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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Breakthrough Research for Floating Wind

February 2022

corewind.eu

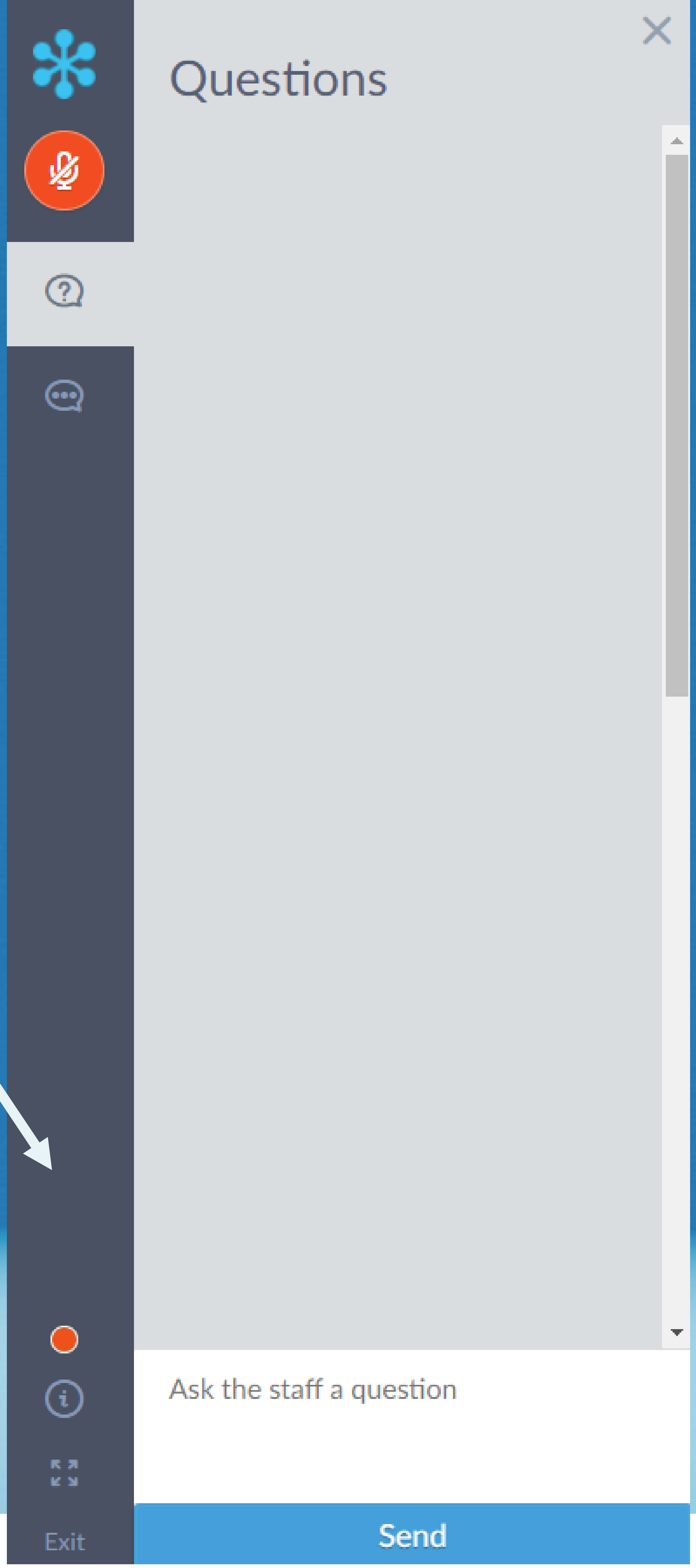
Disclaimer:
This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 815083.

Project details:
Duration:
1 Sep 2019 - 28 Feb 2023
Grant agreement:
No: 815083

Lizet Ramírez
Analyst, Offshore Wind

Got a question?

Type your question and hit 'Send'



AGENDA

1. Welcome and policy context	Lizet Ramírez, WindEurope
2. Introduction to Corewind	José Ignacio Rapha, IREC
3. Optimisation of floating wind farm layout	José Ignacio Rapha, IREC
4. Impact of peak load reduction system of mooring design	Valentin Arramounet, INNOSEA
5. Assessment of Floating Wind O&M Strategies	Marie-Antoinette Schwarzkopf, Ramboll
6. Mooring and cable dynamics: an experimental and numerical approach	Álvaro Rodríguez-Luis, IHCantabria
7. Wrap up and conclusions	Lizet Ramírez, WindEurope

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Welcome and policy context

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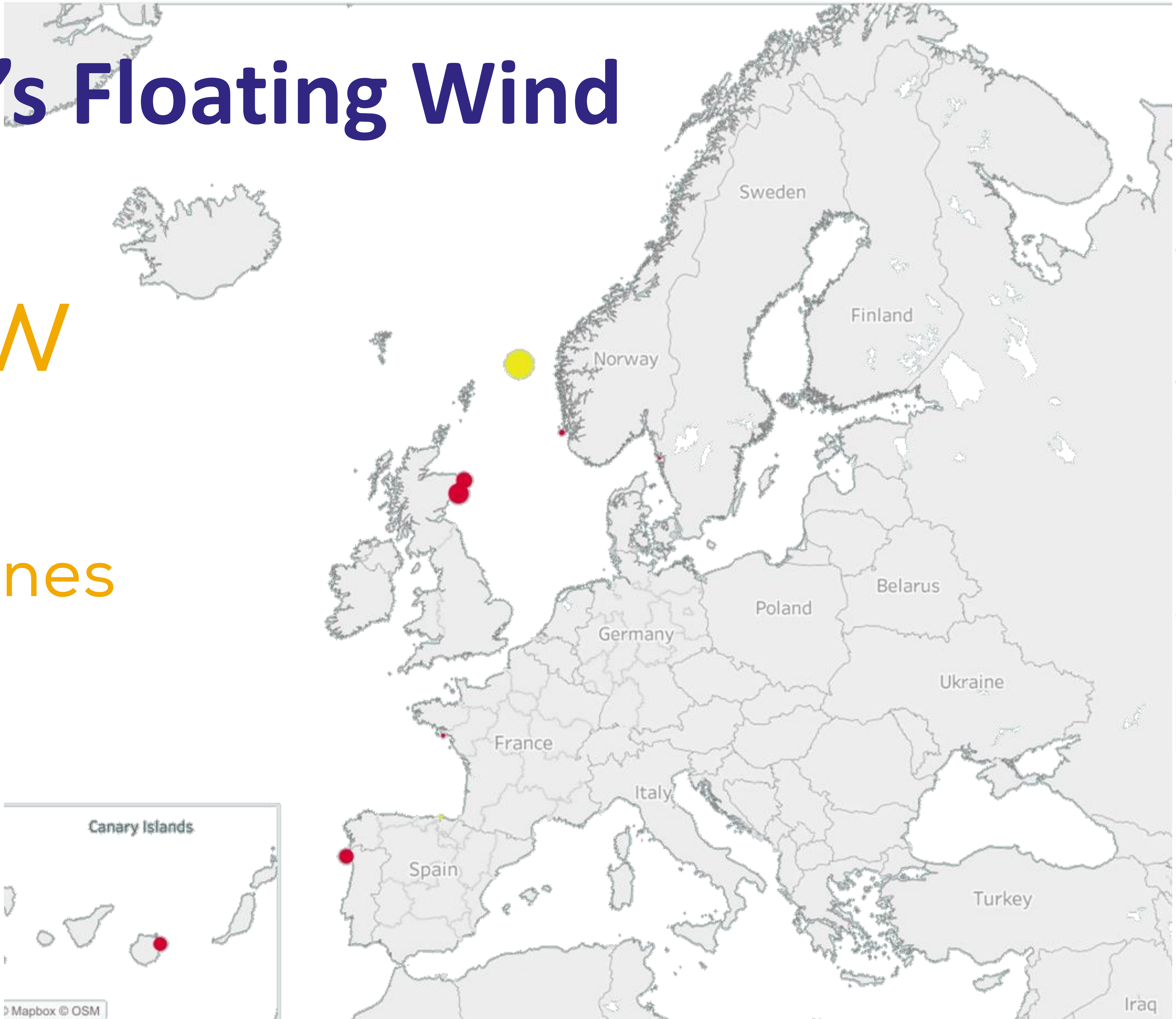
Europe’s Floating Wind

113 MW
online

18 turbines



Europe’s offshore wind
28,333 MW connected to the grid
5,785 turbines connected
122 Wind Farms
12 countries

Status of Offshore Wind Projects	
Online	🟥
Under construction	🟨
With permits	🟩
Under permitting procedure	🟦
Planned	🟦

Technology Floating

Type All

Country Details

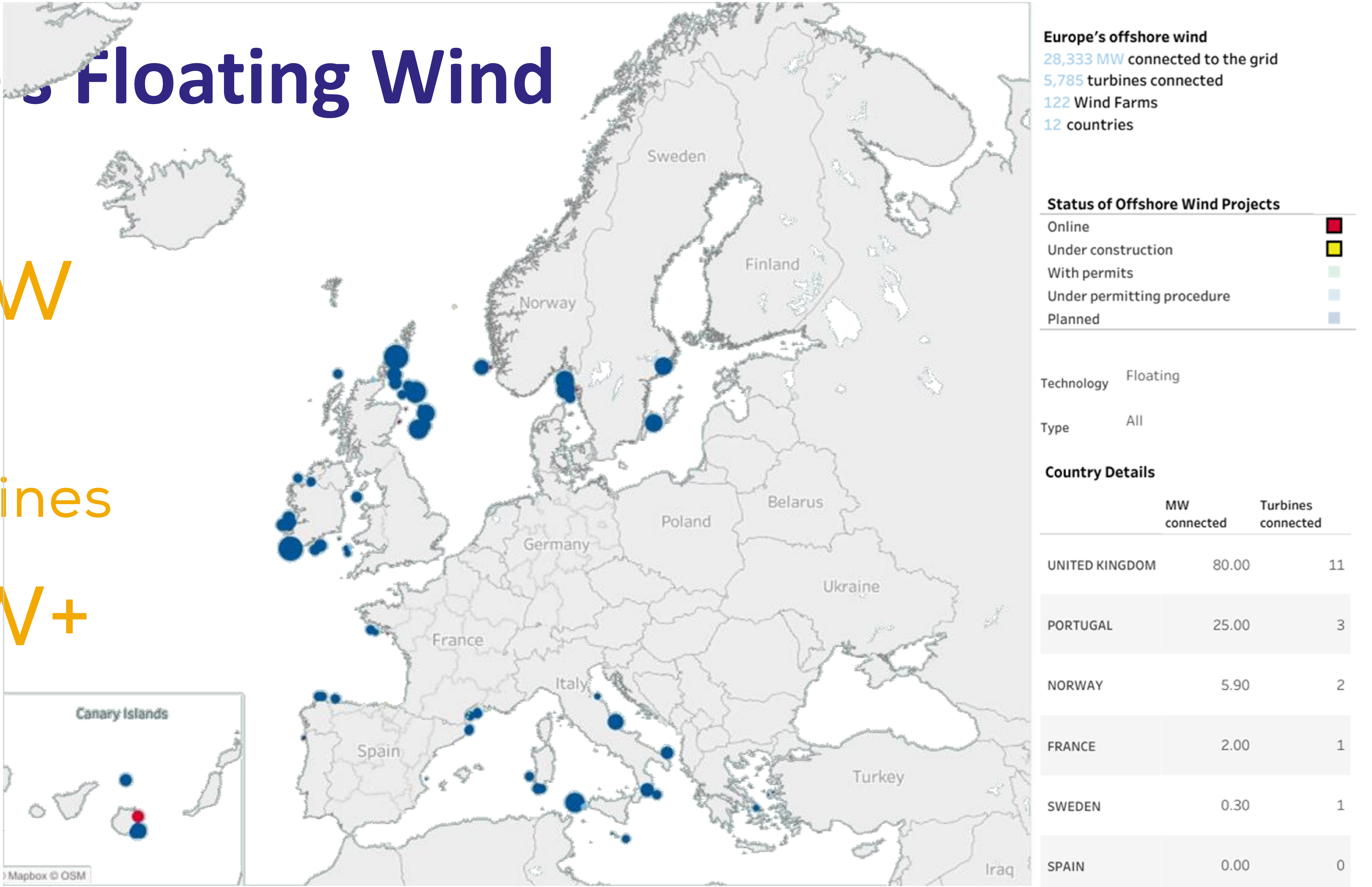
	MW connected	Turbines connected
UNITED KINGDOM	80.00	11
PORTUGAL	25.00	3
NORWAY	5.90	2
FRANCE	2.00	1
SWEDEN	0.30	1
SPAIN	0.00	0

Europe's Floating Wind

113 MW
online

18 turbines

20 GW+
pipeline



Europe's offshore wind
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SWEDEN	0.30	1
SPAIN	0.00	0

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Kincardine
50 MW

Online

Largest operational floating wind farm

Photo courtesy of Ocean Winds

Turbines:
5 turbines –
V164-9.6MW

Foundations:
Semi-sub

TetraSpar
3.6 MW

Online

Testing foundation tubular steel concept

Photo courtesy of RWE

🇳🇴

Turbines:
1 turbines – SWT-3.6-120

Foundations:
Spar

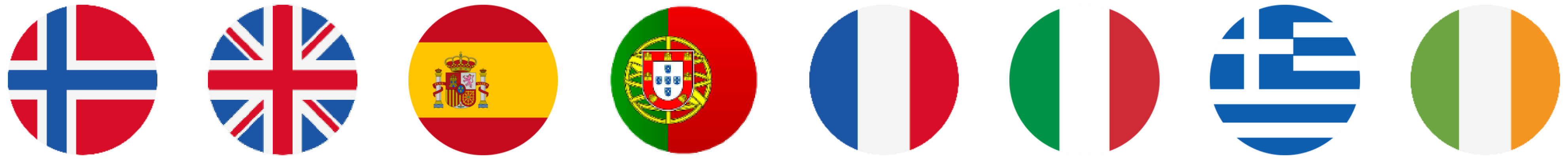
But countries can still go an extra mile…

Scaling up Floating Offshore Wind towards competitiveness

NOVEMBER 2021

Wind EUROPE
windeurope.org

Read the policy paper here



1. Review NECPs in line with EU's increased targets and allocate area for floating wind;
2. Technology specific auctions
3. Tackle financing costs
4. Make floating grid connections a top priority for EU research and TSOs
5. Facilitate industrialization of supply chain, ports and other mass-production infrastructure

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COREWIND project: a quick overview

February 2022

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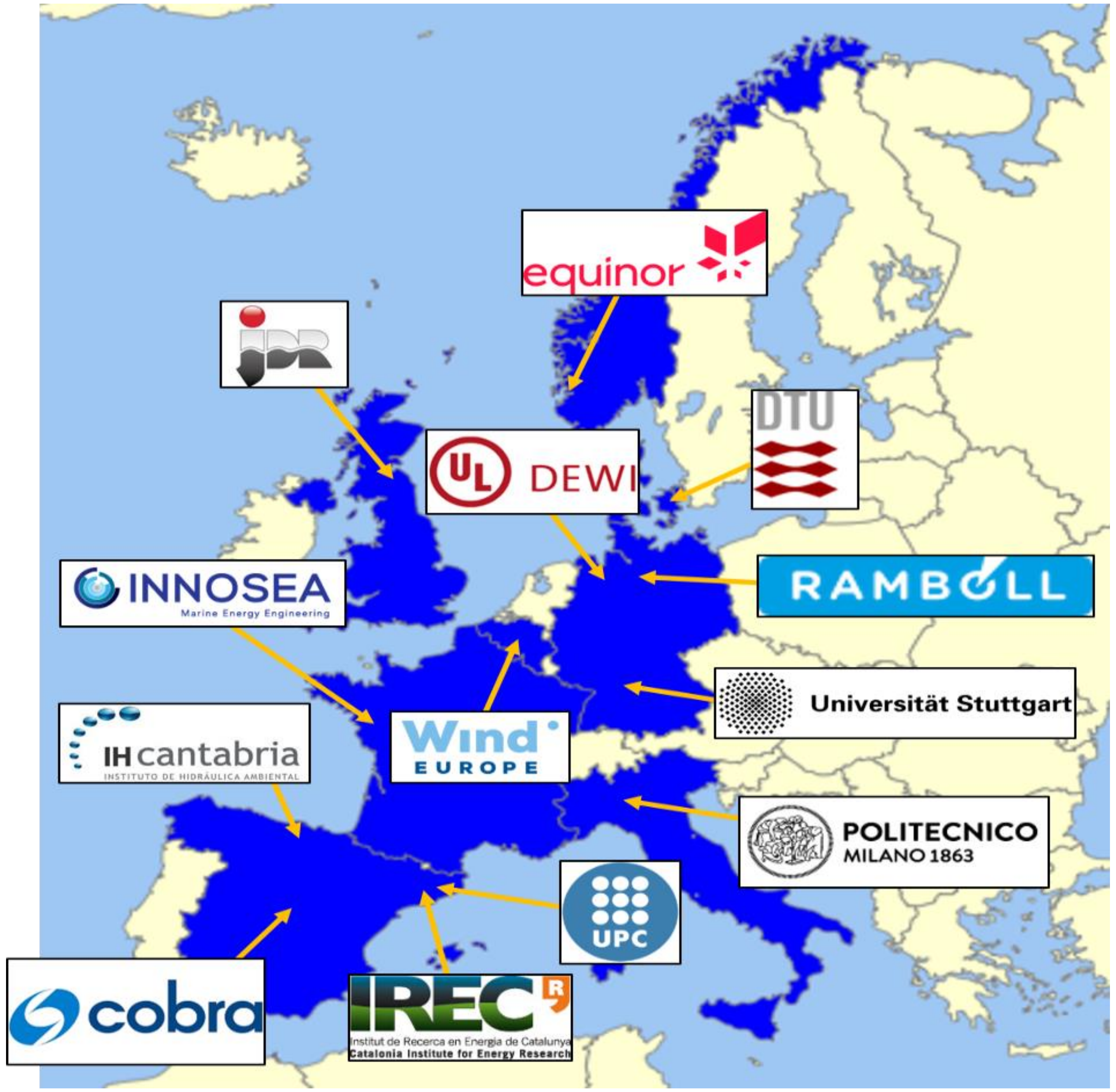
José Ignacio Rapha
IREC

Project partners and advisory board



UC
UNIVERSIDAD DE CANTABRIA

ESTEYCO

UL

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

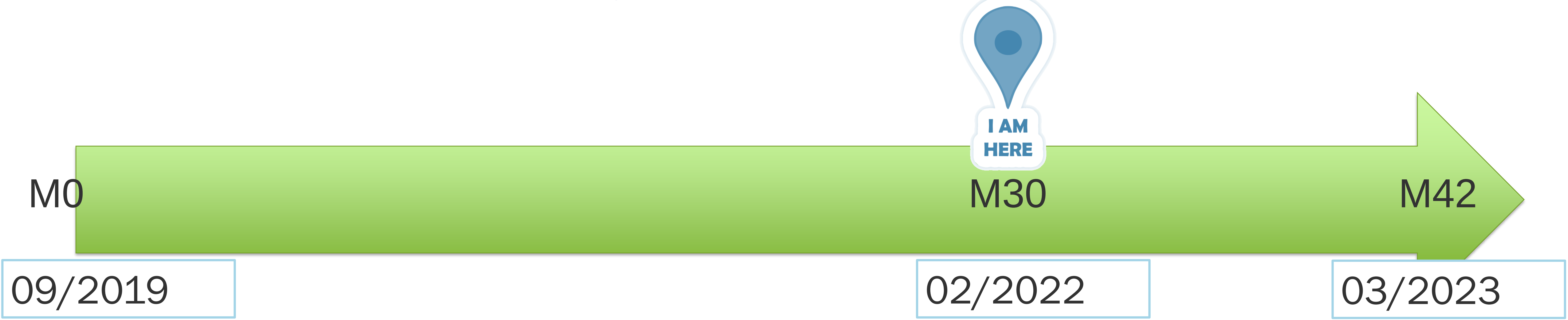
DEME
Dredging, Environmental
& Marine Engineering

eit | European Institute of Innovation & Technology

CARBON TRUST

WINDSY

Current status of the project



- **Ongoing actions:**
  - Mooring and dynamic cable optimization
  - Experimental validation of developments with Scaled-prototypes
  - Development of Digital tools (BIM, advanced control of WindFarm, ML for O&M)
  - LCOE and LCA updates

Current outcomes and developments

- **Public Deliverables:**
  - They can be found at: http://corewind.eu/publications/

- **Public models (available under different CC licenses):**

  https://zenodo.org/communities/corewind/?page=1&size=20

  - ☐ UPC-WindCRETE OpenFAST – Grand Canary Island (License: Creative Commons by 4.0 International)
  - ☐ COREWIND - ACTIVEFLOAT OpenFAST model 15 MW FOWT Grand Canary Island site (License: Creative Commons by NonCommercial Non Derivative 4.0 International)

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COST REDUCTION OF
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Floating wind farm layout optimisation

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José I. Rapha
Research Engineer at IREC

