

A wide-angle photograph of an offshore wind farm. Numerous wind turbines are visible, stretching across a vast expanse of blue-grey water under a sky filled with large, white, fluffy clouds. The perspective is from a low angle, looking out over the sea towards the horizon.

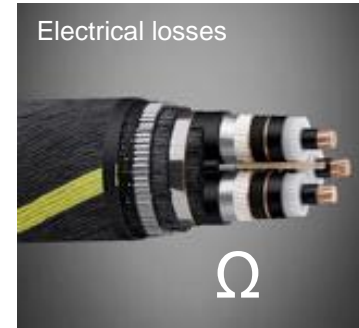
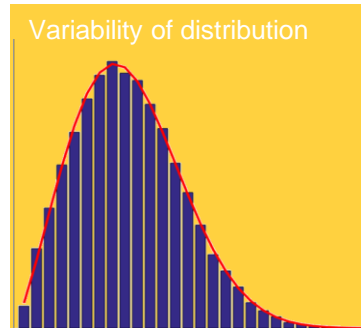
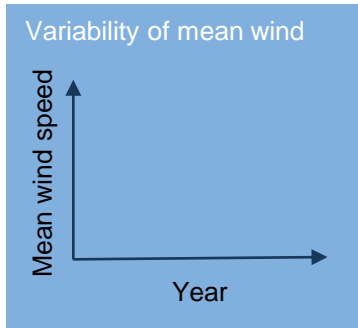
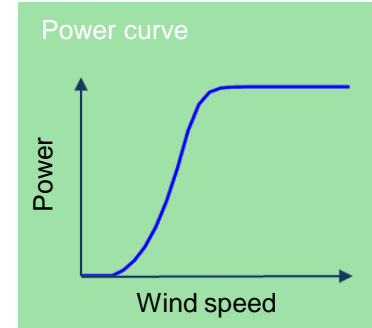
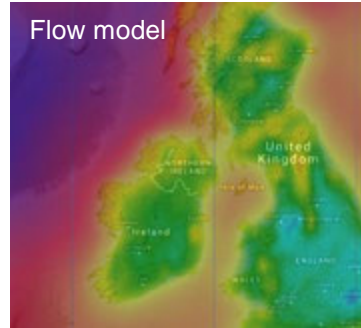
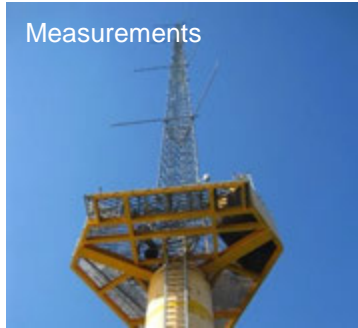
UNCERTAINTY IN WIND PLANT DESIGN

