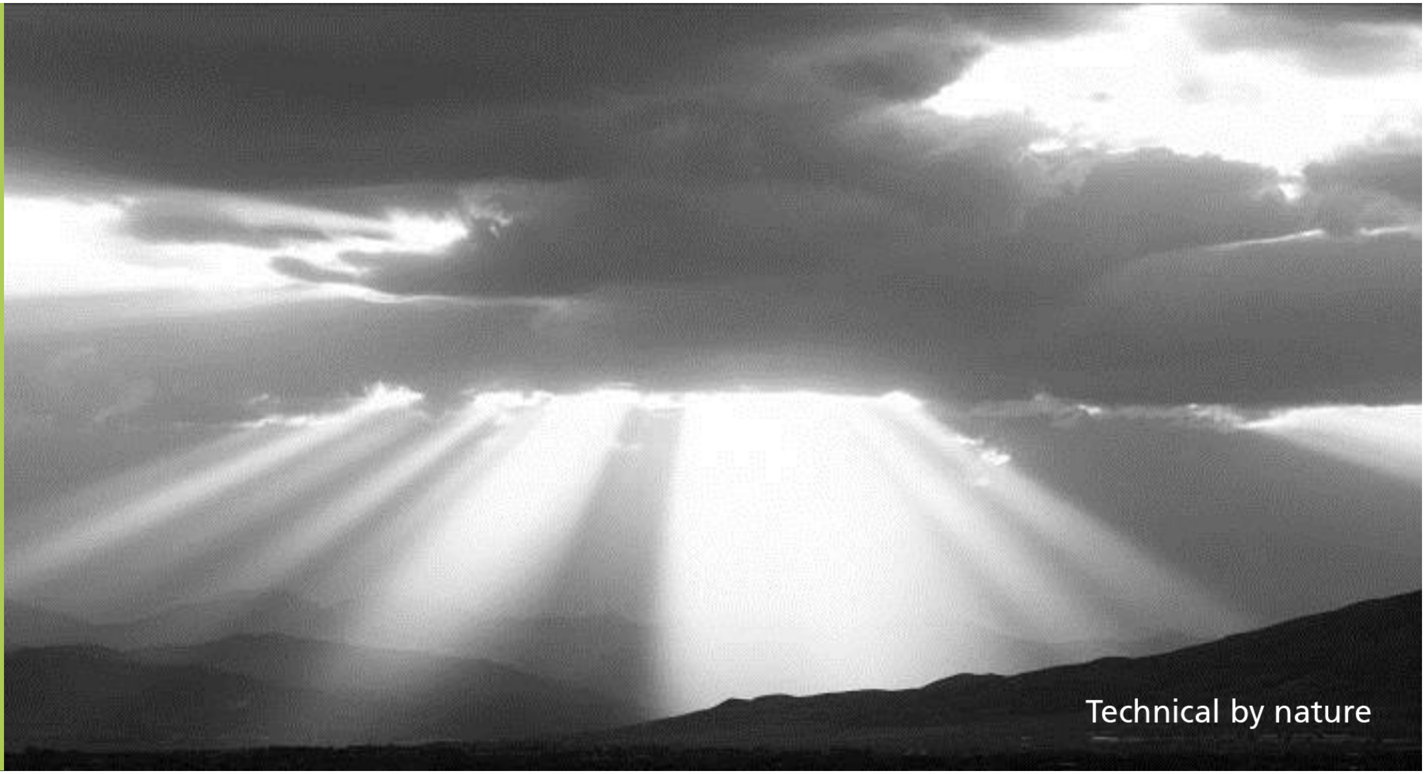
Renewable energy consultants

GL Garrad Hassan

Power Curve Behaviour in Energy Analysis

25th June 2013 Andrew Tindal, SVP Head of Energy



