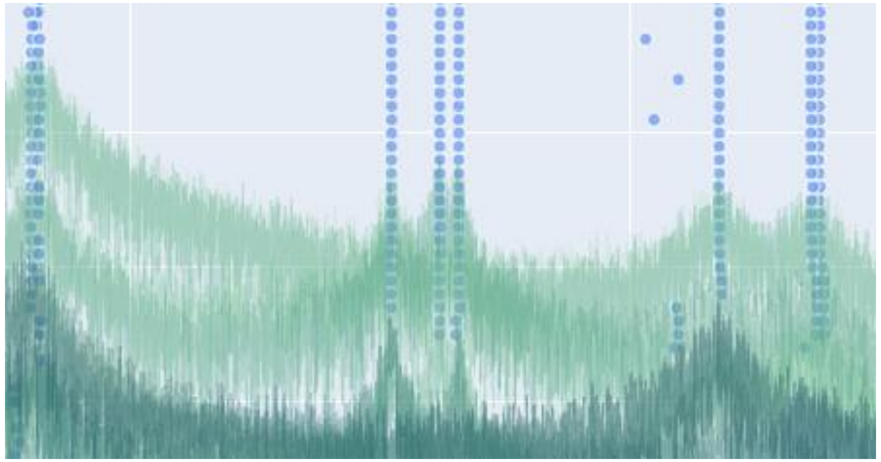
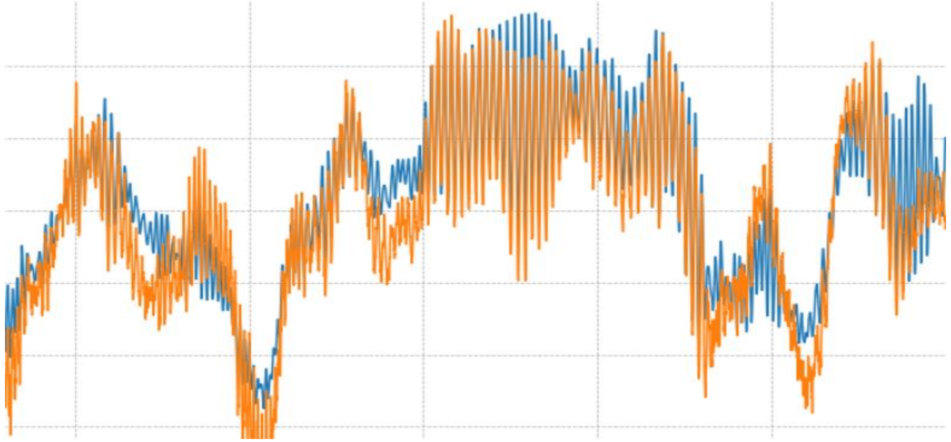



# ANOMALY DETECTION

## FOR OPTIMIZING OPERATION & MAINTENANCE OF WIND FARMS

Jean-Lou PFISTER & Pascal DUCHÊNE, IFP Energies nouvelles

Master GDM project, 25/01/2025, IFP School




Energies nouvelles

# MODERN WIND ENERGY IN (VERY) SHORT

**Massive dynamic structures:**
the world's largest rotating machines, designed for millions of cycles


*How to assess the structural integrity?*

**Mass production:**
Hornsea 2 offshore wind farm → 165 turbines ; 1.3 GW capacity[1]

*How to plan maintenance?*

**Great variety of operational conditions:**
onshore, offshore and floating offshore installations with stochastic loading

