Living Lab 70 GW Offshore Wind

FACT SHEET

Condition monitoring of offshore wind turbines:

Lifetime prediction and predictive maintenance

When wind farms reach their design lifetime, knowledge about their actual remaining lifetime becomes essential for planning their future use. Various uncertainties, such as changing weather conditions, irregular loads and unforeseen operating events, can cause the actual lifetime to differ from the lifetime assumed during design. Condition monitoring provides insights into the factors influencing lifetime. It enables precise monitoring of structural condition, allowing predictive maintenance, more accurate lifetime assessments, reduced downtime and maximised operating periods.

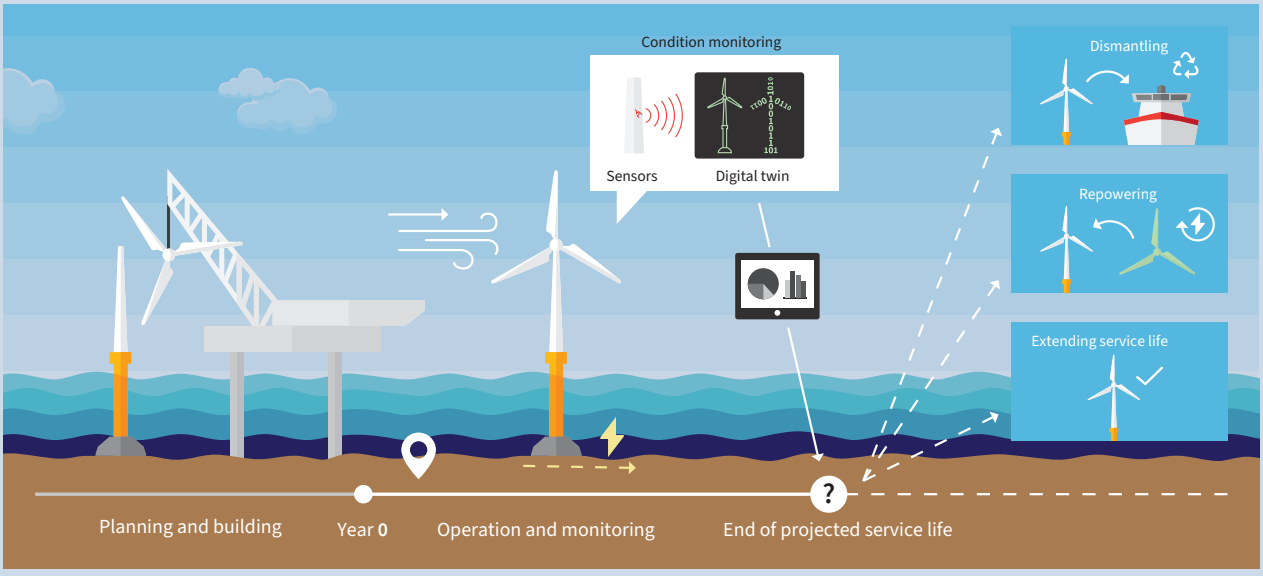
- **Monitoring strategies aim to improve lifetime estimates for the support structure (tower and foundation structure), enabling service life extension.**
- **For rotor blades, measurement data are used to determine the actual stresses experienced. Finite element models are then developed to estimate fatigue and service life.**

▸ Why is offshore wind expansion in the German Bight necessary? Reaching the target of 70 GW of offshore wind capacity by 2045 requires innovative solutions across the entire value chain. Living Lab 70 GW Offshore Wind investigates how existing and future wind farms can be planned and operated more efficiently, and how marine space can be used and protected effectively and sustainably, taking account of competing interests such as fishing, shipping and nature conservation.

▸ This project aims to enable low-maintenance operation and to use condition monitoring to assess, predict and, where possible, extend the service life of offshore wind turbines. It also investigates which sensor configurations and measurement periods are needed for reliable monitoring, and how findings from one turbine can be transferred to others.

Life cycle of offshore wind turbines

During the operational phase, condition monitoring provides precise monitoring of structural condition, for example to detect damage in real time. At the end of the predicted service life, the insights gained can be used to make informed decisions about future use: decommissioning (dismantling and shutting down the turbine), repowering (upgrading or replacing the turbine), or service life extension (continued operation through maintenance).



- **The structural condition of wind turbine components (support structures and rotor blades) is continuously monitored using sensors.**
- **Predictive maintenance to locate potential damage and minimise maintenance costs and operational downtime.**

► Condition monitoring bridges the gap between the assumptions made during design and the actual environmental and operating conditions experienced by turbines. It enables early damage detection, supports predictive maintenance strategies and provides insights into how real loads and environmental influences affect the stresses experienced by turbines. This makes it possible to identify influencing factors and reduce unplanned downtime, which can ultimately improve estimates of wind turbine service life.

► Offshore wind turbines are subject to many forms of uncertainty, both external, such as scour formation or varying environmental conditions, and structural, such as differences between the actual geometry and material properties of support structures and rotor blades and the values assumed in the design. These challenges must be addressed to understand the factors that influence service life.

- **Digital twins and virtual sensing provide insights into actual loads and support lifetime estimation.**
- **Fatigue damage in rotor blades can be investigated using numerical simulations under site-specific loading conditions.**

► Digital twins of wind turbines integrate condition monitoring data to provide real-time insights into actual loading conditions. Virtual sensing also allows monitoring of areas without direct sensor coverage. Extrapolation over time can support lifetime estimation when measurements are available for only limited periods. Based on SCADA data, rotor blade loads can be determined using blade element momentum theory. Fatigue damage is simulated using progressive energy-based fatigue damage models.

- **What are the optimal strategies for wind turbine condition monitoring?**
- **Can control strategies be optimised to reduce fatigue damage and maximise service life?**

► The project will address the following open research questions: How can measurement data be used in wind turbine life cycle management? What sensor configuration and data collection period are optimal? In addition, how can condition assessments be transferred from one wind turbine to others? Finally, which strategies can be used to slow the progression of damage in support structures and rotor blades and achieve the maximum service life of the turbine?

- **Improved lifetime estimation and damage prediction support targeted maintenance and reduce downtime.**
- **Minimal sensor instrumentation and models for transferring monitoring results from one turbine to similar turbines enable cost-effective monitoring of entire wind farms.**

► Offshore wind farm operators benefit from more precise lifetime estimates, reduced downtime and better-informed maintenance planning. By identifying areas susceptible to fatigue and analysing damage progression under site-specific conditions, the project aims to enable optimised operation with targeted interventions. Minimal sensor requirements and transferable models reduce the long-term monitoring effort and support cost-effective scaling across a fleet. This can directly contribute to longer service life, increased efficiency and improved economic profitability of offshore wind energy.

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