Consequences, sources and mitigation

Nicolai Gayle Nygaard

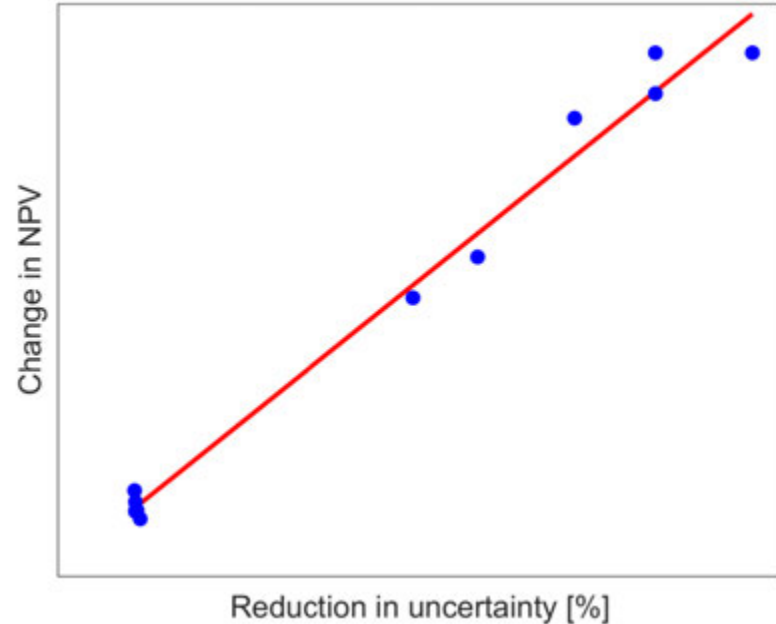
Wind Energy System Engineering workshop

Sources of uncertainty affecting wind plant design



The cost of uncertainty

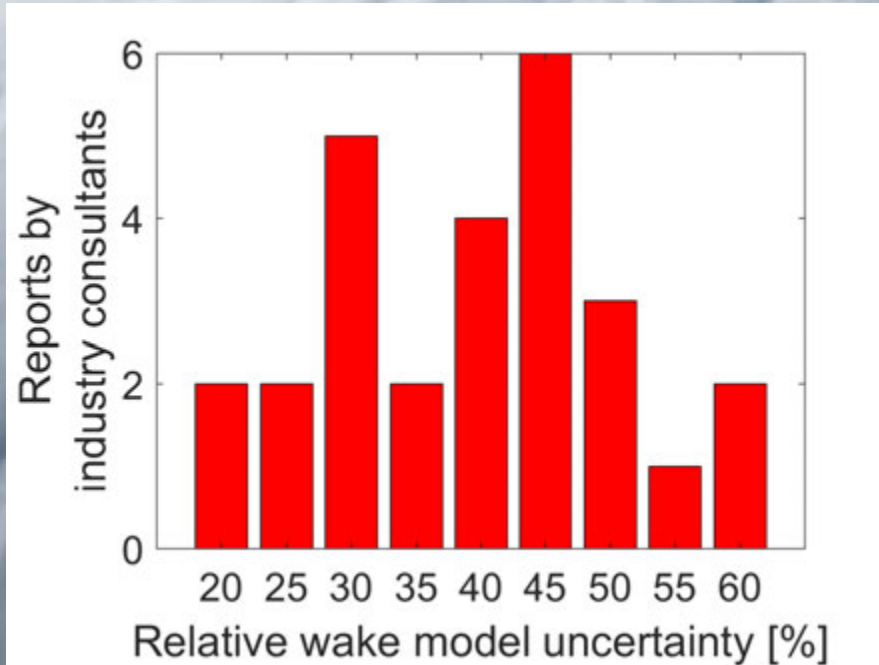
- Uncertainty is financial risk
- Reducing uncertainty reduces debt financing cost
- This increases project net present value
- **Reducing uncertainty by 1% increases NPV by 10 M€**



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

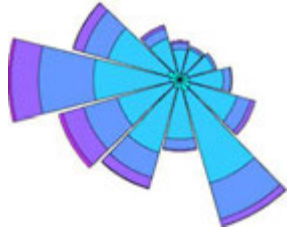
Wind and
production
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**Observed
wake loss**

Bootstrap
sample
wind climate



Systematic quantification of uncertainty

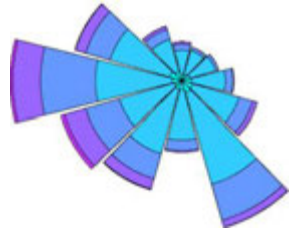
Wind and production time series

Random sampling with replacement

Bootstrap sample net and gross power

Observed wake loss

Bootstrap sample wind climate



Input to wake model

Modelled wake loss

Systematic quantification of uncertainty

Wind and production time series

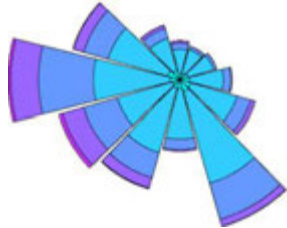
Random sampling with replacement

Bootstrap sample net and gross power

Observed wake loss

Bootstrap sample wind climate

Relative model error $\varepsilon = \frac{\text{Loss}_{\text{obs}} - \text{Loss}_{\text{model}}}{\text{Loss}_{\text{obs}}}$



