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Monitoring fatigue accumulation of offshore wind support structures

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Bremen
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Why monitor fatigue accumulation?

- Without monitoring, there is little insight in remaining lifetime
  - No insights in structural health
  - Accelerated fatigue accumulation is not picked up
  - Operations and **maintenance** could be optimized based on fatigue accumulation
- Support **lifetime extension**
- Reduce conservatism in future **designs**
- However, currently few foundations are actively monitored and instrumenting them is **expensive**.

Monitor Joint Industry Project

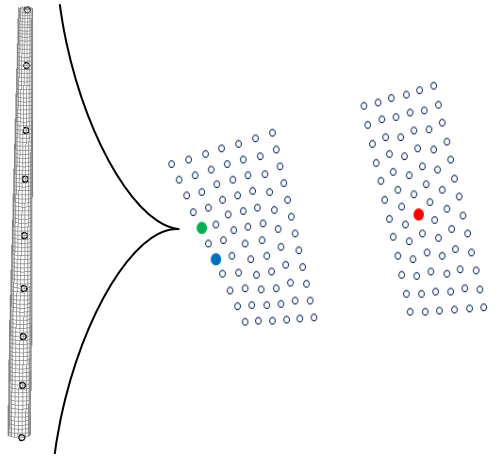


Two phases. Currently ~75% into first phase

- Phase 1: Develop methodology for a robust and *efficient* monitoring system
- Phase 2: Carry out monitoring campaign to validate tools & methodology

Our approach

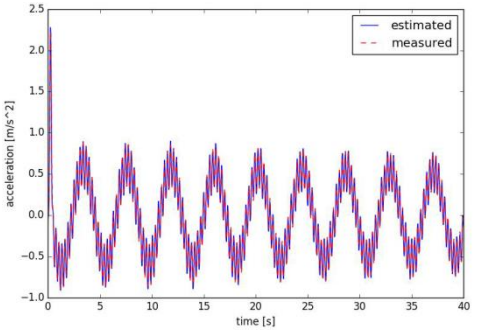
- Monitoring system single offshore wind turbine
  - Evaluation of hotspot stress
- Extrapolating findings throughout entire wind farm using ‘Fleet Leader’ concept
- Assessing uncertainties

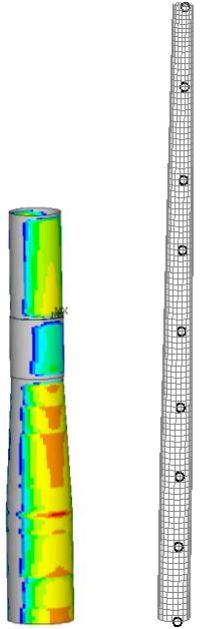


Monitoring system
- single offshore wind turbine

Monitoring system
- single offshore wind turbine

- Measure Strain & acceleration in transition piece & tower
- Using FE model and TNO ‘Optimal State Estimator’ to determine hotspot stresses
- Tested with simulated turbine response





Monitoring system
- entire offshore wind turbine

Monitoring system
- entire offshore wind farm

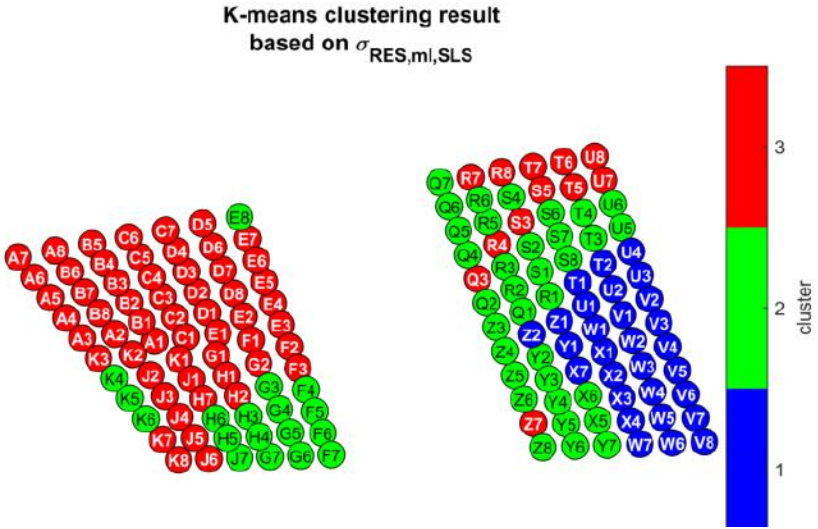
1. Define clusters of structures with similar structural behaviour.

