Tipspeed

Wind EUROPE TECHNOLOGY WORKSHOP 2025 19-20 JUNE ISTANBUL

Quantifying operational wake losses using timeseries analysis

Insights into neighboring wind farm contributions

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Co-founder & Science lead

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Also see: Poster PO017

Tipspeed: wind & power digital twin for performance assessment

50+ years of experience in Wind

- Lidar expertise (ex Vaisala)
- Wind resource, wake modeling (ex GE)
- Engineering software development (ex GE)
- Collaboration, partnerships & standards (DTU, NREL, IEC-12-1)

Speaker at technical conferences

View all presentations

+1GW assessed across 3 continents

Winner of the Iberdrola Challenge (April 2025) Efficient wind measurements campaigns for turbine assessment

“Is it underperformance
or ~~lack of resource~~?”

higher wakes losses?

This turbine seems to be underperforming...
should I focus on it, or is it just wakes?

Can I tell our stakeholders recent lower production
is due to wake-heavy wind sectors?

What is the real impact of the new
neighboring farm on our production?

Was our pre-construction wake loss estimate correct?

Wake losses are widely studied, but rarely monitored during operations

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3 200

Number of scientific publications on wake losses in the last 5 years

16%

Of WindEurope TW presentations in the last 5 years on wake losses

<5%?

Of operators monitor operational wake losses weekly/monthly

Available techniques are focused on wake models validation

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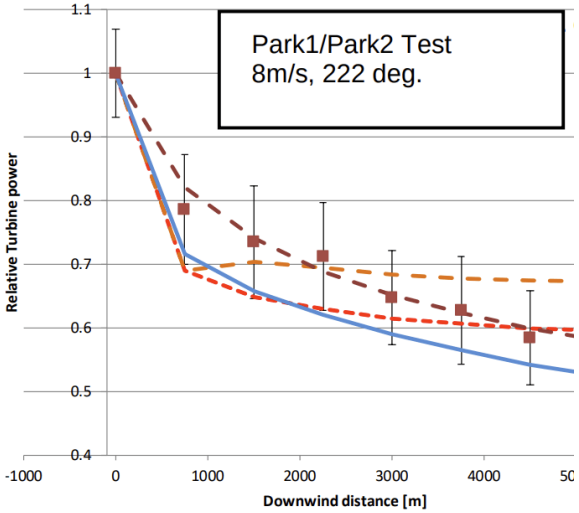
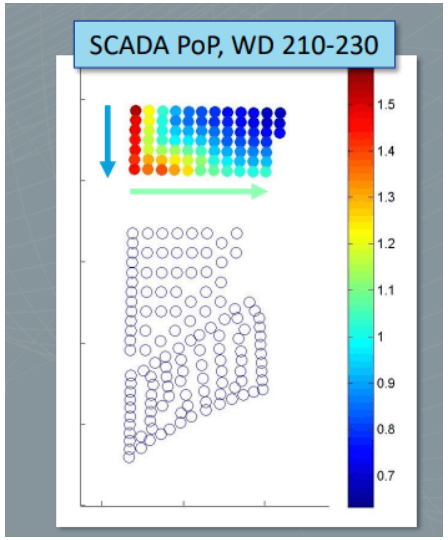
Ratios to front row



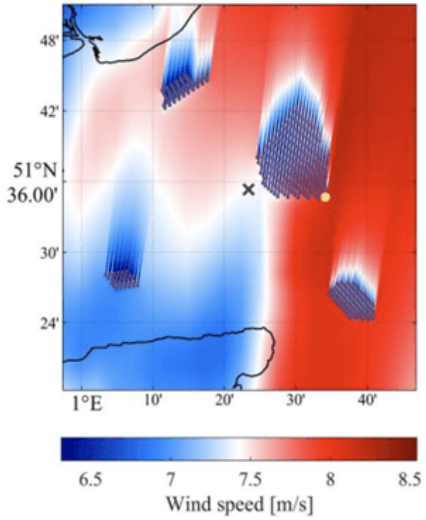
Rathmann, O. S., et al. (2018). The park2 wake model-documentation and validation.

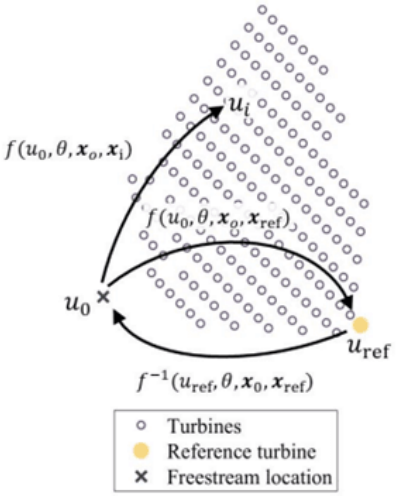
Patterns of production



Rodaway, C., et al. Big cluster & far-field wakes-an assessment of multi-fidelity models against North Sea wind farms' SCADA data.

