Wind Farm Maintenance

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TWIND course - Design and testing of offshore wind turbines and farms
Thursday 20th October 2022

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Outline

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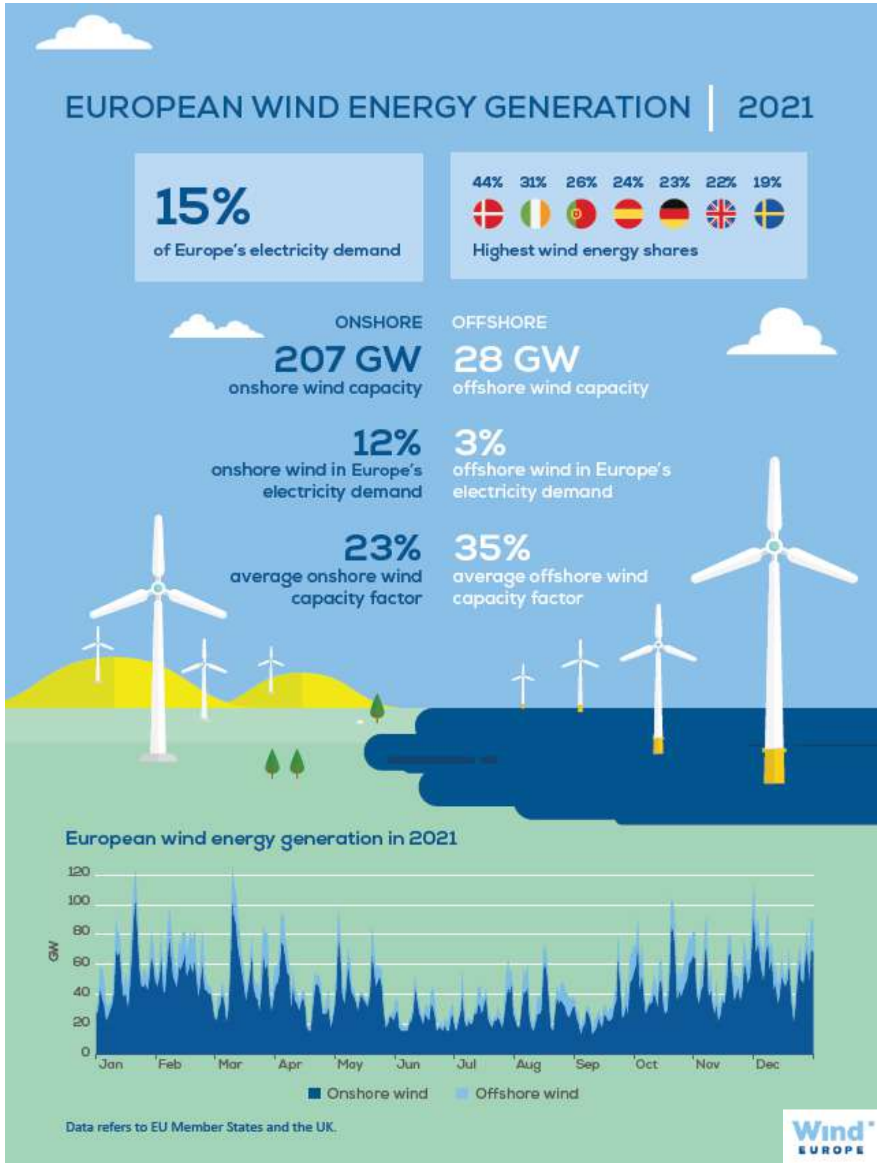
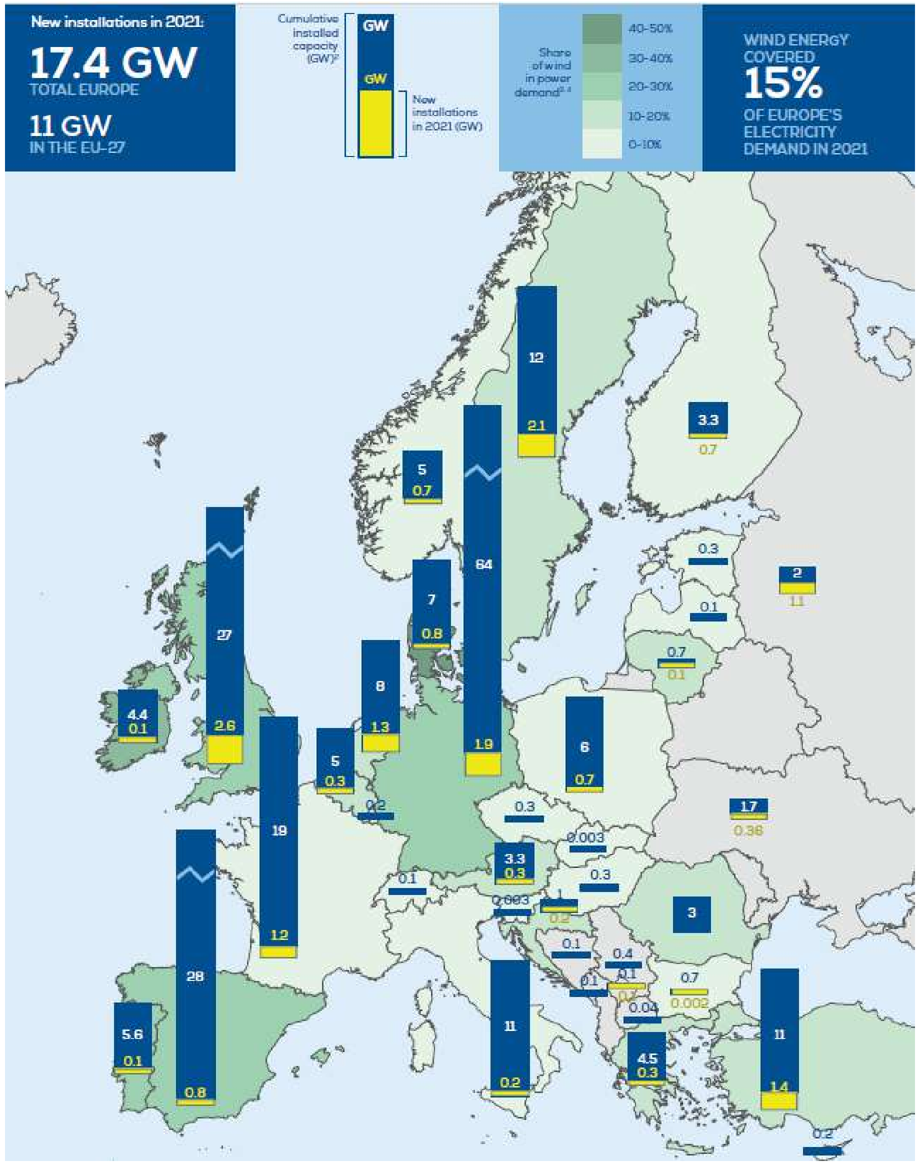
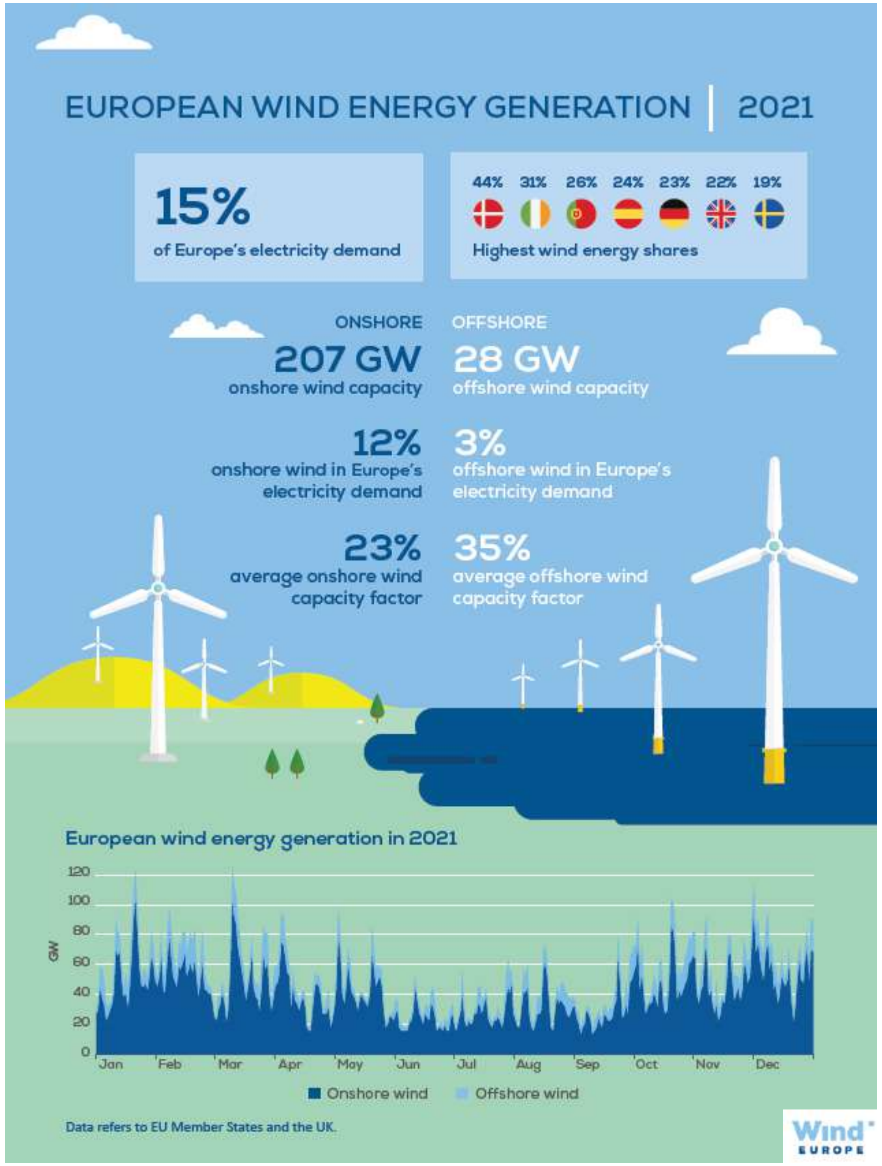
Wind Energy Today - Europe

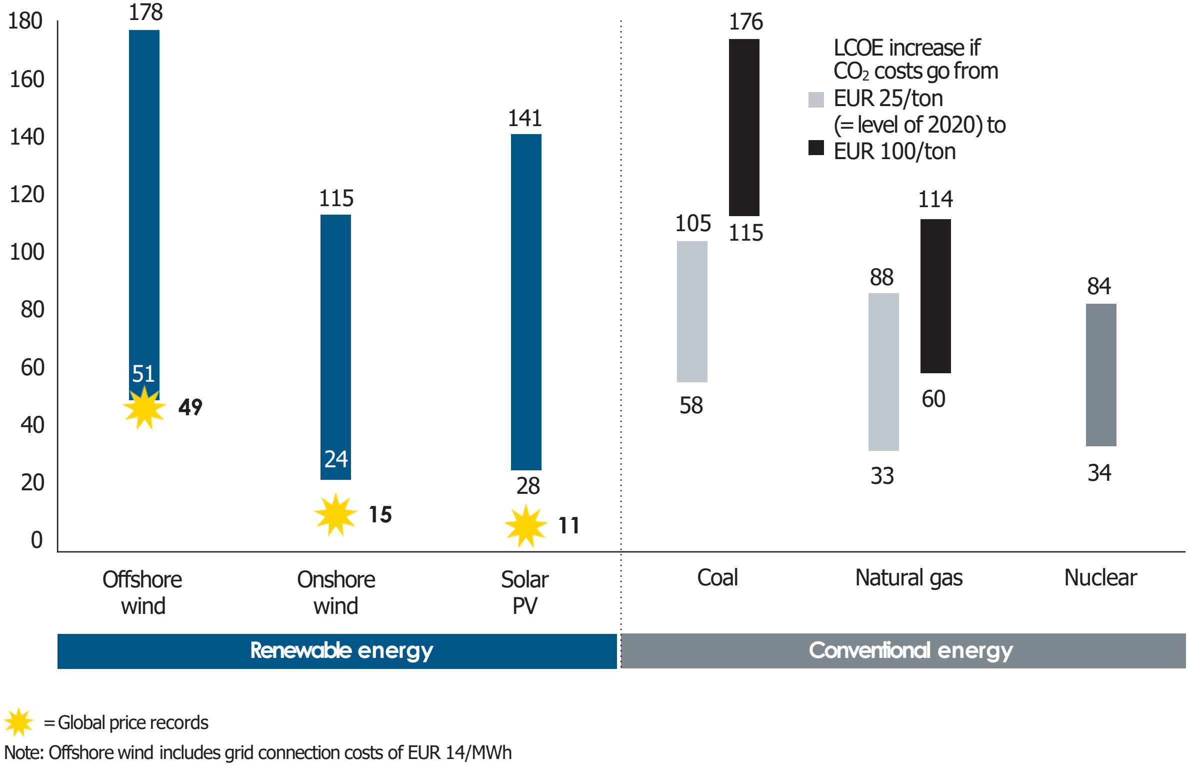




Wind Energy Today - Europe



LCOE [EUR/MWh]