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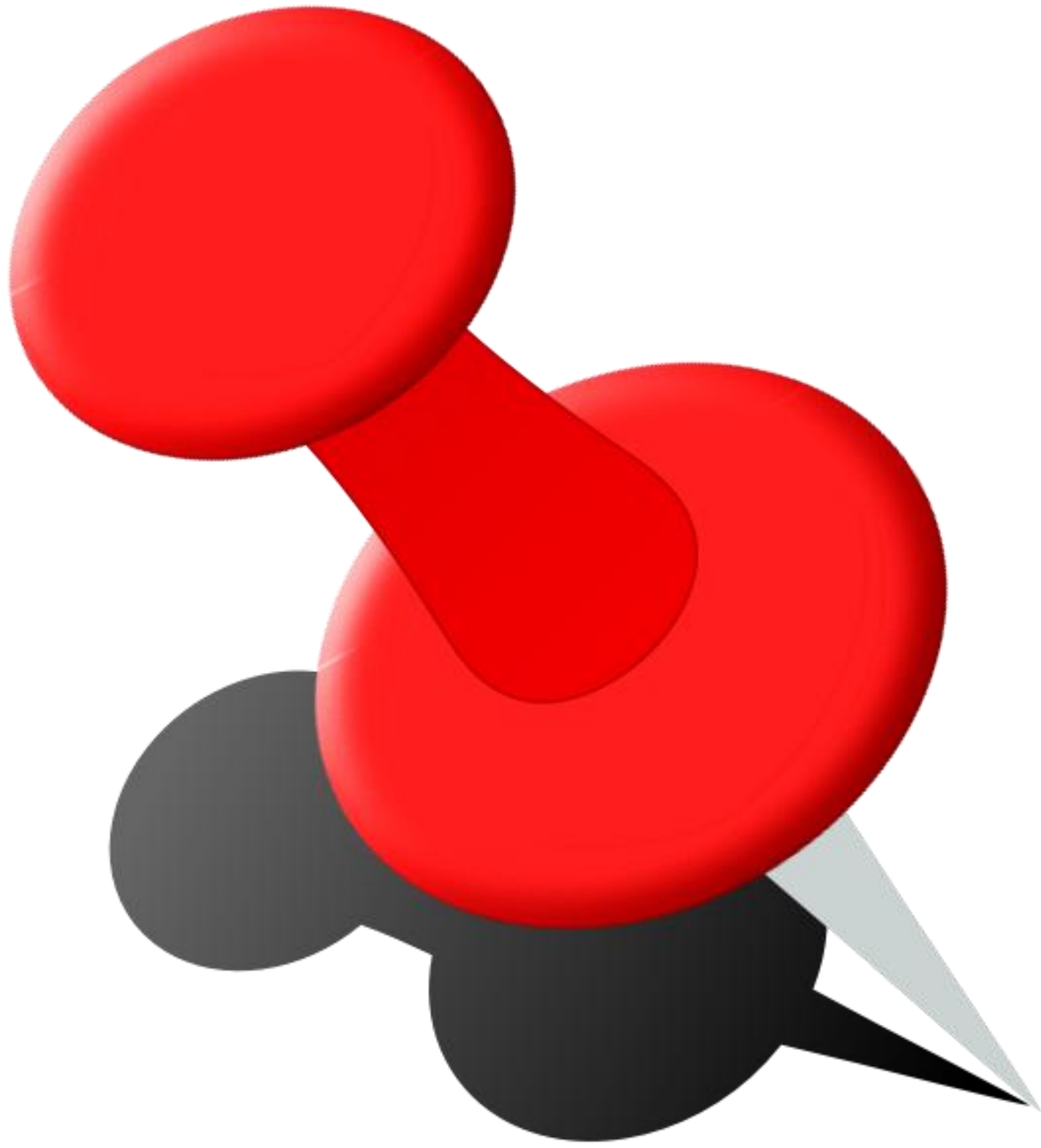


Problem description

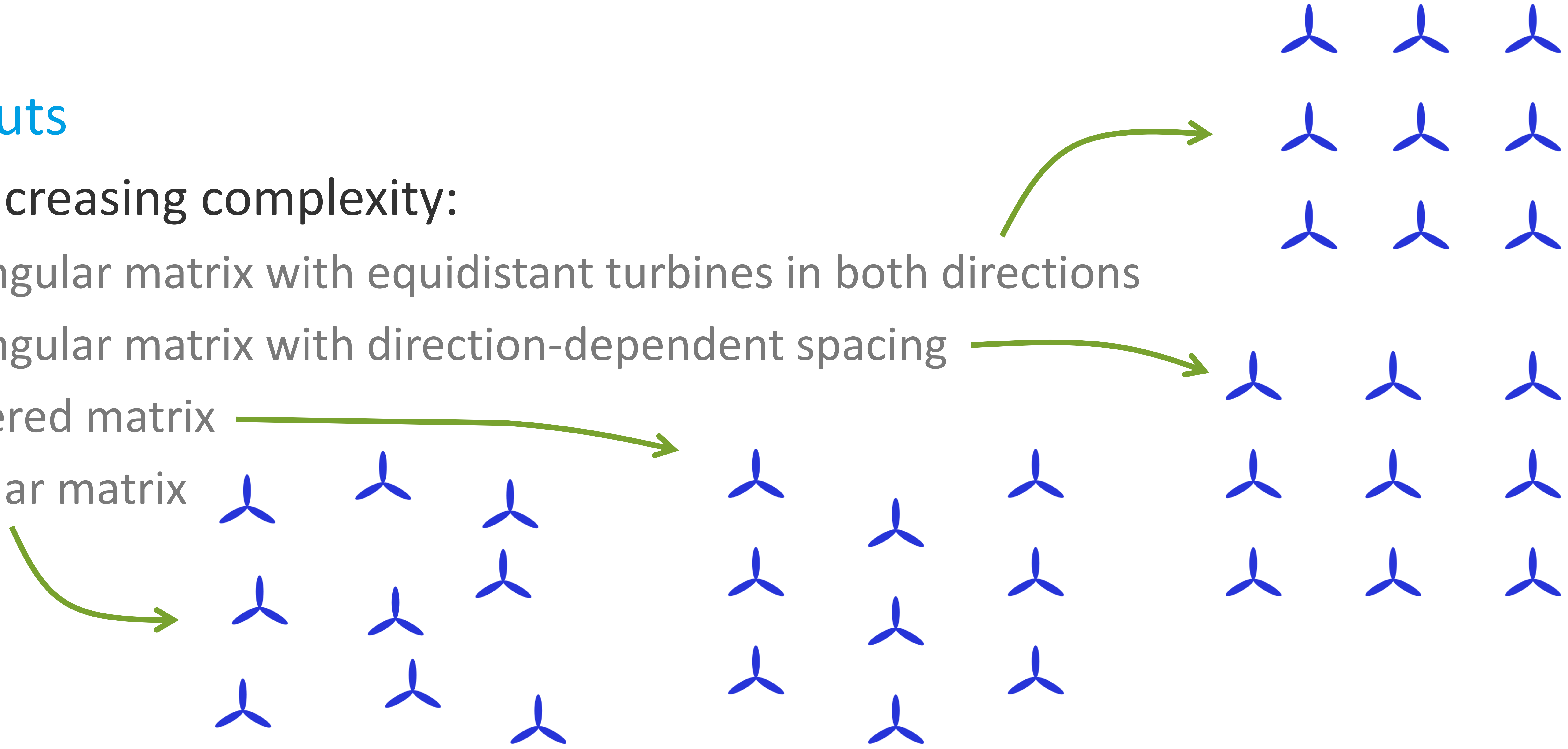
- Wind farm micro-siting

  It is the process of establishing the exact location of each turbine in the farm and the offshore substation(s), if applicable.

- Typical layouts

  Sorted by increasing complexity:

  - Rectangular matrix with equidistant turbines in both directions
  - Rectangular matrix with direction-dependent spacing
  - Staggered matrix
  - Irregular matrix



Problem description

- Key drivers

  A number of parameters influence the layout definition. The most relevant are:

  - Wakes
  - Local wind speeds
  - Bathymetry
  - Soil conditions
  - Lease fee
  - Mooring design
  - Electrical layout
  - Minimum distance from shore
  - Distance to the base port

Approach

- Options

  Depending on the year and country:

  - Simplicity: first offshore wind farms with regular layouts
  - Low LCOE (levelised cost of energy): minimal cost of energy
  - High energy density: maximal energy yield per km^2

- Selected approach

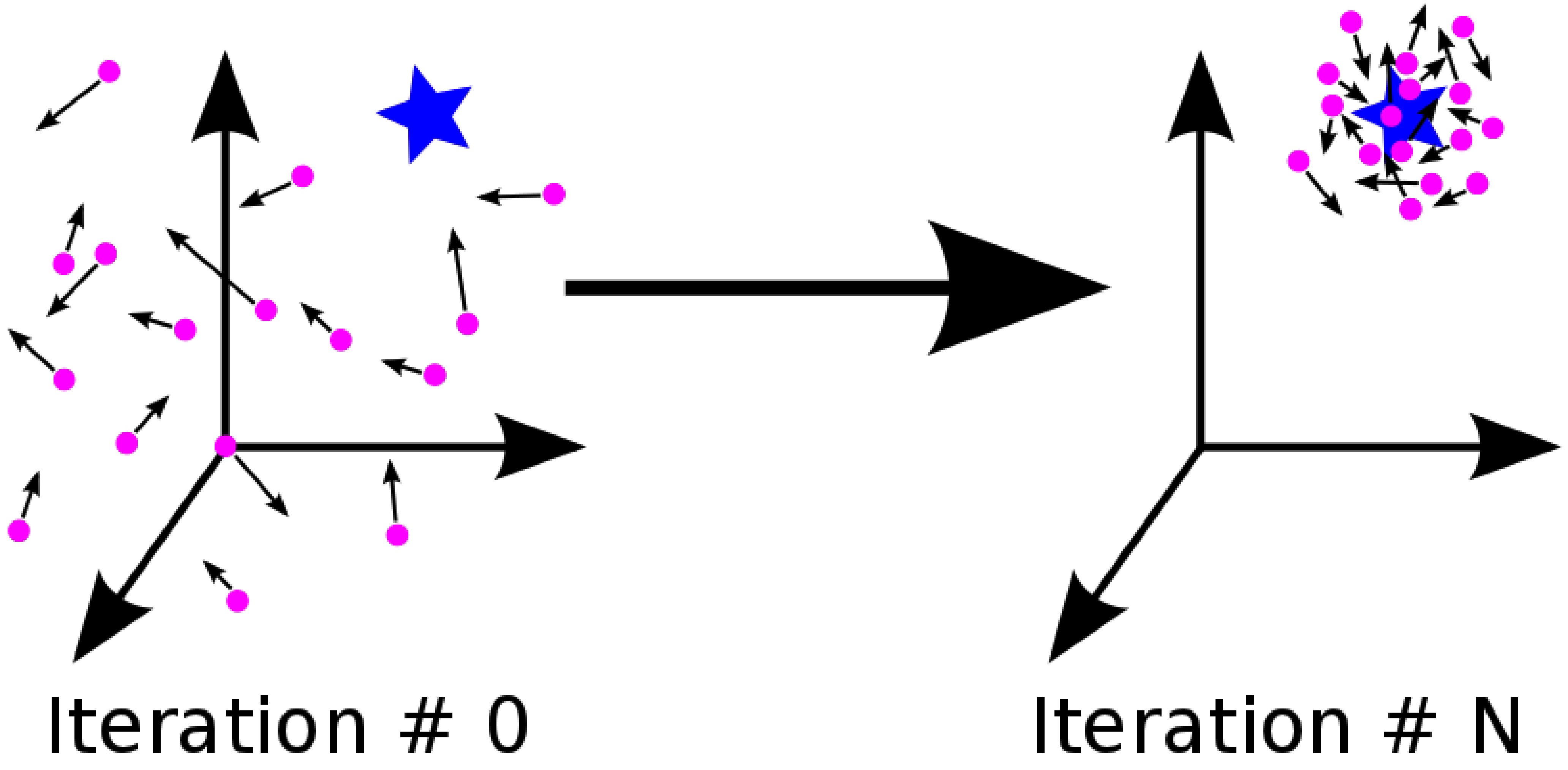
  Low LCOE

Approach

- Selected algorithm

  The PSO (particle swarm optimisation)

  - It is a population-based heuristic optimisation algorithm
  - It replicates the behaviour of some collective animals
  - It was presented in 1995
  - Generally, it leads to good results and converges quickly
  - It allows parallel computation



Approach

- Key drivers treatment

Methodology:

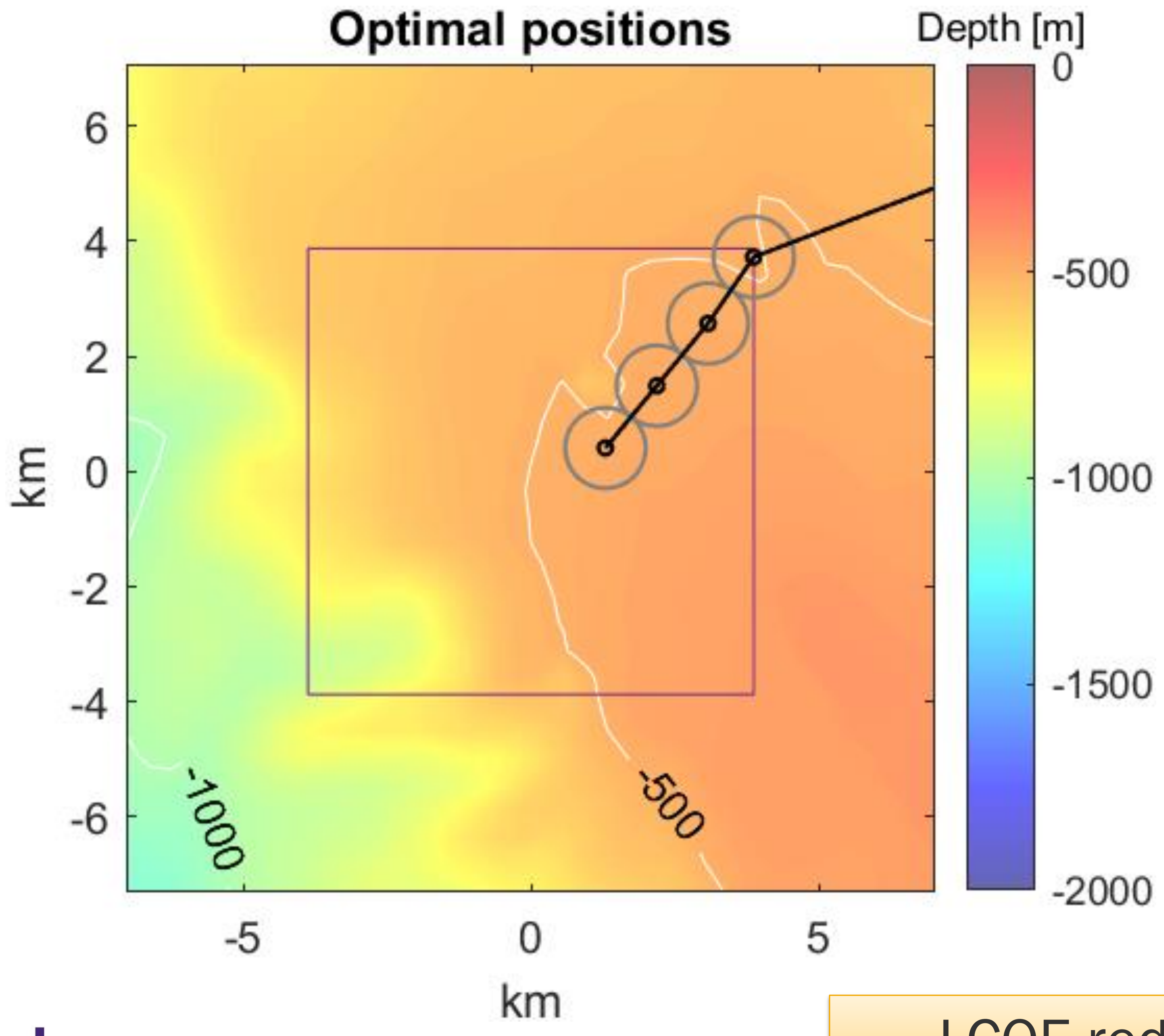
- To allow a fast wake calculation, the Jensen model is used
- Electrical grid losses are calculated using power flows
- The initial solution is a 7Dx7D regularly spaced matrix

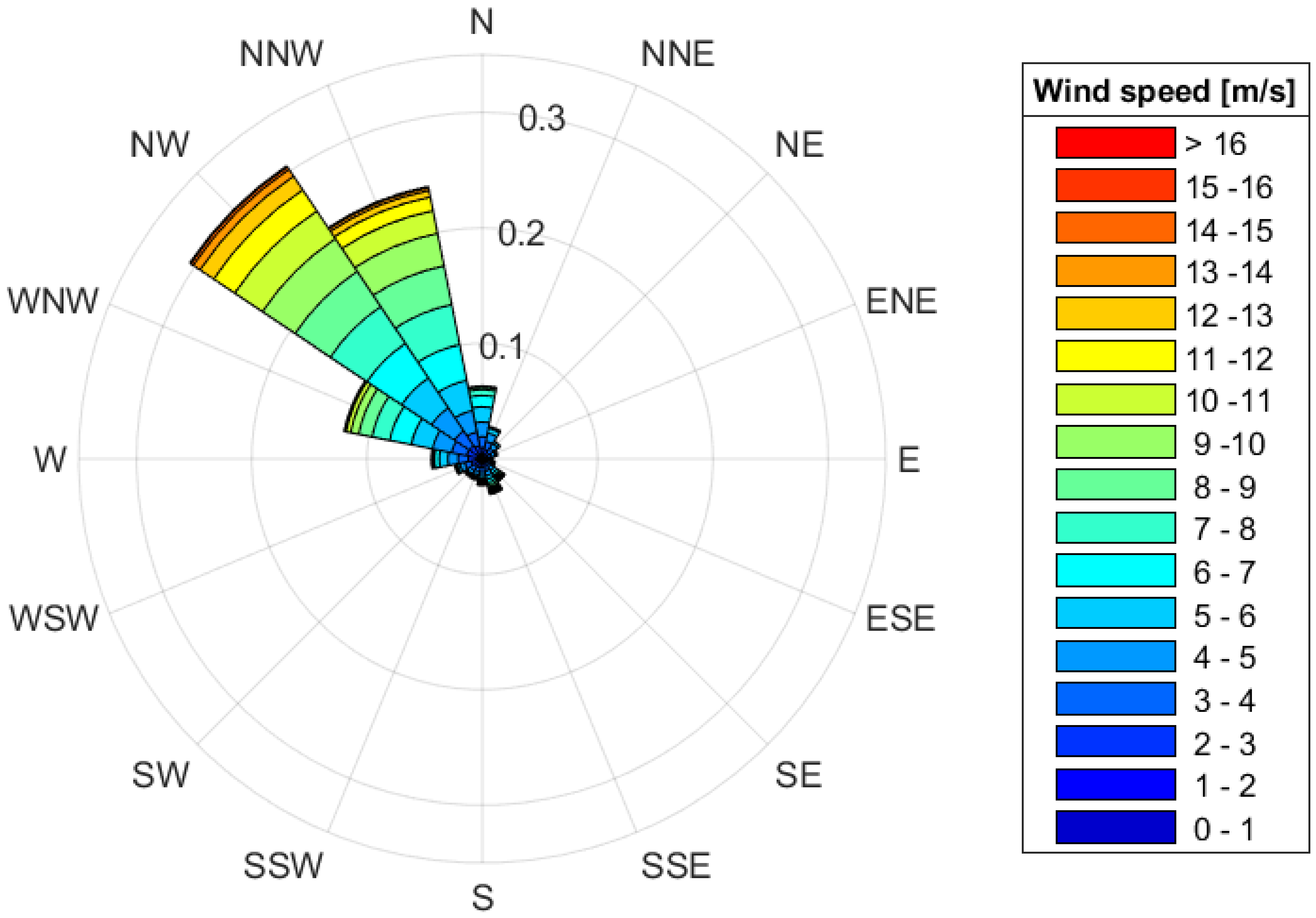
Assumptions:

- The free-stream wind speed is constant along the site
- Mooring and riser costs increase linearly with water depth
- Cables and mooring lines crossing is not allowed
- The mooring footprint is constant
- The same anchor is used for all turbines
- A one-time lease fee of 0.2 €/m^2 is considered
- The electrical layout is predefined, therefore only the cable lengths change
- The O&M cost is constant

Results

- Scenario with 4 turbines in mostly-flat area
  - Initial LCOE: 131.8 €/MWh
  - Achieved LCOE: 126.7 €/MWh

