EWEA Technology Workshop

Post Construction Yield Analysis Techniques – An industry survey

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Survey rationale and aims

- Conceived as a follow up to the successful "Comparison of Resource and Energy Yield Assessment Procedures" exercise from the last technology workshop
- A round-robin analysis of data from operating wind farm would have been impractical!
- How do we, as an industry, determine the value of our operating projects? The aim of the survey is to gauge opinion on the following key issues:
  - Relevant data sources
  - Validation of loss factor assumptions using operational data
  - Defining long-term wind speed trends
  - The general approach to availability analysis
  - The general approach to power curve analysis
  - Undertaking long-term correlations
  - Defining future loss factors
  - Defining uncertainties
- Where are the areas of consensus and where are the inconsistencies in our collective approach?

Section 1 – Industry Experience

- How well established are EPA techniques for operational wind farms?
- How experienced are the people and organisations undertaking these assessments?
- Is operational EPA work concentrated in any one market?

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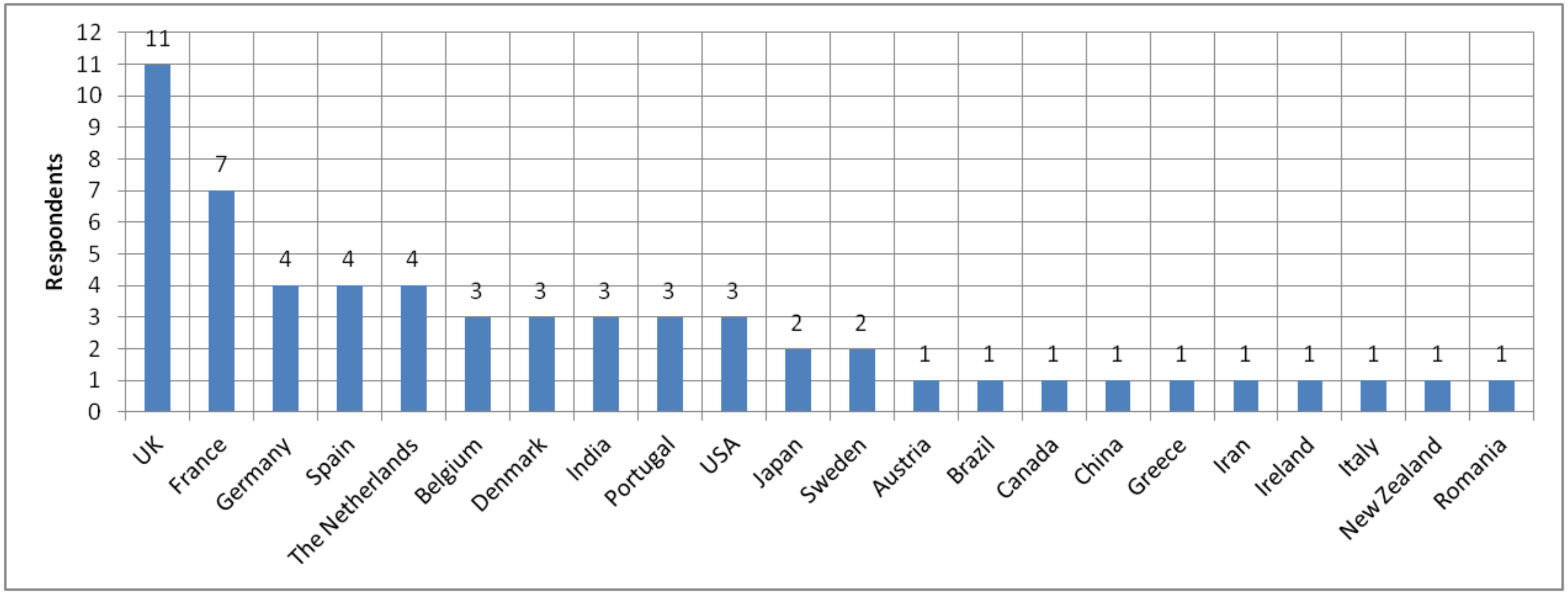
Survey Participants

- 59 respondents
  - 48 completed some or all of the questions
  - 42 answered all questions
- Respondents were from 22 countries