Input to wake model

Modelled wake loss

Systematic quantification of uncertainty

Wind and production time series

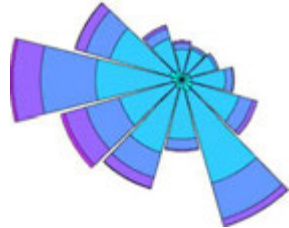
Random sampling with replacement

Bootstrap sample net and gross power

Observed wake loss

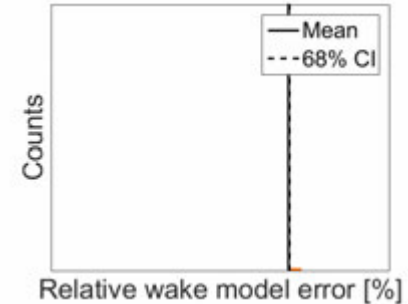
Bootstrap sample wind climate

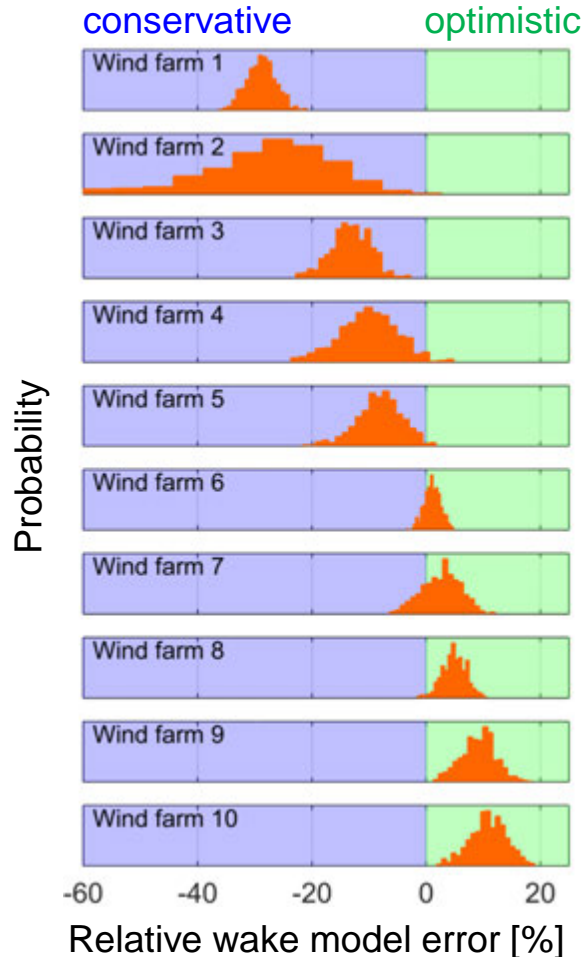
Relative model error $\varepsilon = \frac{\text{Loss}_{\text{obs}} - \text{Loss}_{\text{model}}}{\text{Loss}_{\text{obs}}}$



Input to wake model

Modelled wake loss





Bootstrap distributions of
relative model error

Example:

10% wake loss

15% uncertainty

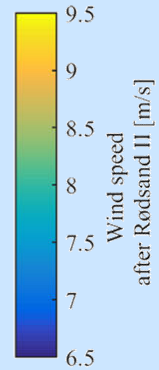
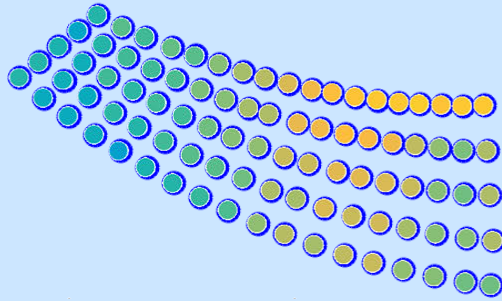
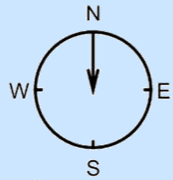
Loss=10%±1.5%

Portfolio estimate:

