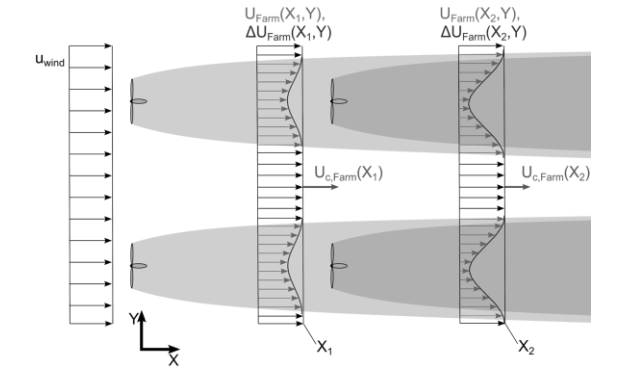
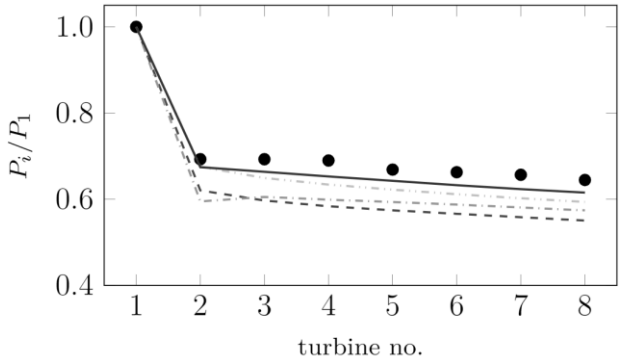
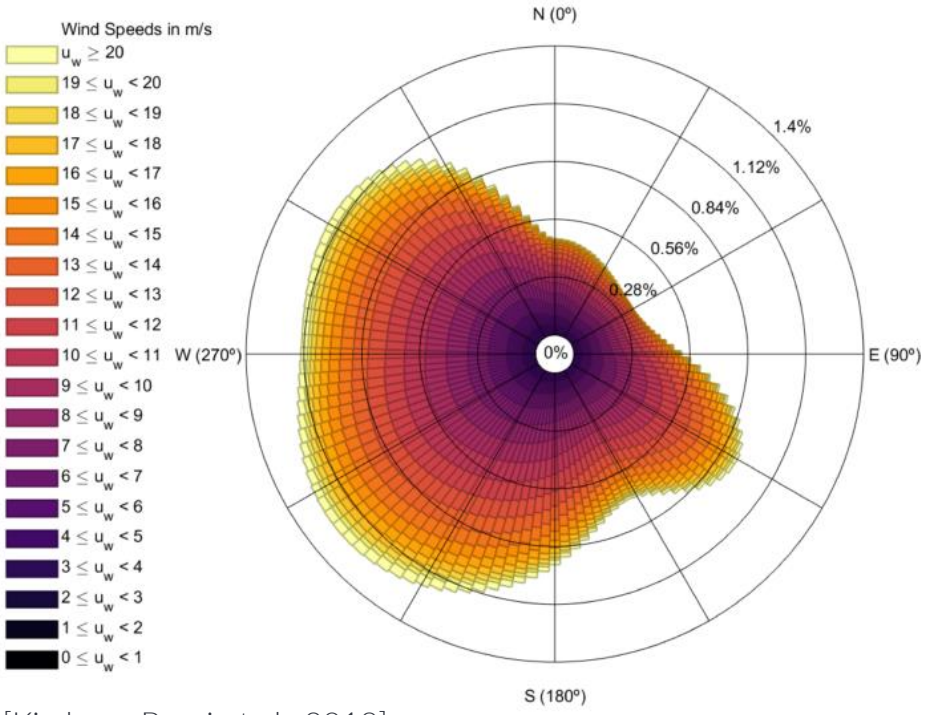