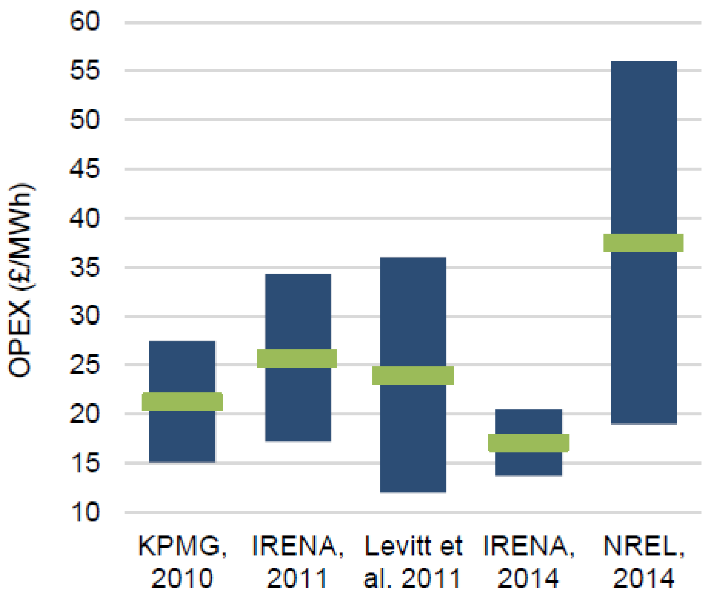
*How to adapt to changing conditions?*



[1] https://orsted.com/en/media/news/2022/08/20220831559011

# MAINTENANCE COSTS ARE SIGNIFICANT IN OFFSHORE WIND

- Operation & maintenance costs typically account for 20% to 25% of the total cost of electricity




**Range values of operations & maintenance expenditures (OPEX) in existing literature (2015£)[1]**

**Example** : offshore wind farm of 500 MW with capacity factor of 40% (e.g. St-Brieuc wind farm, France)

- Electricity revenues (fixed feed-in tariff hypothesis)
  - 155 €/MWh (St-Brieuc) : 270 M€/year[2]
- Operations & maintenance expenditures (OPEX) per year
  - lower bound : about 30 M€/year [10% of revenue]
  - upper bound : more than 100M€/year [37% of revenue !]

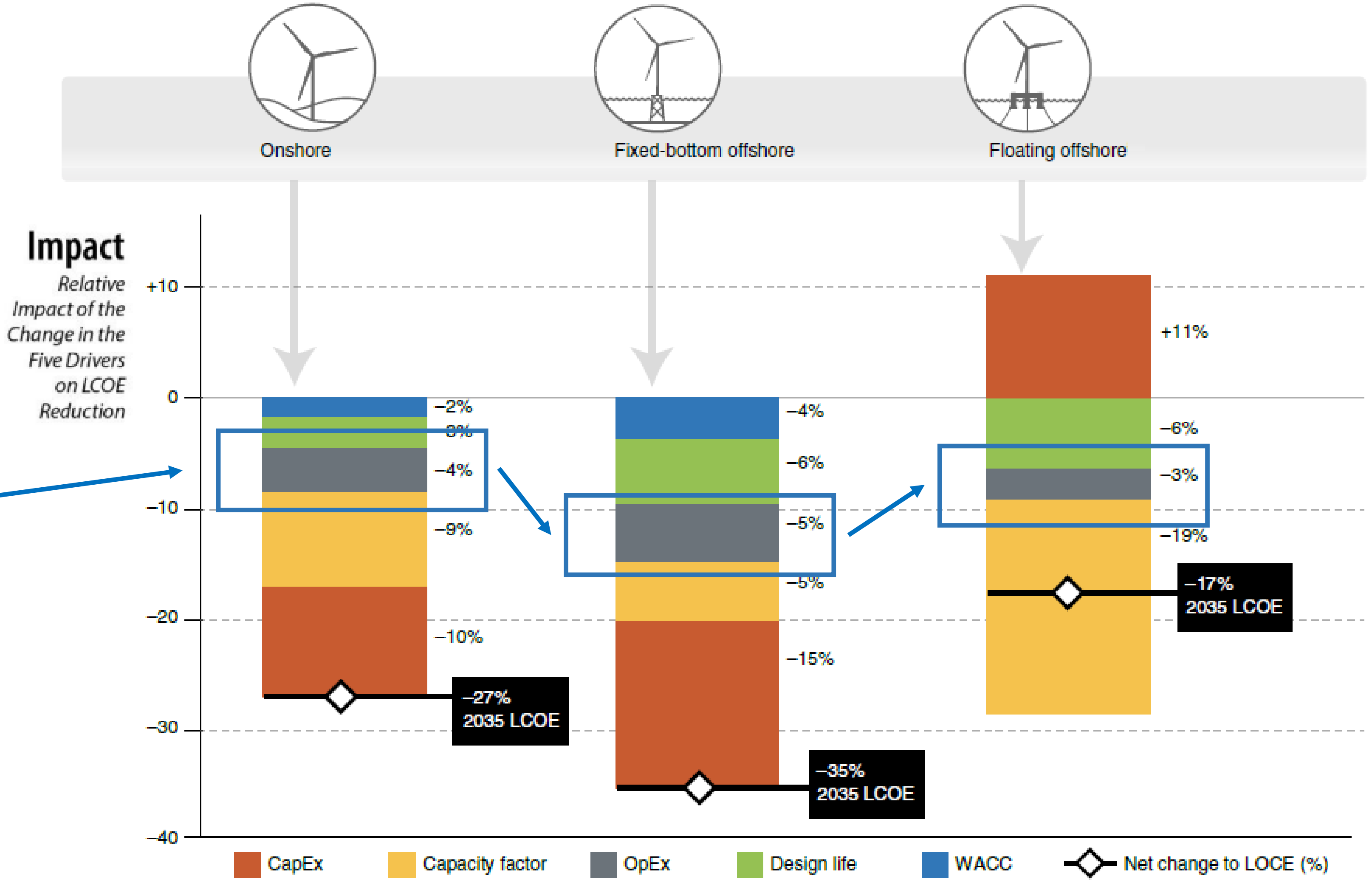
- To keep pace with the need for falling offshore wind electricity prices (new FiTs less than 50€/MWh[3]) , we also need to reduce maintenance costs.

