

ENERGY

Long-term Performance of Wind Farms

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9 December 2014

Does wind turbine performance degrade over time?

- Recent studies from academic institutes in the UK suggest that wind farm production degrades by a significant margin each year
- Resulting in a loss of confidence from wind energy operators and the investment community
- DNV GL draws on extensive experience and high quality, high resolution data to test these claims and perform a root cause analysis



Experience matters: >50 GW of operational analysis; forecasting for >40 GW; Inspections for >700 turbines per year; Largest independent provider of wind farm SCADA

Factors Affecting Turbine Performance

Environmental
effects

Wind conditions

Sub-optimal
performance

Drive train
degradation

Factors Affecting Turbine Performance

Environmental effects

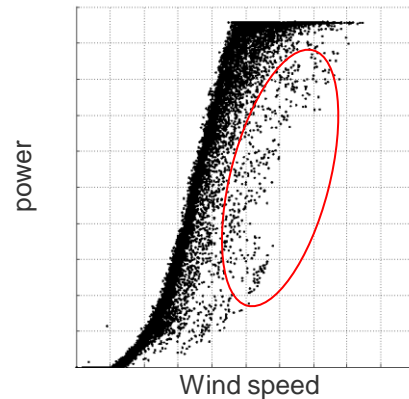
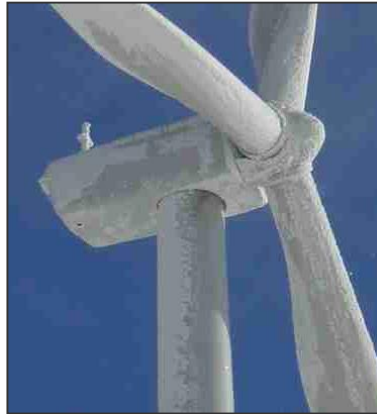
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Drive train degradation

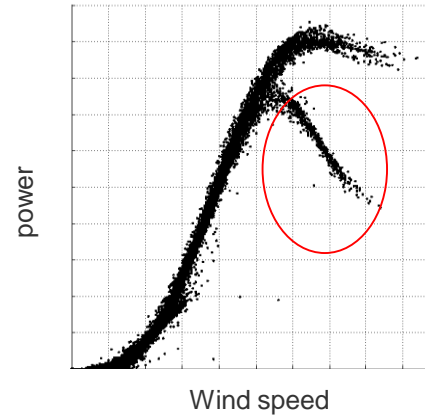
Icing

High impact on some sites



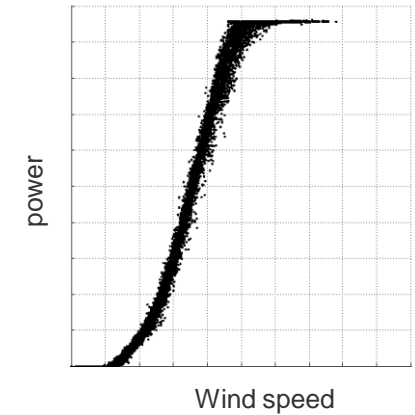
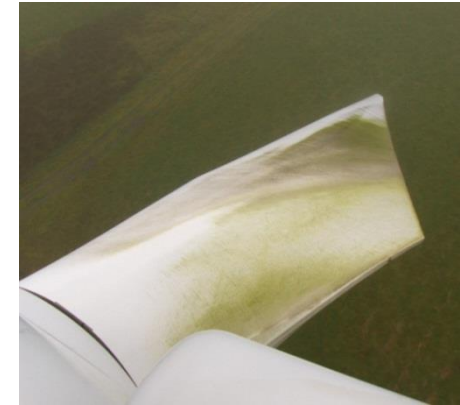
Insects

High impact for short periods



Dirty blades

Subtle impact but persistent



Factors Affecting Turbine Performance

Environmental effects

| | |
|---------------------|-----------------------|
| Typical energy loss | -0.5% (site specific) |
| Annual Trend? | Flat |

Wind conditions

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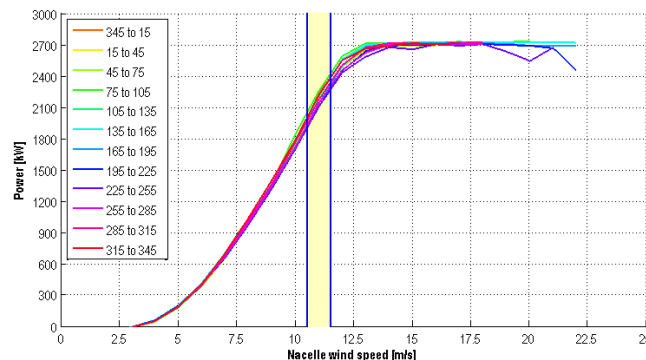
Drive train degradation

Parameters that impact the power curve:

- Flow inclination
- Turbulence intensity (TI)
- Shear profile
- Air density

Conditions that influence these parameters:

- Atmospheric stability (TI, Shear, density)
- Topography (flow inclination, TI, and shear)
- Forestry (TI and shear)