Contents

Energy Analysis Lessons Learned

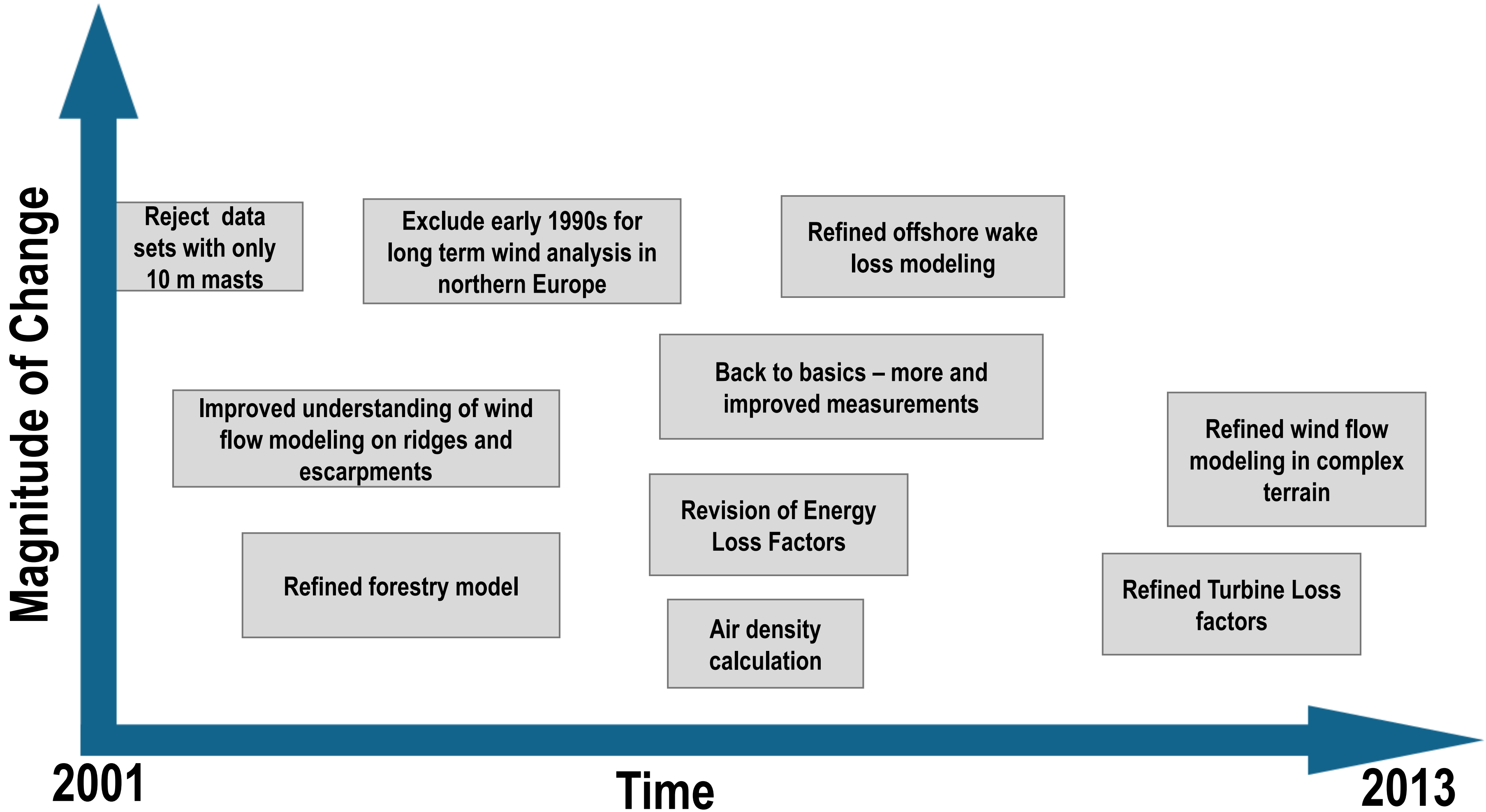
What general lessons have we learned and which of these relate to power curve behaviour?