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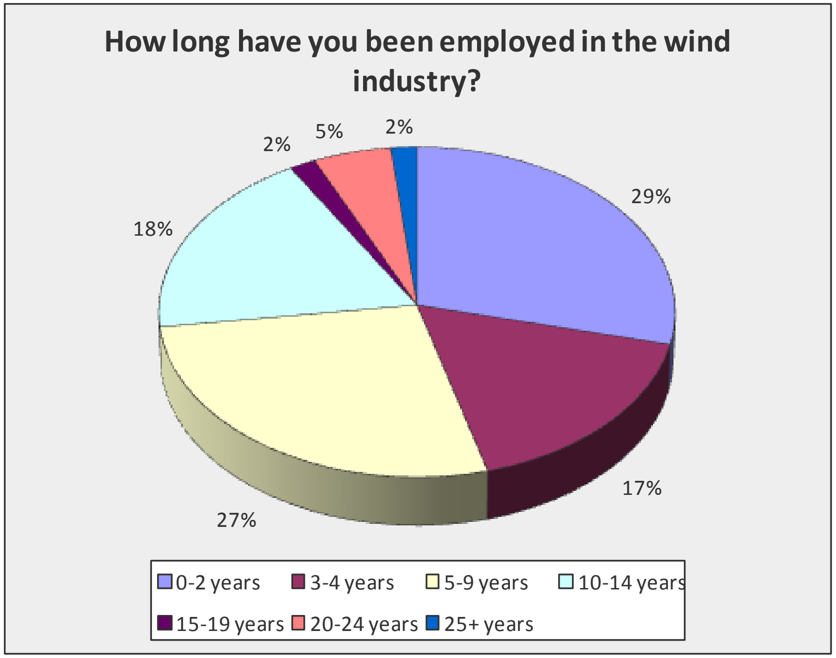

