Summary of Actual vs. Predicted Wind Farm Performance – Recap of WINDPOWER 2008

Clint Johnson

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2008 AWEA Wind Resource Assessment Workshop
Portland, OR

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Summary of 3 presentations given WINDPOWER 08

- Eric White, AWS Truewind
  - “Understanding and Closing the Gap on Plant Performance”
- Steve Jones, DNV-GEC
  - “Project Underperformance: 2008 Update”
- Clint Johnson, Garrad Hassan
  - “Validation of Energy Predictions by Comparison to Actual Performance”

Purpose of the presentations

The magnitude of the issue:

- Comparison of actual energy output to pre-construction estimates

Understanding the issue:

- Observations and explanations for wind farm under-performance

Rectifying the issue:

- Adjustments to existing methods and next steps for the industry

Actual vs. predicted production - The magnitude of the issue

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Energy production databases

	AWST	DNV-GEC	GH
Number of Wind Farms	56	59	41
Number of Wind Farm Years	112	243	113
Range of Project Age	1 to 9 years	1 to 14 years	1 to 8 years
Locations of Projects	North America	North America	North America
Source of Predicted Output	Multiple Consultants	Multiple Consultants	GH only
Source of Actual Output	Public and Private	Public and Private	Public and Private

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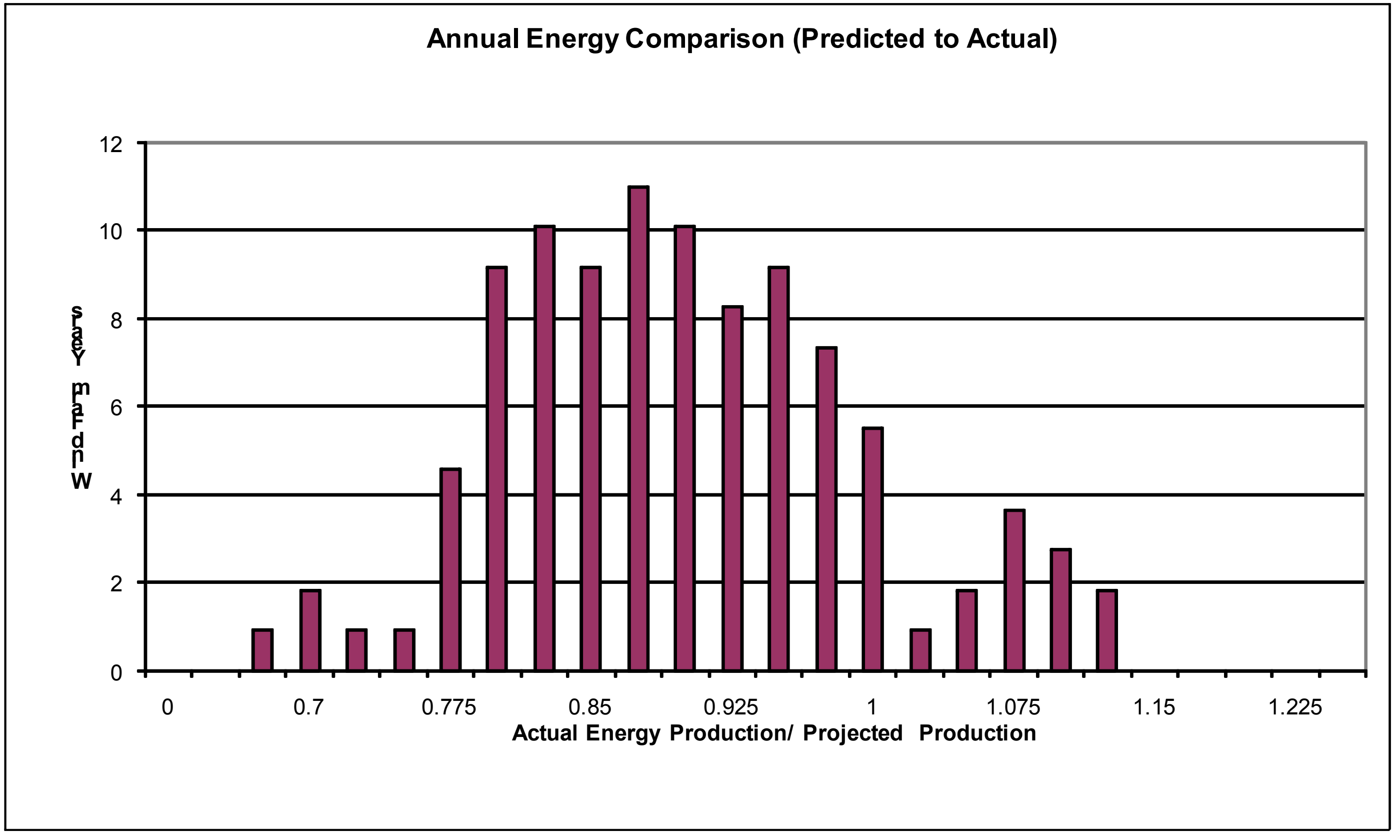
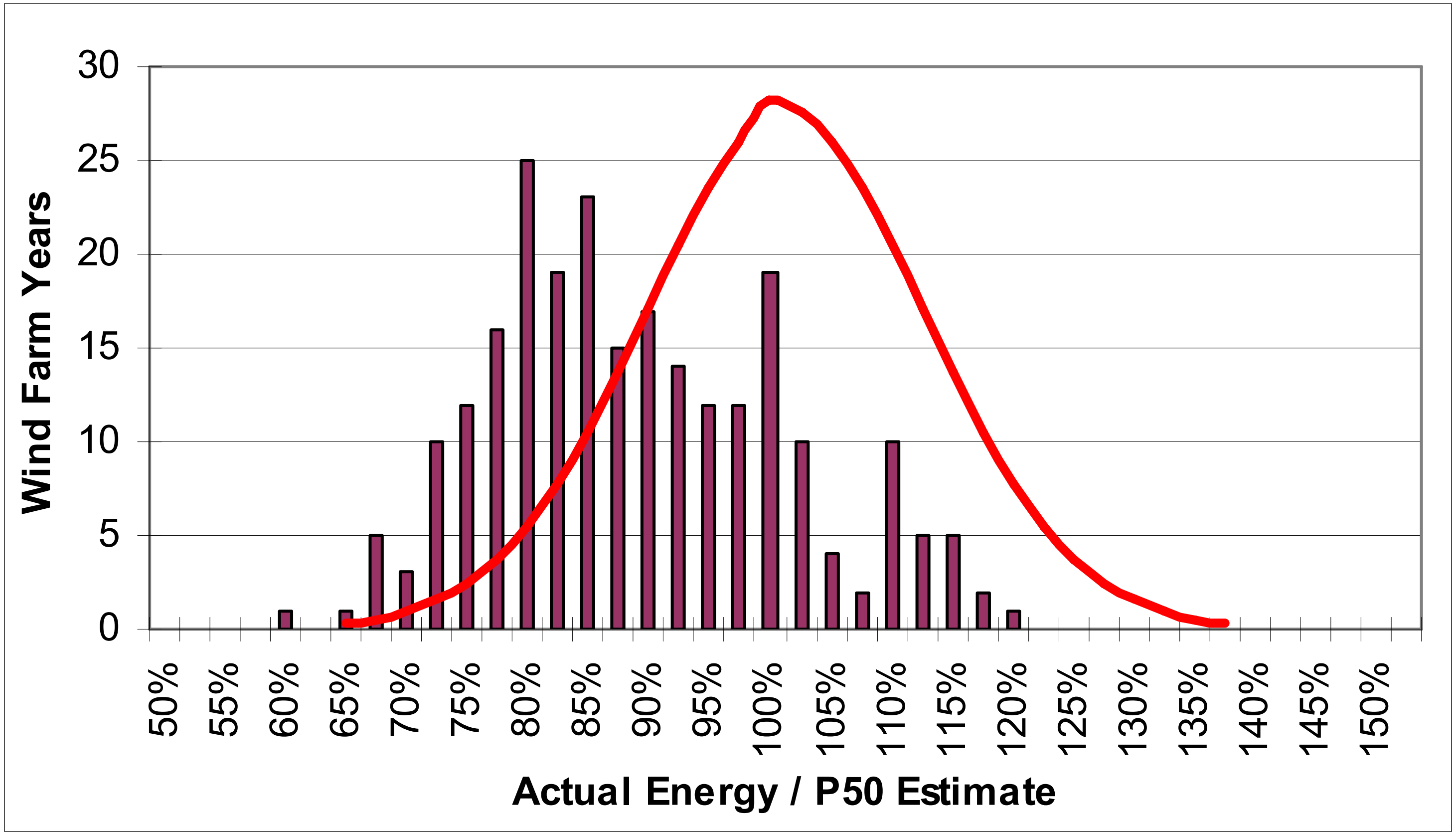
AWST Presentation:
Distribution of Annual Energy Production



