Introduction to Wind Turbines and their Reliability & Availability

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“*When one recognises how much the sum of our ignorance exceeds that of our knowledge, one is less likely to draw rapid conclusions.*”
Louis de Broglie

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Overview

- Wind Conditions, Turbine Taxonomy & Technology
- Basic reliability
- Wind power Cost of Energy, Availability and Reliability
- What we know about wind turbine Availability & Reliability Onshore & Offshore
- Conclusions

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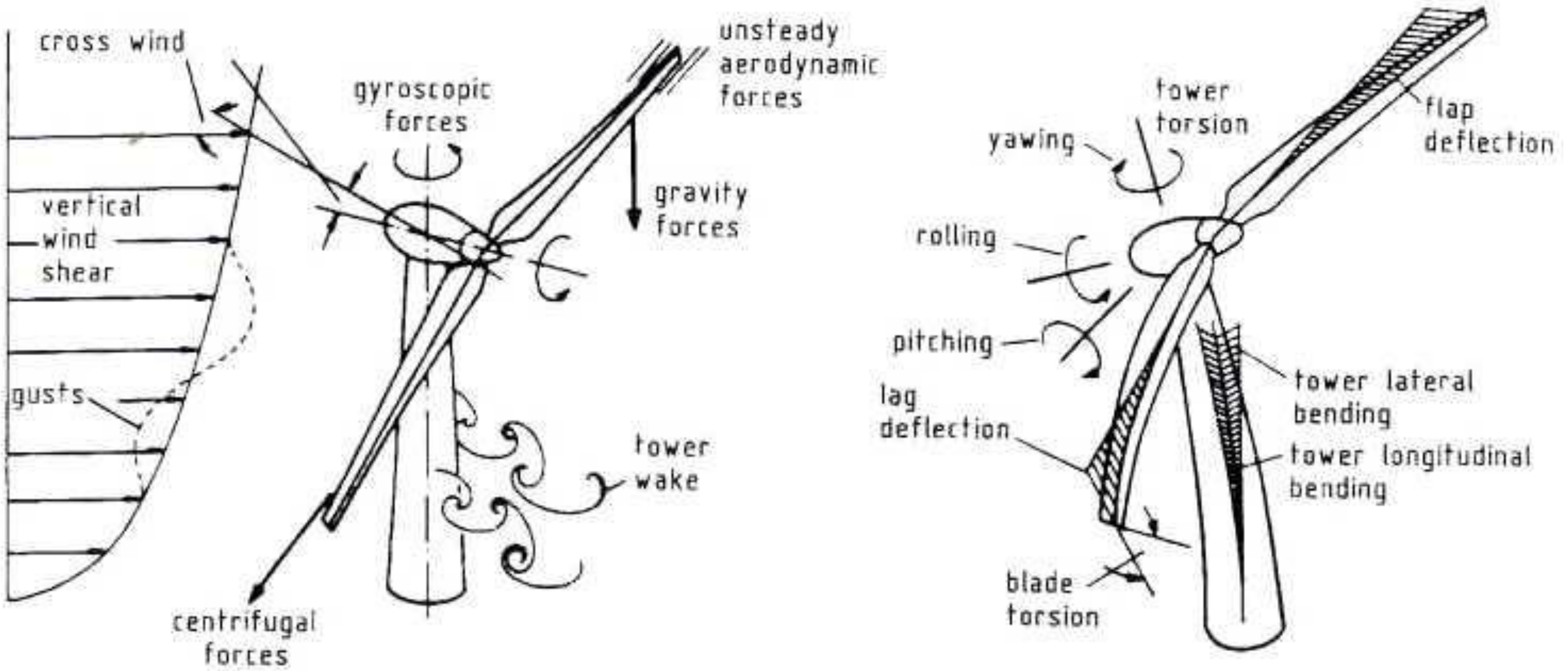
Wind Conditions
Turbine Taxonomy
& Technology

Variation of turbine forces, time & space
Turbulent forces



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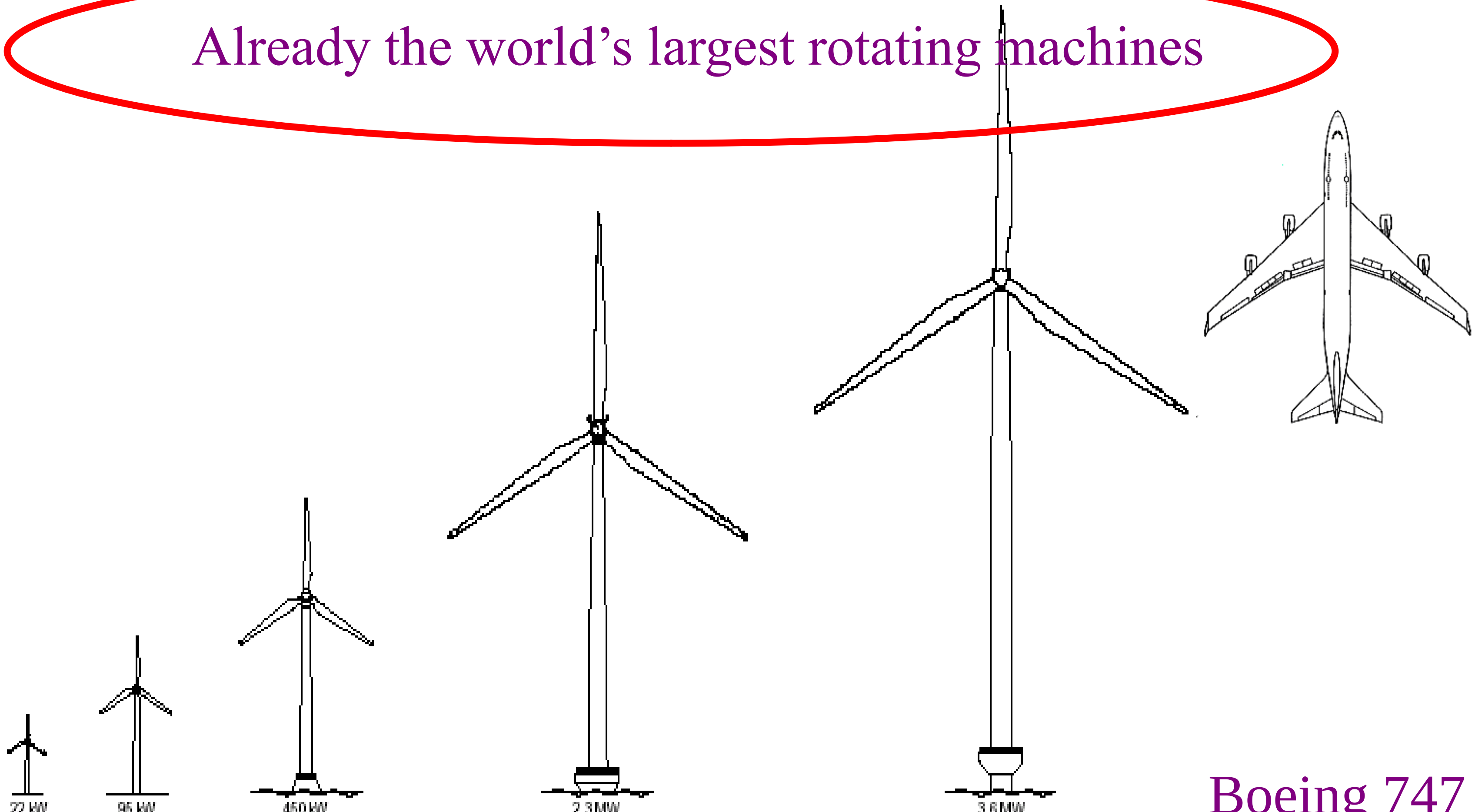
Scale

Already the world's largest rotating machines



Boeing 747

22 kW **95 kW** **450 kW** **2.3 MW** **3.6 MW**

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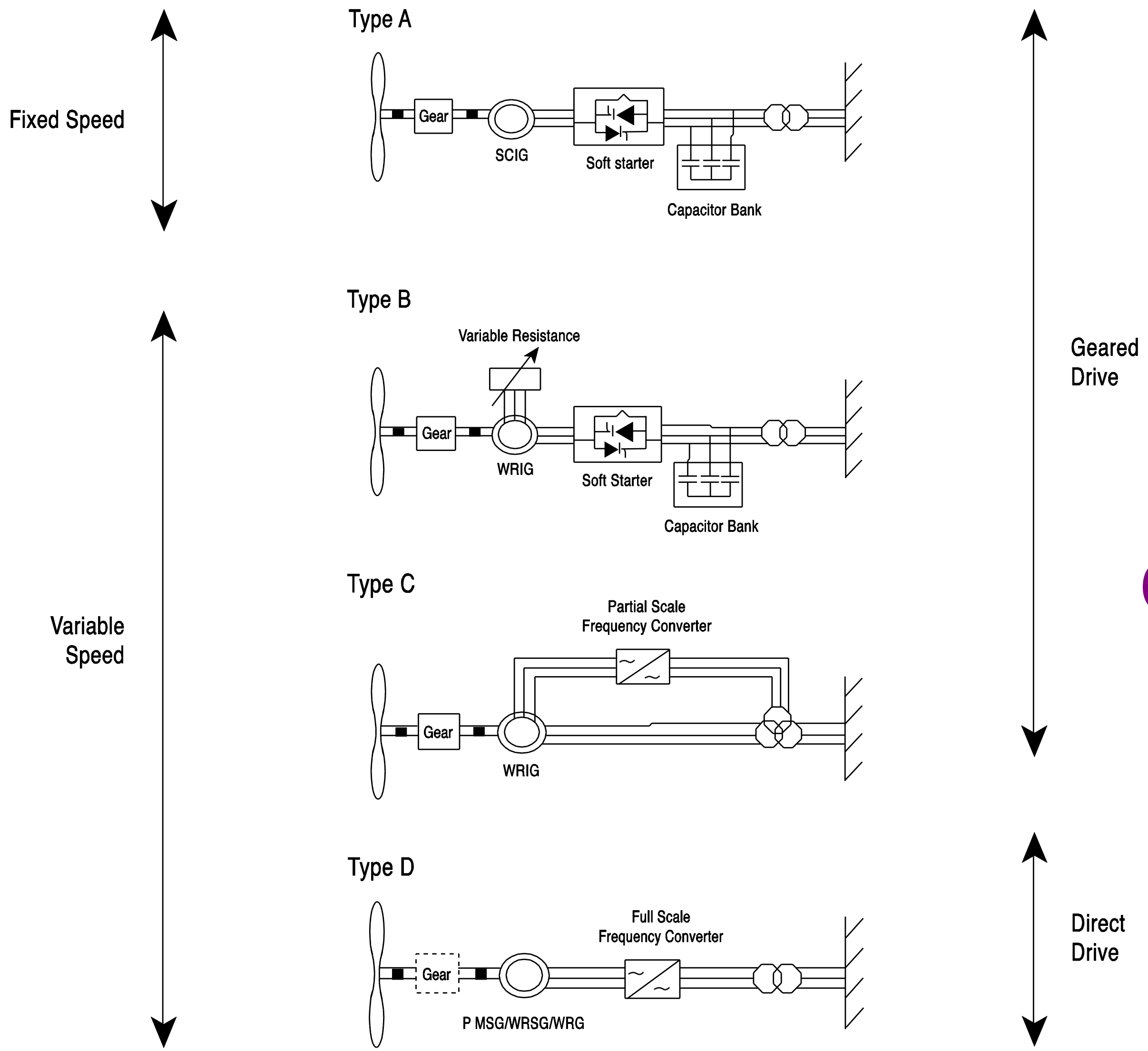
Wind Turbine Configurations