Bias ≈ 0

Uncertainty = 16%

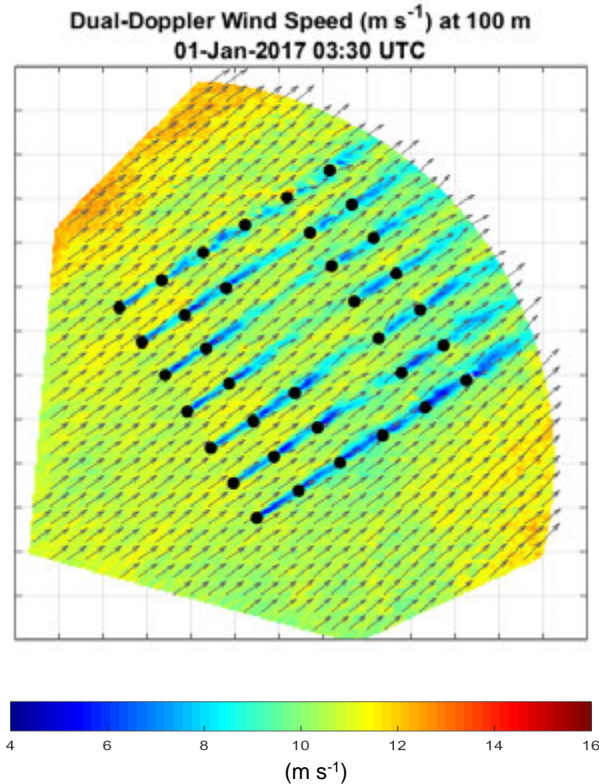
Do we just need better models?



