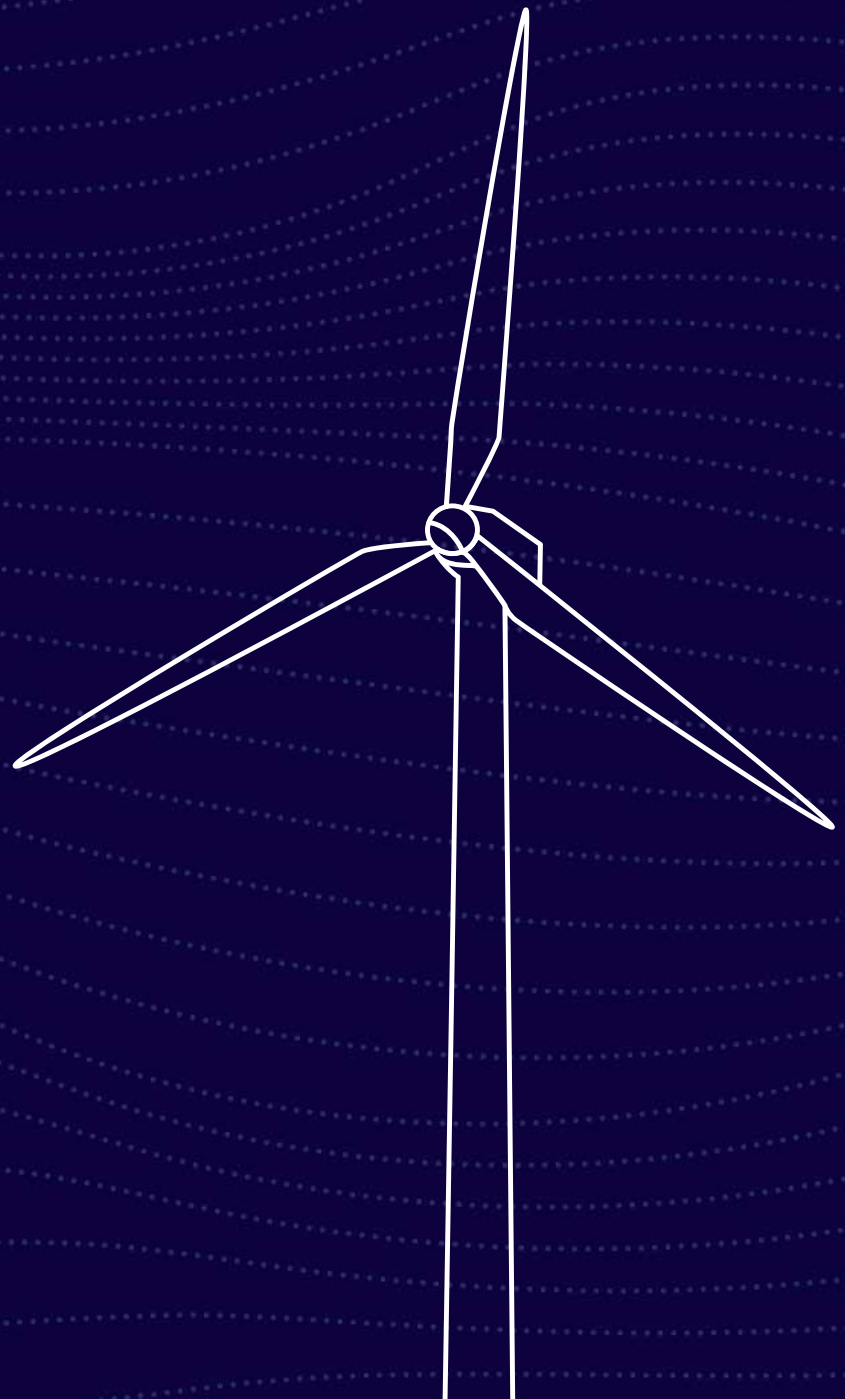
Wind Turbine Towers & Foundations health monitoring

