UNCERTAINTY IN WIND PLANT DESIGN

Consequences, sources and mitigation

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Wind Energy System Engineering workshop
Sources of uncertainty affecting wind plant design

- Measurements
- Flow model
- Wake model
- Power curve

- Variability of mean wind
- Variability of distribution
- Electrical losses
- Turbine availability
The cost of uncertainty

- Uncertainty is financial risk
- Reducing uncertainty reduces debt financing cost
- This increases project net present value

- Reducing uncertainty by 1% increases NPV by 10 M€
Perceived wake model uncertainty
Perceived wake model uncertainty

Average wake model uncertainty:
40% of the wake loss
Systematic quantification of uncertainty

Wind and production time series

Random sampling with replacement
Systematic quantification of uncertainty

Wind and production time series

Random sampling with replacement

Bootstrap sample net and gross power

Observed wake loss
Systematic quantification of uncertainty

Wind and production time series

Random sampling with replacement

Bootstrap sample wind climate

Bootstrap sample net and gross power

Observed wake loss
Systematic quantification of uncertainty

Random sampling with replacement → Bootstrap sample net and gross power

Wind and production time series

Bootstrap sample wind climate

Input to wake model

Modelled wake loss

Observed wake loss
Systematic quantification of uncertainty

Relative model error

\[ \epsilon = \frac{\text{Loss}_{\text{obs}} - \text{Loss}_{\text{model}}}{\text{Loss}_{\text{obs}}} \]

Bootstrap sample
net and gross power

Observed
wake loss

Wind and
production
time series

Random
sampling with
replacement

Modelled
wake loss

Input to
wake model

Bootstrap sample
wind climate

Wind and
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Relative model error \( \varepsilon = \frac{\text{Loss}_{\text{obs}} - \text{Loss}_{\text{model}}}{\text{Loss}_{\text{obs}}} \)

Input to wake model

Modelled wake loss

Observed wake loss

Wind and production time series

Bootstrap sample net and gross power
Bootstrap distributions of relative model error

**Example:**
10% wake loss
15% uncertainty
Loss = 10% ± 1.5%

**Portfolio estimate:**
Bias ≈ 0
Uncertainty = 16%
Do we just need better models?

Nygaard and Hansen, TORQUE2016
Reducing uncertainty through measurements
Reducing uncertainty through measurements

- Highly resolved measurements of wakes
- Spatial variation of wind speed
- Spatial variation of wind speed profile
- Effect of flow variability
- Testing multiple power curves
Reducing uncertainty through validation
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Reducing uncertainty through validation
If the warranted power curve matches measurements at $X=2.5D$, an induction correction factor should be applied when calculating AEP.
How can we use uncertainty?

- What factors should guide decisions on layouts?
- Optimizing layout under uncertainty
- Picking the right battles
Thank you for your attention