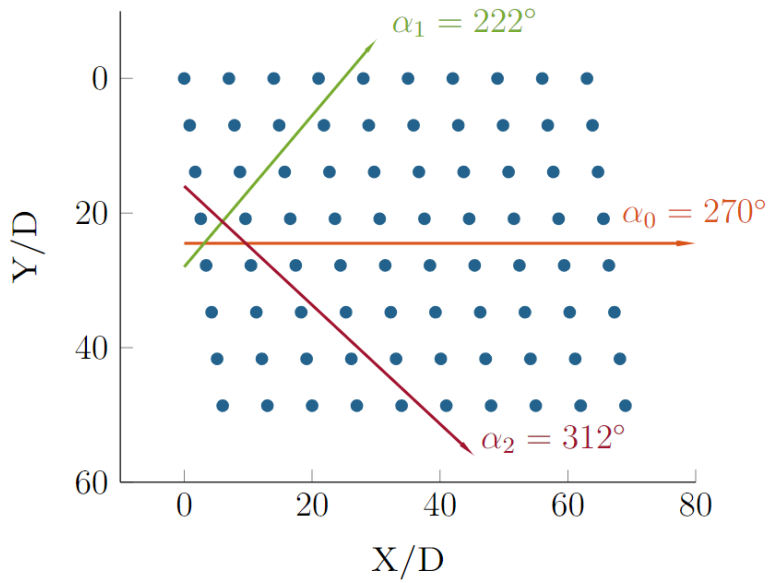


Optimization: Case



[Kirchner-Bossi et al., 2018]

