

Validation of Energy Predictions by Comparison to Actual Performance

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Overview

- Comparison of actual production vs. GH predictions
- Observations and explanations for deviations
- Amendments to GH methods
- Next steps for GH and the industry

Comparison of actual vs. predicted production

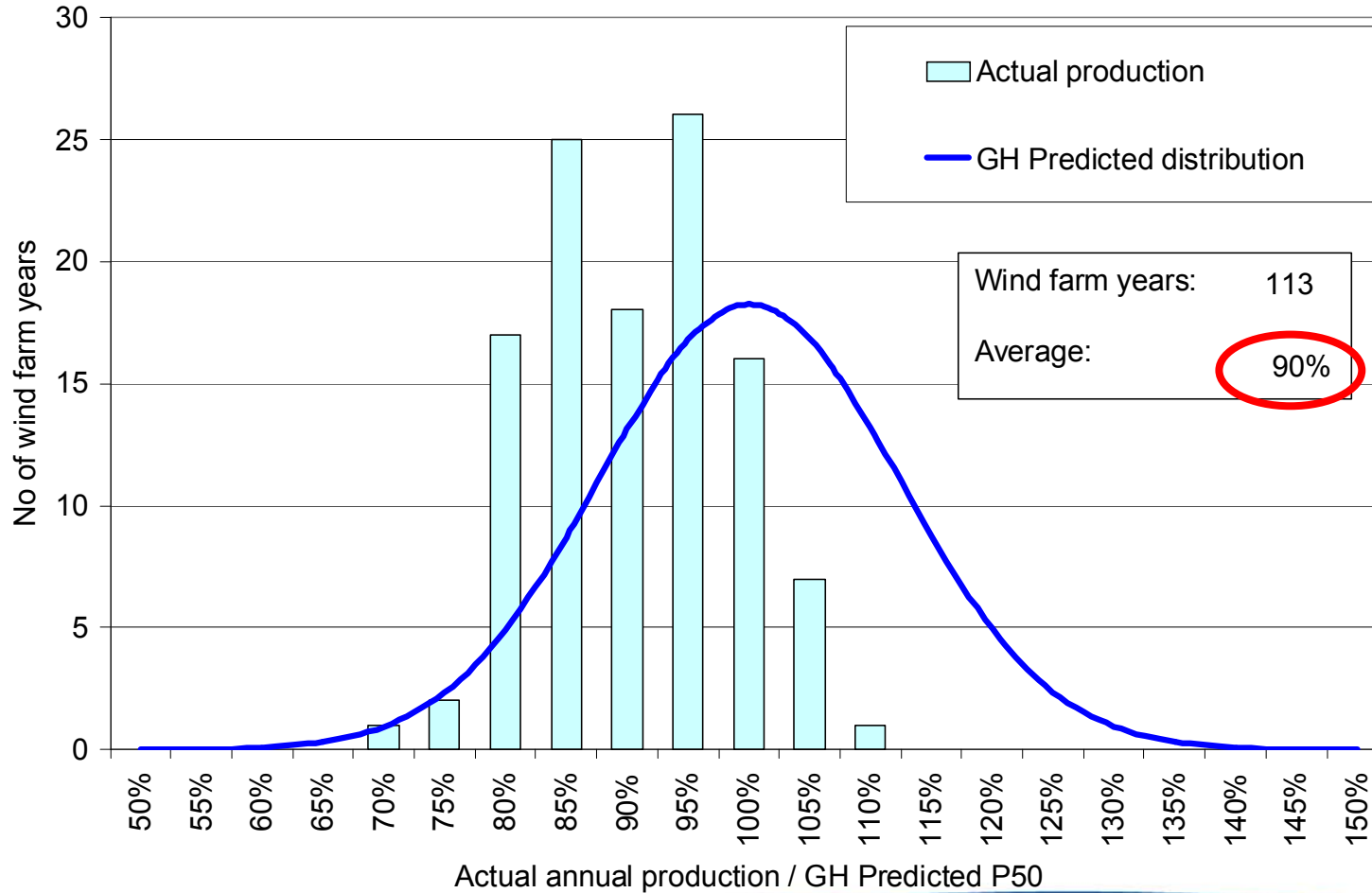


Energy production validation database

- Contains 41 wind farms in North America
- Operational periods from 1 to 8 years
- Contains 113 wind farm years of energy production
- Raw metered substation production
- Unit is “wind farm year”
- Includes some public domain data from the Energy Information Administration (EIA)
- Availability data from 31 wind farms

