DNV GL ENERGY

3. Rüzgar Enerji Sempozyumu

Rüzgar Ölçümündeki Belirsizliklerin Enerji Analizine Etkisi

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Creating a world leader in safety, quality and environment

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One of the world's leading classification societies and maritime advisory

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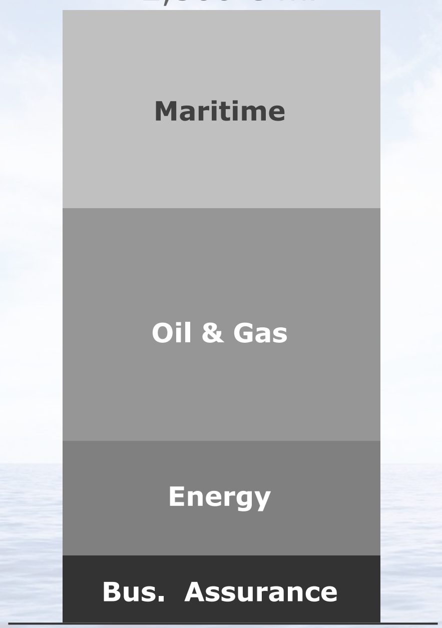
A leading provider of risk management services to the oil and gas industry

Revenue 2012 by business unit
~ 2,500 € mill.



Energy

An energy powerhouse, leading in onshore and offshore wind, and a strong player in power transmission & distribution, and its sustainable use

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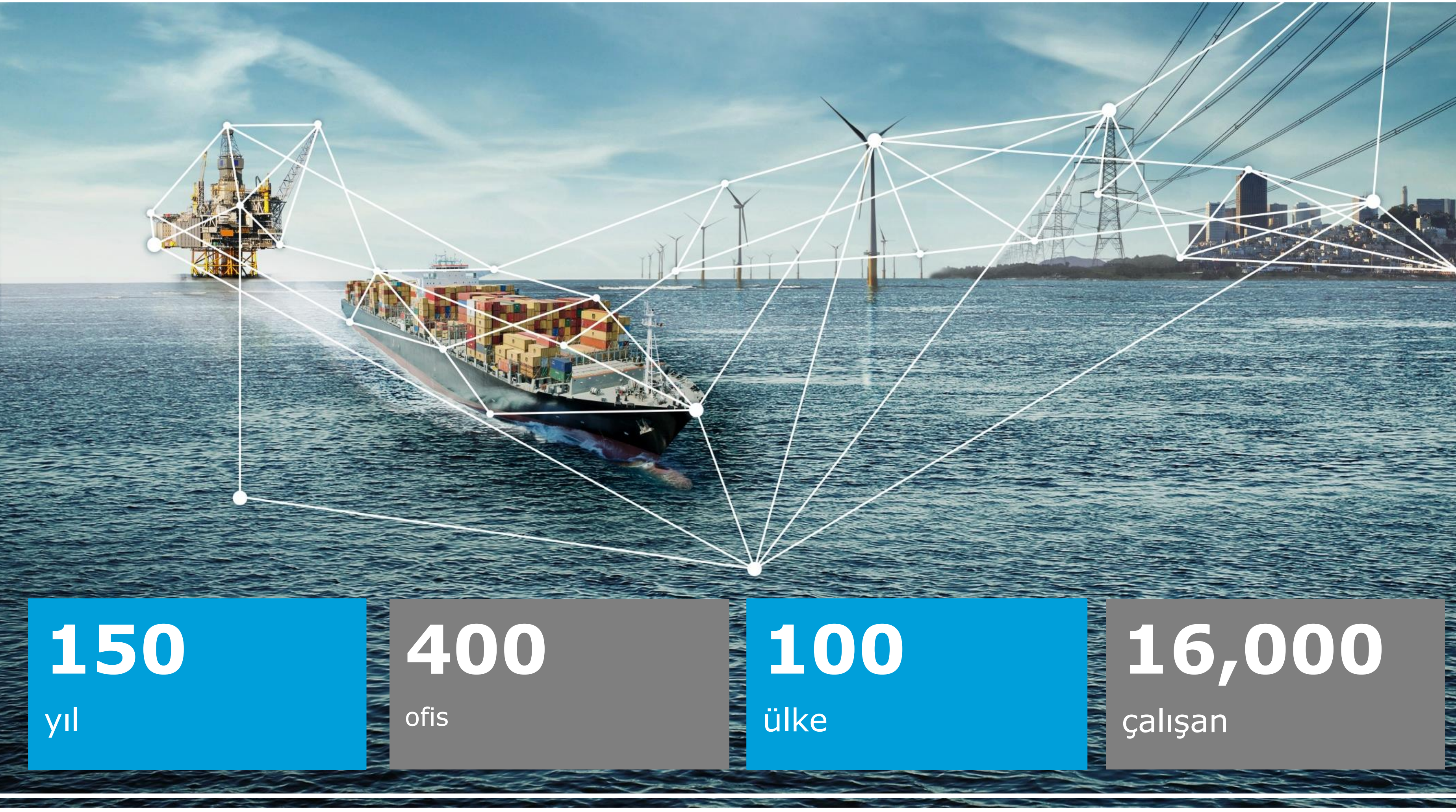

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We are a world leader in testing, certification and advisory services for companies and organisations in the electrical power value chain.

- 2,500 Energy experts
- KEMA + Garrad Hassan
- Headquartered in Arnhem, the Netherlands
- Worldwide competence centres and laboratories
- Offices and agents in over 30 countries

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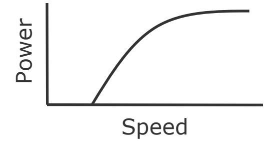
Prediction steps

Wind Speed

- Usually site wind measurements
- Germany: Often based on production data
- Required wind depends on market and WT

Power Curve

- Power available is proportional to the cube of speed



Gross Capacity Factor

- 25% to 40% is typical

Modeling/Losses

- Topography
- Wake
- Availability
- Electrical
- Other

Net Capacity Factor

Example

Gross Capacity Factor	38%
Availability	97%
Other Losses	
Wake	98.7%
Electrical	97%
Gust / Turbulence	99.2%
Blade Icing/contamination	99.5%
Other	99.8%
Net Capacity Factor	35%

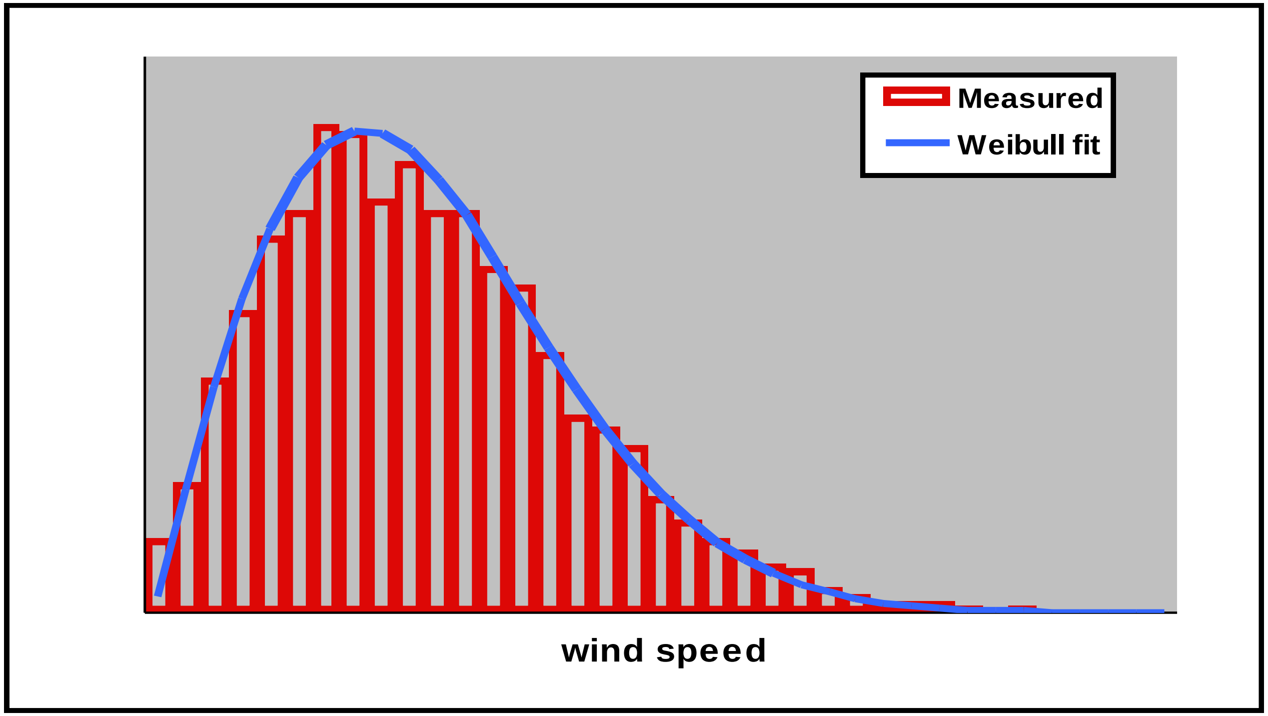
8 to 15% reduction

Often underestimated

The Methodology

- Analyze and predict the long-term wind regime at site masts
- Predict the wind speed variations over the site
- Predict gross energy output of all turbines
- Predict likely energy losses
- Result: Predicted long-term net energy output of the wind farm
- At each step quantify the mean value of energy and the uncertainty