Underperformance of ~ 10 % is typical and prevalent across industry

DNV-GEC Presentation: Distribution of Annual Energy Production



- Average is about 11% below P50
- 2006 presentation: 13% below P50

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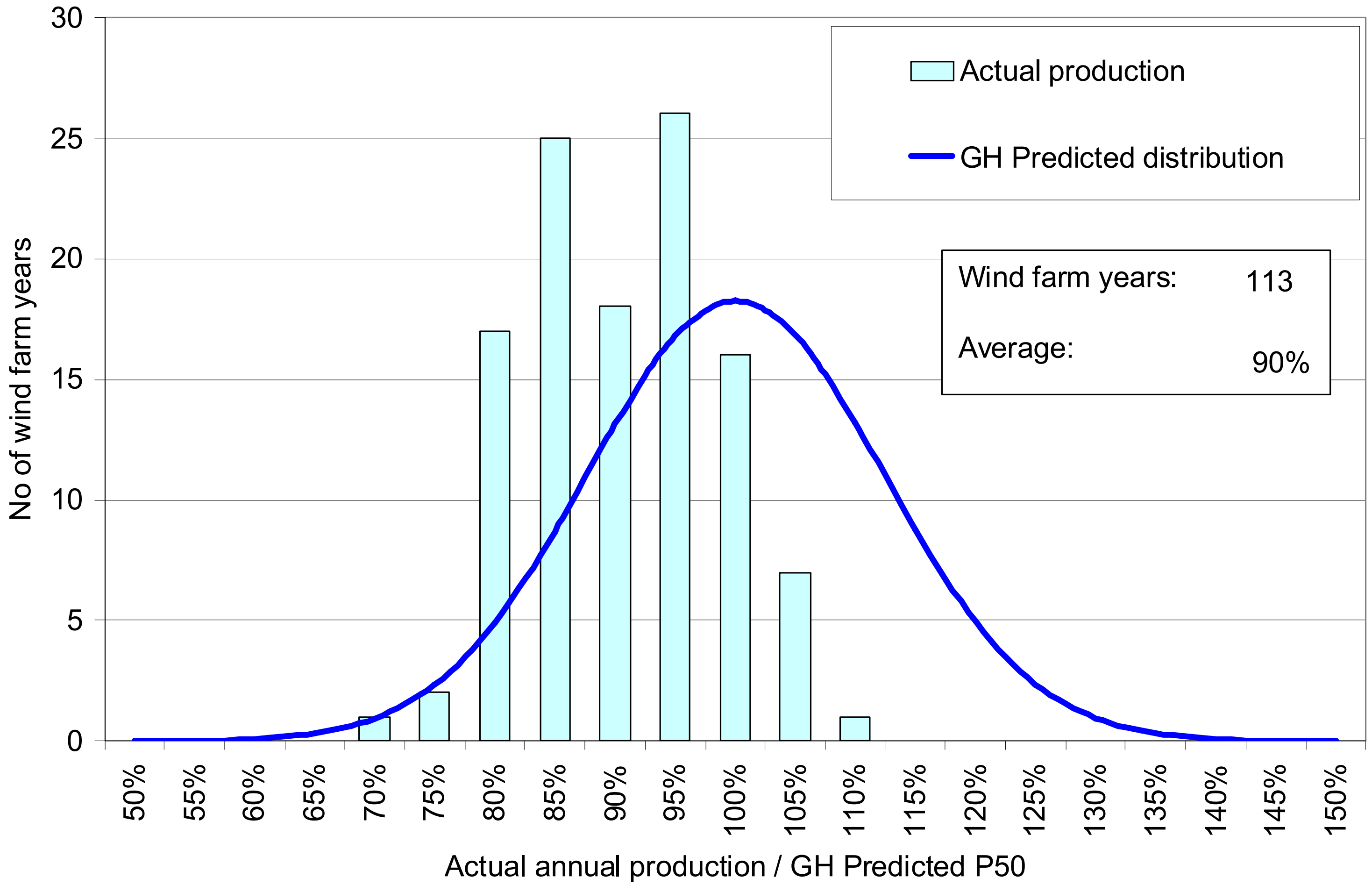
GH Presentation
Distribution of Annual Energy Production



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Understanding the Issue: Observations and Explanations

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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

- Natural wind variability

Limitations and Challenges

- **Multiple variables contribute to the problem**
  - How to separate wind flow modeling errors from wake loss modeling errors
  - Original long-term reference often lost – what is the true mean wind speed?
- **Accurate data not always available**
  - Availability
  - Actual production data – what is the source?
- **Reimbursements for lost production not often considered**
  - Insurance (e.g. lightning damage)
  - Availability warranty claims turbine against manufacturer
  - Curtailment forced by grid operator or power purchaser
- **Time lags and evolving methods**
  - Assessment methodologies may have evolved over several years
  - Much of the production data reflects older projection methods
  - Limited data available for comparison on current methods

Key factors contributing to under-performance

- **Actual wind farm availability**
  - Significant source of deviation (all consultants concur)
- **Inter-annual wind variability**
  - Regional wind farm clustering has exacerbated issue (AWST and GH)
- **Turbine power performance**
  - Sub-optimal operation (all consultants)
  - Site specific power curve issues such as turbulence (GEC and GH)
  - Blockage effect bias (GH)
- **Wake effects**
  - General bias (GEC)
  - Large wind farms (GH)
- **Wind flow modeling**
  - Failure to capture topographic effects (AWST and GEC)
  - Changes of turbine locations after pre-construction projections (AWST)
- **Measurement bias**
  - Instrument mounting effects (AWST and GEC)

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Specific Observations and Explanations