Timeseries loss estimation





Nygaard, N. G., et al. (2022, May). Large-scale benchmarking of wake models for offshore wind farms. In Journal of Physics: Conference Series (Vol. 2265, No. 2, p. 022008). IOP Publishing.

Open source tools

OpenOA

Perr-Sauer, J., et al. (2021). Openoa: an open-source codebase for operational analysis of wind farms. Journal of Open Source Software, 6(NREL/JA-2C00-75851).

Operational wake losses monitoring present methodological and practical challenges

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Methods requirements

- ⚠️ **Deal with periods of low turbine availability in normal operation**
- 🧭 **Account for unreliable nacelle direction and wind speed data**
- 🏞️ **Account for non-homogeneous flow (aka speed-up)**
- 🧩 **Work for layouts with mixed turbine types**
- 🏗️ **Account for external wakes (while defining "freestream“)**

Easily updatable
(weekly/monthly)

Limited tuning

From production data to turbine and site-level wake losses quantification over time

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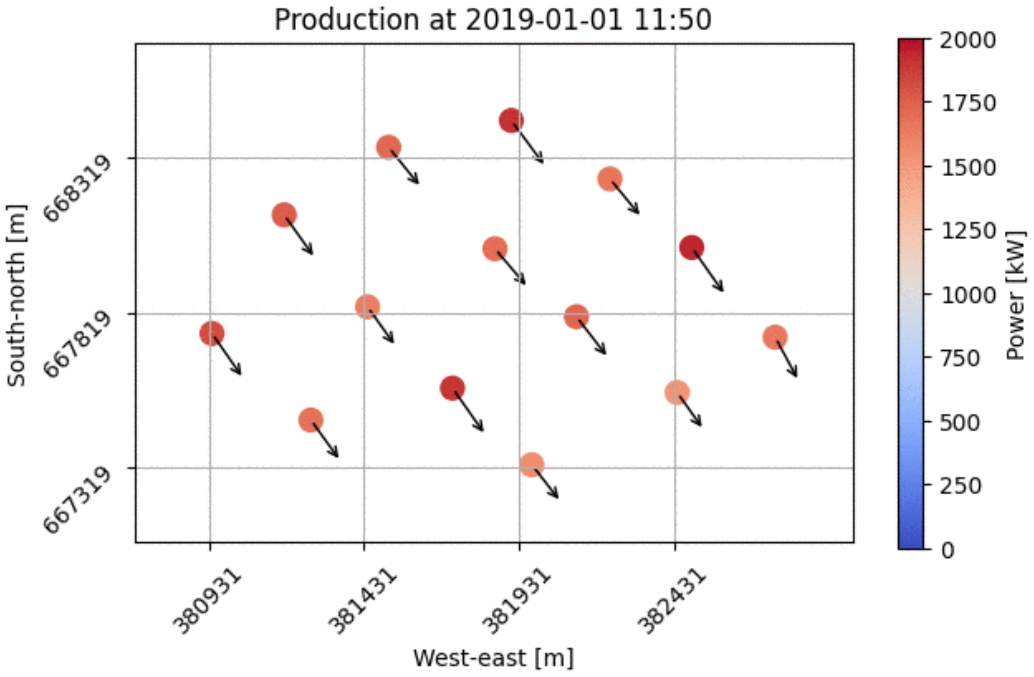
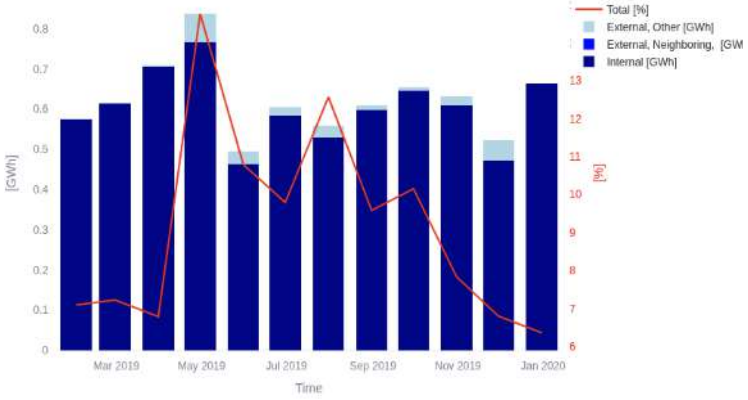


Turbine level wake loss aggregation

Site temporal wake loss aggregation



Data credit: Plumley, C. (2022) « Penmanshiel Wind Farm Data ». Zenodo. doi: 10.5281/zenodo.5946808.