[1] Kolios et al. ROMEO EU project deliverable D8.1
[2] Feed-in tariff for French AO1 tender (2011) https://www.eoliennesenmer.fr/facades-maritimes-en-france/facade-manche-mer-du-nord/projet-centre-manche/centre-manche-1
[3] Feed-in tariff for French AO4 tender (2021) https://www.eoliennesenmer.fr/facades-maritimes-en-france/facade-nord-atlantique-manche-ouest/saint-brieuc

# O&M IS CONTRIBUTOR TO WIND ENERGY COST DECREASE

Breakdown of contributions to wind electricity cost reduction in 2035[1] →

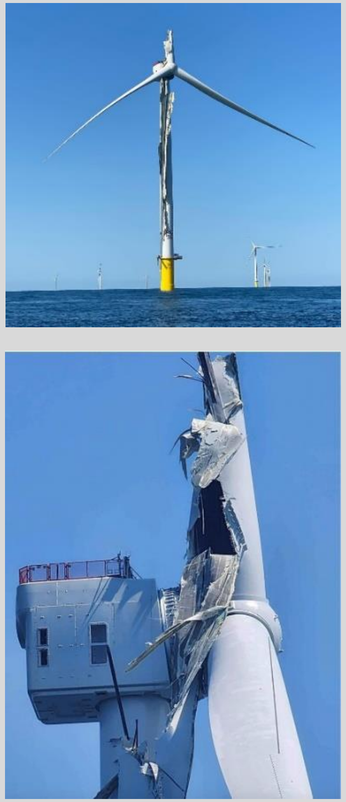
- Significant room for improvement forecasted by experts
- OpEx (operation & maintenance expenditures) counts by about **15-20% of the cost reduction effort**






[1] Wilser et al. Expert elicitation survey predicts 37% to 49% declines in wind energy costs by 2050, *Nature Energy* (2021)