Source: Roland Berger, 2021

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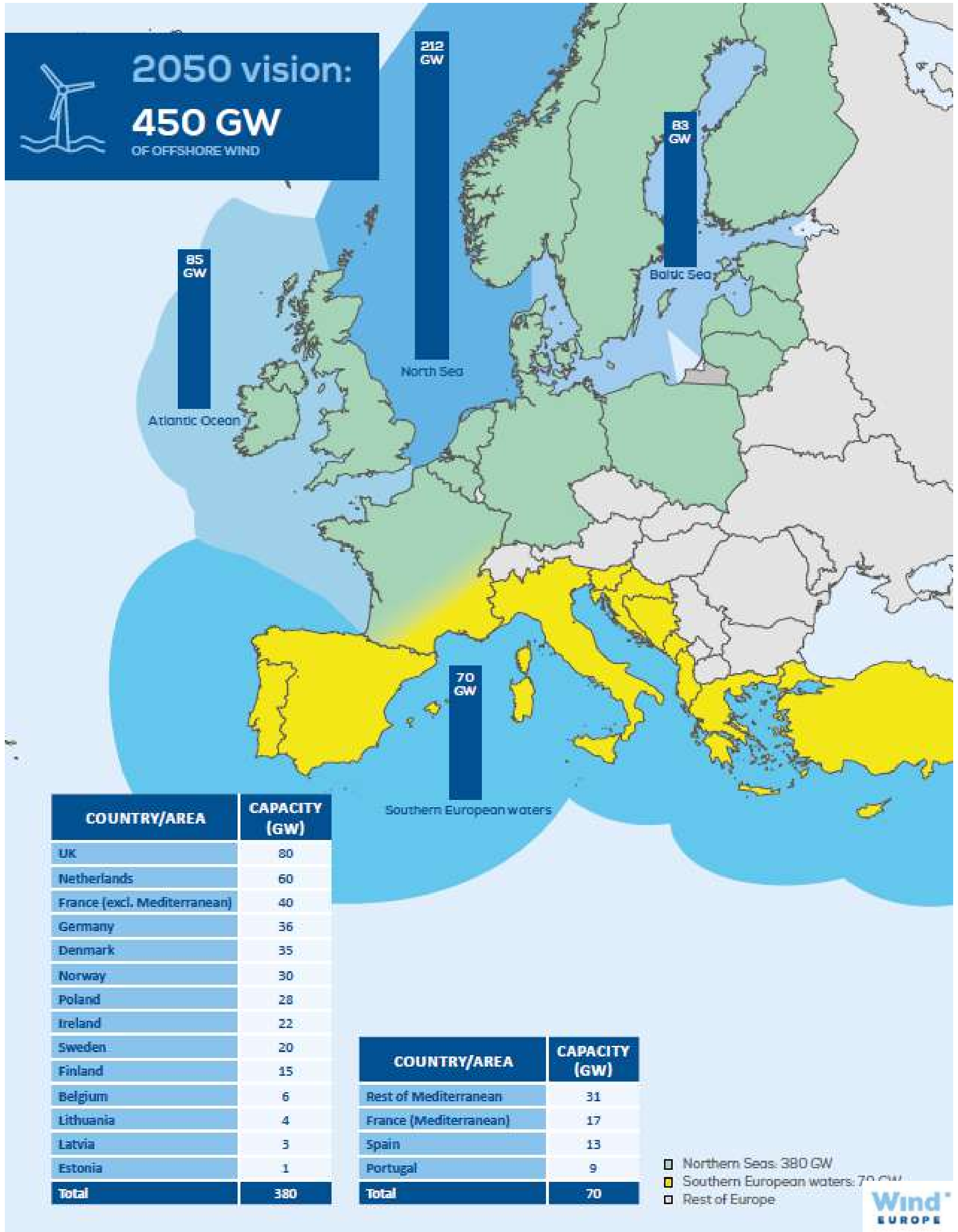
European Green Deal

- All the energy used will come from renewable sources **by 2050**
- **Offshore** wind energy is <u>**THE**</u> key player in meeting the net-zero carbon emission target
- **The European Commission** has proposed to increase **Europe's offshore wind capacity from** the current **28 GW up to 450 GW by 2050**
- One third of offshore wind capacity is expected to be generated by **floating wind turbines** in **deep waters** (>50m)



COUNTRY/AREA	CAPACITY (GW)
UK	80
Netherlands	60
France (excl. Mediterranean)	40
Germany	36
Denmark	35
Norway	30
Poland	28
Ireland	22
Sweden	20
Finland	15
Belgium	6
Lithuania	4
Latvia	3
Estonia	1
Total	380

COUNTRY/AREA	CAPACITY (GW)
Rest of Mediterranean	31
France (Mediterranean)	17
Spain	13
Portugal	9
Total	70

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Wind Energy Cost Reduction 2020-2050

Source: ETIPWind – Wind Europe, 2021

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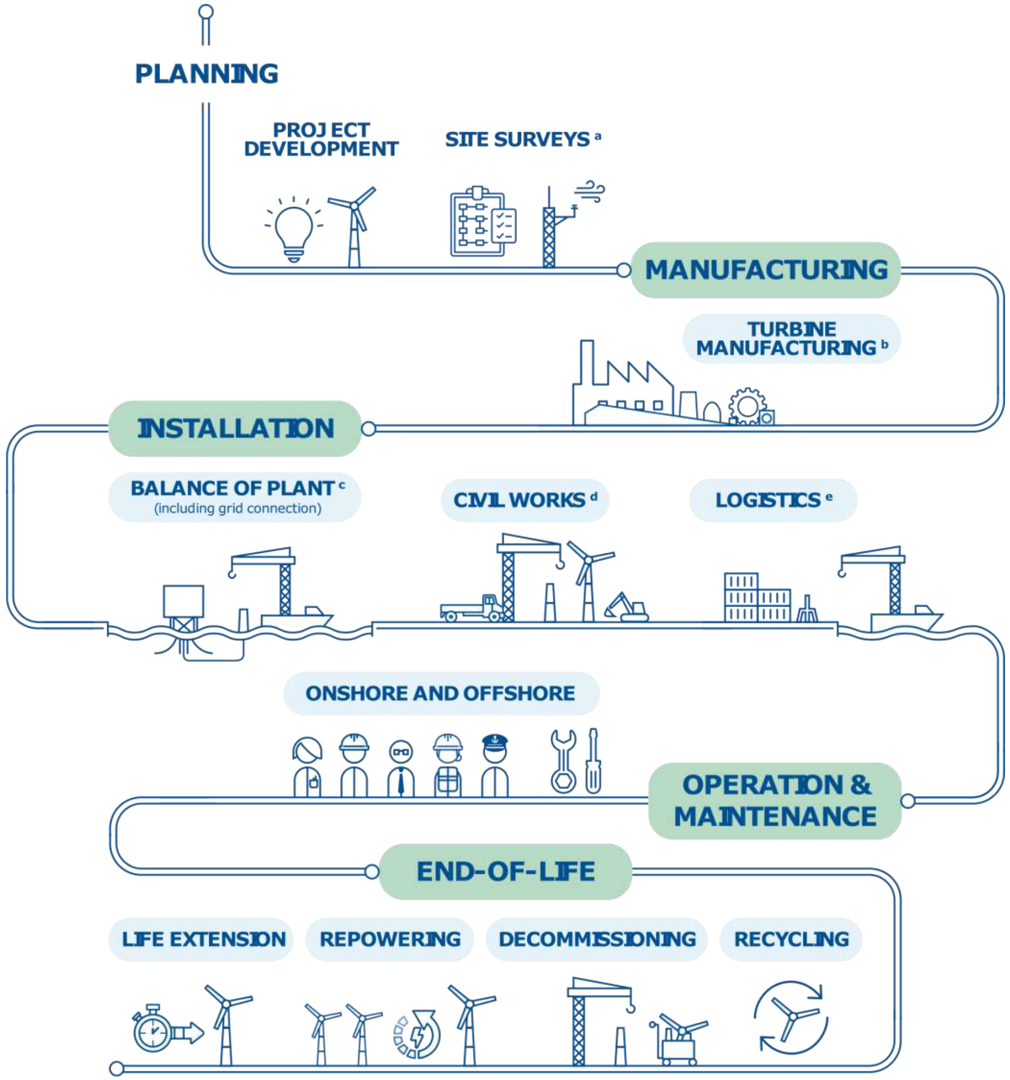
Wind Farm Asset Management

Asset management is a systematic process of deploying, operating, maintaining, upgrading, and disposing of assets cost-effectively

Goal: minimise the total expected life-cycle costs and maximise profitability

- Design for availability
- Operate for availability
- Maintain for availability



a. Resource assessments, environmental impact, landscape, archaeological and unexploded ordnance (UXO) assessments.
b. Hub, pitch, blades, nacelle, gearbox, bearings, forgings, cast ngs, generator, converter and tower.
c. Onshore foundat ons, intra-array cabling, substat on, of shore foundat on, subsea export cabling, converter, and transformer stat ons.
d. Onshore and of shore foundat ons.
e. Ports, warehouses, road transportat on and vessels.

Life-cycle of a wind farm. Source: WindEurope, 2020

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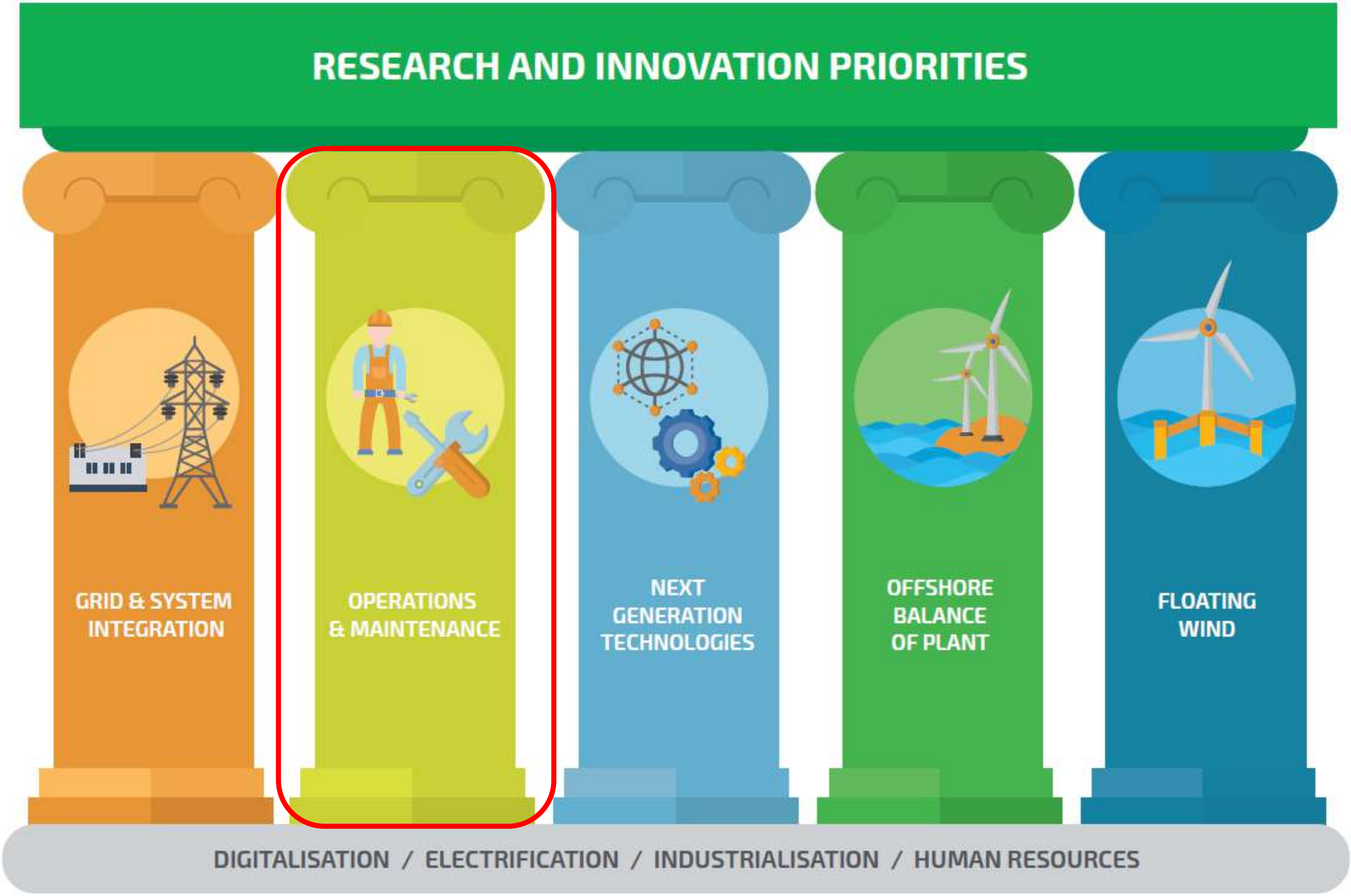
Wind Energy Research & Innovation Priorities