Eric White, AWST

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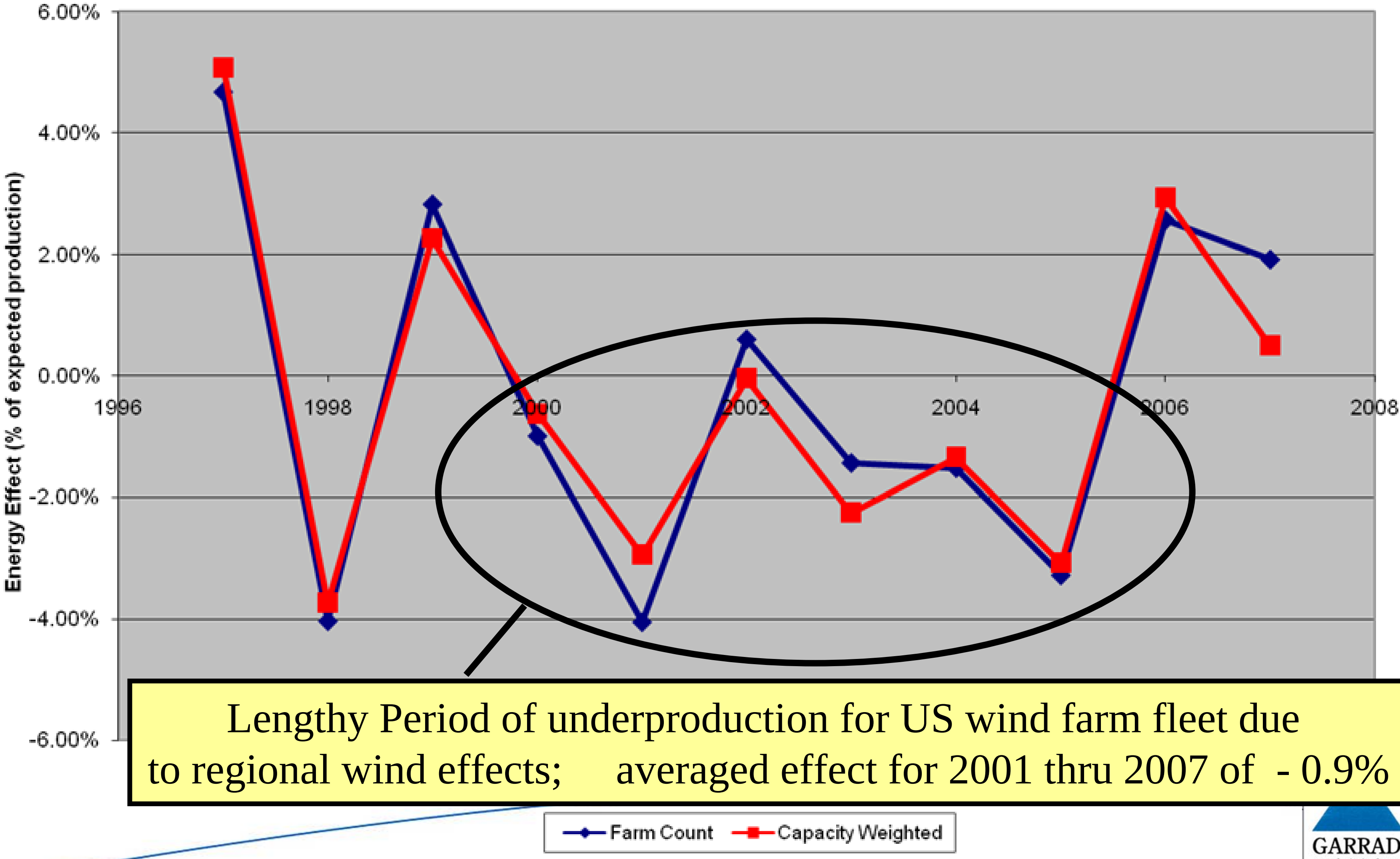
Effect of regional wind variability

Estimated Effect of Climate Variation on Annual Output of US Wind Farm Fleet

(Continental US wind farms, 20 MWs or greater capacity, with full year commercial operation in calendar year; 1.8X Energy to Wind Speed ratio)



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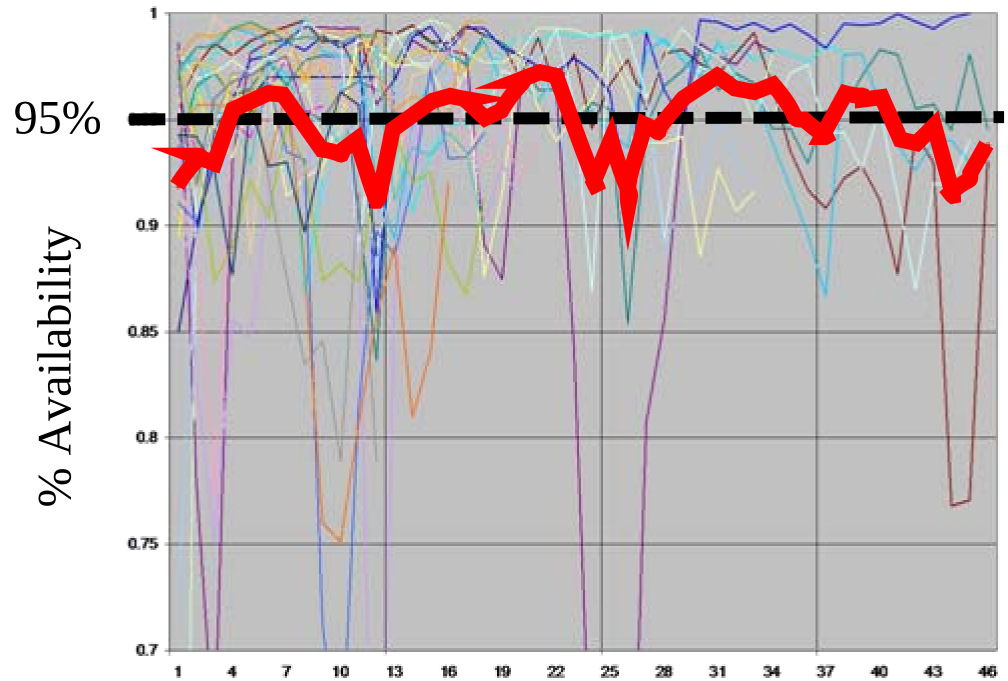
Actual Availability

- Often falls below expectations
  - Plant affects
  - Grid affects
  - Weather out time
    - Where is it counted?
  - Other issues “not in the contract”



- Two key factors

TURBINE CONTRACT ≠ ACTUAL PLANT	LOST ENERGY > LOST TIME

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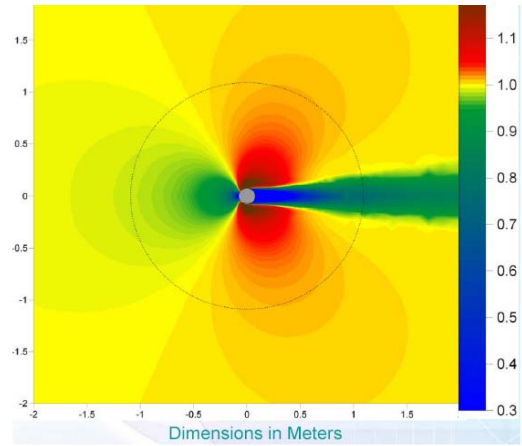
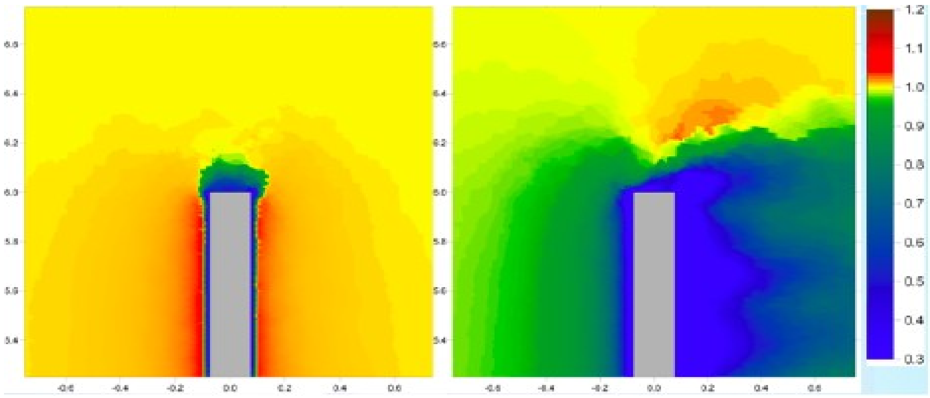
Resource Assessment Campaign Bias

- Many sources of bias from very early in the project life cycle
- Some examples
  - ASOS shifts
  - Instrument mounting effects
  - Tower siting & modeling approach





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Sub-Optimal Operation

Sub-Optimal Operation: Turbine operation at performance below potential for the given environment and application.

