Predicting climate conditions for turbine performance

Mark Žagar, Vinay Belathur Krishna, Alvaro Matesanz Gil

Vestas Data Engineering & Analytics / Advanced Plant Modelling

Public

Resource assessment, power curve, and AEP[1] estimate

Usual process

- Wind as distribution
  - Measurements (~1 year) + ~3km weather model → corrected long-term series
  - Sectorwise (12-36)
  - Fitted Weibul distributon → shape and scale (the A and the k)
- Verified power curve
  - Standard
  - Good quality data
    - Met-mast in front of the turbine
    - Meticulously filtered
  - Assumed production $\sum P(v(t),\rho(t))$ during a few months compared with actual production
- AEP estimate using the power curve, and:
  - A wind speed distribution from the A and the k, and one density (common)
  - A wind speed time-series instead of the A and k (better, not so common)

1 Annual Energy Production

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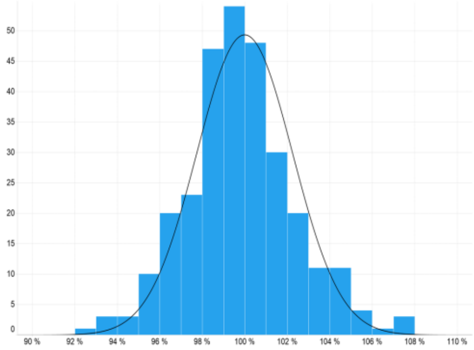
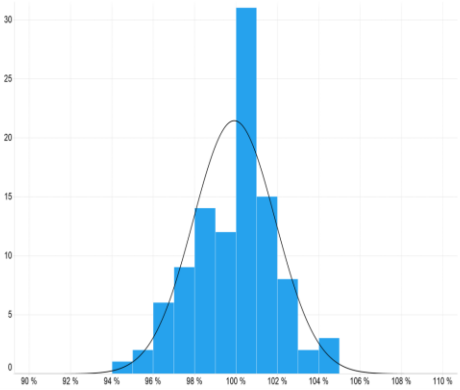
Vestas turbine performance during power curve verification

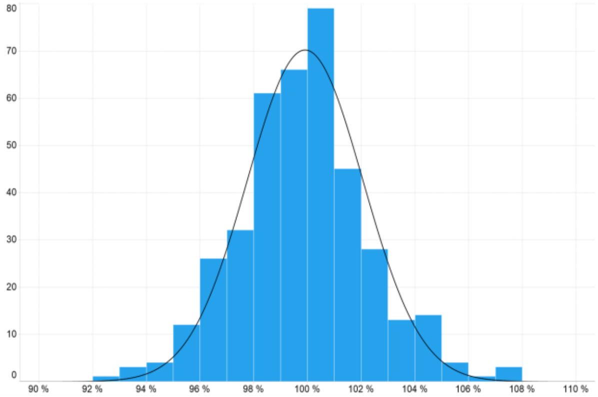
- Established by independent tests. By family, and together

2 MW Product family	
Turbine type	Tested turbines
V80 - 1.8/2.0/3.0 MW	21
V90 - 1.8/2.0/3.0 MW	135
V100 - 1.8/2.0/2.2/2.6 MW	92
V110 - 2.0/2.2 MW	41
Performance	
Average	99.8%
Minimum	92.9%
Maximum	107.6%
Standard deviation	2.5%
No. of tests	289



4 MW Product family	
Turbine type	Tested turbines
V105 - 3.45 MW	1
V112 - 3.0/3.3/3.45 MW	63
V117 - 3.3 MW	21
V126 - 3.3/3.45/3.6 MW	14
V136 - 3.45/3.6 MW	4
Performance	
Average	99.9%
Minimum	94.4%
Maximum	104.8%
Standard deviation	2.0%
No. of tests	103





Average	99.8%
Minimum	92.9%
Maximum	107.6%
Standard deviation	2.4%
No. of tests	392