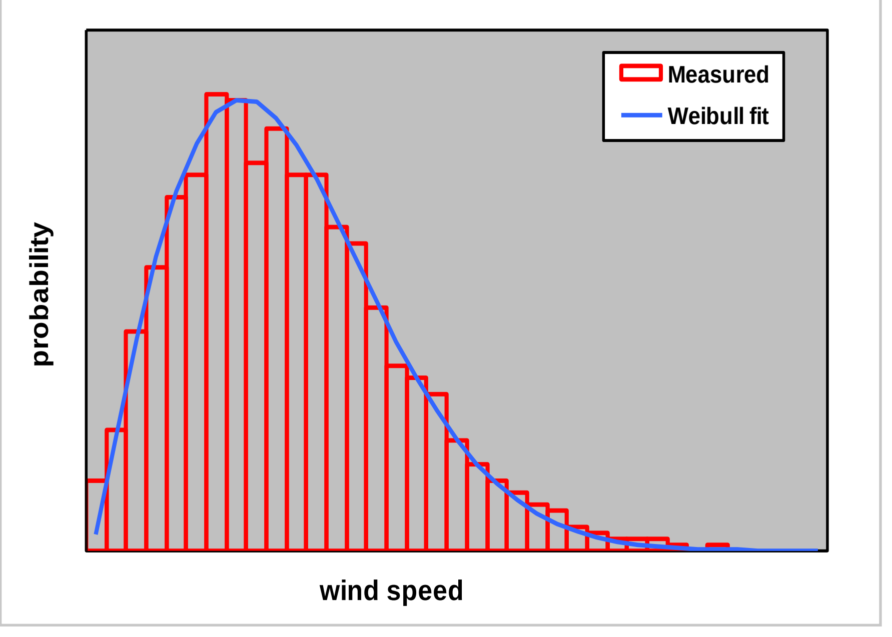
Probability distribution of mean wind speeds

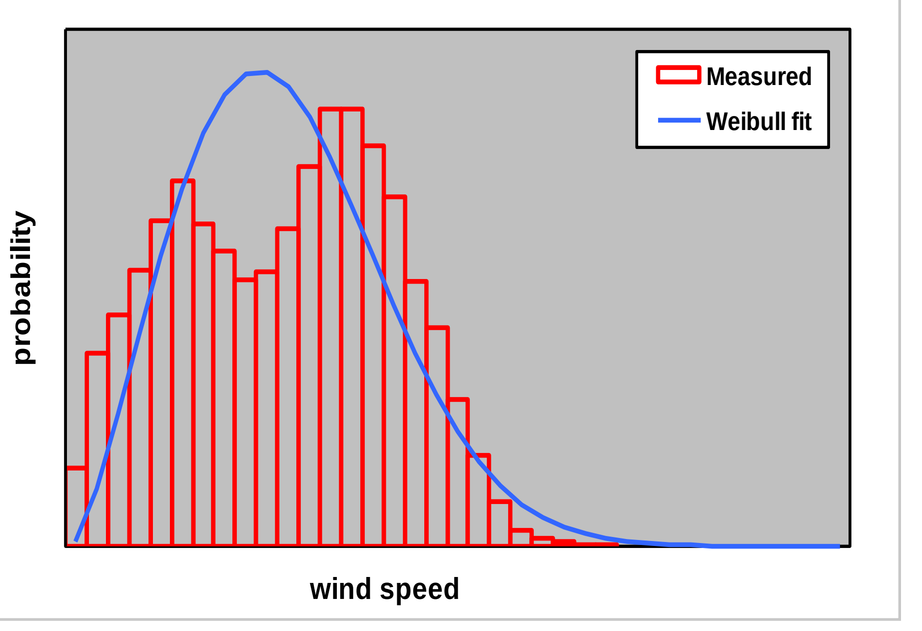


Weibull frequency distribution is found to conform well to many observed distributions: described by
A (scale parameter) and k (shape parameter)

Example results

- Wind speed frequency distribution

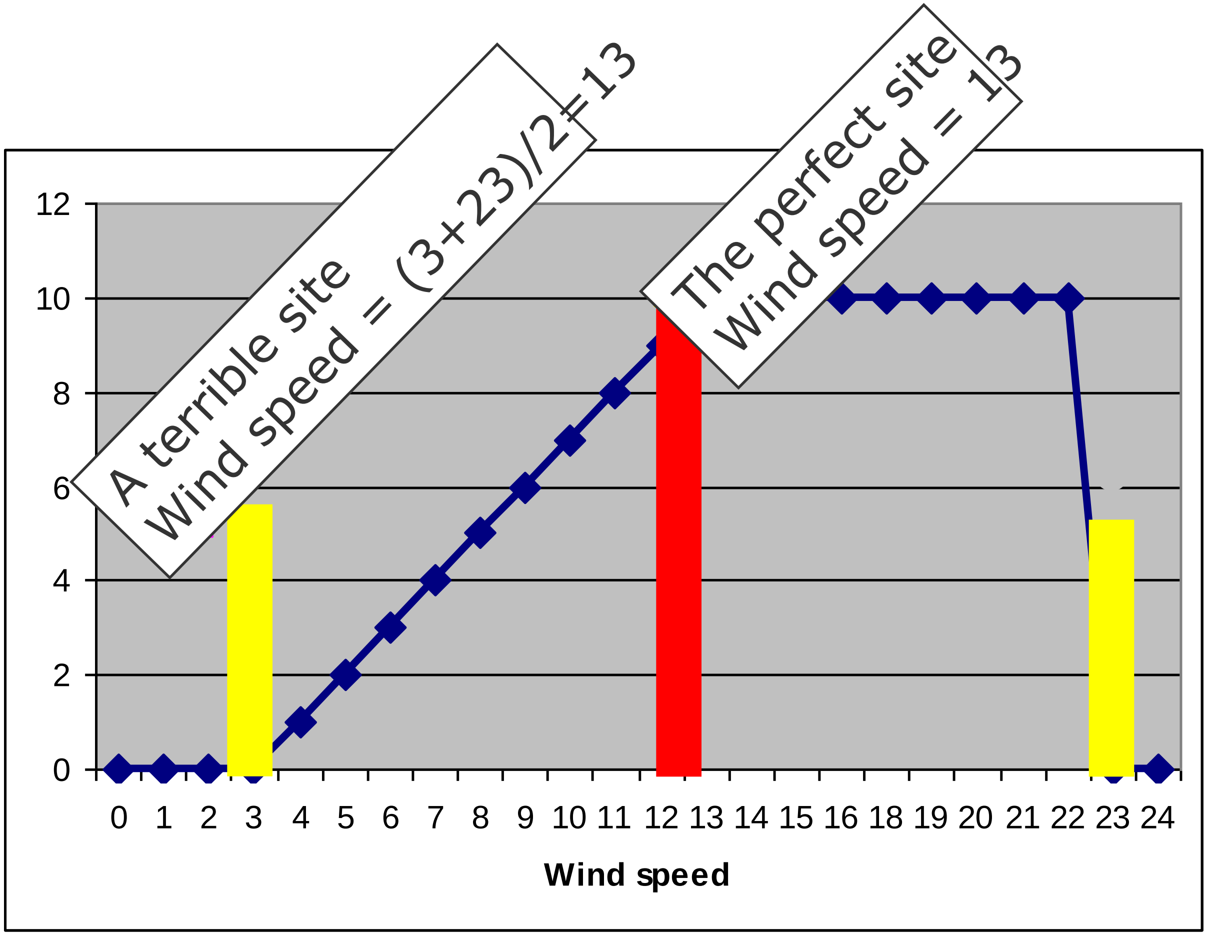




Good Weibull fit

Poor Weibull fit

The importance of wind speed distribution



What is the minimum requirement for on-site data?