Inverse model from power to freestream power

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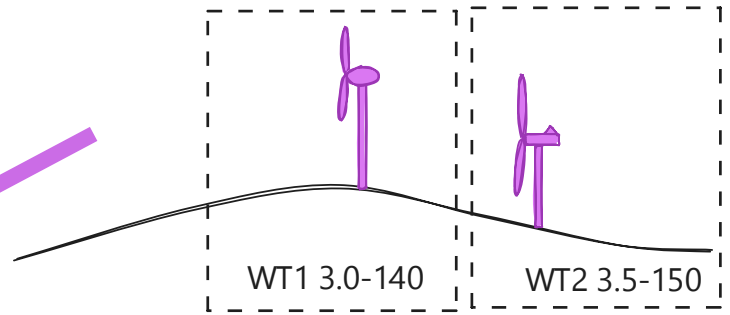
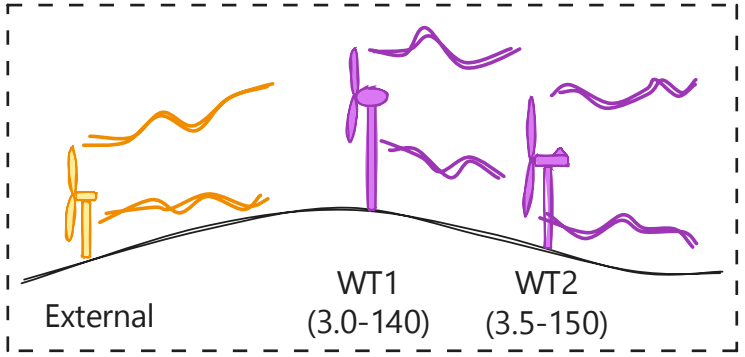
```python
class PowerToFreestreamPowerMaskedRegressor():
    def fit(X,y):
    def predict(X):

# training
p2fp = PowerToFreestreamPower().fit(x_train, y_train)

# predictions
masked_power = power.copy()
masked_power[~least_waked] = np.nan
freestream_power = p2fp.predict(masked_power)
```