- ***Lost performance that can reasonably be recovered at a given site***

- Can and does occur
- Not an "availability" issue - by definition, for better or worse
- A variety of causes
- No good means to track
- May be no incentive for some parties to address the issues

Energy Effects Table

Contributing Element	Rough Estimate of Contribution to Fleet Shortfall
Short Term Climatology	1%
Availability inc. first year effects	3-5%
Resource Assessment Biases	1%
As Built Plant Changes	1%
Sub Optimal Operation	1%
Total	~ 7 to 9%

A significant portion of the exhibited shortfall is accounted for in the above elements

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Specific Observations and Explanations

Steve Jones, DNV-GEC

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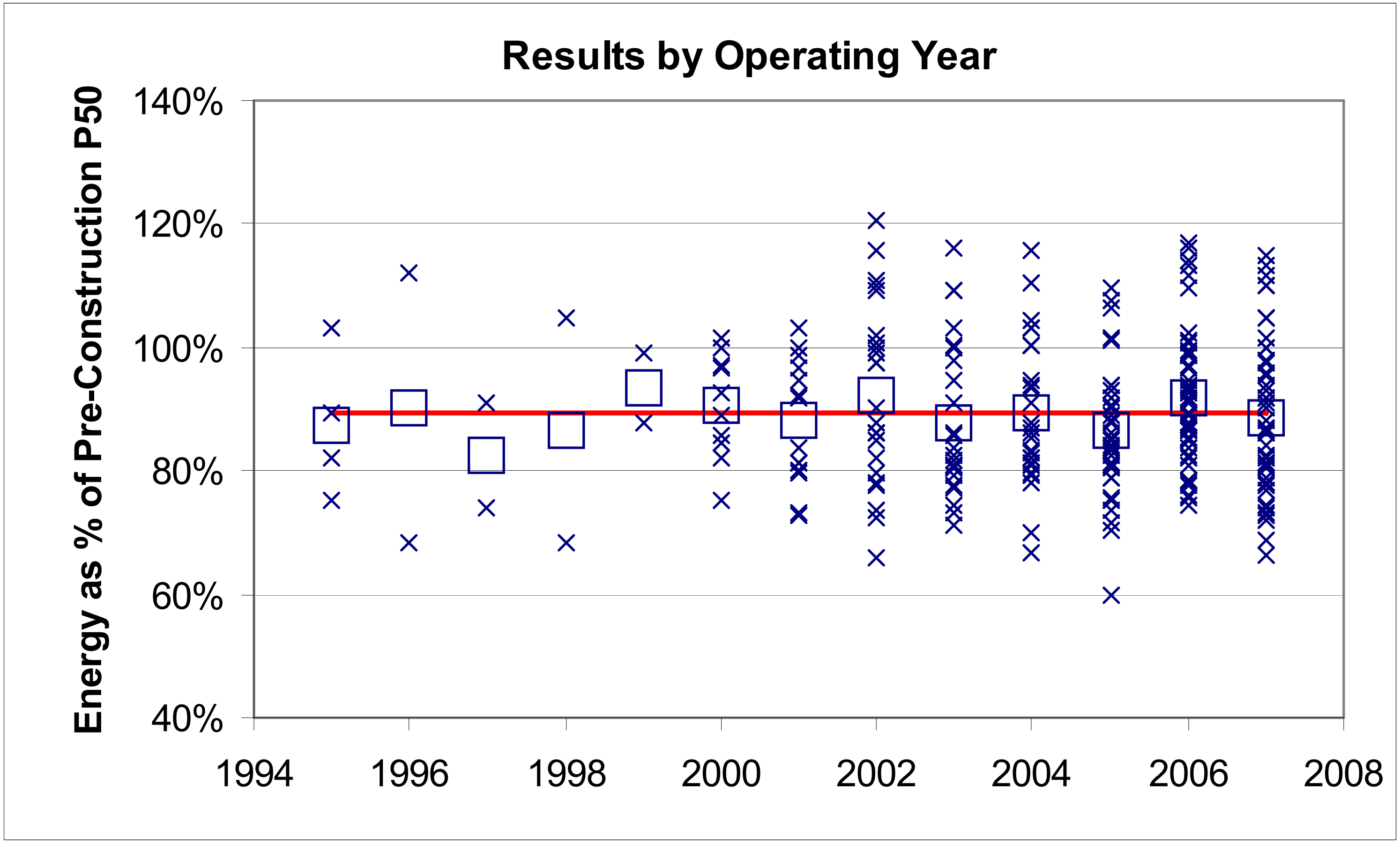
Energy: Year of Operation



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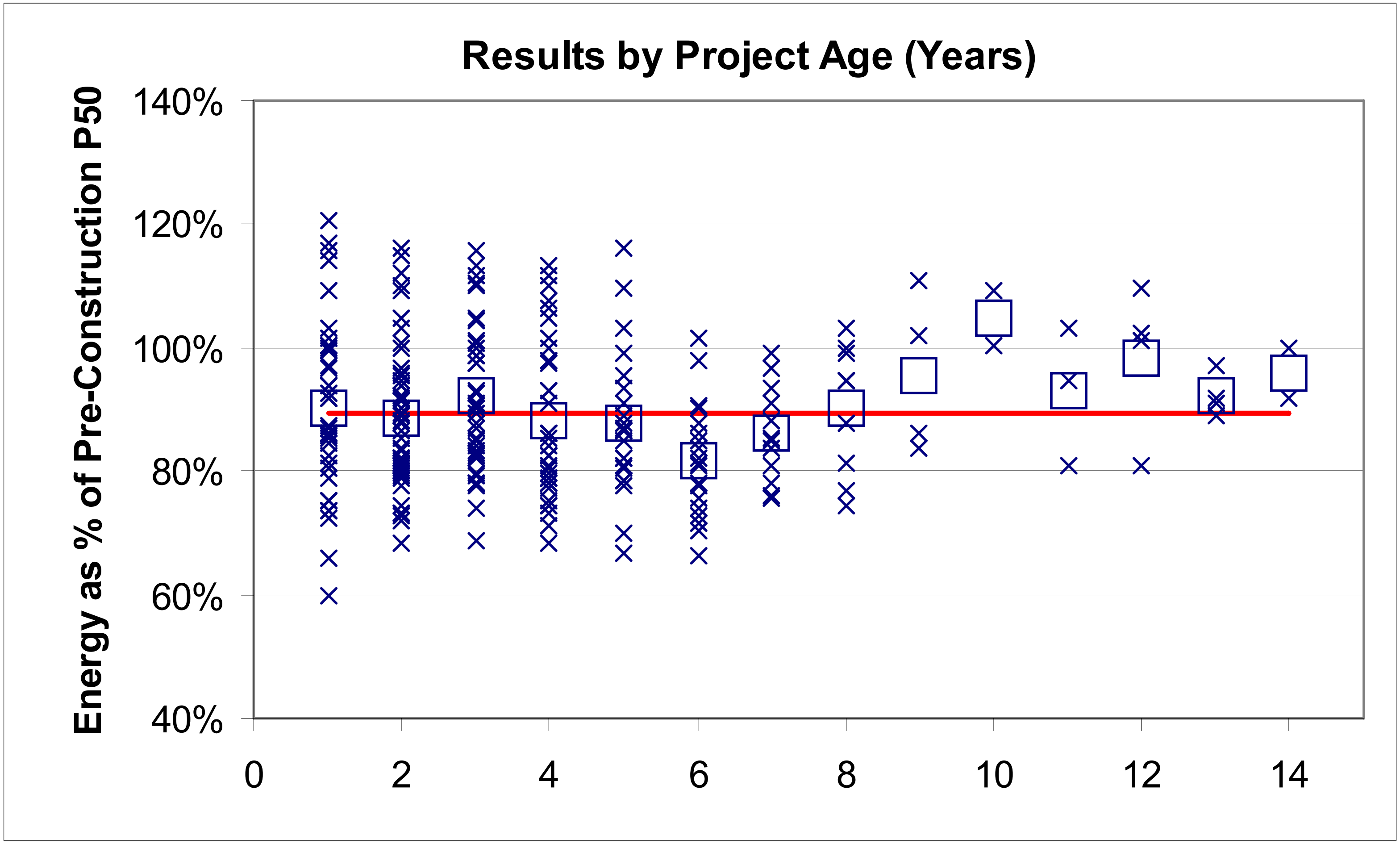
Energy: Age of Project