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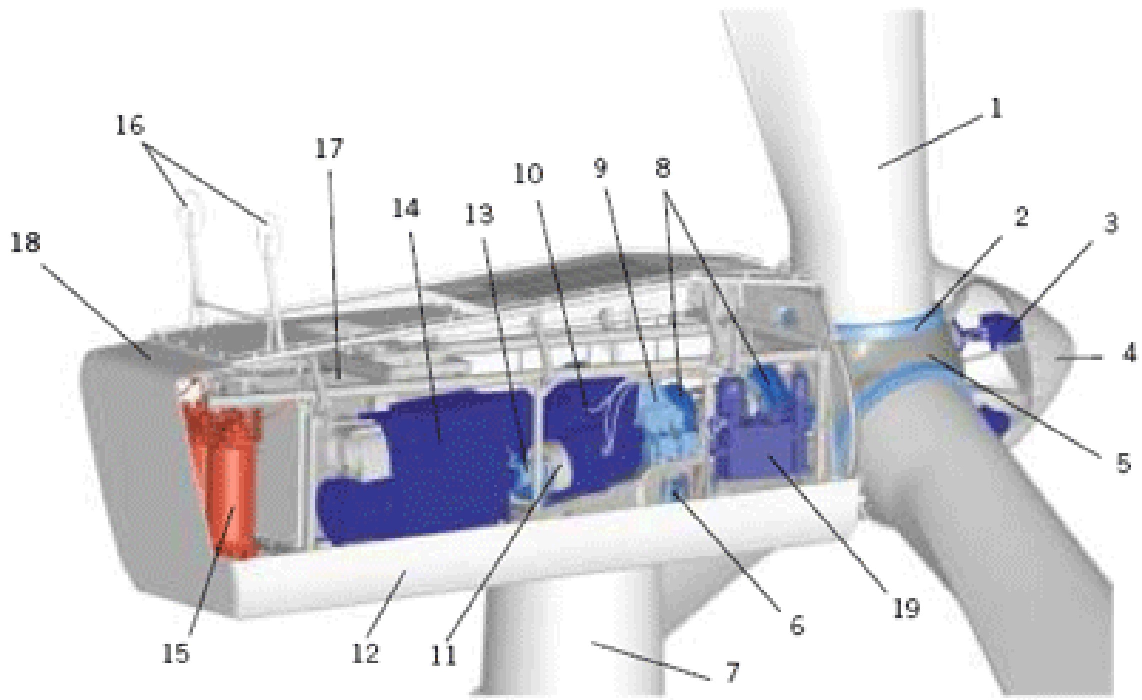
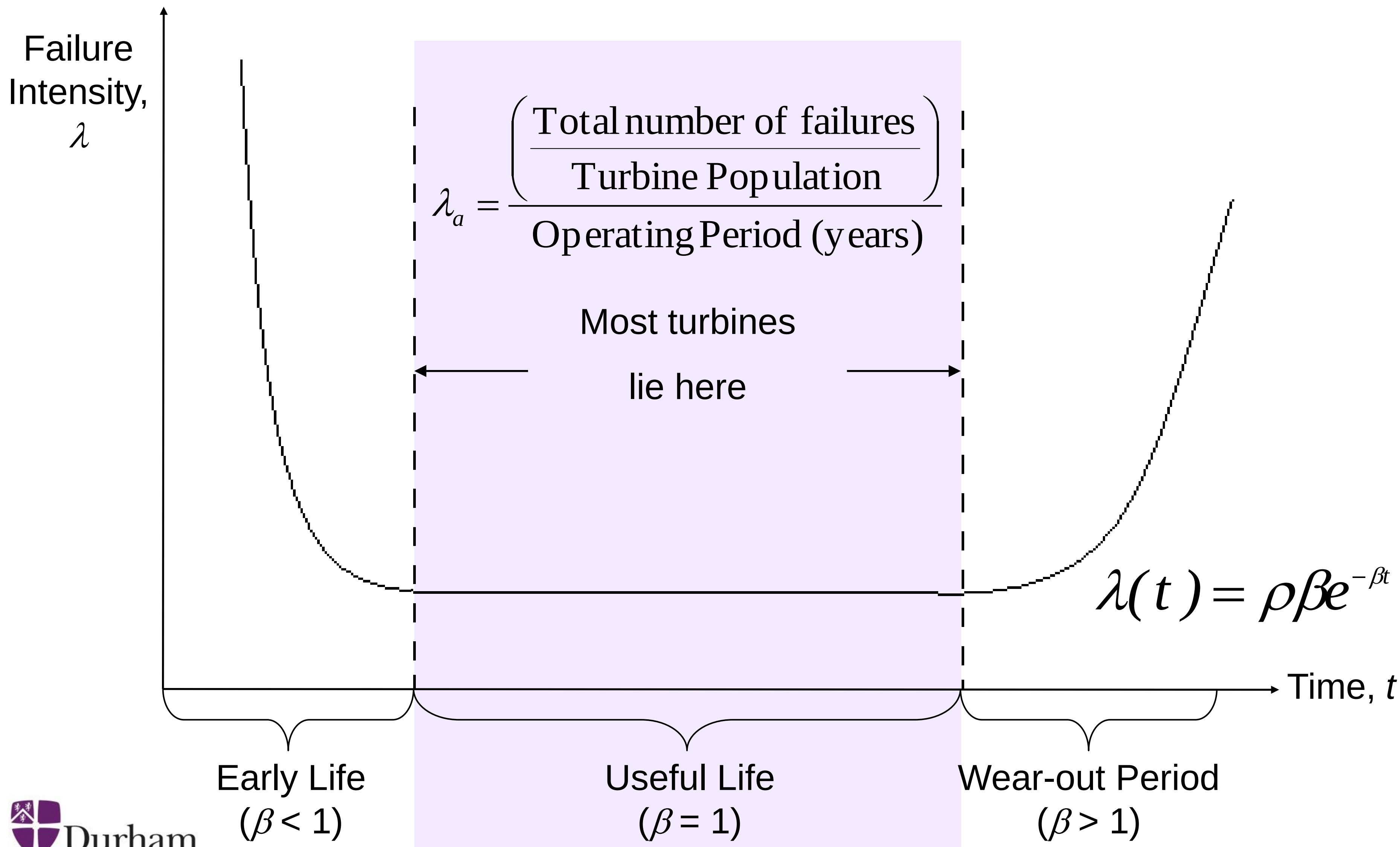
Geared Drive Wind Turbine, R80



Basic Reliability

The Bathtub Curve

ReliaWind



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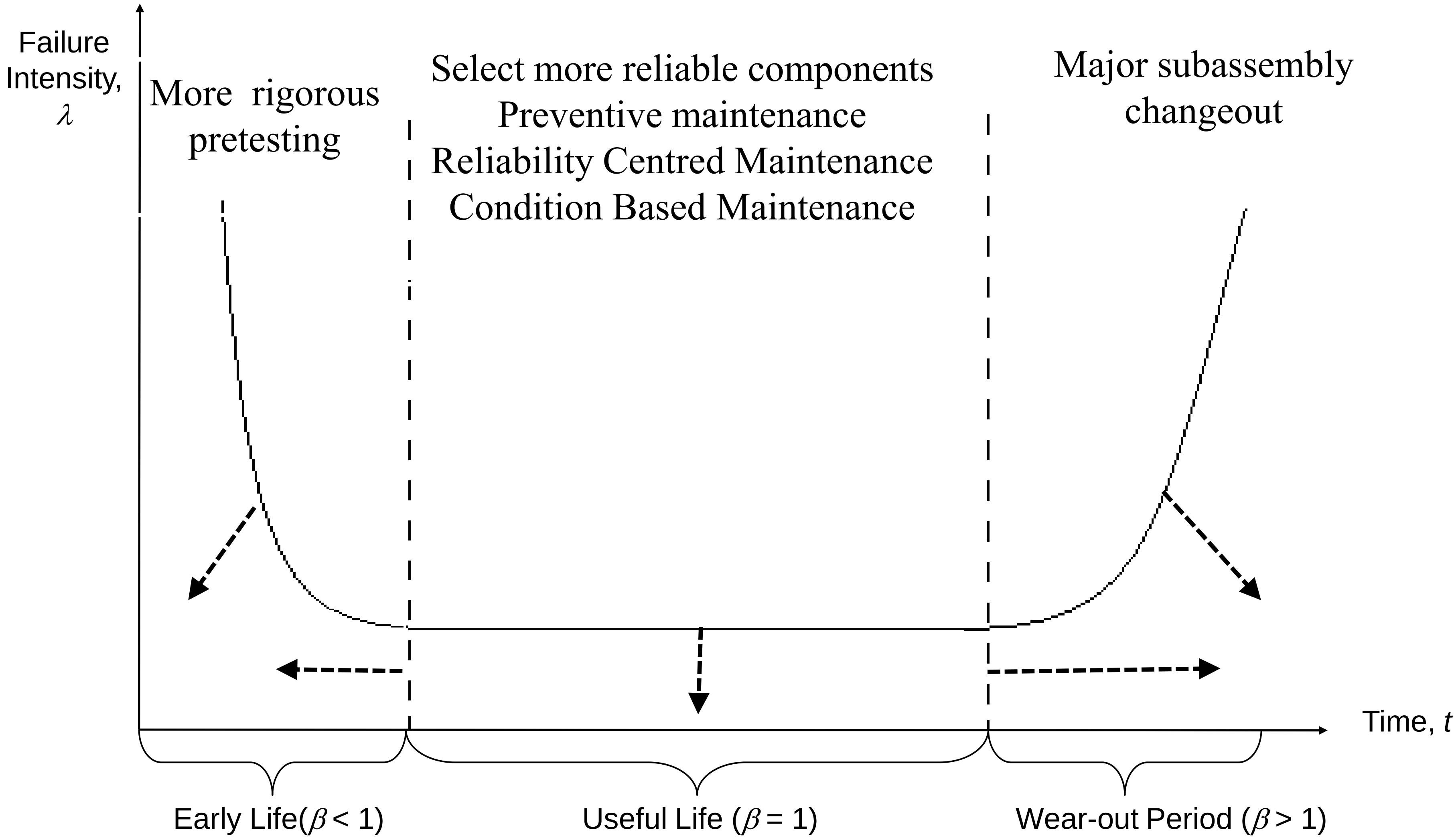
The Bathtub Curve