Distribution of Annual Energy Production

113 North American wind farm years relative to GH Projected P50





Observations and Explanations



Possible Sources of Under-performance

- Analysis methodology
 - Wind Resource Prediction Error
 - Measurement bias
 - Long-term adjustment
 - Extrapolation to hub height
 - Wind flow modelling
 - Energy loss factor prediction error
 - Wake loss modelling
 - Availability
 - Turbine performance
 - Curtailment
 - Electrical

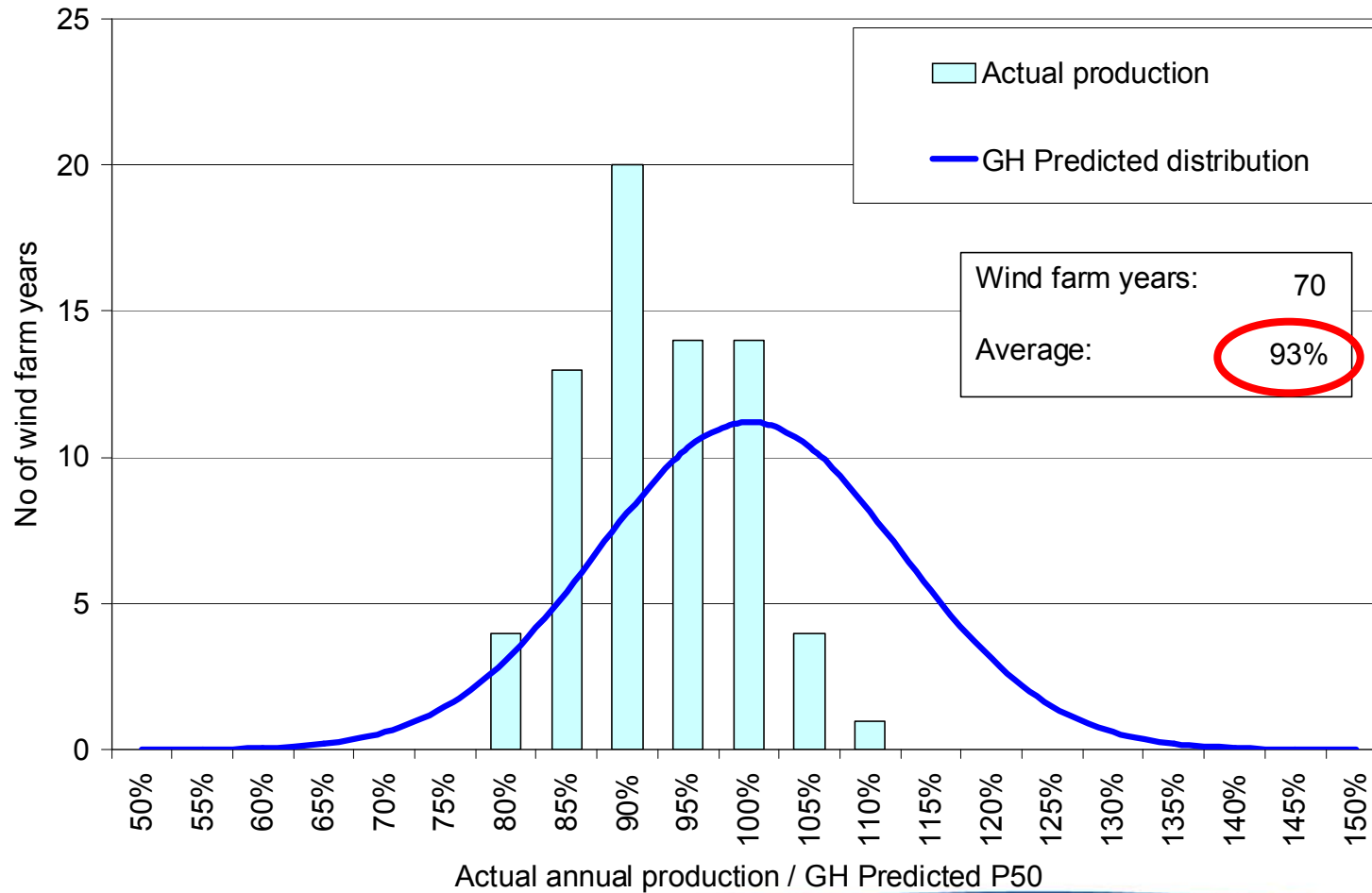
Quality measurements are still crucial!