- Must capture seasonal variation
- Estimates improve with added data
- In complex terrain no machine more than 1,5 km from a mast
- Risks can be calculated from one year's data

Data required

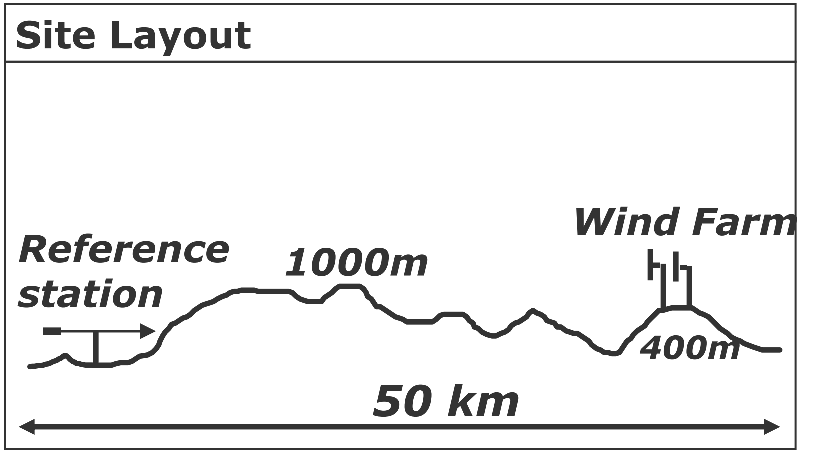
- Ideally:
  10+ years of data recorded on site

- In reality:
  Measure-Correlate-Predict method with reference station to reproduce long term site wind regime

- Site data required for MCP
- 1+ year of data close to hub height
- Interim analysis possible with less data

Assessing long-term wind resource

- Short-term measurement
  - Site data
- Long-term measurement
  - Reference station
  - Absolute accuracy not vital
  - Consistency is vital
  - Often there is no reference station
  - Inspect reference site
- Methodology
  - Industry standard : Measure Correlate Predict (MCP) methodology



Choice of reference station

- Requirements:
- historical period > 5 years
- plus concurrent time series
- proximity
- consistency
- simple exposure

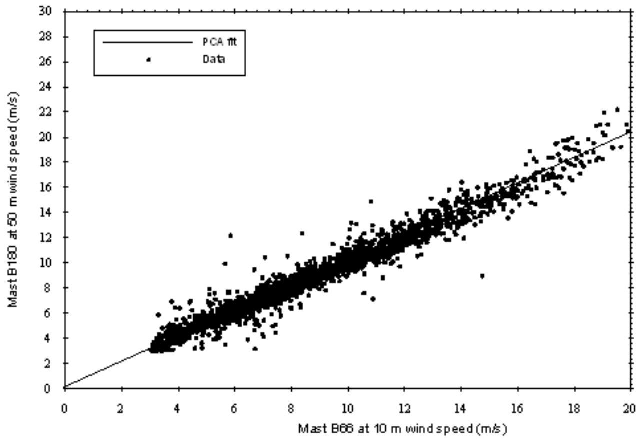
- Options:
- National Meteorological Stations
- others
- - wind farms
- - sites with existing MCP
- - reanalysis data

MCP or not?

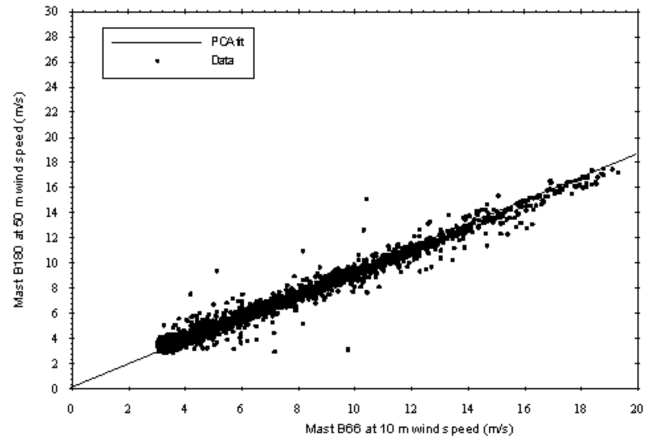
- If there is a reference station available and it is consistent then try it
- Do not accept uncritically – visit, interview, evaluate, document
- Test the results
- If you have enough on site data you may be better off without the reference