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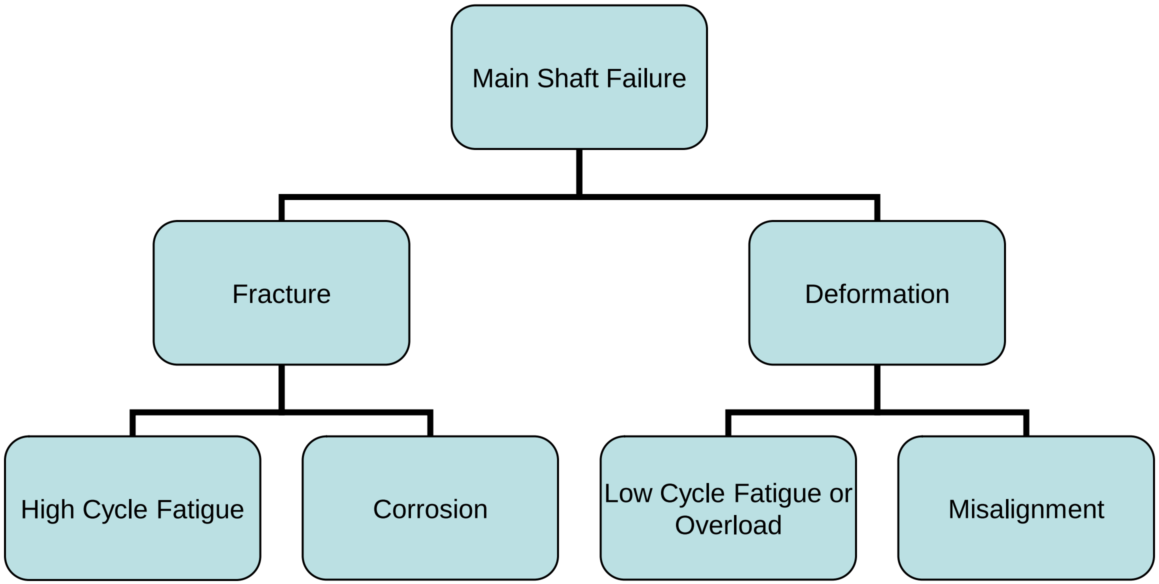
Root Causes & Failure Modes Example: Main Shaft Failure

Failure Mode

Why?

Root Cause Analysis



Root Causes

How?

SCADA

Analysis

CM

& Diagnosis

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Wind Power Cost of Energy, Capacity Factor and Availability

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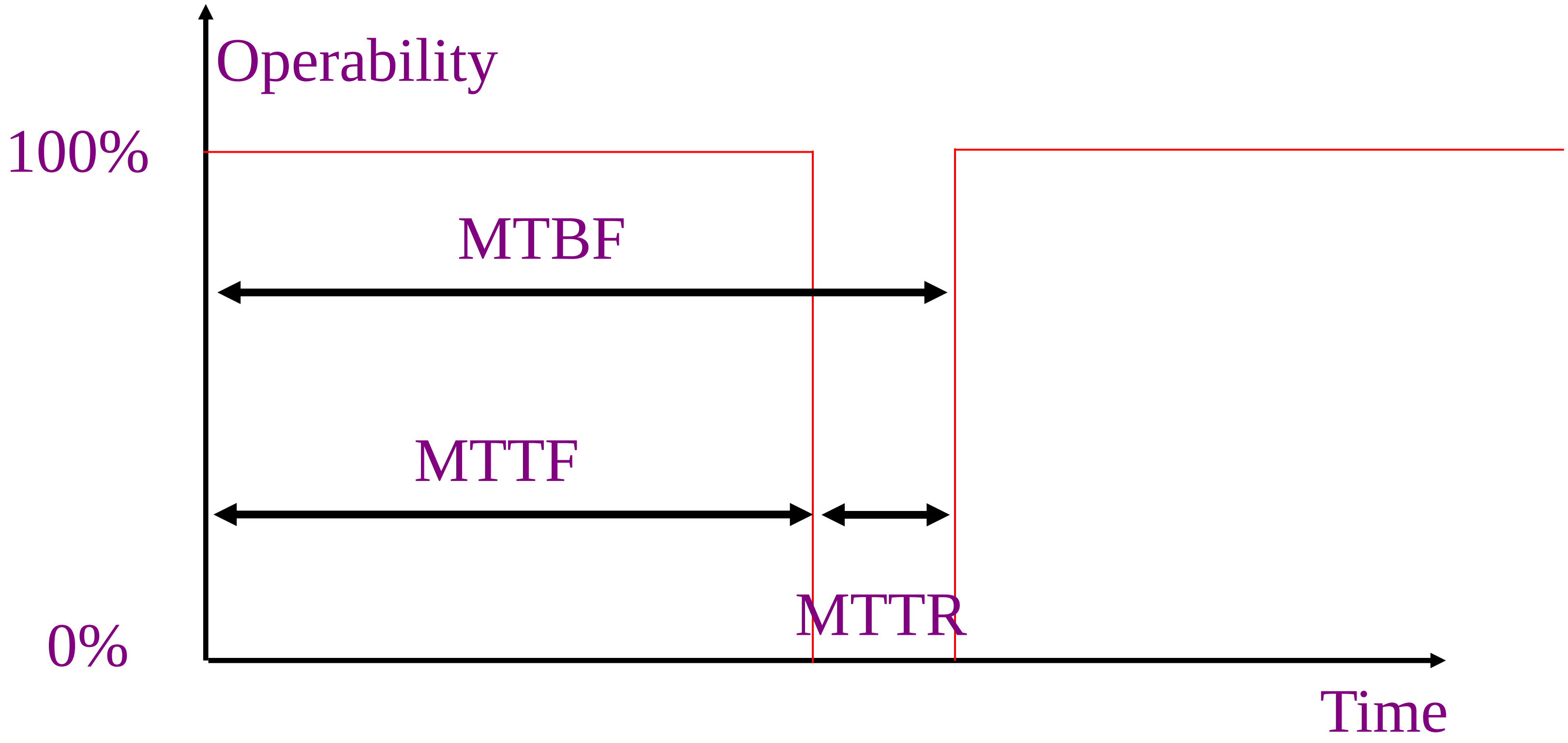
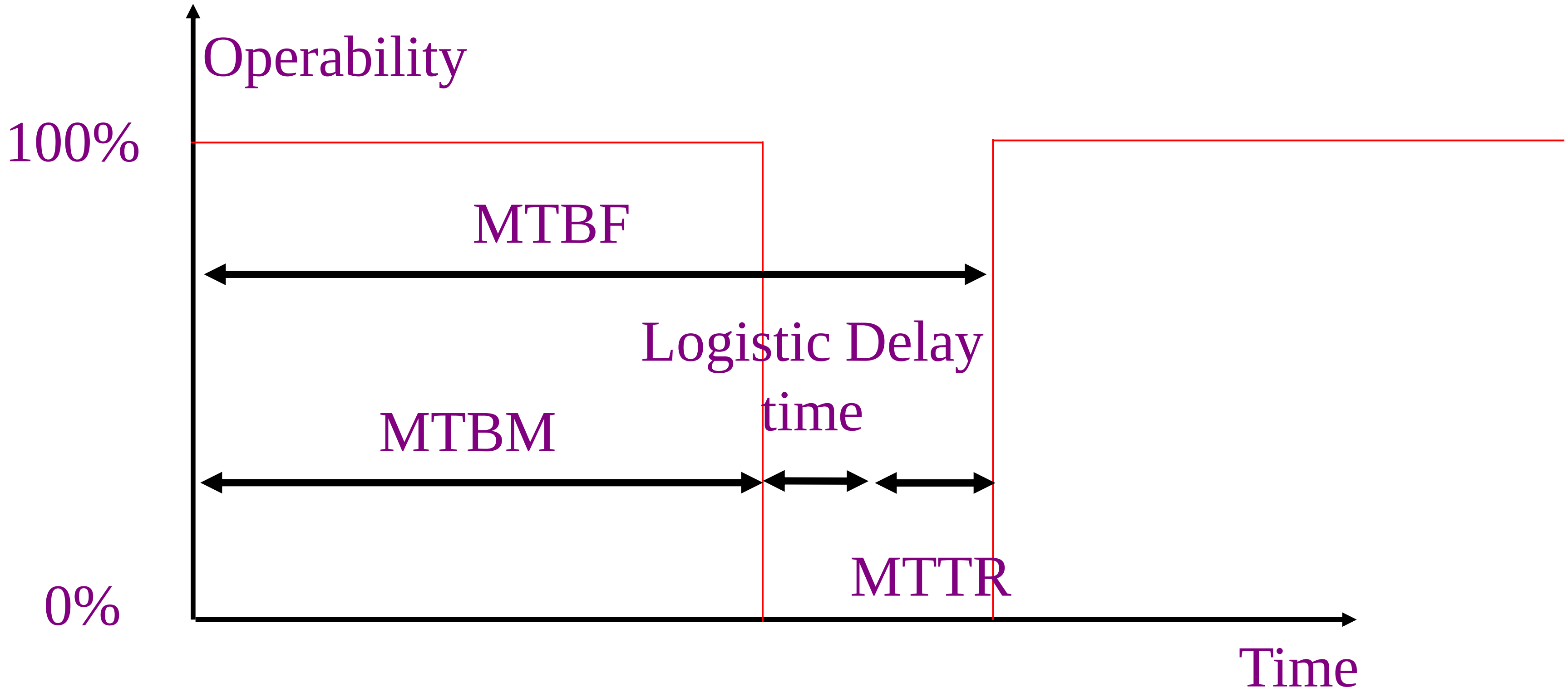
Availability, Inherent