Largest contributing factors

- Windiness of operating period

Distribution of Annual Energy Production

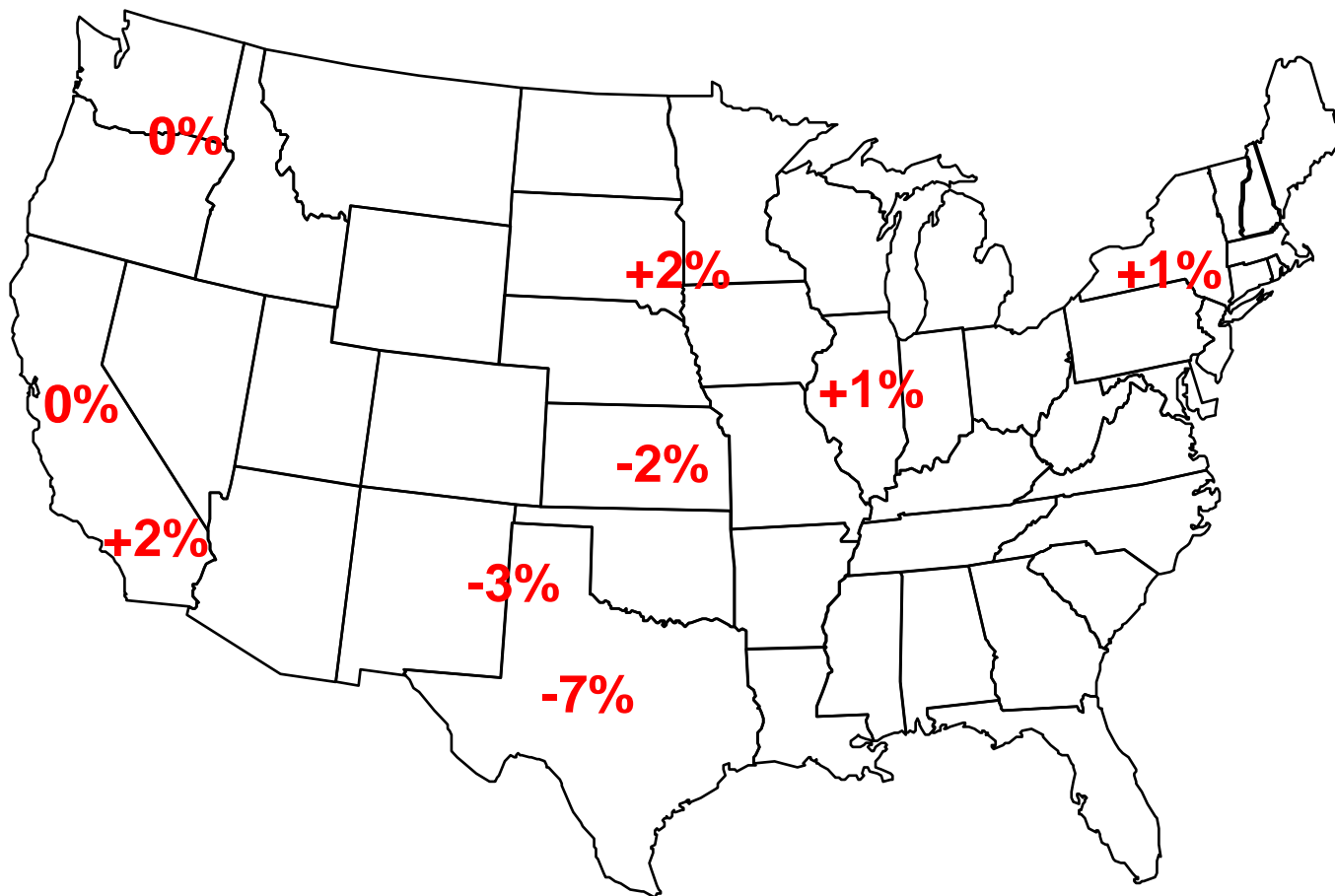
70 **Availability corrected** wind farm years relative to GH Projected P50