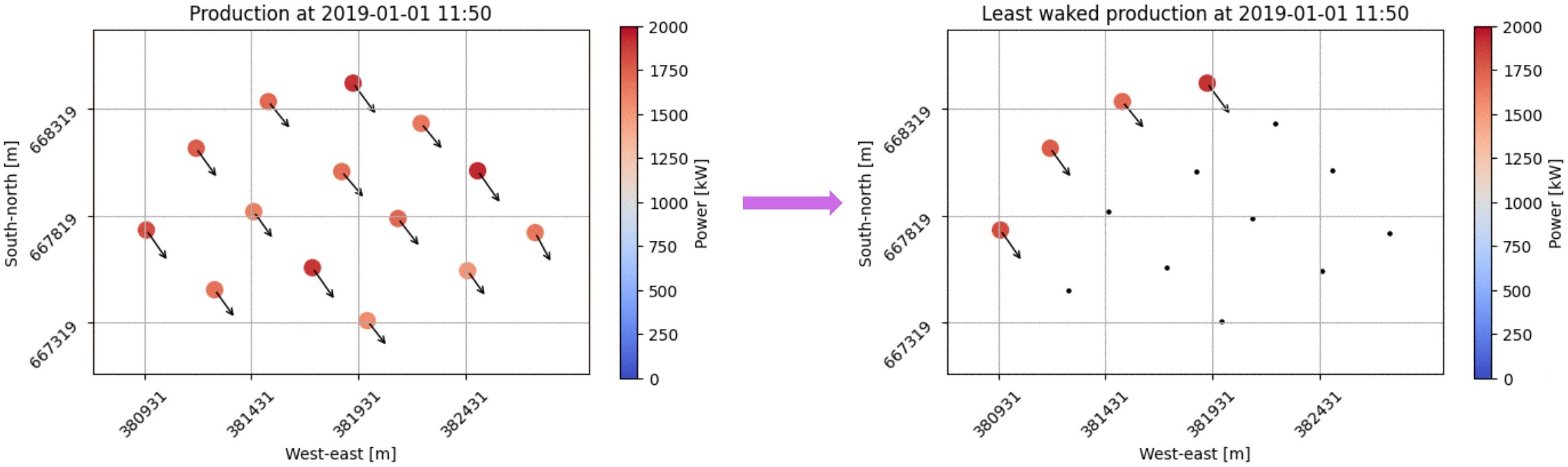
Freestream power prediction set



Interacting power prediction set



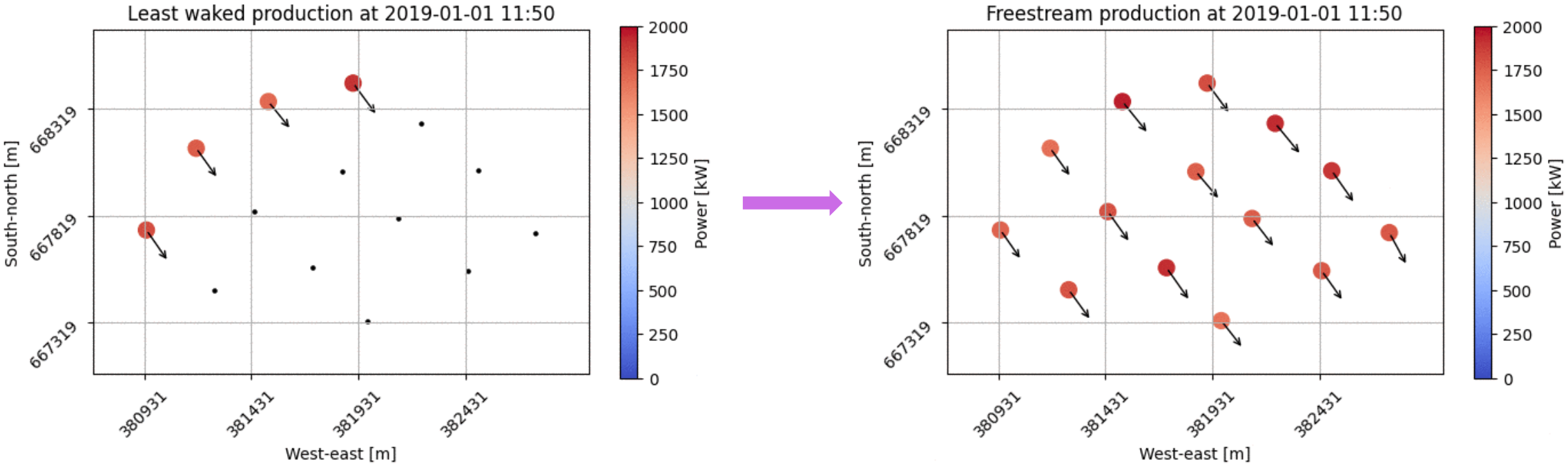
Step 1: determine least waked turbines



Sub-steps:

1. 100% available power for turbines not in full performance
2. Correct for nacelle direction biases
3. Rank for each timestep turbines from least to most waked
4. Select a suitable minimal number of least waked turbines for that timestep

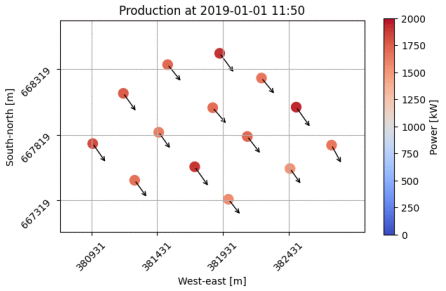
Step 2: predict freestream power from least waked turbines using the inverse model