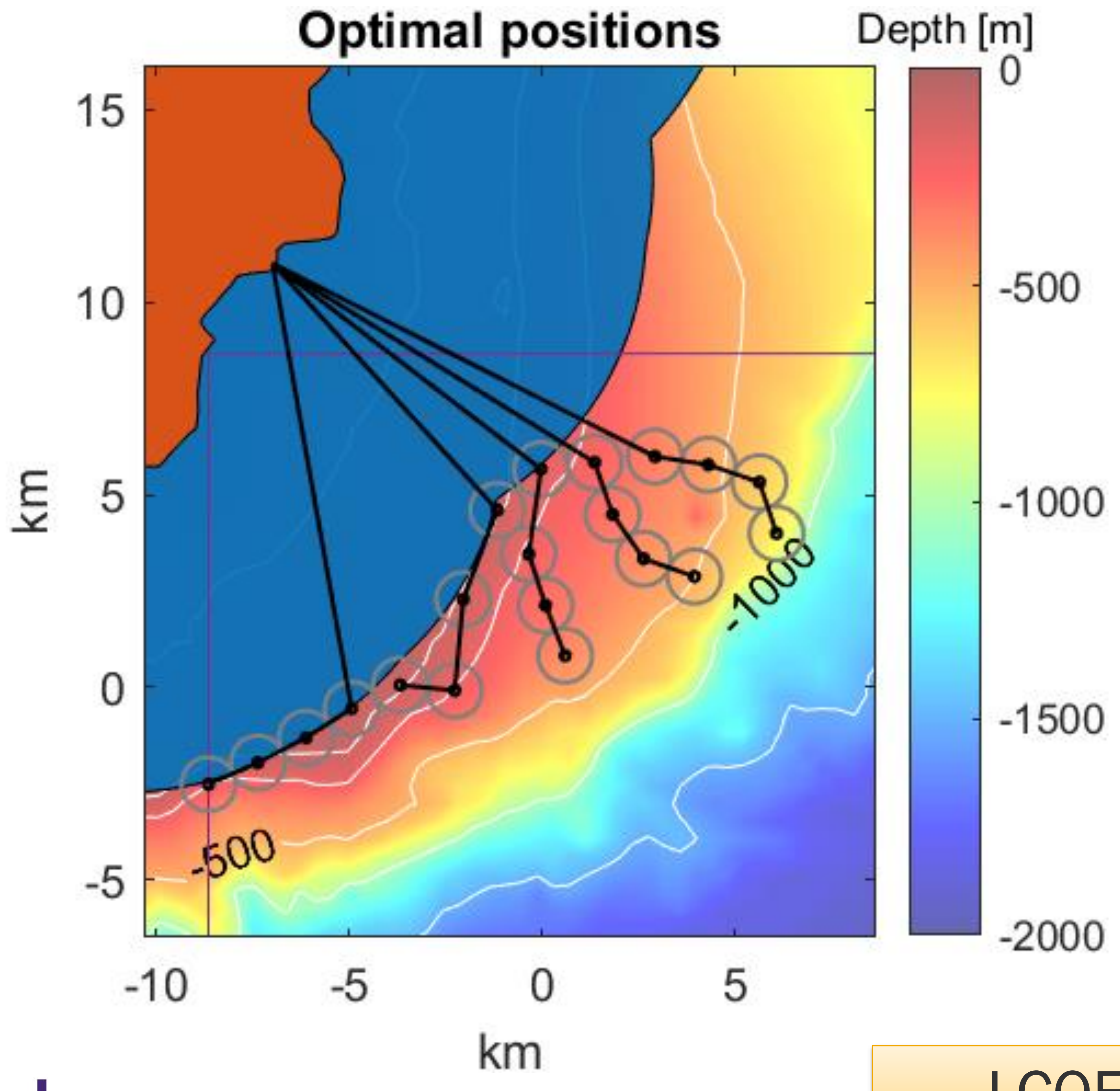


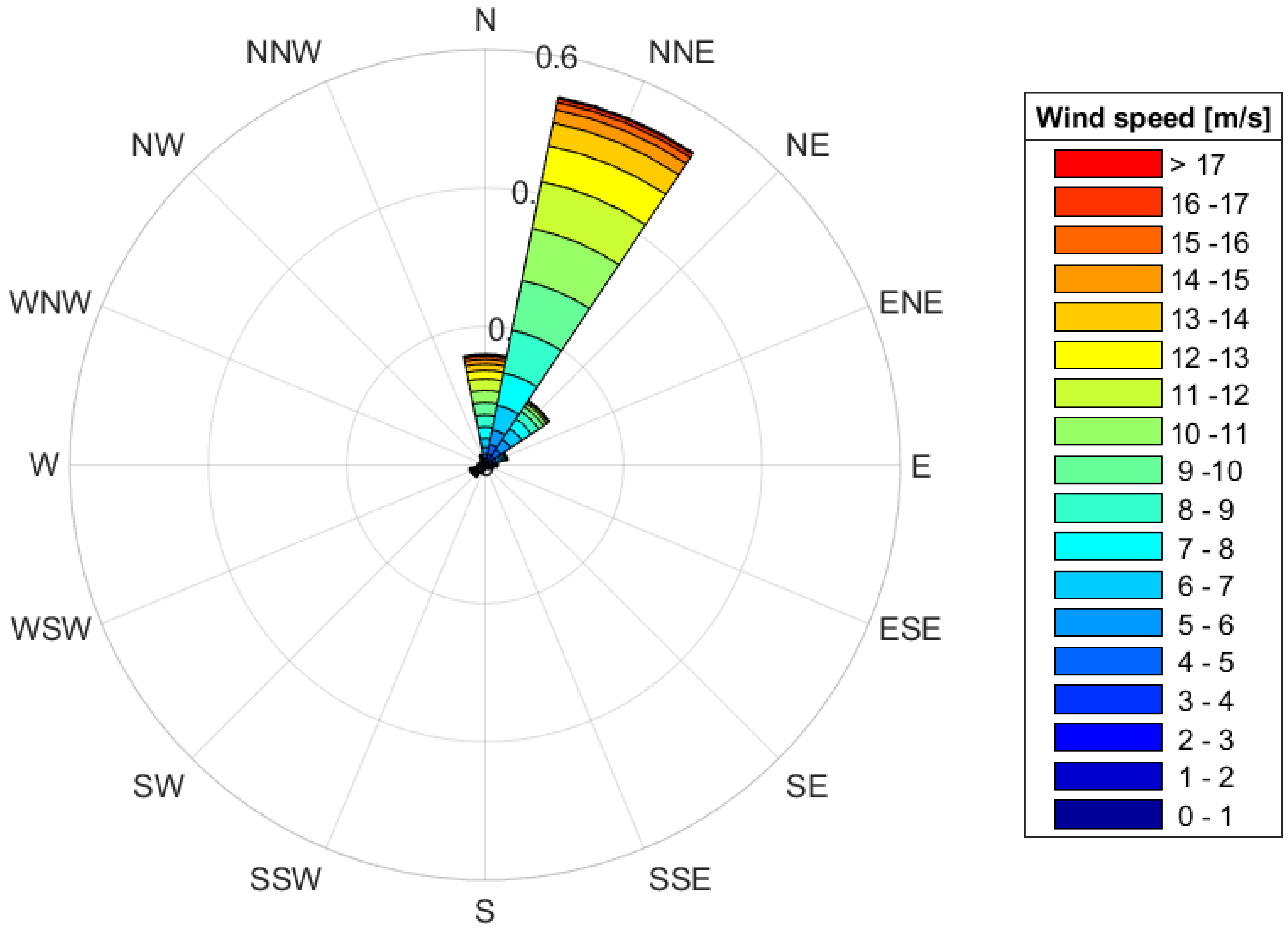


LCOE reduction: 3.9%

Results

- Scenario with 20 turbines in steep area
  - Initial LCOE: 64.0 €/MWh
  - Achieved LCOE: 60.9 €/MWh

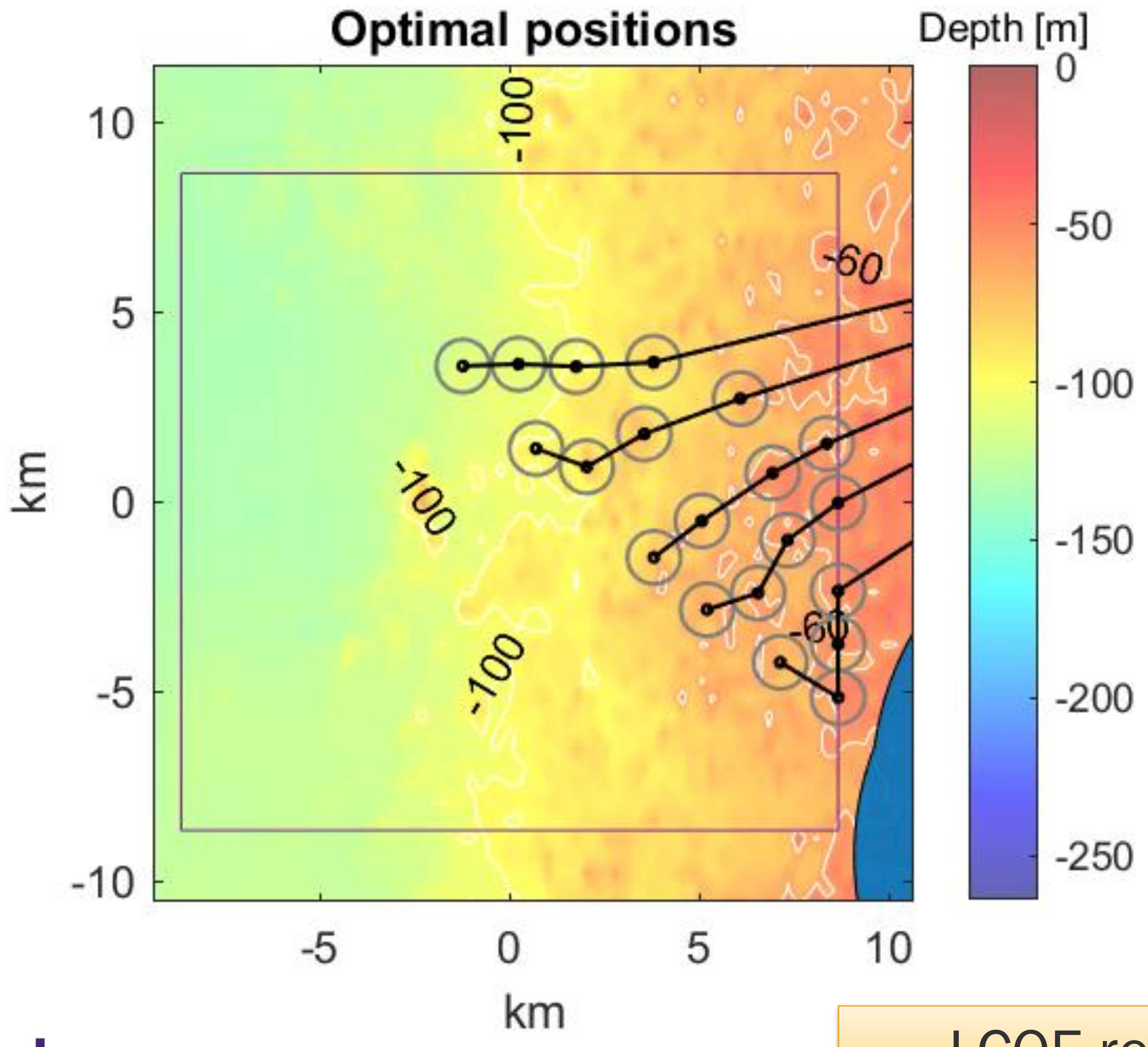


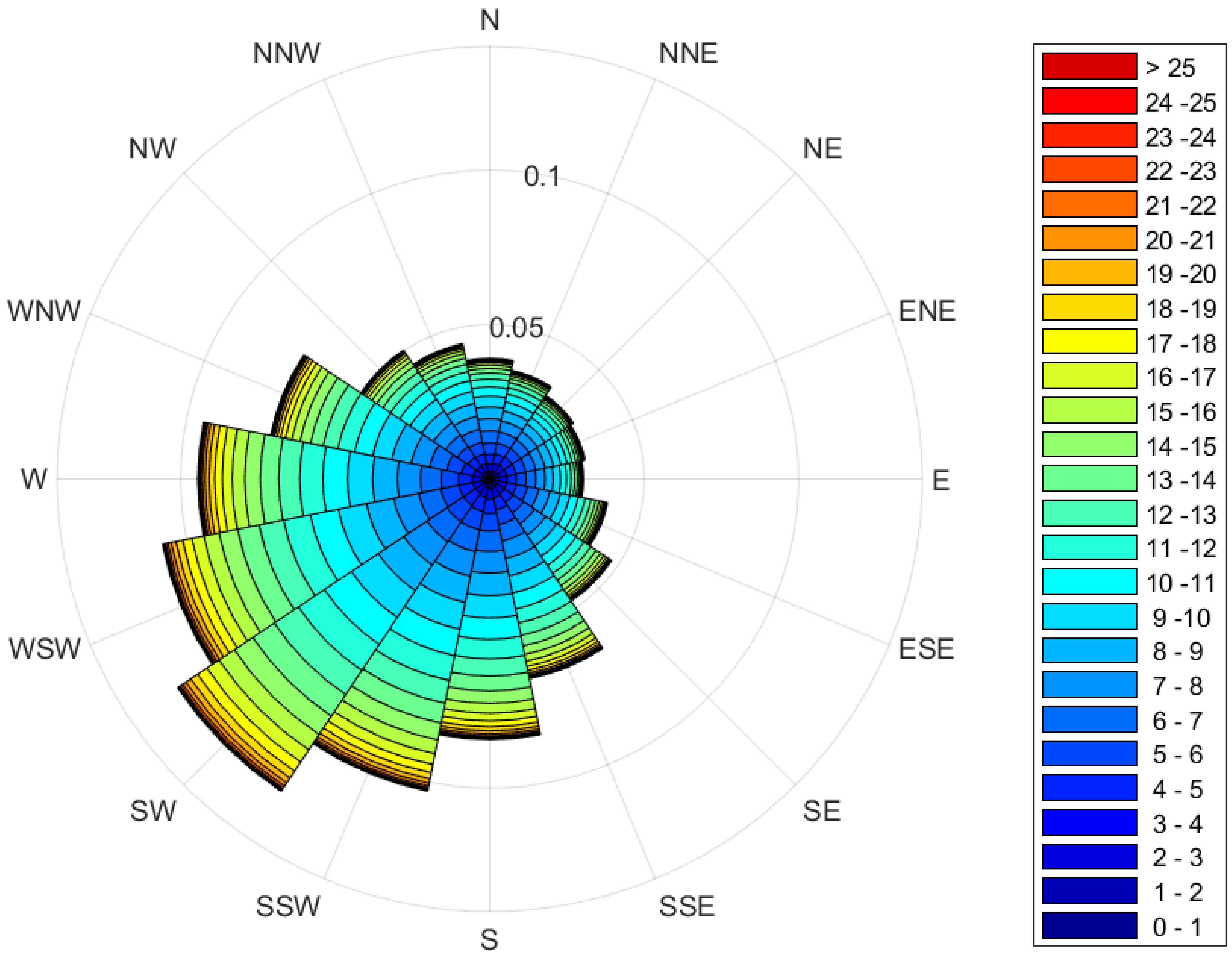


LCOE reduction: 4.8%

Results

- Scenario with 20 turbines in irregular area
  - Initial LCOE: 247.5 €/MWh
  - Achieved LCOE: 236.8 €/MWh





LCOE reduction: 4.3%

Conclusions

- Floating offshore wind farms micro-siting depends on multiple factors, which increases its complexity and requires a multi-disciplinary work
- The proposed PSO behaves correctly when optimising the layout, converging to optimal solutions in 1 hour for 4 turbines and 4 hours for 20 turbines; near-optimal solutions may be found in minutes.
- When the LCOE is minimised during the micro-siting, a reduction between a 3% and a 5% can be achieved, compared to a regular 7Dx7D spacing
- The results show that the bathymetry, wind climate, anchor radius and cable lengths are relevant, but with varying weights depending on the site

Further work

Many aspects may be improved to achieve more realistic results. The ones expected to have a greater impact on the micro-siting are:

- Consider free-stream wind speed variations in large wind farms
- Consider the soil conditions for anchor selection
- Consider variations on the O&M costs
- Perform de optimisation given the site area (instead of a point), with fixed and variable capacity

Thanks for your attention

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Impact of peak load reduction system on mooring design

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Valentin Arramounet
Technical lead Ocean Engineering

Exploration of innovations and breakthroughs of station keeping systems for FOWT

- Breakthrough analysis / Technological benefits regarding peak loads reduction

  The aim of this subtask is to focus on peak load reduction.

  Reduction in peak loads and maximum tension will aim to define lower grade or lower capability (Minimum Breaking Load) equipment's thus lowering station keeping system cost.

- Two systems are beeing studied : TFI and IMS

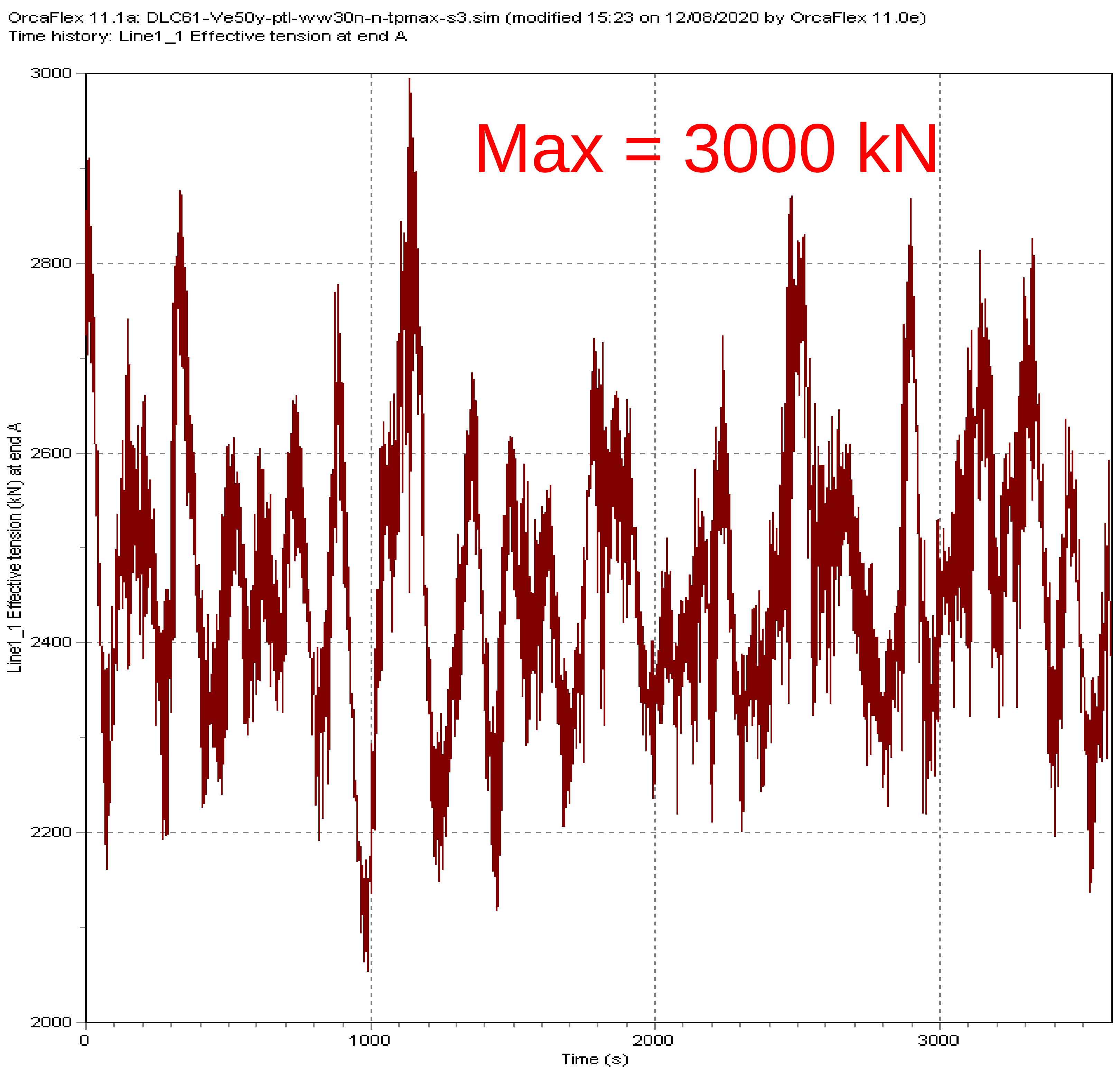
Breakthrough analysis / Technological benefits regarding peak loads reduction

- TFI-Polymer Mooring Spring solution
  - Spreadsheet shared with us to set up spring into OrcaFlex
  - Cost function has been provided
  - TFI system has been added to the optimization process (number, target SLS)
  - Reduce peak loads (allow to reduce chain diameter)
  - Increase Max surge (might be challenging for dynamic cable design)