Focus on 2007

- Adjust database for actual availability achieved by wind farms in 2007
- Adjust database for windiness of 2007
 - Use publicly available wind speed data from long-term meteorological stations
 - Identify regions of similar wind patterns

2007 Indicative windiness across the US



Note wind speed NOT energy

Focus on 2007

**Comparison of actual production against GH Projected P50
after adjusting each wind farm production to average wind speed
and for availability**

	All data (41 wind farms)	Windiness adjusted (41 wind farms)	Windiness and availability adjusted (27 wind farms)
Average ratio Actual/predicted	90%	92%	96%

Conclusion: Average ratio within 5 % of ideal result

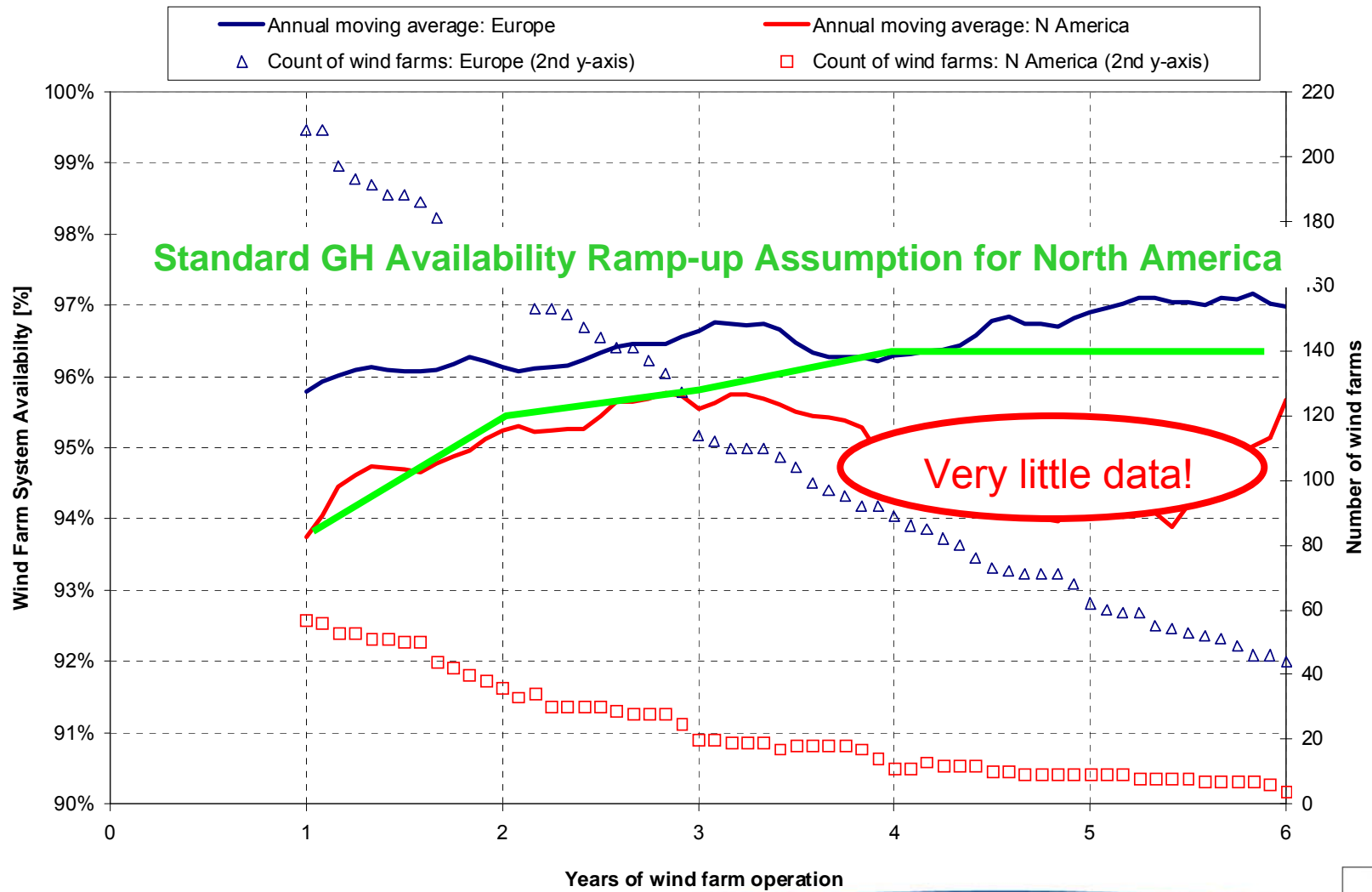
Critical Appraisal of Methods

- GH have gone through a process to attempt to identify what elements of our analysis may lead to bias
- This has involved the very detailed analysis of the 10-minute SCADA data from many North American wind farms
- We have identified areas where we believe there is potential for bias and have amended our processes in the light of these findings

Further Investigation of Energy Loss Factors

- Availability
 - What levels of availability are being achieved?
 - What availability levels do we expect to see in the future?
- Turbine Performance
 - Are we interpreting manufacturer power curves correctly?
 - How does power performance vary in different wind regimes?
 - Are individual turbines within a wind farm operating as they should?
- Wake loss modelling
 - Are existing models sufficient for very large wind farm developments?

Availability Data – North America vs. Europe



Are we interpreting manufacturers' power curves correctly?