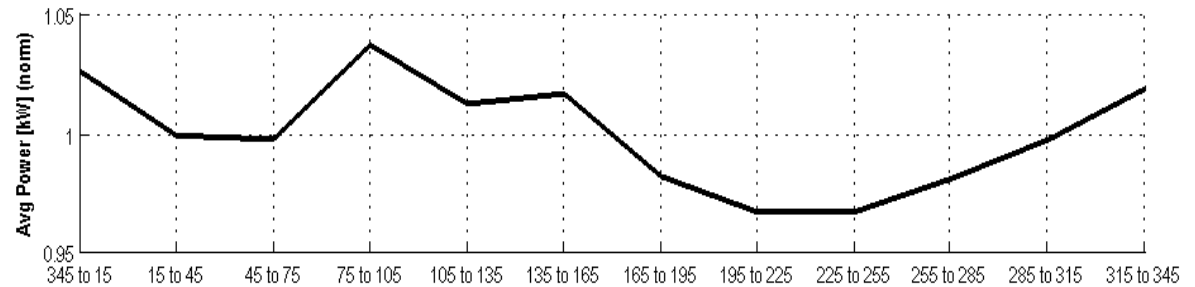
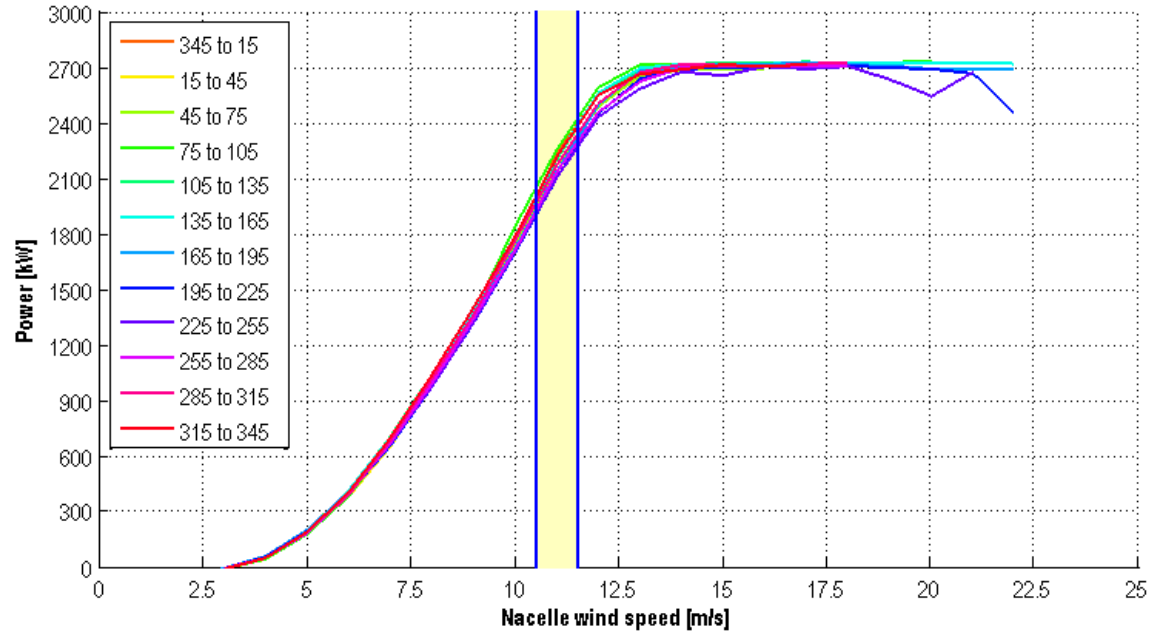
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Wind conditions

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| Typical energy loss | -1% (site specific) |
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Sub-optimal performance

Drive train degradation

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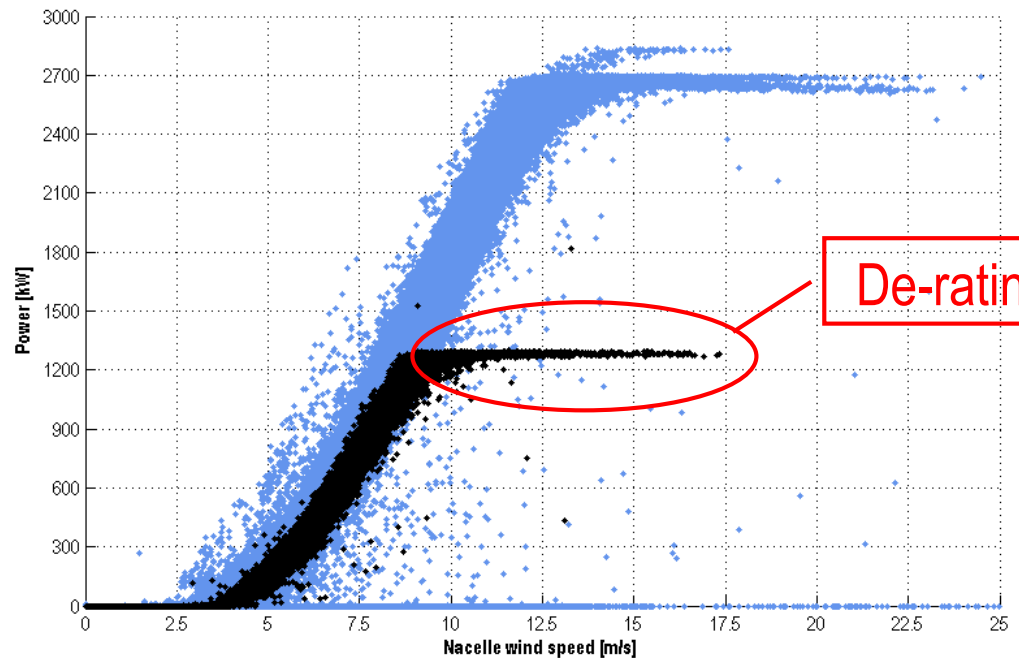
Drive train degradation

Usually intermittent effects:

- De-rating
- Lower power curve
- Power curve scatter

Resulting from:

- Maintenance
- Control modes
- Sensor errors
- Component misalignment



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Sub-optimal performance

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Drive train degradation

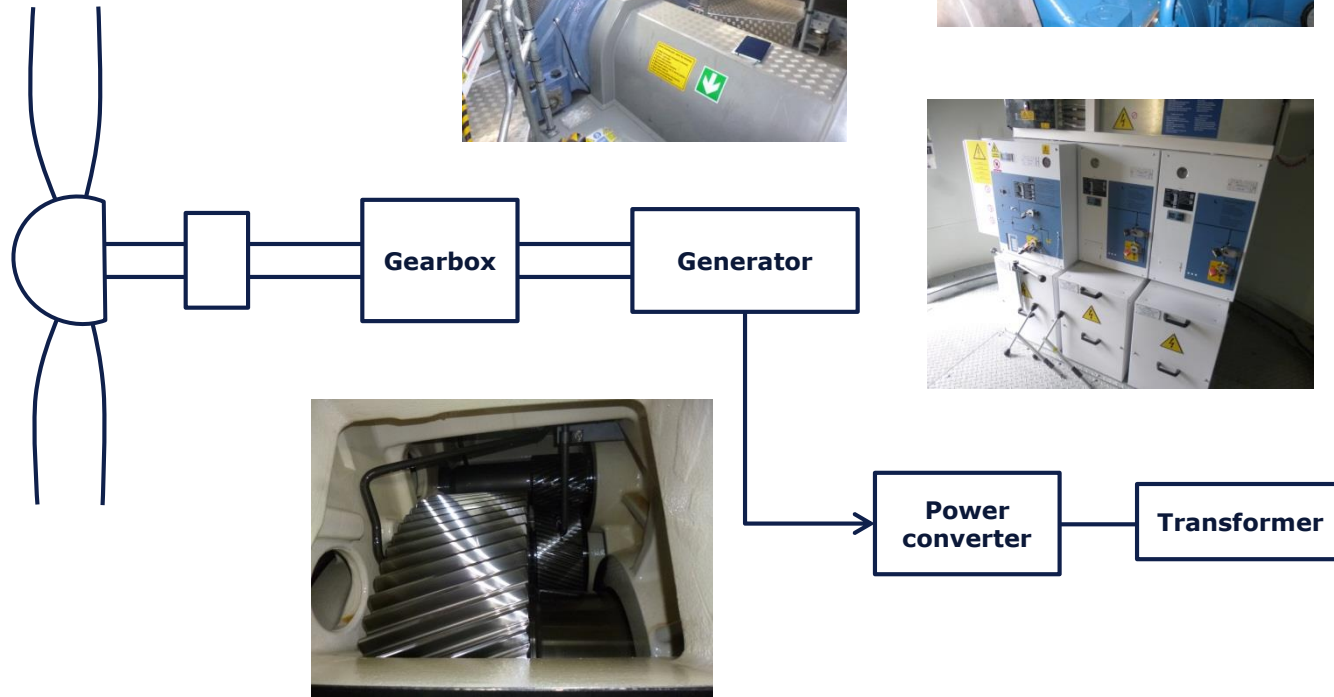
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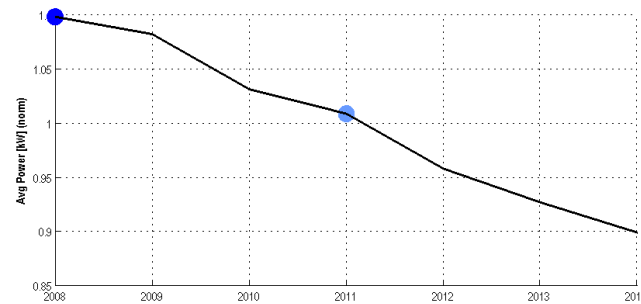
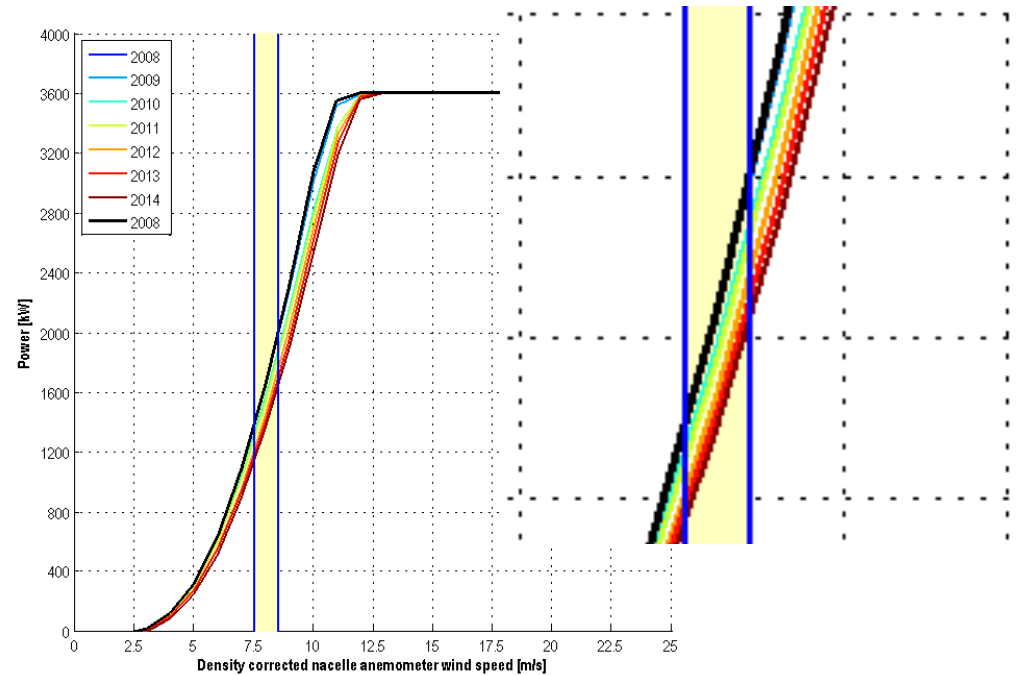
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| Drive train degradation | Typical energy loss | ??? |
| | Annual Trend? | ??? |

Drive Train Degradation Study - Method

Identify suitable projects

Remove intermittent effects

Make binned 'clean' power curve

Calculate energy loss

| Category | Control Mode Change | Consistent Anemometry |
|----------|---------------------|-----------------------|
| 1 | NO | YES |
| 2 | YES | YES |
| 3 | NO | NO |
| 4 | YES | NO |