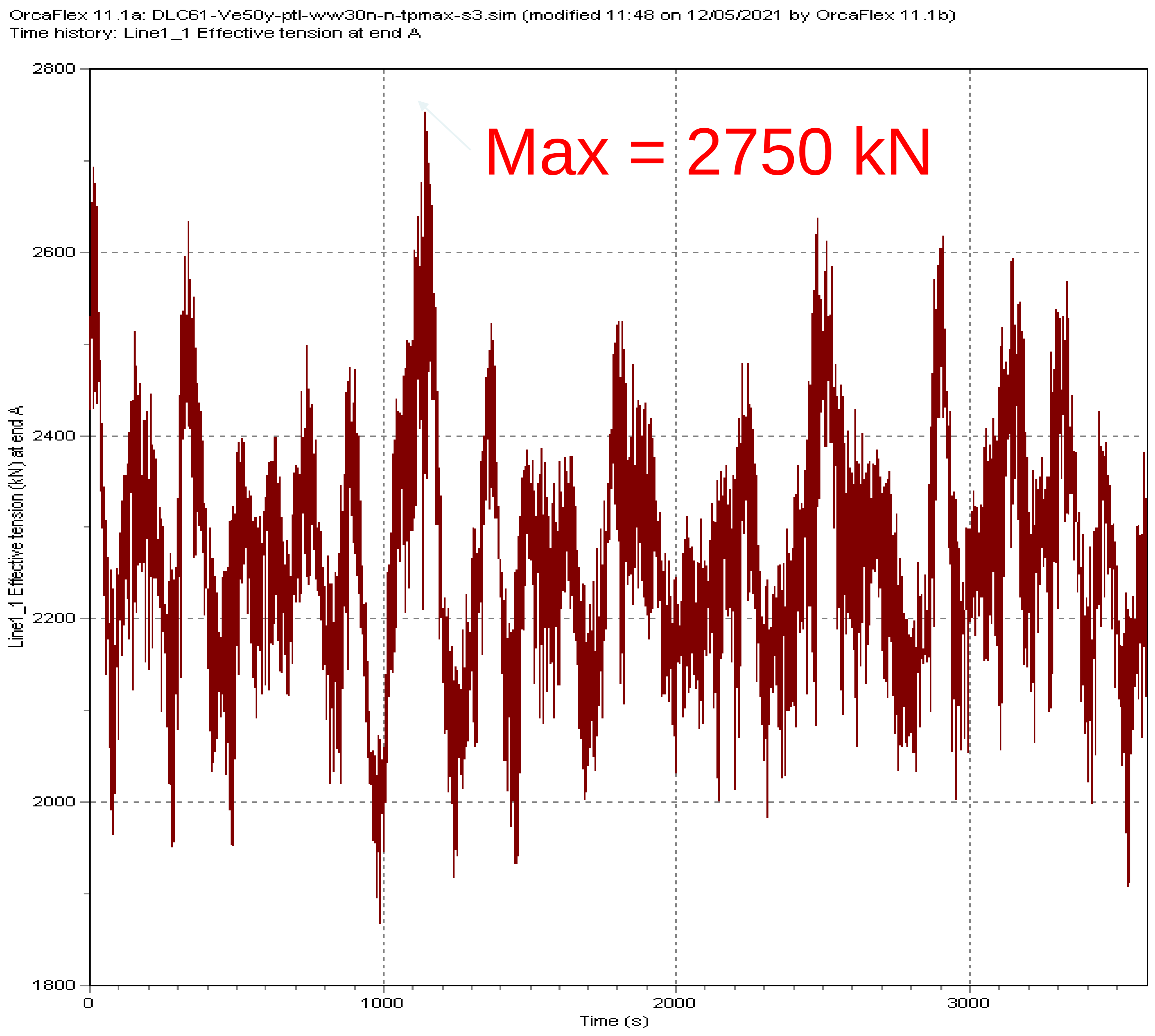
Figures from TFI presentation

Breakthrough analysis / Technological benefits regarding peak loads reduction

- TFI-Polymer Mooring Spring solution
  - Exemple on ActiveFloat site B : 8% peak loads reduction at the fairlead on upwind line



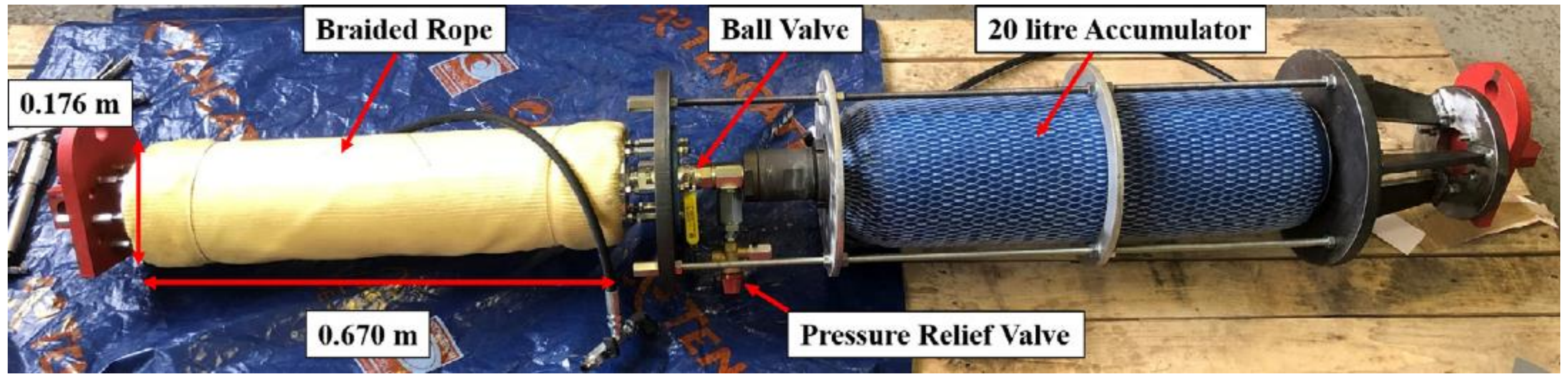
Max = 3000 kN



Max = 2750 kN

Breakthrough analysis / Technological benefits regarding peak loads reduction

- IMS – Intelligent Mooring System
  - Non-linear stiffness, which can be varied by changing the system pre-charge pressure in the accumulator.



  - Previous simulations on NREL 5MW FOWT showed from 9% to 21% peak loads reductions, depending on device's scale (lengths of 2.67m & 20m).
  - Surge increased, especially in cases of semi-submersible platforms.

Breakthrough analysis / Technological benefits regarding peak loads reduction

- Implementation in Corewind project
    - Data shared with us for OrcaFlex set up and for scaling method.
    - The system has been added to the optimization process (number, target MBL and pre-charge pressure).
    - 5 different pre-charge pressures & 2 different pre-loading of the system were studied

Breakthrough analysis / Technological benefits regarding peak loads reduction

Sites and floaters studied cases:

- TFI&IMS have been implemented to all the optimized mooring of phase 1 for both 3 sites and 2 floaters, re-optimized and ULS checked (DLC61 and 62, start and end of life).

- Except IMS for Site A that could not be implemented due to the high stiffness of the system in the range of tensions observed on this site due to very extreme conditions.

			Mooring optimization	Start of Life		End of Life	
				DLC61	DLC62	DLC61	DLC62
TFI	WindCrete	Site B	Done	Done	Done	Done	Done
		Site C	Done	Done	Done	Done	Done
	ActiveFloat	Site A	Done	Done	Done	Done	Done
		Site B	Done	Done	Done	Done	Done
		Site C	Done	Done	Done	Done	Done
IMS	WindCrete	Site B	Done	Done	Done	Done	Done
		Site C	Done	Done	Done	Done	Done
	ActiveFloat	Site A	Aborted	Aborted	Aborted	Aborted	Aborted
		Site B	Done	Done	Done	Done	Done
		Site C	Done	Done	Done	Done	Done

Case Study: COREWIND

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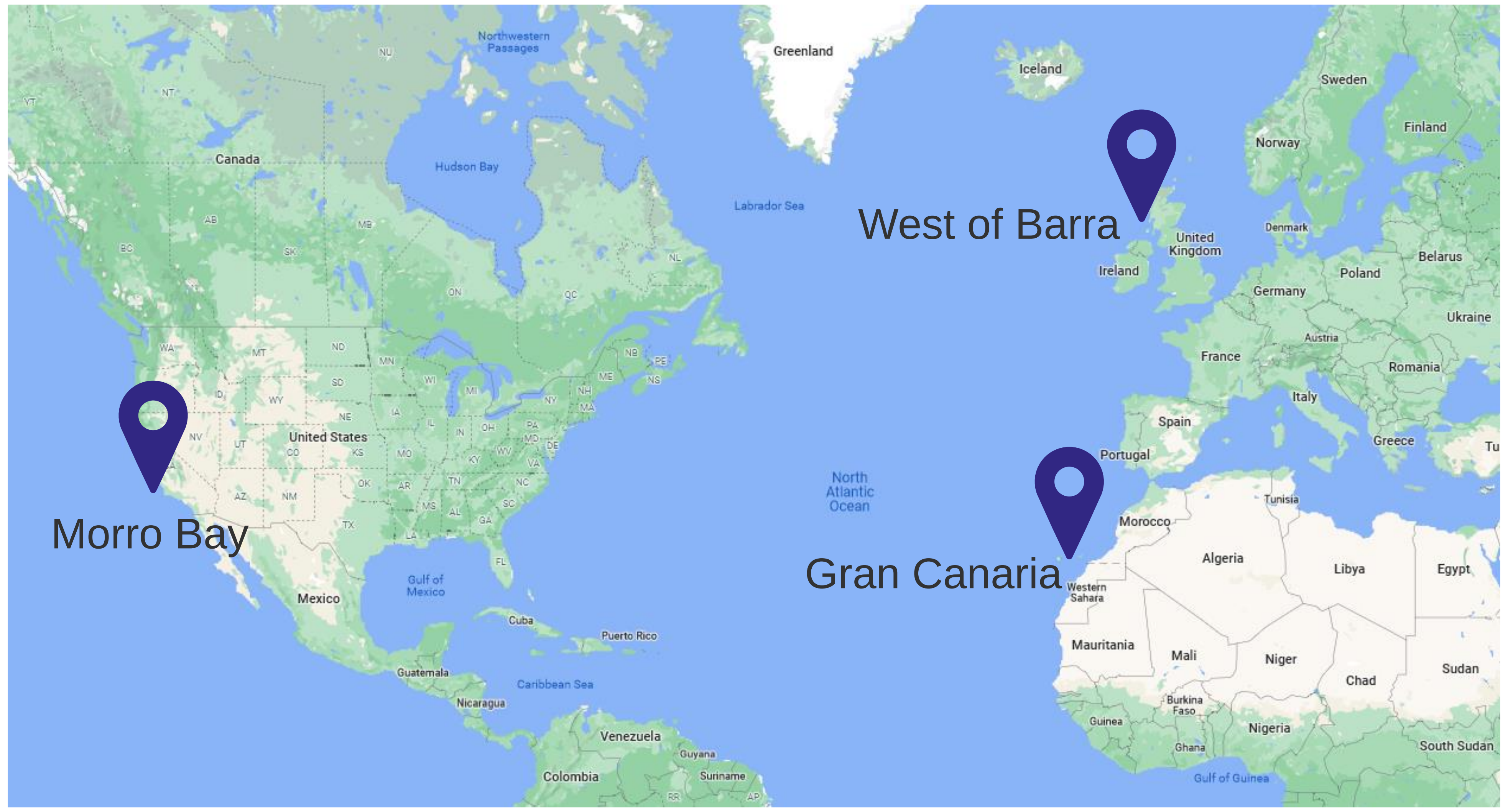
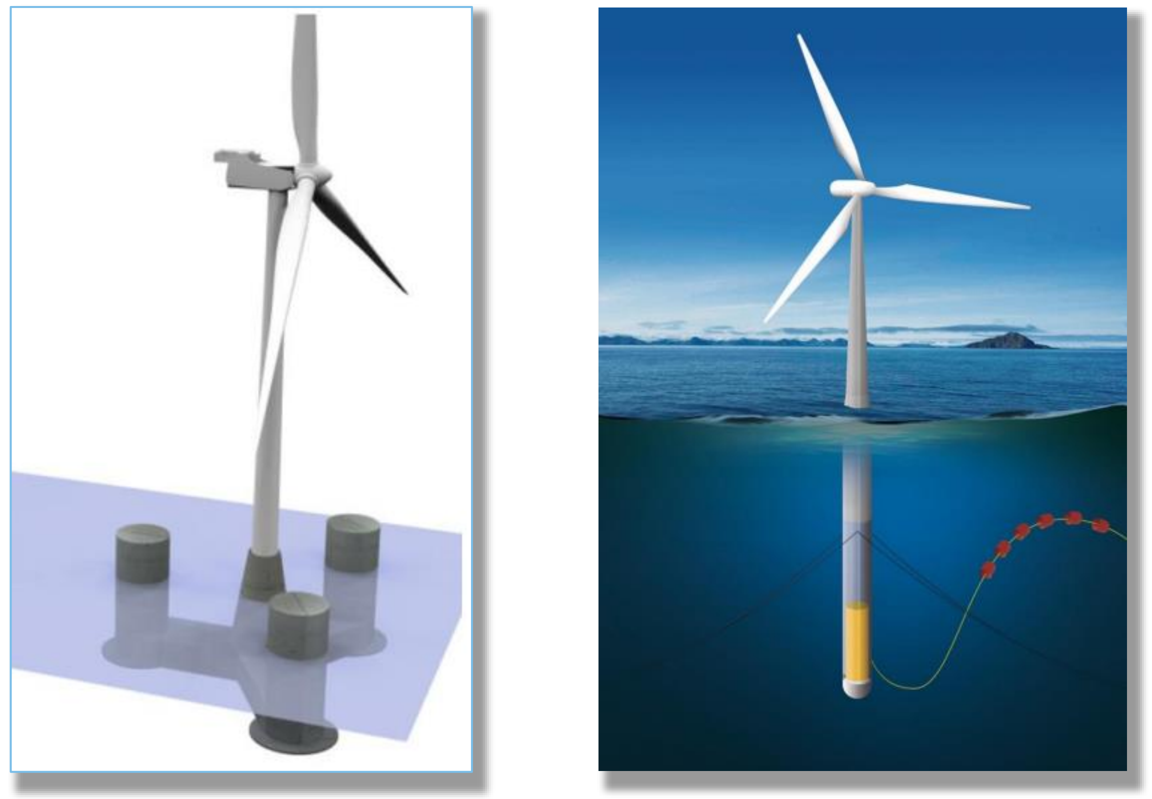
- 2 reference concepts:
    - Windcrete spar (UPC)
    - ActiveFloat semi-submersible (COBRA)
- 3 reference sites of varying metocean conditions & water depths (beyond Jack-Up)





[Source: COREWIND, Deliverable D1.2 Design Basis]

All findings will be published in:
Deliverable D2.3
September 2022
Uploaded on:
http://corewind.eu/publications/

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site A West of Barra – ActiveFloat - TFI

Site A	WOB	TFI

		Donnée d'entrée
Number of lines	**Upwind**	6
	Downwind	6
Type of floater		ActiveFloat
Type of mooring		Catenary
Type of chain		Studless
Total cost of the mooring		**5651 k€**
Cost increase		15%

	Upwind	Downwind
Chain diameter (mm)	114	100
Nylon diameter (mm)	240	240
Chain grade	3	4
Chain section length (m)	222,5	253
Nylon section length (m)	147,5	87
Number of TFI per line	2	2
MBL (kN)	11500	10500

DLC61 & 62 (SOL&EOL) results	Upwind	Downwind
Max tension criterion (chain)	0,974	0,927
Max tension criterion (nylon)	0,822	0,676
Max tension criterion (TFI)	0,861	0,776
Minimum touchdown point (m)	14	10
Max offset (m)	32,407	
Max pitch (°)	8,942	
Max yaw (°)	6,629	
Max horizontal acceleration (m/s2)	2,908	

- Chain/TFI mooring system leads to 15% cost increase.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site A West of Barra – ActiveFloat – TFI

- The implementation of TFI systems is responsible for 44% increase of the total cost of the mooring.

- This is compensated by 17% decrease of the total cost of the mooring thanks to lower chain grades and diameters, which also leads to a 12% decreasing of the anchors cost.

- Unfortunately, the high number of lines (12) leads to a total of 24 TFI spring systems used in the mooring, which is very difficult to compensate by decreasing lines diameters and chain grades.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site A West of Barra – ActiveFloat – IMS

- The implementation of IMS systems led to higher tensions in the mooring lines due to the stiffness of the system.

- No configuration configuration found. IMS implementation on this site aborted for the moment.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site B Gran Canaria – ActiveFloat

Site B	Gran Canaria	**TFI**
Number of lines	**Upwind**	1
	Downwind	2
Type of floater		ActiveFloat
Type of mooring		Catenary
Type of chain		Studless
Maximum pretension (kN)		533,93
Total cost of the mooring		**713 k€**
Cost reduction		*18%*

	Upwind	Downwind
Chain diameter (mm)	90	56
Chain grade	R4	R3
Chain section length (m)	990	865
Number of TFI per line	1	1
MBL (kN)	6400	2400

DLC61 & 62 (SOL&EOL) results	Upwind	Downwind
Max tension criterion (chain)	0,960	0,936
Max tension criterion (TFI)	0,949	0,696
Minimum touchdown point (m)	12	11
Max offset (m)	58,216	
Max pitch (°)	1,653	
Max yaw (°)	4,968	
Max horizontal acceleration (m/s2)	0,682	

Site B	Gran Canaria	**IMS**
Number of lines	**Upwind**	1
	Downwind	2
Type of floater		ActiveFloat
Type of mooring		Catenary
Type of chain		Studless
Maximum pretension (kN)		543,35
Total cost of the mooring		**766 k€**
Cost reduction		*11%*

	Upwind	Downwind
Chain diameter (mm)	94	56
Chain grade	R3S	R3
Chain section length (m)	950	900
Number of IMS per line	1	1
MBL (kN)	7600	3100
Pre-charge pressure (kPa)	100	350
Pre-load (%MBL)	0	10

DLC61 & 62 (SOL&EOL) results	Upwind	Downwind
Max tension criterion (chain)	0,971	0,999
Max tension criterion (IMS)	0,800	0,578
Minimum touchdown point (m)	16	14
Max offset (m)	57,166	
Max pitch (°)	2,147	
Max yaw (°)	4,029	
Max horizontal acceleration (m/s2)	1,464	

- Chain/TFI mooring system leads to 18% cost reduction.
- Chain/IMS mooring system leads to 11% cost reduction.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site B Gran Canaria – WindCrete

Site B	Gran Canaria	**TFI**
Number of lines	**Upwind**	1
	Deltalines	6
	Downwind	2
Type of floater		WindCrete
Type of mooring		Caténaire
Type of chain		Studless
Yaw mooring stiffness (kN.m/rad)		376369,56
Maximum pretension (kN)		1 264,24
Total cost of the mooring		**944 k€**
Cost reduction		*27%*

	Upwind	Deltalines	Downwind
Chain diameter (mm)	88	80	78
Chain grade	R4	R3S	R3S
Chain section length (m)	750	50	750
Number of TFI per line	1	-	1
MBL (kN)	7200	-	5600

DLC61 & 62 (SOL&EOL) results	Upwind	Deltalines	Downwind
Max tension criterion (chain)	0,778	0,975	0,989
Max tension criterion (TFI)	0,707	-	0,921
Minimum touchdown point (m)	12	-	17
Max offset (m)	7,993		
Max pitch (°)	2,148		
Max yaw (°)	3,843		
Max horizontal acceleration (m/s2)	1,576		

Site B	Gran Canaria	**IMS**
Number of lines	**Upwind**	1
	Deltalines	6
	Downwind	2
Type of floater		WindCrete
Type of mooring		Caténaire
Type of chain		Studless
Yaw mooring stiffness (kN.m/rad)		370343,41
Maximum pretension (kN)		1 249,79
Total cost of the mooring		**948 k€**
Cost reduction		*27%*

	Upwind	Deltalines	Downwind
Chain diameter (mm)	100	78	72
Chain grade	R3	R4	R4
Chain section length (m)	670	50	815
Number of IMS per line	1	-	1
MBL (kN)	6400	-	4200
Pre-charge pressure (kPa)	250	-	300
Pre-load (%MBL)	0	-	0

DLC61 & 62 (SOL&EOL) results	Upwind	Deltalines	Downwind
Max tension criterion (chain)	0,792	0,952	0,967
Max tension criterion (IMS)	0,847	-	0,912
Minimum touchdown point (m)	12	-	12
Max offset (m)	7,260		
Max pitch (°)	2,132		
Max yaw (°)	4,323		
Max horizontal acceleration (m/s2)	1,574		

- Chain/TFI mooring system leads to 27% cost reduction
- Chain/IMS mooring system leads to 27% cost reduction

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site B Gran Canaria – Costs detail

- The implementation of TFI or IMS systems is responsible for 12% to 20% increase of the total cost of the mooring.

