Floating Wind *Solutions*

Mooring System Redundancies and Maintenance Considerations

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Organized by QFWE Quest Offshore

FWS

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AGENDA

- Technip Energies
- Introduction
- Mooring Design Considerations
- Improved Reliability and Robustness
- Response based Life Cycle Loading
- Predictive Analysis and Maintenance
    - Smart Monitoring
- Conclusions

TECHNIP ENERGIES

- Providing end-to-end project management
- Beginning with concept and design, we deliver comprehensive management expertise to optimize a project's schedule and budget.
- From start to finish, we apply our extensive offshore engineering and marine operations skills to deliver on time and meet all client specifications.

TECHNIP ENERGIES AS A SOLUTIONS INTEGRATOR MANAGING RISK AND INTERFACES

- Floater and mooring design
- Overall design management: Interaction between floater, mooring, IAC, T&I, fabrication
- Mooring procurement
- Overall T&I execution: Floater + mooring + hookup

TECHNIP ENERGIES

GENESIS | cybernetix (A Technip Energies Company) | inocean (A NAUTICAL MILE AHEAD)

https://www.technipenergies.com/media/floating-offshore-wind-brochure

Design maturity

- Cost-competitive floater design scale-able with an in-house automated sizing tool
- Proprietary floater technology, simple and well suited for mass production
- Design validated through an Ocean basin model test as part of a 4 year JIP program.

Marine operations, logistics and commissioning

- Extensive worldwide track record with logistics, T&I, mooring & hook-up activities, offshore commissioning that will allow reduced installation and commissioning cycles.

Post-delivery/ Life of field/ Asset management and maintenance

- In-house O&M expertise (e.g. Coral FLNG), including digital twin
- Innovative monitoring and inspection solutions with Cybernetix*

Industrialized fabrication

- Worldwide footprint with global procurement
- Strong relationship and experience with Asian fabrication yards
- Proven track record in modular design and fabrication
- Yard partnership for certainty in delivering commercial scale projects
- Digitalized suite of tools from fabrication to installation

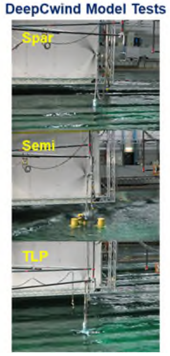
*Inocean and Cybernetix are Technip Energies fully owned companies

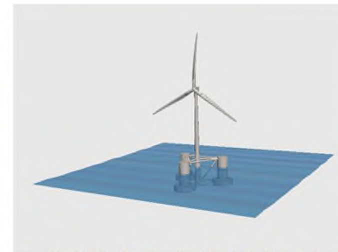
Floating Offshore Wind Turbine

- DeepCwind Floating Wind Turbine Model Tests (2011-2012)
  - World first most comprehensive FOWT model tests
- MLTSIM/FAST Development (2011-2014)
  - T.EN's floating wind turbine analysis software
- Key References in Floating Offshore Wind projects include:
  - World's first floating turbine (Hywind Demo 2.3MW) in Norway
  - World's first floating wind turbine park (Hywind Scotland - 5x6MW)
  - Hywind Tampen FEED (2019)
  - Makani Energy Kite Pilot EPCI and Decommissioning (2019-2020)
- CFD JDP: Offshore Wind Turbines in Waves with NREL (2021)
  - Integration of FAST with CFD ongoing
- NYSERDA Project (2021)
  - Techno-Economic mooring for shallow water FOWT