Operation, repower and life extension plans



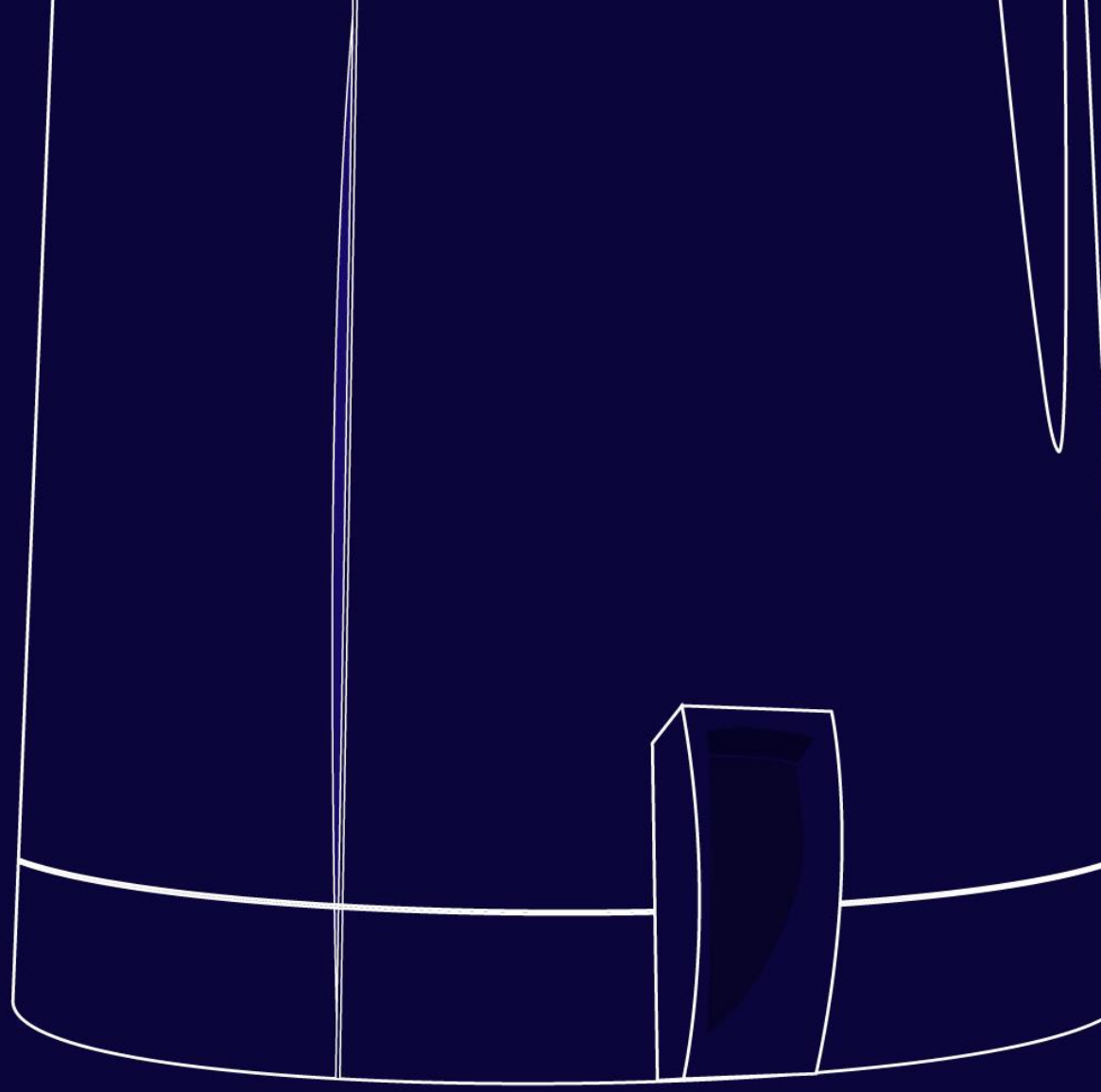
ONYX Insight

Wind farm life cycle

- **Repowering** and **life extension** are real and profitable opportunities under actual wind energy market situation.
- *"Up to **22 GW of onshore** wind turbines in Europe will reach the **end of the original design life by 2023**, of which **2 to 4 GW will be repowered**, and up to **18 GW** of units' **life will be extended**,"* Source: Uli Suedhoff, Director Business Development, EMEA at GE Renewable Energy

Foundations are critical to the success of partial repowers and life extension

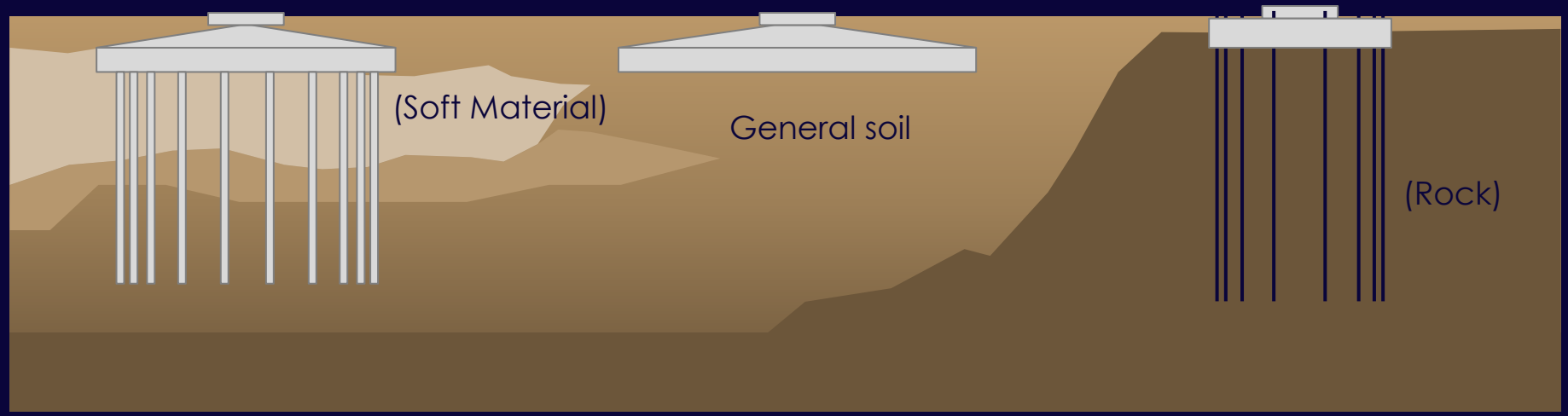
- By definition, the foundations are always reused
- Critical part for WTG integrity – Catastrophic consequences
- Analytical review - not enough
  Onsite checks – Destructive tests