2. Select a few turbines to instrument (‘Fleet Leaders’)

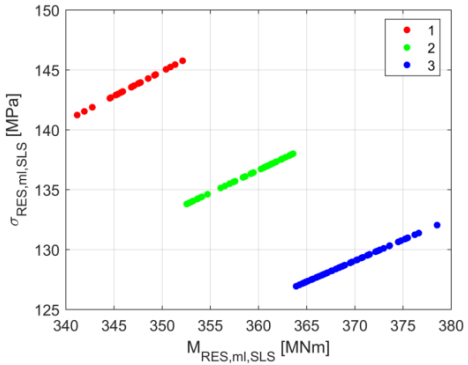
3. Find relations between standard turbine signals (SCADA) and hotspot stress by training artificial neural network.

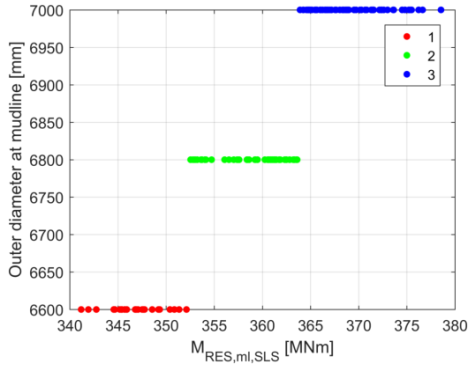
4. Use the relations to estimate hotspot stress at un-instrumented turbines, using standard SCADA signals as an input.

1. Clustering structural behaviour

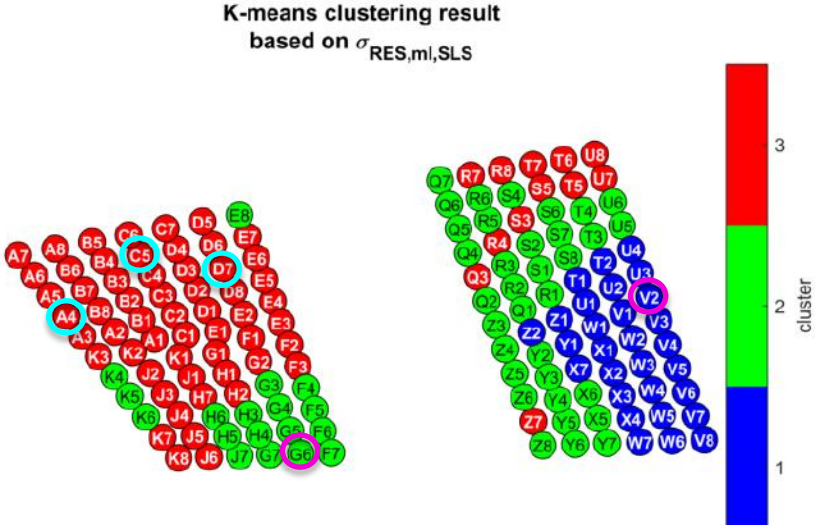


- K-means clustering algorithm
- SLS loadcase for all 150 turbines (design documentation)



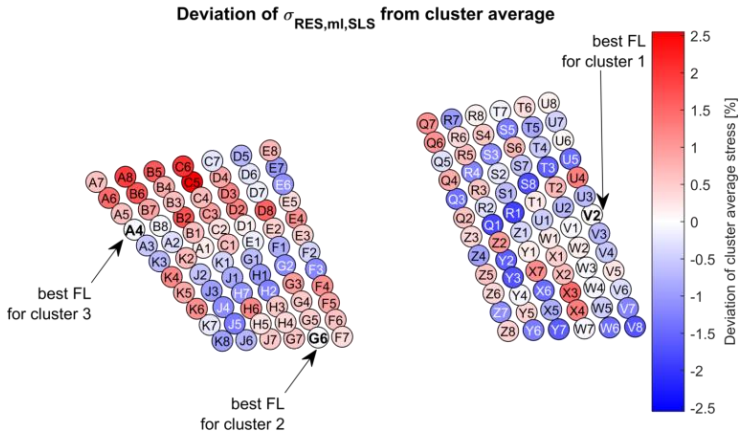


2. Select ‘Fleet Leader’ turbines

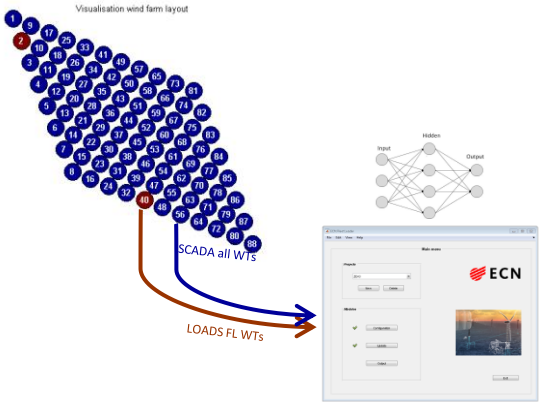


Take into account:

- Deviation from cluster average
- Wake effect
- Validation function
- Redundancy



3. Find relation SCADA and hotspot stress



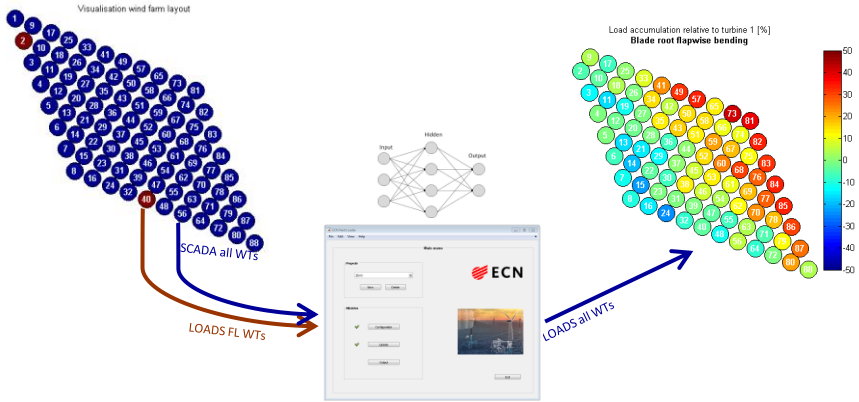
Train relations SCADA and hotspot stress in artificial neural network (instrumented turbines)

Categorization in operational mode and wake condition

SCADA: 10 minute statistics
Hotspot stress → Rainflow → fatigue equivalent

SCADA	LOADS
Generator power	Overturning moment
Rotor speed	Shear force
Pitch angle	Hotspot stress
(Acceleration)	

4. Determine fatigue at un-instrumented turbines



Use relations to estimate the loads of un-instrumented turbines for its own set of SCADA parameters

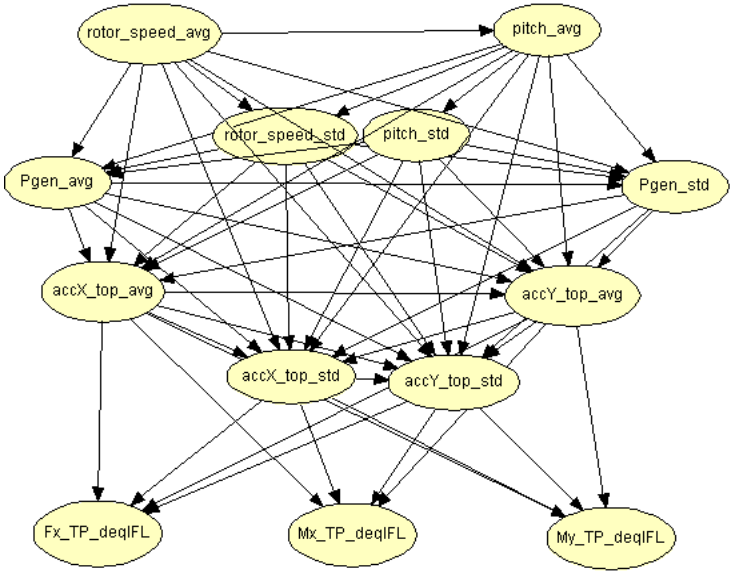
Validation using two sets of simulation data for different geometries

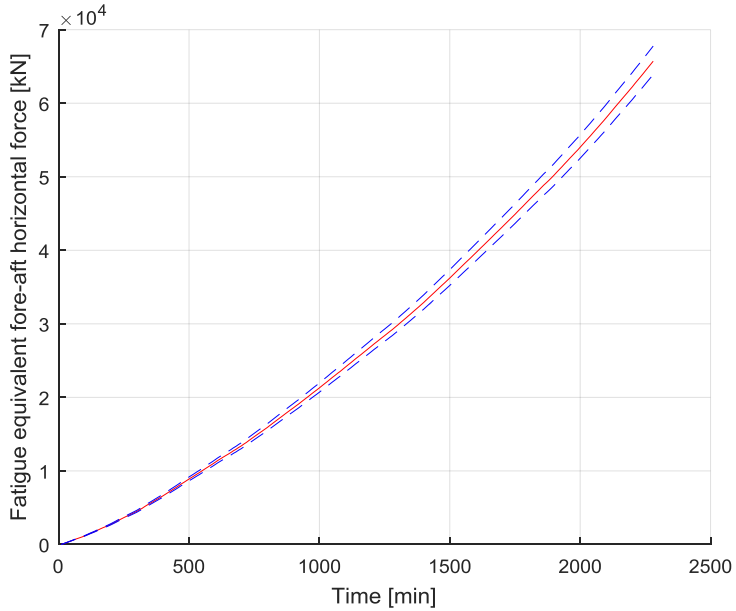
ECN Fleet Leader Concept has been proven in onshore and offshore test campaigns.