Availability, Operational



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Availability & Reliability

- Mean Time To Failure, *MTTF*
- Mean Time to Repair, or downtime *MTTR*
- Mean Time Between Failures,

$$MTBF \approx MTTF$$

$$MTBF \approx MTTF + MTTR = 1/\lambda + 1/\mu$$

$$MTBF = MTTF + MTTR + LogisticDelay\ Time$$

- Failure rate, λ $\lambda = 1/MTBF$
- Repair rate, μ $\mu = 1/MTTR$
- **Inherent Availability,**

$$\boldsymbol{A = (MTBF - MTTR)/MTBF = 1 - (\lambda/\mu)}$$

- **Operational or Technical Availability,**

$$\boldsymbol{A = MTTF/MTBF < 1 - (\lambda/\mu)}$$

- Typical UK values
  - Operational Availability 97%,
  - Inherent Availability 98%

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Capacity Factor

- *Energy generated in a year= C x Turbine rating x 8760*
- Capacity Factor, *C*
- 8760 number of hours in a year
- Therefore:
- *C=Energy generated in a year/ Turbine rating x 8760*
- *C* incorporates the Availability, *A*, and therefore the MTBF, $1/\lambda$
- Typical UK values
  - Onshore, *C* 27.3%
  - Early offshore, *C* 29.5%
- Typical EU values
  - Offshore, C 35%

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Cost of Energy, *COE*

- *COE, £/kWh=*

  $$(ICC \times FCR + O\&M)/AEP$$

  - *ICC*=Initial Capital Cost, £
  - *FCR*=Fixed Charge Rate, interest, %
  - *O&M*=Annual Cost of Operations & Maintenance, £
  - *AEP*=Annualised Energy Production, kWh
- *COE , £/kWh =*

  $$(ICC \times FCR + O\&M(1/\lambda, 1/MTTR))/AEP(A(1/\lambda, 1/MTTR)\}$$

- Reduce failure rate λ, Reliability MTBF $1/\lambda$ improve and Availability *A* improve, O&M cost reduces;
- Reduce Downtime MTTR, Availability *A* improve, O&M cost reduces;
- Therefore *COE*, reduces

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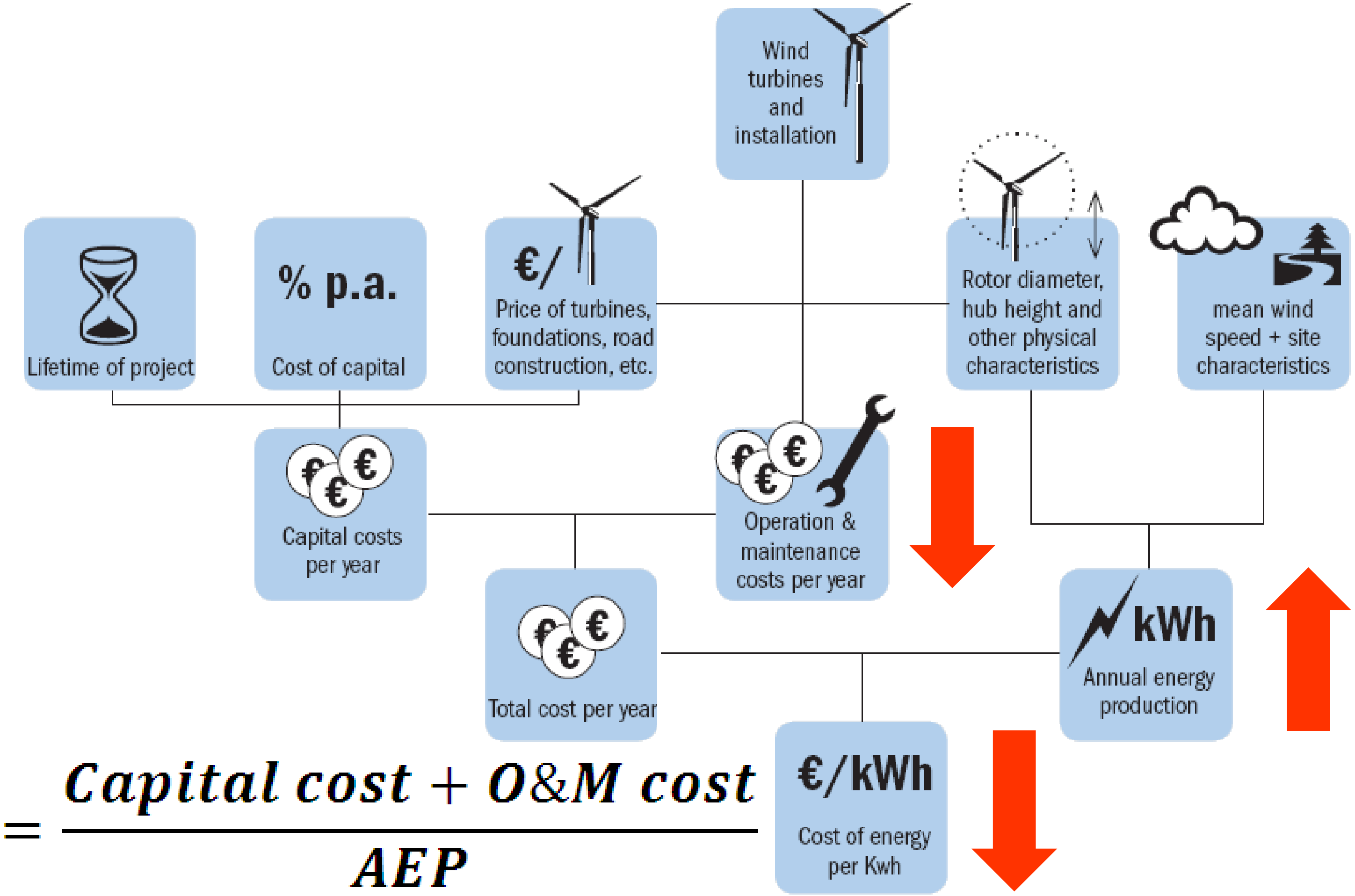
Impact of the Reliability on *COE*



$$COE = \frac{Capital\ cost + O\&M\ cost}{AEP}$$

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What we know about wind turbine Reliability

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Sources of Failure Data

- Eurowin data
- EPRI data from California
- Windstats data from Germany and Denmark
- LWK data from Germany
- WMEP data from Germany
- Data from UK Round 1 offshore wind farms
- Data now coming from RELIAWIND WP 1, see later

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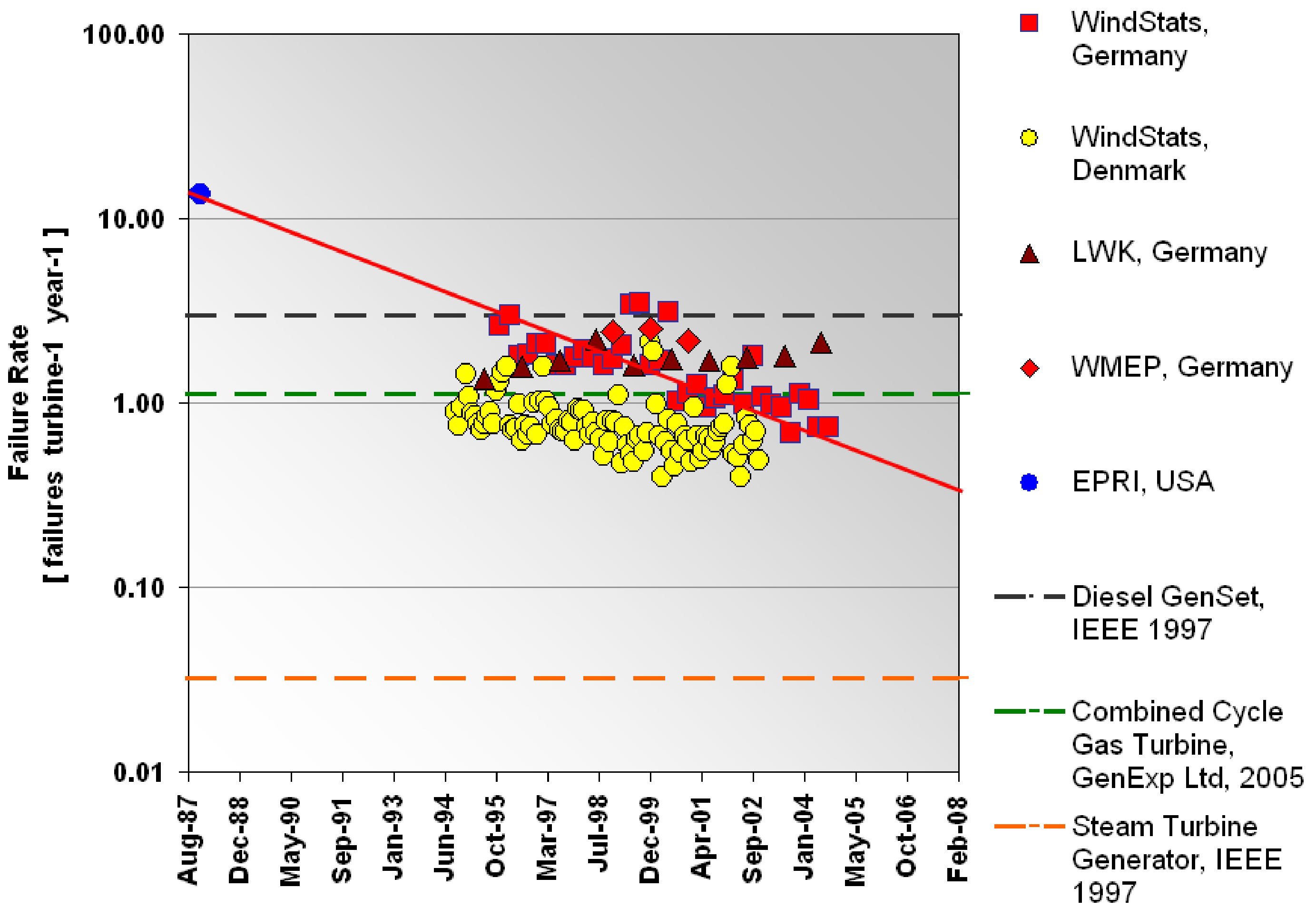
Trend in Turbine Failure Rates with time