Reducing uncertainty through measurements

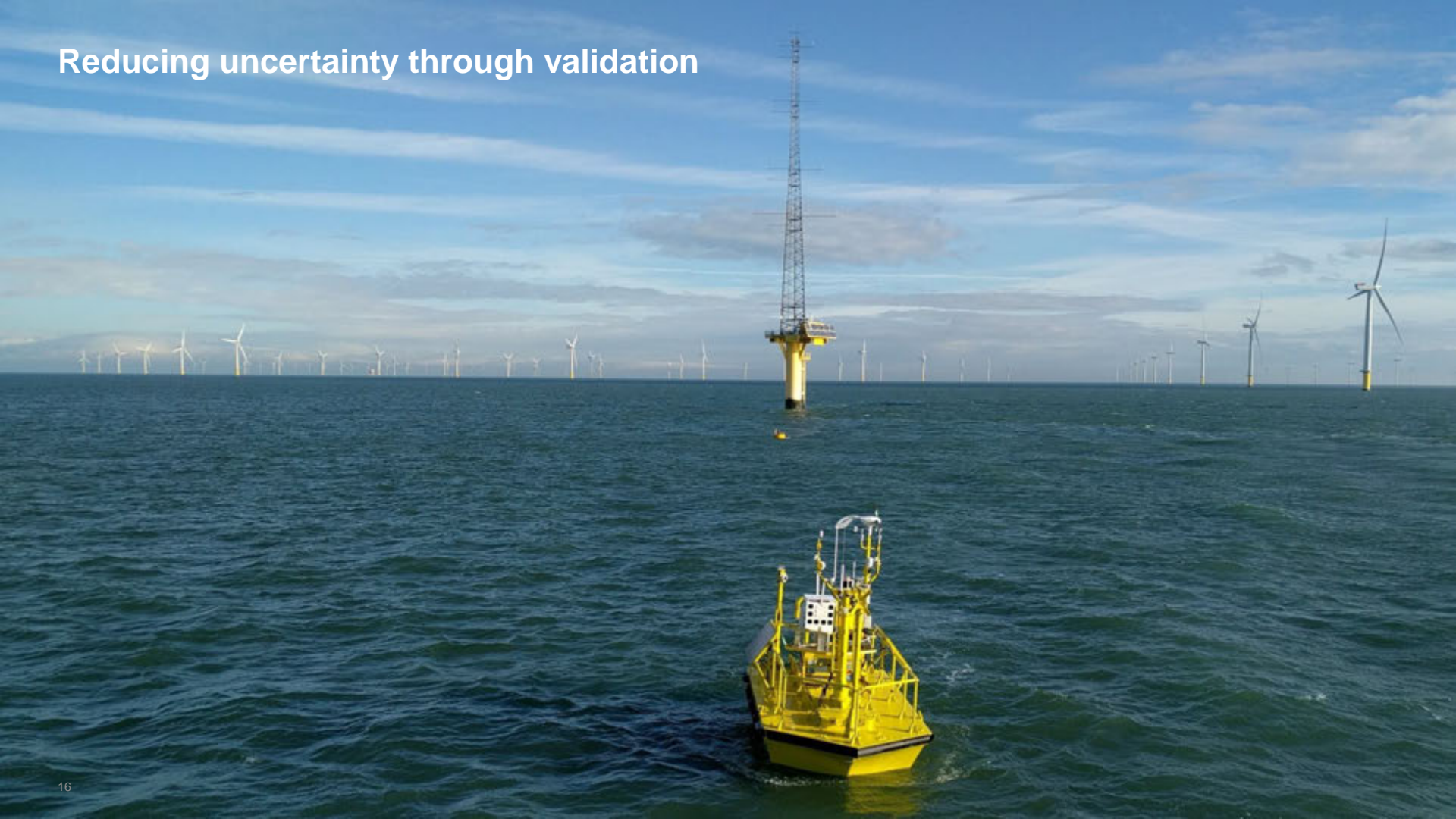


Reducing uncertainty through measurements

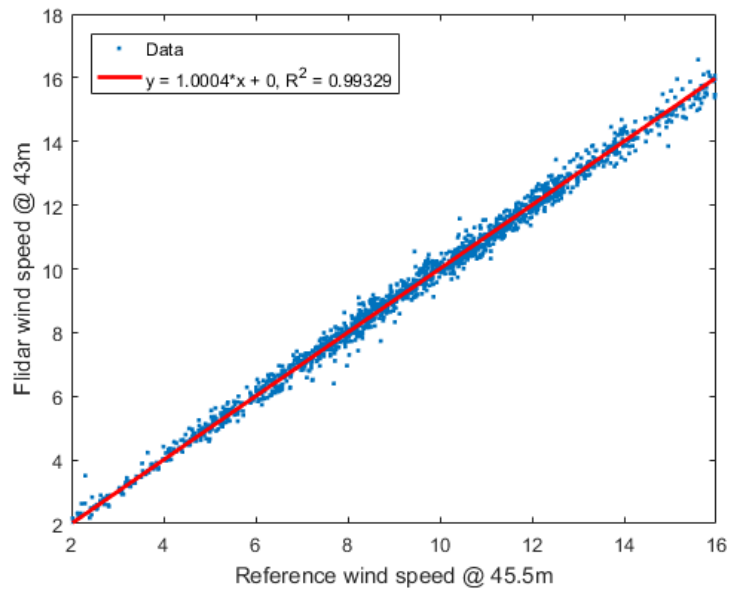


- Highly resolved measurements of wakes
- Spatial variation of wind speed
- Spatial variation of wind speed profile
- Effect of flow variability
- Testing multiple power curves