- 31 wind farms
- 235 turbines
- Across Europe

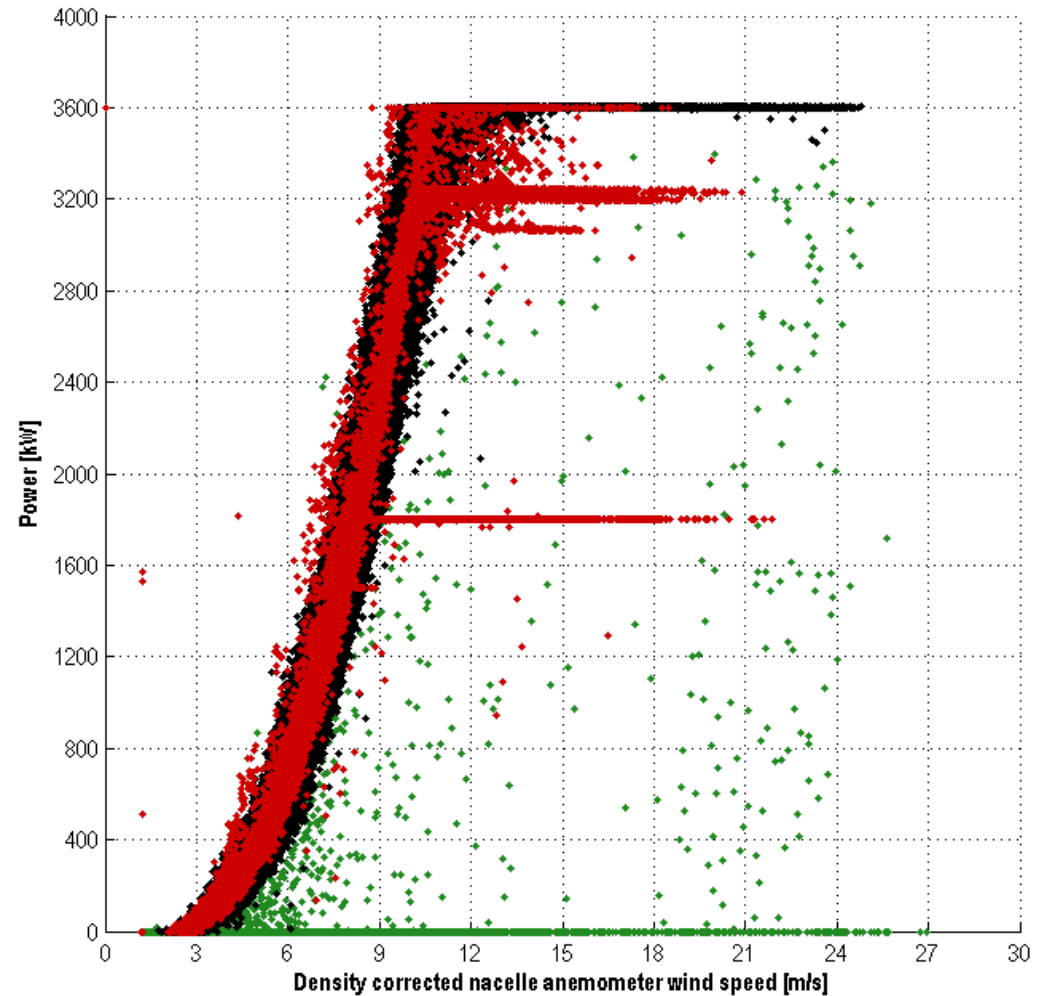
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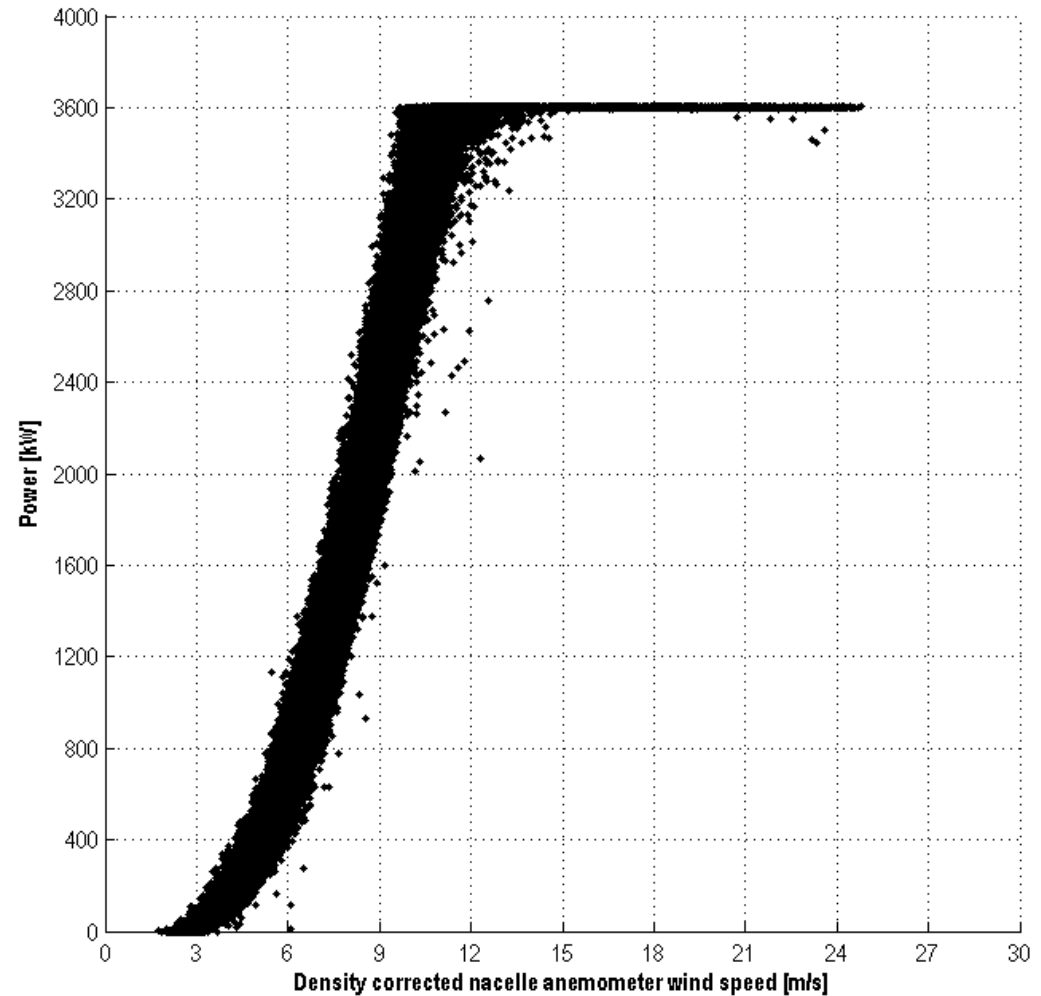
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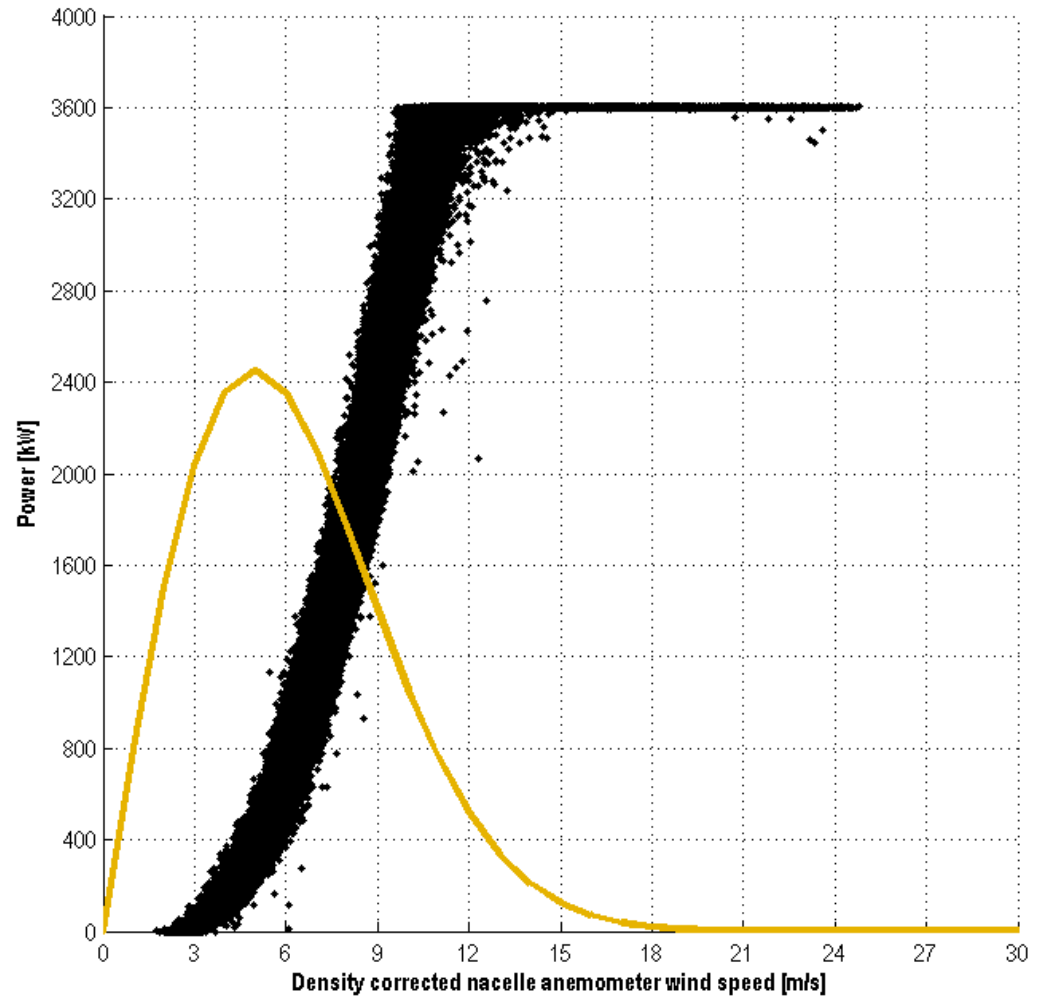