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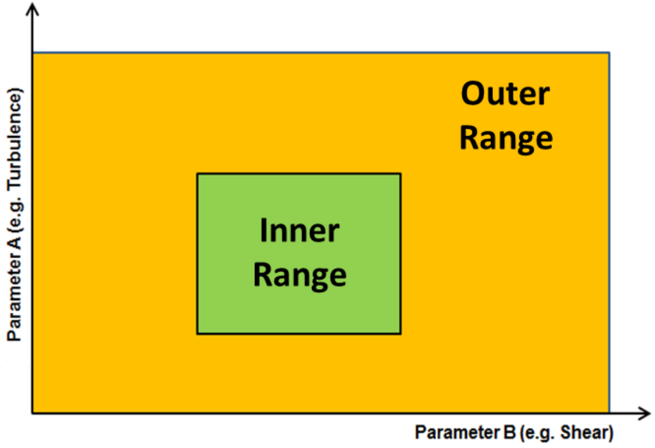
Uncertainty

Outer range wind conditions affecting calculation of yearly production (AEP)

- PCV tests cannot sample the whole range of atmospheric conditions (< 1year)
- Filtering of time periods is common (shear α and turbulence TI in a range)
- AEP is calculated using one power curve but assumed valid for a whole year
- Addressed by the Power Curve Working Group (pcwg.org)



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Prediction of inner and outer range conditions

Turbine performance assessment during the resource assessment phase

- From pre-construction data
  - Unclear how well the wind shear measured at the mast can be extended upwards
  - LIDAR promising but not quite bankable yet
  - Horizontal extrapolation (from mast to all WTGs) requires a model capable of capturing the real atmospheric structure
- Shear α and turbulence TI , and what else?
  - Low-level jets
  - Veer
  - …
- Think 150m rotor at 150m HH

Example: on one flat site, temperate climate, more than 15º veer across the rotor occurred during **12.4%** of the time when WSP > 4m/s

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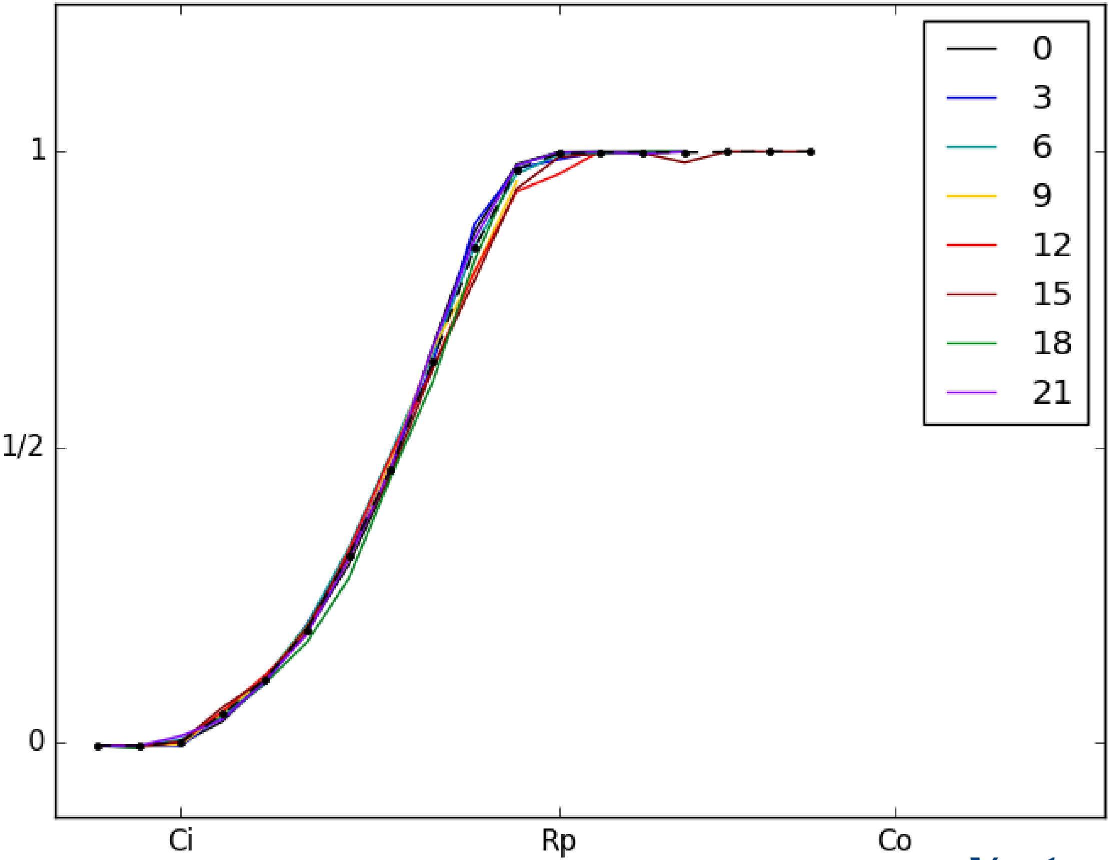
Example of variable performance