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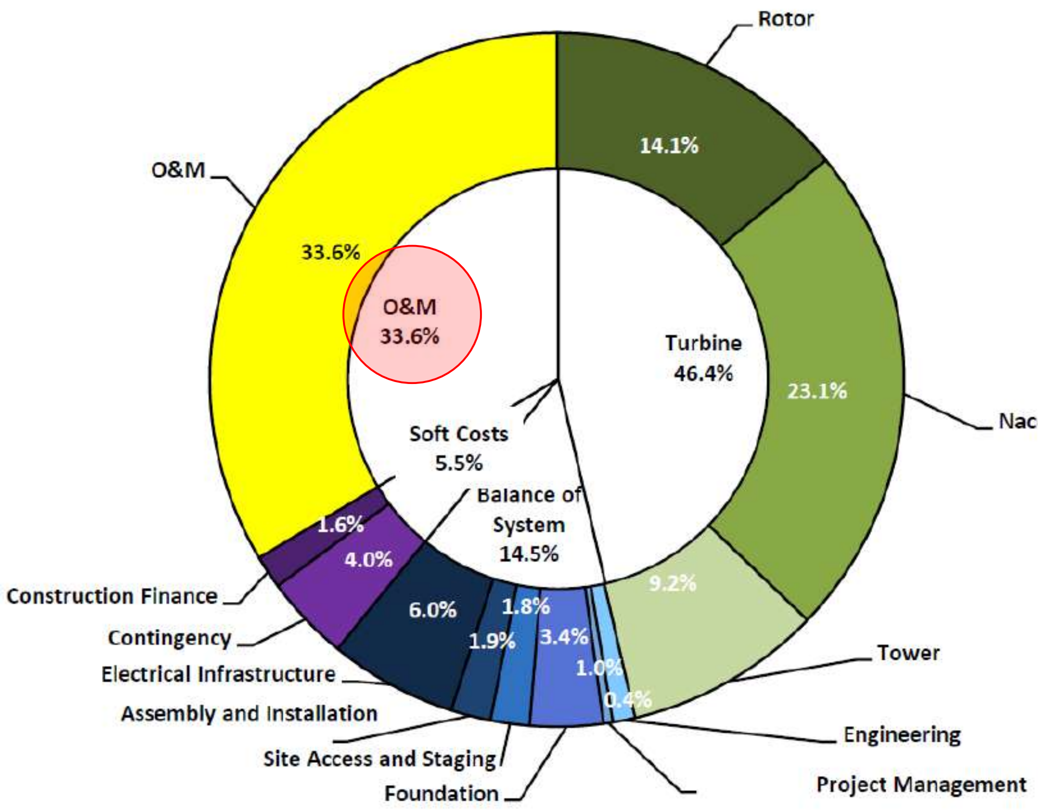
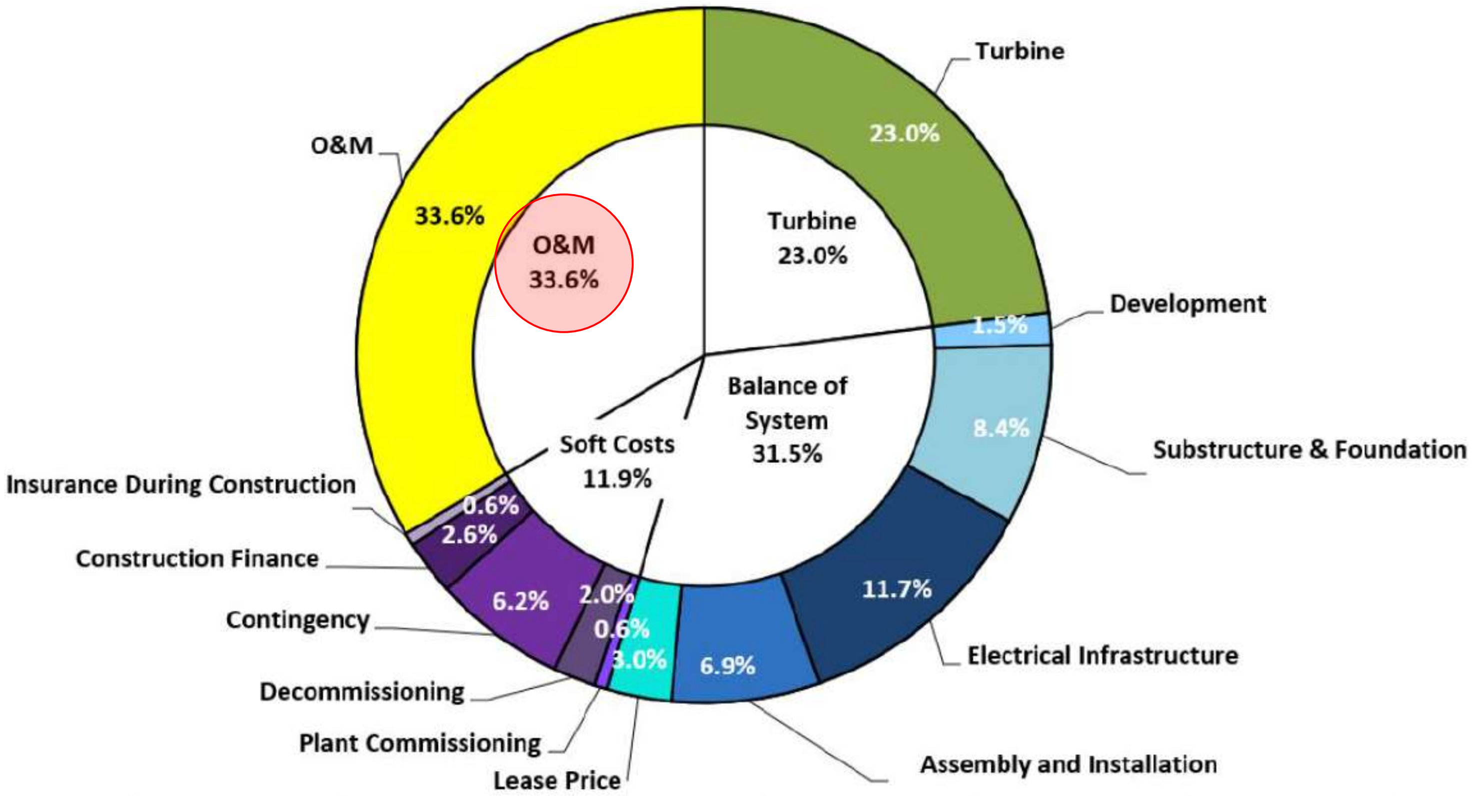
Source: ETIPWind, Strategic Research & Innovation Agenda, 2018

Wind Energy LCOE – O&M



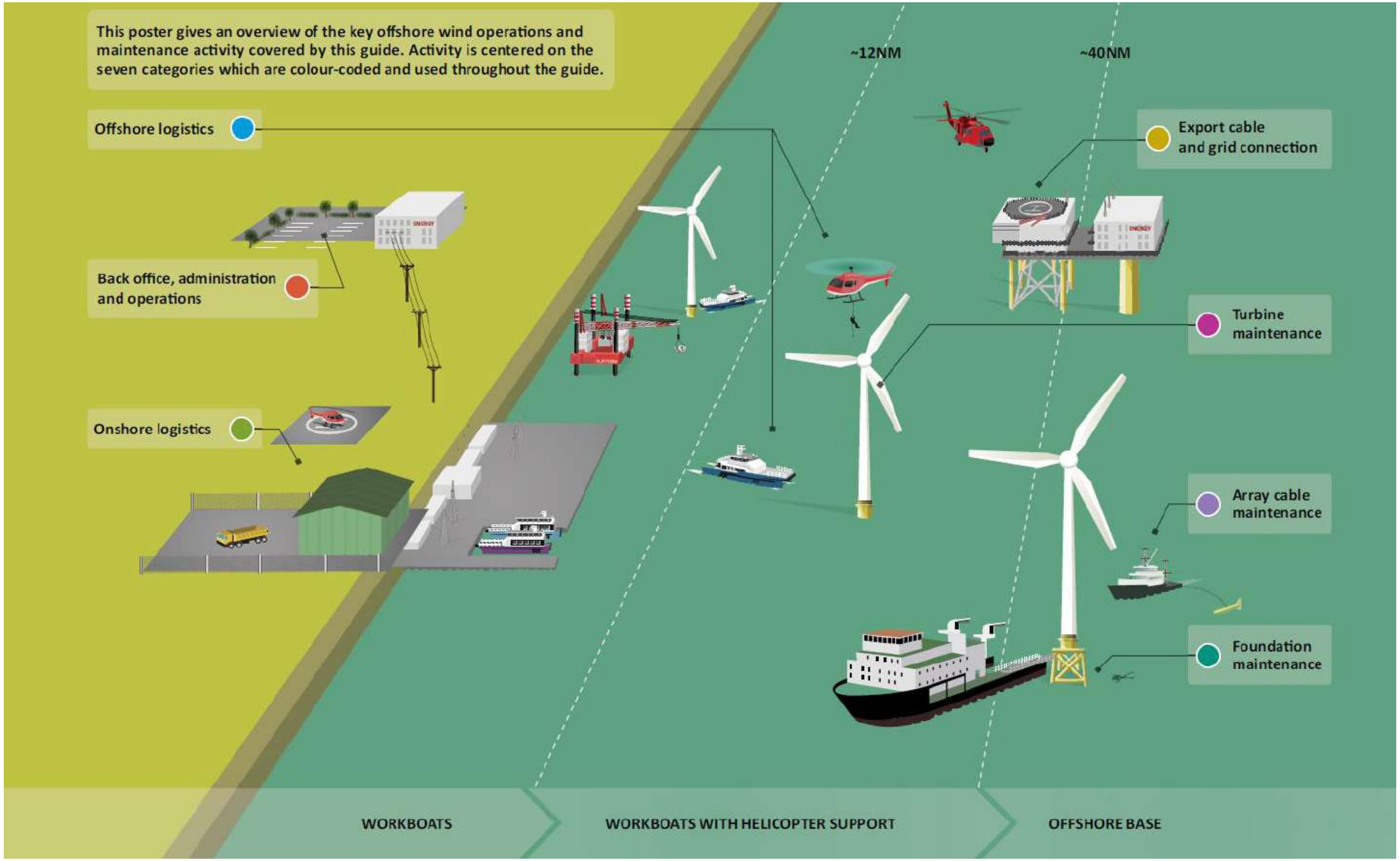
Onshore

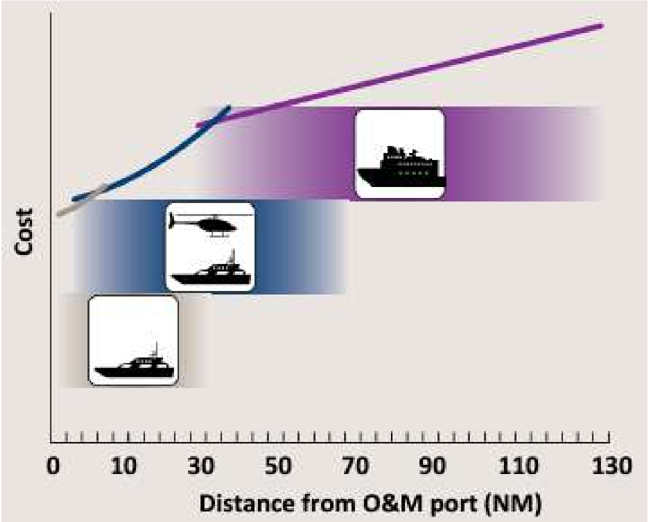


Offshore (Bottom-fixed)