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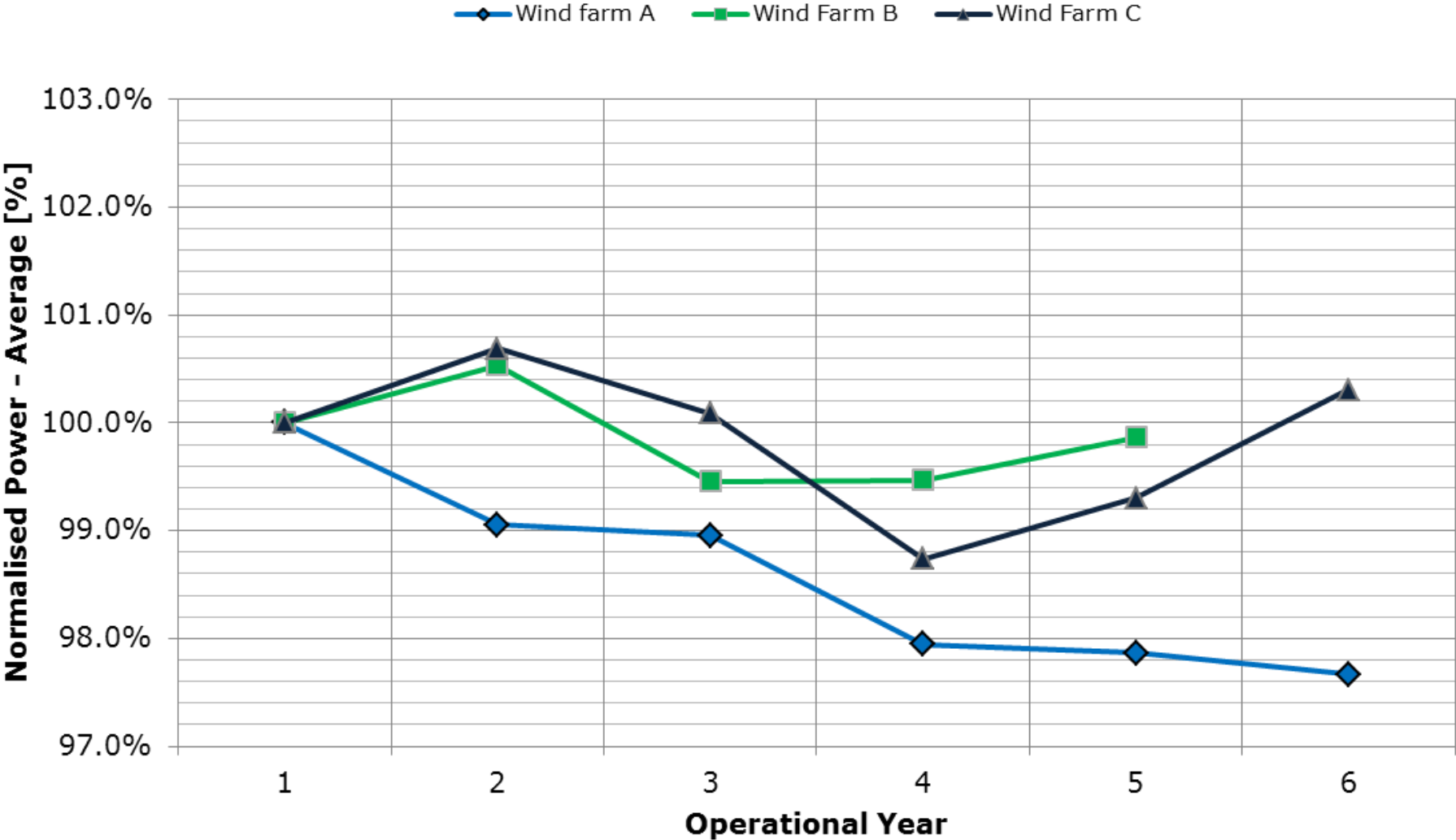
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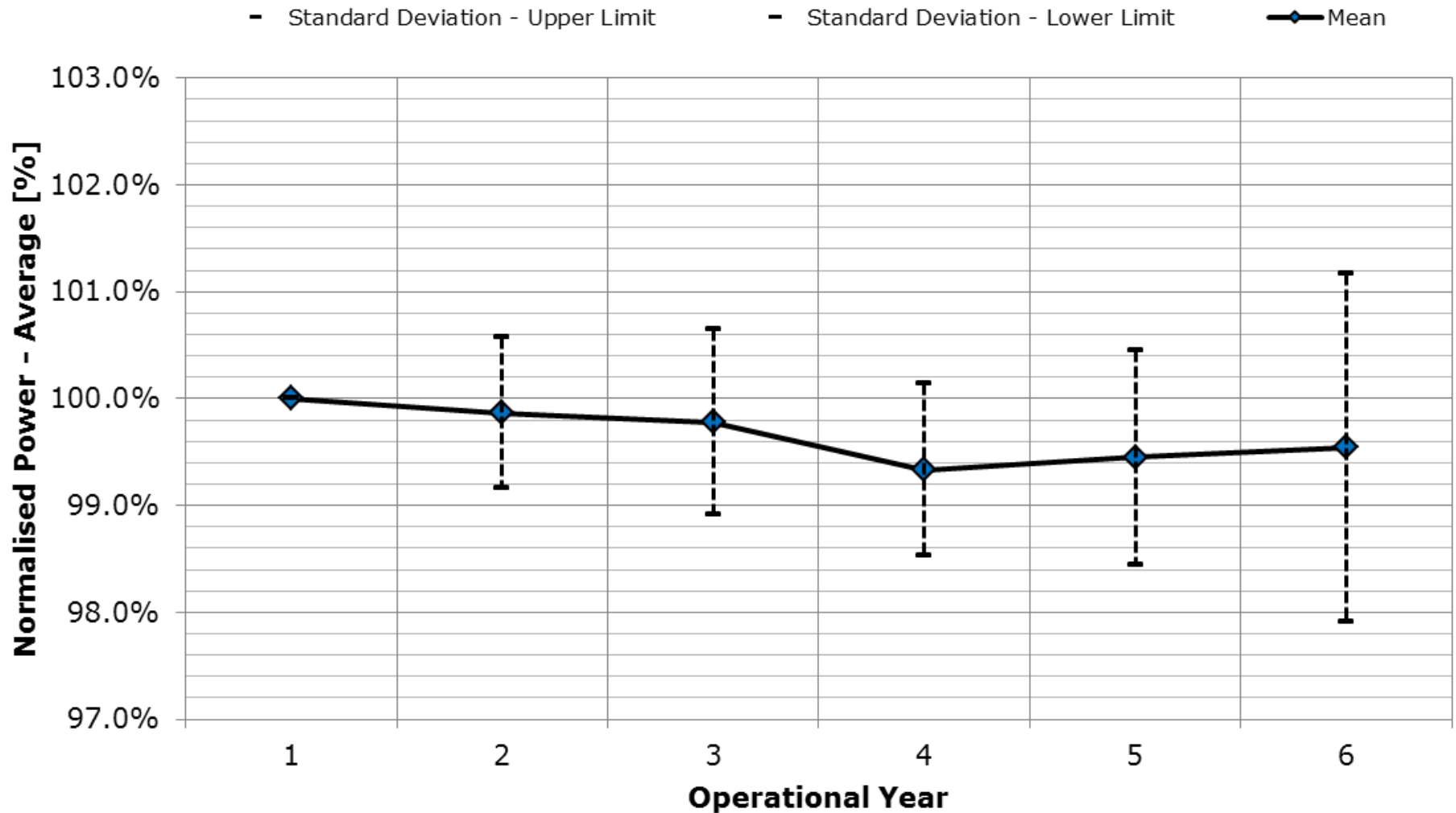
Drive Train Degradation Study - Results