- PCV data (i.e. perfect)

- Test performance 98.7%
- Aggregated by local time (h)
  - Warm colors: day
  - Cold colors: night



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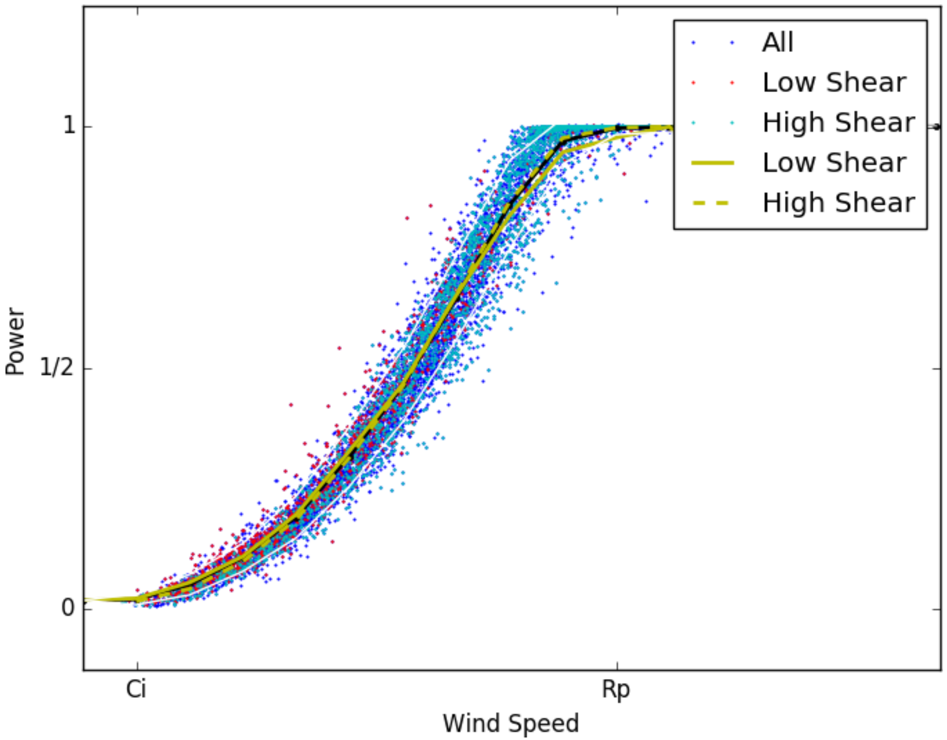
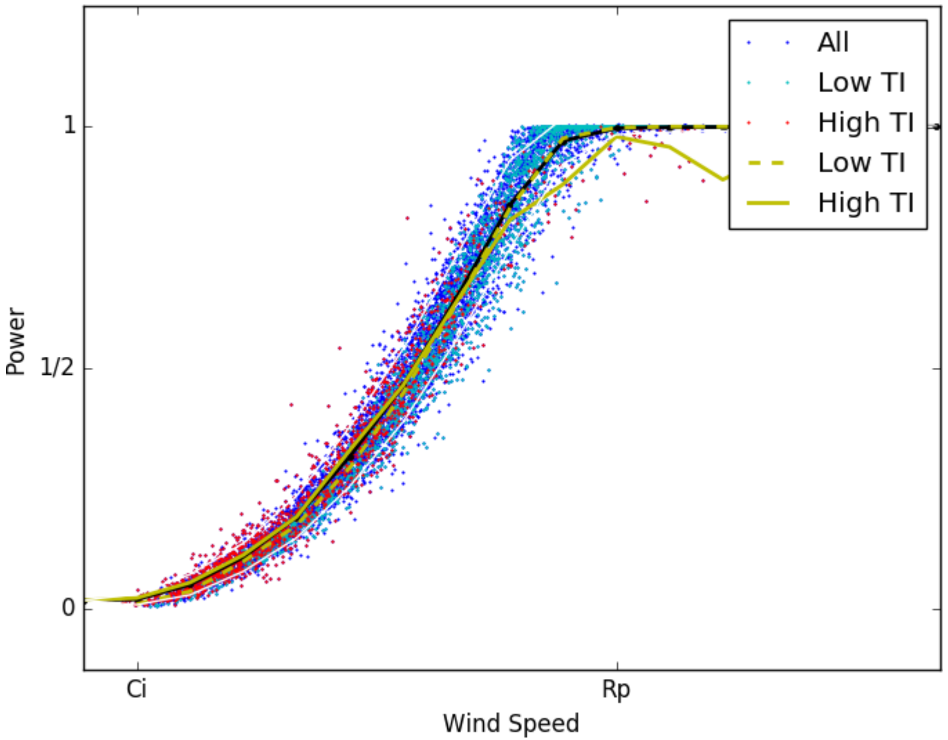
Example of variable performance