Source: Stehly et al., NREL, NREL/TP-5000-81209, 2021

O&M of Offshore Wind Farms

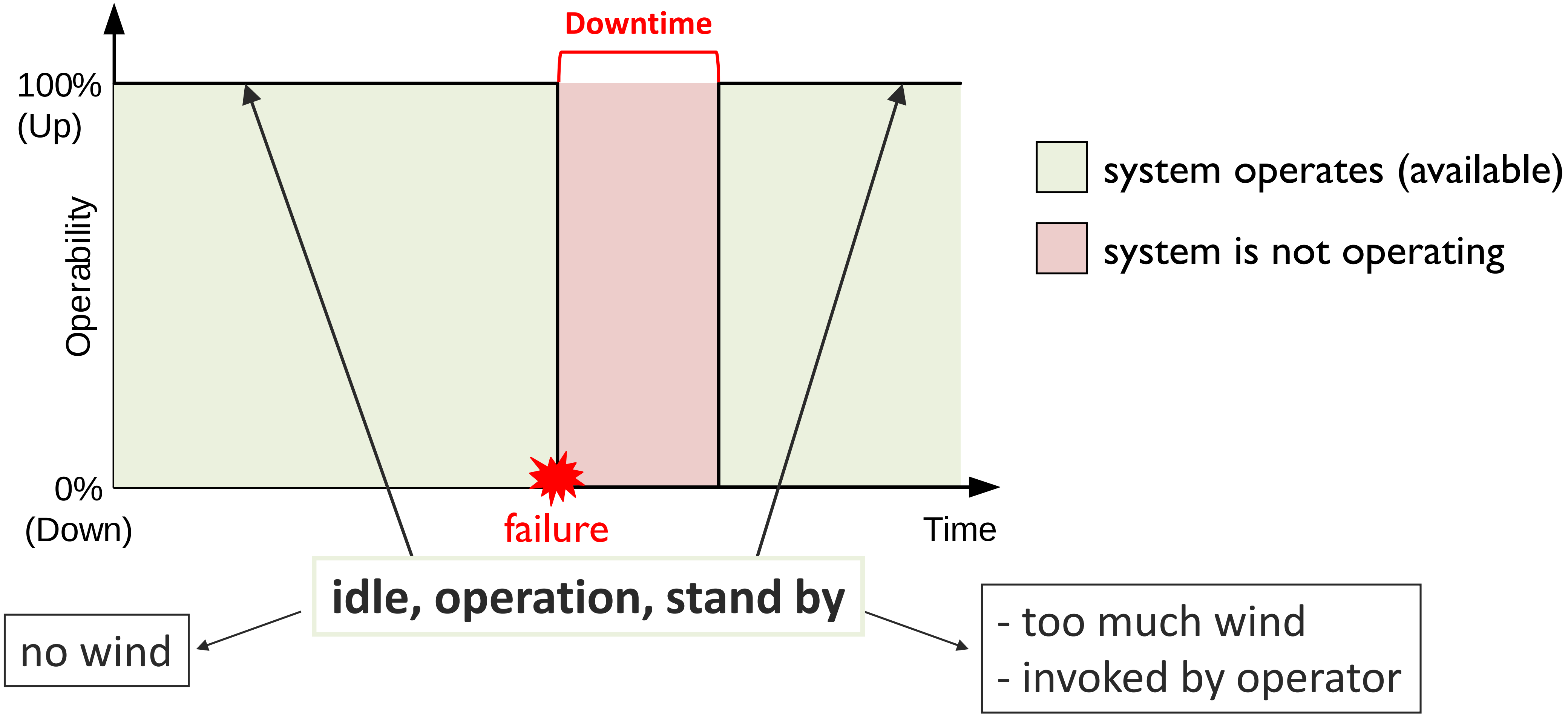




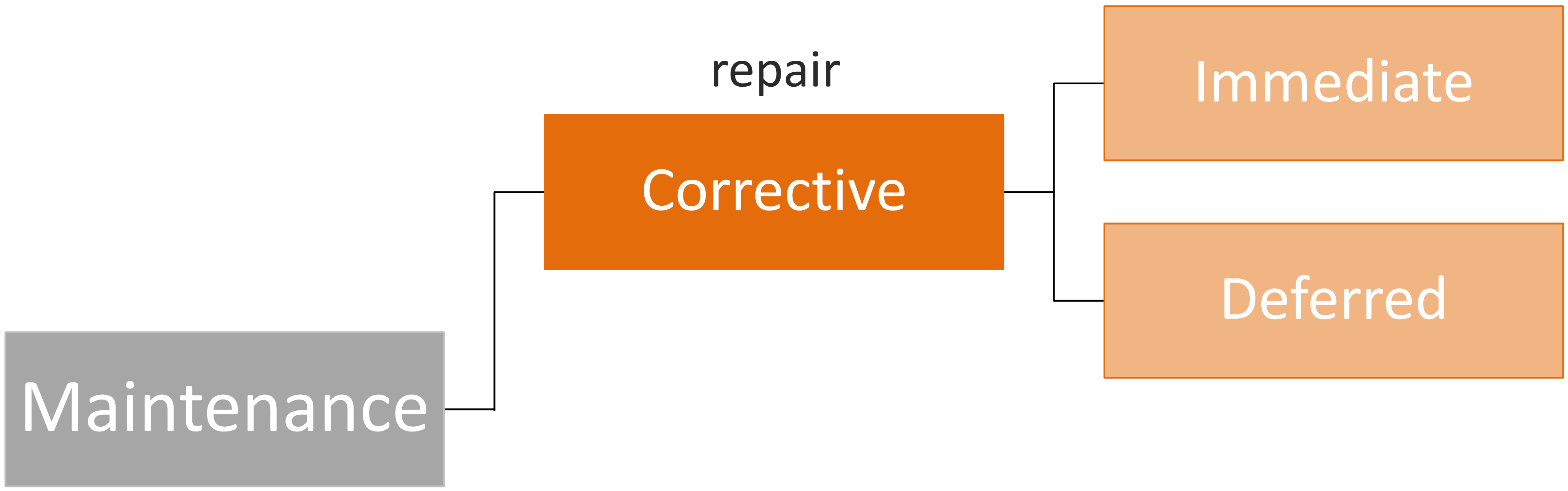
Source: GL Garrad Hassan, A Guide to UK Offshore Wind Operations and Maintenance, Scottish Enterprise and The Crown Estate, 2013

States of a System

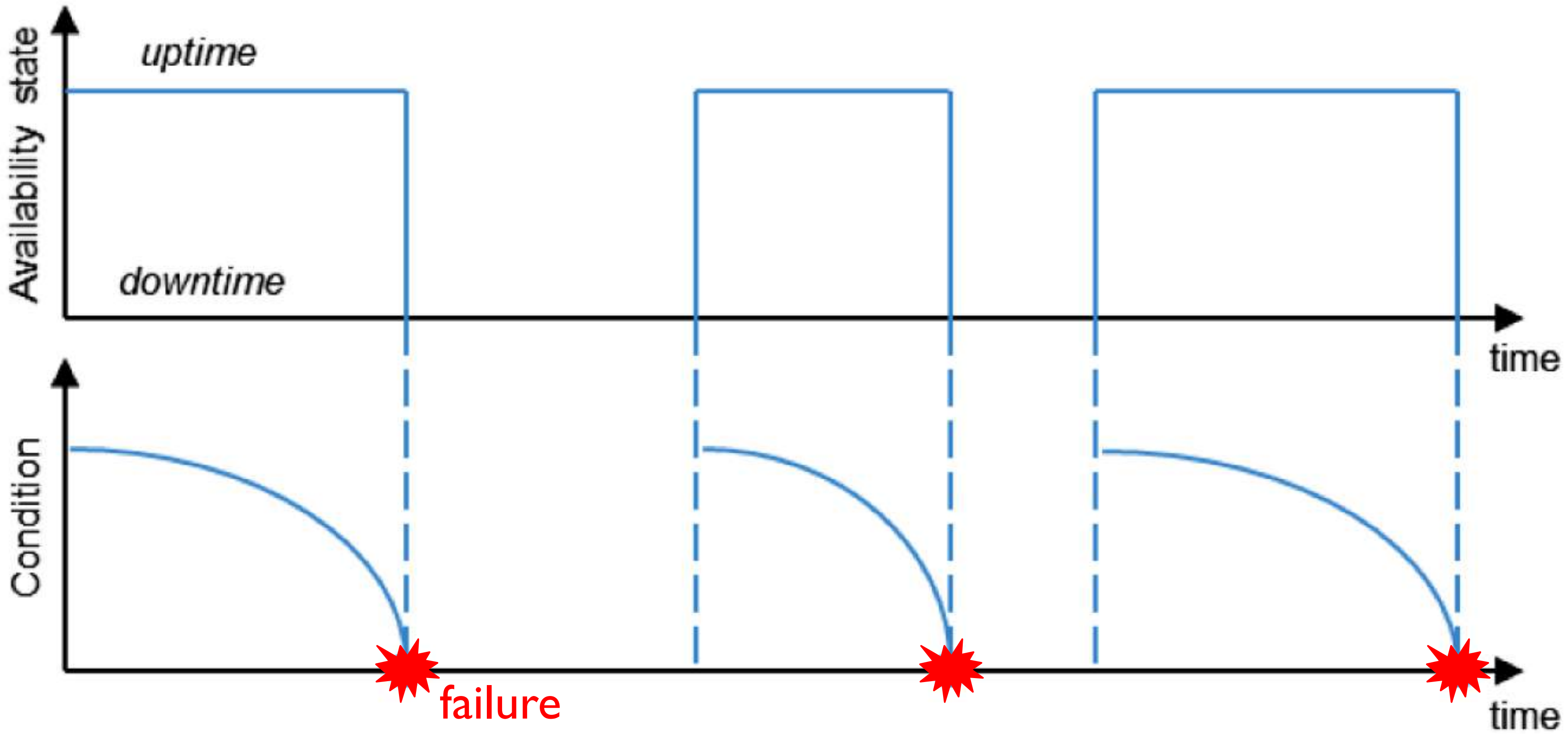
Downtime is the time during which a turbine does not produce power output due to a failure



Maintenance Strategies



Corrective Maintenance



Run to **failure** and replace (failure-based)