ONYX Insight

Onshore foundations – types

	Piled / Deep Foundations	Gravity / Spread / Shallow Foundations	Rock Anchored Foundations
Ground Conditions	Compressible layers below the foundation	General conditions	Shallow bedrock



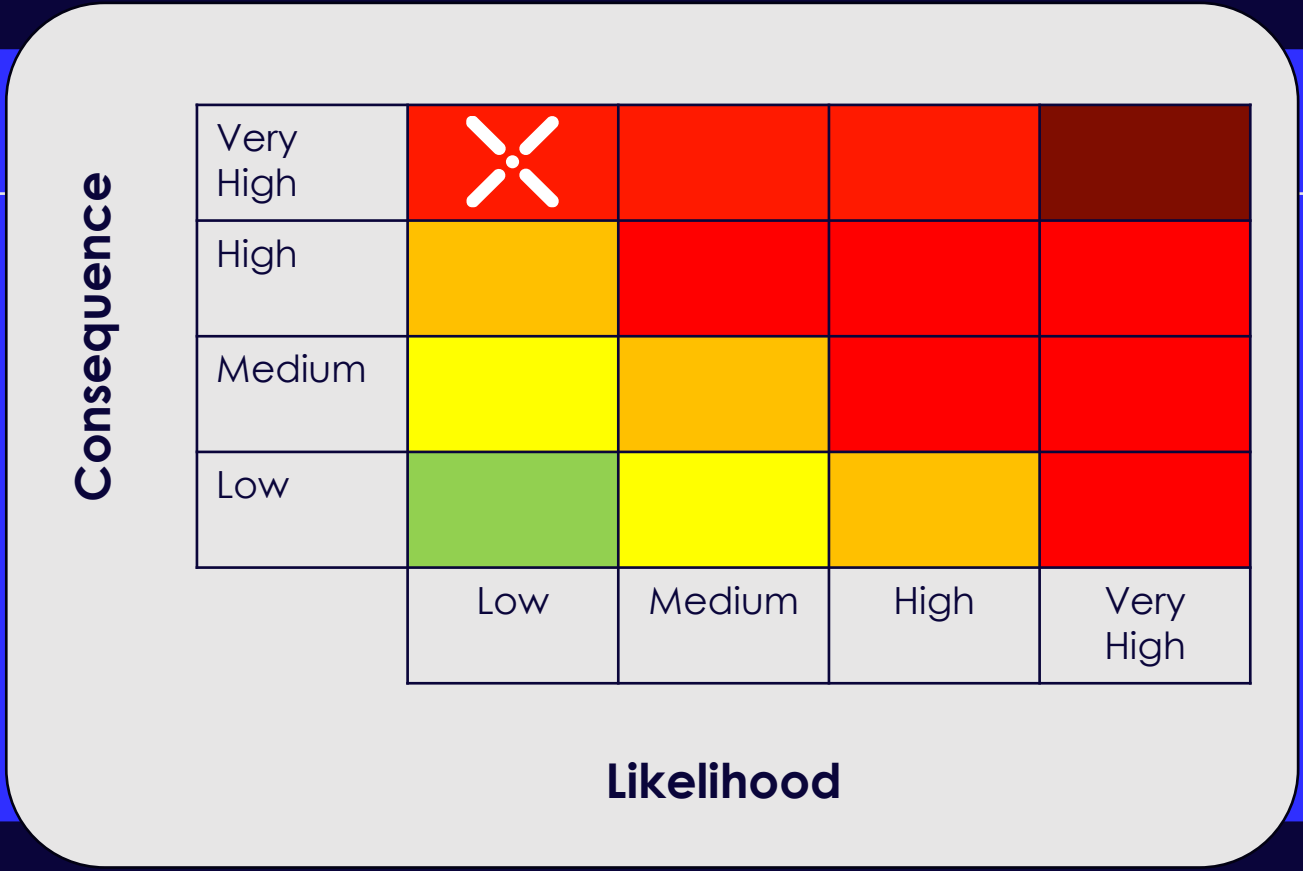
The Good (and Bad) News for Foundations

Low Likelihood – Very High Consequence

Likelihood

Catastrophic failures are rare
(1 in 10,000 in US & Canada)

Observed failures may not have been identified in an analytical assessment.