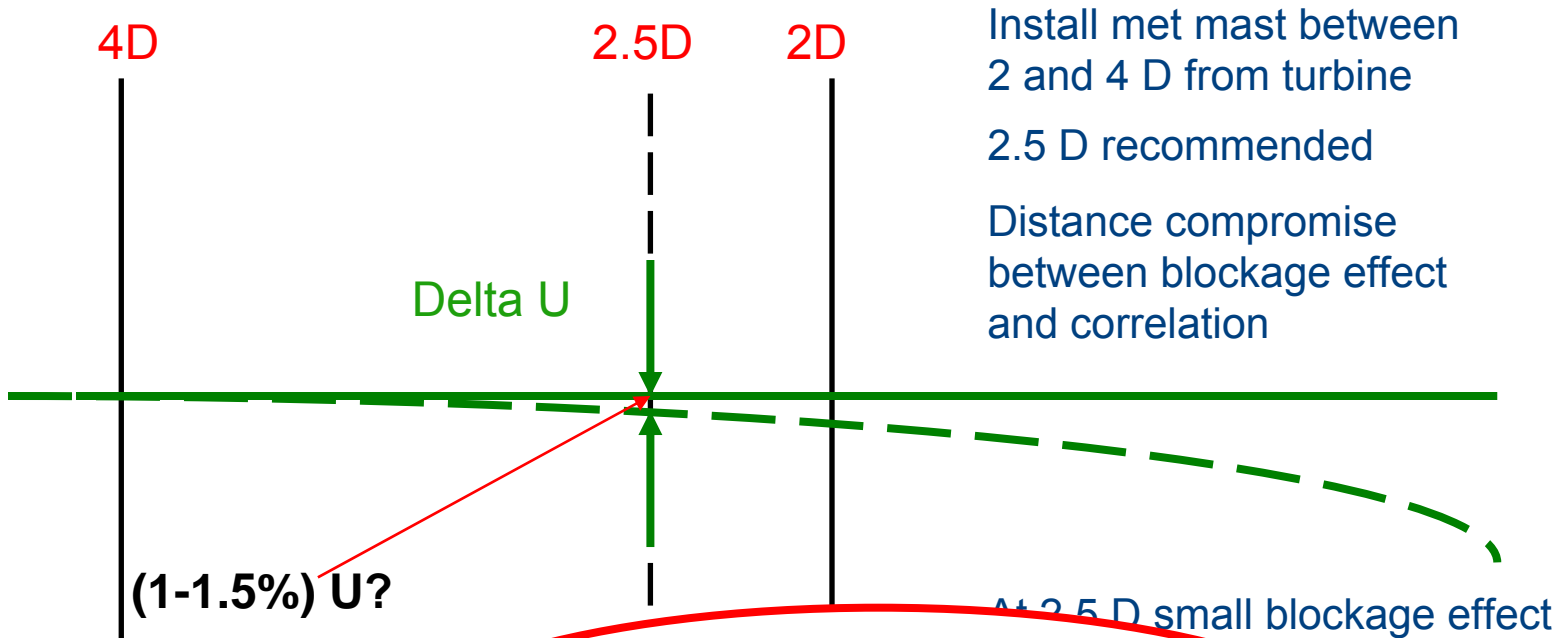
IEC 6-1400 Pt 12 says:

“Care shall be taken in locating the meteorological mast. It shall not be too close to the wind turbine since the wind speed will be influenced/changed/affected in front of the wind turbine”

- Is the presence of the turbine reducing the wind speed measured during a power curve test?
- Is there an industry-wide, systematic bias in energy production assessments?