Minimise uncertainties, be critical, use the value with least uncertainty

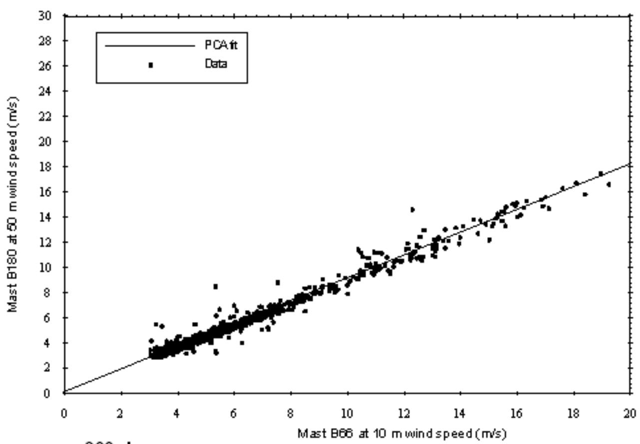
Good wind speed correlation by sector



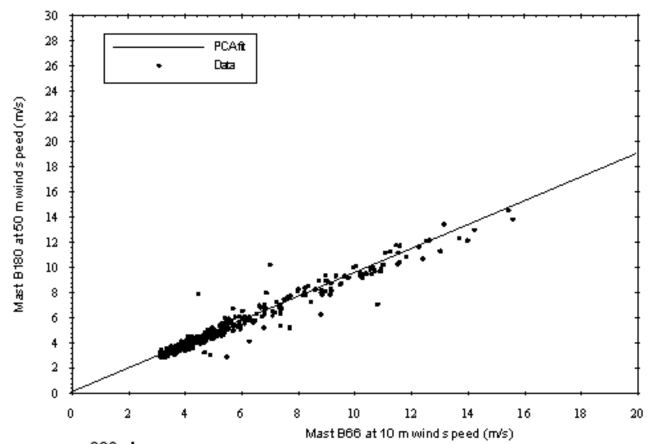
240 degrees



270 degrees

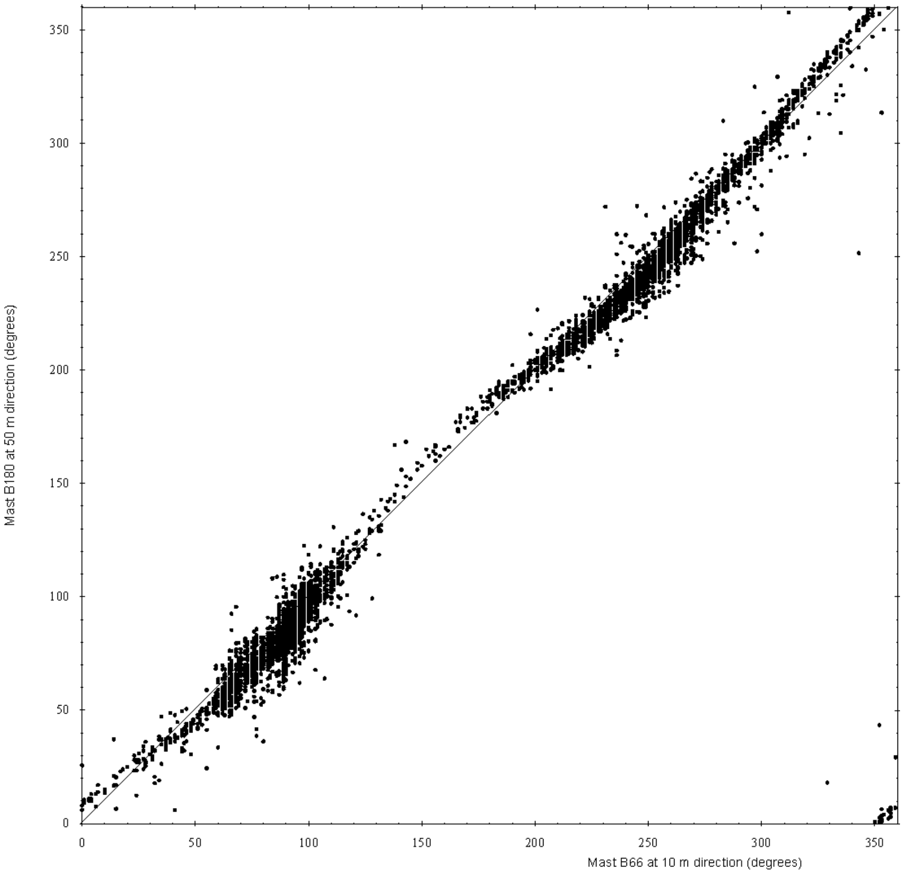


300 degrees



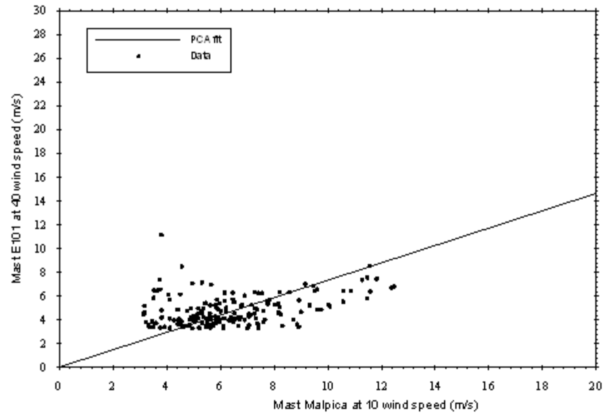
330 degrees

Good direction correlation

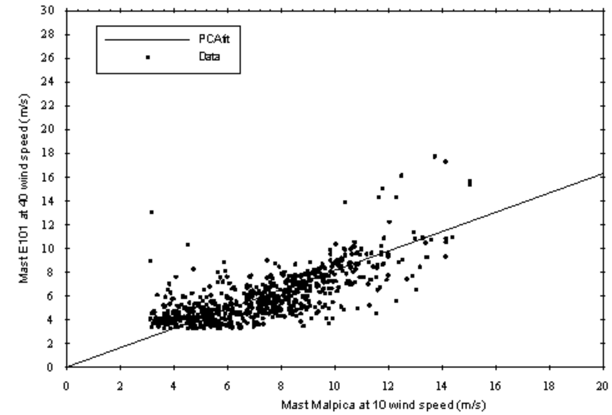


Wind speeds greater than 5.0 m/s

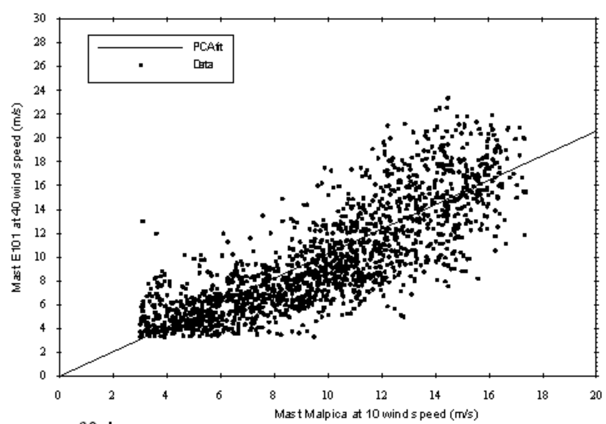
Poor wind speed correlation by sector



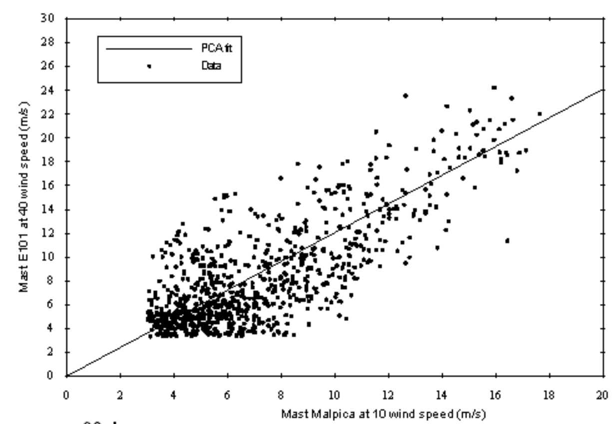
0 degrees



30 degrees

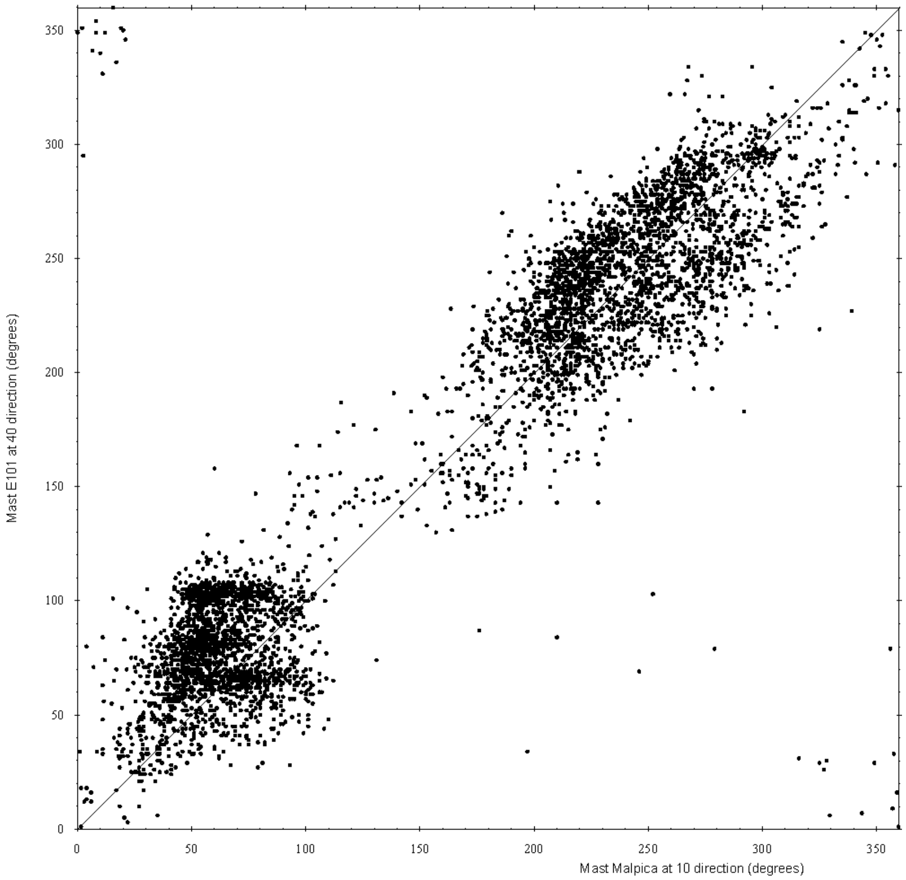


60 degrees



90 degrees

Poor direction correlation



Wind speeds greater than 5.0 m/s

Shear

– Turbines are growing in height

– Extrapolation is a risk – shear shape can change – (over forests, north, south)

– Hub height or blade tip measurement?