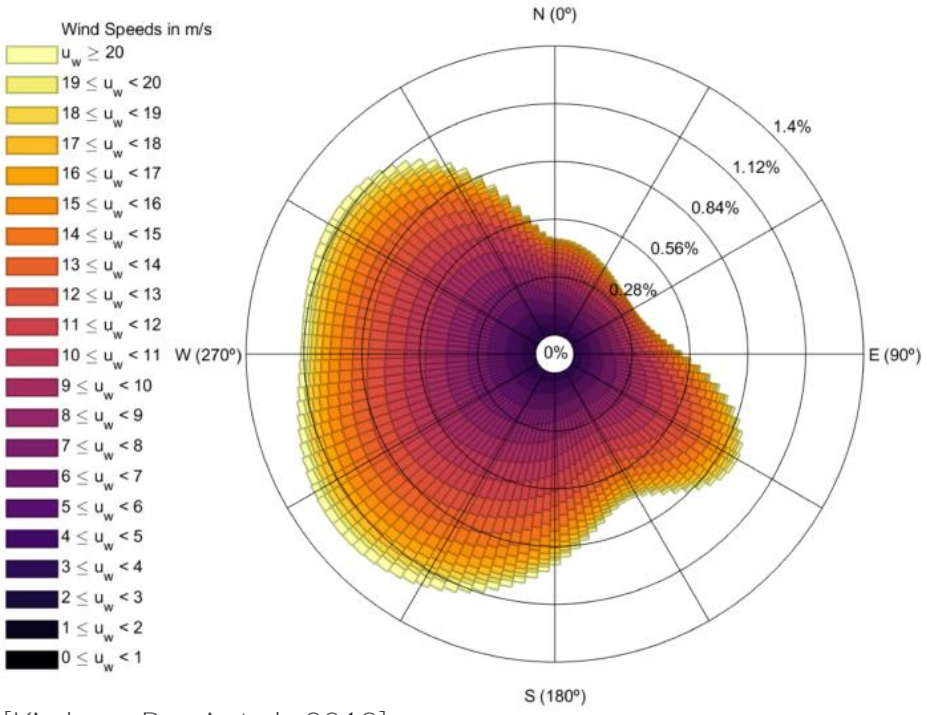
Horns Rev 1 wind rose



Horns Rev 1 Layout

Optimization: Case

$120 \cdot 22 = 2640$ combinations

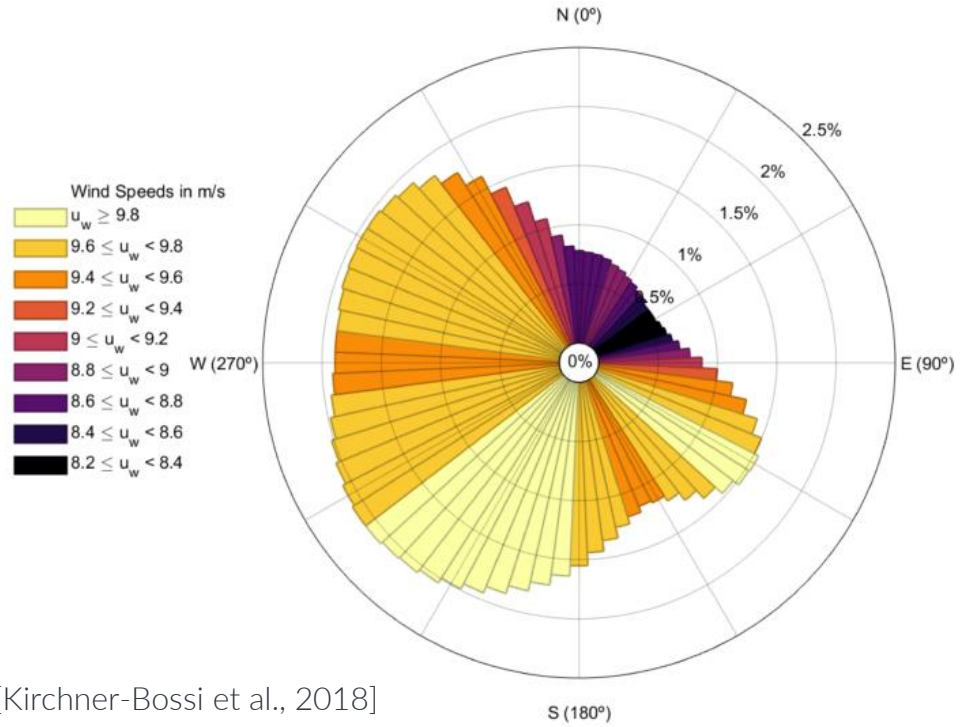


[Kirchner-Bossi et al., 2018]