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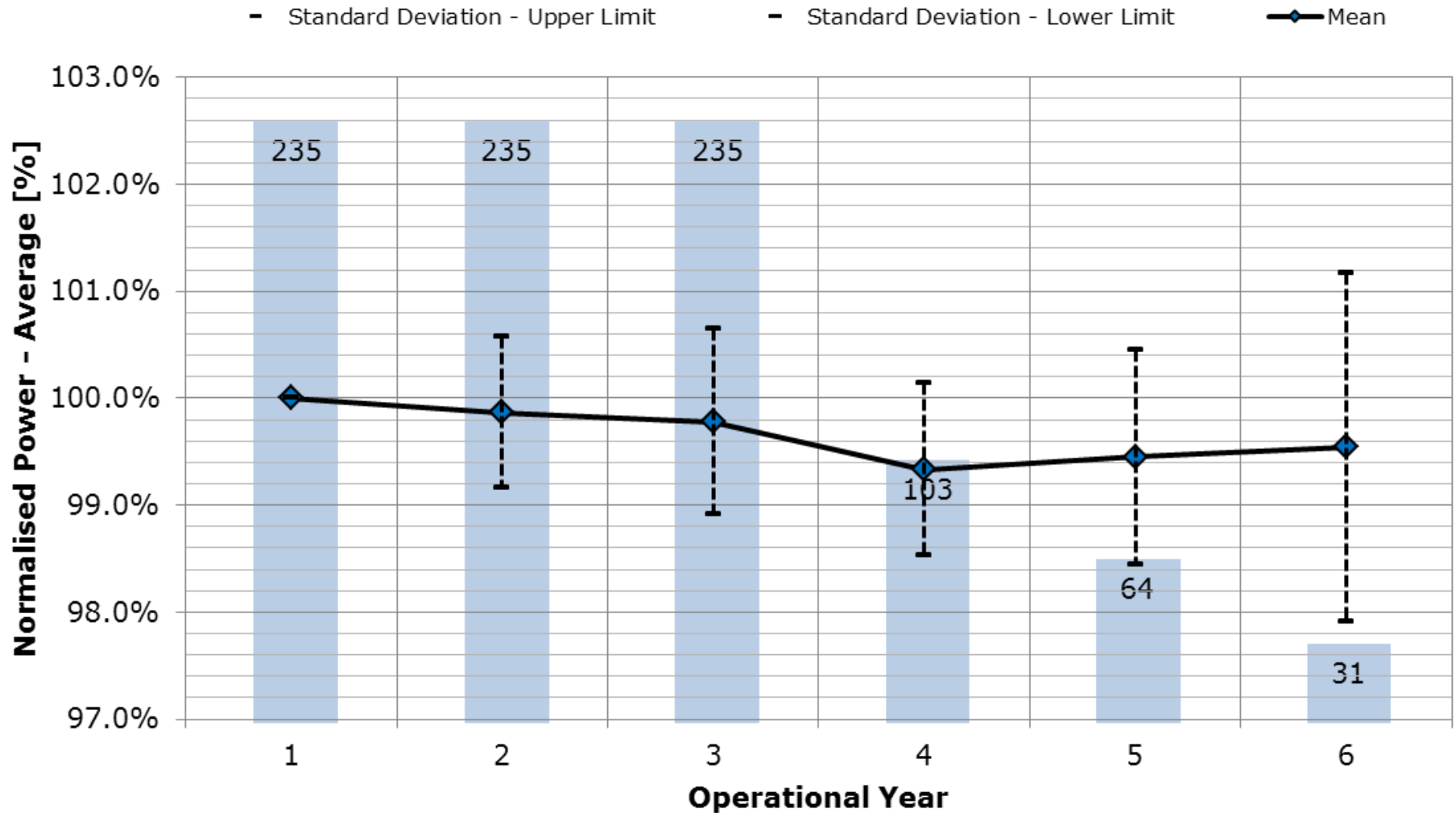
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| Drive train degradation | Typical energy loss | -0.2% / year for the first 5 years |
| | Annual Trend? | Downward trend |