  – Should be improved to > hub height on at least one location

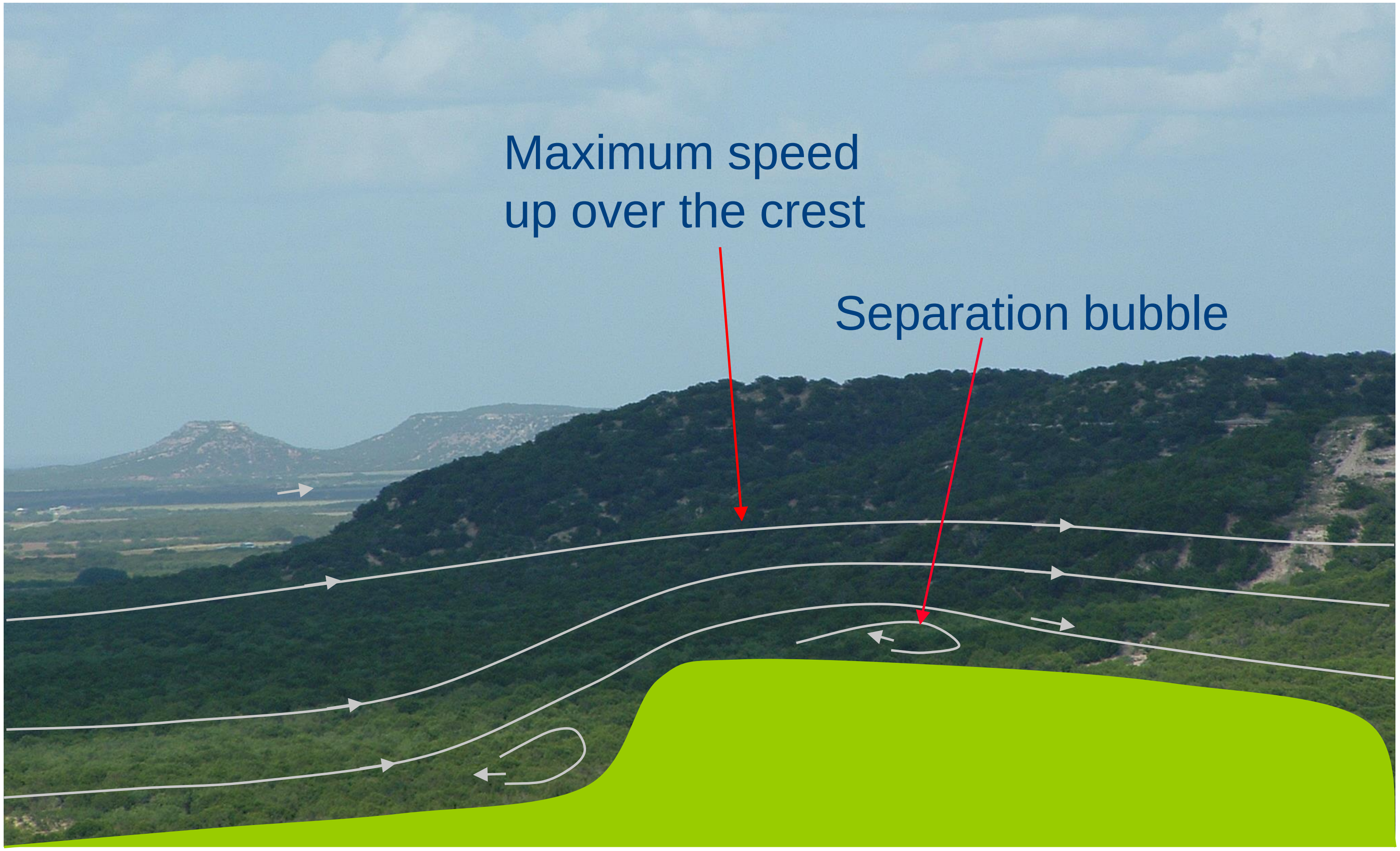
– Use multiple measurement heights

Remove uncertainty through tall masts
Quantify through knowledge of meteorology

Predicting wind flow behaviour at real sites

- Simple equations assume uniform roughness and flat ground over a large area
- In practice there will be:
  - Multiple changes in surface roughness, causing transitions in height profile
  - Complex hill geometries
  - Obstacles
- Computer-based models used for full wind flow analysis
- All directions considered
- Continual development to address increasingly complex sites

Wind flow over hills



Changes in surface roughness

Changes in roughness propagate up through the boundary layer

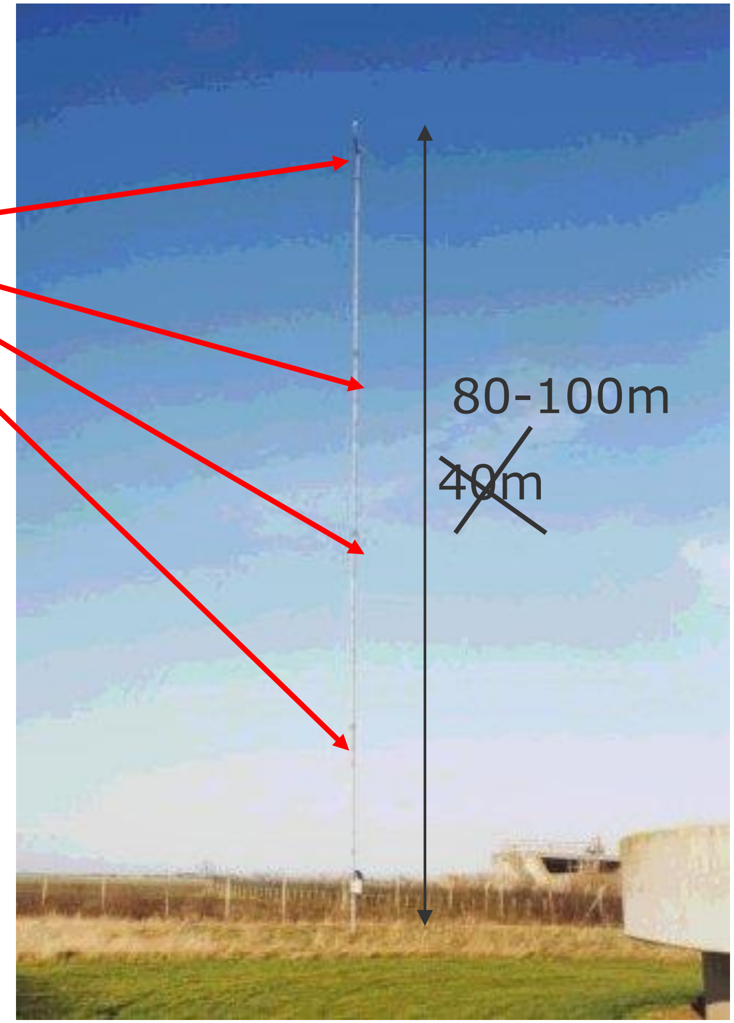
Remote sensing

LIDAR

SODAR

An anemometer – choose carefully

Meteorological mast



Instruments and mounting

- Do not economise!
- Mount according to IEC
- Keep good records for DD inspection
- Reduce uncertainty through good maintenance

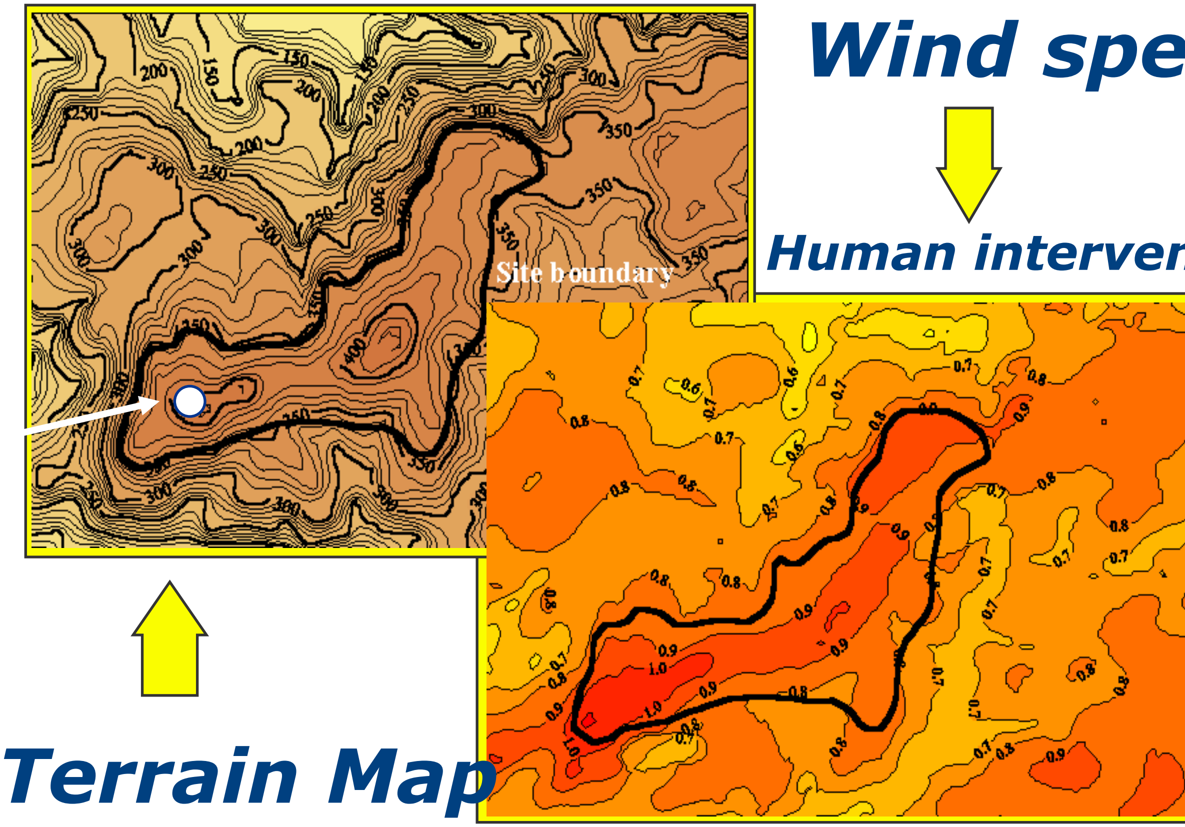
Quantify through evaluation of calibration testing
Shortcuts lead to higher uncertainties

Extrapolation (interpolation) of wind speed

Wind speed map

Human intervention!!