Consequence

Loss of the turbine

Economic impact
- Foundation retrofit or replacement for others
- Possible replacement of lost turbine

Negative publicity

ONYX Insight

Onshore foundations – health checks

- Foundation damage
  - Crack development
    - Concrete
    - Rebar
  - Material crushing and bursting
    - Concrete
    - Grout
  - Loss of anchor tension
- Geotechnical damage
  - Soil cracking
  - Settlement
  - Erosion

Grout failure

Concrete Cracking

Geotechnical Failure

Pedestal Pullout

Source: CBC - https://www.cbc.ca/news/canada/new-brunswick/cracks-in-foundation-led-to-wind-turbine-collapse-1.6312668

Using an Analytical Lifetime Evaluation

Strengths

- Analytical results, though not specifically predictive, are informative
- Illustrate the level of risk in comparison to other projects

Common pitfalls

- Misunderstanding the probabilistic basis
- Over-confidence in a positive result
- Ignoring an undesirable result

ONYX Insight

Onshore foundations – health checks

- Destructive tests – “Live” opinion
  Visual inspections of the concrete
- 90° around foundation – predominant wind direction mainly
- Rebar fractured? Damaged? Take some pictures
- Repair – Never reach the same quality after repair

360° view of your WTG

Advanced SCADA analytics

Drivetrain CMS

ecoCMS By ONYX Insight

ecoCMS Flex

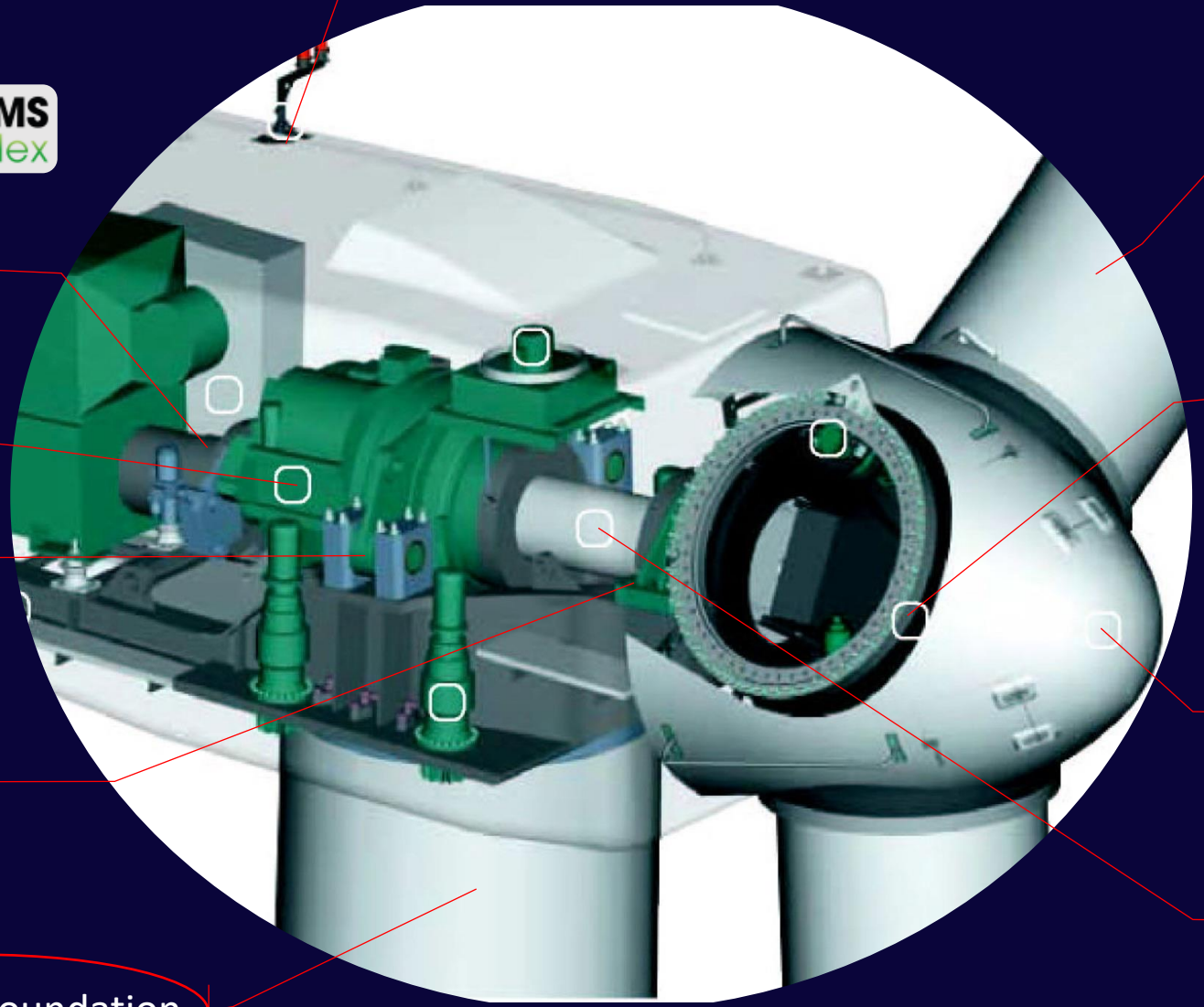
Generator bearings

Gearbox

Oil sensing

Main bearings

Tower and foundation



Whole turbine CMS

Drone inspections

ONYX Insight | In partnership with NEARTHLAB

Pitch bearing and blade root monitoring

ecoPITCH By ONYX Insight

Rotor imbalance

Shaft cracks

Overcoming Barriers to Unlocking a Bigger Monitoring Population

Small Investment
Get more out of your drivetrain CMS

Installation Simplicity
Only requires x1 additional sensor

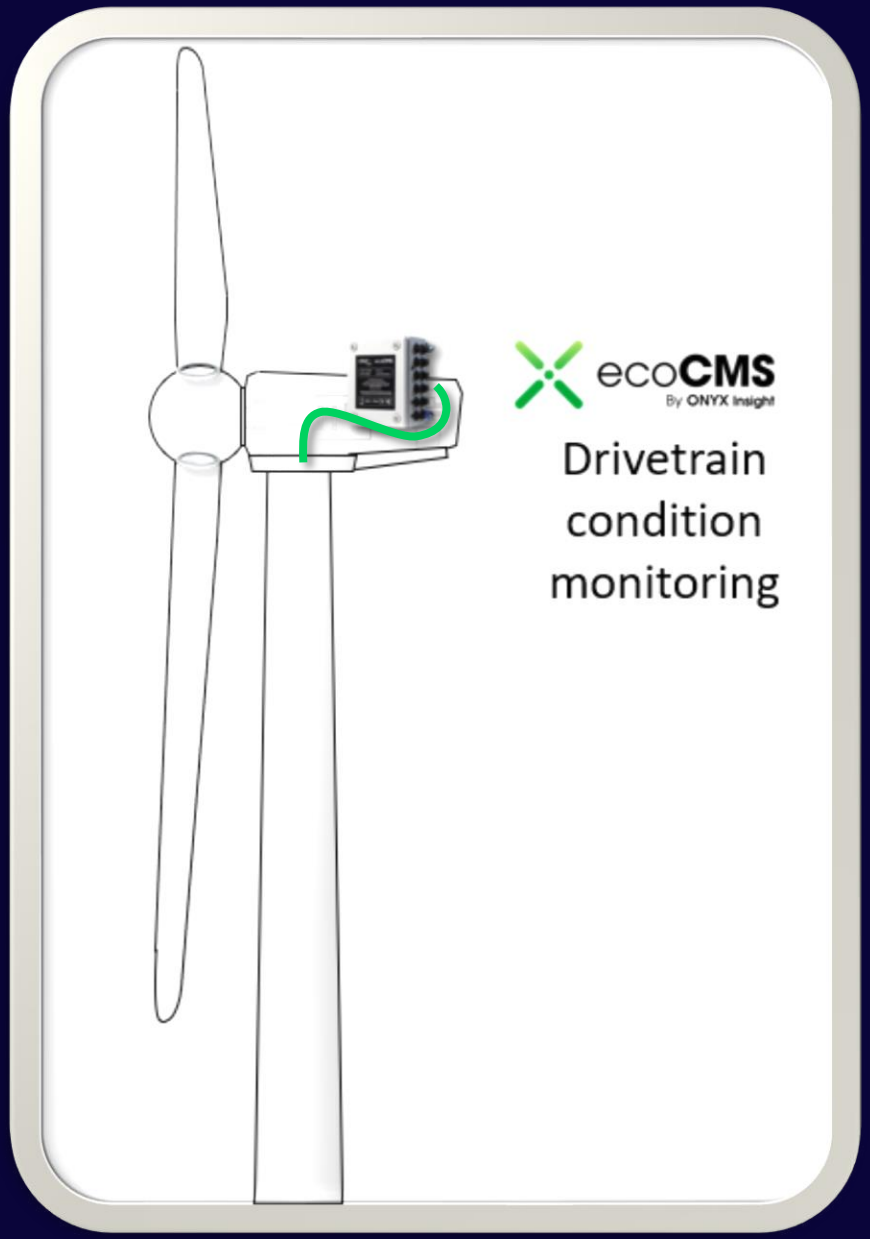
Common Infrastructure
Utilize established comm's channels

ONYX Insight

ecoCMS
By ONYX Insight

Simple and easy

- Take advantage of drive train ecoCMS
- 1 additional MEM sensor installed up tower
  - Easy installation → Epoxy
  - No WTG modification required
- Continuous monitoring
- Frequency vs time
  - Frequency changes with mass or stiffness
  - Stiffness changes imply degradation or damage