We learn by seeing what really happens at operational projects

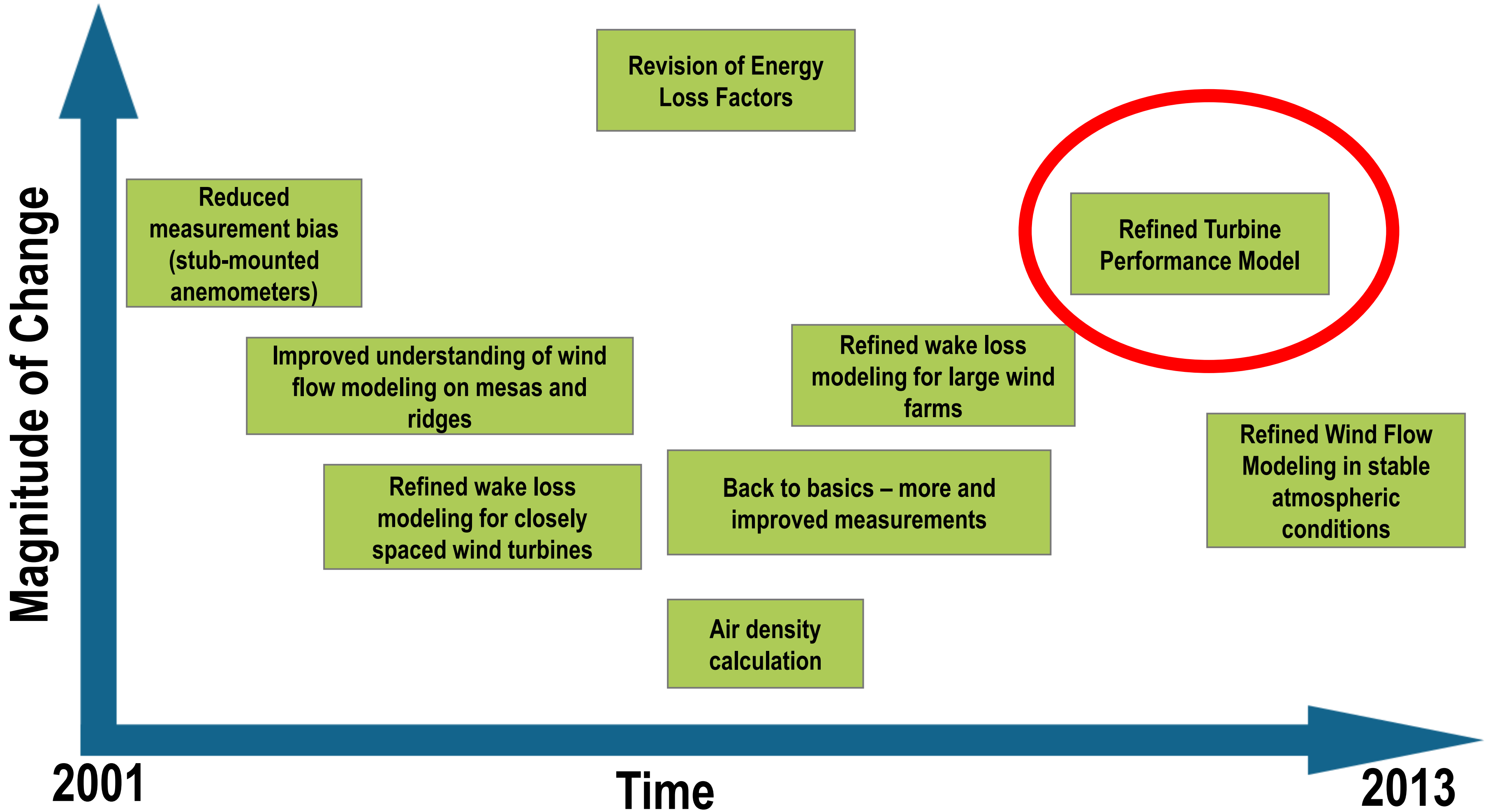
- Drilling down into the detail on individual projects
- Looking at aggregate results

Key refinement areas North American and European markets identified

Lessons Learned from GL GH Energy Assessments
Europe - Performance modelling not identified as key an issue



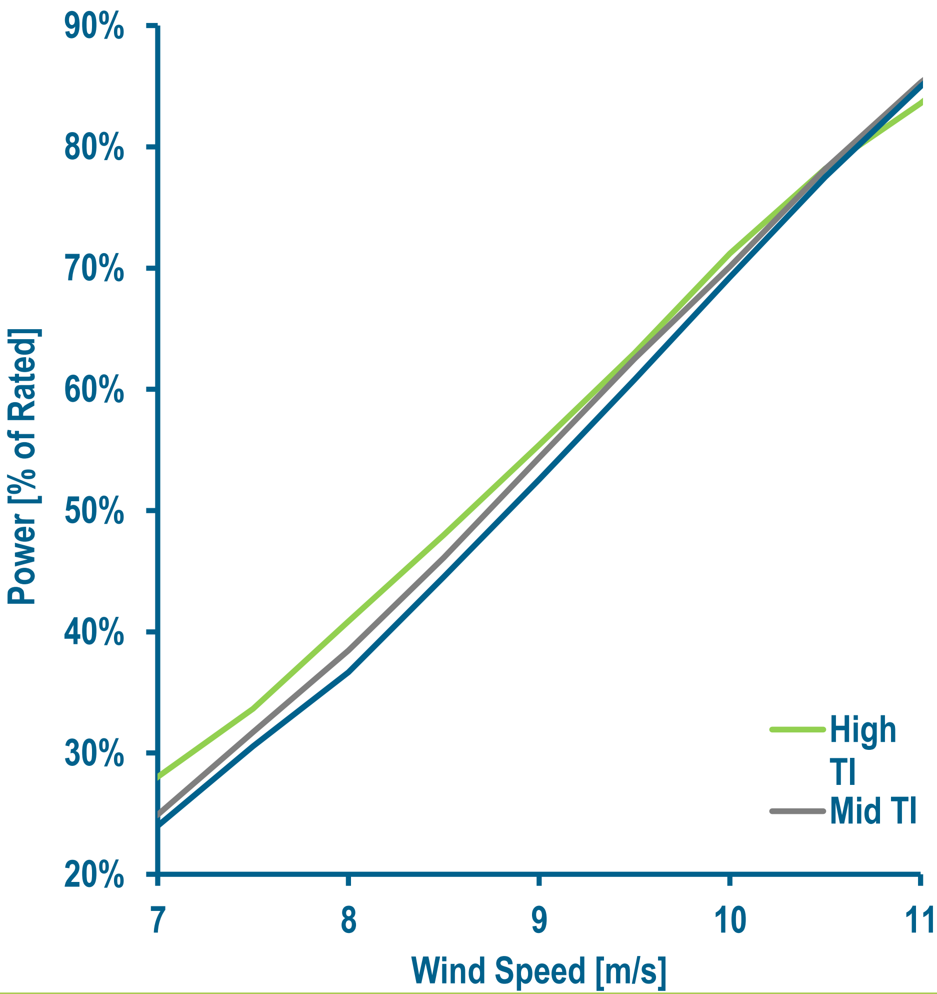
Lessons Learned from GL GH Energy Assessments
North America – Performance modelling identified as key an issue