NYSERDA: New York State Energy Research and Development Authority

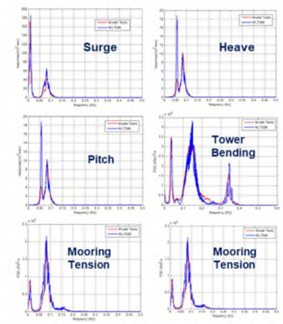
DeepCwind Model Tests

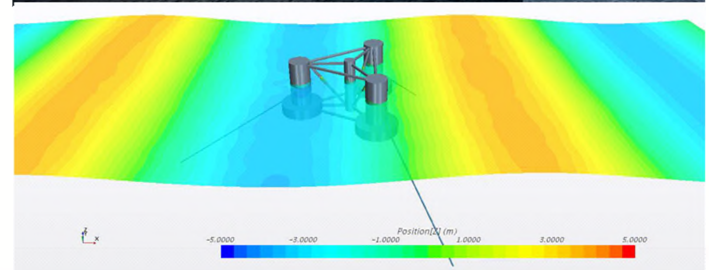




MLTSIM/FAST Floating Wind Turbine Solver

Model Test Correlation

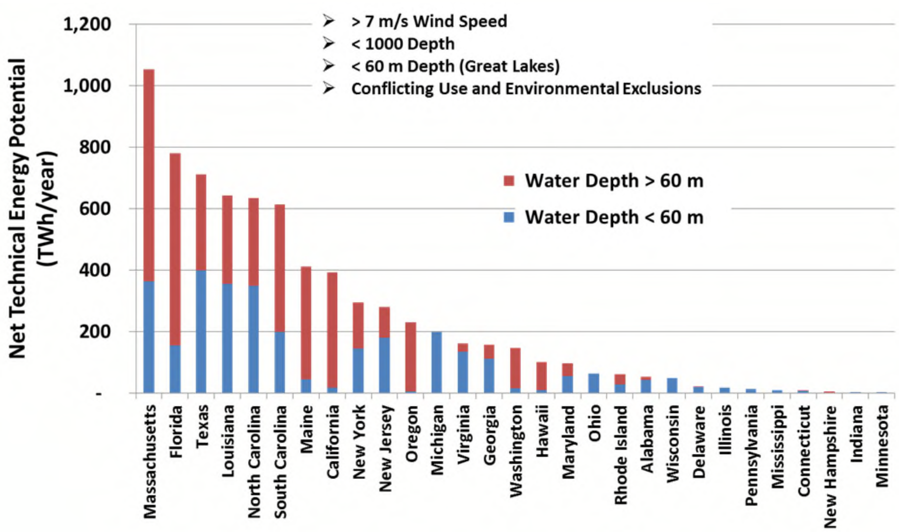




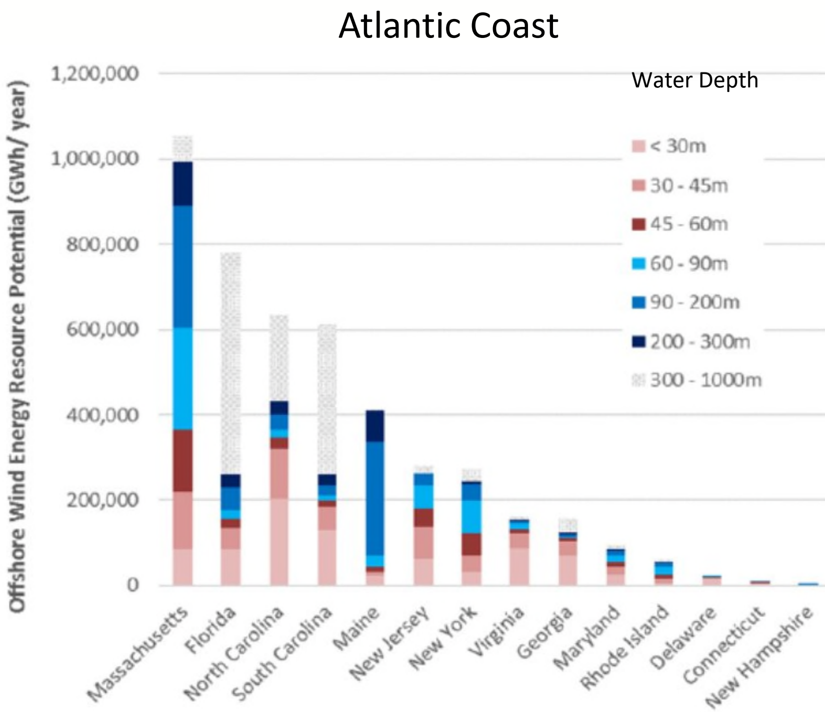
Floating Wind Solutions

INTRODUCTION

- Floating Wind Platforms is key in meeting the wind energy target.
  - 68% of Atlantic Coast Wind Energy Resource Potential is in water depth greater than 60m where floating wind platforms will be required