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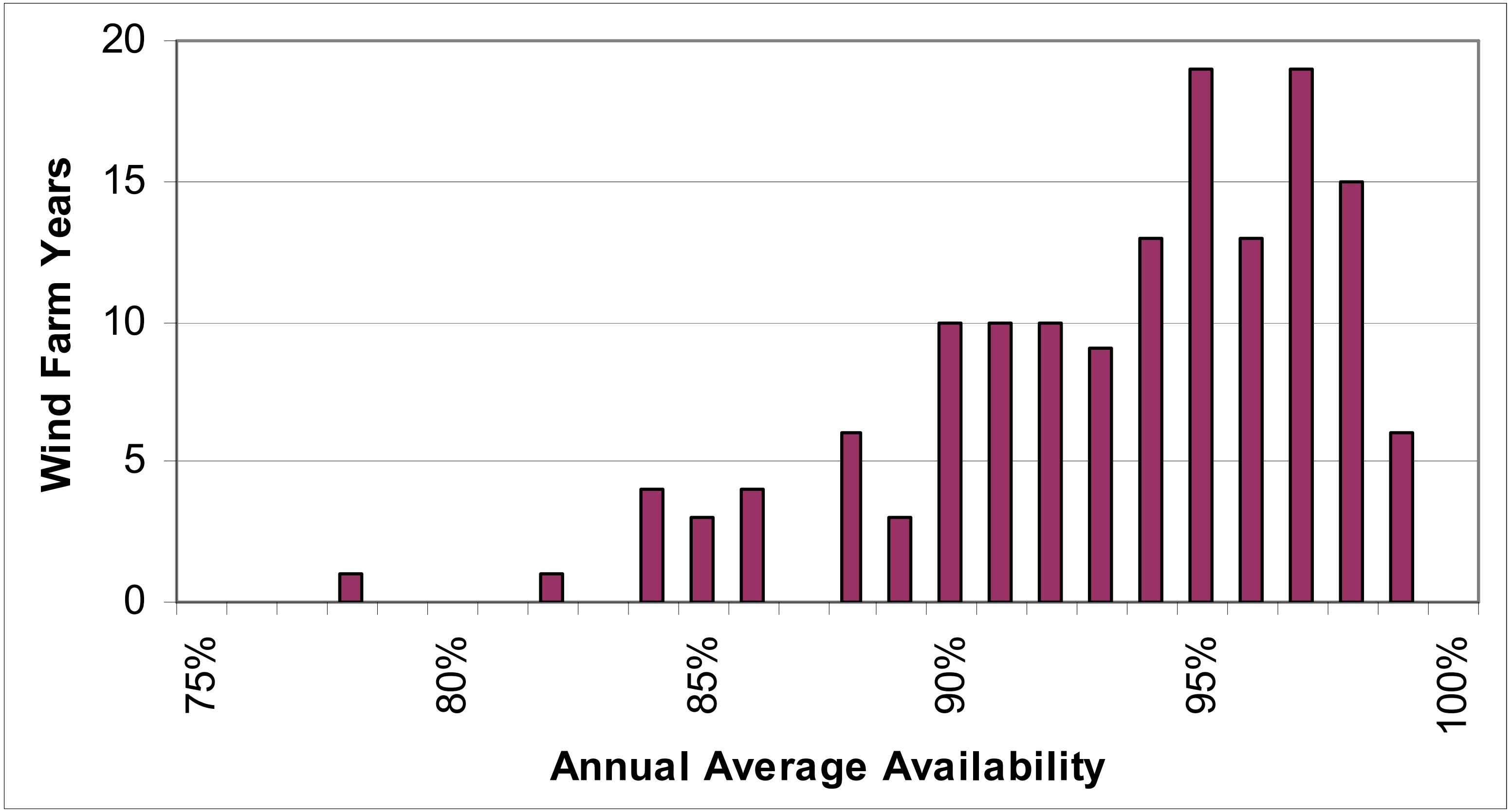
Survey Results: Availability



Less data on availability than on production

Average is about 93%

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Availability: Age of Project