Mast



Terrain Map

This process has the biggest uncertainty

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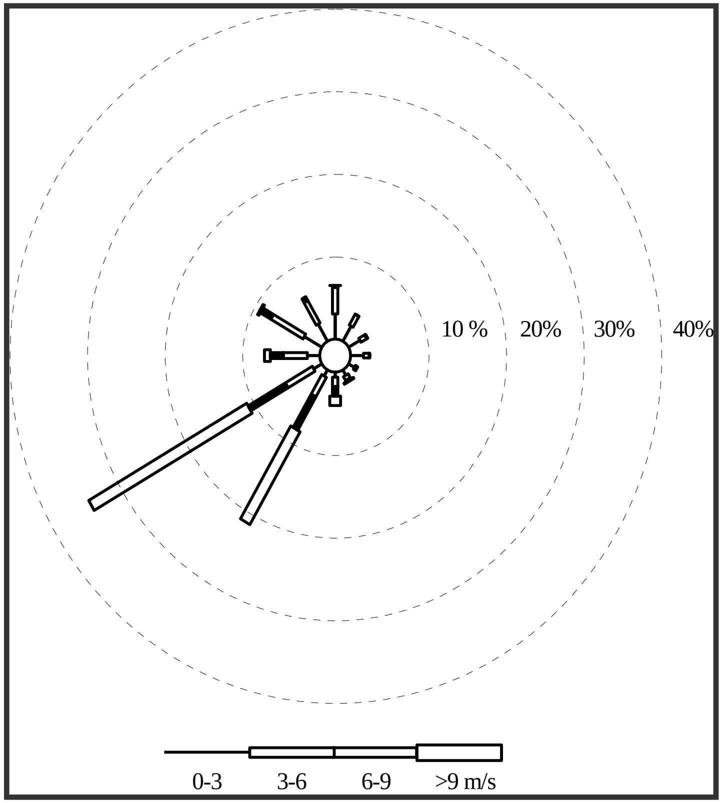
The wind rose

Small changes in wind rose may produce significant changes in energy



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Direction and frequency distribution

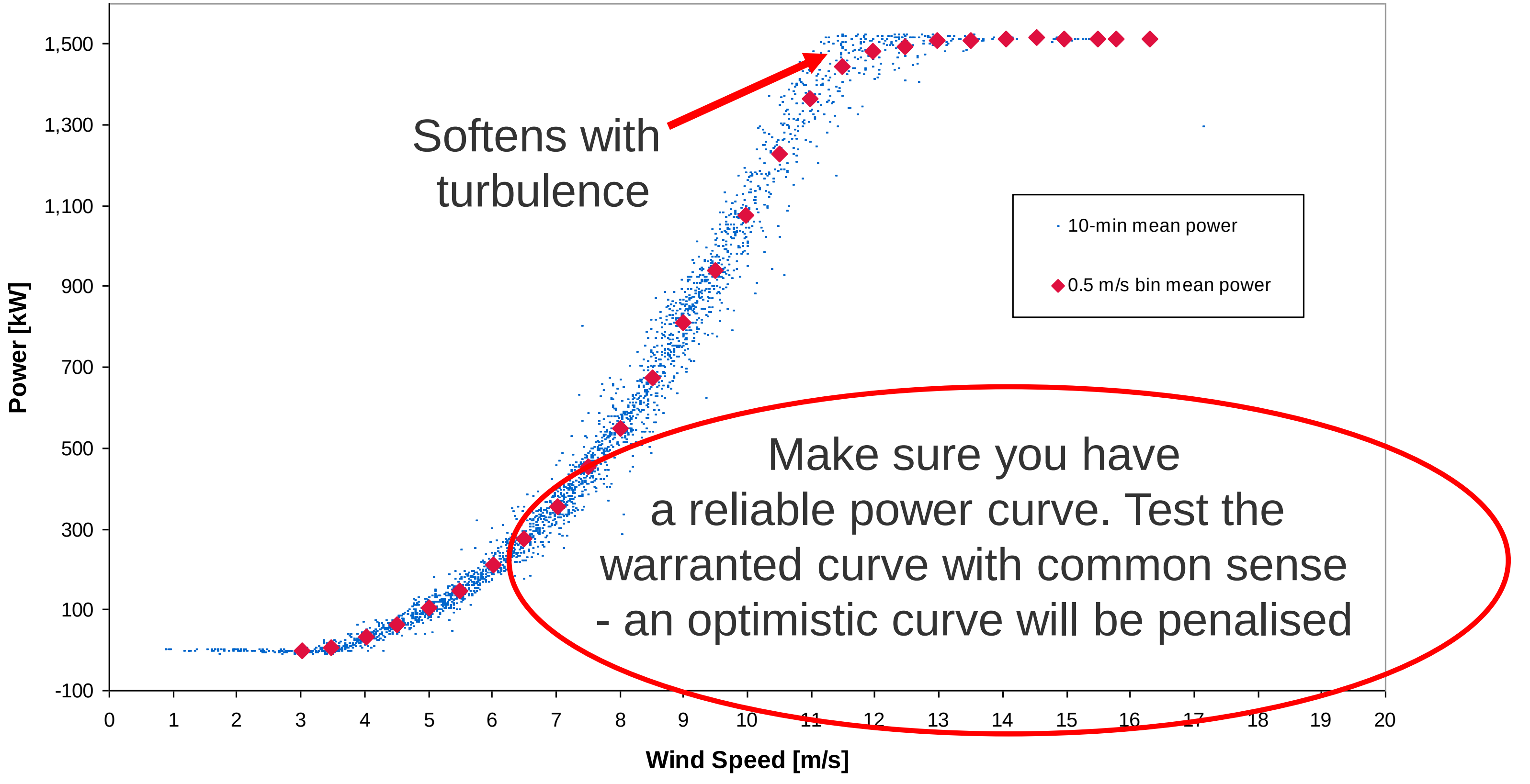
– Must consider wind direction and frequency distribution

– Site dependent :
  – Omnidirectional (eg US East coast, Europe)
  – Bi-directional (eg Texas, Spain)
  – Uni-directional (Palm Springs, Turkey)

Measure / predict wind direction and frequency distribution carefully
Uncertainty can be quantified and part of standard procedure.

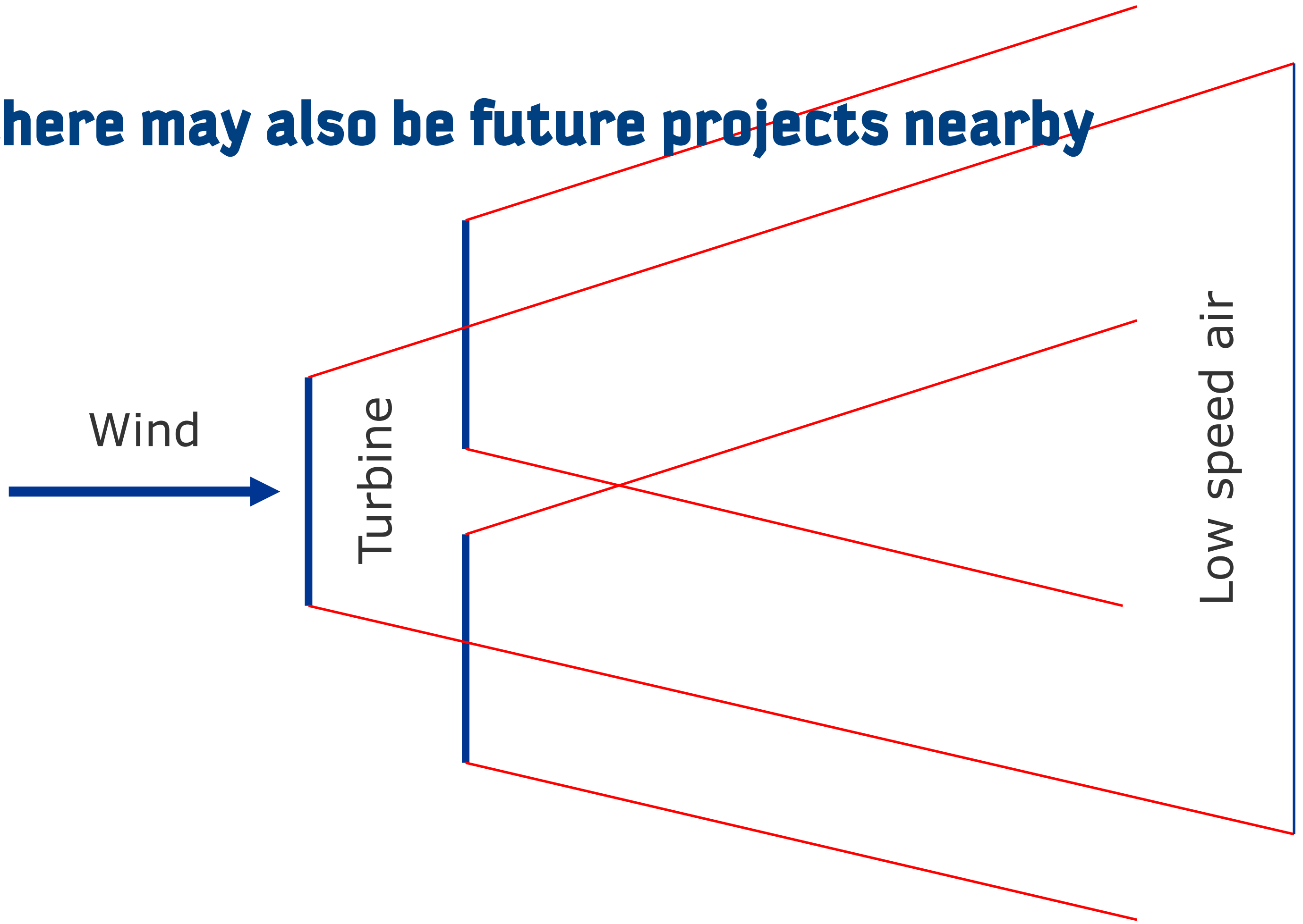
Power Curve – wind speed to power

- Power curve measured on GE 1.5 MW turbine
- Shows measurement scatter but consistent pattern