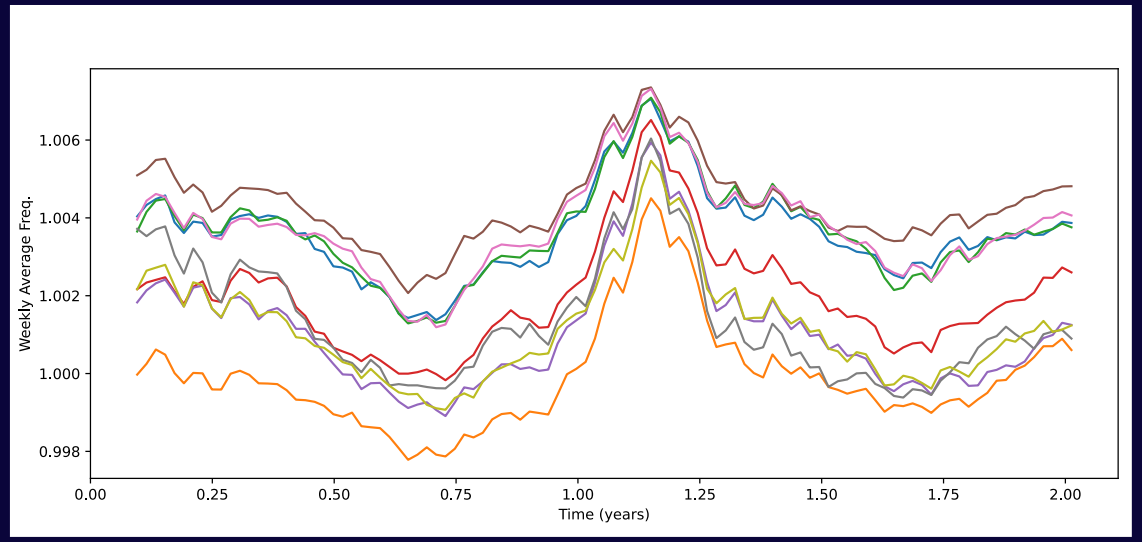
ONYX Insight

Case study

ONYX Insight

Tower frequency monitoring – foundation health

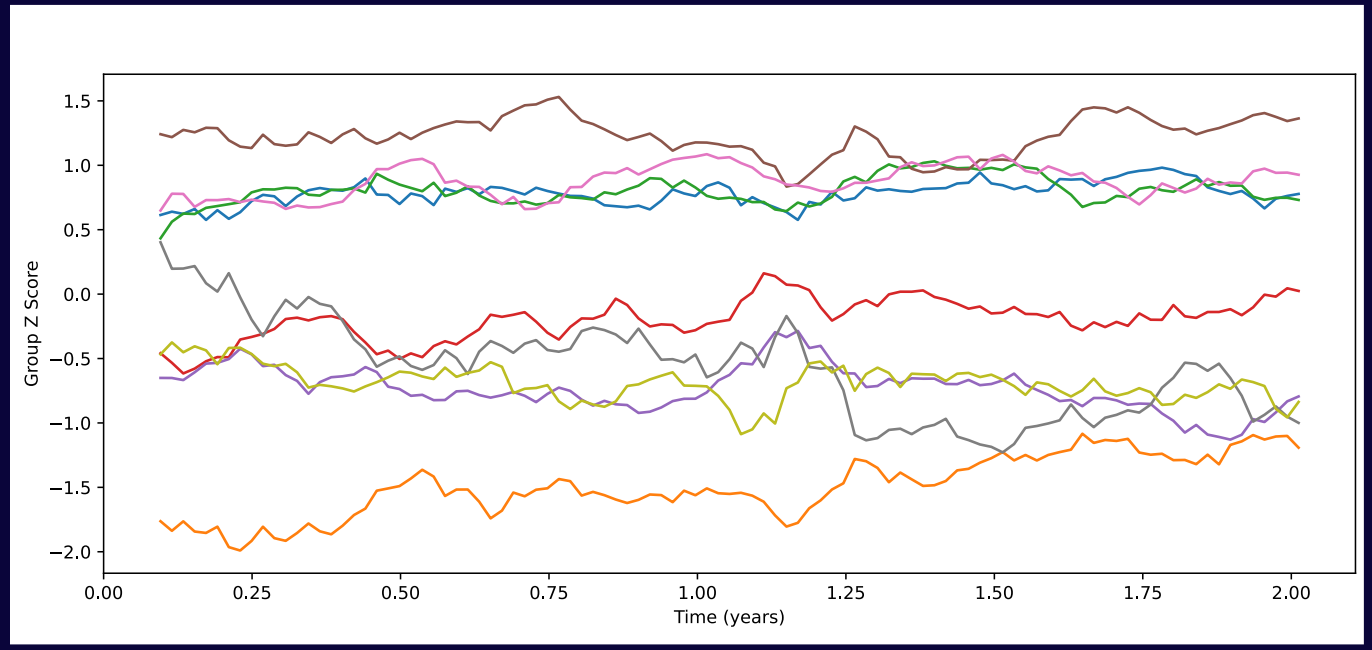
- Continuous measurements register over 2 year
- Frequency vs time
- Onshore seasonality tends to be periodic on an annual basis and dominated by temperature fluctuation