- This is compensated by 23% to 33% decrease of the total cost of the mooring thanks to lower chain grades and diameters, which also leads to a decreasing of the anchors cost.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site C Morro Bay – ActiveFloat

Site C	Morro Bay	TFI

Number of lines	**Upwind**	1
	Downwind	2
Type of floater		ActiveFloat
Type of mooring		Semi-tendu
Type of polyester		Acordis 855TN
Maximum pretension (kN)		1 297,79
Total cost of the mooring		**2660 k€**
Cost increase		*20%*

	Upwind	Downwind
Chain diameter (mm)	130	95
Polyester diameter (mm)	190	155
Chain grade	R3	R4
Chain section length (m)	192,5	181,25
Polyester section length (m)	807,5	818,75
Number of TFI per line	3	1
MBL (kN)	12000	8000

DLC61 & 62 (SOL&EOL) results	Upwind	Downwind
Max tension criterion (chain)	0,66	0,97
Max tension criterion (polyester)	0,69	0,91
Max tension criterion (TFI)	0,64	0,86
Max offset (m)	44,13	
Max pitch (°)	6,52	
Max yaw (°)	3,11	
Max horizontal acceleration (m/s2)	3,37	

Site C	Morro Bay	IMS

Number of lines	**Upwind**	1
	Downwind	2
Type of floater		ActiveFloat
Type of mooring		Semi-tendu
Type of polyester		Acordis 855TN
Maximum pretension (kN)		1 751,15
Total cost of the mooring		**2586 k€**
Cost increase		*16%*

	Upwind	Downwind
Chain diameter (mm)	135	110
Polyester diameter (mm)	190	155
Chain grade	R3	R3
Chain section length (m)	200	188,75
Polyester section length (m)	850	861,25
Number of IMS per line	3	1
MBL (kN)	12000	10000
Pre-charge pressure (kPa)	350	250
Pre-load (%MBL)	0	0

DLC61 & 62 (SOL&EOL) results	Upwind	Downwind
Max tension criterion (chain)	0,763	0,949
Max tension criterion (polyester)	0,786	0,975
Max tension criterion (IMS)	0,730	0,735
Max offset (m)	31,984	
Max pitch (°)	6,601	
Max yaw (°)	2,849	
Max horizontal acceleration (m/s2)	3,258	

- Chain/TFI mooring system leads to 20% cost increase.
- Chain/IMS mooring system leads to 16% cost increase.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site C Morro Bay – WindCrete

Site C	Morro Bay	TFI

Number of lines	**Upwind**	1
	Deltalines	8
	Downwind	3
Type of floater		WindCrete
Type of mooring		Semi-tendu
Type of polyester		Acordis 855TN
Yaw mooring stiffness (kN.m/rad)		5,86E+05
Maximum pretension (kN)		1 793,66
Total cost of the mooring		**1529 k€**
Cost reduction		*6%*

	Upwind	Deltalines	Downwind
Chain diameter (mm)	106	92	106
Polyester diameter (mm)	152	-	158
Chain grade	R3	R3S	R3
Chain section length (m)	240,5	50	178,5
Polyester section length (m)	1079,5	-	1061,5
Number of TFI per line	2	-	1
MBL (kN)	7600	-	7800

DLC61 & 62 (SOL&EOL) results	Upwind	Deltalines	Downwind
Max tension criterion (chain)	0,786	0,978	0,852
Max tension criterion (polyester)	0,977	-	0,966
Max tension criterion (TFI)	0,928	-	0,978
Max offset (m)	15,221		
Max pitch (°)	4,448		
Max yaw (°)	10,312		
Max horizontal acceleration (m/s2)	2,400		

Site C	Morro Bay	IMS

Number of lines	**Upwind**	1
	Deltalines	8
	Downwind	3
Type of floater		WindCrete
Type of mooring		Semi-tendu
Type of polyester		Acordis 855TN
Yaw mooring stiffness (kN.m/rad)		5,72E+05
Maximum pretension (kN)		1 749,52
Total cost of the mooring		**1491 k€**
Cost reduction		*8%*

	Upwind	Deltalines	Downwind
Chain diameter (mm)	100	100	100
Polyester diameter (mm)	165	-	155
Chain grade	R3S	R3S	R3
Chain section length (m)	201	50	189
Polyester section length (m)	1139	-	1071
Number of IMS per line	1	-	1
MBL (kN)	12000	-	12000
Pre-charge pressure (kPa)	200		200
Pre-load (%MBL)	0		10

DLC61 & 62 (SOL&EOL) results	Upwind	Deltalines	Downwind
Max tension criterion (chain)	0,961	0,988	0,994
Max tension criterion (polyester)	0,853	-	0,908
Max tension criterion (IMS)	0,617	-	0,571
Max offset (m)	14,543		
Max pitch (°)	4,563		
Max yaw (°)	11,245		
Max horizontal acceleration (m/s2)	2,417		

- Chain/TFI mooring system leads to 6% cost reduction.
- Chain/IMS mooring system leads to 8% cost reduction.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Site C Morro Bay – Costs detail

- The implementation of TFI or IMS systems is responsible for 10% to 19% increase of the total cost of the mooring.

- WindCrete : This is compensated by 12% to 17% decrease of the total cost of the mooring thanks to lower polyester diameters, and by around 5% decrease of the total cost of the mooring thanks to lower chain grades and diameters.

- ActiveFloat : The increase in the total cost due to the implementation of TFI or IMS cannot be compensated, because of the yaw stiffness limitation here. High yaw mooring stiffness is necessary to ensure max yaw < 15°.

Breakthrough analysis / Technological benefits regarding peak loads reduction

Overview

Peak load reduction system	Floater	Site	Cost difference
TFI	WindCrete	Gran Canaria	-27%
		Morro Bay	-6%
	ActiveFloat	West of Barra	+15%
		Gran Canaria	-18%
		Morro Bay	+20%
IMS	WindCrete	Gran Canaria	-27%
		Morro Bay	-8%
	ActiveFloat	West of Barra	No results
		Gran Canaria	-11%
		Morro Bay	+16%

Thanks for your attention

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Assessment of Floating Wind O&M Strategies

February 2022

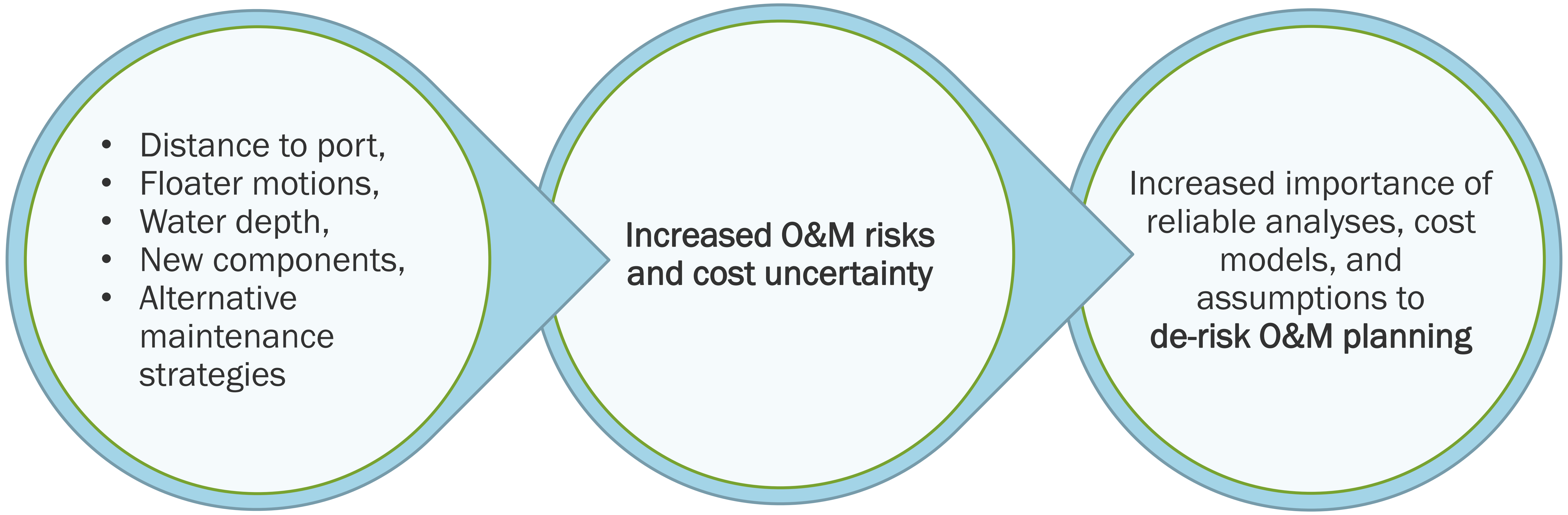
corewind.eu

Disclaimer:
This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under grant agreement No 815083.

Project details:
Duration:
1 Sep 2019 - 28 Feb 2023
Grant agreement:
No: 815083

Marie-Antoinette Schwarzkopf
Project Engineer at Ramboll

New Challenges



- Distance to port,
- Floater motions,
- Water depth,
- New components,
- Alternative maintenance strategies

Increased O&M risks and cost uncertainty

Increased importance of reliable analyses, cost models, and assumptions to **de-risk O&M planning**

Major Component Exchange

Accessibility

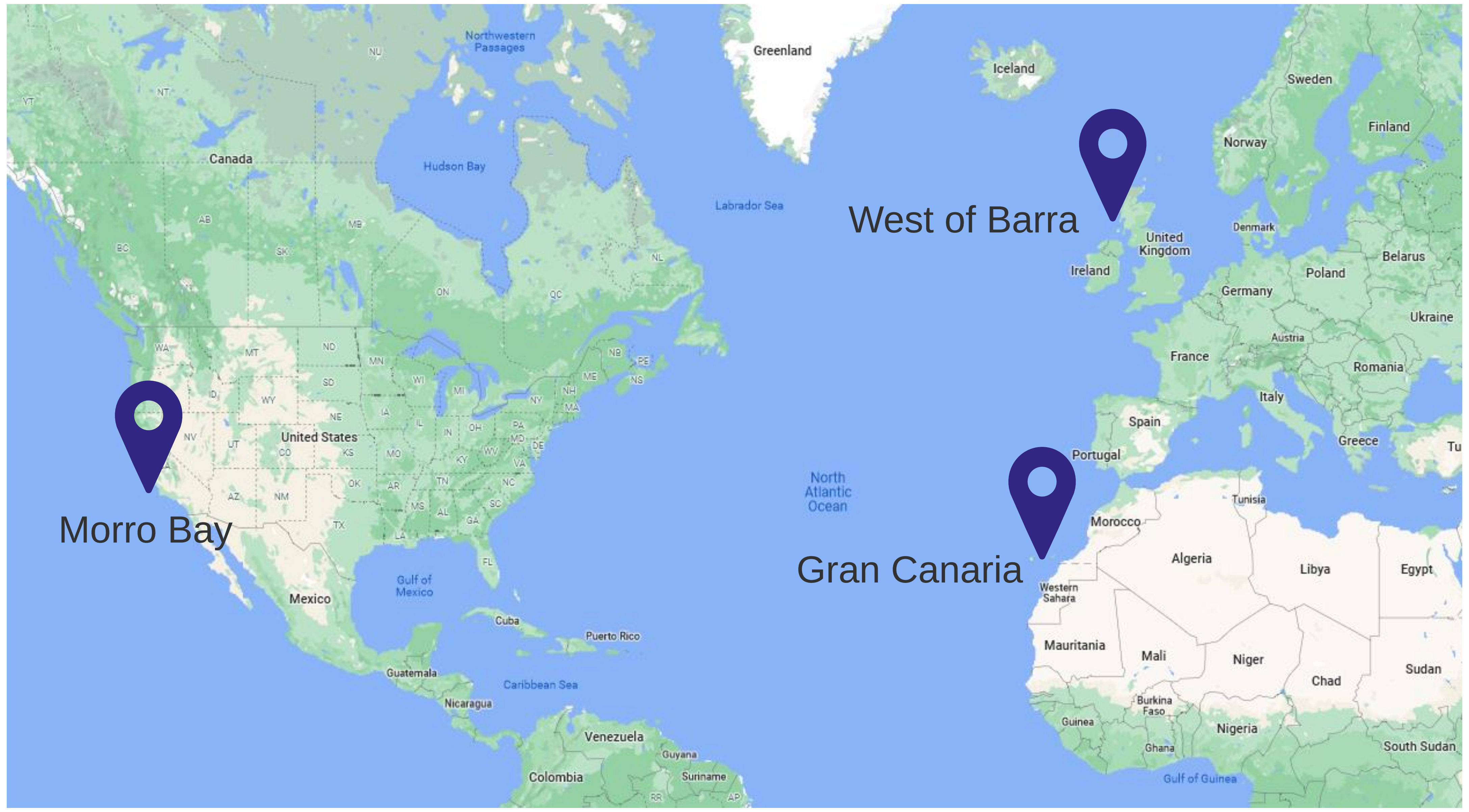
Workability / Transportability

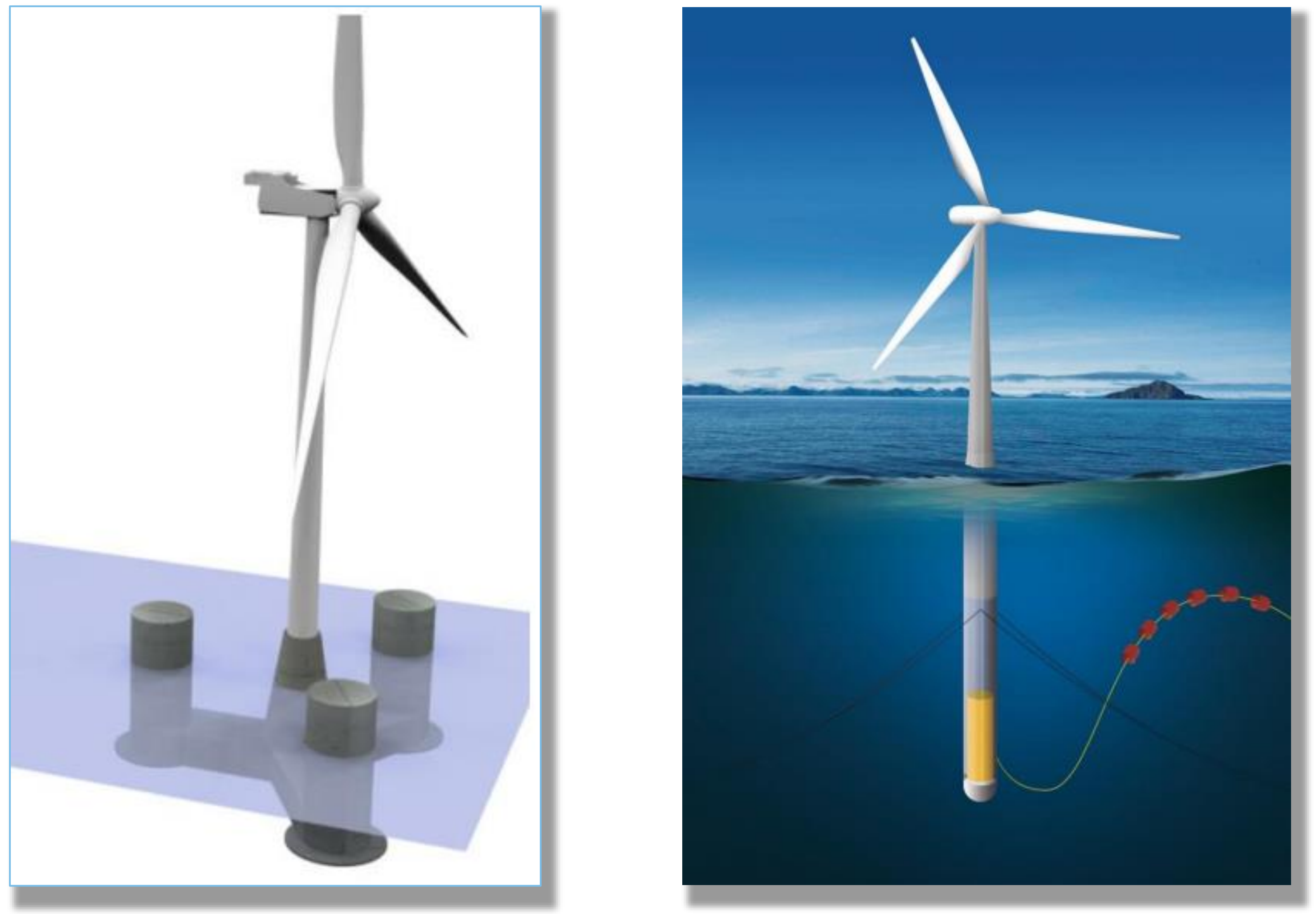
Maintenance Strategy

Reliability

Case Study Overview

- 2 reference floater concepts:
    - Windcrete spar (UPC)
    - ActiveFloat semi-submersible (COBRA)
- 3 reference sites of varying metocean conditions & water depths (beyond Jack-Up)





[Source: COREWIND, Deliverable D1.2 Design Basis]

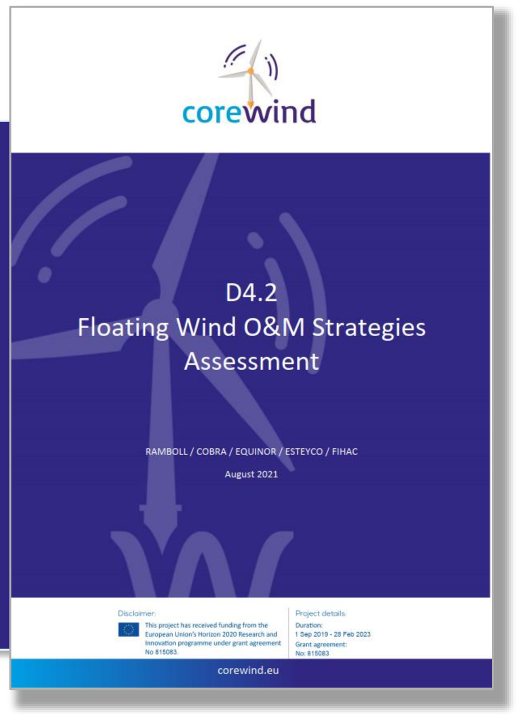
All findings published in:

Deliverable D4.2

"Floating Wind O&M Strategies Assessment"

Uploaded on:

http://corewind.eu/publications/



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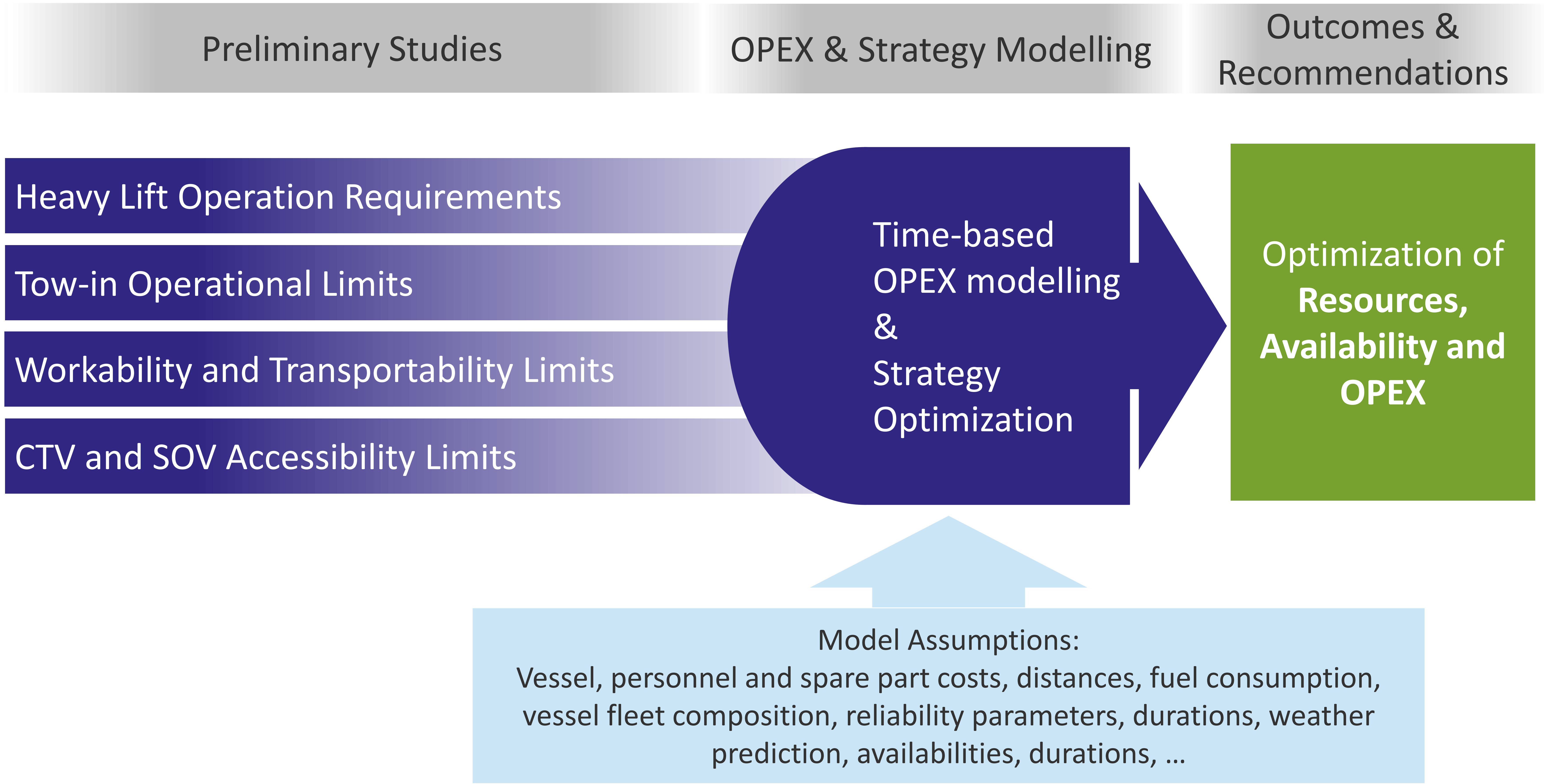
D4.2
Floating Wind O&M Strategies Assessment

August 2021

Overview of the Assessment



Preliminary Studies

OPEX & Strategy Modelling

Outcomes & Recommendations

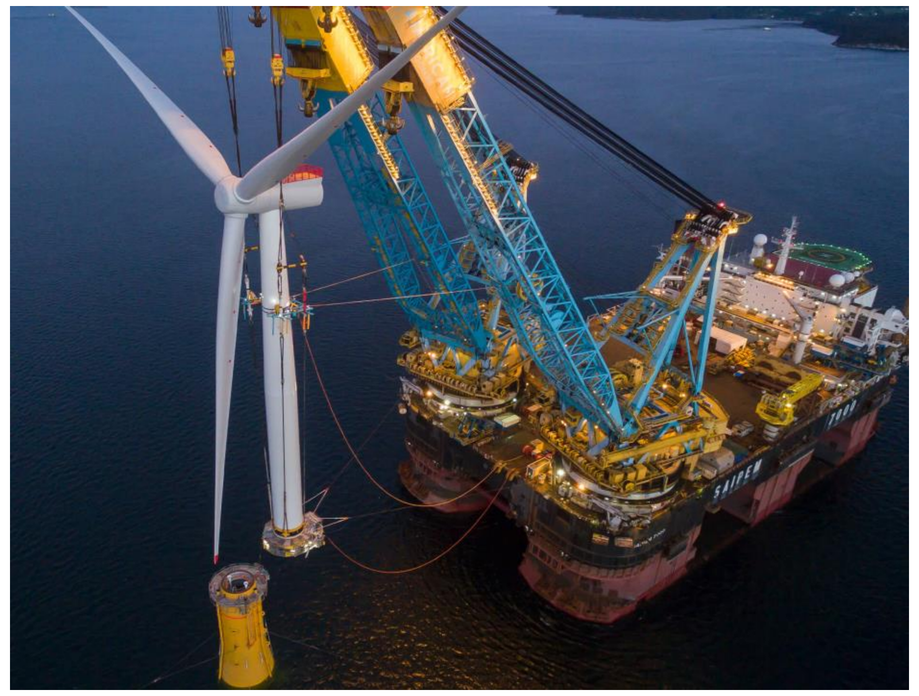
- Heavy Lift Operation Requirements
- Tow-in Operational Limits
- Workability and Transportability Limits
- CTV and SOV Accessibility Limits