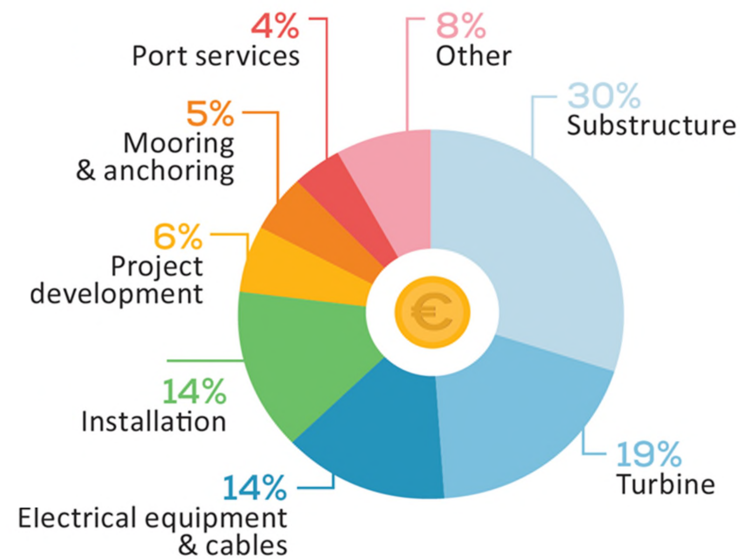
Source: https://www.energy.gov/eere/articles/computing-americas-offshore-wind-energy-potential



Source. 2019 Offshore Wind Technology Data by NREL

INTRODUCTION

- Mooring is a critical component to keep the wind turbine platform in place to generate and transfer electricity, protect the electric cable, integrity of the wind farm
- Mooring cost is proportionally small relative to the overall development cost
- Simple and robust mooring system design supplemented with monitoring important to control the installation, operating and maintenance cost



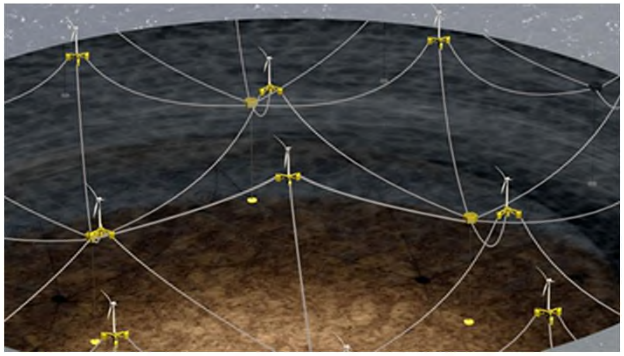
CAPEX of a pre commercial floating offshore wind farm

Source: ETIPWInd 2020

Critical Mooring System Elements

- Strength
  - Platform Chain (Corrosion and Wear, Loading), Bridle Line for Spar
  - Mooring Connection to the hull
  - Anchors

- Fatigue
  - Semisubmersible – Higher wave dynamics in the entire line
  - Spar – Wave response lower, but need to consider Vortex Induced motions due to current
  - Mooring Chain
  - Polymer line segment material fatigue particularly for shallow water moorings
  - Anchors
    - Shared anchors experience higher varying loads
  - Connection to the hull



Floating Wind *Solutions*

Mooring Strength Design

- Strength Design based on Mooring System Redundancy
  - Redundant / Consequence Class 1
  - Non-Redundant / Consequence Class 2
- 50-Year Environment Load

DNV Strength Design (DNVGL-ST-0119)

$$T_d = \gamma_{mean} \cdot T_{c,mean} + \gamma_{dyn} \cdot T_{c,dyn} \qquad S_C > T_d$$

Limit State	Load Factor	Consequence Class	
		1	2
ULS	γ_{mean}	1.30	1.50
ULS	γ_{dyn}	1.50	2.20
ALS	γ_{mean}	1.00	1.00
ALS	γ_{dyn}	1.10	1.25

T_d – Design Tension, Sc – Characteristic Strength (Generally MBL)

$T_{c,mean}$ $T_{c,dyn}$ – Characteristic mean, dynamic tension corresponding to 50-year value

Safety Factors (ABS, BV)

Redundancy	Condition	ABS	BV
Redundant	Intact	1.67	1.67
	One line Failure	1.05	1.25
Non Redundant	Intact	2.00	2.00

Mooring Fatigue Design Criteria

- Recommended practice
  - DNV Fatigue Design (DNV-ST-0119)

D_D = DFF x D_C $\qquad$ $D_D \leq 1.0$

D_C - Characteristic Cumulative Fatigue Damage
DFF - Design Fatigue Factor
D_D - Design Cumulative Fatigue

Consequence Class	DFF
1	5
2	10

Fatigue Design Factors (ABS, BV)