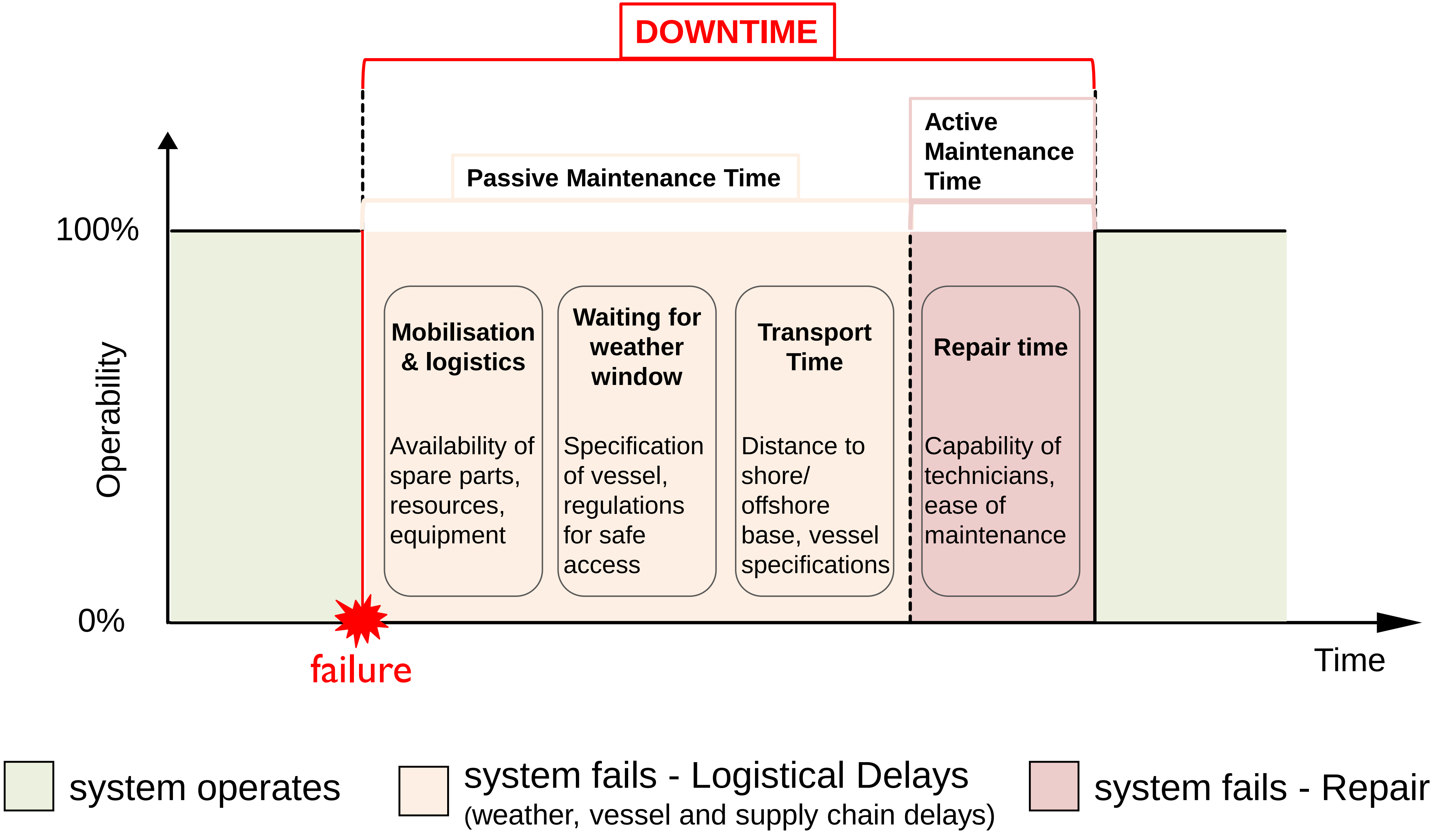
✓ Full use of the asset useful life, avoid unnecessary maintenance

✓ <u>Low criticality</u> (cost and reliability) components

✗ Not cost-effective if access is limited (offshore wind farms)

Source: Koukoura et al., Reliab. Eng. Syst. Saf., 2021

Operational Failure Characteristics



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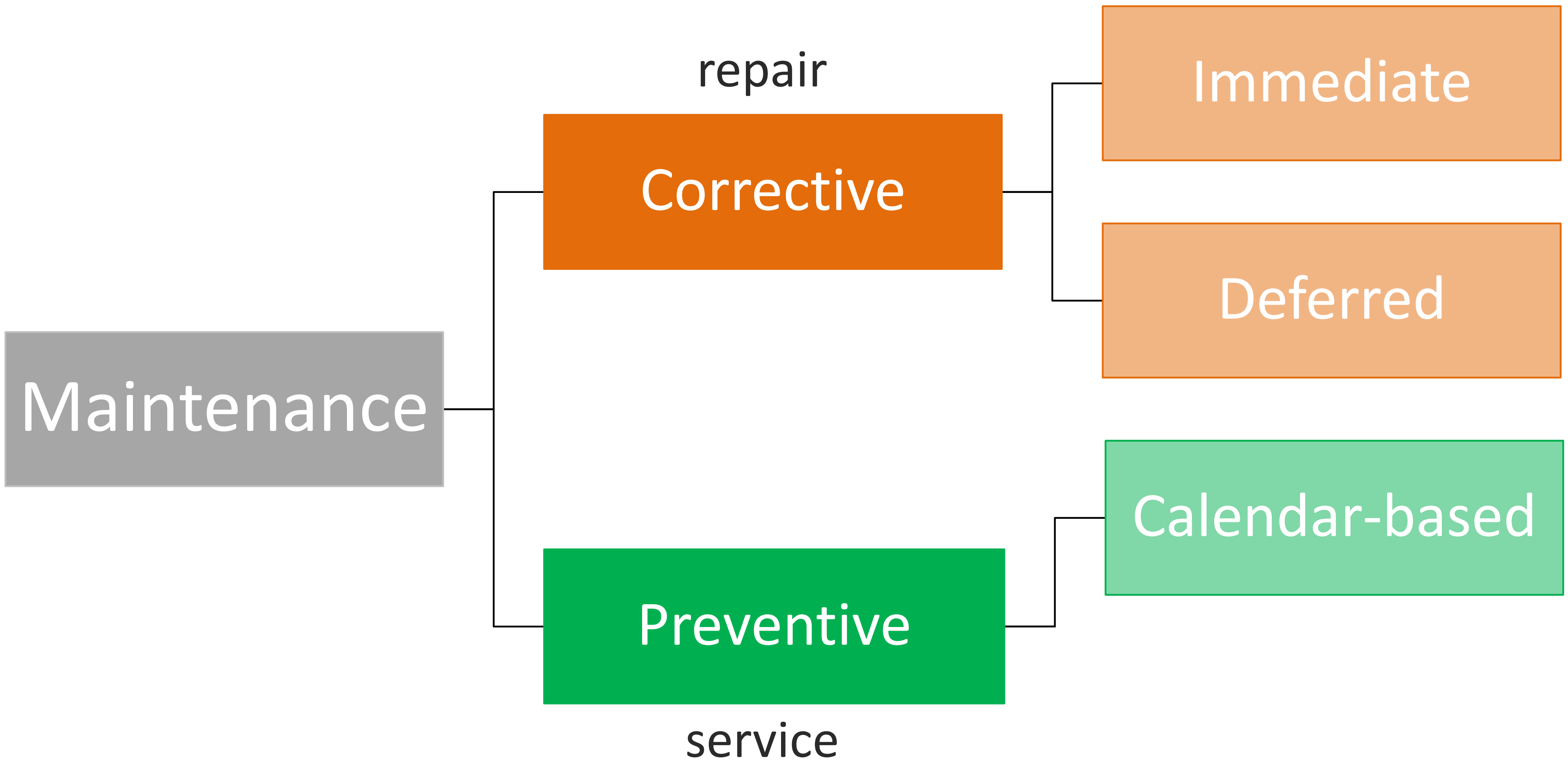
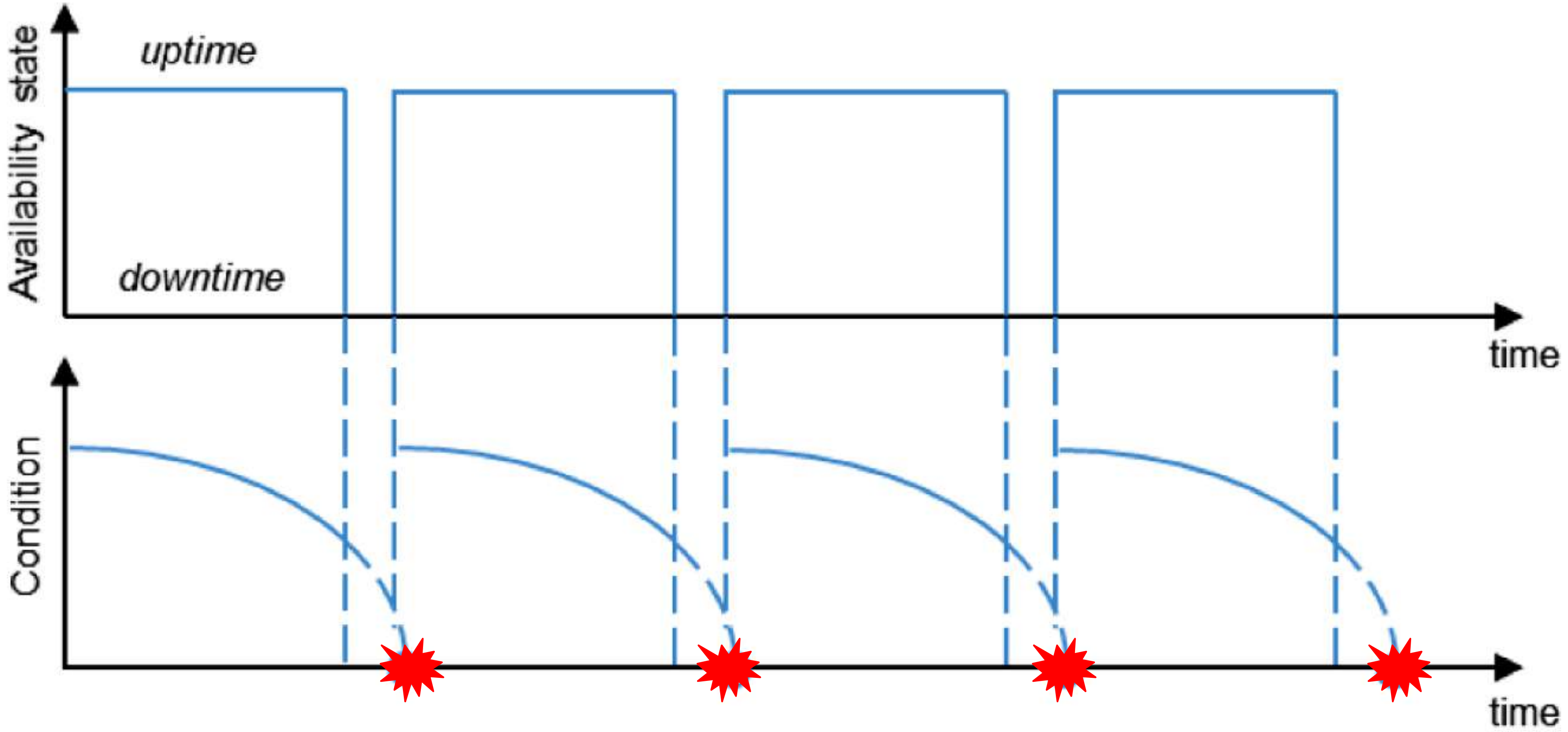
Maintenance Strategies



Preventive Time-based Maintenance



Scheduled inspection and replacements to prevent major failures

✓ Asset delivers more predictable and reliable electricity

✓ For assets with <u>well-known</u> and <u>consistent failure-time</u> correlation