Time-based OPEX modelling & Strategy Optimization

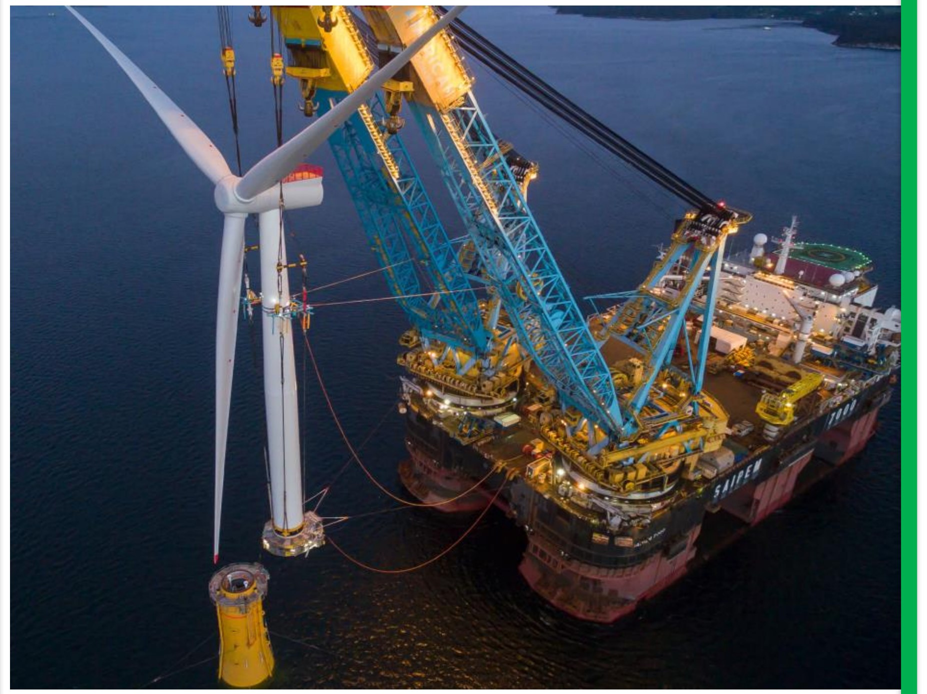
Optimization of **Resources, Availability and OPEX**

Model Assumptions:
Vessel, personnel and spare part costs, distances, fuel consumption, vessel fleet composition, reliability parameters, durations, weather prediction, availabilities, durations, …

Major component exchange – A Major cost driver

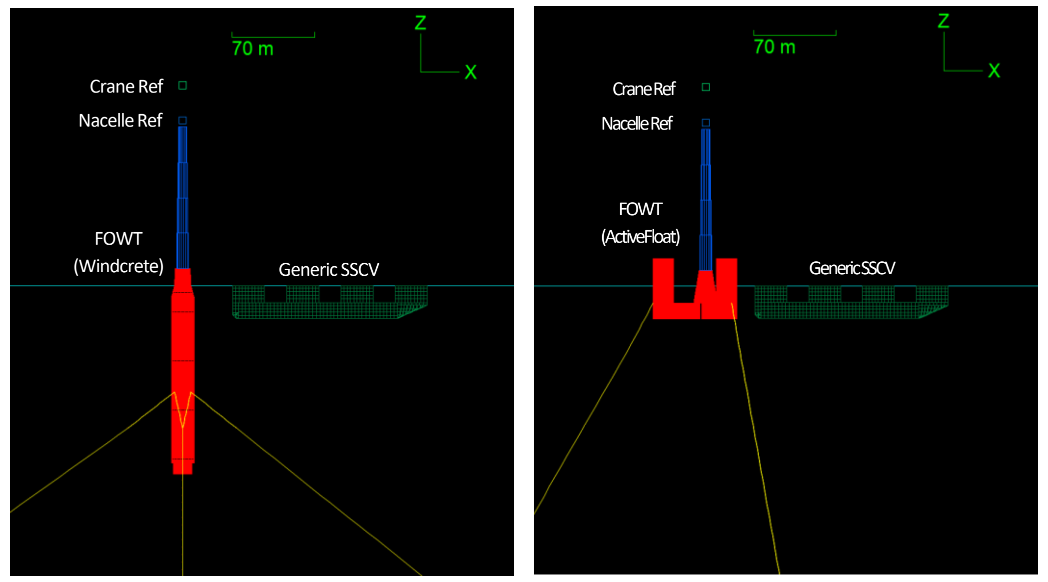
From/ To	Fixed	Floating
Fixed	 Installation of bottom fixed offshore wind turbine using JUV [Source: DEME].	 Turbine integration of WindFloat Atlantic at outer harbour of Ferrol, Spain [Source: Vestas].
Floating	 Turbine integration of DOT wind turbine on monopile using HLV [Source: Heerema].	 Turbine integration with Hywind Scotland spar using HLV [Source: Saipem].

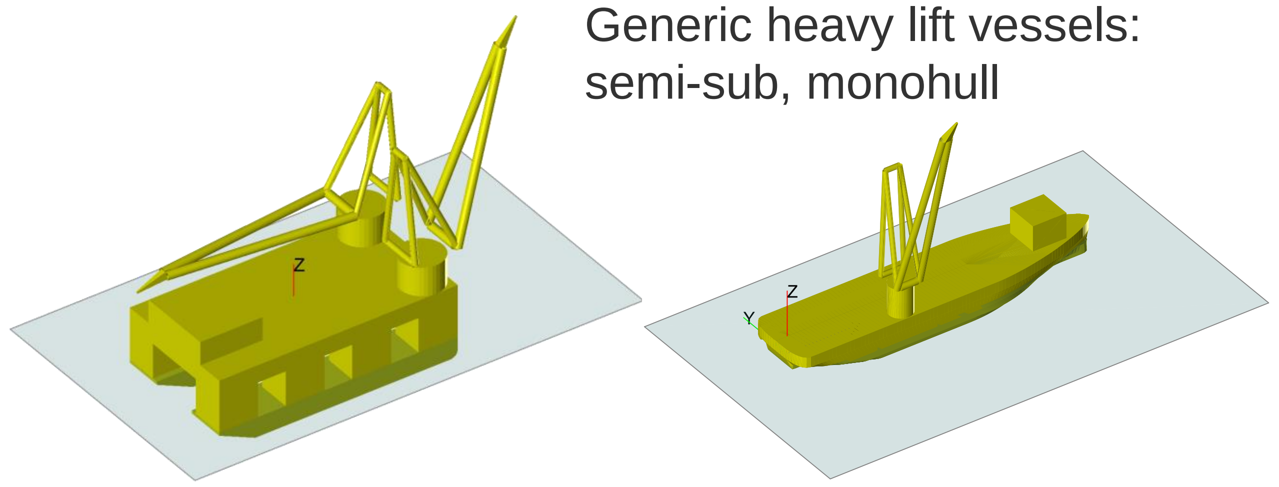
Major component exchange – A Major cost driver

From/ To	Fixed	Floating
Fixed	 Installation of bottom fixed offshore wind turbine using JUV [Source: DEME].	 Turbine integration of WindFloat Atlantic at outer harbour of Ferrol, Spain [Source: Vestas].
Floating	 Turbine integration of DOT wind turbine on monopile using HLV [Source: Heerema].	 Turbine integration with Hywind Scotland spar using HLV [Source: Saipem].

Floating-to-Floating (F2F) Scenario:

Approach: Time-domain OrcaFlex simulations (≈3000) with variations of vessel, orientation, Hs, Tp, direction





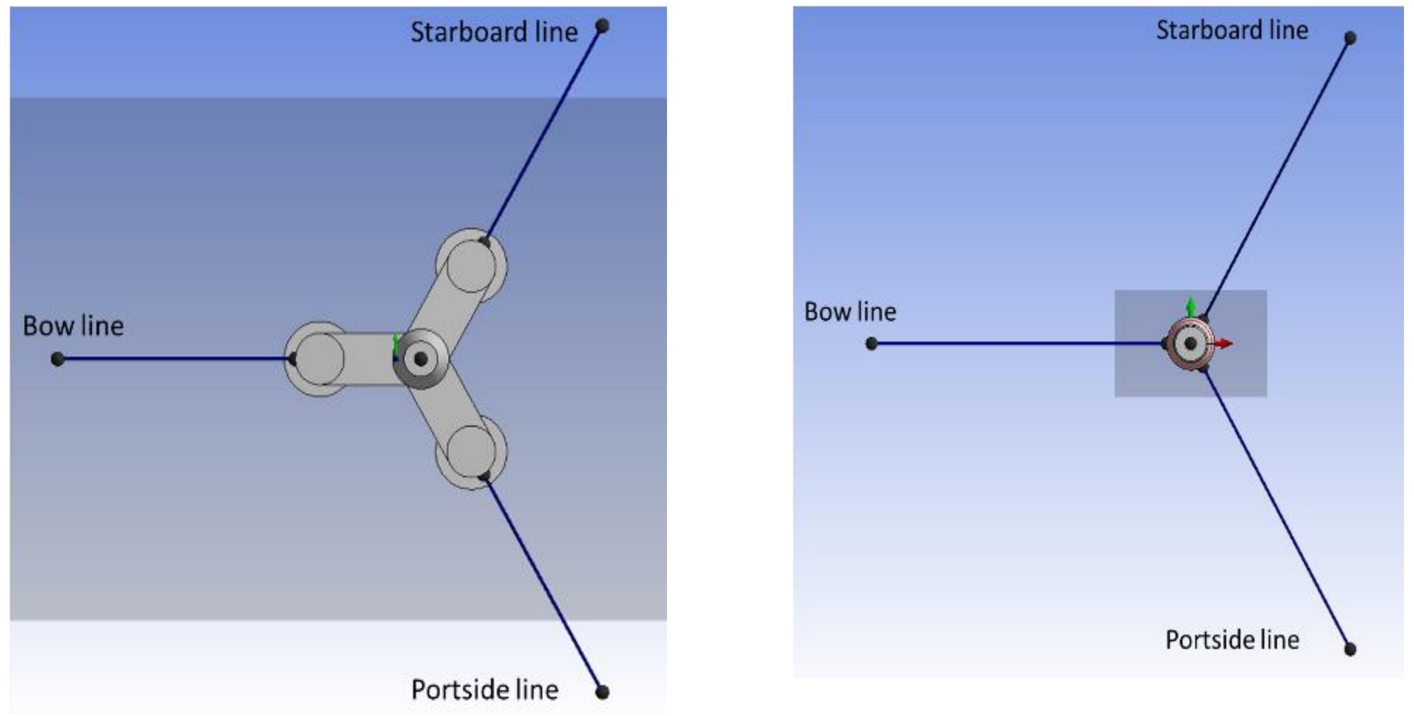
Generic heavy lift vessels: semi-sub, monohull

Results: Operational limits based on relative motions and compensation requirements (relative vertical velocity)

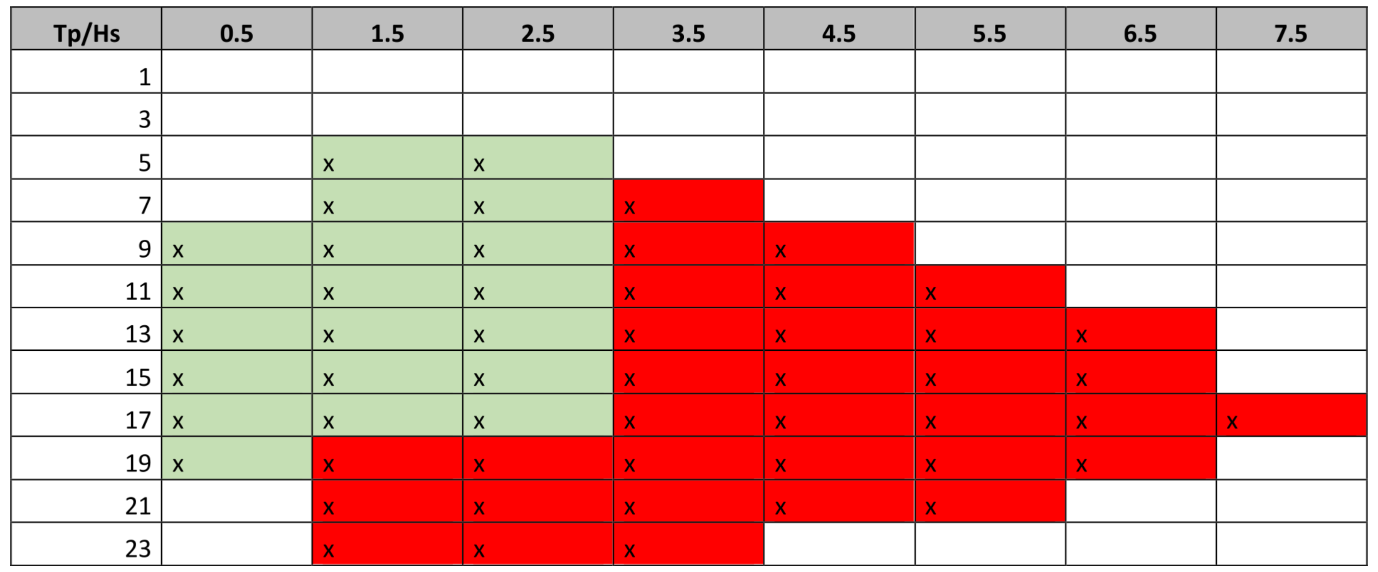
VelZ [m/s]	1.5					
Tp/WaveHs	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
4	1	1	1	1	1	1
6	1	1	1	1	1	1
8	1	1	1	1	1	1
10	1	1	1	1	1	1
12	1	1	1	0	0	0
14	1	1	0	0	0	0
16	1	0	0	0	0	0
18	1	0	0	0	0	0

Tow-In Scenario[1]:

Approach: Frequency- and time-domain simulations using ANSYS AQWA to assess weather limits



Results: Operational limits based on motion criteria



Tp/Hs	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
1								
3								
5		x	x					
7		x	x	x				
9	x	x	x	x	x			
11	x	x	x	x	x	x		
13	x	x	x	x	x	x	x	
15	x	x	x	x	x	x	x	
17	x	x	x	x	x	x	x	x
19	x	x	x	x	x	x	x	
21		x	x	x	x	x		
23		x	x	x				

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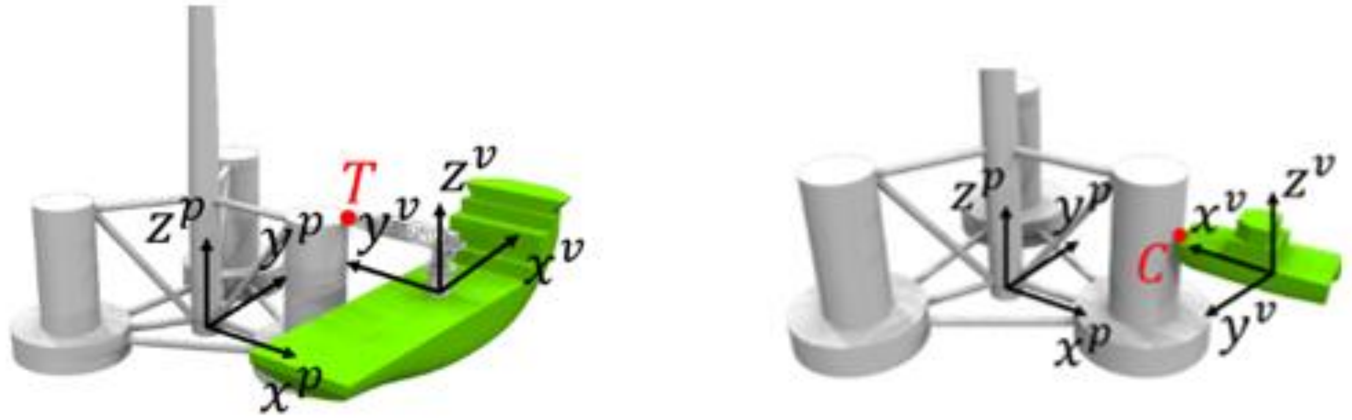
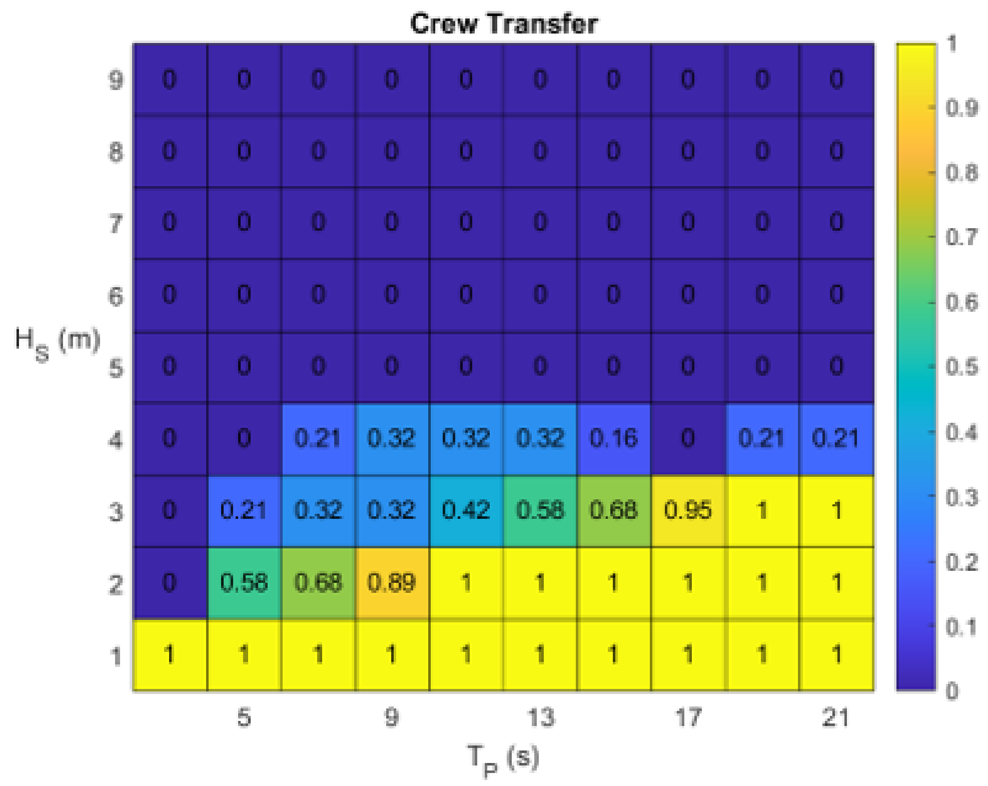
[1] *Analysis performed by COREWIND partner ESTEYCO*

Accessibility for CTV and SOV[1]:

Approach: Frequency domain post-processing of coupled RAO signal to assess weather limits in different sea states



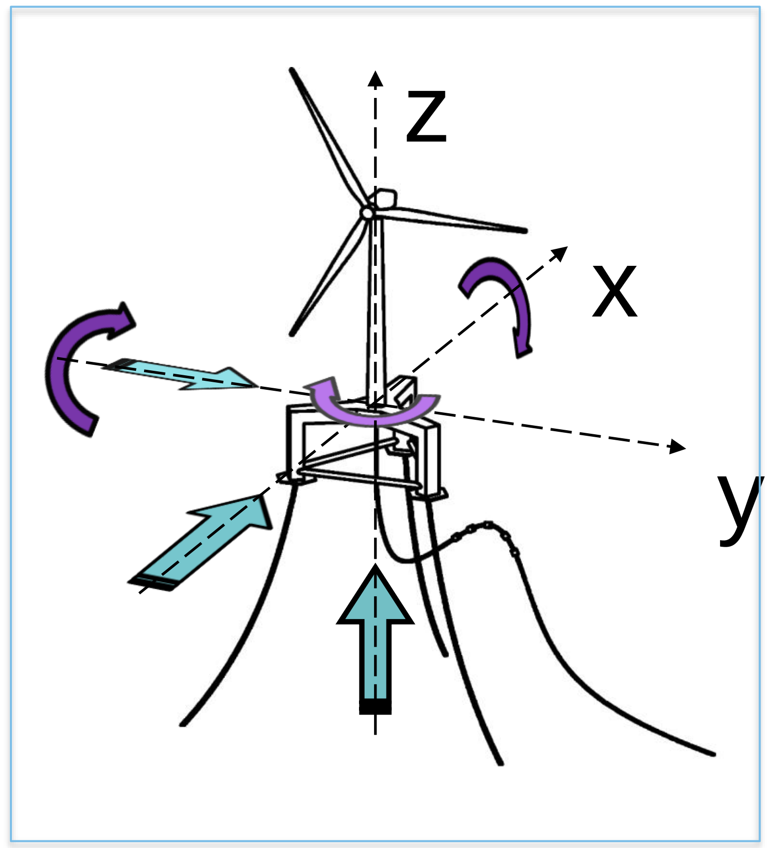
Results: Operational limits based on motion criteria