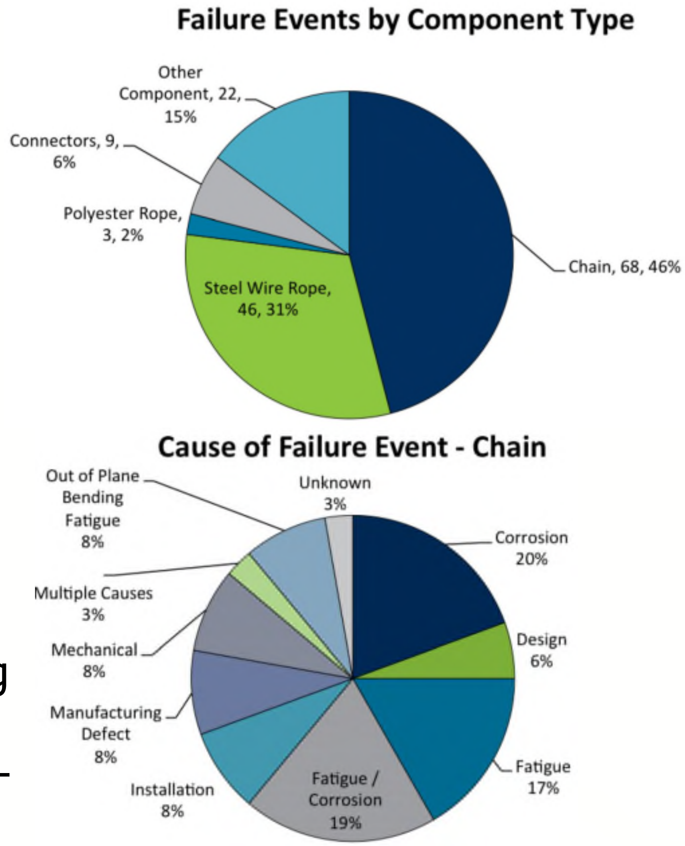
Redundancy	Inspectable and Repairable	Fatigue Design Factors
Redundant	Yes	2
	No	**5**
Non-Redundant	Yes	3
	No	**10**

Mooring Design Considerations

- Recommended design practice is adequate if manufactured, installed and operated as designed

- However mooring damage does occur from
  - Improper strength and fatigue loads estimation or phenomena
  - Manufacturing defects
  - Improper installation
  - Larger than designed environment loads
  - Corrosion and wear

- Mooring design in water depth range of 60m to 150m is challenging for managing offset and long-term performance and reliability
  - Expertise and experience important to develop a smart mooring system and de-risk the execution plan



Source: Fontaine *et al.* (2014)

Mooring Design Considerations

- Any line failure in three-line systems causes very large offset
  - Could damage power cable
  - Could collide with other structures in the wind farm or other structures around the platform
  - Unfavorable loading on shared anchors leading to reduced capacity and domino effect in a wind farm

- Optimization of the mooring systems may lead to non-redundant systems
  - Redundancy considerations are an important part of mooring design

- For floating wind turbine platforms, no long-term performance data available

- In a large wind farm the soil properties could vary significantly at the different anchor locations. Soil samples should be obtained at multiple anchor locations for reliable anchor performance

Improved Mooring Reliability and Robustness

- Higher safety factors for strength and fatigue design of mooring lines and anchors
  - May be a more economic life cost solution relative to the installation cost, replacement cost and loss due to power production disruption
  - Could be applied only for limited highly loaded lines and connectors if the environment is directional

- Use underwater chain tensioners to reduce corrosion of the line by avoiding exposing chain to splash zone region, also helps to avoid inspection and maintenance of onboard equipment

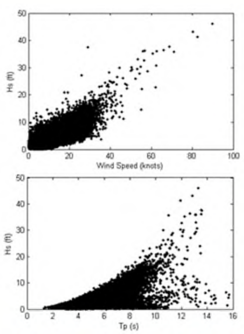
- Additional components in the mooring system for the most critical components or weak link to provide redundancy
  - Additional parallel slack synthetic section in the line for shallow water applications if required fatigue design life cannot be met with practical design

- Use proper interpretation of environment data, more reliable load estimation and fatigue analysis methods, proper modeling of synthetic ropes

Conventional versus Response Based Time Domain Direct Simulation of Mooring Fatigue