✗ Potentially expensive and risk of over-maintenance

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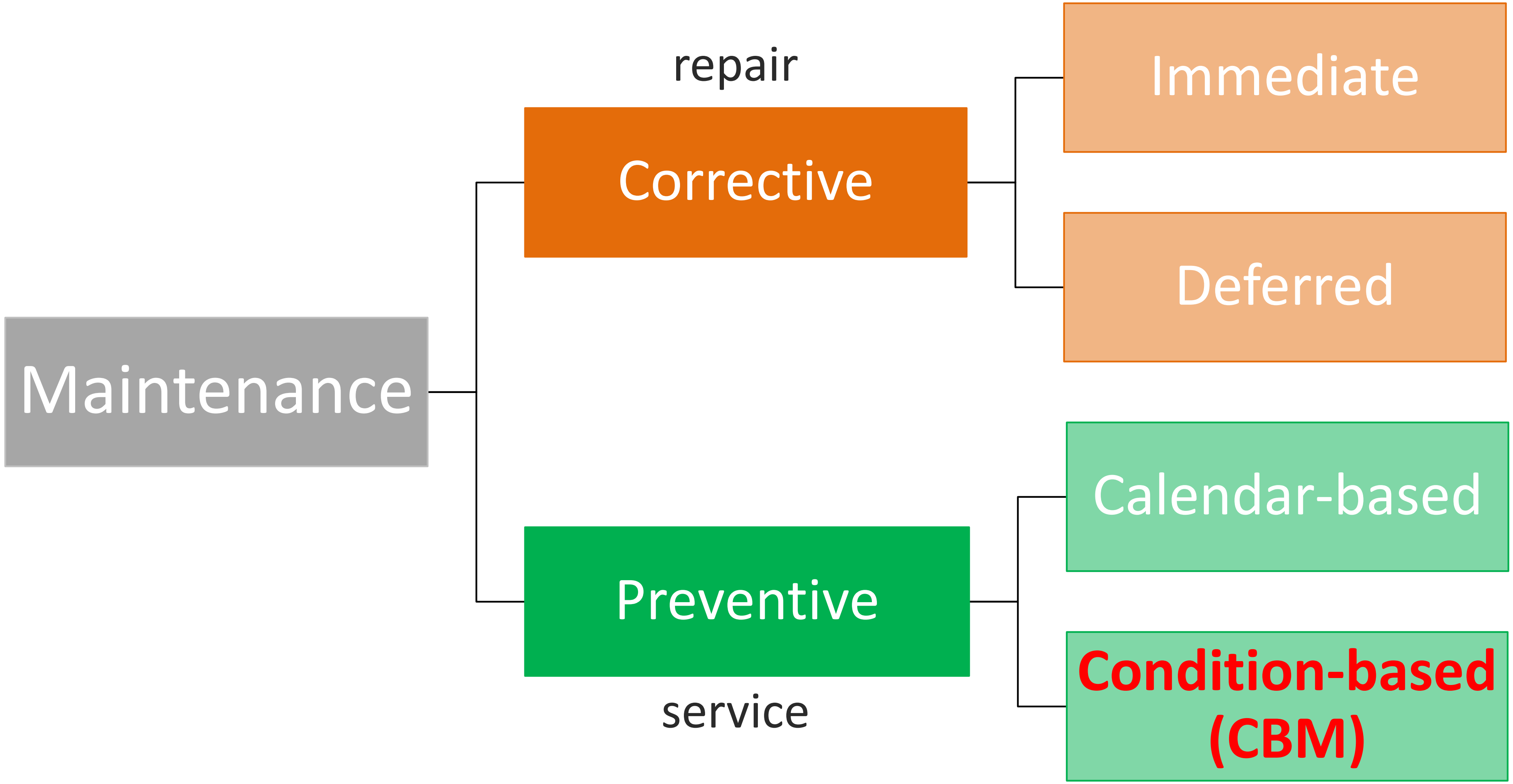
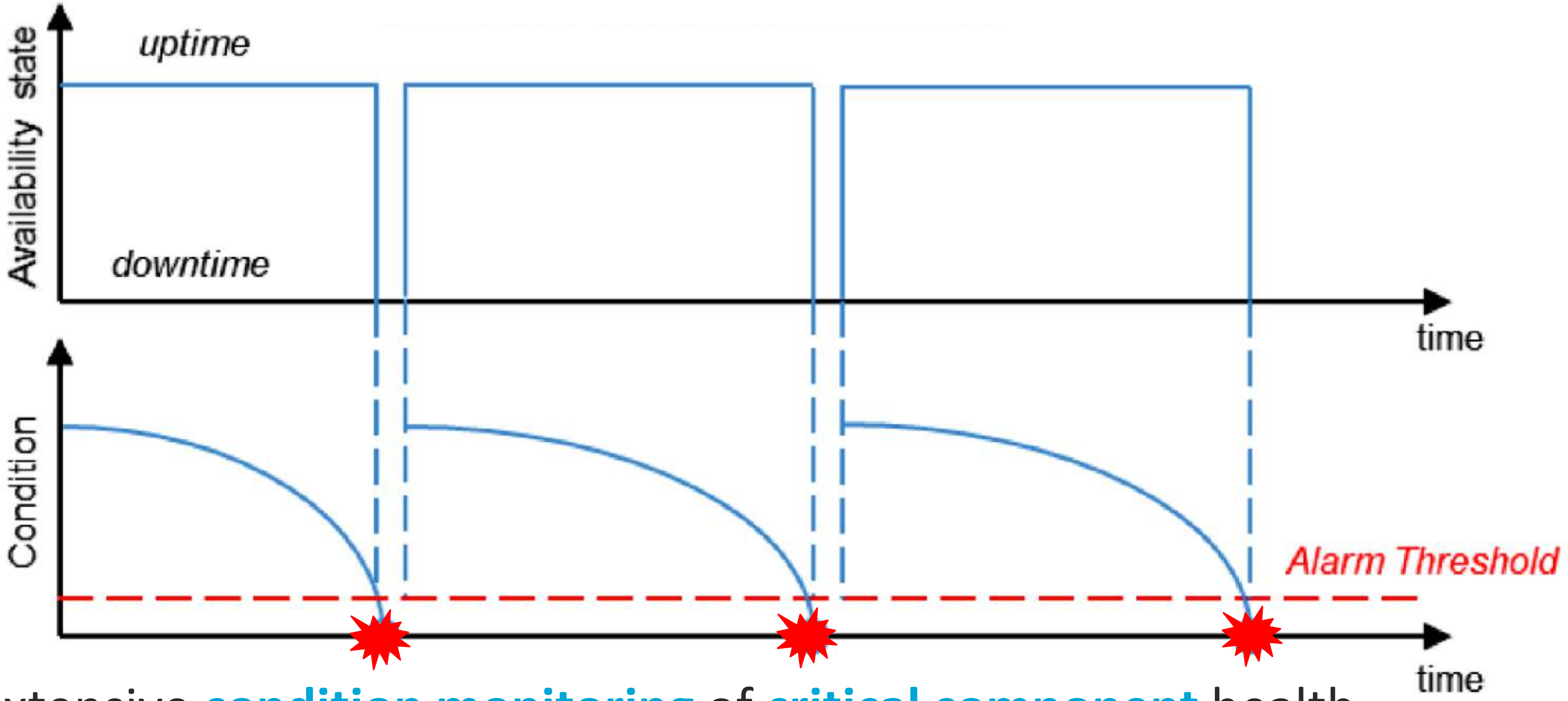
Source: Koukoura et al., Reliab. Eng. Syst. Saf., 2021

Maintenance Strategies



Preventive CBM



Extensive **condition monitoring** of **critical component** health

- ✓ Detailed analysis to predict and pre-empt early failures
- ✓ Plan the most effective maintenance actions on a dynamic schedule
- ✓ Reduce unnecessary repairs and unplanned downtime
- ✓ Improve asset availability and performance

Source: Koukoura et al., Reliab. Eng. Syst. Saf., 2021

How to Optimize a CBM Strategy?

Reliability Analysis

- Most critical wind turbine components
- Failure modes and effect analysis (FMEA)
- Failure mode and symptom analysis (symptoms, fault indicators)

Cost-effective and Holistic Condition Monitoring

- **Detection**
  Something happened! where?
- **Diagnosis**
  What did happen?
- **Prognosis**
  What will happen? When?
  Remaining useful lifetime estimation

O&M - Prescriptive actions
Maintenance decision
Optimal maintenance scheduling

Optimisation: O&M feedback, Field data

What is Reliability?

- Probability of successful operation

  How long will [a sub-assembly] perform its intended function without a breakdown?

What is Reliability?

Reliability is the probability that an item will meet its required function under stated conditions for a specified period of time

- It can be expressed as the number of failures over a period of time - Failure rate (λ)

$$\lambda = \frac{\left(\frac{\text{Total Number of Failures}}{\text{Turbine Population}}\right)}{\text{Operating Period}}$$

- Reliability is essential when **designing** and **operating** any engineering system

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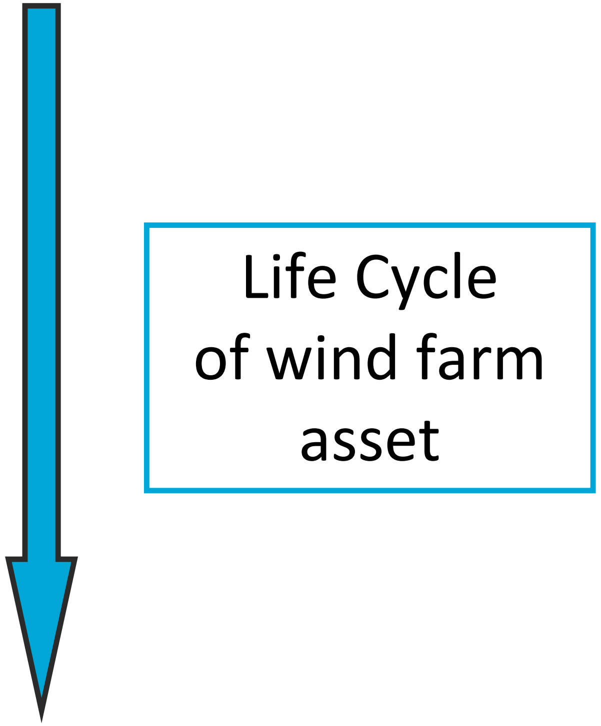
Causes of a Failures

- **Design** failure
- **Manufacturing** failure
- **Installation** failure
- **Maintenance** failure
- **Operation/Handling** failure

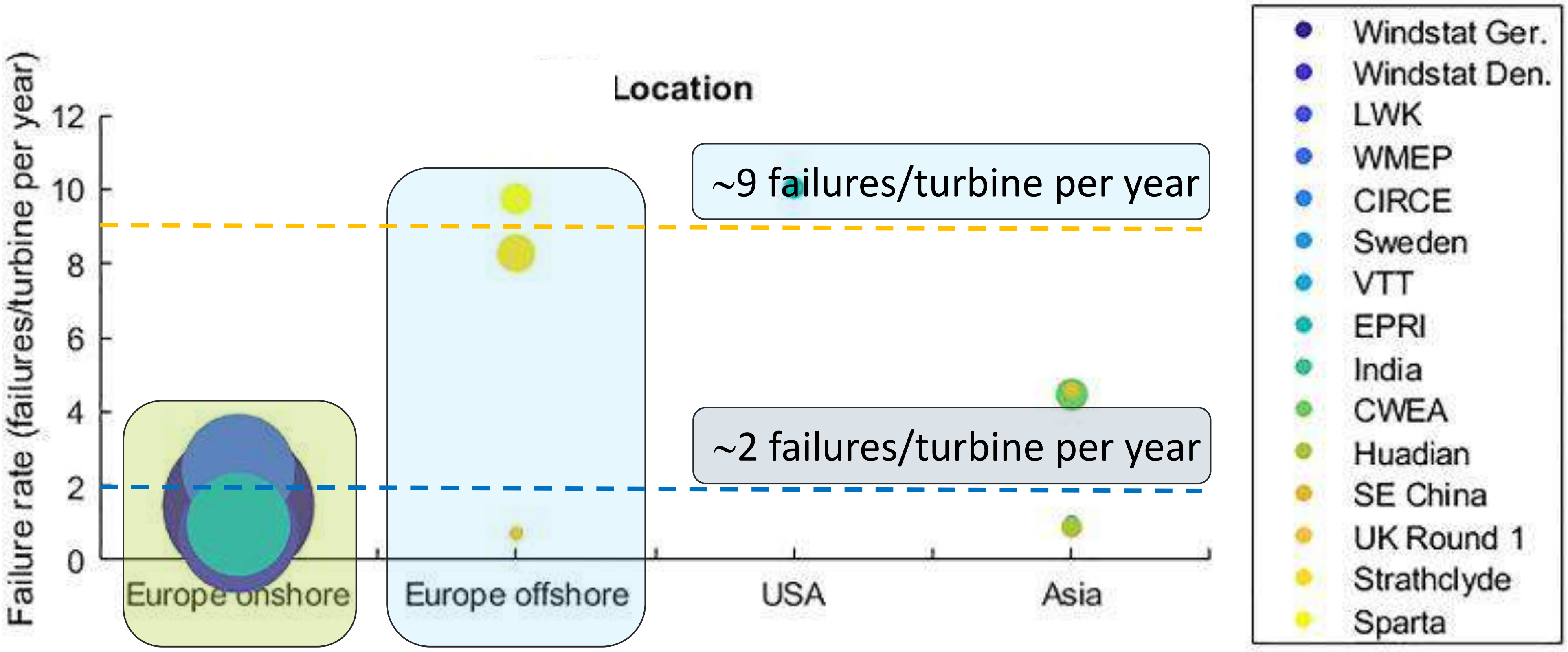


Think, Pair & Share: Wind Turbine Reliability

	Sit in pairs and discuss with partner: ➢ What is the typical reliability of onshore and offshore wind turbines? ➢ What is the most unreliable wind turbine component[*]? ➢ What is the component causing the longest downtime[*]?	3 min
Mentimeter	Share with everybody	3 min