- Shear and TI. Below 25th percentile and above 75th percentile ("Low" and "High")





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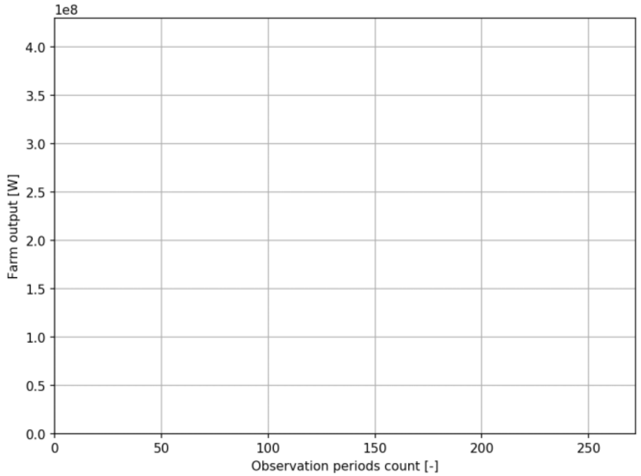
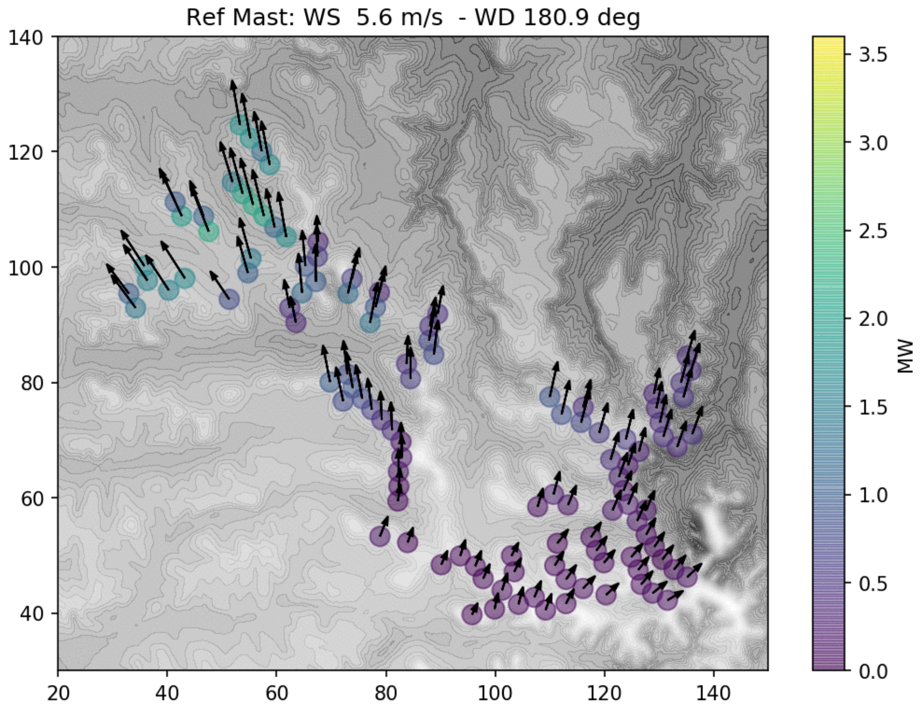
The goal

- High penetration of wind energy, combined with solar and other renewable sources
- Accurate prediction of wind power at any time is fundamental