ONYX Insight

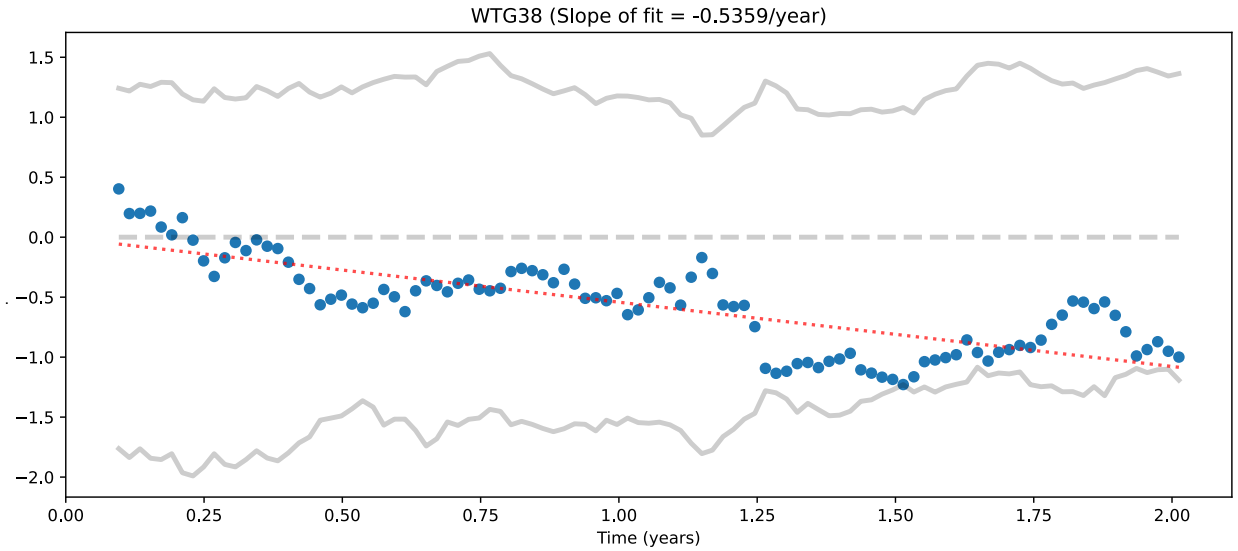
Group and Self Comparison

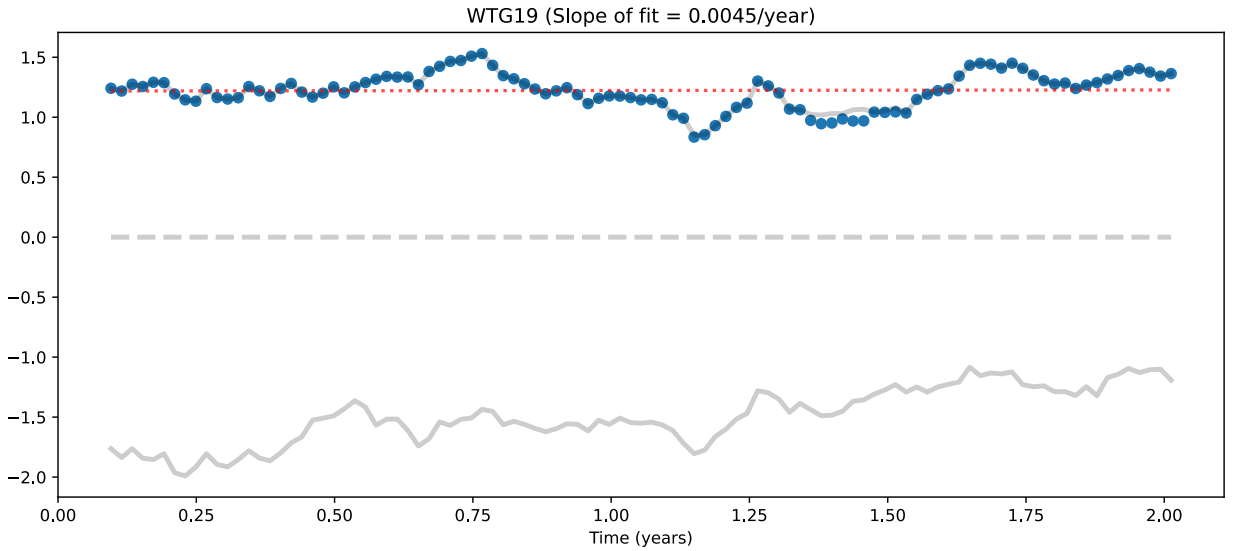
- Evaluating statistics of the group clarifies the picture and minimizes seasonal noise
- Some turbines are simply "healthier" than others
  - Stiffer soils
  - Higher strength concrete
  - Variation in foundation design
  - Variation in towers
  - etc.