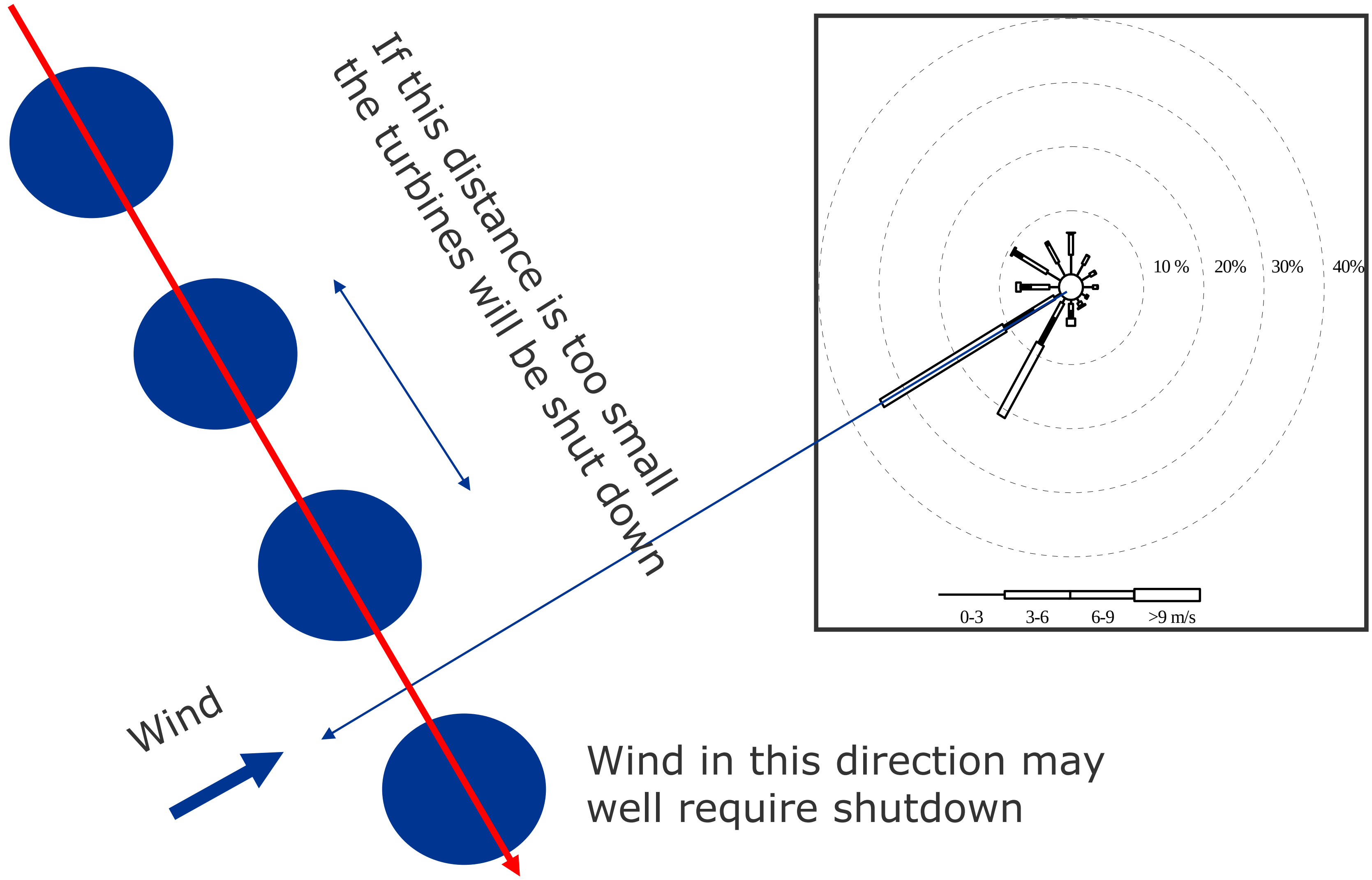


Wakes

– there may also be future projects nearby



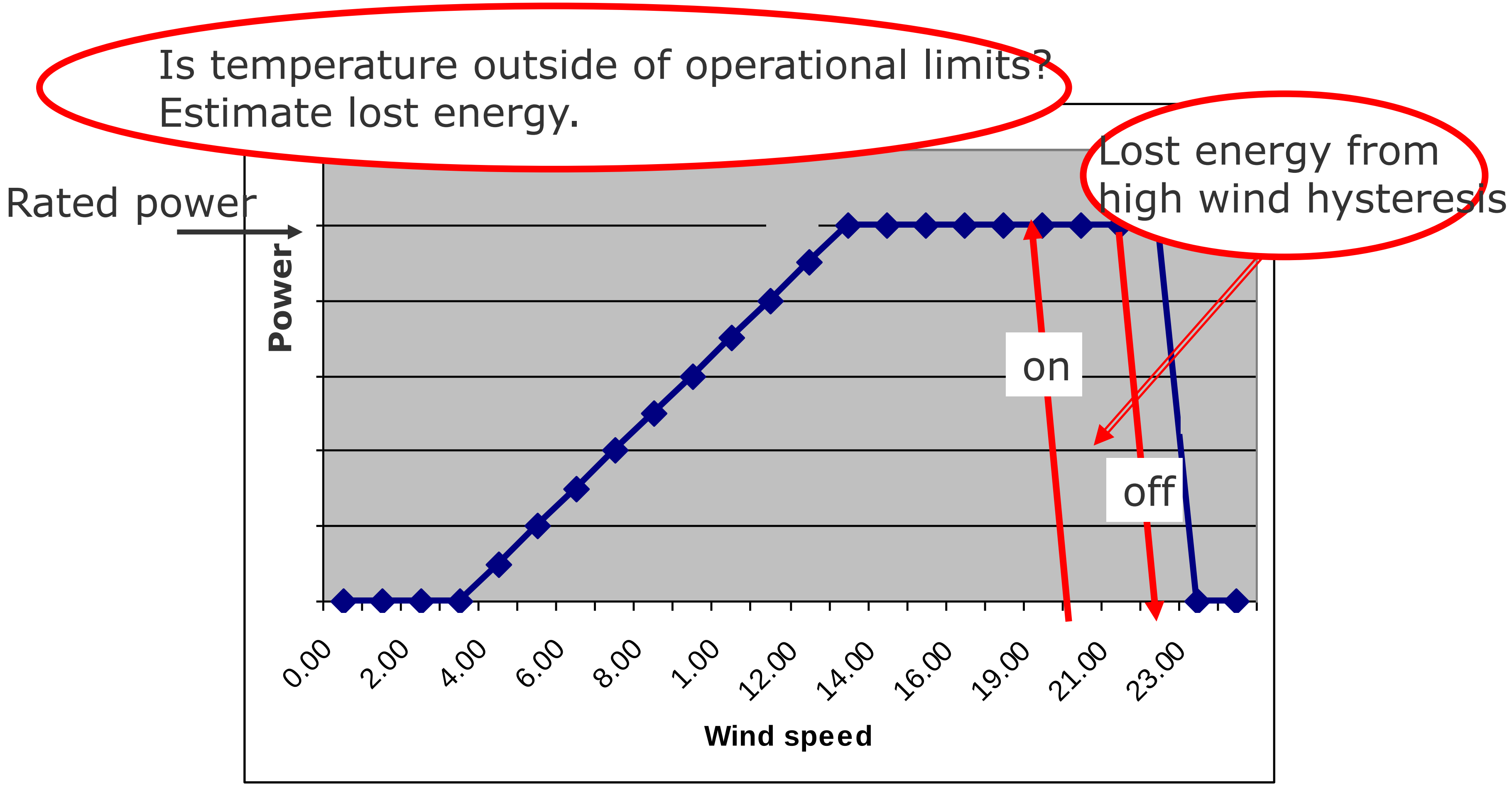
Conform to manufacturer's spacing



Wind in this direction may well require shutdown

Energy losses…

High wind speed hysteresis and cold weather

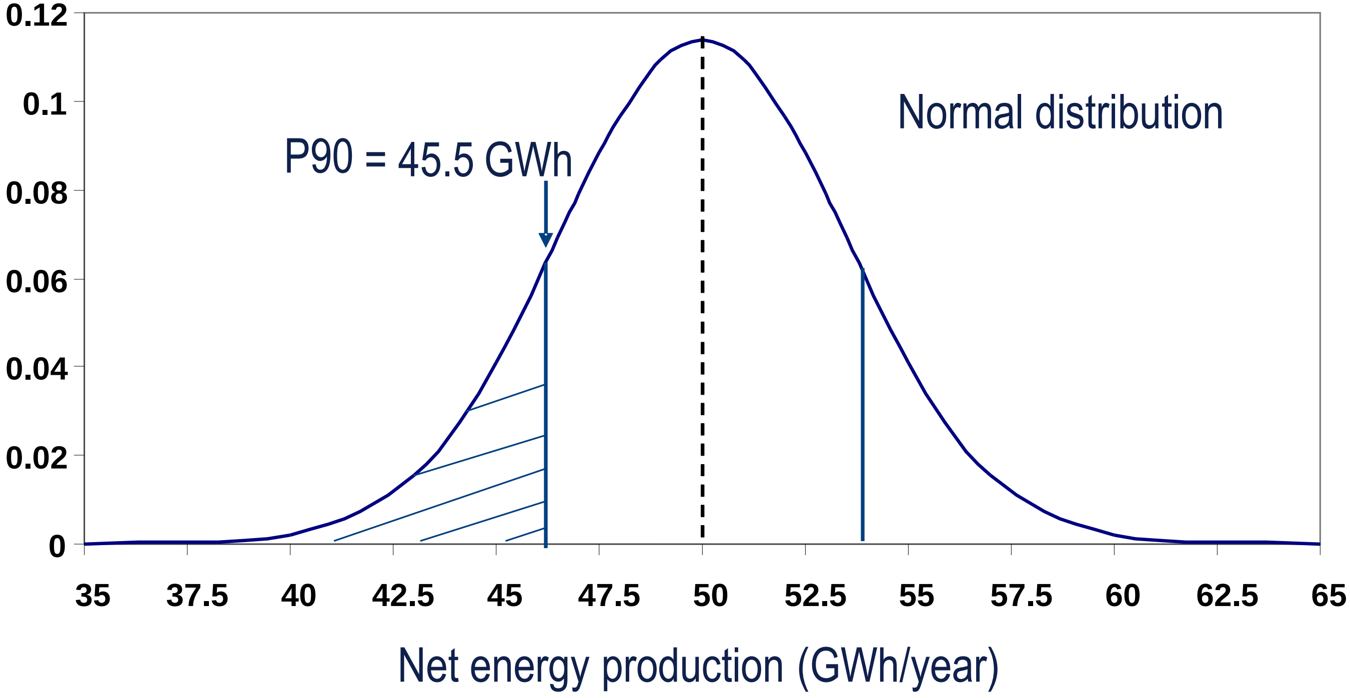


List of losses to obtain net energy

Rated Power	**50**	**MW**
Gross Output	**170**	**GWh/annum**
Wake effect	98.7%	Calculated
Electrical efficiency	97.0%	Calculated
Availability	97.0%	GH assumption
Icing and blade degradation	99.5%	GH assumption
High wind hysteresis	99.2%	Calculated
Substation maintenance	99.8%	Typical value
Utility downtime	100.0%	GH assumption
Power curve adjustment	98.5%	GH assumption
Columnar control loss	100.0%	GH assumption
Cold weather shut down	100.0%	GH estimate
Wake effect of future projects	100.0%	GH assumption to be covered in the Finance Agreement
Net output	**153.2**	**GWh/annum**

Probability Distribution

- Mean = 50 GWh/year
- Standard deviation = 3,5 GWh/year (in this example)



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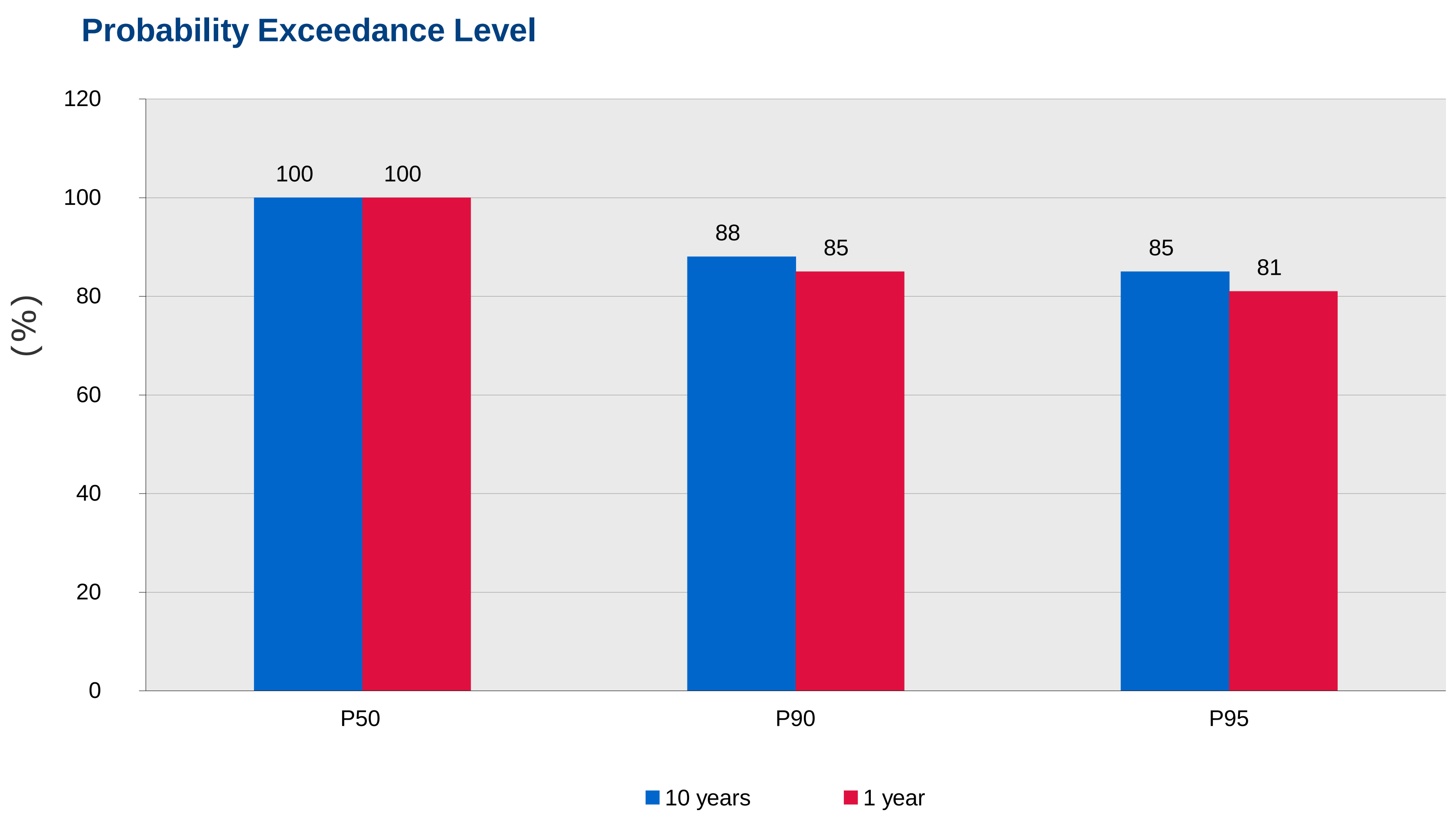
Cumulative Probability Distribution
Definition of P50 and P90

If you run the wind farm for ten years and calculate the mean annual production over that ten year period then there is a 50% chance that the recorded energy will be greater than the P50 value. There is also a 50% chance that it will be less than the P50 value.

There is a 90% chance that the recorded value will be greater than the P90.

Energy yield – Typical net values



Conclusions Uncertainty