# WHAT MAINTENANCE IS SUPPOSED TO PREVENT

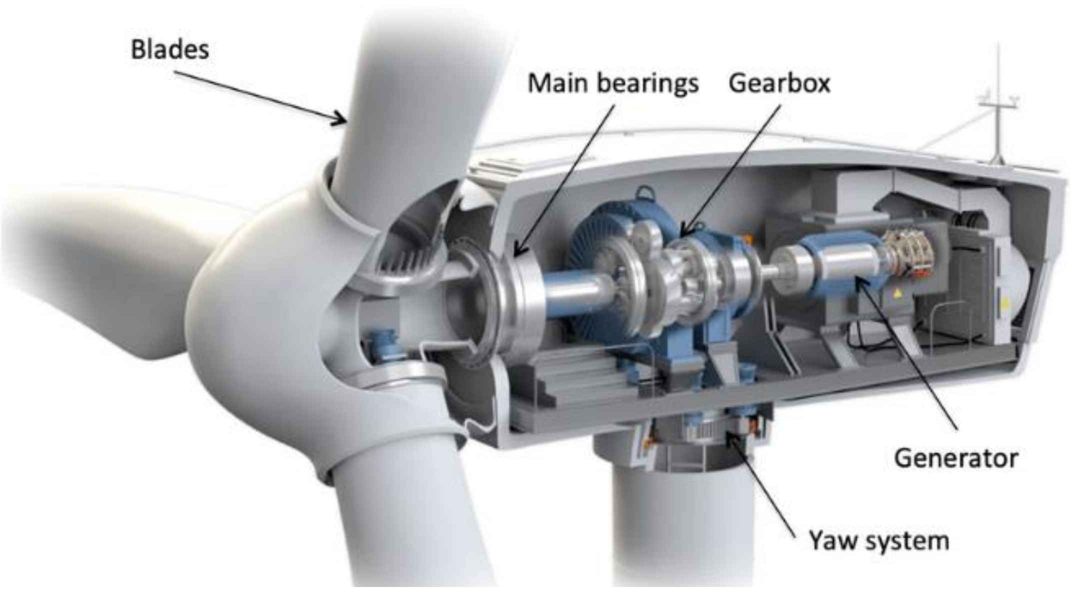


2024 Vineyard wind farm blade failure

*Abrasive wear of bearings*[1]

*Gearbox gear failure*[2]

*Generator windings failure*[3]

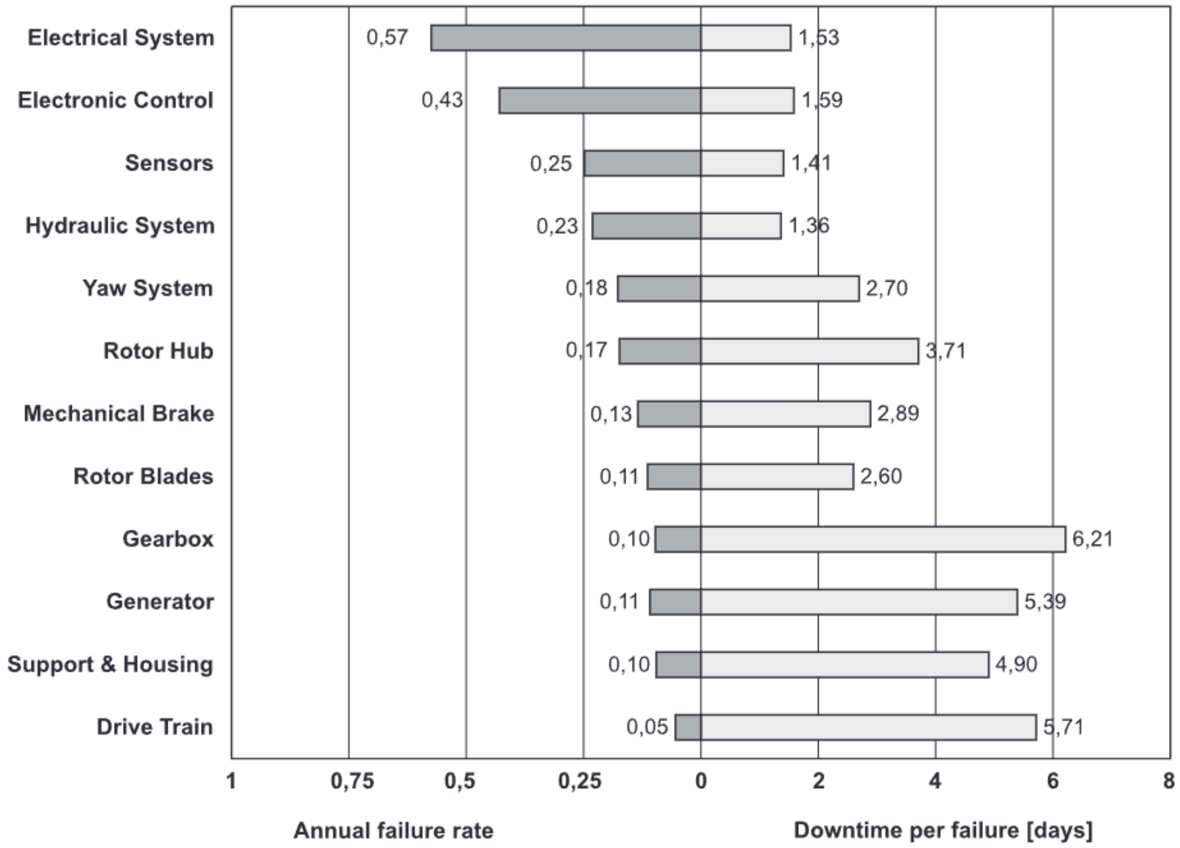



*Oil leaks*[4]