Conclusions and Further Work

Factors affecting turbine performance have been reviewed

Long-Term Degradation Study

- Drive train degradation has been investigated
- 35 wind farms with 235 turbines from across Europe included in the study
- Individual sites show differences, but overall a small downward trend is identified
- -0.2% / year for the first 5 years

Further work

- Can we quantify degradation in individual components?
- What happens after year 5/6?



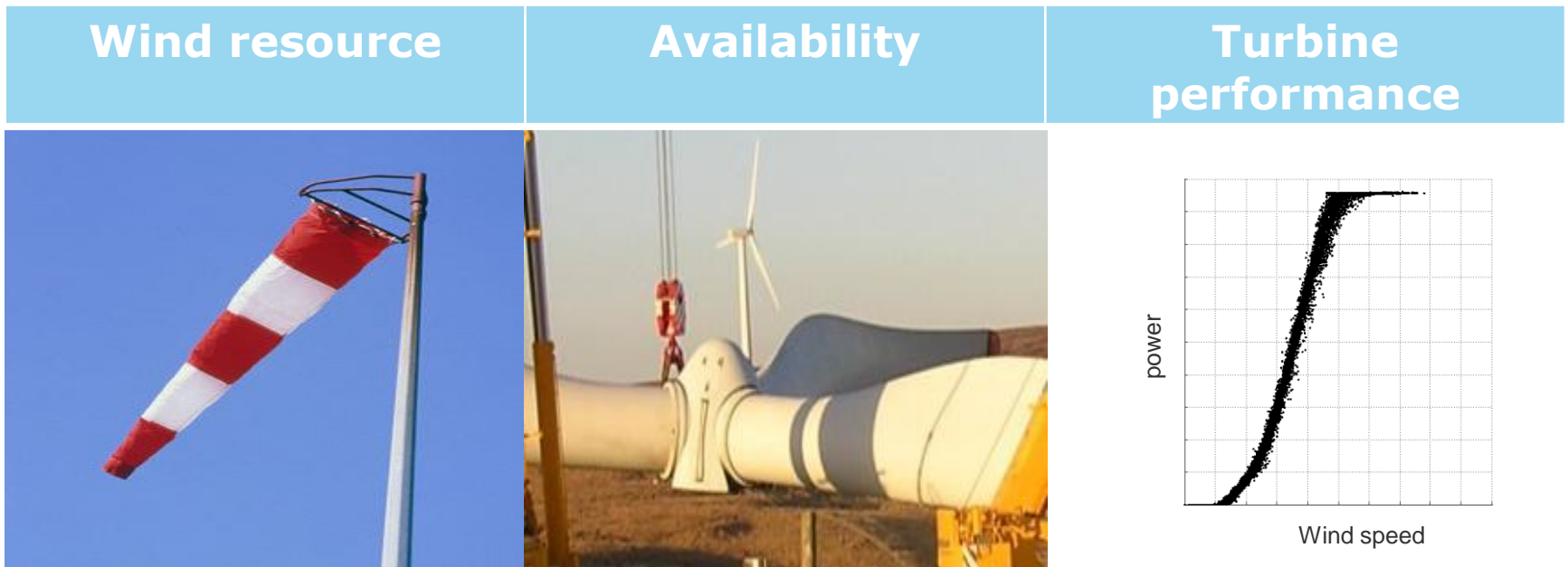
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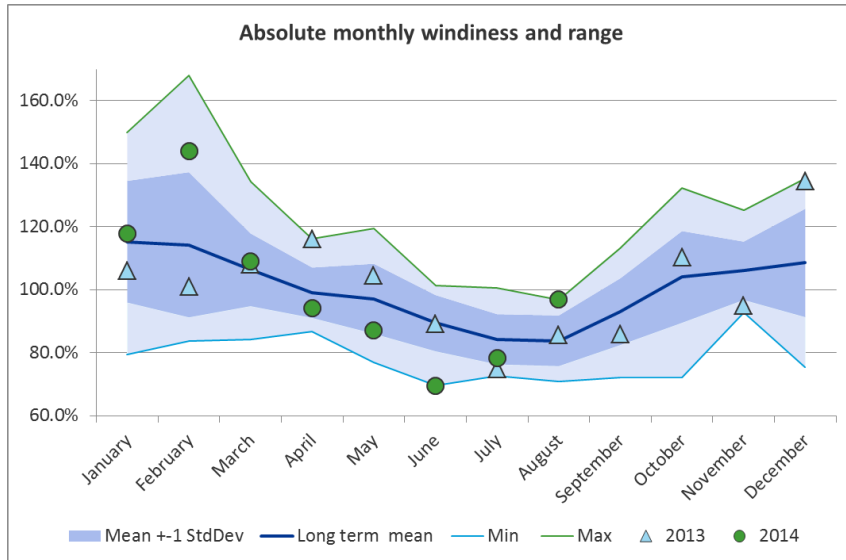
SAFER, SMARTER, GREENER

What could cause production degradation?