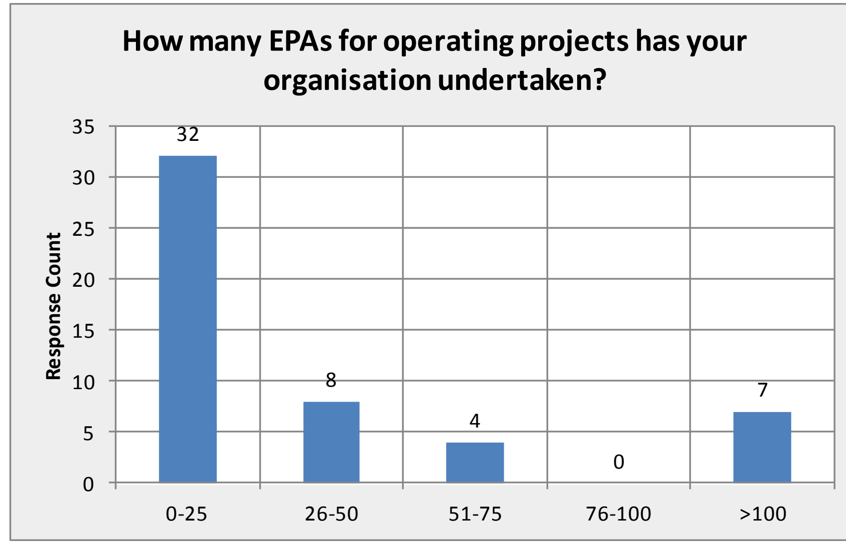

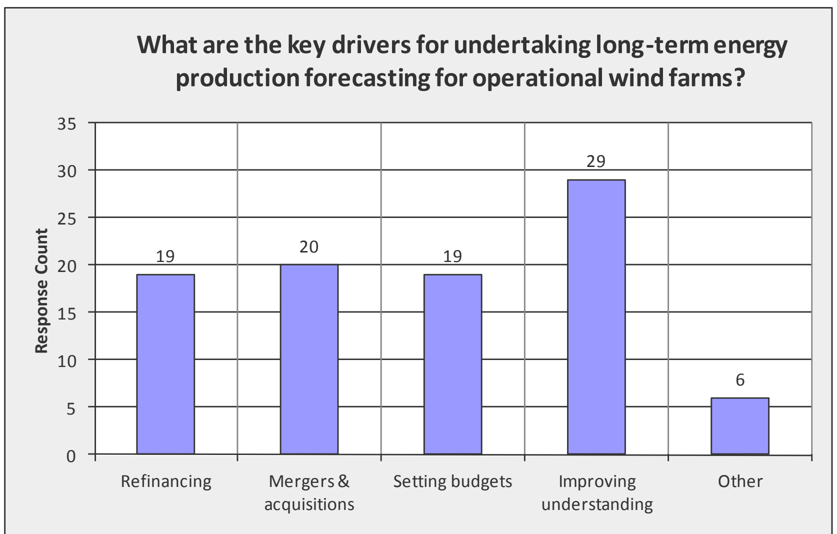

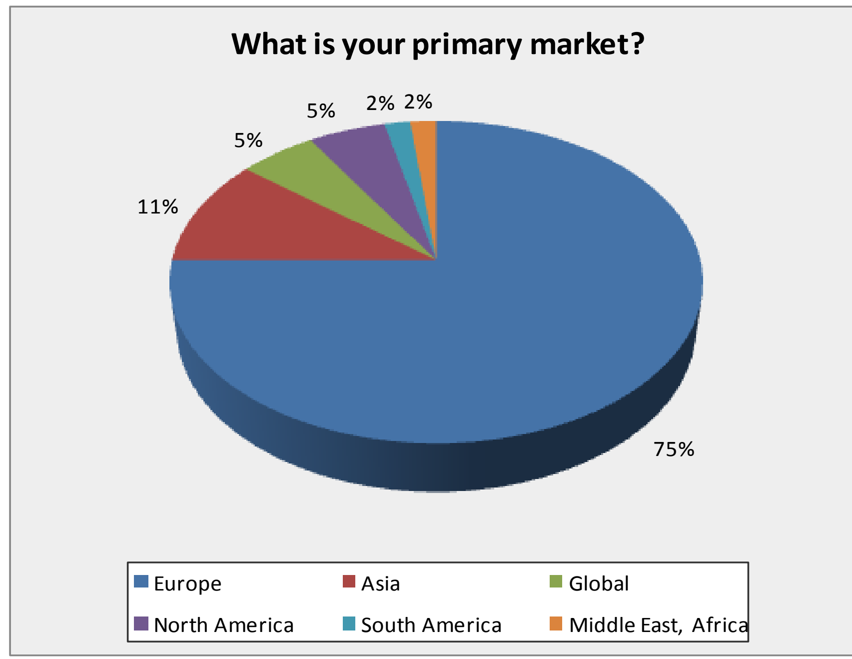

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Industry Experience – Conclusions

- EPAs of operating wind farms are being undertaken globally, with a significant bias towards Europe
- The cohort is experienced on an individual level, with 54 % of respondents having 5 or more years of experience
- EPAs of operating wind farms appear to be a relatively new type of study, with 62% of companies having undertaken fewer than 25 assessments
- There is a broad spread of motivations for undertaking this type of work

Section 2 – General Techniques

The aim of this section was to understand the industry's perception of:

- Acceptable data sources for analysis of operating wind farms
- The applicability of computational models to operating wind farms
- The need for further standardisation of practices & techniques
- New developments that would improve the reliability of operating wind farm analyses

Data sources

Questions on both 10-minute SCADA data and export meter data were posed

- The majority agreed that both sources of data are suitable inputs to an analysis of an operational wind farm
  - Export meter data are the most accurate measure of overall wind farm production
  - 10-minute SCADA are a necessity for a per-turbine analysis and can complement metered production data
- The majority also agreed that an individual turbine analysis is a requirement, but a significant minority (10 %) disagreed with this

Computational Models

The suitability of basing EPAs of operating wind farms on wind flow and energy models (e.g. WAsP, CFD, WindPro, WindFarmer) was questioned

- A clear lack of consensus on this issue was identified
  - 42 % agreed that computational models should not form the basis of an EPA for an operating wind farm
  - 31% neither agreed nor disagreed
  - 23% disagreed
  - 4% had no opinion
- Respondents' comments highlighted the subtlety of this issue
  - The utility of models for assessing alternative scenarios was mentioned repeatedly (e.g. wakes from new wind farms, amended control strategies, wind regime sensitivities)
  - The calibration of models using SCADA data was also discussed

Standardisation & Data Sharing

Respondents were asked for their opinions on:

- The need for greater standardisation of EPA techniques and wind measurement campaigns
- The benefits of increased data sharing throughout the industry

- In general, there was agreement that an increased level of standardisation and data sharing is needed
- However, there was also agreement that these goals are difficult to reach!
- Respondents' comments showed conflicting opinions on the way forward
  - Some suggested existing standards are sufficient
  - Others suggested standardisation of terminology, rather than methodology
  - The ability of standards to react to an evolving market was questioned by some
  - Data sharing may be hampered by confidentiality and negative marketing issues

New developments

Respondents were asked to suggest other concepts that should be developed by the industry in order to improve accuracy and reliability of EPAs for operational wind farms.