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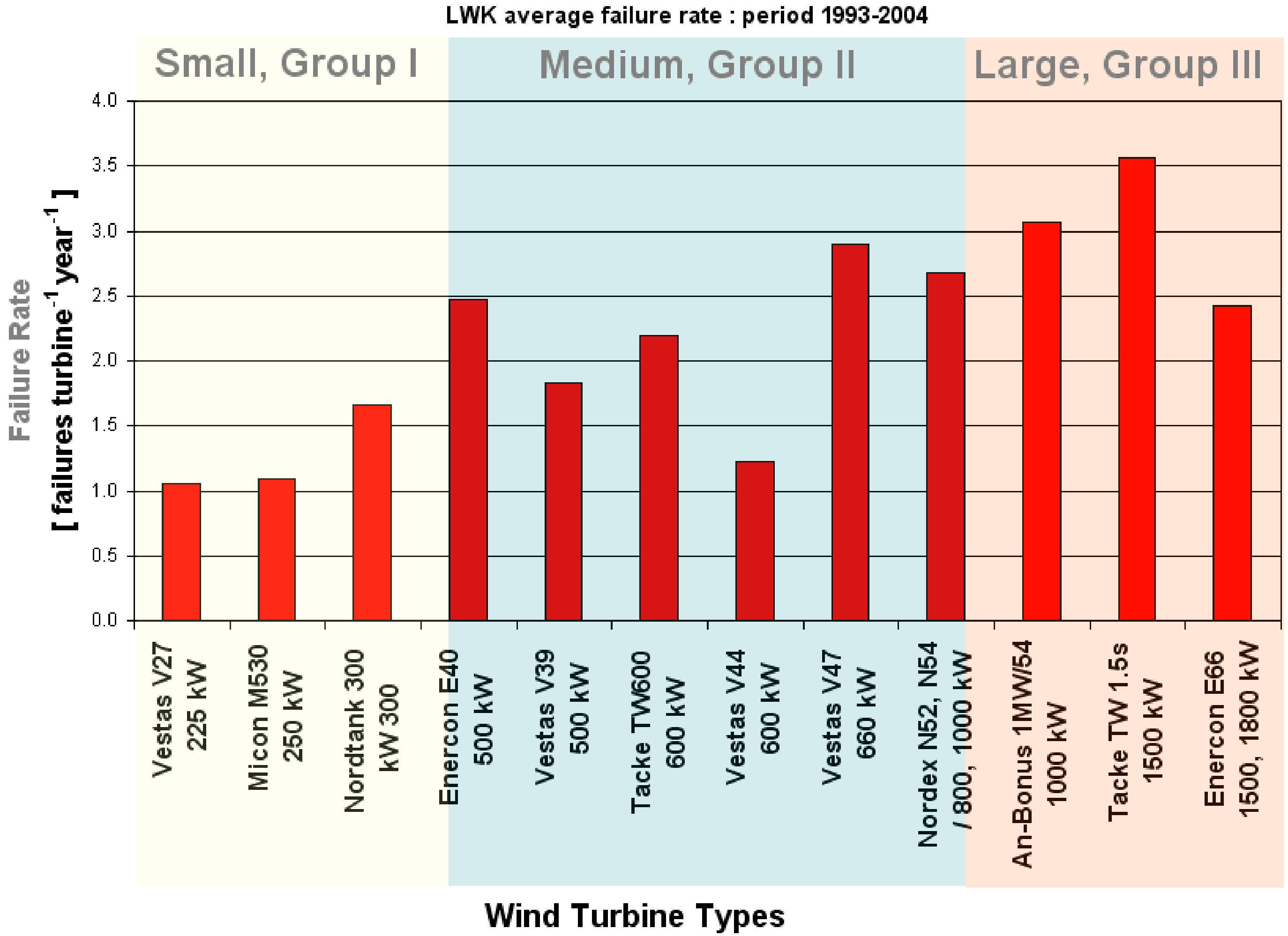
Reliability & Size, EU



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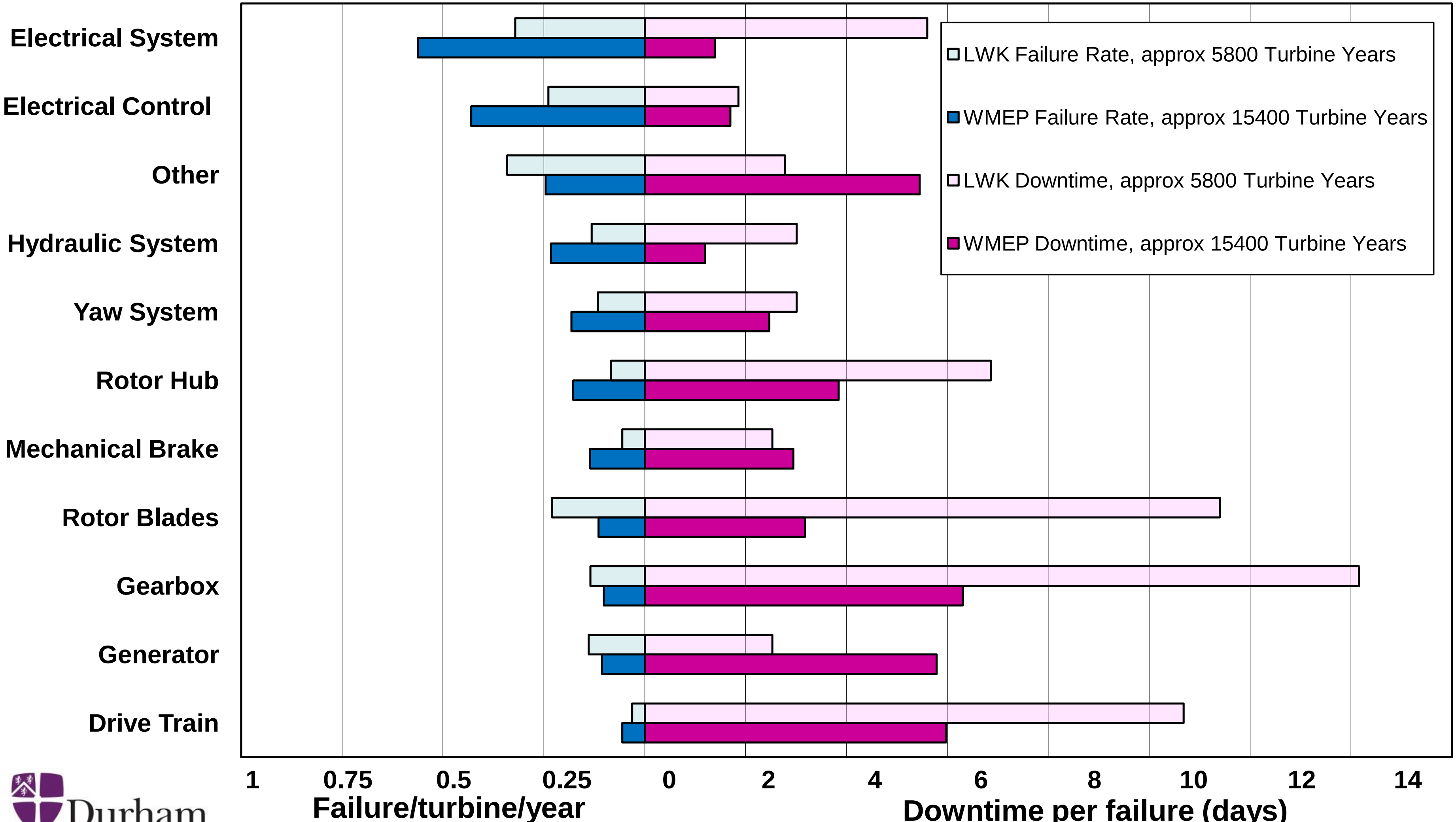
Reliability & Downtime & Subassemblies, EU

Failure/turbine/year and Downtime from 2 Large Surveys of European Wind Turbines over 13 years



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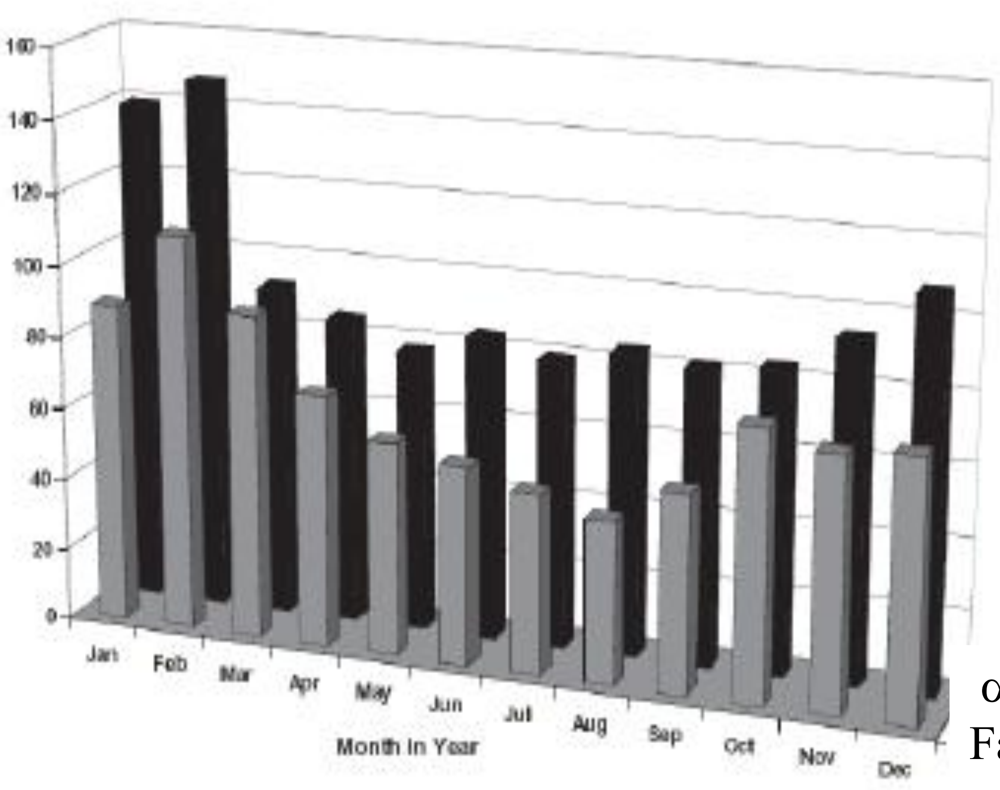
Reliability & Weather, WS DK



αWind Speed
Failure Rate

Figure 3 - Average monthly Failure Rate and WEI for each of the 12 months over the Survey period 1994-2004[7]