[*]Refer to the geared wind turbine configuration

Overall Failure Rates – Onshore vs Offshore



Source: Dao et al., 2019, Wind Energy, 22(12), 1848-1871

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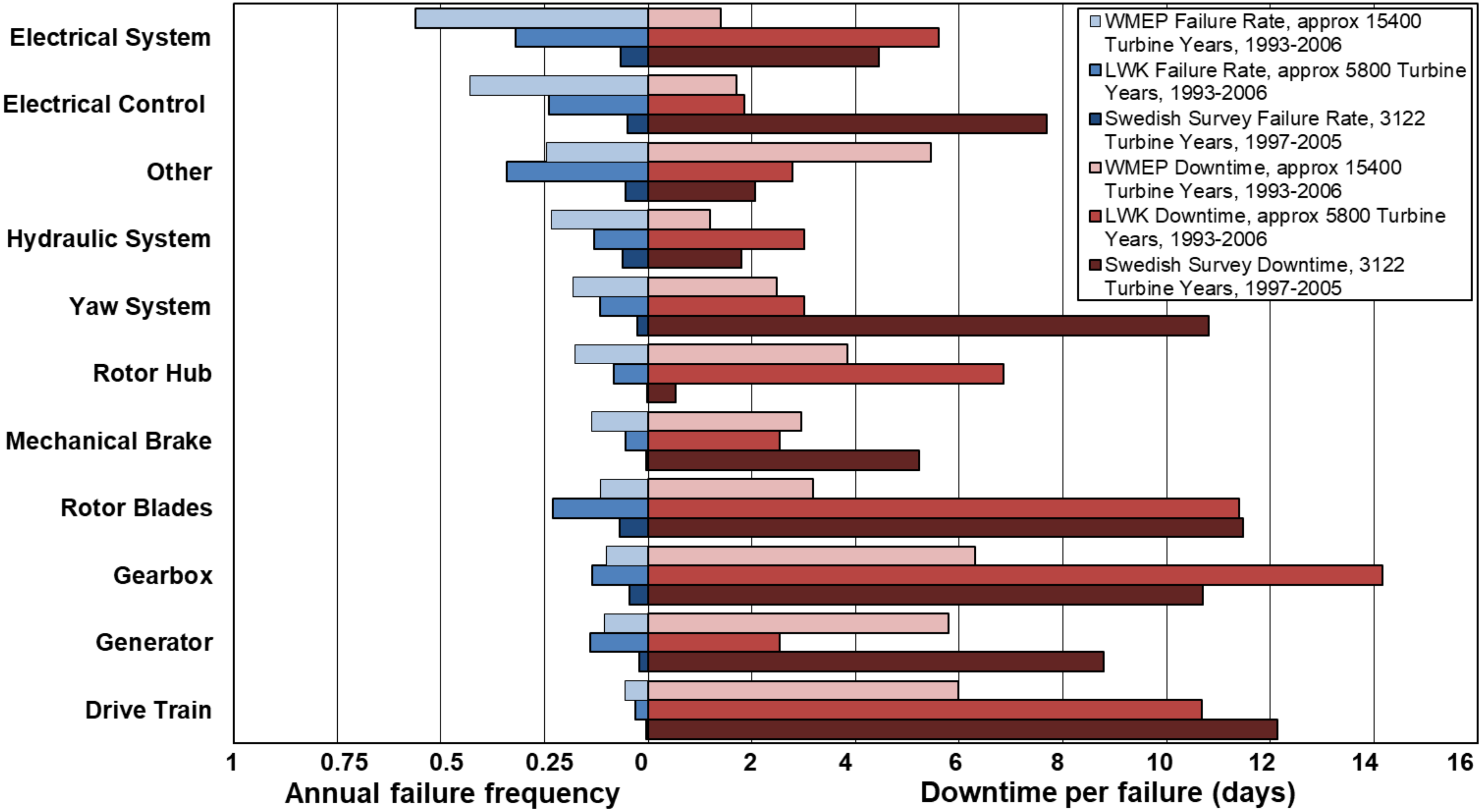
Failure Rates & Downtime per Sub-system - Onshore



Source: Ribrant & Bertling, 2007, IEEE Power Engineering Society General Meeting, 1-8; Tavner et al., 2010, EPE Journal, 20(4), 45-50

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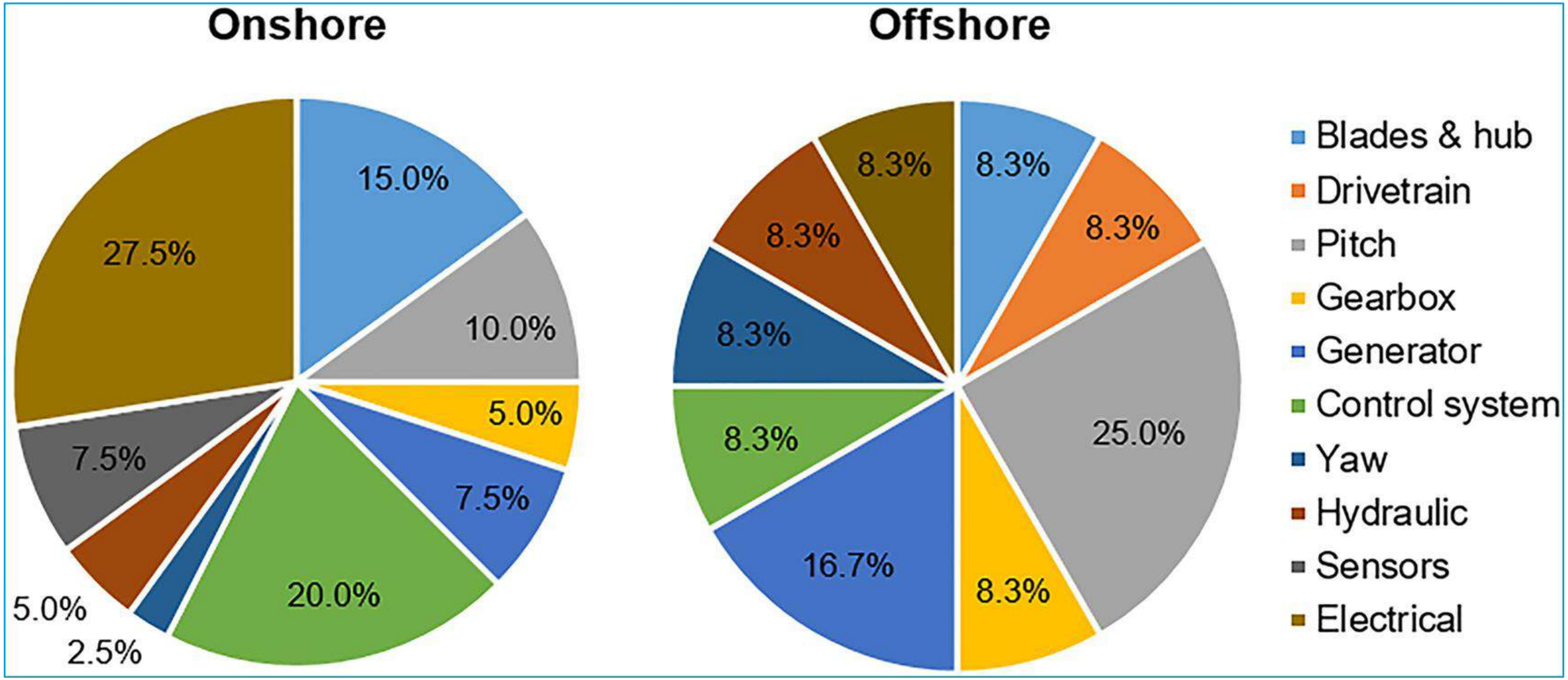
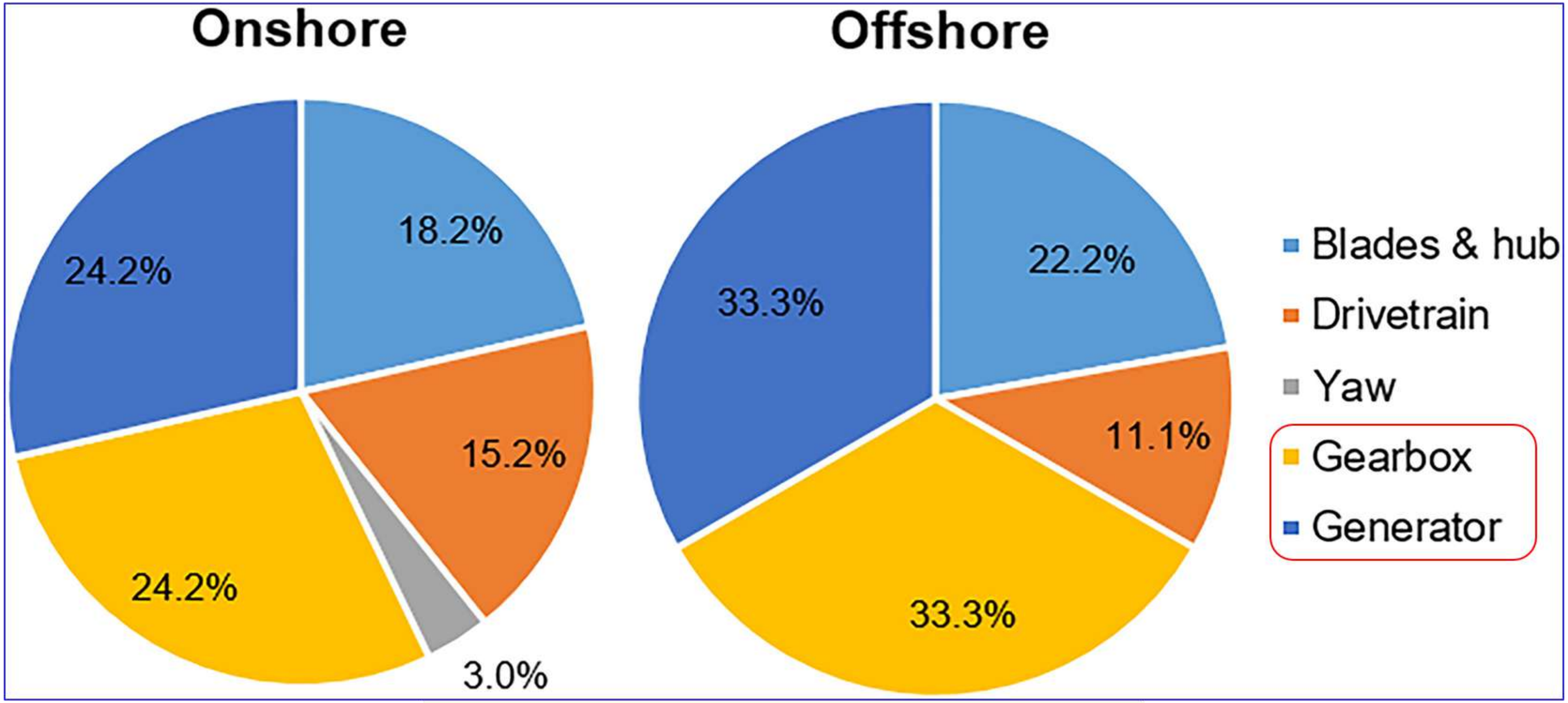
Failure rates – Onshore vs. Offshore