Uncertainty

Uncertainty

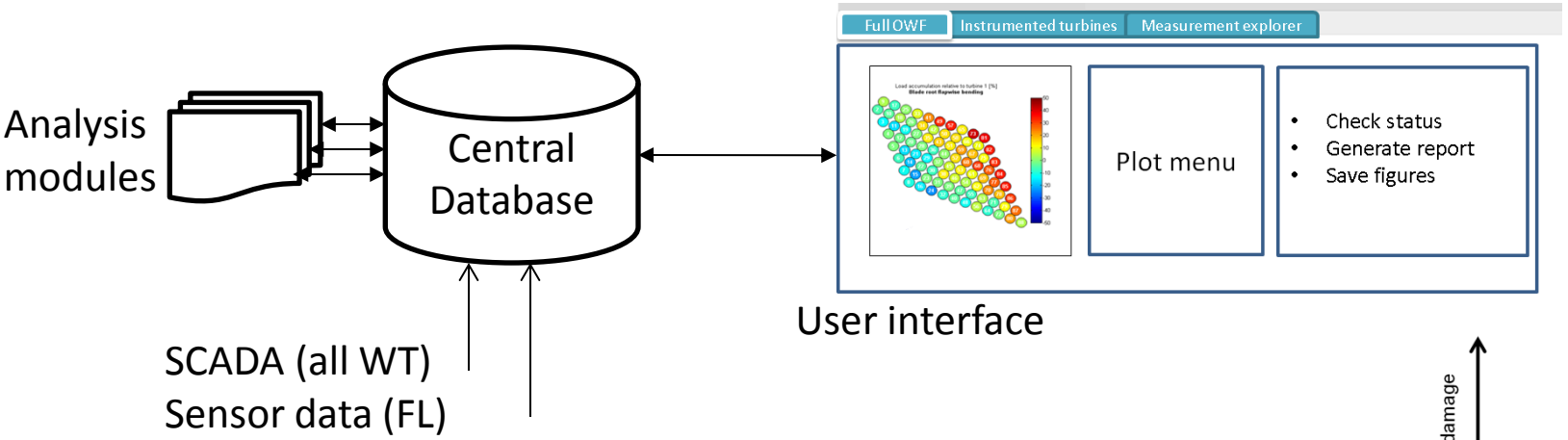
Bayesian network in TNO Multi Asset Correlation tool

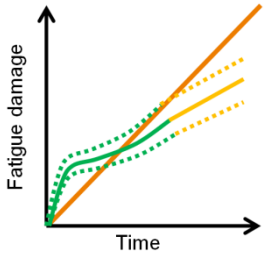




Future work

Finalize measurement plan and set up automated storage and data analysis.





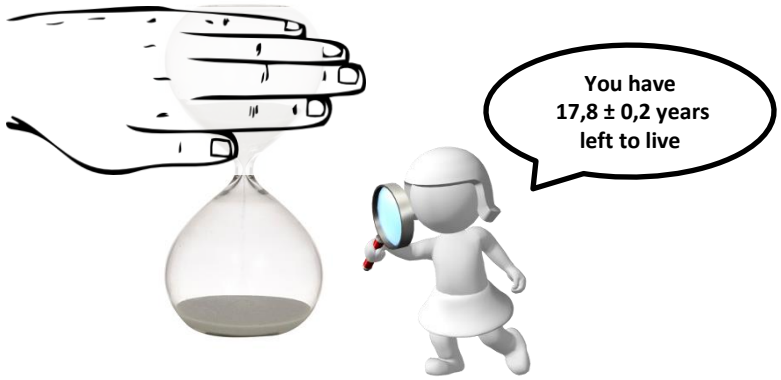
Technical recap

- Hotspot stresses can be found by measuring the **global dynamic response** of the support structure and applying Optimal State Estimator.
- Instrumenting all support structures is costly and unrealistic. **Fleet Leader** approach uses findings from a small set of instrumented turbines to estimate fatigue stress throughout the wind farm.
- The uncertainty in the predictions can be found using a **Bayesian network**.
- Because of the variation in structures, **clustering** is recommended to reduce the estimation errors.