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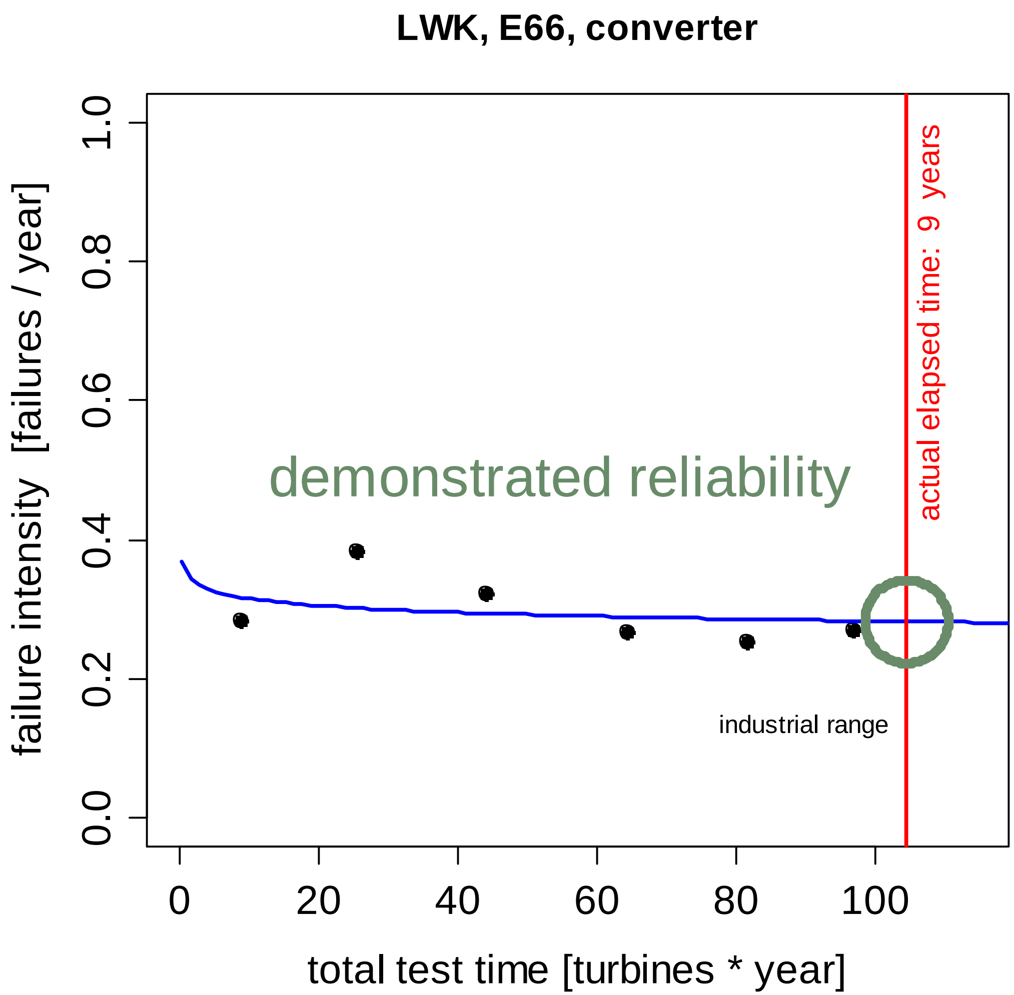
Reliability & Time, LWK



Reliability & Time, LWK Generators

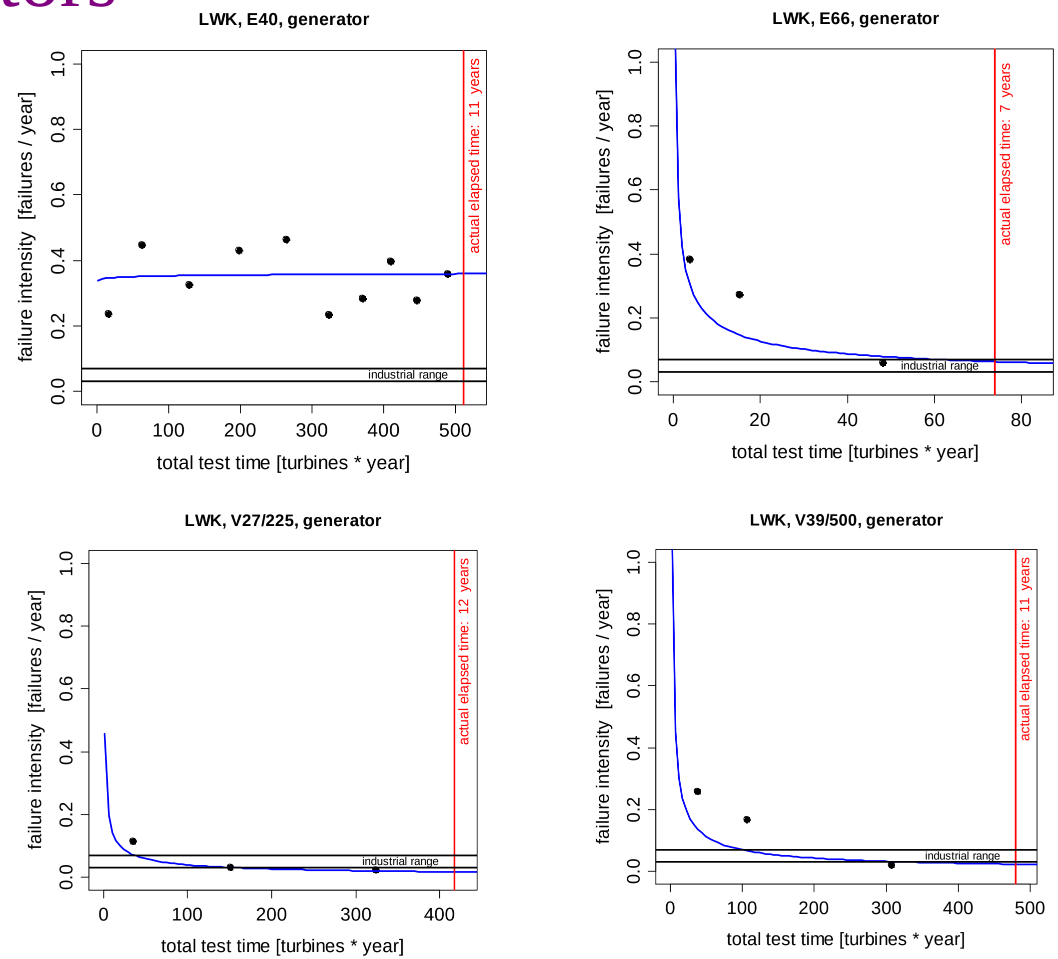


Figure 4.4: Variation between the failure rates of generator subassemblies, in the LWK population of German WTs, using the PLP model.
The upper two are low speed direct drive generators while the lower two are high speed indirect drive generators.

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Reliability & Time, LWK Gearboxes

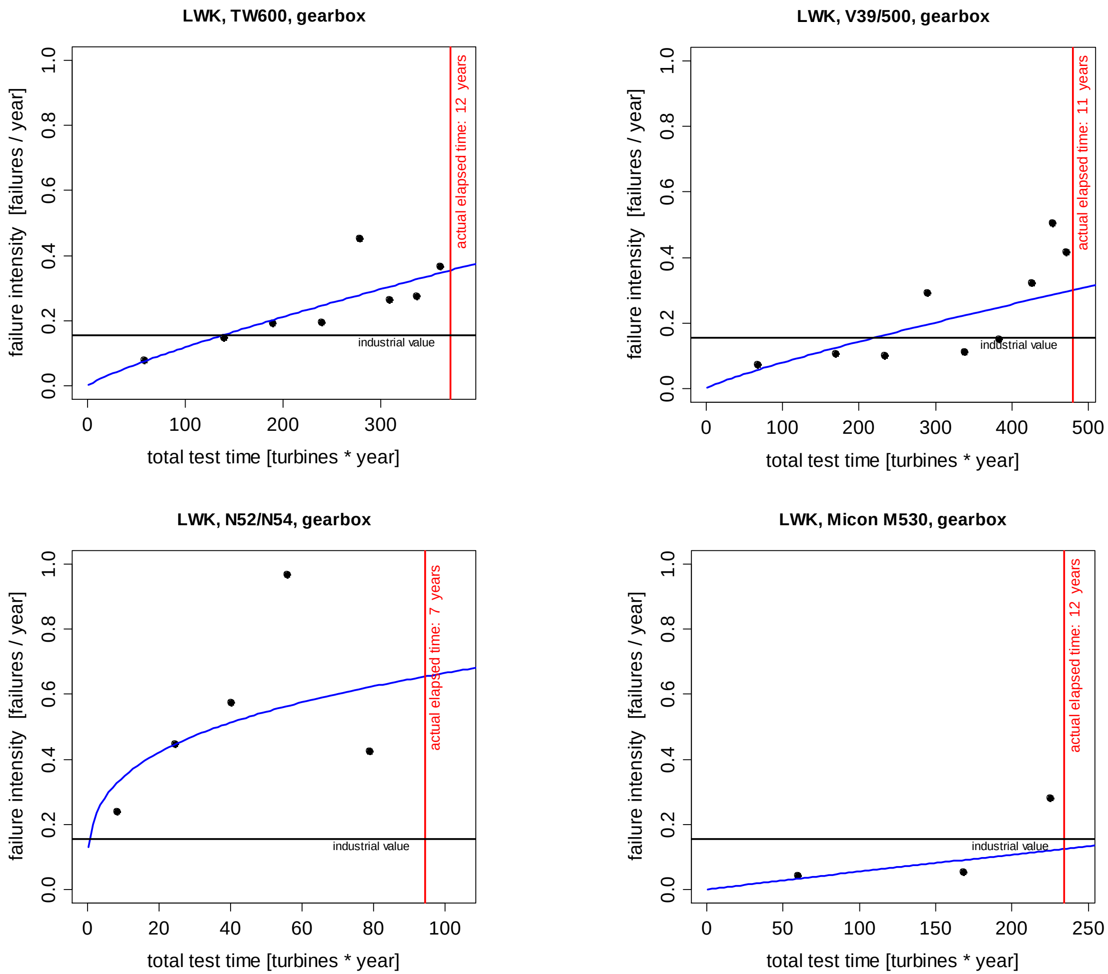

Figure 4.5: Variation between the failure rates of gearbox subassemblies, using the PLP model, in the LWK population of German WTs.

