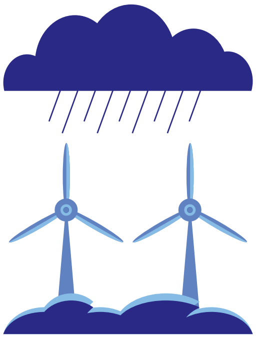
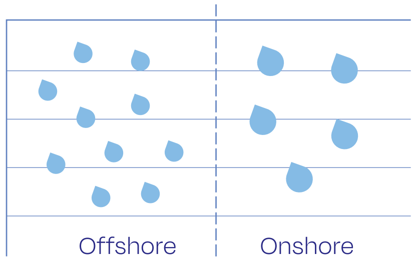
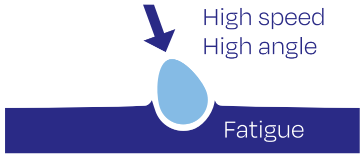
High tip speeds, combined with frequent precipitation and harsh conditions, are the leading cause of blade erosion



Rain droplets are smaller but more numerous offshore

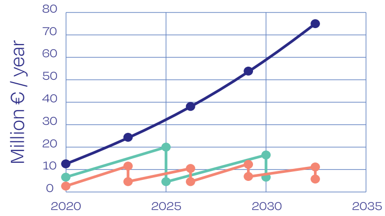


Fast travelling blades hitting droplets cause significant damage at the blade leading edges

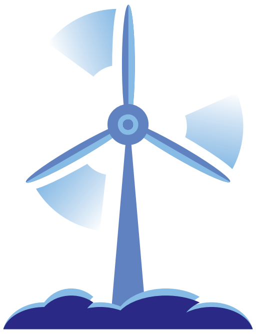


Blade leading-edge erosion causes up to €1.3 million per turbine for its entire lifetime

Total financial loss of electricity due to blade leading-edge erosion for all offshore wind farms in Belgium



Offshore turbine tip speeds can be up to 30% higher than for onshore turbines



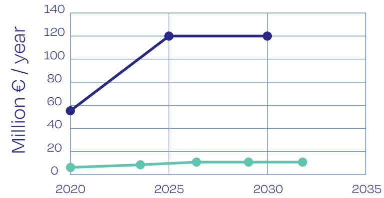
Erosion level	1	2	3	4
Example picture of a blade's leading edge				
Typical cumulative exposure time (yr)	0 → 10			

Picture adapted from Eisenberg et al., DOI: 10.1002/we.2200

Potential losses in AEP due to leading-edge erosion are reported in literature to vary between 1 and 5 %.

Herring et al., DOI: 10.1016/j.rser.2019.109382

Repair costs of all offshore wind turbine blades in Belgium



Today's practice: major repairs
Solution: minor repairs supported with innovative inspection and monitoring

For the next generation of wind farms (2030) → **New materials and new protection systems** → **More protected wind turbine blades** → **Longer lifetime**

Existing or newly build wind farms (until 2024) → **The solution for lower levelized cost of energy is minor repairs with innovative monitoring**

Enhance the maintenance planning and operational control of current and future offshore wind farms in Belgium

BLEEPID project | executive summary

Blade **L**eading-**E**dge **E**rosion **Pr**ediction and **D**rone-based **I**nspection

By leveraging cutting-edge technology, rigorous experiments, and advanced modelling techniques, the BLEEPID project strives to enhance maintenance practices, optimize operational control, and minimize leading-edge erosion in Belgian offshore wind farms. Ultimately, these efforts aim to improve the efficiency, reliability, and sustainability of wind energy generation.

UGent in collaboration with Sirris, and ENGIE Laborelec, has initiated the BLEEPID project to enhance the maintenance planning and operational control of current and future offshore wind farms in Belgium. This endeavour employs camera-equipped drones for remote inspection of wind turbine blades, enabling accurate assessment of erosive wear of the blades' leading edges through precise imaging and comprehensive wear characterization via experiments and multi-physics modelling.

4 key objectives

The project aims to achieve four key objectives, each contributing to the reduction of leading-edge erosion (LEE):

1. **Development of image capture and analysis methods:** The project focuses on creating high-precision drone-based inspections specifically designed for LEE identification.
2. **Advancement of predictive maintenance tools:** By developing both data-driven and physics-based models, the project seeks to establish reliable tools for predicting the progression of leading-edge erosion. These models will consider factors such as the blade's current state and precipitation parameters.
3. **Comprehensive understanding of liquid droplet impact:** Controlled experiments and multi-physics modelling will be conducted to gain detailed insights into the effects of liquid droplet impact on representative leading-edge protections. This research aims to improve the durability of materials used in future wind farm constructions or establish minimum specifications for leading-edge protections for wind park owners.
4. **Socio-economic impact assessment:** The project intends to develop a framework and model to evaluate the socio-economic implications of the newly developed LEE detection and prediction models. This assessment will include factors such as the levelized cost of energy (LCOE) and carbon footprint. Furthermore, the project plans to simulate the socio-economic impact of these models on the Princess Elisabeth offshore wind farm development zone.

4 Work Packages

- **Perform drone-based high-accurate 3D reconstruction of the blade's leading edge**, to perform AI-based quantitative damage assessment from the acquired 3D model under varying environmental conditions and to translate these findings to optimize LEE inspection in the field.
- **Replicate accurately the fundamental process of Liquid Droplet Impingement Erosion (LDIE)**, the primary cause of leading-edge erosion (LEE), **on laboratory scale**. This involves developing and equipping novel lab-scale apparatus to quantitatively examine and monitor droplet impacts on curved polymer-composite surfaces. The equipment will allow for controlled conditions, including droplet formation and air-flow, to study the initiation and progression of damage resulting from droplet impacts.
- Create a simulation framework to elucidate **the micro-scale erosion process caused by liquid droplet impact on leading-edge materials** using multi-physics modelling. This iterative modelling approach combines fluid-structure interaction simulations of high-speed droplet impact, continuum modelling to obtain hydrostatic pressure and shear stress profiles, and particle-based solid structure simulations to incorporate fatigue modelling.
- Develop a framework to **evaluate the overall cost impact of the advanced LEE modelling and monitoring methods and combine it with a novel carbon footprint model**. A systems engineering approach will be employed by taking the entire life cycle of an offshore wind farm into account. The Princess Elisabeth offshore wind development zone will be modelled and the impact of the new LEE model and detection methods will be evaluated on this location.

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