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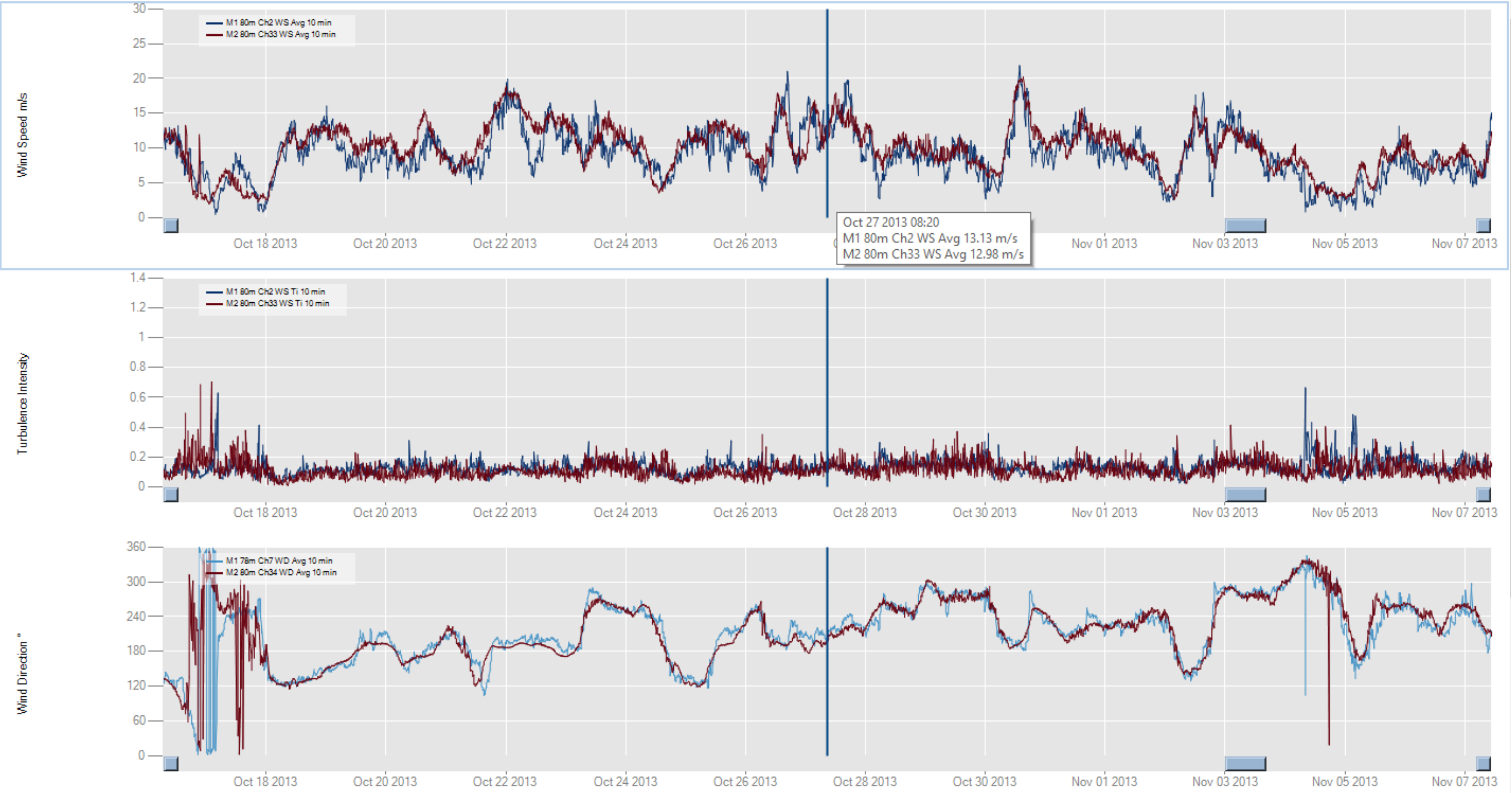
Model prediction of relevant atmospheric conditions

- Complete physics for describing precise profiles of all relevant variables from the surface to above rotor-top
  - Wind speed — power, curtailment, loads
  - Wind direction — plant layout, wake
  - Temperature (also profile - stability) — wake, hot/cold climate operation
  - Turbulence — power, wake dissipation, loads
  - Solar radiation — correlation, hybrid, battery sizing
- All above in a 10-minute time-series, every WTG location
- Coupled with a mesoscale model to capture life-time year-to-year variability
- Calibrated with local data if available