Blockage of wind speeds in IEC test

IEC 6-1400-12-1 guidance



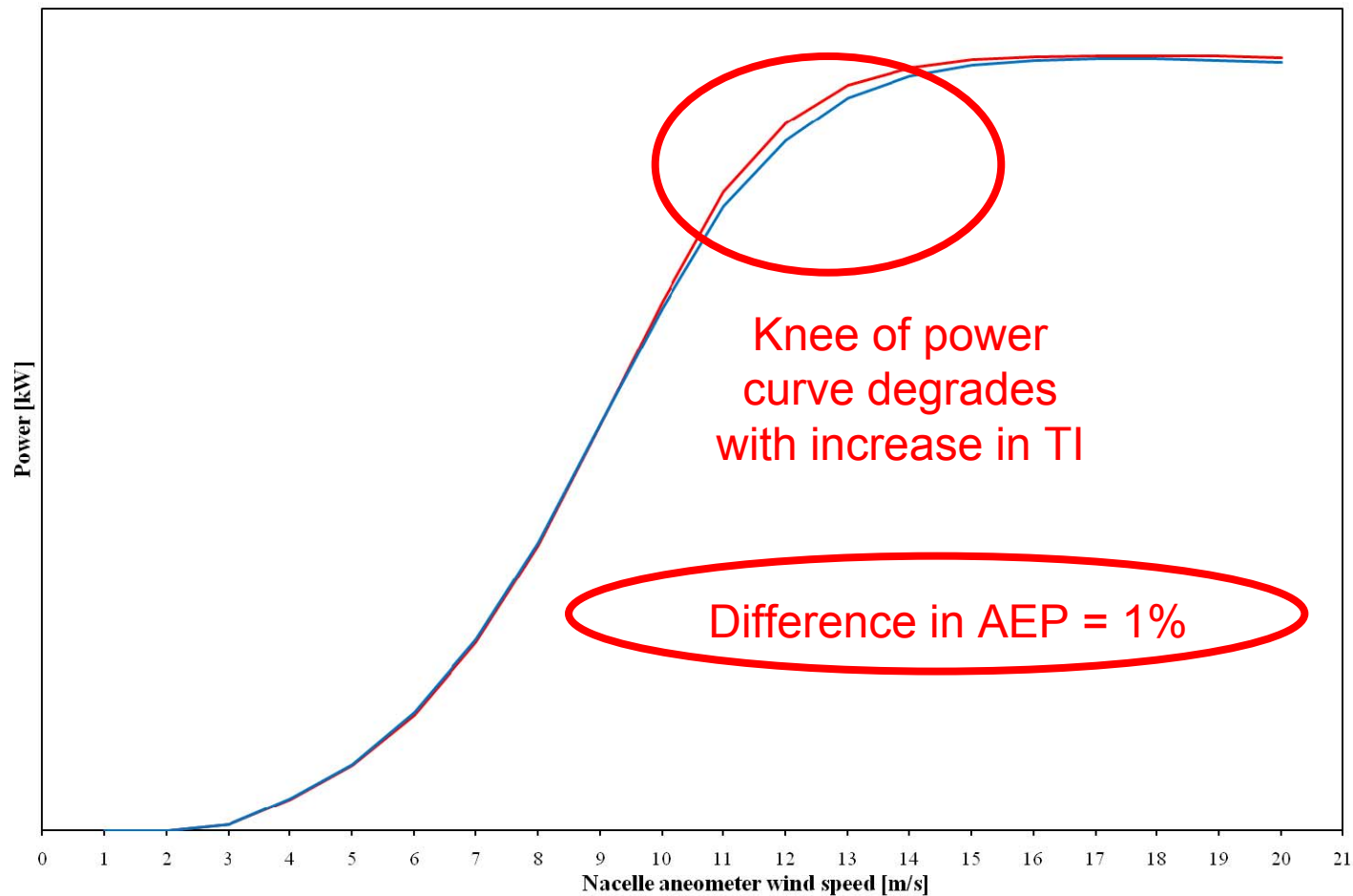
***Not questioning validity of measurements
Questioning the interpretation***

Site Specific Power Curve Adjustments

- Analysis of 10-minute SCADA data and general industry knowledge indicate:
 - Reduced power performance in high turbulence
 - Reduced power performance at sites with steep slopes
- GH is making site specific adjustments to power curves