Horns Rev 1 wind rose

reduction

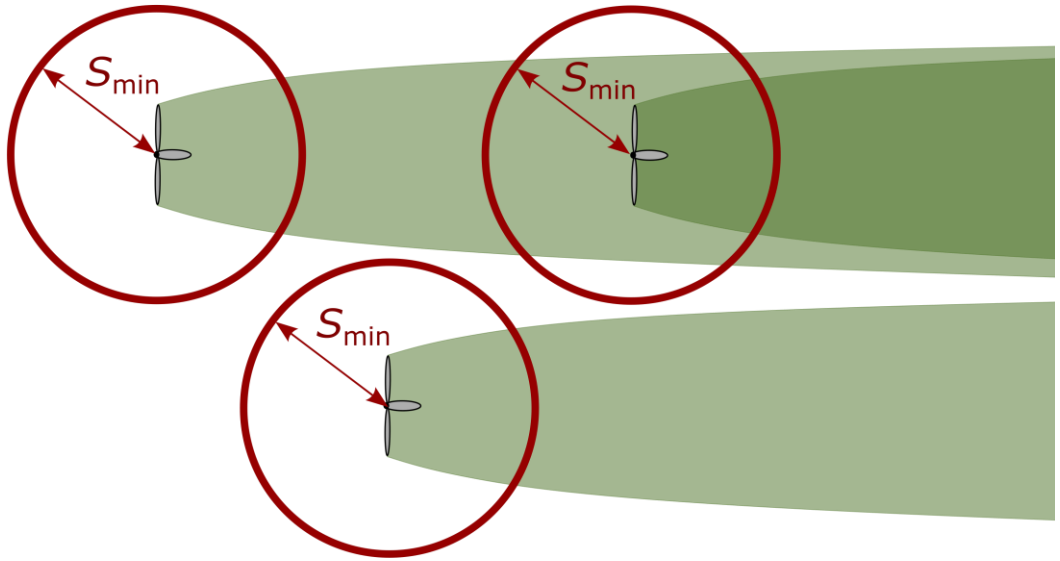
$72 \cdot 1 = 72$ combinations



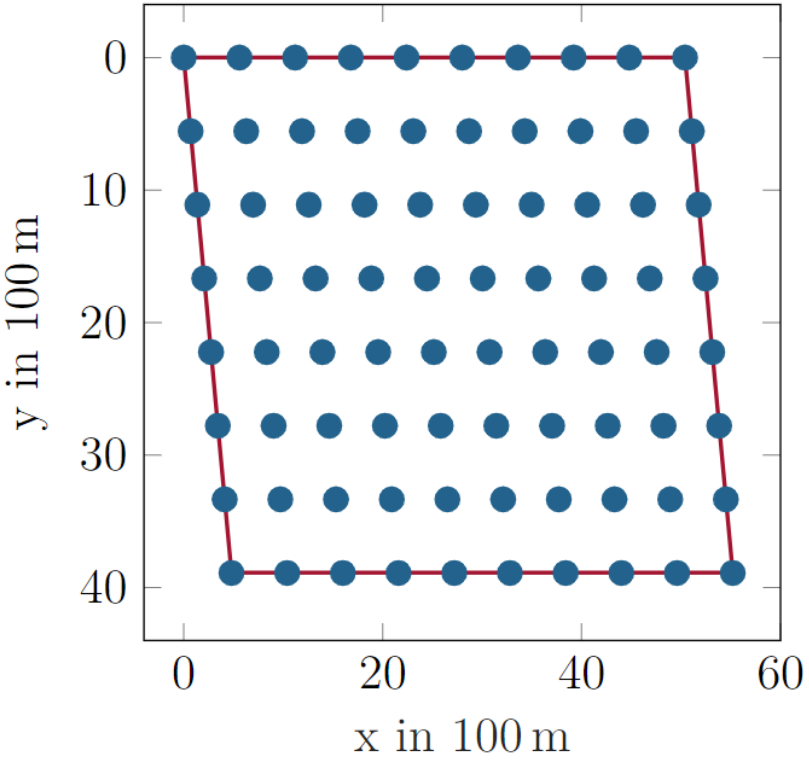
[Kirchner-Bossi et al., 2018]