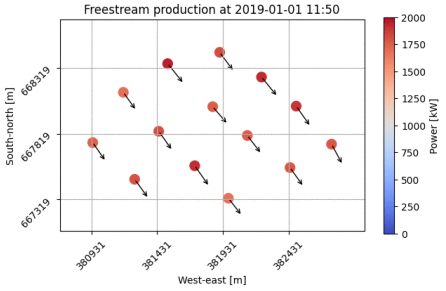


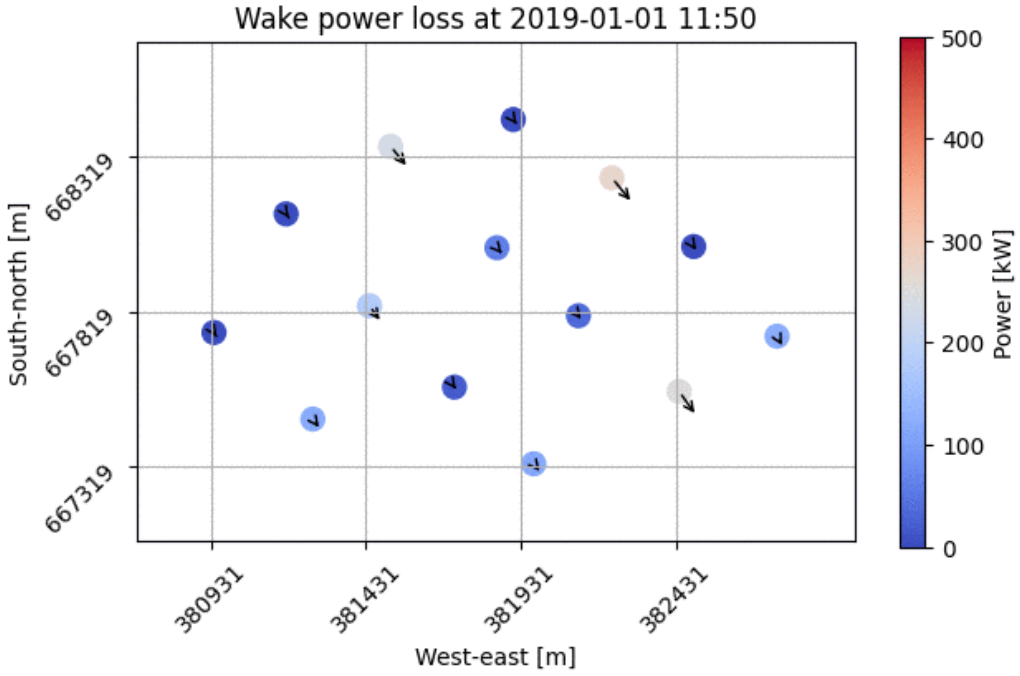
Sub-steps:

1. Run two site-specific power output simulations for the site (one freestream, one waked)
2. Build an inverse model which predicts freestream power given power from least waked turbines.
3. Optional: iterate on the site-specific model to minimize the potential modeling errors

Step 3: subtract power to freestream power to determine wake loss timeseries







Sub-steps:

1. Derive the wake loss timeseries from freestream estimated power and power
2. Use site-specific wake model to calculate internal vs external wake losses
3. Assign a fraction of internal vs external loss for each turbine and timestep

This turbine seems to be underperforming...
should I focus on it, or is it just wakes?

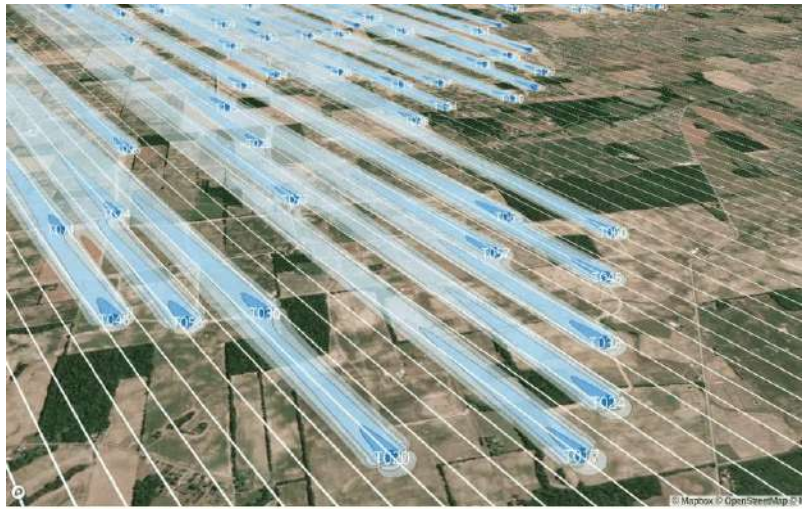
Can I tell our stakeholders recent lower production
is due to wake-heavy wind sectors?

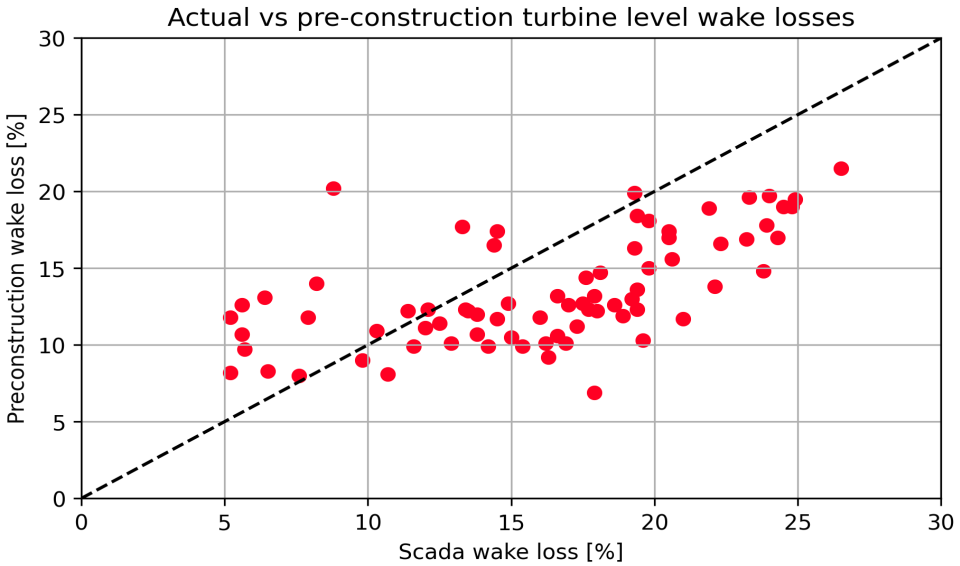
What is the real impact of the new
neighboring farm on our production?