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Reliability & Time, LWK Electronics

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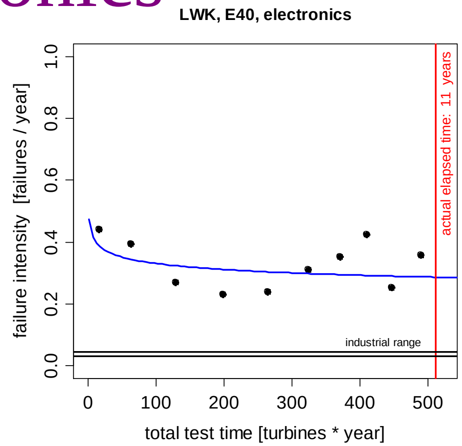

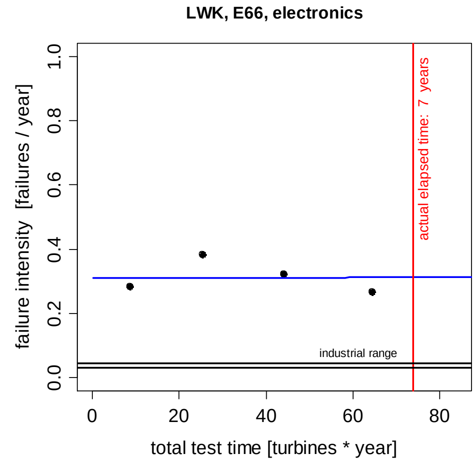

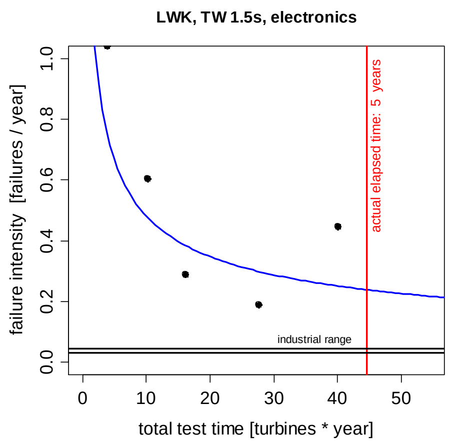

Figure 4.6: Variation between the failure rates of electronics subassemblies, or converter, using the PLP model, in the LWK population of German WTs.

The upper two are low speed direct drive generators with fully rated converters while the lower two are high speed indirect drive generators with partially rated converters.

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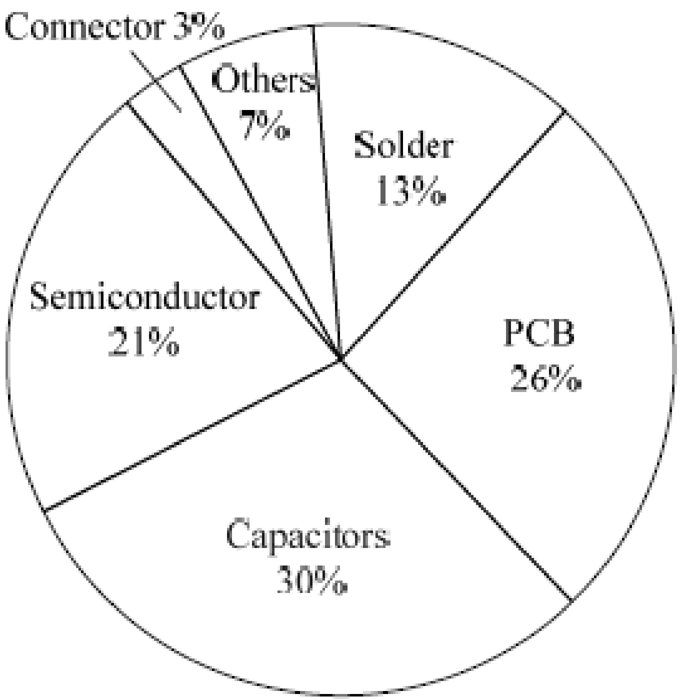
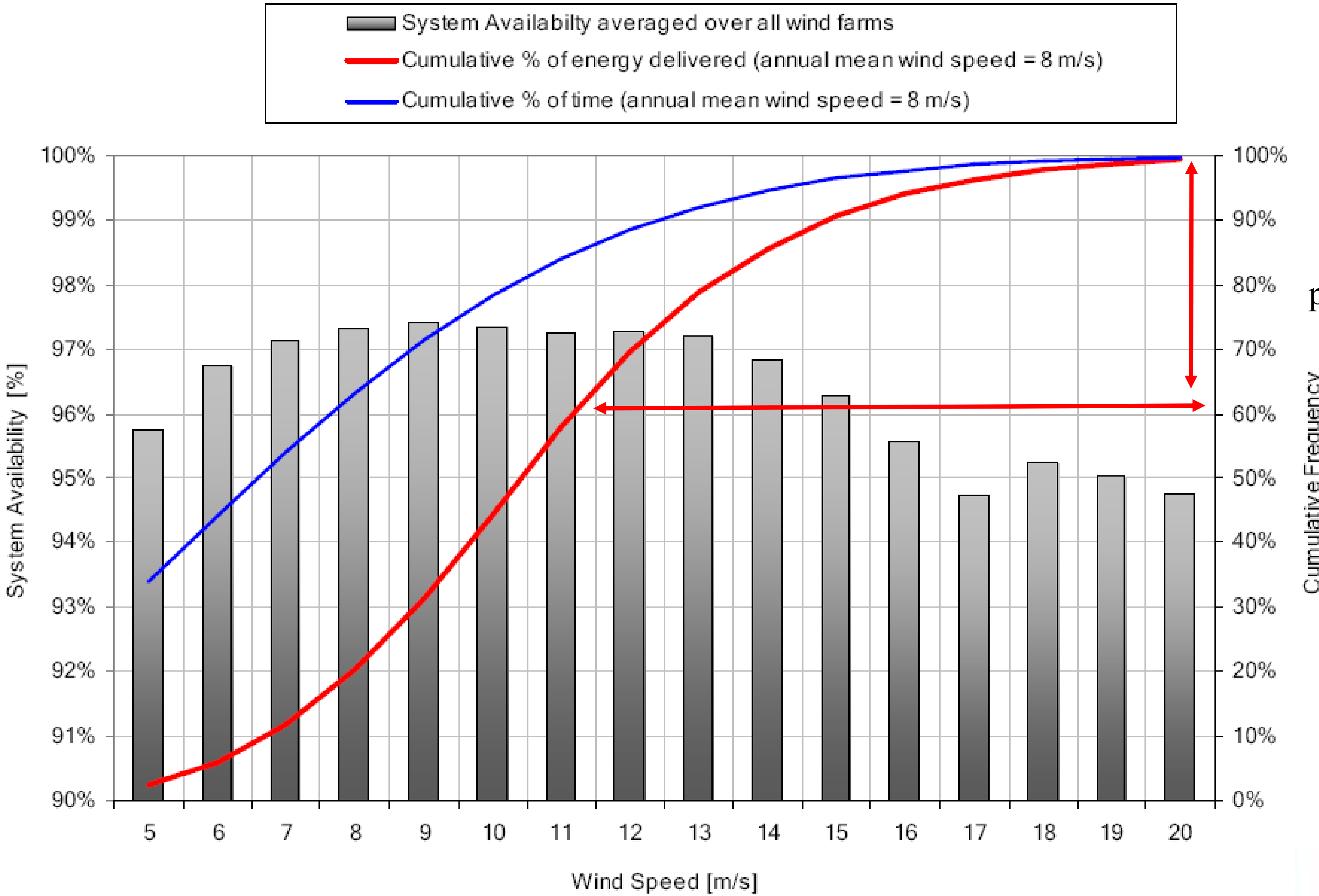
Reliability of Power Electronics