reduced wind rose

Optimization: Boundary conditions

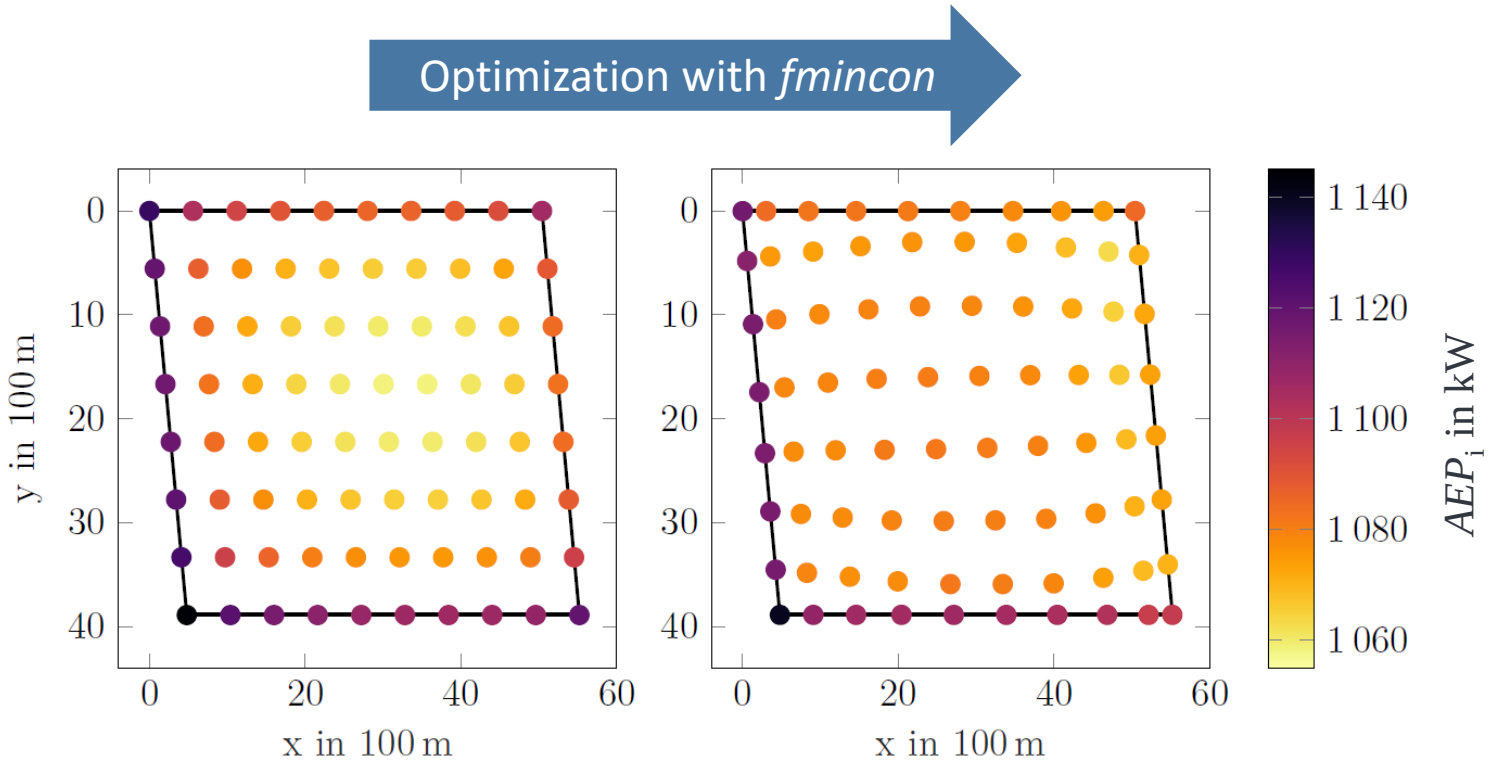


Schematic view of minimal turbine spacing.



Outer boundaries.