Was our pre-construction wake loss estimate correct?

Analysis of wake losses compared to pre-construction EYA assumption

Performance analysis carried out on a large onshore farm with mixed turbine types

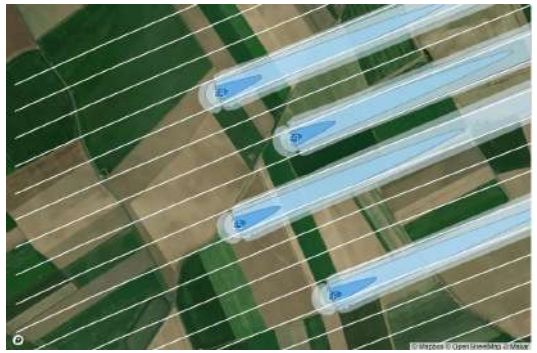




The analysis of operational wake losses allowed to determine that pre-construction external studies underestimated wake losses by 3.5% compared to observed losses derived from the Scada.

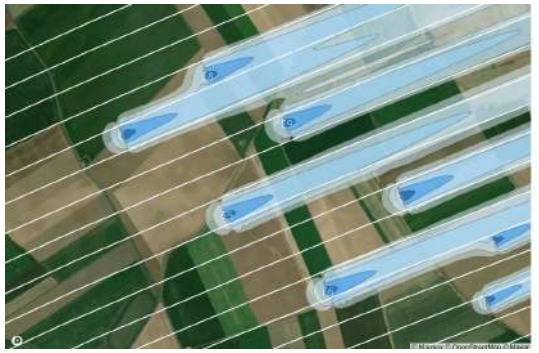
These insights allowed to put in context the performance of the site.

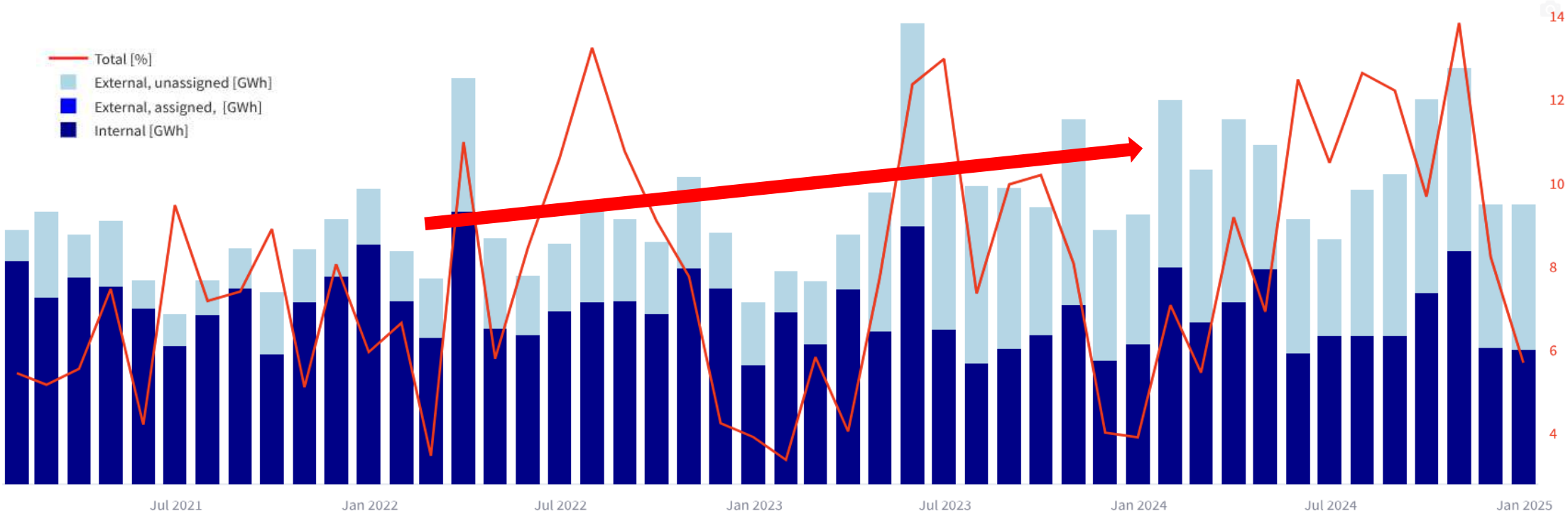
Operational monitoring reveals increasing external wake losses