Failure root cause distribution for power electronics from E Wolfgang, 2007

Onshore Availability & Wind speed, World



40% energy produced at wind speeds >11m/s

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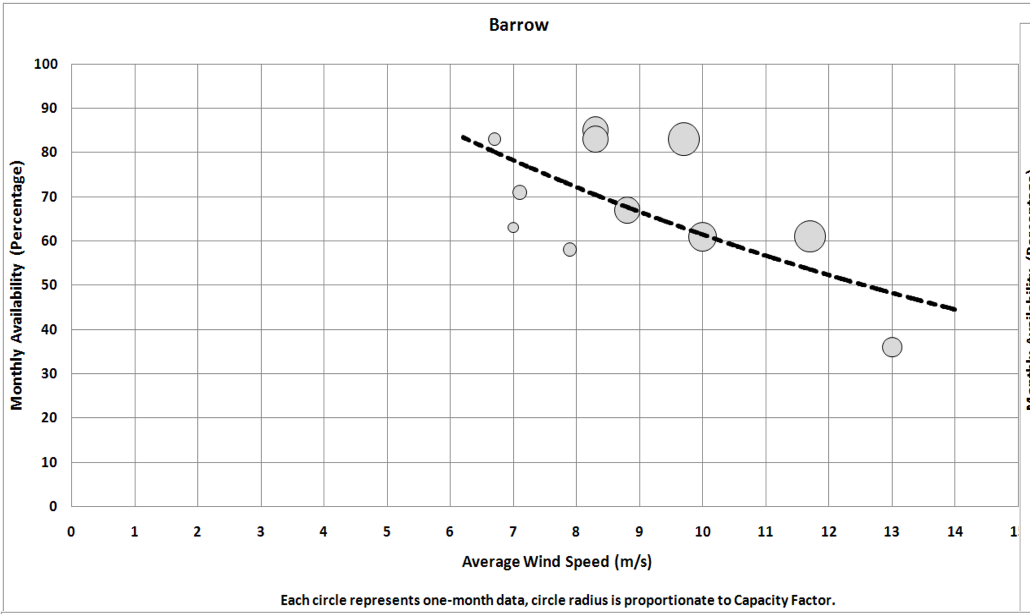
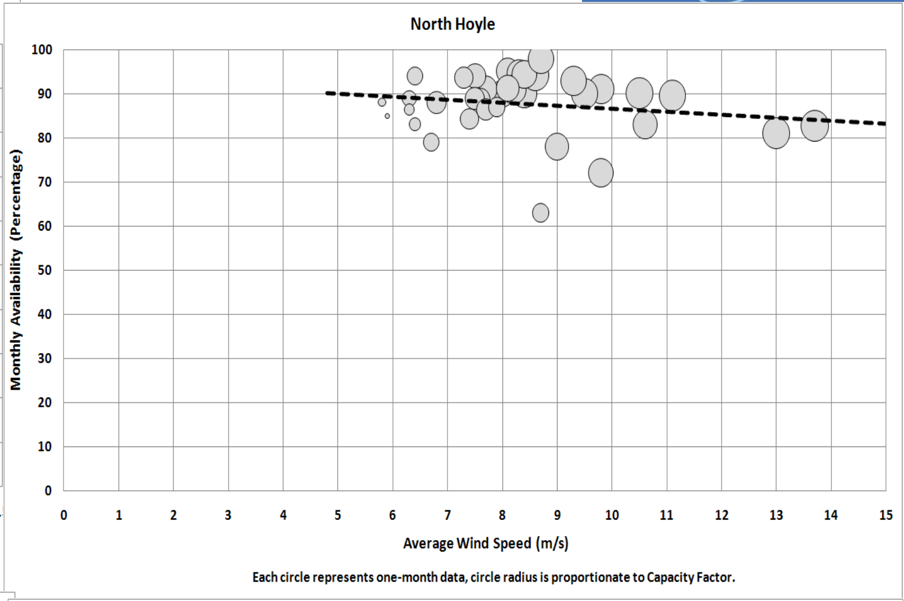
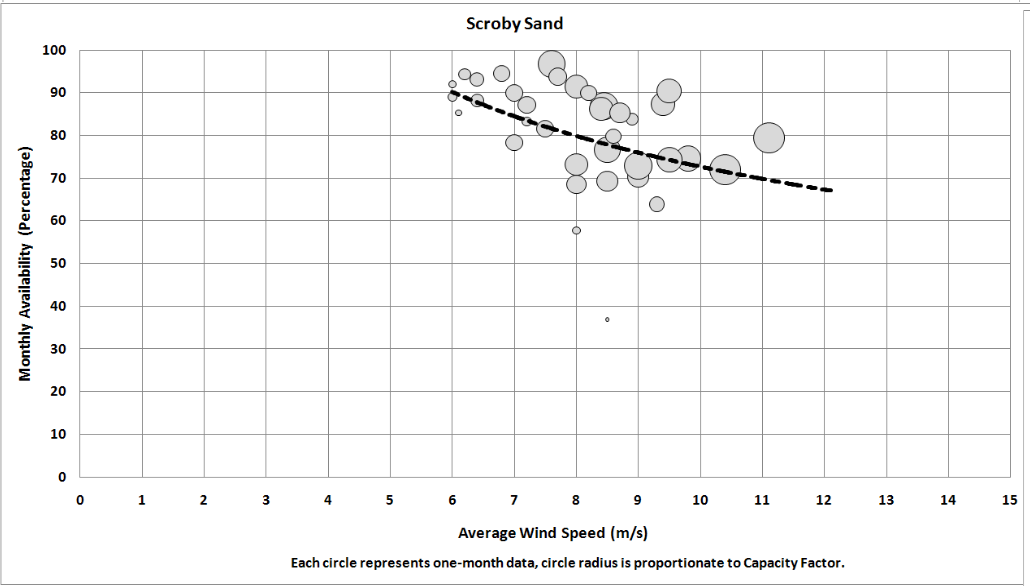
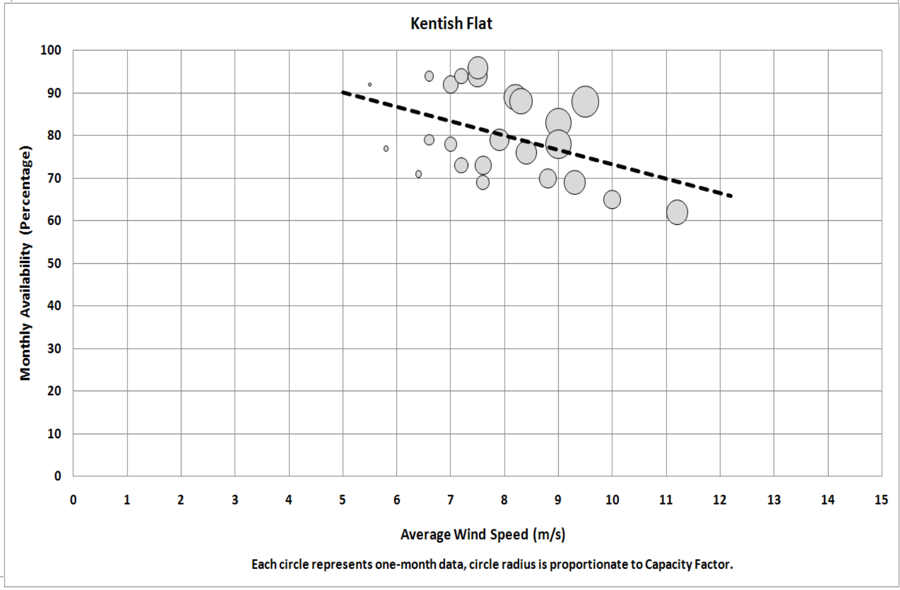
Offshore Availability & Wind speed, UK

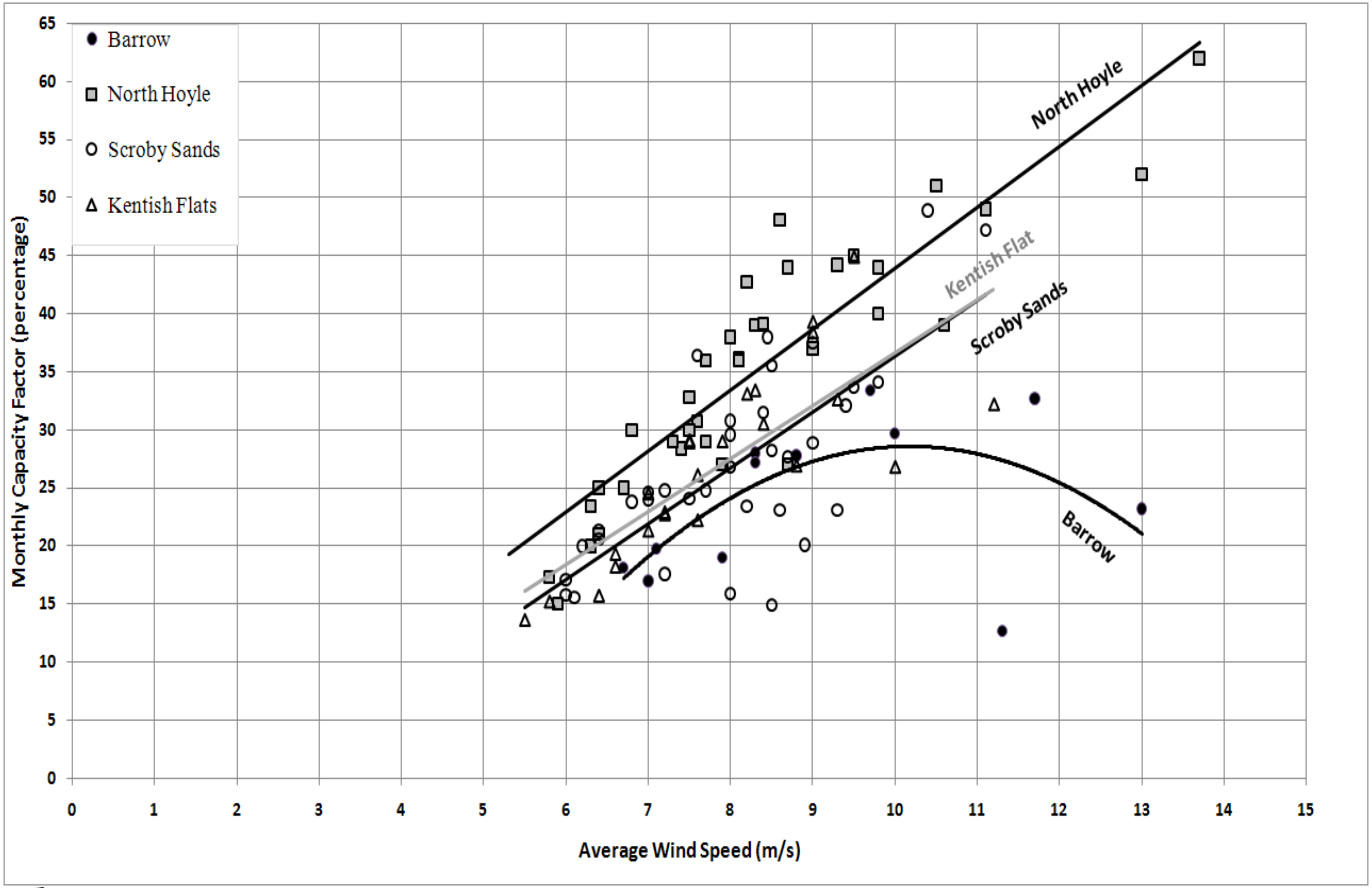








Offshore Capacity Factor & Wind Speed, UK



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Wind Turbine Reliability Analysis

Condition Monitoring Signals → SCADA Signal Analysis → Failure Modes & Effects Analysis, FMEA

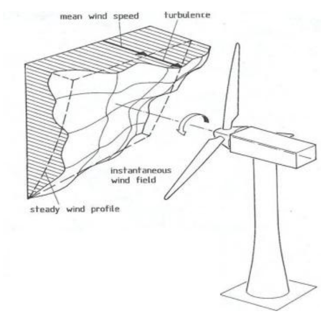
Wind condition
Weather
Faulty design
Faulty materials
Poor maintenance

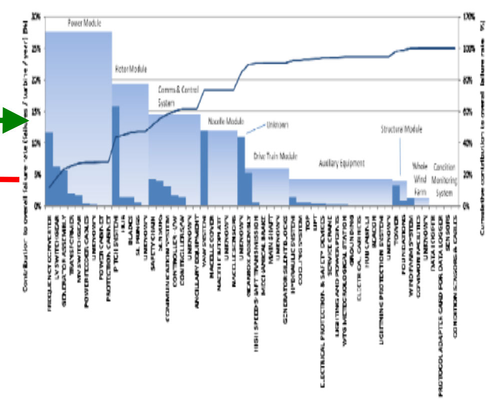
Results of WP3 analysis | Results of WP2 analysis | Results of survey data WP1

How?

SCADA Analysis

& Diagnosis





Why?

Root Cause Analysis

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Conclusions

- WT reliability is improving
- WT concepts have different reliabilities
- Generally failure rates are constant
- The subassemblies with high failure rates are consistent
- Downtime or *MTTR* and cost are also important
- Failure rates of subassemblies can improve with time
- Definitions of Availability are important and need to be standardised
- Offshore availability A_i is worse than onshore

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Thank you

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