Turbine Power Performance – US Midwest
Example Power Curve

Case	TI Range	Time	AEP*
High	TI>12%	44%	100%
Mid	8%<TI< 12%	33%	98.0%
Low	TI<8%	23%	96.4%

* Normalized to High TI case

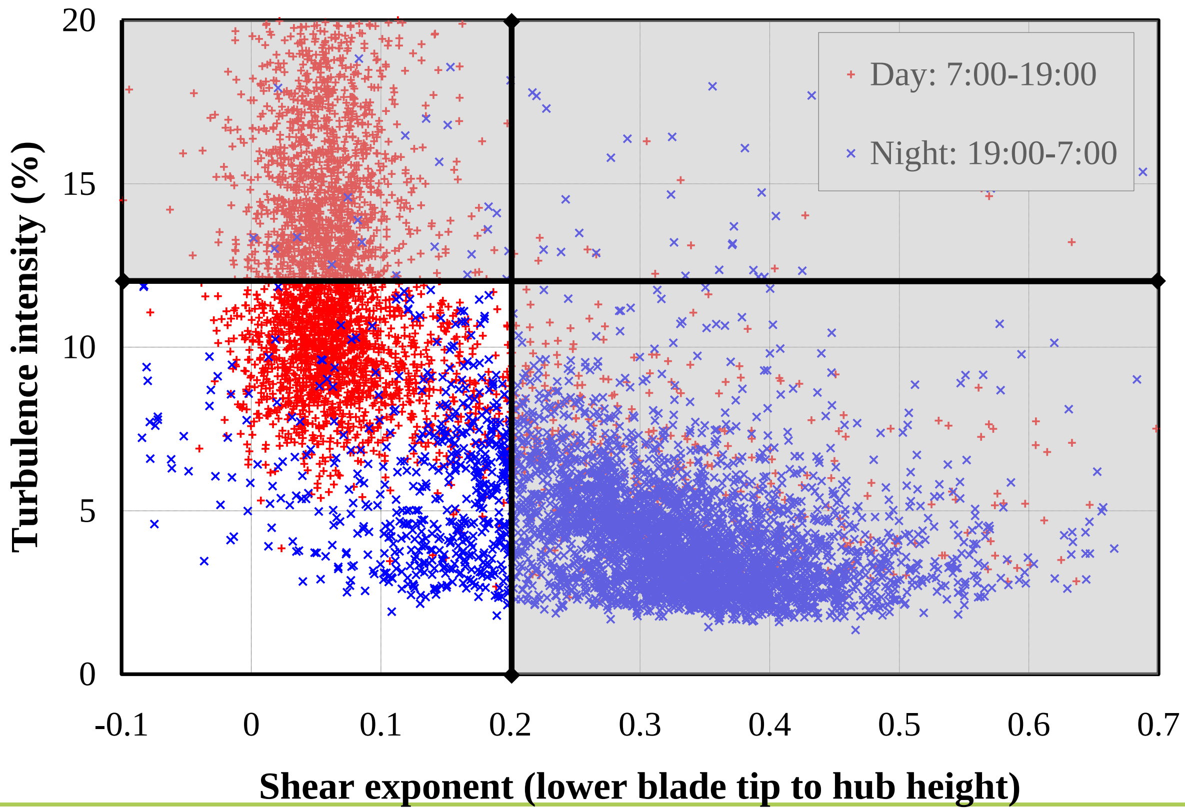


Power curve variation observed:
Significantly lower performance during periods of low turbulence intensity, which corresponds to stable atmospheric conditions

Turbine Power Performance - US Midwest

Application of example power curve screening filters for a US Midwest site.

Data exclusions cover 73% of data.