Condensed Bin approach vs Response Based Time Domain Direct Simulations

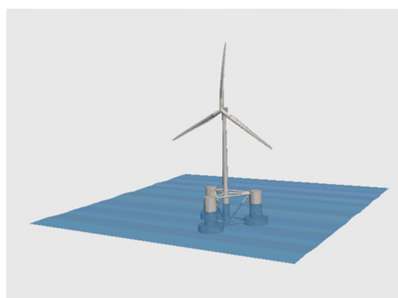
- Condensed Fatigue Bins approach shows
  - high variation in fatigue life according to selected random wave seed
  - estimated fatigue life is less than direct simulation results



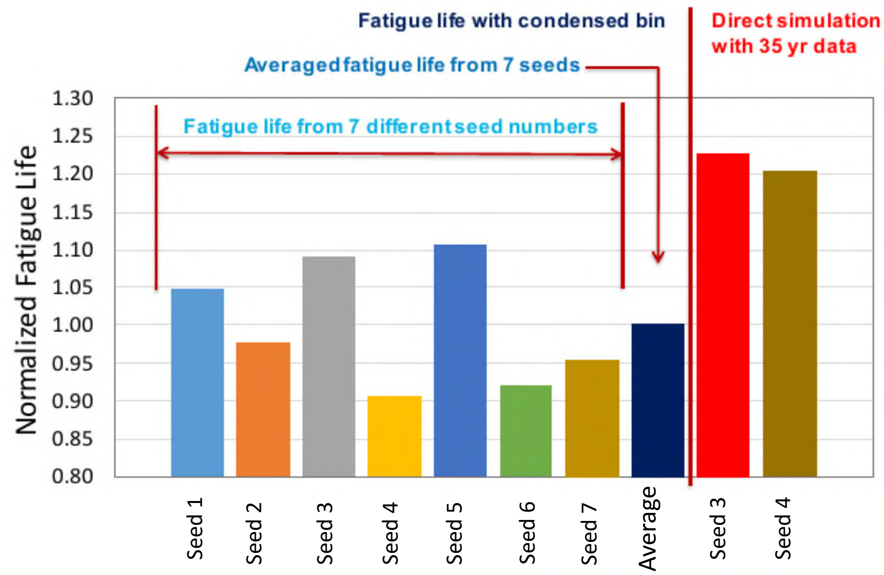
35YR Environmental Data

Direct simulation for 35YR responses using HPC
Computation time is less than one day
(~ = 100,000 simulations)

MLTSIM-FAST



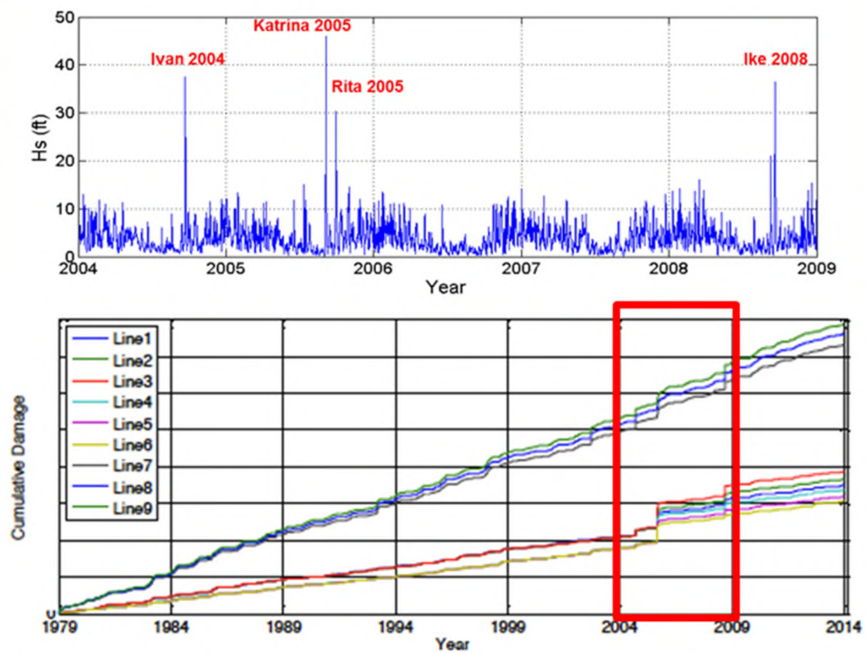
Animation Tool (by NREL)