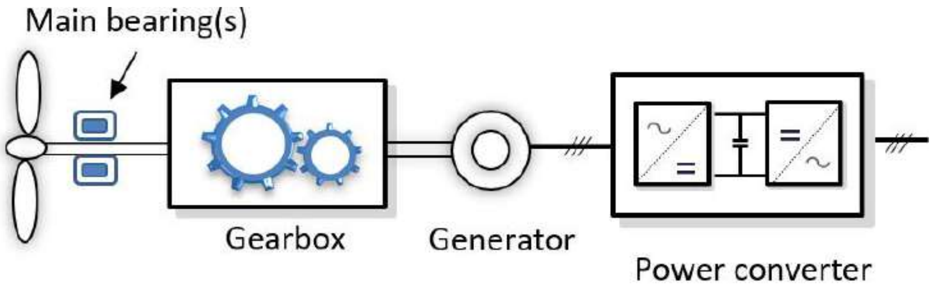
Source: Dao et al., 2019, Wind Energy, 22(12), 1848-1871

Downtime – Onshore vs. Offshore

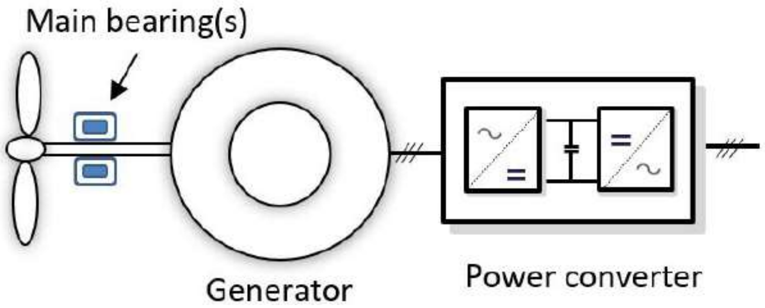


Source: Dao et al., 2019, Wind Energy, 22(12), 1848-1871

Wind Turbine Drivetrain Configurations



Doubly Fed Induction Generator (DFIG) with partial-power-converter



Permanent Magnet Synchronous Generator (PMSG) with full-power converter

Source: adapted from Nejad et al., Wind Energ. Sci., 2022

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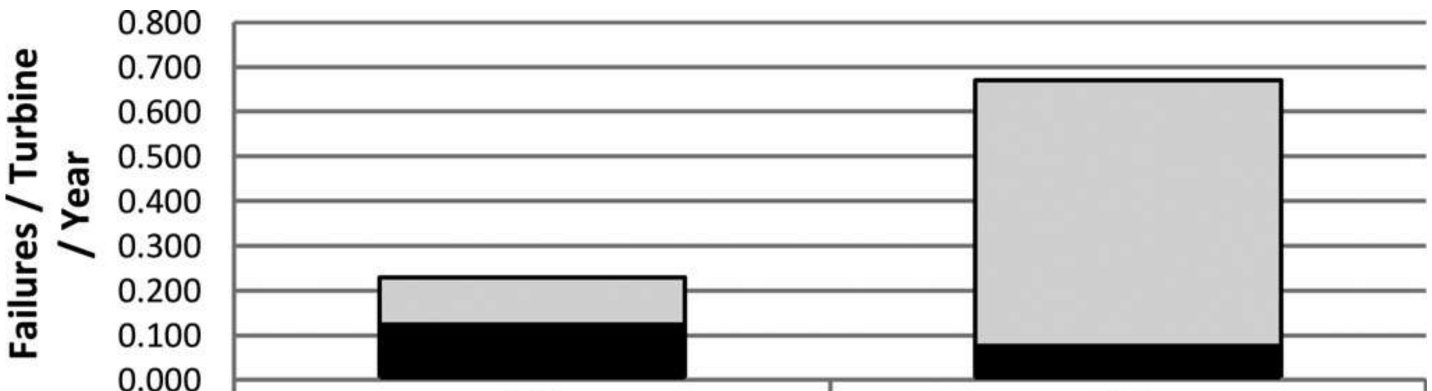
DFIG vs PMSG



	DFIG	PMG
Converter	0.106	0.593
Generator	0.123	0.076
	0.229	0.669

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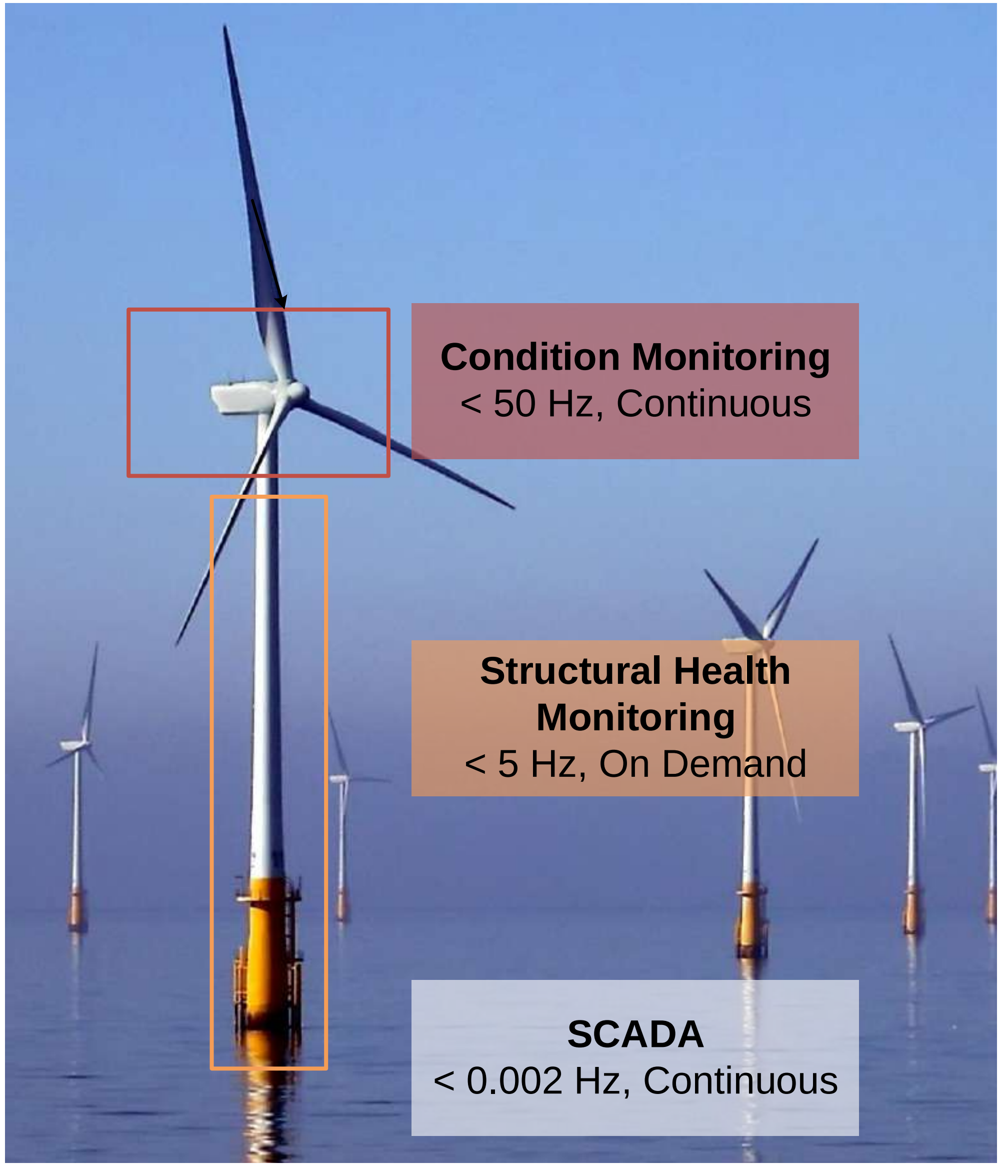
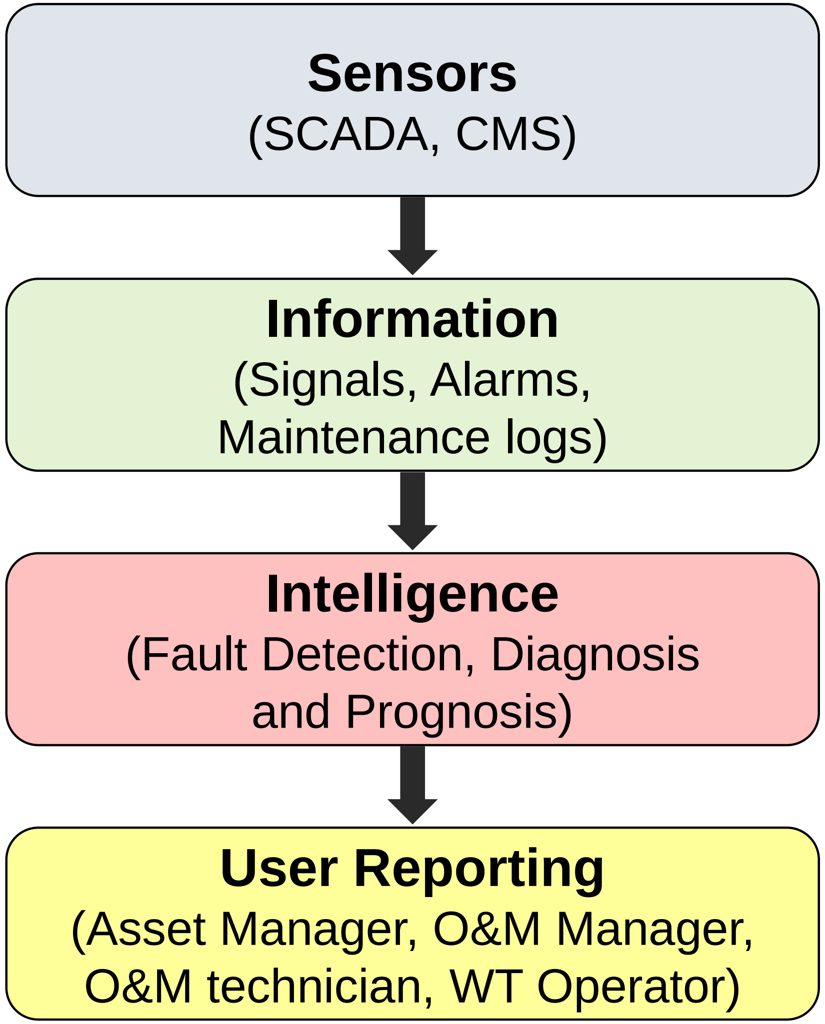
Source: Carroll et al., IEEE Trans. Energy Conversion, 2015

Cost-effective Condition Monitoring





How Are We Doing?

Sensors	Information	Intelligence	User Reporting
Large choice of sensors available. Challenge is to decide which can provide meaningful signals.	Potentially lots of SCADA and CMS data available. Need to filter what is and what is not suitable. Need standardisation of data and reporting.	Some ability to detect faults. Diagnosis of specific faults limited. Prognosis still difficult.	Difficult to interpret some of the intelligence. No real demarcation of reporting depending on user requirements. Danger that users are 'swamped' with unnecessary information.
9/10	**7/10**	**5/10**	**2/10**

Conclusions

O&M contributes up to around 34% to the cost of wind energy

CBM minimizes O&M costs → reducing inspection visits and corrective maintenance actions

Reliability data is essential to identify the most critical components and perform failure mode and symptom analysis.

Reliability studies show variation, however, generally…

- Offshore: greater failure rates and downtime than onshore
  → severe offshore operating environment
  → difficulty in repair/maintenance accessibility
- Electrical systems have highest failure rate
- Generators and gearboxes contribute most to downtime

Advanced monitoring techniques, using existing SCADA and CMS data, are essential for effective CBM

Thank you for your attention

Any questions?

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