Crew Transfer

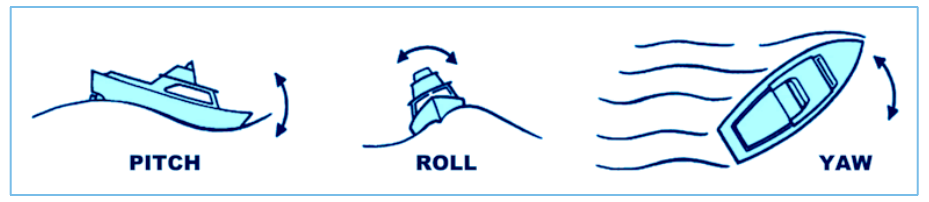
H_S (m)		5		9		13		17		21
9	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
4	0	0	0.21	0.32	0.32	0.32	0.16	0	0.21	0.21
3	0	0.21	0.32	0.32	0.42	0.58	0.68	0.95	1	1
2	0	0.58	0.68	0.89	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1

Workability and Transportability[2]:

Approach: Post-processing of motion signal to assess its effect on Human Comfort (e.g. sea-sickness)

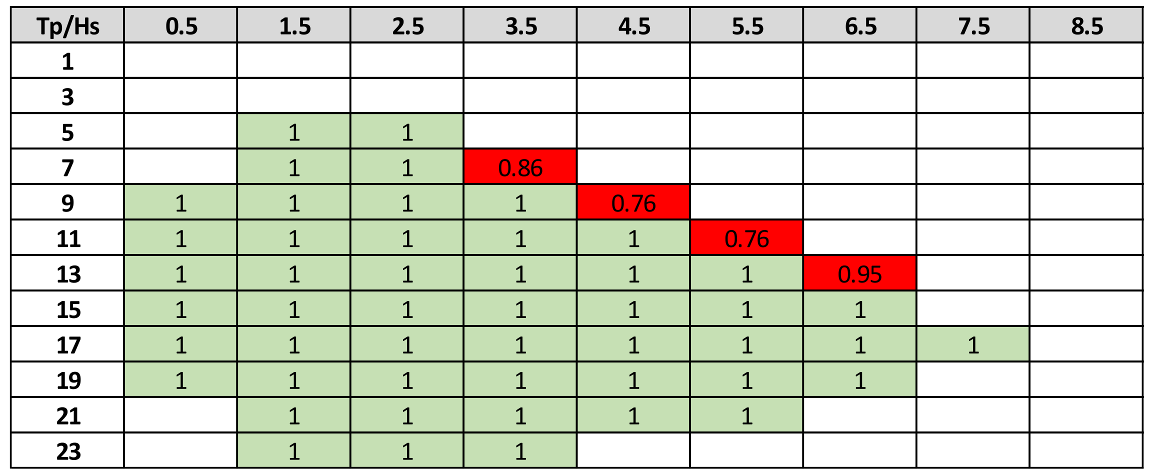


Source: Schwarzkopf 2018, RWTH University

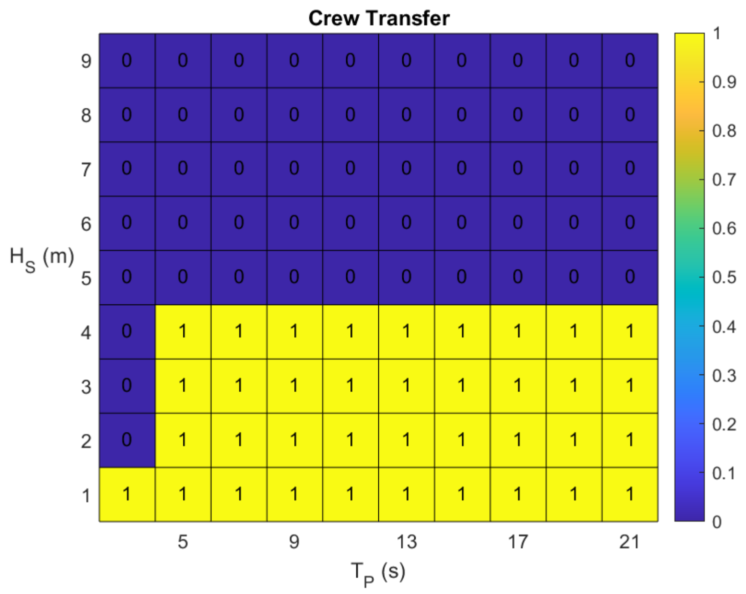


Source: https://mechanicalelements.com/trailer-attitude-pitch-yaw-roll/

Results: Generic Matrices with Workability Indices and accessible sea states for the transportation vessel and the wind turbine



Tp/Hs	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5
1									
3									
5		1	1						
7		1	1	0.86					
9	1	1	1	1	0.76				
11	1	1	1	1	1	0.76			
13	1	1	1	1	1	1	0.95		
15	1	1	1	1	1	1	1		
17	1	1	1	1	1	1	1	1	
19	1	1	1	1	1	1	1		
21		1	1	1	1	1			
23		1	1	1					


Crew Transfer

H_S (m)		5		9		13		17		21
9	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
4	0	1	1	1	1	1	1	1	1	1
3	0	1	1	1	1	1	1	1	1	1
2	0	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1

---

[1] *Analysis performed by COREWIND partner FIHAC*

[2] *Analysis performed by RAMBOLL and COREWIND partner FIHAC*

Results: Influence of Workability & Transportability

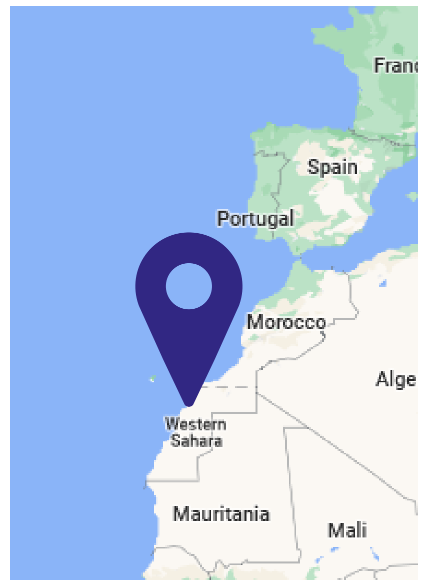
- The **workability limits are rather high** for large 15 MW floating wind turbine structure
- ➢ Therefore, the **accessibility limits are the decisive factor** for defining and restricting the weather window for the operation.

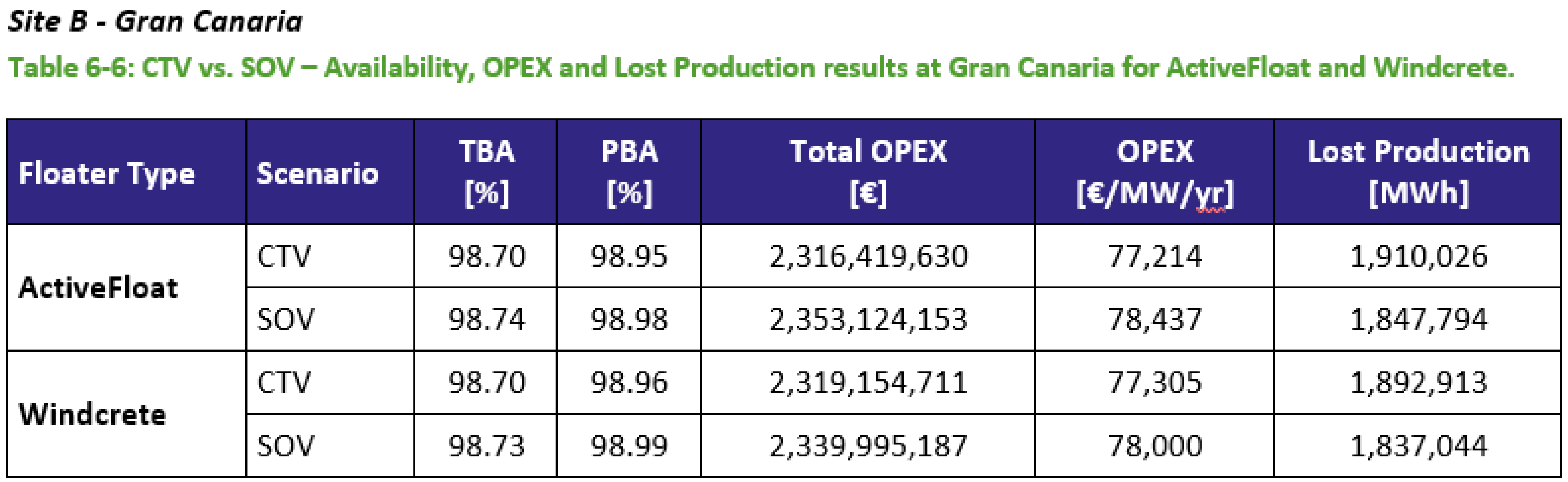
- Similar trend for access vessels: the larger is the vessel, the smaller is the impact of the vessel motions on the transportability of the passengers.

- ➢ Therefore **no effect** could be seen, when trying to study the influence of **workability on the OPEX and availability of the wind farm**.

Results are floater and site specific and might vary for other designs.

Results: Influence of Vessel Type on Lifetime OPEX

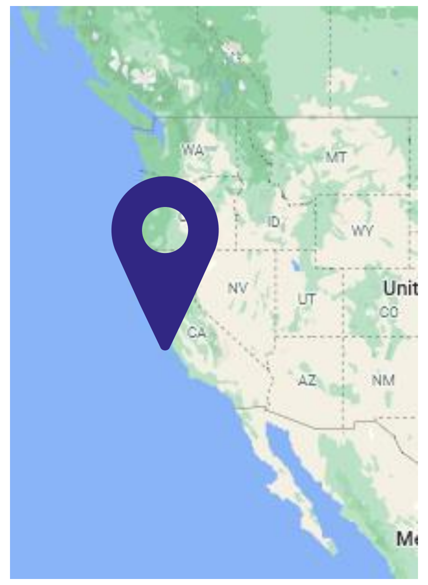


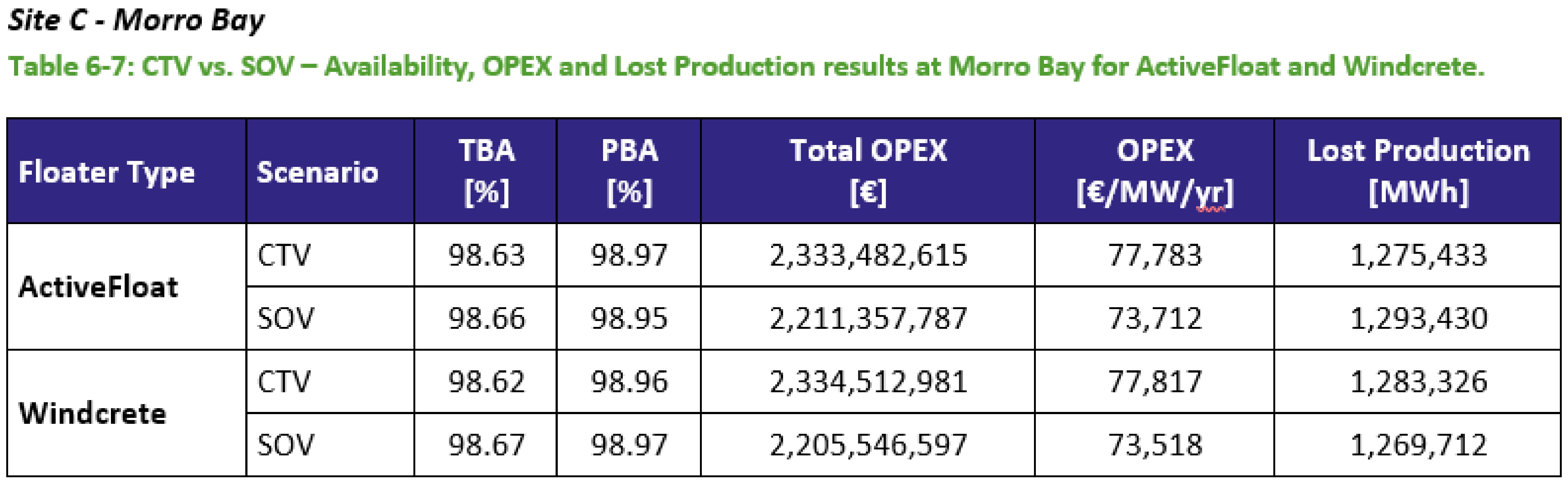


Site B - Gran Canaria

Table 6-6: CTV vs. SOV – Availability, OPEX and Lost Production results at Gran Canaria for ActiveFloat and Windcrete.

Floater Type	Scenario	TBA [%]	PBA [%]	Total OPEX [€]	OPEX [€/MW/yr]	Lost Production [MWh]
ActiveFloat	CTV	98.70	98.95	2,316,419,630	77,214	1,910,026
	SOV	98.74	98.98	2,353,124,153	78,437	1,847,794
Windcrete	CTV	98.70	98.96	2,319,154,711	77,305	1,892,913
	SOV	98.73	98.99	2,339,995,187	78,000	1,837,044





Site C - Morro Bay

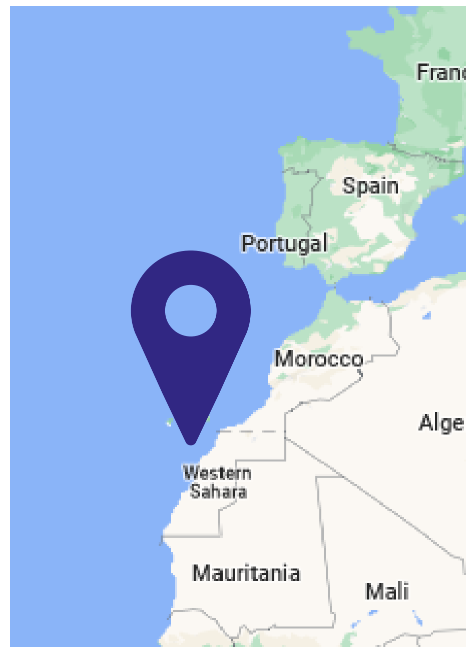
Table 6-7: CTV vs. SOV – Availability, OPEX and Lost Production results at Morro Bay for ActiveFloat and Windcrete.

Floater Type	Scenario	TBA [%]	PBA [%]	Total OPEX [€]	OPEX [€/MW/yr]	Lost Production [MWh]
ActiveFloat	CTV	98.63	98.97	2,333,482,615	77,783	1,275,433
	SOV	98.66	98.95	2,211,357,787	73,712	1,293,430
Windcrete	CTV	98.62	98.96	2,334,512,981	77,817	1,283,326
	SOV	98.67	98.97	2,205,546,597	73,518	1,269,712

- Choice of access vessel mainly driven by weather conditions at site.
- In the calm region of **Gran Canaria, either of the access solutions** provided have similar impact to OPEX estimate.
- At **Morro Bay**, where the average wave heights are higher, it exists a clear trend towards the **SOV** solution.

Results: Influence of Major Component Exchange Strategy on Lifetime OPEX

- **Mobilisation costs and dayrates** of vessels have significant impact on how scenarios compare and on overall OPEX
- Site conditions have significant impact on differences between scenarios

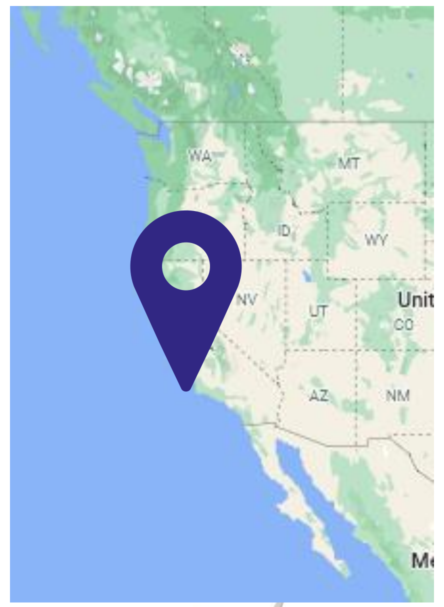


Site B - Gran Canaria

Table 6-3: Tow-in vs. F2F – Availability, OPEX and Lost Production results at Gran Canaria for ActiveFloat and Windcrete.

Floater Type	Scenario	TBA [%]	PBA [%]	Total OPEX [€]	OPEX [€/MW/yr]	Lost Production [MWh]
ActiveFloat	Tow-in	98.70	98.95	2,316,419,630	77,214	1,910,026
	F2F	98.68	98.91	2,530,931,822	84,364	1,967,521
Windcrete	Tow-in*	98.70	98.96	2,319,154,711	77,305	1,892,913
	F2F	98.67	98.90	2,533,618,601	84,454	1,986,517

*Theoretical scenario due to draft of Windcrete spar and port restrictions.



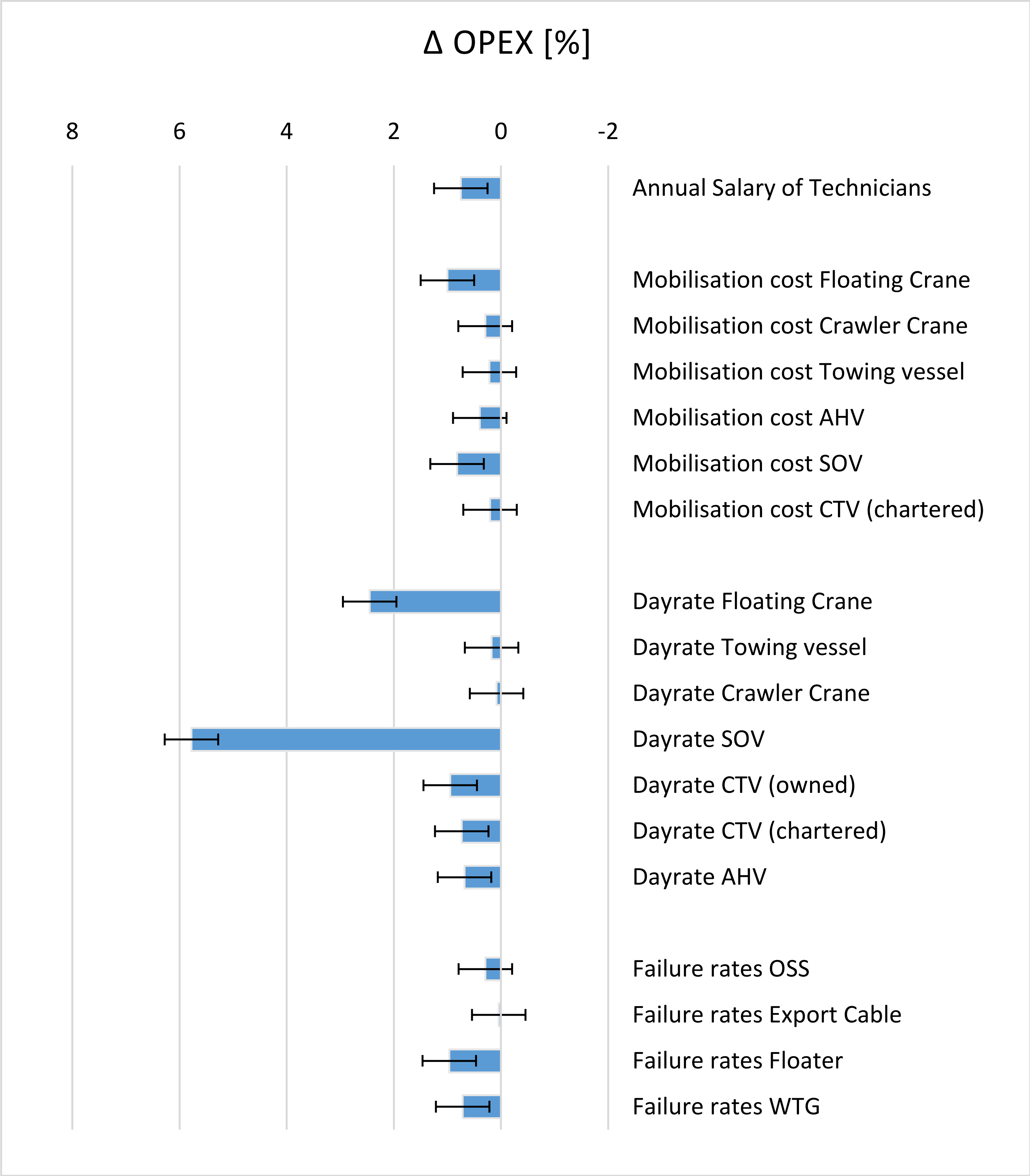
Site C - Morro Bay

Table 6-4: Tow-in vs. F2F – Availability, OPEX and Lost Production results at Morro Bay for ActiveFloat and Windcrete.

Floater Type	Scenario	TBA [%]	PBA [%]	Total OPEX [€]	OPEX [€/MW/yr]	Lost Production [MWh]
ActiveFloat	Tow-in	98.63	98.97	2,333,482,615	77,782	1,275,433
	F2F	98.39	98.74	2,961,801,300	98,726	1,560,215
Windcrete	Tow-in*	98.62	98.96	2,334,512,981	77,817	1,283,326
	F2F	98.02	98.33	3,494,669,406	116,489	2,067,675

*Theoretical scenario due to draft of Windcrete spar and potential port restrictions.

Sensitivity



West of Barra Results

- The study results for the site of **West of Barra** showed significant availability losses and unrealistic OPEX. This can be explained by the **very harsh weather conditions at the site**.
- Only very small weather windows are available for maintenance, leading to unfinished workorders and downtimes summarised over the farm’s lifetime.
- Under the weather conditions of that site **no cost-effective maintenance strategy** was deduced.