- 28 responses
- Nacelle anemometry was the most common theme
  - Improved understanding is critical
  - Reliability/accuracy of nacelle anemometry seems to be a key concern
  - Interest in the application of remote sensing is increasing
- Other recurring issues:
  - Improved understanding of indirect wind measurement data
  - Standardisation of availability measures
  - Wind farm power curve testing
  - Software for analysis of operating wind farms

General Techniques – Conclusions

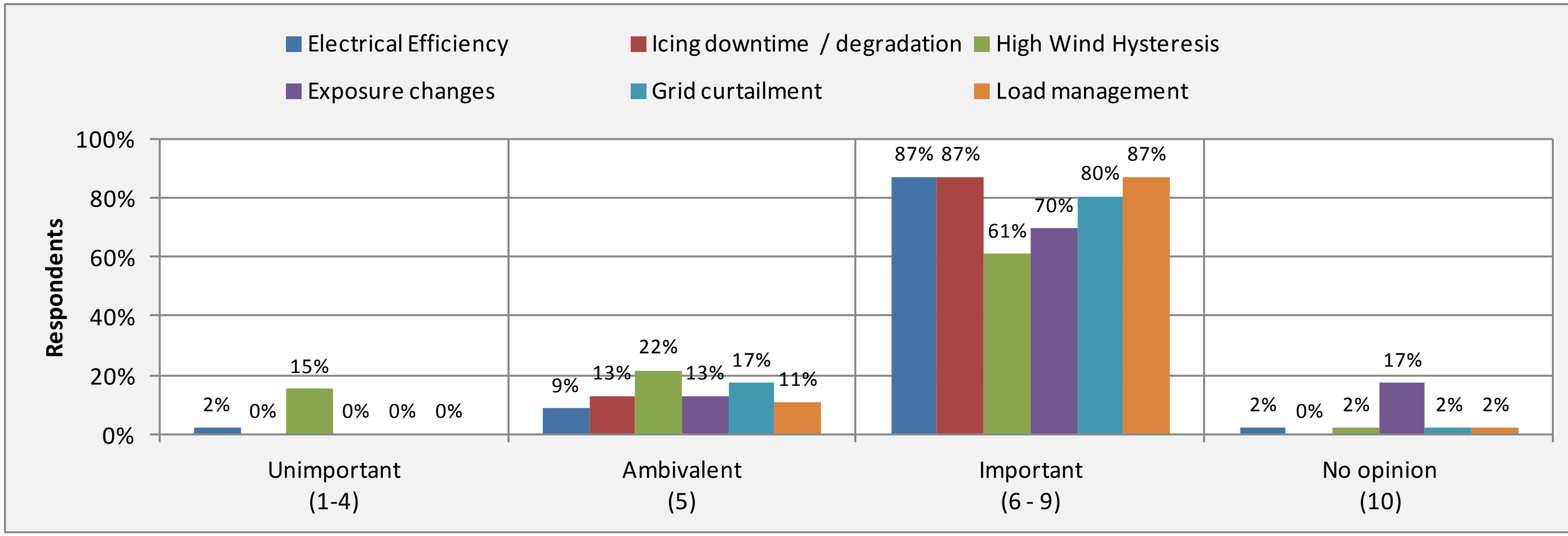
- Analyses based on multiple sources of data (10-min SCADA and export meter) seem to be preferred
- Greater standardisation of wind farm analysis techniques is desirable, but difficult to achieve
- Computational models have a role, in combination with measured turbine data
- Improved understanding of nacelle anemometers and incident wind conditions is a common concern

Section 3 – Estimating Operational Losses

The aim of this section was to determine the importance of validating estimates of a number of commonly occurring operational losses:

- Electrical efficiency
- High wind hysteresis
- Icing downtime / performance degradation
- Exposure changes
- Grid curtailment
- Load management strategies (e.g. Wind sector management)
- Other

Operational losses – Conclusions



- Validation of all losses is considered to be important
- Least importance placed on high wind hysteresis – typically a small loss
- Other losses cited as being important:
  - Wake losses; this is perceived as being critical feedback into pre-construction work
  - Environmental curtailment (e.g. noise reduction, shadow flicker)
  - Grid downtime
  - Balance of plant downtime
  - Lifetime availability profiling

Section 4 – Defining long-term wind speed trends

The aim of this section was to examine the industry's approach to defining the long-term wind resource:

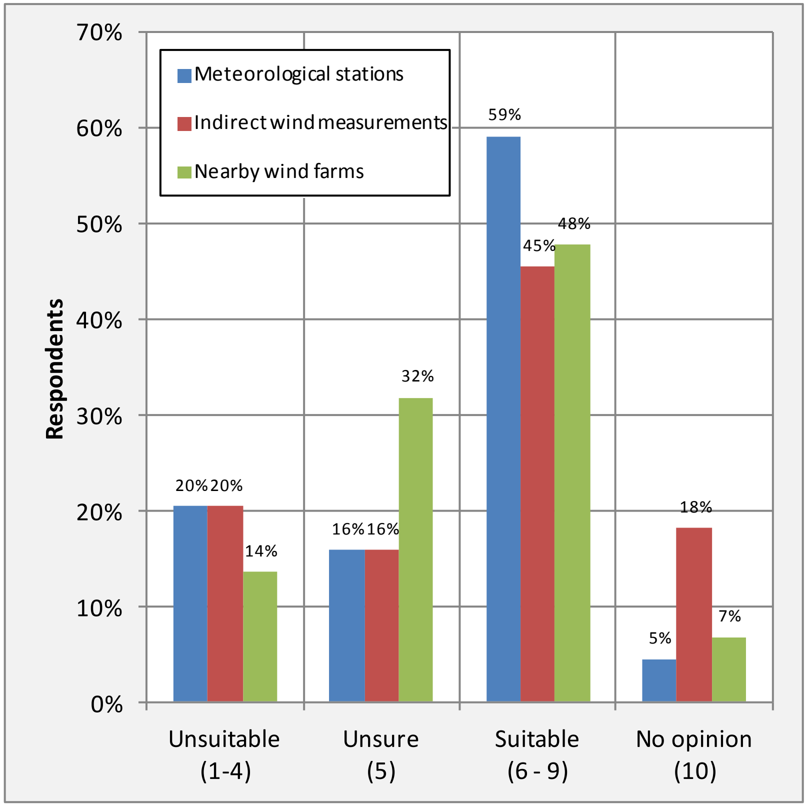
- Suitability of a range of reference data sources
- An "ideal" long-term period?
- The desirability & availability of permanent meteorological masts

Reference Data Sources

Respondents were questioned on the suitability of a number of reference data sources:

- Surface meteorological stations
- Indirect wind measurements (e.g. MERRA, Reanalysis, etc)
- Production data from nearby wind farms

- All three sources are seen as being suitable for long-term assessments
- Meteorological stations have the highest rate of approval
- Less frequent use of indirect measurements & wind farm data (greater level of "no opinion" or "unsure" results)
- Respondents' comments made reference to a need for more research on indirect measurements



An "Ideal" Long-Term Period?

Respondents were questioned on the suitability of a number of assumptions relating to long-term data sets

- Is there an "ideal" length of data set?
- Can long-term trends be assumed to be approximately stationary?
- Does climate change pose a significant risk for long-term energy assessments?

- The majority (45%) agreed that there is not an 'ideal' long-term period
- A significant minority (32%) thought there was an "ideal" period, but with no consensus on the length of this period – an even spread between 10 years, 20 years and "as long as possible"
- The majority (59%) accepted the assumption that long-term trends are stationary. However, if respondents did disagree they tended to disagree strongly (20% disagreed, 14% disagreed strongly)
- A slim majority (41%) agreed that climate change poses a risk for long-term EPAs. However, significant minorities were either unsure (27%), or disagreed (23%). As one commentator put it: "*Probably but in fact, no one knows....*"

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Permanent Meteorological Masts

Respondents were questioned on whether the installation of permanent meteorological masts was (a) desirable (b) normal at operating wind farms

- A large majority (73%) agreed that it is desirable to have a permanent meteorological mast on an operating wind farm
- However a much smaller group (57%) agreed that installation of permanent meteorological masts is normal
- Respondents' comments highlighted a number of issues associated with permanent met masts
  - Data quality; gaps and errors in data sets are common
  - The location of the mast has a strong impact on its usefulness; wakes are a key driver
  - The cost of a mast is difficult to justify on small projects

Defining long-term wind speed trends - Conclusions

- No clear preference between meteorological stations, indirect measurements or nearby wind farm data
- Meteorological stations seem to be the most established source of long-term reference data
- The assumption that long-term wind resource is a stationary quantity seems to be accepted; but the method of determining this is less well defined
- No "ideal" period of long-term measurements; the consensus seems to be towards "as long as possible"
- Climate change is a risk, but a poorly quantified one at present
- Permanent masts on wind farms are desirable, but not the norm
- Mast location and instrument maintenance dictate usefulness

Section 5 – Availability analysis

The aim of this section was to understand the industry's perception of:

- IEC 61400-26
- Analytical factors affecting availability calculations

IEC 61400-26

Respondents were questioned on their familiarity with this new standard and their intentions for implementation of the models it describes

- 43% indicated that they were familiar with the standard, although few (7%) showed a high level of familiarity
- 27% were not familiar with the standard
- 30% were either not sure or had no opinion

- For implementation of the IEC 61400-26 models, the majority (52%) were not sure or had no opinion
- 43% said they would be implementing the models
- Only 5% said they would not be using the standard's models
- Comments suggested that availability calculations are not within the respondents' remit, hence the high level of ambivalence to this question

Availability Calculation Issues

Respondents were questioned on their attitude to a range of issues associated with availability calculations:

- The relationship between downtime & wind speed
- The effect of data loss & its relationship to downtime
- The reliability of raw reported availability & other sources of availability data

- There was a strong consensus that:
  - Energy weighting needs to be considered when assessing availability
  - It is important to account for periods of data loss, if possible

- Opinion was mixed on the following issues:
  - The relationship between data loss and downtime
  - Confidence in operator reported availability; this was driven by the somewhat subjective nature of the term "operator"

Availability Analysis - Conclusions

- Potentially a need to improve knowledge of IEC 61400-26
  - This will be addressed in Session 4 of this event!
- Accounting for the energy weighting of downtime and the impact of data loss is important
- Operator reported availability statistics can be useful, but exclusion categories need to be carefully understood

Section 6 – Power Curve Analysis

The aim of this section was to examine the industry's perception of:

- The merits of relative and absolute measures of turbine performance
- The suitability for nacelle anemometers in power curve analysis
- The potential for remote sensing to improve our understanding of turbine performance

General Power Curve Analysis

Respondents were questioned on general power curve analysis principles

- Strong consensus that a detailed understanding of individual turbine power curves is required
- Clear consensus that power curves based on nacelle anemometers cannot be compared directly with warranted power curves
- However, respondents were lukewarm about the need for absolute power curve measurement (i.e. IEC 61400-12 testing)
- Very strong agreement that the industry needs to better understand the performance of turbines in complex flow conditions
- No consensus on the approach to predicting future turbine efficiency. Respondents' comments showed the subtlety of this issue
  - Dependent on turbine age
  - Requires interaction with the site operator / turbine manufacturer
  - Ramp down of turbine efficiency may be required in later years of the Project

Measuring Incident Wind

Respondents were questioned on the suitability of nacelle anemometers and the potential benefits of remote sensing

- A majority considered that nacelle anemometers are unsuitable for individual power curve analysis, but may be used for relative comparisons
- Respondents' comments highlighted a number of issues with nacelle anemometry
  - Instrument calibration & documentation
  - Derivation & application of free stream correction factors
- Strong consensus that remote sensing has potential to improve understanding of turbine power curves
- Opinion was mixed on the relative merits of ground based vs. nacelle based remote sensing

Power Curve Analysis – Conclusions

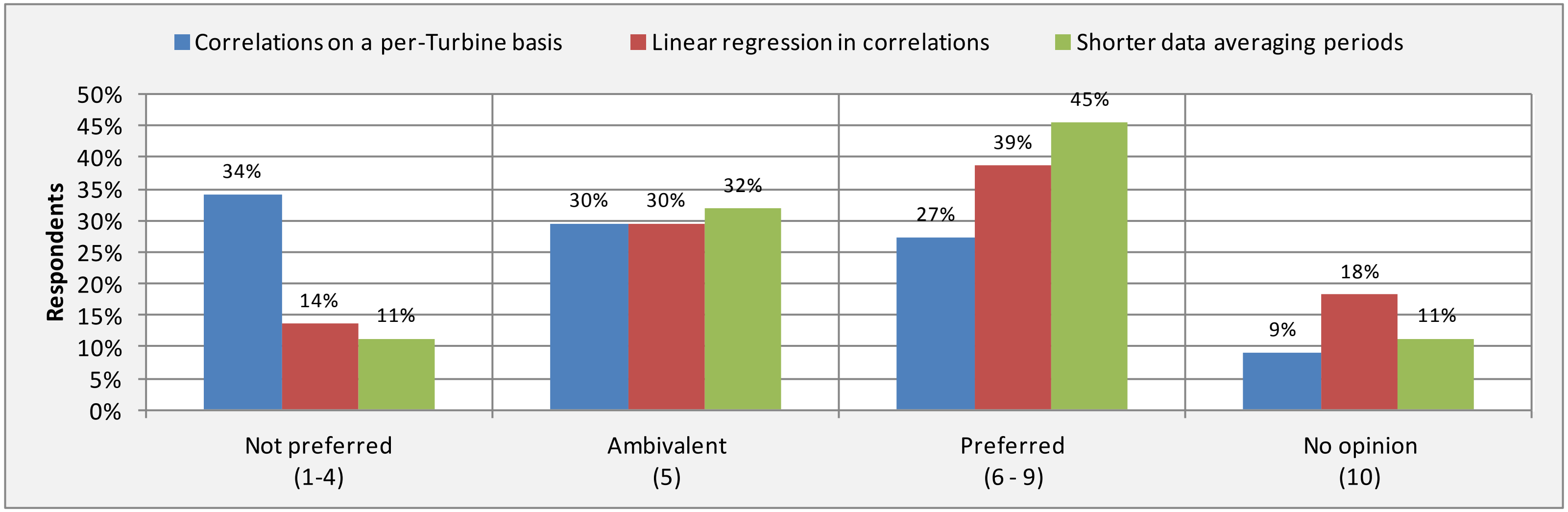
- Individual power curve analysis is a “must-have” for a robust assessment
- Absolute power curve tests are not seen as “mission critical”
- Nacelle anemometer power curves are only seen as being suitable for relative comparisons of turbine performance
- Remote sensing is viewed positively, but there is not one preferred solution at this stage
- Improved understanding of turbine performance in complex terrain is critical – the strongest agreement of the entire survey