Concluded we needed to review the industry approach to interpretation and application of power curves

The current power curve model

Input → Output

Site wind conditions | Power curve | Energy prediction

Current power curve variables:

Wind speed
Air density

In reality the situation is more complex

Input → Output

Site wind conditions

Power curve

Energy prediction

Additional power curve variables

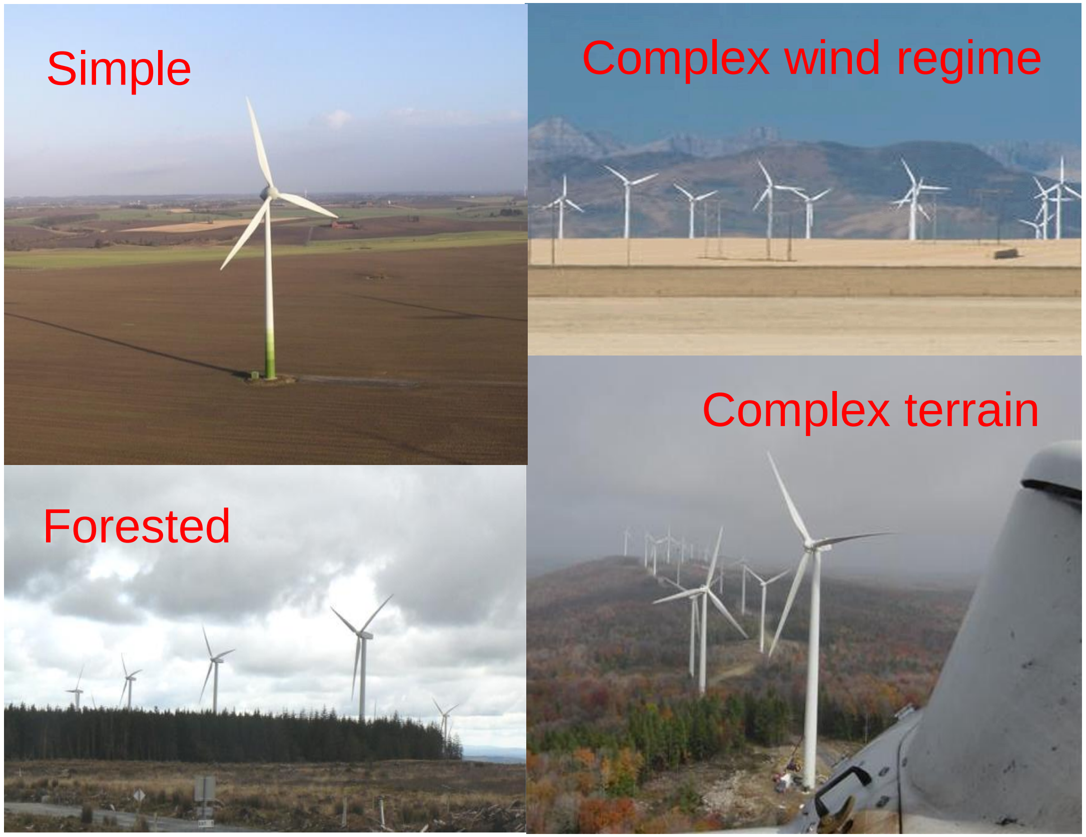
- Wind speed
- Air density

- Anemometer characteristics ?

- **Turbulence Intensity**
- **Vertical Wind Shear**
- Vertical Wind Veer
- Directional Variation
- Inflow Angle

These parameters vary with effects of terrain, roughness, atmospheric conditions and wakes of other turbines

Where would we like to be?



To have increased confidence in the applicability of the power curve used in an energy assessment for different "real world" sites

What are the first steps to help refine predictions?

Increasing dialog between turbine suppliers, developer / owners and energy analysts

Agreement of the variables to which a power curve is sensitive

What are the roles of the Turbine Supplier, the Developer / Owner and the Analyst?

The role of the Turbine Supplier - 1

Agreement of the variables to which a power curve is sensitive

Provide energy analysts a clear starting point for an analysis with a specific definition of the conditions for which a sales power curve is representative

The role of the Turbine Supplier - 2

Provide a matrix / guidance allowing the power curve to be adjusted to account for site specific conditions

Consider providing increased access to measured power curve reports

The role of the Developer / Owner

Design pre-construction measurement campaigns with Power Curve issues in mind e.g.

- Measure wind speed up to tip height – with Remote Sensing
- In complex terrain measure inflow angle

Include these data in tender pack

Consider including tip height Remote Sensing measurements in any contractual power curve testing which takes place on site

The role of the Energy Analyst

[Whether in a consultant, developer or turbine supplier]

Undertake analysis of site wind data and undertake modelling to prepare inputs for power curve assessment

Receive Sales Power Curve with a full definition of the conditions for which power curve is representative

Review whether corrections are needed and if so apply correction models

Supply data to Turbine Supplier in tender pack if appropriate

Other Power Performance related Loss Factors

Input → Output

Site wind conditions

Power curve

Energy prediction

Power curve – additional issues which impact energy prediction

- Blade issues
  - Fouling
  - Icing
  - Surface degradation

- Curtailment and load control
  - Loads
  - Power
  - Environmental

- Hysteresis algorithms
  - Cut in parameters
  - Cut out parameters

- Sub-optimal performance
  - Sensor issues
  - Software issues
  - Other issues

What would help improve predictions?