[1] Liu & Zhang, Measurement 149 (2020)
[2] Peng et al. Sustainability 15 (2023)
[3] Alewine & Chen, IEEE (2011)
[4] https://www.laiier.io/use-cases/wind-turbine-oil-leaks

# MAINTENANCE CRITICALITY PER COMPONENT

Reliability characteristics for different wind turbine subassemblies, from a dataset of 64k maintenance reports covering 15k operational turbine-years[1]




Major faults (>1 downtime days) represent 25% of all failures but account for 95% of the downtime:
→ interest for predicting the failures *before* they become major



[1] Faulstich, Hahn & Tavner, Wind turbine downtime and its importance for offshore deployment, *Wind Energy* 2011

# Predictive maintenance: why? how?

# THREE TYPES OF MAINTENANCE

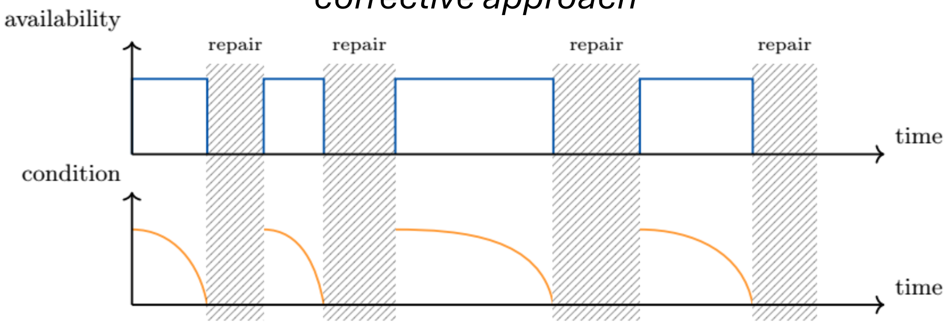
- **Corrective maintenance : when something fails, we repair it**
  - pros : cheap when there are no failures
  - cons : risk of severe failures, unanticipated repairs

- **Preventive maintenance : we plan regular inspections**
  - pros : should make it possible to avoid severe defects
  - cons :  can lead to over-maintenance of the assets

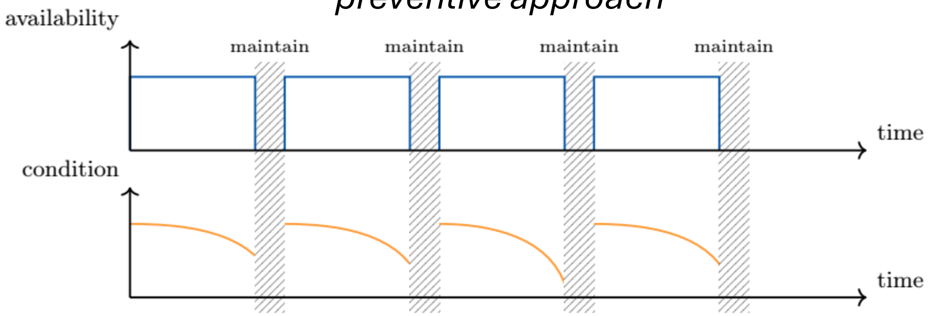
- **Condition-based maintenance : we plan maintenance based on health indicators**
  - pros : optimum maintenance planning
  - cons : indicators threshold are difficult to establish & requires a condition monitoring system

If we monitor enough data & have a failure database, we may design data-based condition-based maintenance