- Risks are defined and quantified - amenable to statistical treatment
- The bank will choose a probability level to use for its Base Case – this level will include specific treatment of uncertainties
- Some use P75, P90, additional conditions, depends on bank and market
- There will also be sensitivities (low wind, sequencing)
- The better data and analysis you provide the bigger the loan you will receive

Summary / Important Issues

- At each step quantify the mean value AND the uncertainty
- Spend as much money as you can possible afford
- Use the best possible instrumentation
- Use as many masts as possible
- Keep them there for as long as possible
- Document and maintain
- Review Met Office data for consistency changes / visit
- High uncertainty may reduce feasibility
- Modelling is important; input data are critical

Dealbreakers

Insufficient / inappropriate data such that a "Bankable" assessment not possible

- Home made instruments
- Masts too low / too distant / unrepresentative
- Masts no longer in place and no traceability
- Period of data too short

No uncertainty analysis possible

Solutions include recalculation

Checklist of data required for energy due diligence

- Raw wind data, not pre-processed
- Installation and maintenance records, to include
  - Calibration certificates and logger settings
  - Full details of the mounting, including diagrams / photos
- Ideally, same for reference stations
- Digital contours, in same system as mast and turbine coordinates.
- Possibly detailed survey of forestry

Don’t be optimistic be realistic!

Kontak

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