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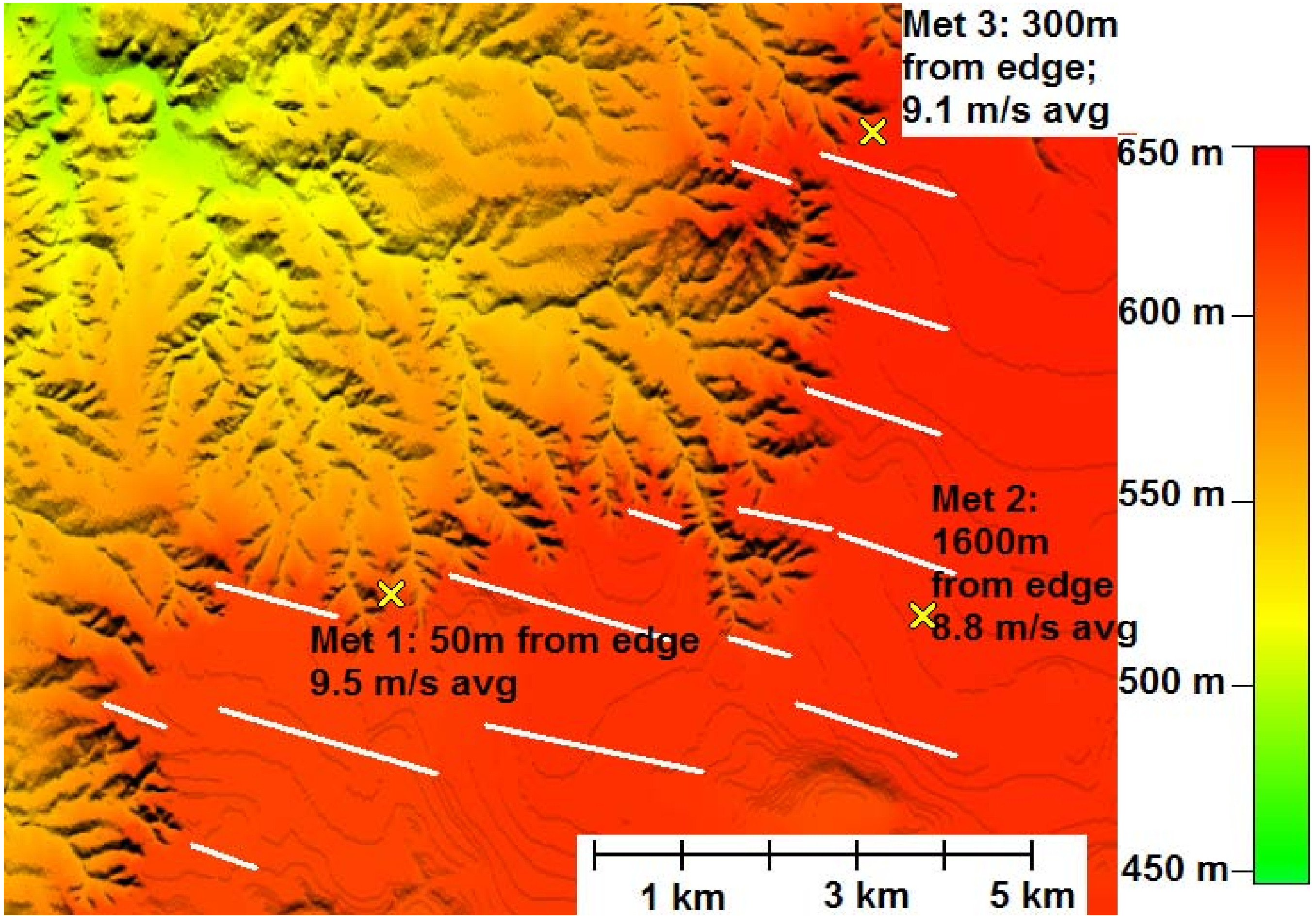
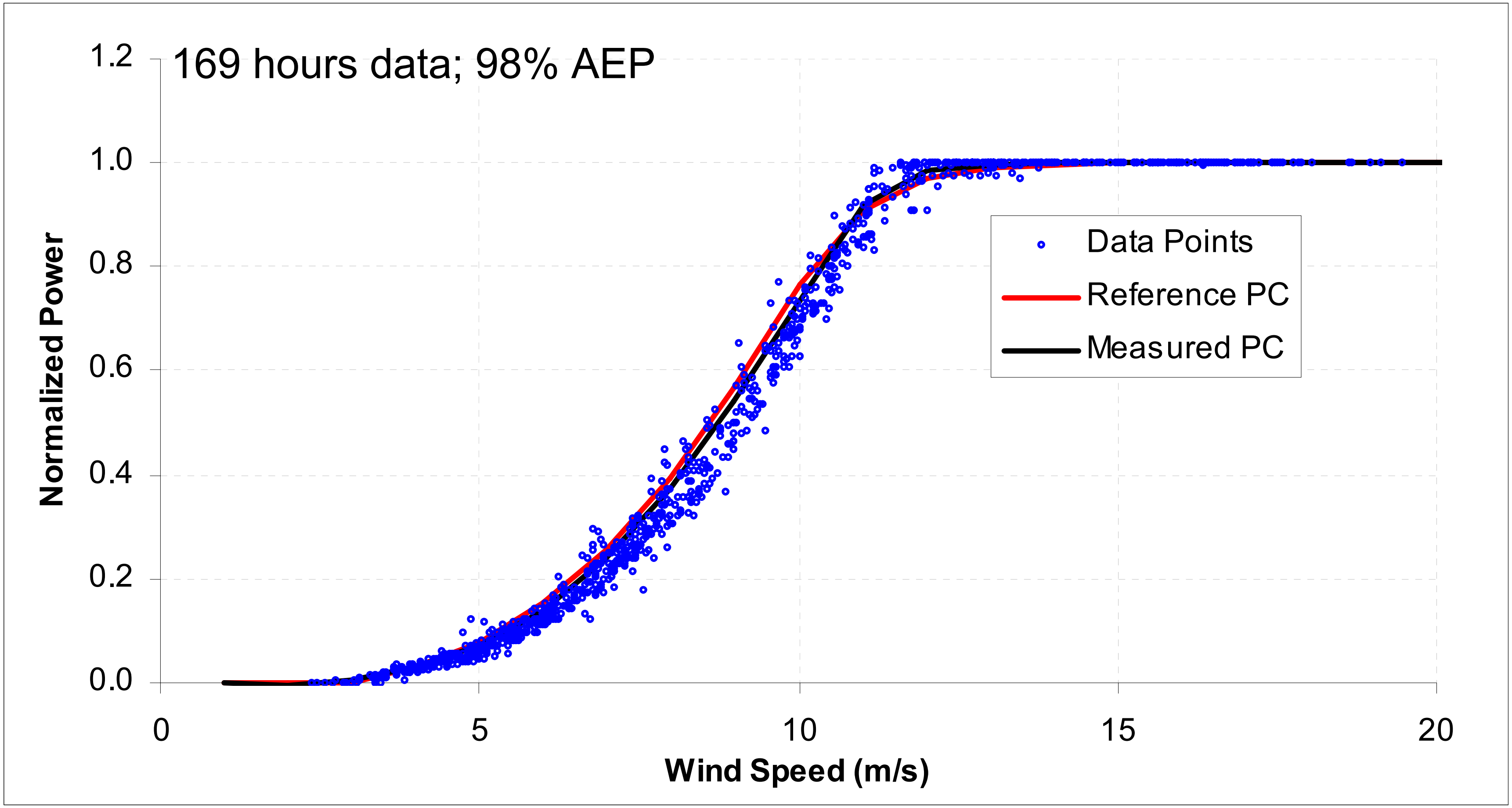
Biases: Topographic Effects (Southwest Example)



Power Performance Example:

Excluding for High Shear and High Turbulence Per Manufacturer's Test Specifications



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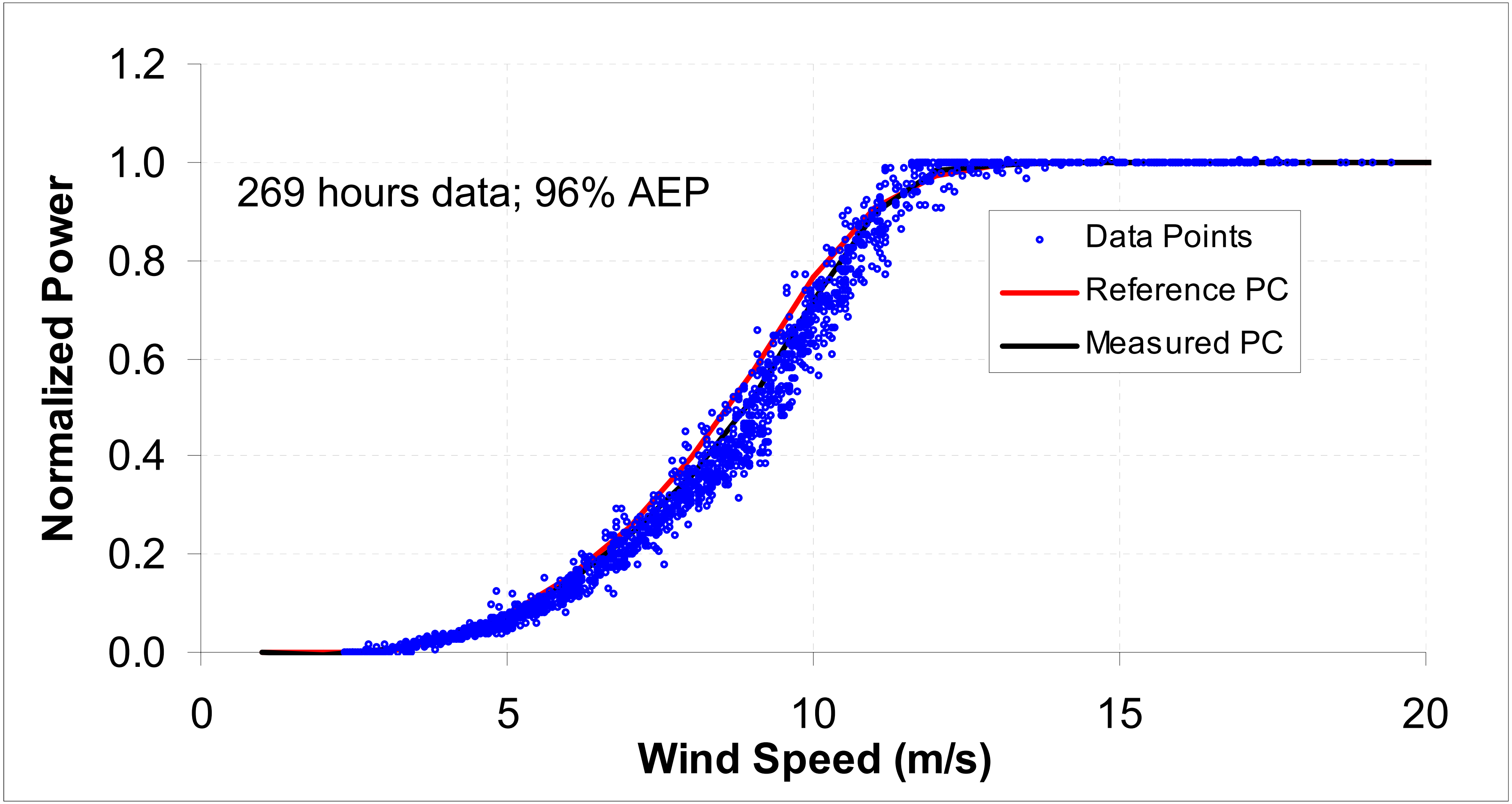
Power Performance Example: All Data