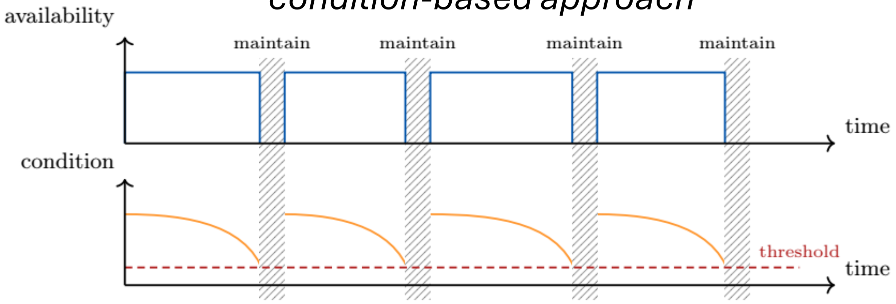
*corrective approach*




*preventive approach*




*condition-based approach*



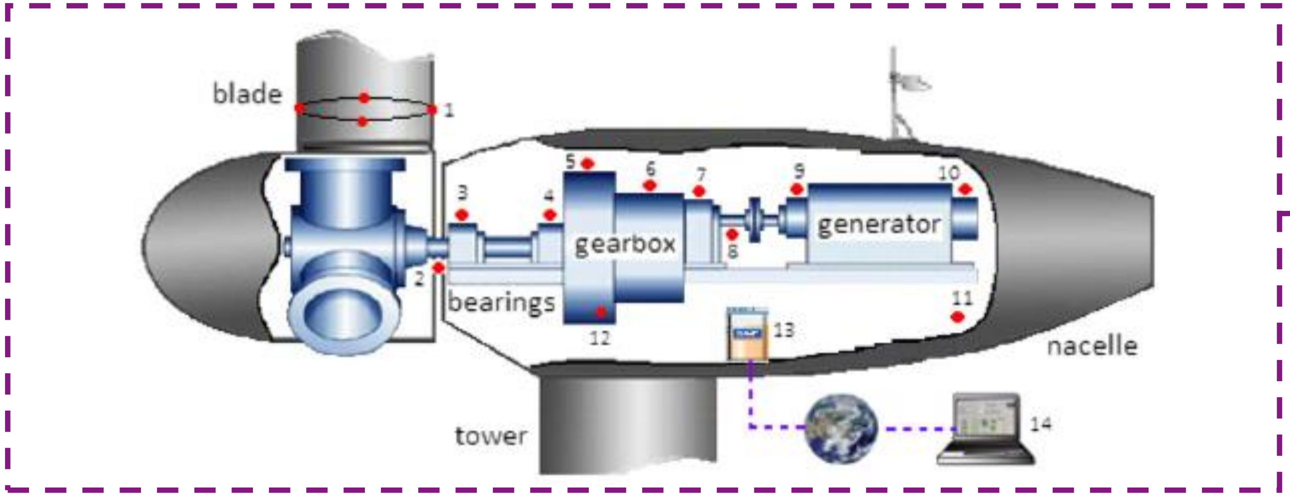



[1] Gück et al. arXiv preprint arXiv:2404.10320, 2024 - arxiv.org

# CONDITION MONITORING SYSTEMS

**Condition monitoring system** : set of sensors used to monitor industrial assets in real-time, then centralize and make data available for further analysis[1] by means of a Supervisory Control And Data Acquisition (**SCADA**) system.

- We will focus on components in the wind turbine nacelle, where energy conversion takes place




1 --- fibre optic transducers; 2, 8 --- speed transducers; 3, 4, 5, 6, 7, 9, 10, 11 --- accelerometers;
12 --- oil debris counter; 13 --- online CMS; 14 --- PC at control center.

- Typical sensors: wind anemometer, temperature sensors, hydraulic pressure gauges, electrical currents and intensities measures, etc. → typically about O(100) data channels in modern wind turbines, per 10-min time intervals.