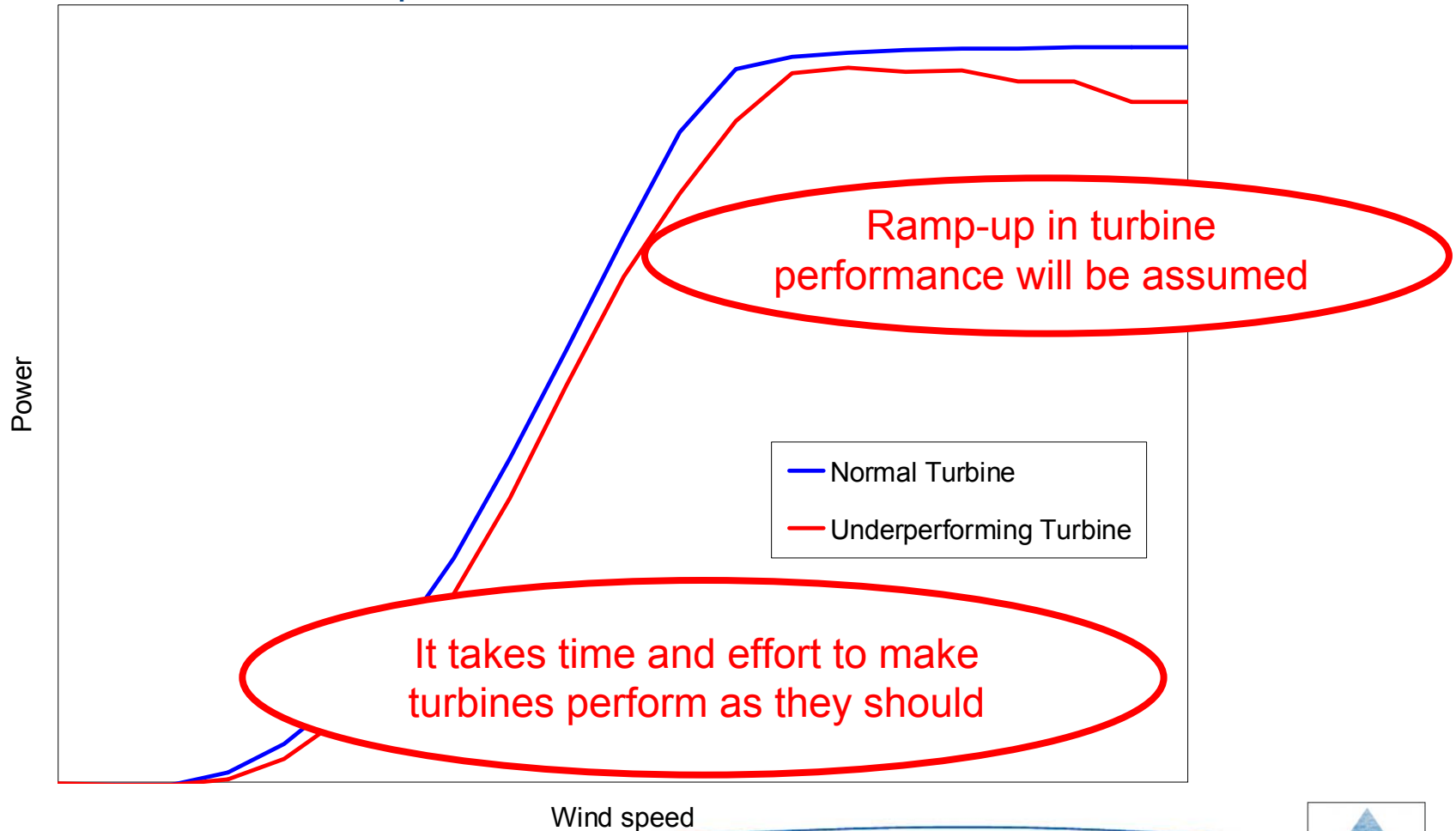
Site Specific Power Curve Adjustments

Variation of performance with turbulence intensity



Are turbines performing as they should?

Power curve comparison of 2 turbines in the same wind farm



How good are our wake models in large wind farms with low ambient turbulence?



GH Eddy Viscosity Model has been validated against actual production

Recent validation of large offshore projects shows some under-prediction

- Similar effect may be happening in large onshore projects
- Apply adjustment informed by offshore experience

Summary and Conclusions

- “Raw” results show over-prediction
- 2007 results within 5 % of ideal result when availability and windiness are considered
- Availability data show long ramp-up
 - Key question for medium term availability levels – will O&M money be spent to achieve and maintain high availability?
 - Why would the industry not do this?

Summary and Conclusions

- Critical appraisal of methods based on science and data. From this five potential causes of bias identified and adjustment made:
 1. **Availability**
 2. **Power curve blockage effect adjustment**
 3. **Steep slope / high turbulence adjustment**
 4. **Poor power performance in initial years of operation**
 5. **Large wind farm wake model adjustment**
- Net reduction in AEP of 2 % to 5 % depending on site

Summary and Conclusions

- From the above discussion and GH revised methods, under-performance can be explained
- Industry needs to continue to critically review actual performance data from wind farms
- Industry needs to review analytical methods based on science and data – GH has extensive R&D program.
- Wind measurement campaigns and good data have a VITAL role to play in good predictions



Thank you!