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Specific Observations and Explanations

Clint Johnson, GH

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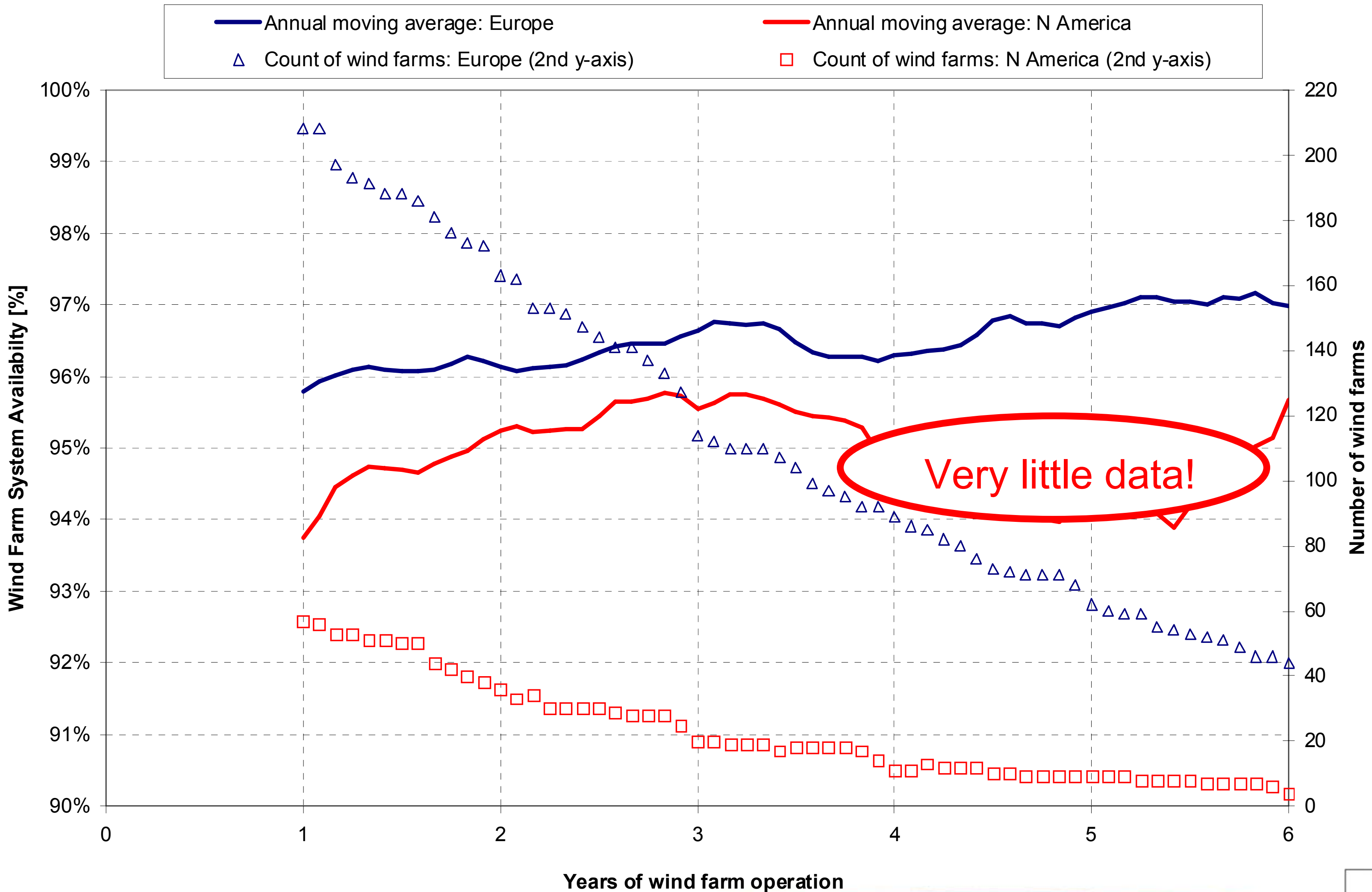
Availability Data – North America vs. Europe (GH)



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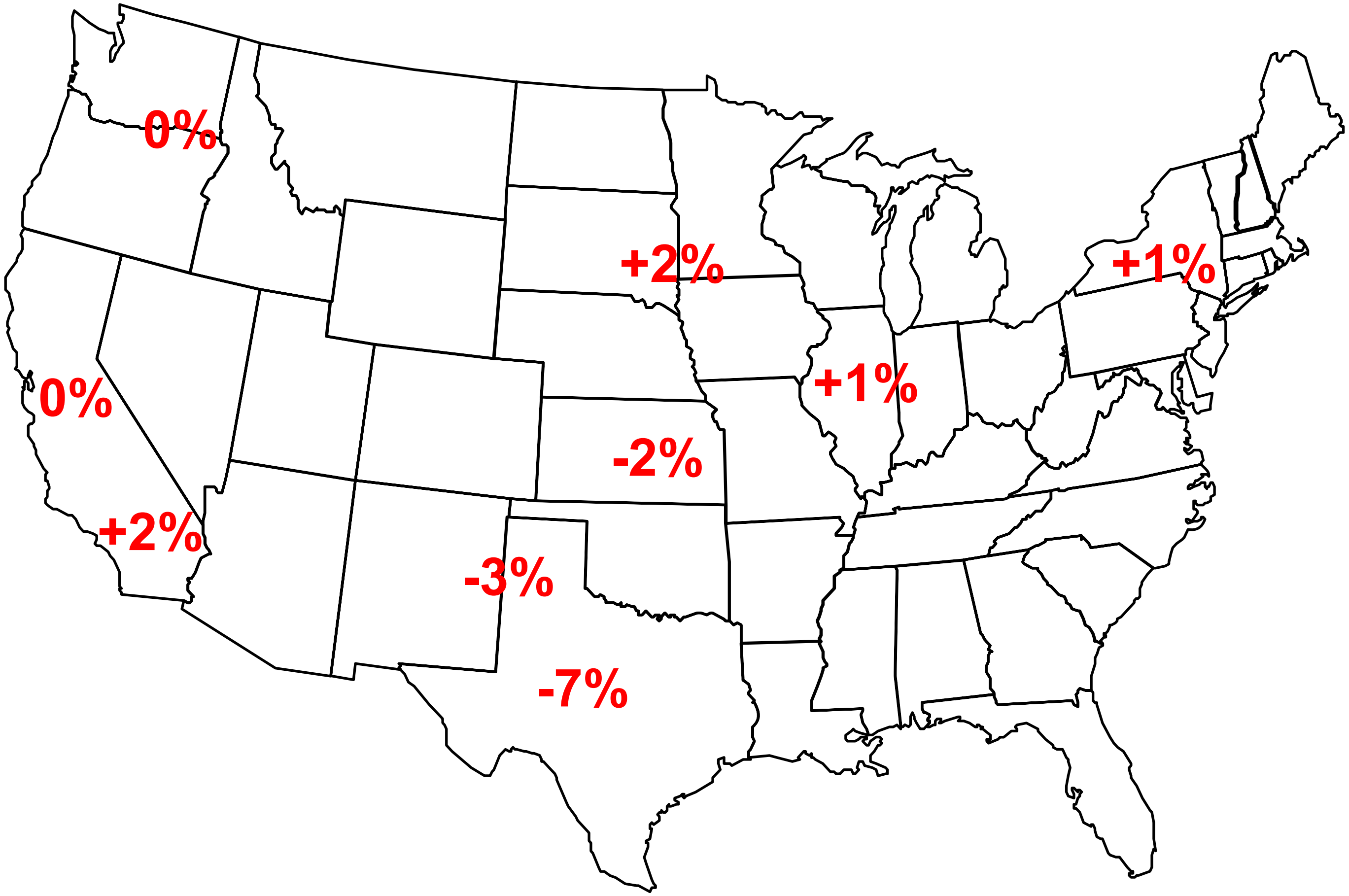
2007 Indicative windiness across the US



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

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Are we interpreting manufacturers' power curves correctly?