- 3 possible elements that could cause degradation of wind farm production over time:

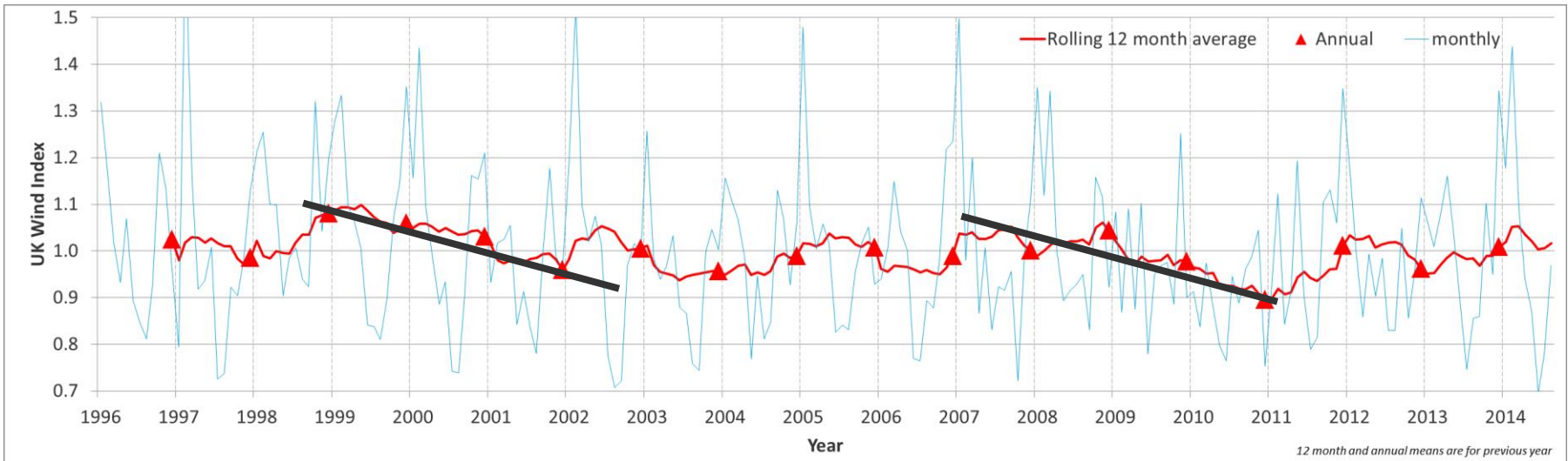


Wind resource

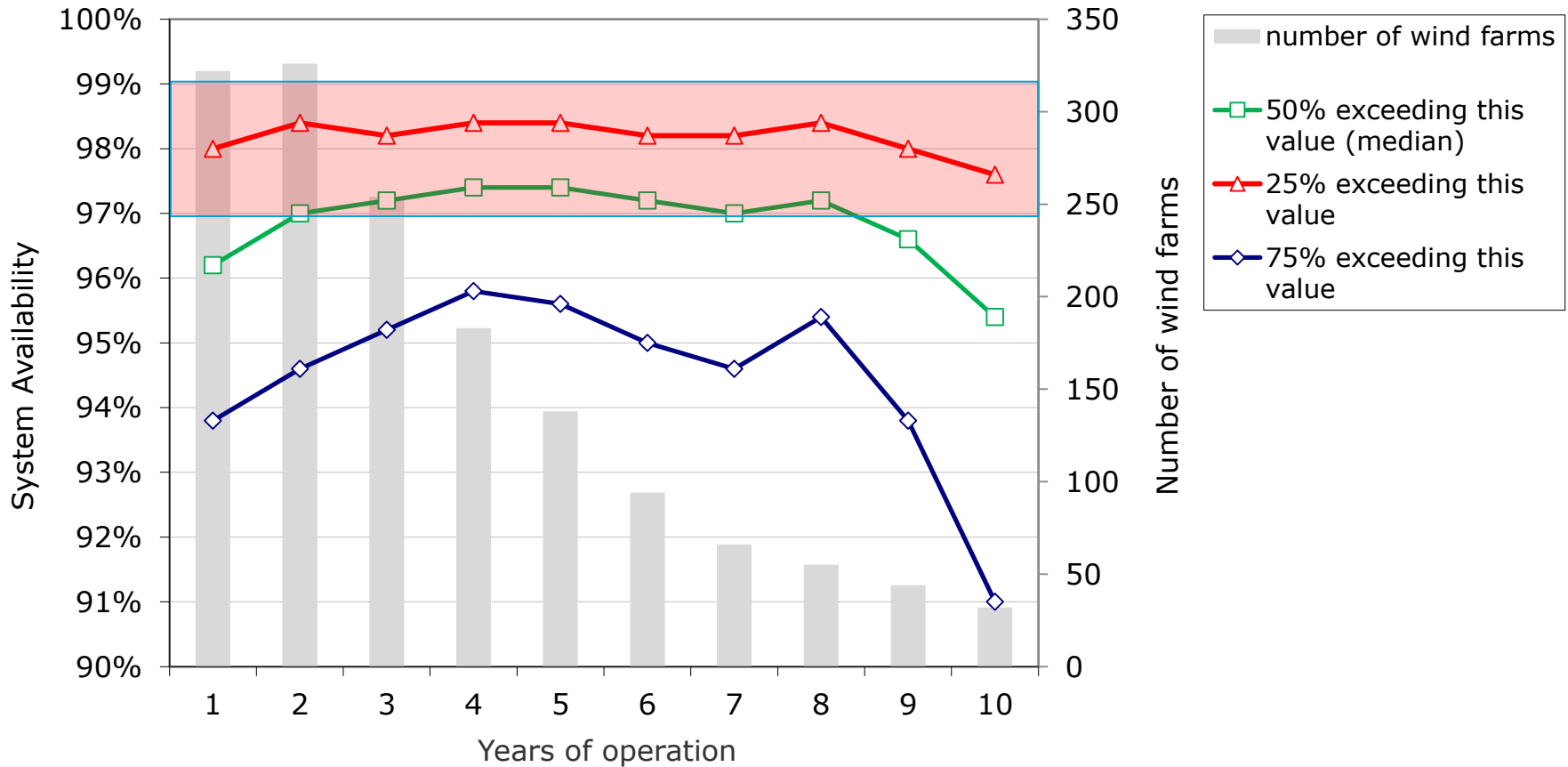


DNV GL Wind Index

- Historical wind data from 1996 to 2014
- 50 meteorological stations spread across the mainland of the UK
- Each station has measured consistent wind speed data for 10 years or more



Availability



Source: Optimising the UK operational fleet in a mature market (Harman et al., Renewable UK 2013)

Database

- Over 300 wind farms across Europe
- Between 1 and 15 years of operation
- >1,500 wind farm years
- All major turbine suppliers to UK represented

Definition

$$\text{System Availability} = \frac{\text{Time ready to operate, or operating}}{\text{Total time}}$$