Improved information exchange to better model:

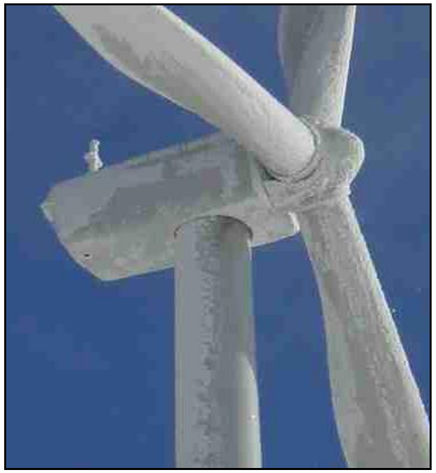
- Blade issues
- Hysteresis algorithms
- Curtailment
- Sub-optimal performance

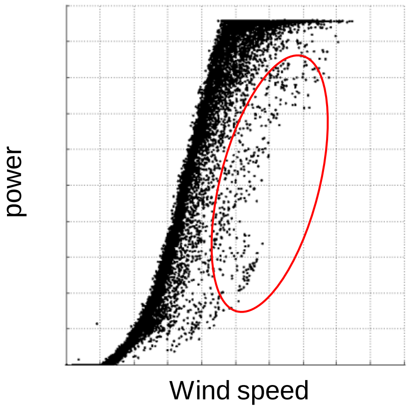
Also may be possible to reduce “lost” production and gain MWhs and so €

Blade issues

Icing

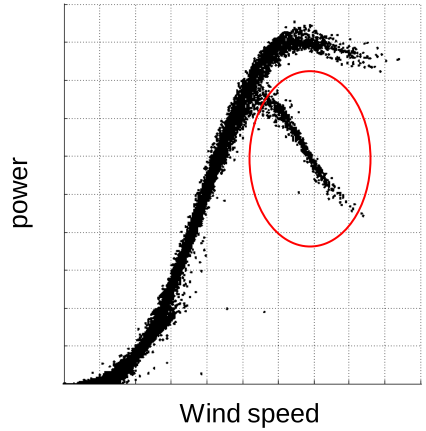
High impact on some sites





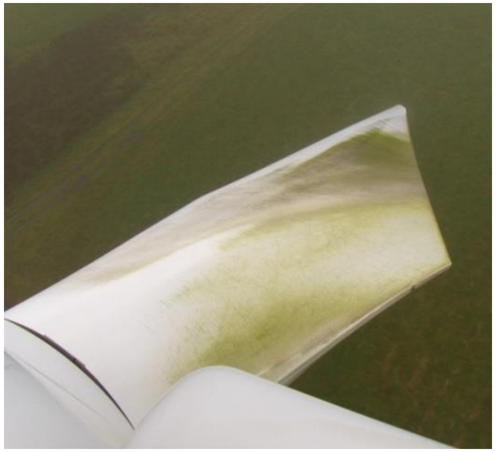
Bugs

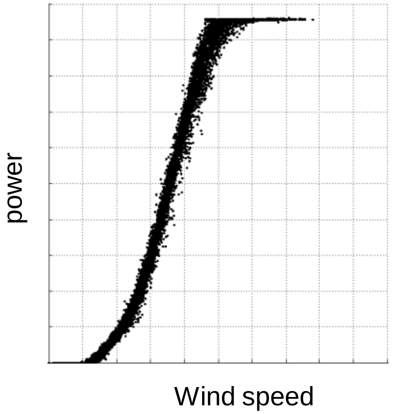
High impact for short periods



Dirty blades

Subtle impact but persistent



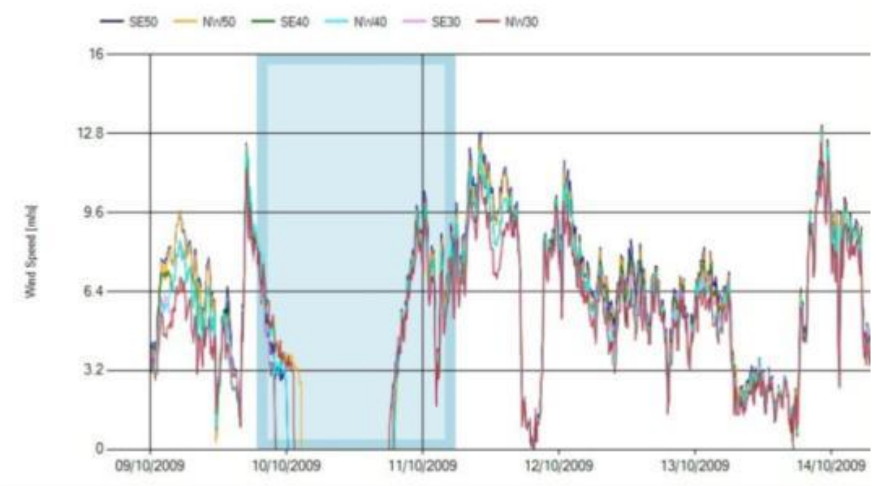


Could models of these issues and blade degradation be improved?