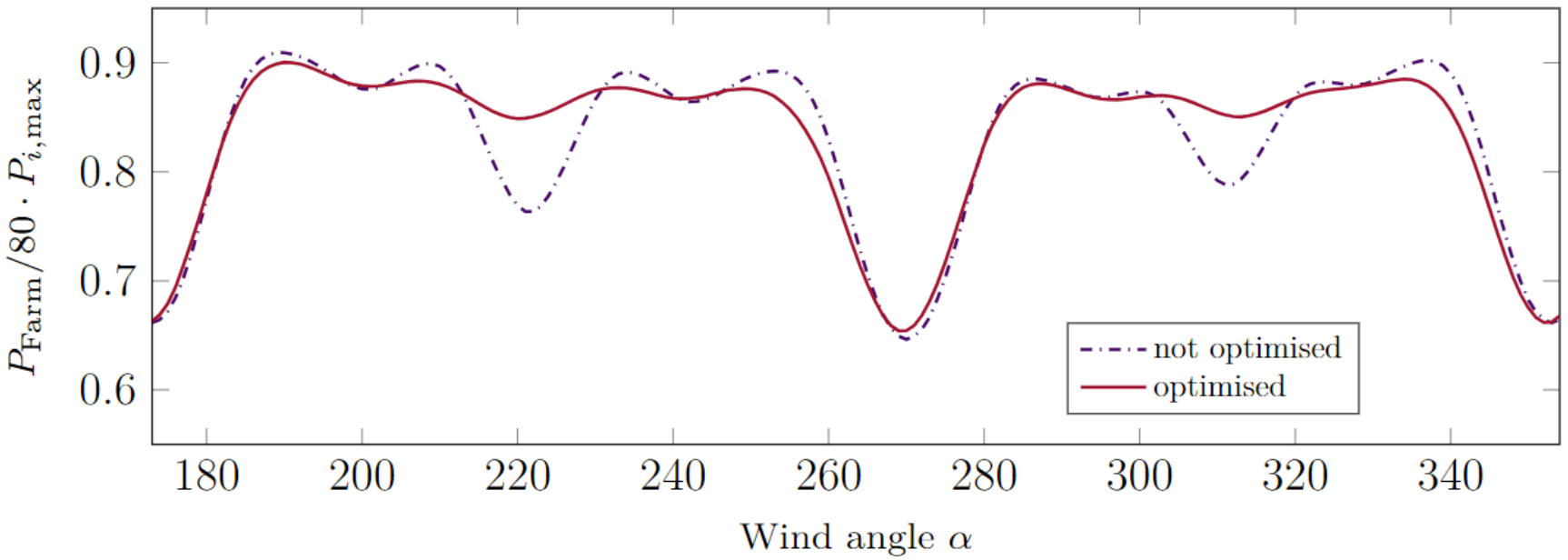
Optimization: Result



Reference layout (left) and optimised proposal (right). The colour indicates the annual power production of each single turbine.

Optimised results suggest a convex shape of turbine rows.

Optimization: Result



Power output of the reference and optimised layouts at a wide variety of wind angles. Inflow conditions: $u_{wind} = 8$ m/s, $TI_a = 7.7$ %.

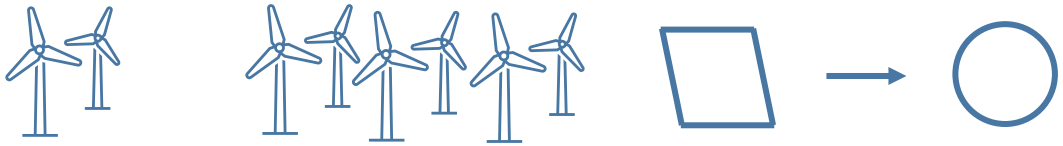
Increased area under the curve for the optimised proposal.

yielding

$$\boldsymbol{\Delta AEP_{\text{Farm}} = +0.12\% \cong +720\ \text{MWh}}$$

Conclusion

- $\Delta AEP_{\mathrm{Farm}} = +\,720\ \mathrm{MWh} = 43\ \emptyset$  .
- Optimum agrees with magnitudes proposed by similar study [Kirchner-Bossi et al., 2018].
- Meandering correction & momentum conserving superposition have a signifficant effect on power prediction.
- Possible future inclusions:
  - Energy density



  - Further aspects

Offshore wind turbines [Tagesschau, 2023]

Offshore wind turbines [Tagesschau, 2023]

Thank You!

Sources

[Barthelmie et al., 2007] Barthelmie, R. J., Pryor, S. C., Frandsen, S. T. et al.: “Quantifying the Impact of Wind Turbine Wakes on Power Output at Offshore Wind Farms”. Journal of Atmospheric and Oceanic Technology, 27(8) (2010), pp. 1302-1317.

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[Tagesschau, 2023] Martin Polansky: Neuer Fahrplan für Offshore-Windenergie. Berlin, Germany. Arbeitsgemeinschaft der öffentlich-rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland, 2023. url: https://www.tagesschau.de/wirtschaft/energie/windenergie-bundesamt-101.html (visited on 03/01/2024).

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