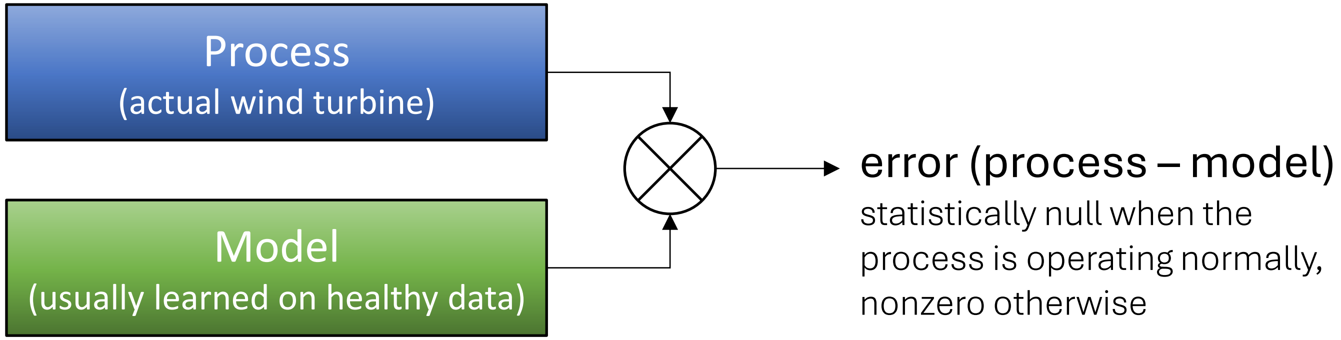
[1] Yang et al. Wind Energ. 2014

# SCADA ANALYSIS FOR EARLY FAULT DETECTION

- Main challenge → how to interpret trends given the variability in the operational conditions?

- Many possible approaches[1]
  - **trending** : try to identify anomalies in relative parameter changes
  - **clustering** : regroup data in *healthy* vs. *damaged* group based on some distance measure
  - **normal behaviour modelling** : compare actual measurements with a model of the normal behaviour

- Focus on NBM:




[1] Tautz-Weinert & Watson IET Ren. Pow. Gen. 11 (2017)

# Project objectives & deliverables

- Project team:
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# DATA-BASED ANOMALY DETECTION CLASSIFIER

- **Project objective** : based on an open-source dataset, train and test machine learning model(s) for anomaly detection

- **Inputs** : wind turbine SCADA datasets (see next slides) & companion papers[1][3]

- **Deliverables** :

  - Working computer codes implementing the data cleaning & summary, training and test metrics for the classifier(s)
    - preferred output : Python notebooks
    - code architecture advice : methods wrapped in a module + scripts in the notebook(s)

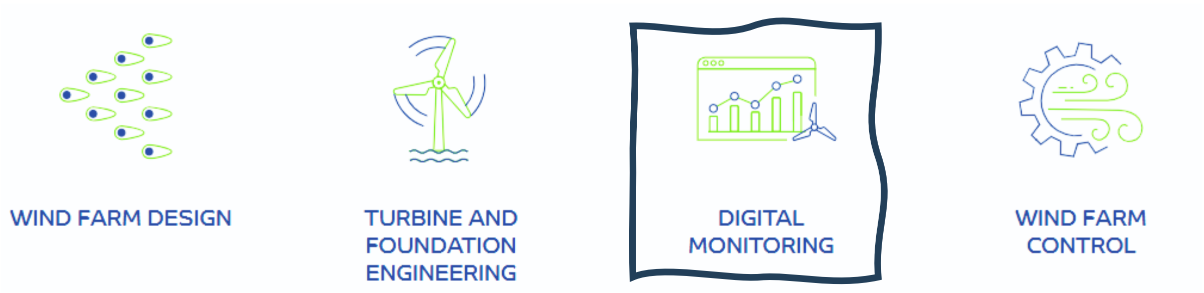
  - Short summary report summarizing the chosen approach, reasons for technical choices, main outcomes of the study
    - can be integrated in the notebooks or sent as a separate PDF
    - the choice of the classifier is to be determined based on your literature survey (start e.g. by reading the related papers)[1][2][3]

[1] Gück et al. arXiv preprint arXiv:2404.10320, 2024 - arxiv.org
[2] Roelofs et al. Energy & AI 2021
[3] Marti-Puig et al. Nature Scientific Data 2024

# GREENWITS AS PROJECT BENEFICIARY

- Creation of the subsidiary company GreenWits[1] by IFPEN in 2023
  - commercial relay for the deployment of IFPEN's R&D solutions in wind energy,
  - organized in four offers :

predictive
maintenance
solutions here




- Outcomes of the projet will be shared with the digital monitoring group of GreenWits