2021

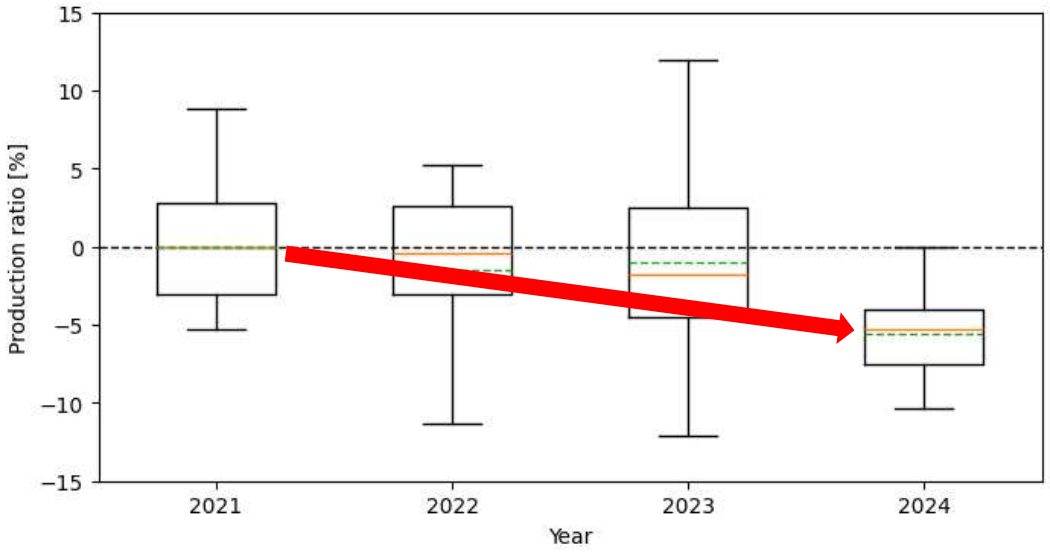
2025



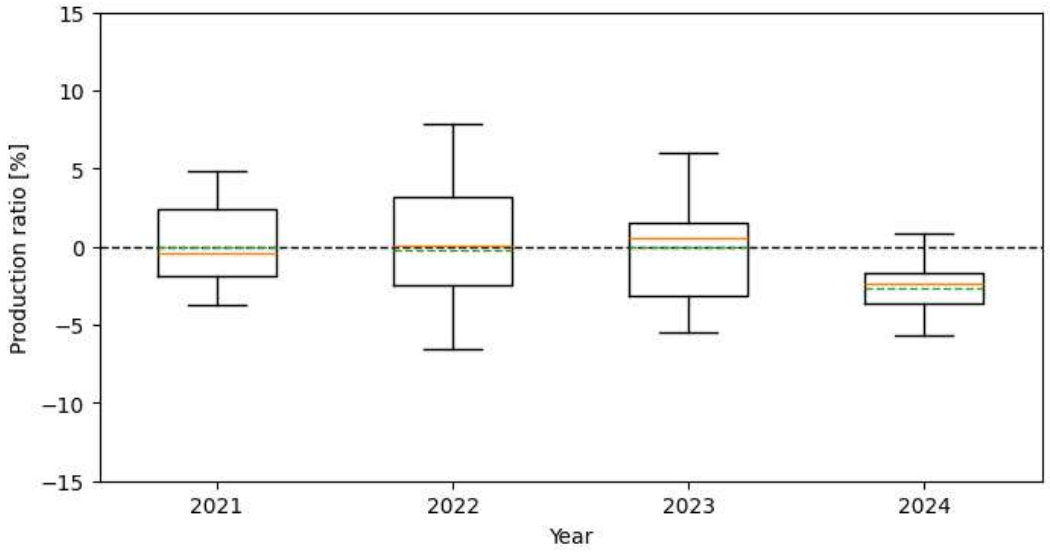


And leads to more reliable assessment of performance through monthly indices

Before accounting for wake losses:
-2.5% bias, 6.5% monthly std variation

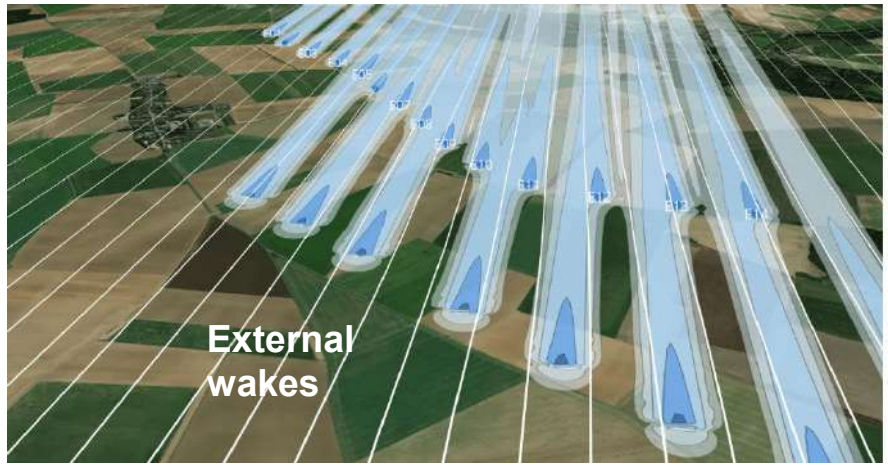


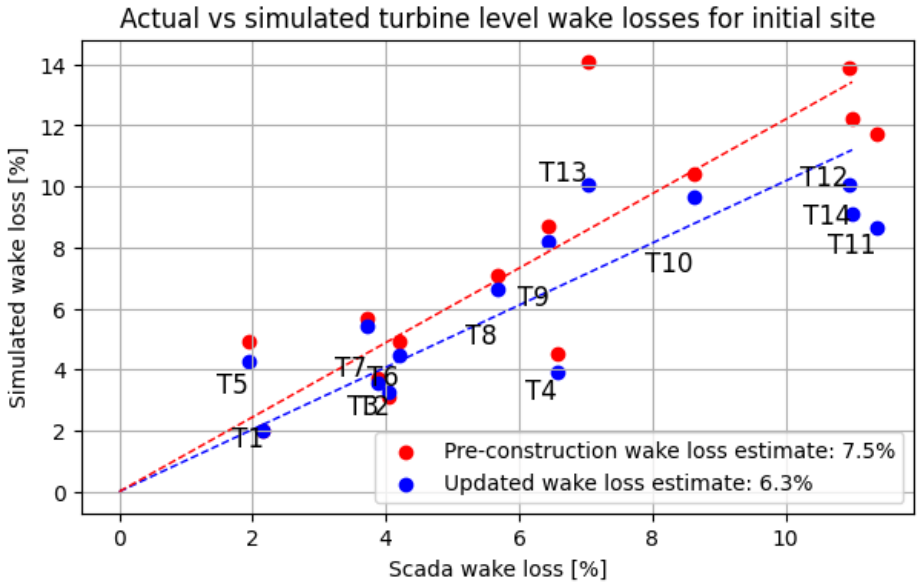
After accounting for wake losses:
-1% bias, 1.7% monthly std variation

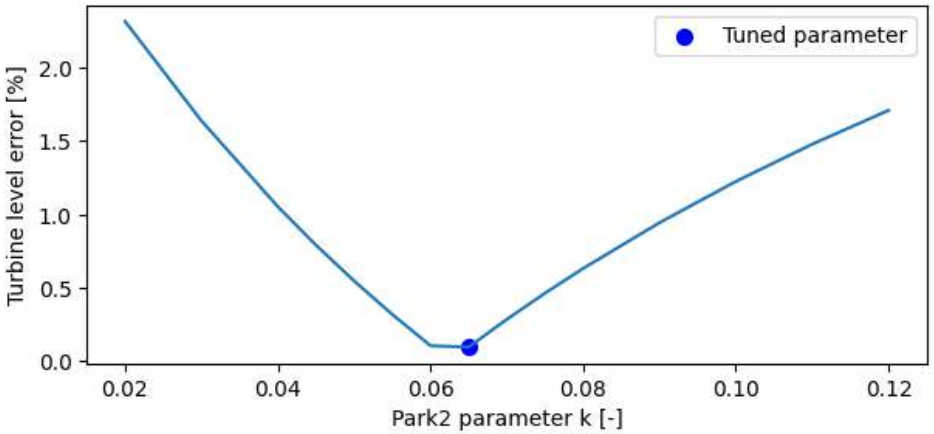


Performance ratio between actual and expected production from monthly indices, aggregated per year, before and after accounting for wakes.

R&D collaboration - Updating pre-construction wake losses estimates







Using operational data allows to update pre-construction wake loss estimates, better anticipate long term site performance and improve wake modeling of future projects.

Operational wake monitoring is feasible using SCADA and physics-based modeling

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- **The shared methodology allows quantification of internal and external wake losses at turbine and farm level**
- **It builds upon extensive research and existing techniques to enable operational use in various environments**
- **Applications could include:**
  - diagnosing and reporting performance more accurately
  - understandig external wake impacts
  - contributes to wake models validations research
- **Risks**: speed up and external wake modeling