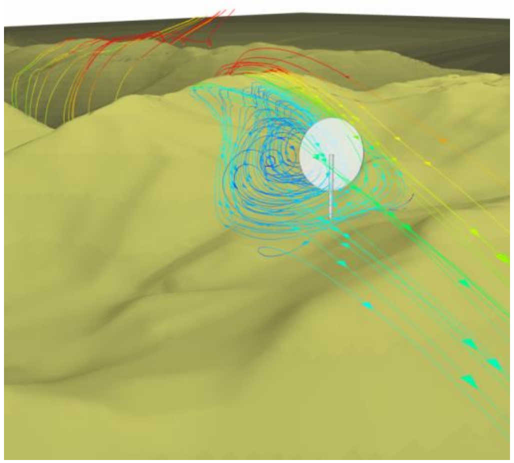
Hysteresis algorithms

For high wind speed sites an understanding of the details of the hysteresis algorithm can be an important input to the analysis

Measured power curves seldom capture this so how confident are we in our ability to model what is really happening?



Curtailment and Load control



Increasingly wind farms have some form of:

- Load curtailment
- Power curtailment
- Noise curtailment or other environmental curtailment

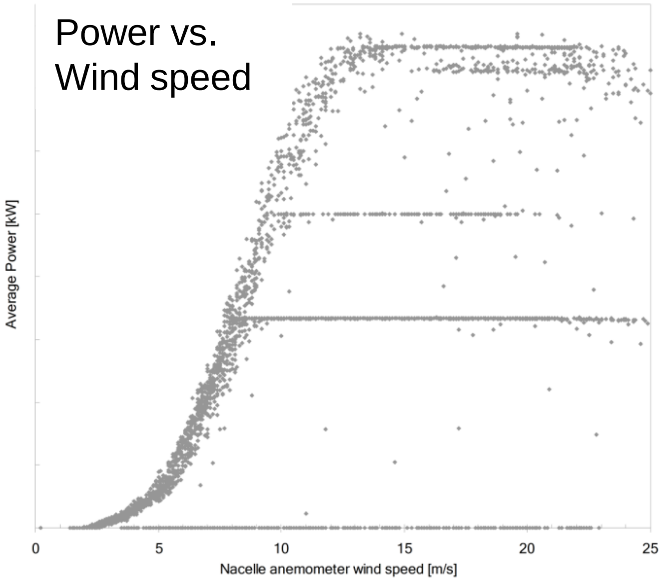
Increased exchange of information on how these curtailments are implemented (including hysteresis) would improve ability to model energy impacts

Dynamic load control of turbines or wind farms has potential benefits for the industry

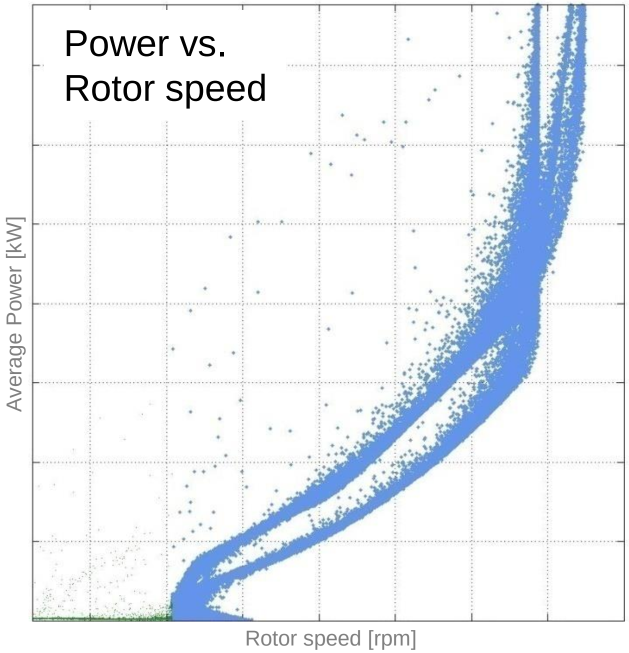
But this causes big challenges for achieving a robust energy assessment for financing – topic for discussion here?