Wind speed, direction, and turbulence intensity (obs. vs. model)



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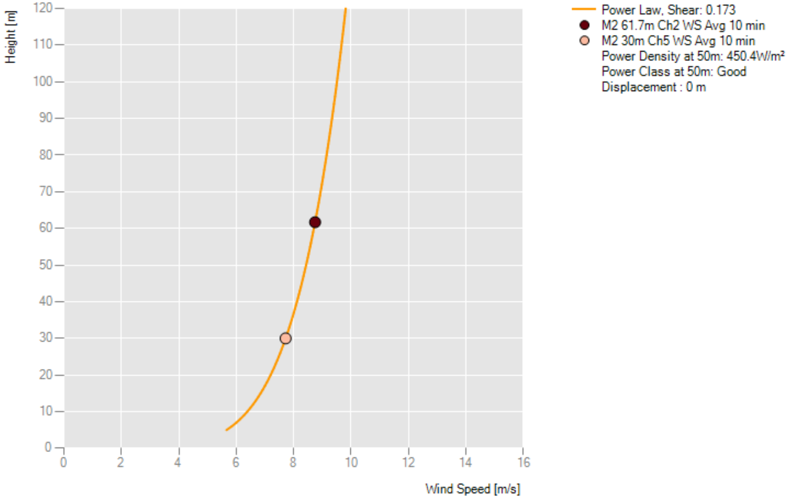
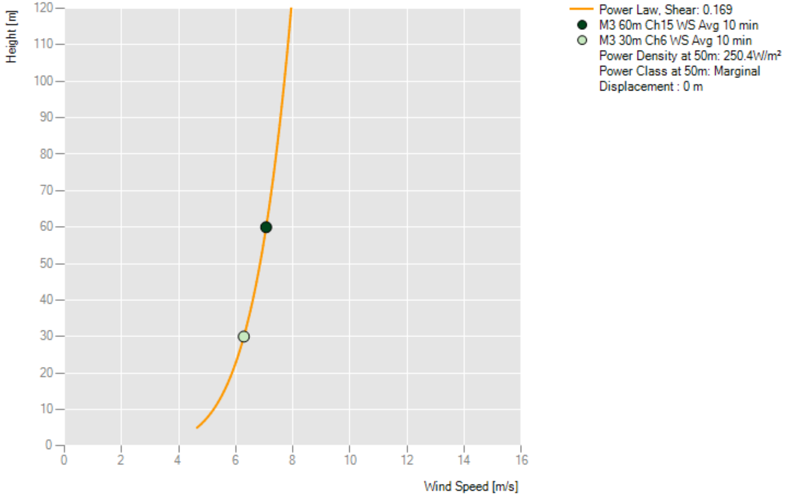
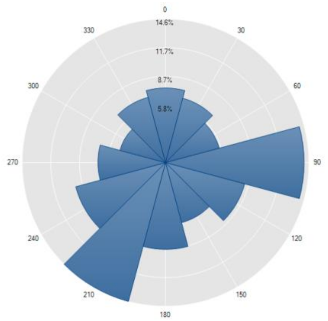
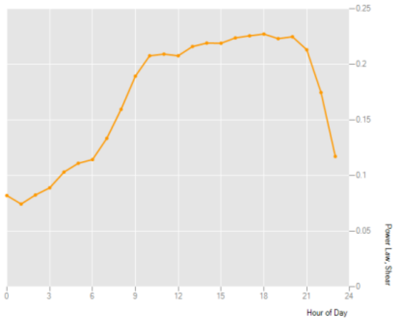
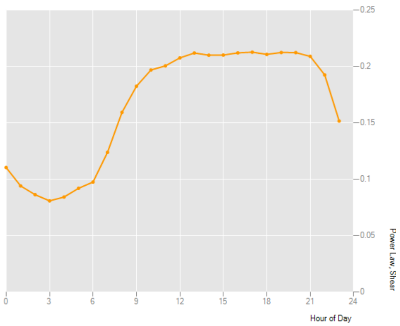
Measured and modelled wind profile, diurnal