IEC 6-1400 Pt 12 says:

Blockage Effect

"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?

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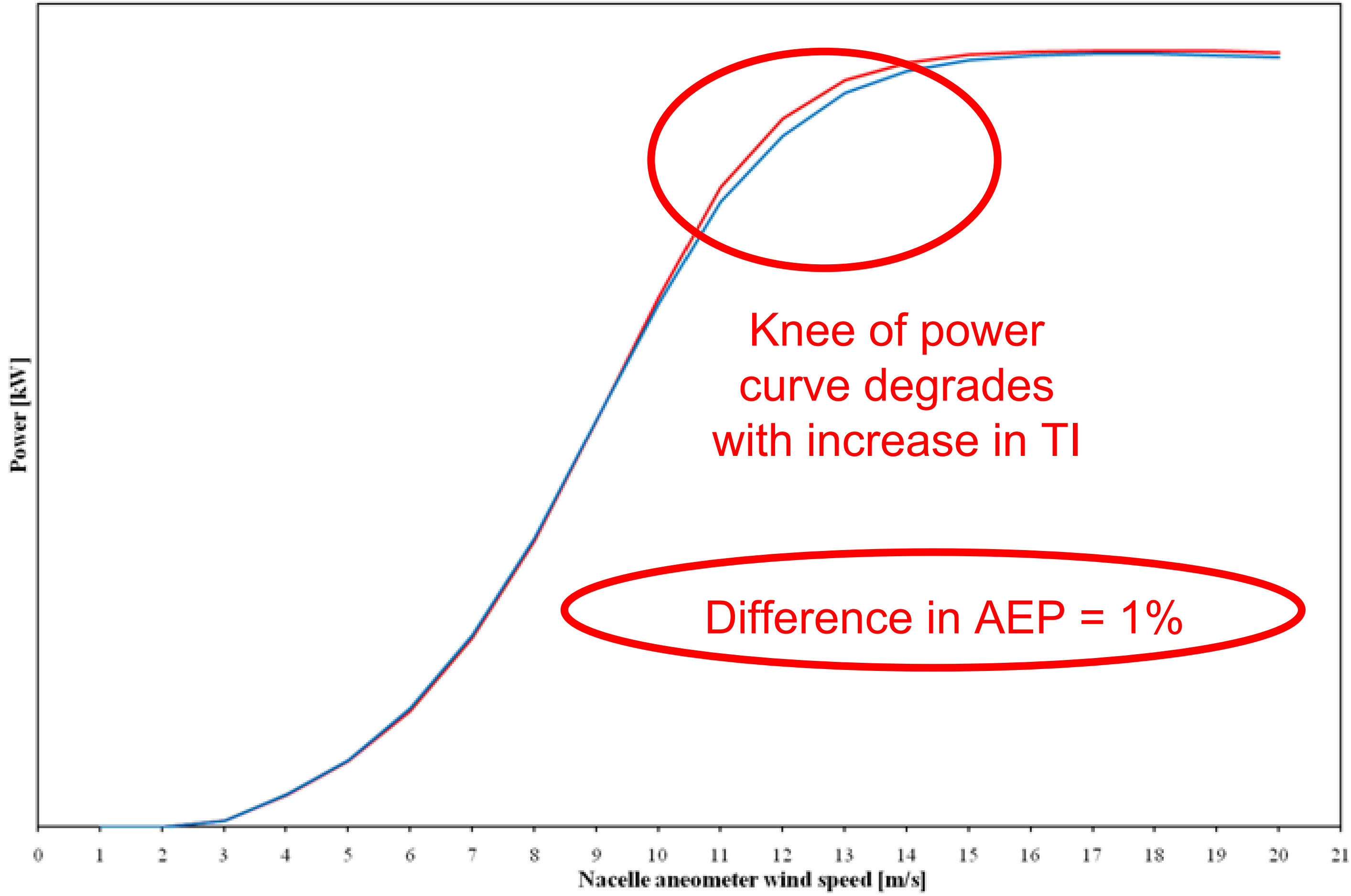
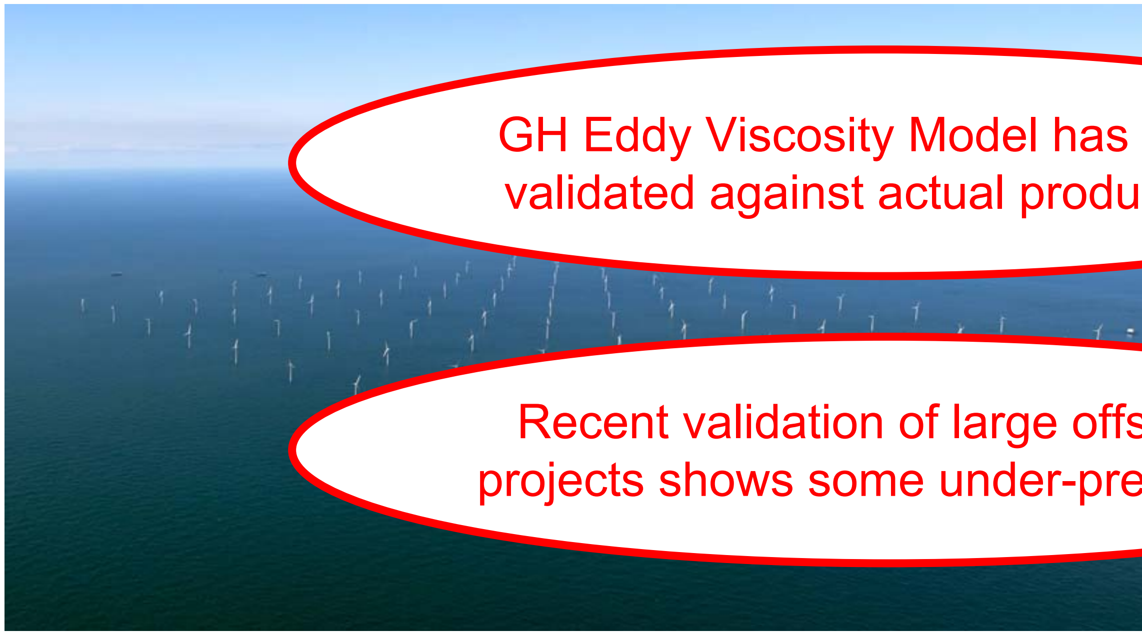
Site Specific Power Curve Adjustments

Variation of performance with turbulence intensity



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

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Conclusions and next steps

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Conclusions (AWST)

- Numerous factors at work in the shortfall; continued investigation needed

- Mother nature plays a role, *but*
  - **Many issues are addressable**

- All parties in the project development chain can play a role in closing the gap
  - Consultants
  - Developers
  - Financial Institutions
  - Owner operators
  - Manufacturers and O&M providers

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Conclusions (DNV-GEC)

As a whole, industry is over predicting energy generation

Data analysis shows many contributing factors

- Some difficult to measure
- Factors vary from project to project
- No “silver bullet” in most cases

Industry working to understand the issues and changes to standard practices underway

More operational data appreciated to help refine the “feedback loop”

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Conclusions (GH)

“Raw” results show over-prediction

Five potential causes of bias identified and adjustments 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**
- 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

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