Sub-optimal performance – common causes

1) De-rating



2) Non-optimal controller settings



3) Component misalignment / Sensor error

Step 1 – Have energy models that capture what happens

Step 2 – Reduce occurrence of Sub-optimal performance

Summary and future direction

Turbines are being deployed at sites with increasing diversity of meteorological conditions and turbine control / wind farm control capabilities are getting more sophisticated

Increasing dialogue between Developers, Turbine Suppliers and Analysts are the way forward to manage this increasing complexity

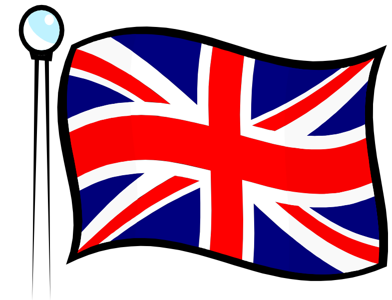
What do we expect in the future?

- Site wind condition measurement campaigns designed to give improving inputs to power curve related elements of energy analysis
- Increasing exchange of information on performance information
- Increasing use of time series analysis techniques

Questions?

Back up slides (if needed) for discussion session

London Meeting



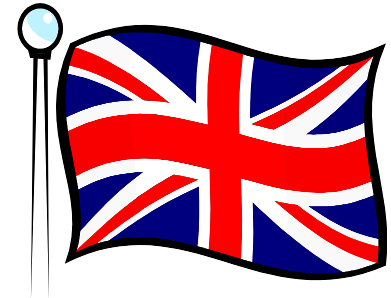
4th December 2012
Key Outcomes Part 1

- The power function of a wind turbine is dependent on wind speed, density, vertical wind shear, vertical wind veer, turbulence intensity, directional variation and inflow angle.

- There is a need for greater clarity on the range of conditions for which power curves are representative. This will give a clear starting point for considering corrections for ‘nonstandard’ conditions.

- Corrections should be applied for ‘non-standard’ conditions which are different from those for which a power curve is representative. These corrections fall into two categories:
  - ➢ Type A: Adjustments made to reflect changes in the energy available for conversion across the rotor in a ten minute period due to ‘non-standard conditions’.
  - ➢ Type B: Adjustments made to reflect changes in the conversion efficiency due to ‘non-standard conditions’.

London Meeting

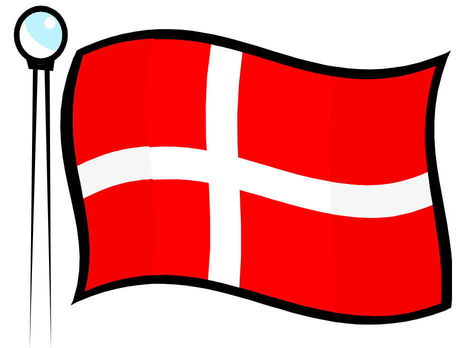


4th December 2012
Key Outcomes Part 2

- The corrections for wind shear, wind veer and turbulence intensity in the current working draft of the IEC Power Performance standard should be considered as candidate methods for incorporation into resource assessment methodologies (Type A corrections).

- Further collaboration between manufacturers, developers and consultants is required to improve communication of power function information and explore corrections for non-standard Conditions.

Brande Meeting



12th March 2013
Key Outcomes Part 1:

- The dependency of power output to five parameters (wind speed, density, wind shear, wind veer and turbulence intensity) should be made more explicit in power curve documentation.

- A proposal was made to improve stakeholder communication by supplying power curves with two ranges of conditions:

    - The ‘inner range’: the conditions for which a manufacturer believes a turbine will achieve its power curve (without correction).
    - The ‘outer range’: the conditions for which a manufacturer expects a turbine’s Performance will degrade below its power curve (and will require correction).

These ranges of conditions could be tied to the level of warranty e.g. X% warranty for the ‘inner range’ and Y% warranty for the ‘outer range’ where Y < X

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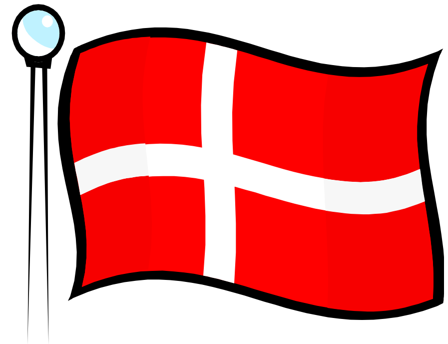
Brande Meeting



12th March 2013
Key Outcomes Part 2:

- The use of rotor equivalent wind speed in wind resource assessment offers the opportunity to correct the wind speed input to the power curve so that it representative of the whole rotor. This approach is an effective way of dealing with the sensitivity of power output to wind shear.

- Tip-height measurements (using remote sensing devices e.g. LiDAR/SoDAR) have a big role to play in improving wind resource assessment. If such information is available it should not just be used in just the ‘traditional’ way (to verify mast measurement wind shear), instead it should form a core part of the resource assessment strategy.

- A round robin exercise will be conducted within the working group using a dataset including tip height measurements from a RES site in Sweden.