Conclusions

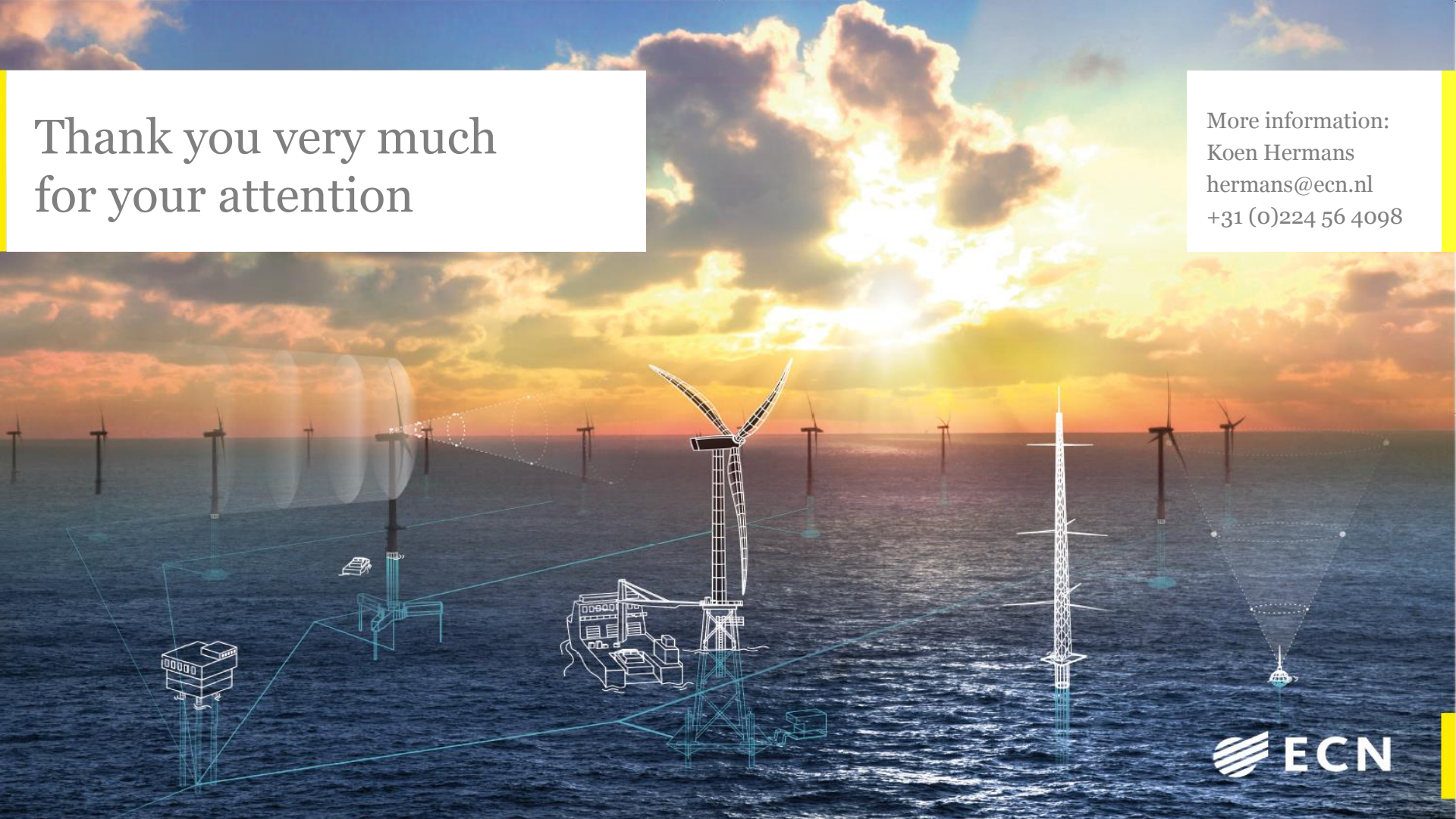
With the approach of this consortium, you can apply *less* sensors on *fewer* turbines, and get to know:

- Hotspot stress
    - Fatigue accumulation
        - Remaining lifetime
            - Uncertainty in predictions



Thank you very much for your attention

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Difference in structural behaviour

- Validating estimations with 2 simulation sets of three different turbines