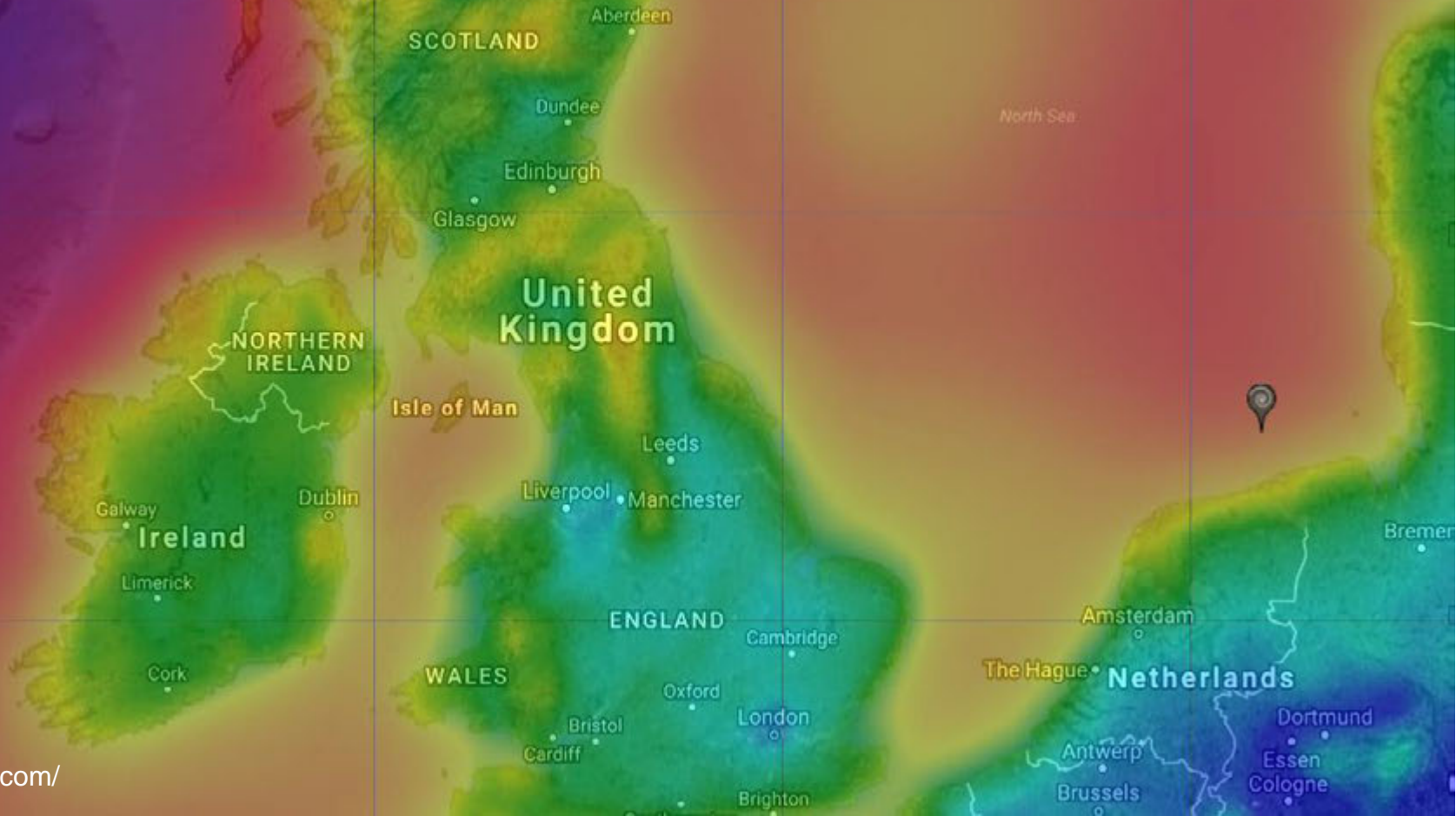
Reducing uncertainty through validation



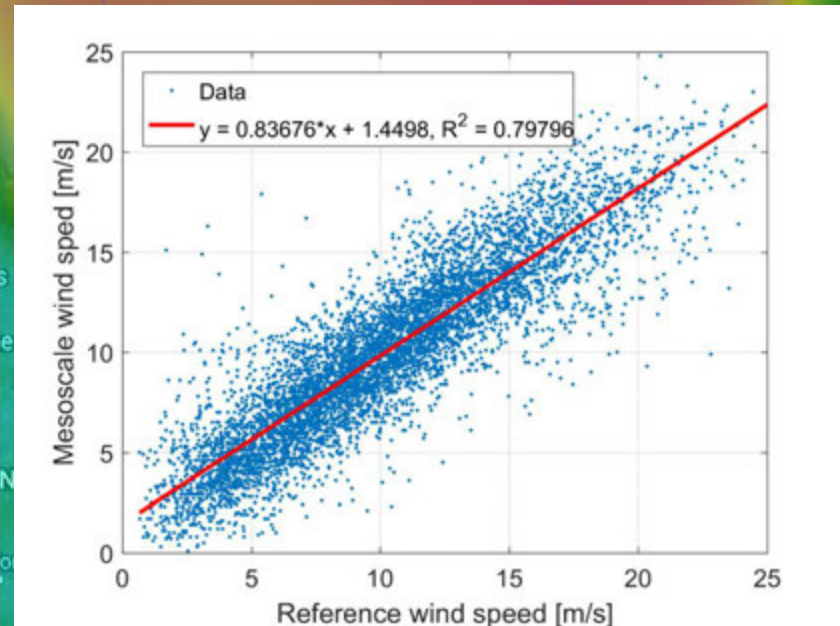
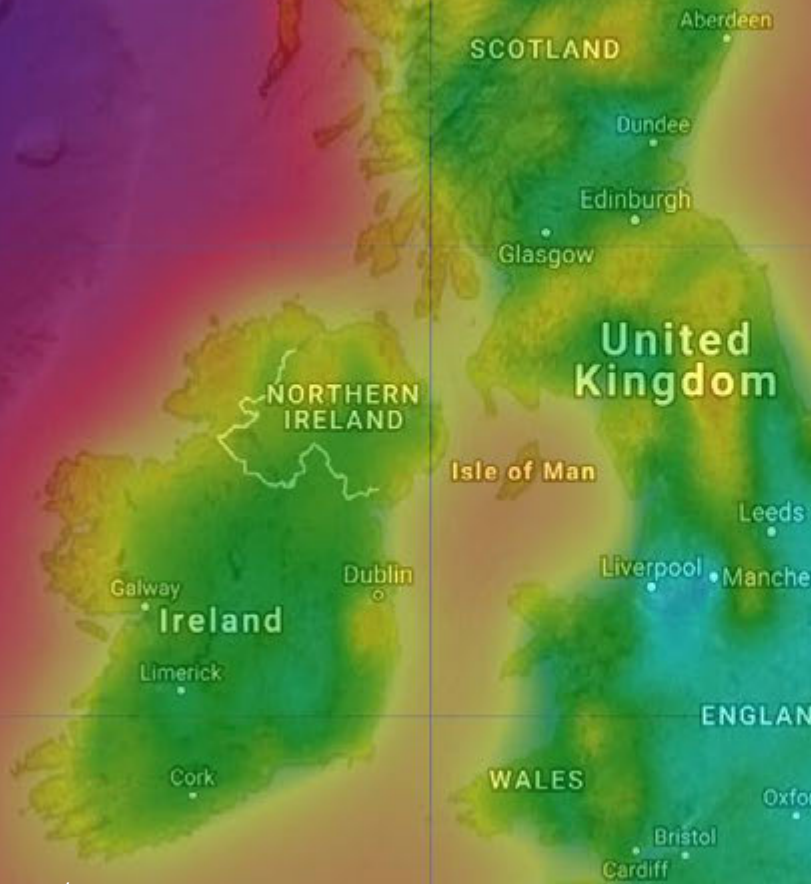
Reducing uncertainty through validation