[1] https://www.greenwits.com/

# Project dataset overview

# "CARE TO COMPARE" DATASET

A real-world dataset for anomaly detection in wind turbine data[1]

**Project input** : an open-source wind turbine SCADA datasets with labeled anomalies

https://zenodo.org/records/14857470

- Data records (anonymized for confidentiality reasons)
  - Wind farm A → 5 wind turbines of an onshore wind farm in Portugal
  - Wind farm B → offshore wind farm in Germany
  - Wind farm C → offshore wind farm in Germany
  - Total : 36 wind turbines and 89 operation-year data

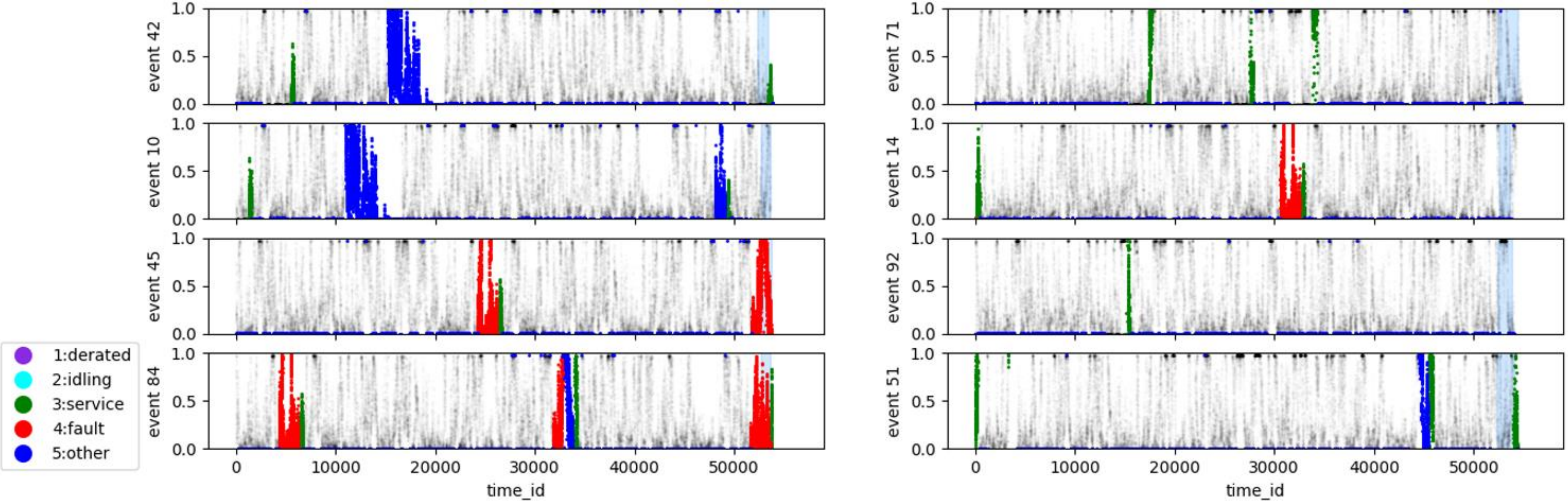
- Type of data
  - labeled anomalies : nature and time of occurence
  - 10-min periods with mean,max/min,std
  - environmental conditions : wind speed & direction, temperature, ...
  - SCADA data from various wind turbine systems : temperatures, generated power, current intensities, ...



[1] Gück et al. arXiv preprint arXiv:2404.10320, 2024 - arxiv.org

# “CARE TO COMPARE” DATASET

Example of data (normalized power production)



# “FÜHRLANDER” DATASET

A real-world dataset for anomaly detection in wind turbine data[1]

**Project input** : an open-source wind turbine SCADA datasets with labeled anomalies

https://github.com/alecuba16/fuhrlander

- Data records
  - 3-years SCADA of five Führlander FL2500 2.5MW wind turbines

- Type of data
  - labeled anomalies : nature and time of occurence
  - 5-min periods with mean,max/min,std
  - environmental conditions : wind speed & direction, temperature, ...
  - SCADA data from various wind turbine systems : temperatures, generated power, current intensities, ...

[1] Marti-Puig et al. Nature Scientific Data 2024

# Here we go!

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