Quantify Health Metrics and Their Rate of Change

- Regularly measure a quantitative metric that represents health
- Observer the change (or lack of change) over time





Use Observation and Statistics to Determine Outliers

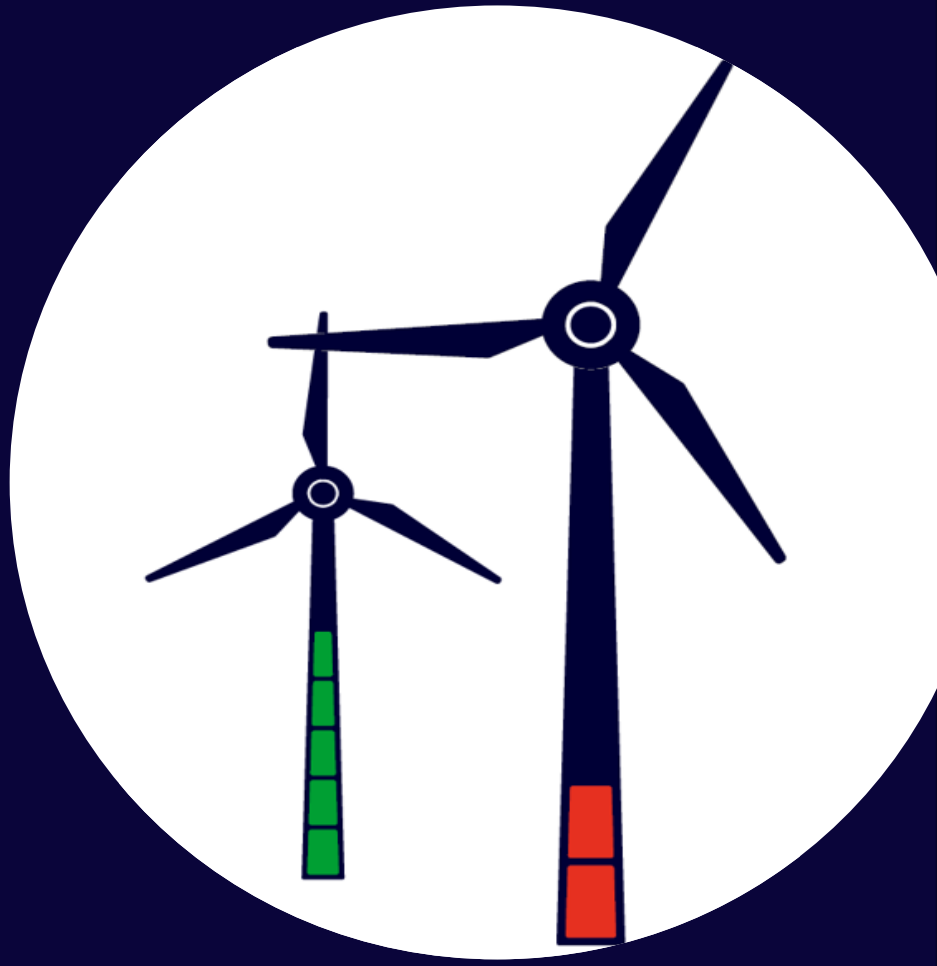
- Estimate Safe Operational Limits and Schedule Action
- Base on observation and not just a projection
- Plan possible remediation activity into budgeting in 2 years
- WT38 requires investigation - Continue operation and revenue generation in the meantime

Turbine	WTG03	WTG09	WTG12	WTG15	WTG17	WTG19	WTG23	WTG38	WTG48
Frequency Slope	0.0002	0.0005	0.0001	0.0003	-0.0003	0.0001	0.0002	-0.0010	-0.0003
Group Health Slope	0.0819	0.3638	0.0687	0.1797	-0.1399	0.0045	0.0909	-0.5359	-0.1137
Self Health Slope	0.05	0.17	0.06	0.10	-0.13	0.02	0.08	-0.31	-0.11

Minimum Value	WTG03	WTG09	WTG12	WTG15	WTG17	WTG19	WTG23	WTG38	WTG48
Current	1.0009	0.9973	1.0005	0.9983	0.9977	1.0014	1.0002	0.9983	0.9981
Projected 1 Year	1.0009	0.9973	1.0005	0.9983	0.9974	1.0014	1.0002	0.9973	0.9978
Projected 2 Years	1.0009	0.9973	1.0005	0.9983	0.9971	1.0014	1.0002	0.9963	0.9975
Projected 3 Years	1.0009	0.9973	1.0005	0.9983	0.9968	1.0014	1.0002	0.9953	0.9972

Outcomes

- Periodic inspections and measurements on a few WTGs are not enough:
  - Un-inspected turbines
  - Long periods of possibly un-observed degradation
  - Expensive and time-consuming repairs after that
- Frequency/stiffness is an indicator of health
- CMS enables frequency monitoring
- Continuous monitoring + Analysis = identify and track foundation degradation



The information in this presentation is confidential

ONYX Insight

Learn more

Offices

UK – Nottingham

USA – Boulder, CO

South Korea – Seoul

Spain – Madrid

Australia – Brisbane

China – Shanghai

Contact

www.onyxinsight.com

info@onyxinsight.com

ONYX Insight

ONYX Insight