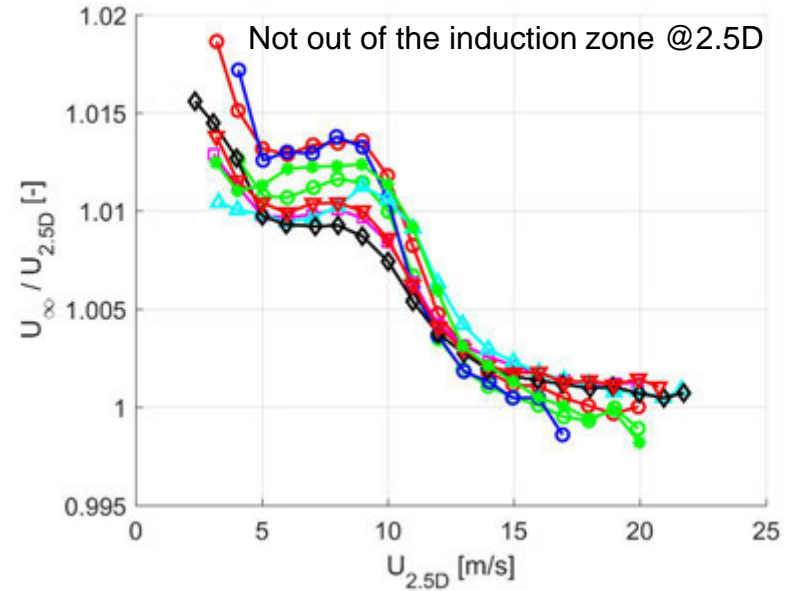
Reducing uncertainty through validation



Reducing uncertainty through validation



Turning uncertainty into bias



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