Ref. OMAE2018-78142

Response Based Time Domain Direct Simulation Fatigue

- Reduced uncertainties in fatigue analysis
- Able to obtain mooring line fatigue consumption time history during operation
- Using HPC, efficient and fast analysis (35-yr mooring fatigue computation takes only half day)



Ref. OMAE2018-78142

Benefits of Response Based Time Domain Direct Simulations

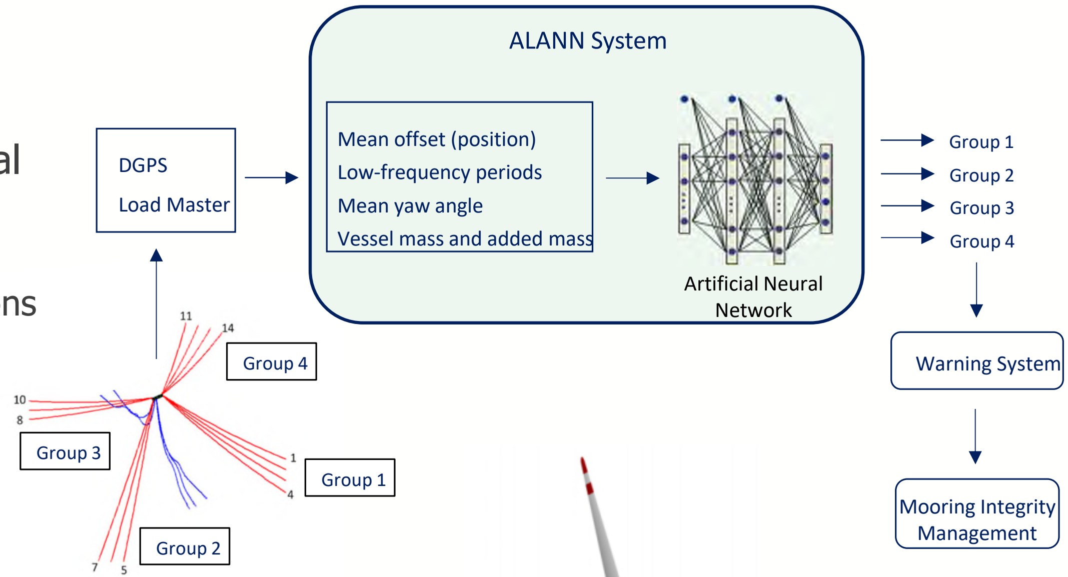
- Direct simulation provides more reliable mooring fatigue calculation by reducing uncertainties
- Instant evaluation of performance during operation is available
- Not limited to mooring fatigue damage, it can be extended to structural damage analysis

Maintenance Considerations

- Continuous evaluation of the extreme events and the fatigue damage of the mooring system is required to understand the condition of the mooring system for all wind turbine platforms in the wind farm
  - Need mooring line tensions
- Use smart monitoring system to determine the mooring line tensions
  - Evaluate the condition of the mooring system
  - Evaluate fatigue damage of the mooring system using digital twin model and environment monitoring
- Data transfer between platform and onshore station similar to unattended oil and gas platforms either by telecommunication, cloud streaming or fiber optic
- Predictive analytics from onsite measurements to schedule inspection and maintenance of mooring system

Smart Monitoring System

- ALANN: Anchor Lines monitoring using Artificial Neural Networks
  - Detection of mooring line failure using DGPS
  - Does not require information of environmental conditions and directions
  - Use simulations to train the system
  - Pilot project planned on FPSO



- Extension to Floating Offshore Wind Farms Application
  - Based on DGPS and Inertial Measurement Unit (IMU)
  - Monitor mooring systems – line tensions and fatigue damage
  - Can also detect system abnormal behavior. For instance, yaw misalignment, blade stall conditions, anchor location shift etc.
  - Feed data to digital twin

Conclusions

- Mooring system is a critical component for the integrity of the Floating Wind Turbine Wind Farm and electricity production

- There are parallels between Unattended floating Oil and Gas platforms and FOWT
  - Several of the technologies and know-how developed in oil and gas industry can be employed for FOWT

- Options to increase reliability and robustness of FOWT mooring system have been discussed which should help with the operability and availability of the platform and reduce life cost of the Wind Farm
  - Mooring procurement CAPEX contribution is relatively small. Any design change to increase robustness will not significantly change the overall CAPEX

- Smart monitoring in combination with a digital twin model can be used to know real time structural health of mooring system detect abnormal behavior of FOWT
  - Help with predictive maintenance planning and reduce OPEX