Section 7 – Long-term Correlation

The aim of this section was to examine the industry's approach to correlating production data with long-term reference data sets. The issues investigated included:

- Correlations per wind turbine
- Use of linear regressions in correlations
- Preferred averaging period for correlation data

Long-term Correlation – Conclusions



- Low level of consensus on all issues, with a significant number of "unsure" responses
- Indicative of a wide variety of approaches to this issue?

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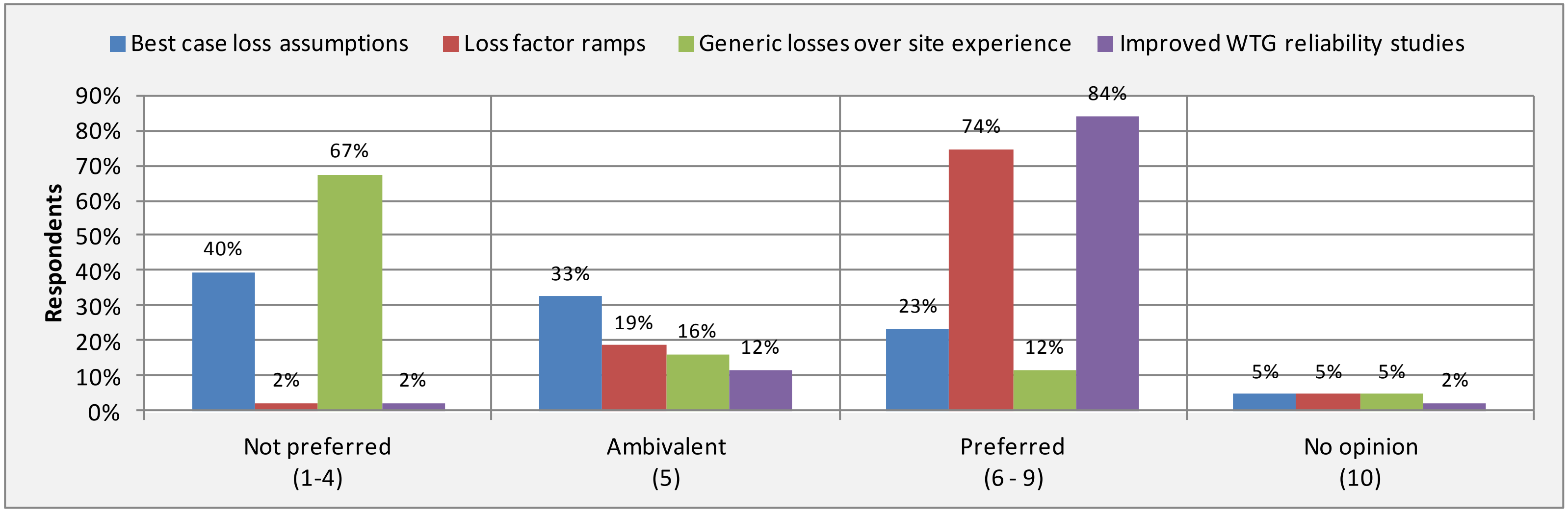
Section 8 – Future operational loss factors

The aim of this section was to examine the industry's approach to establishing long-term loss factor assumptions. The issues investigated included:

- Should loss factors capture a best case scenario?
- The balance between on site behaviour and industry experience
- Loss factor ramps
- The need for better understanding of turbine reliability

Future operational loss factors – Conclusions



The results and respondents' comments reveal some strong consensuses:

- Loss factor assumptions should represent the most realistic case, not a best case
- Ramp ups in losses towards the end of wind farm life are required
- Generic losses should not take precedence over actual site experience; a combined approach seems to be widely favoured
- Improved understanding of turbine reliability is strongly favoured

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Section 9 – Uncertainty analysis

The aim of this section was to understand attitudes towards the uncertainties in analyses of operating wind farms. Respondents were questioned on a number of uncertainty categories:

- Availability
- Power curve efficiency
- Historical wind variability
- Future wind variability
- Future operational losses
- Correlations
- Data sources
- Long-term references
- Overall uncertainty

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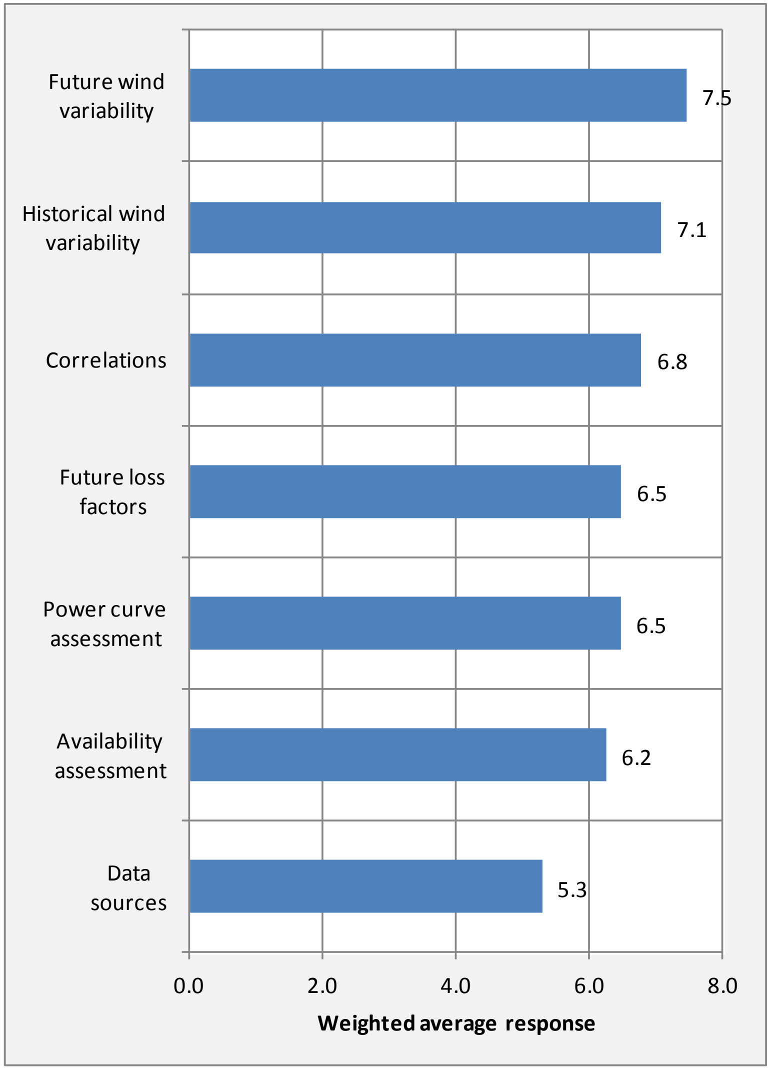
Uncertainty analysis – Conclusions

- Reponses show that the majority consider all uncertainty categories to be significant.
- Varying degrees of significance attached to each category
- A weighted average response used to estimate the perceived significance of each category

- 71% of respondents agreed that EPAs for operating wind farms are more certain than pre-construction assessments



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Overall Survey Conclusions

- The main aim of the survey was to build understanding of how we, as an industry, determine the value of our operating projects
- With 59 respondents from 22 countries this survey is a reasonable starting point for gauging consensus, or disagreement, on key analytical elements
- We hope that this survey will provide food for thought and direction for further development of knowledge & tools

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Many thanks to all participants, who included:

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- Actua ApS, Denmark
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- AWEI, UK
- AWS Truepower, LLC, USA
- AXYS Technologies, Canada
- Barlovento Recursos Naturales, Spain
- BBB Umwelttechnik GmbH, Germany
- DCNS, France
- DNV KEMA, Netherlands
- Dong Energy, Denmark
- DTU Wind Energy, Denmark
- ECN, The Netherlands
- Entegra Ltd, India
- Eole Generation, France
- EOLE-RES, France
- E.ON New Build and Technology, UK
- ERELIA / GDF SUEZ, France
- ESB International, Ireland
- Fundación CIRCE, Spain
- GL Garrad Hassan, UK
- Gotland University, Sweden
- ITOCHU Techno-solutions corporation, Japan
- Kjeller Vindteknikk, Sweden
- MEGAJOULE, Portugal
- Meridian Energy Ltd, New Zealand
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- Natural Power, UK
- REpower Systems, Germany
- RES, UK
- SSE Renewables, UK
- Suzlon, India
- Tractebel Engineering (GDF SUEZ), Belgium
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- Wind-Consult, Germany

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Thank you for listening