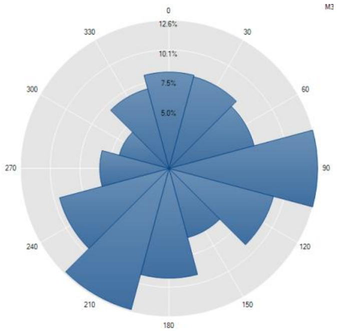




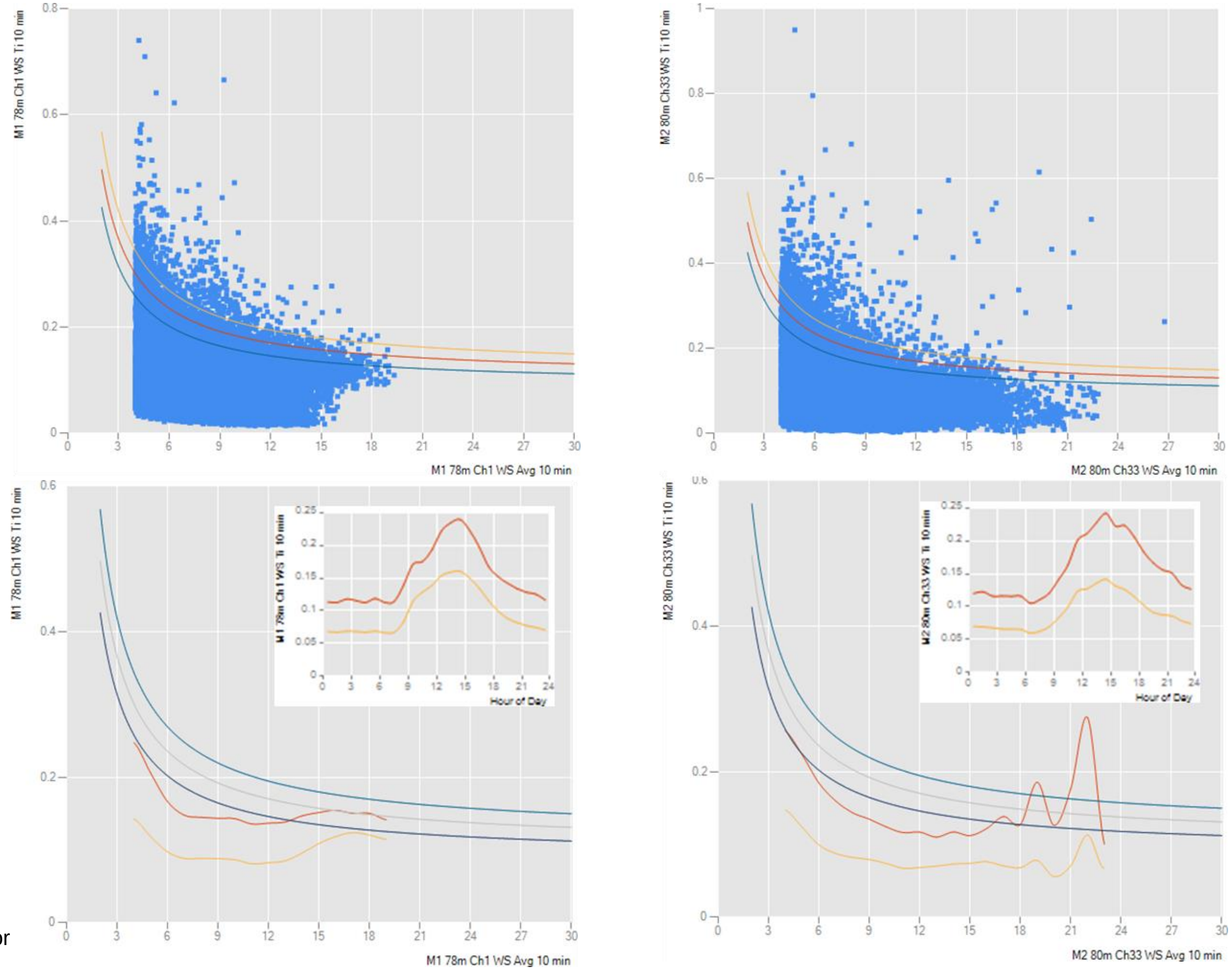








Measured and modelled turbulence intensity, diurnal



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Summary

Wind resource assessment

Turbine performance

Life-time time-series plant power

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