Case Study Conclusions

- **Tow-in solution** is the most economically effective solution for the investigated scenarios
- **Major Cost driver** for F2F are **dayrates and mobilisation costs** of the crane vessels
- **Site Conditions** significantly influence cost differences between solutions reducing differences in benign conditions to less than 10% while in very harsh conditions overall feasibility of certain solutions may be affected

Recommendation:

Early assessment of major component exchange strategies considering project conditions and different strategies' operational limits is key to de-risking O&M and defining most cost-effective strategies.

Thanks for your attention

corewind

COST REDUCTION OF
FLOATING WIND TECHNOLOGY

COREWIND: Break-through research for floating wind

Mooring and cable dynamics: an experimental and numerical approach

9 February 2022

corewind.eu

Disclaimer:

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Grant agreement:
No: 815083

Environmental Hydraulics
Institute of Cantabria (FIHAC)

BsC. Álvaro Rodríguez-Luis
Project Technician at Marine Energy and Offshore Engineering Group

OUTLINE

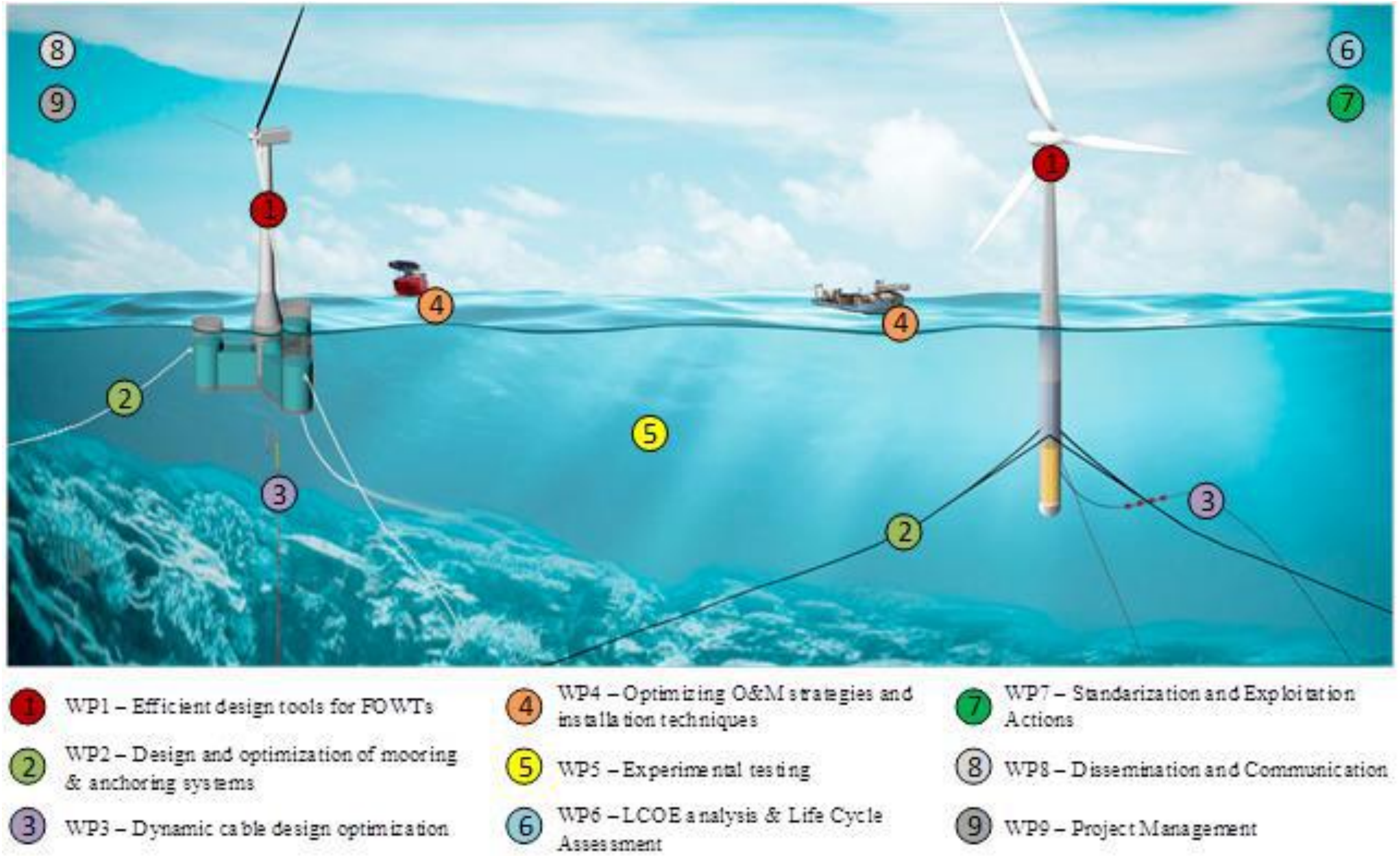
1. Objectives
2. Experimental approach
3. Numerical approach
4. Conclusions

OUTLINE

1. Objectives
2. Experimental approach
3. Numerical approach
4. Conclusions

Problem statement

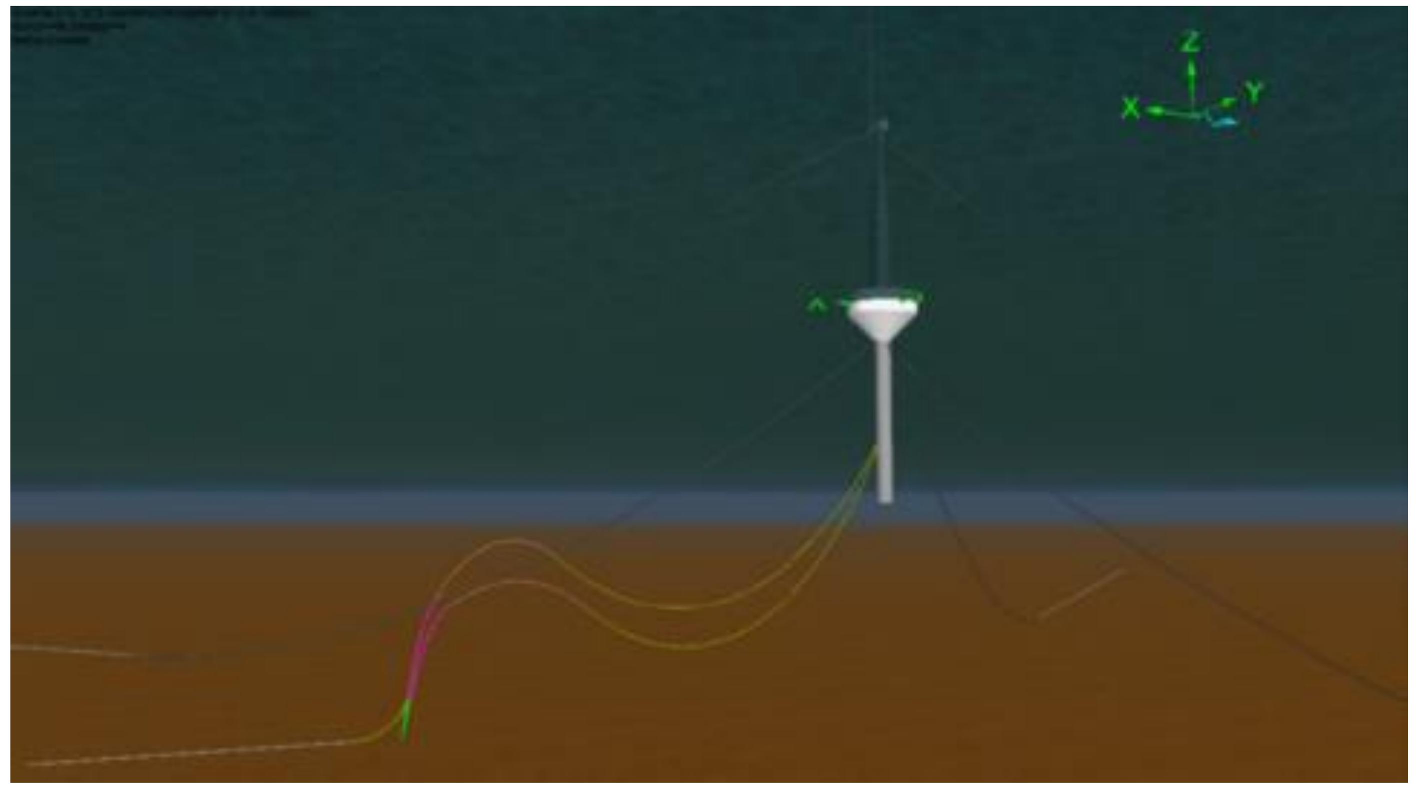
Increasing complexity of mooring and power cable lines are reaching the limitations of current numerical and experimental methodologies.

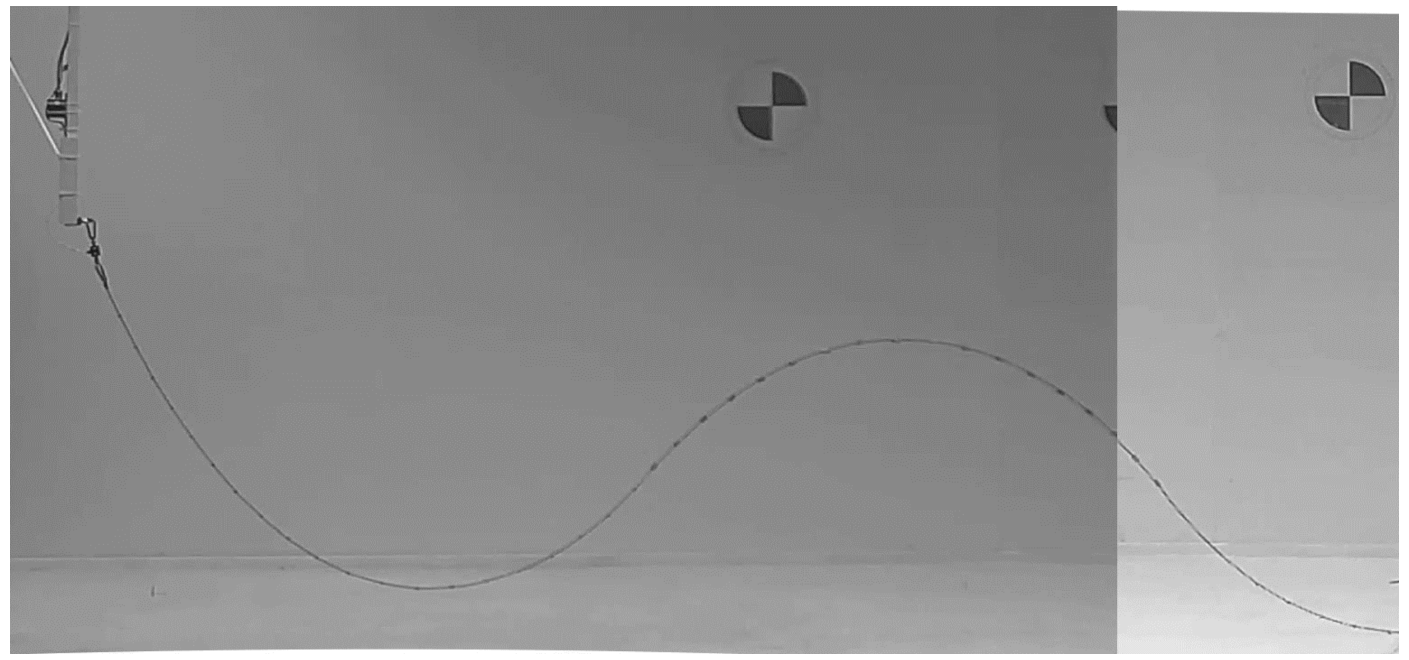


Objectives

Perform numerical and experimental test on a state-of-the-art mooring and power cable designs based on a scaled 15 MW FOWT concept, including:

- Complex bathymetry
- Bending stiffness
- Variable axial stiffness.

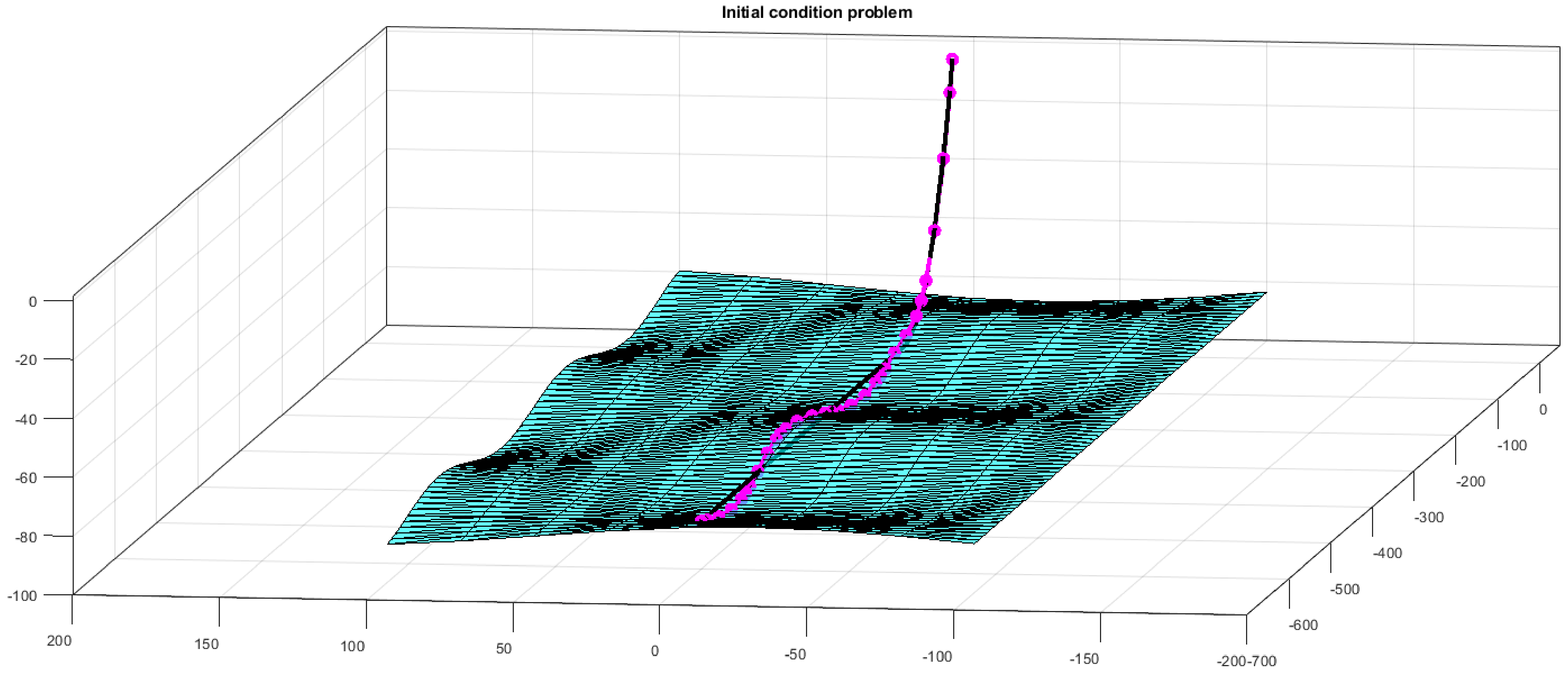




- Development of **new experimental testing techniques/set-ups** to evaluate these effects.

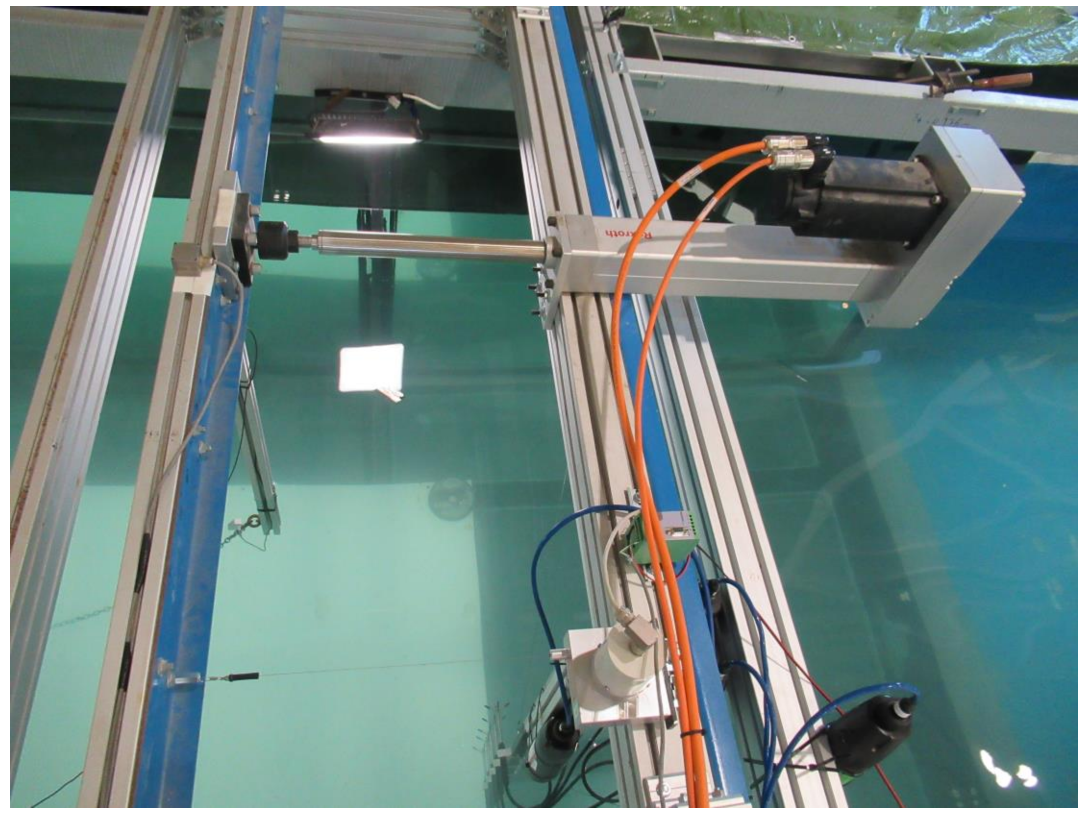
- **Improve existing numerical models** to be able to model these effects.

- **Calibrate and validate** the developed numerical tools, checking both the numerical and the experimental approach.

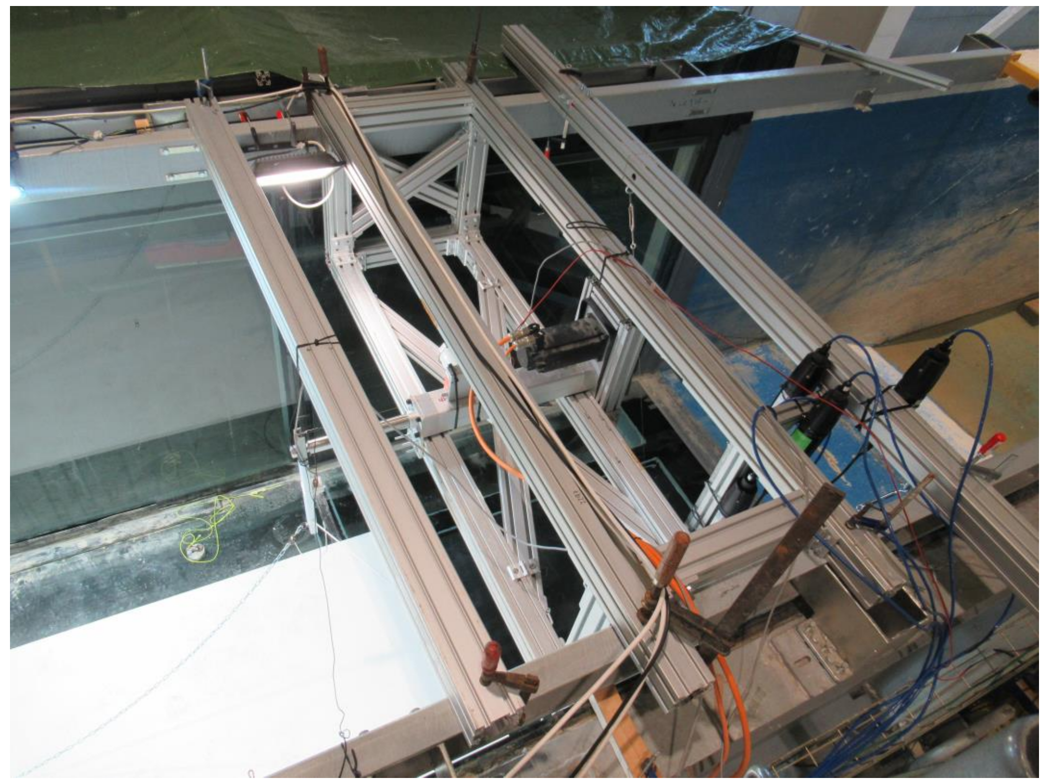


Background

Barrera, C., Guanche, R. & Losada, I. J., 2019. Experimental modelling of mooring systems for floating marine energy concepts. Marine Structures, Volumen 63, p. 153–180.



- The results showed the importance of acceleration on the mooring lines, depending on periods and amplitudes of forced oscillations, as well as on mooring weight. It was therefore possible to establish two different analysis:
  - Quasi-static analysis, appropriate for determining the tension for low frequency displacements.
  - Dynamic analysis, suitable for **high frequency displacements.**
- **Hydrodynamic loads were not dominant** in the tension of the line. The dominant factor was the movement imposed by platform.



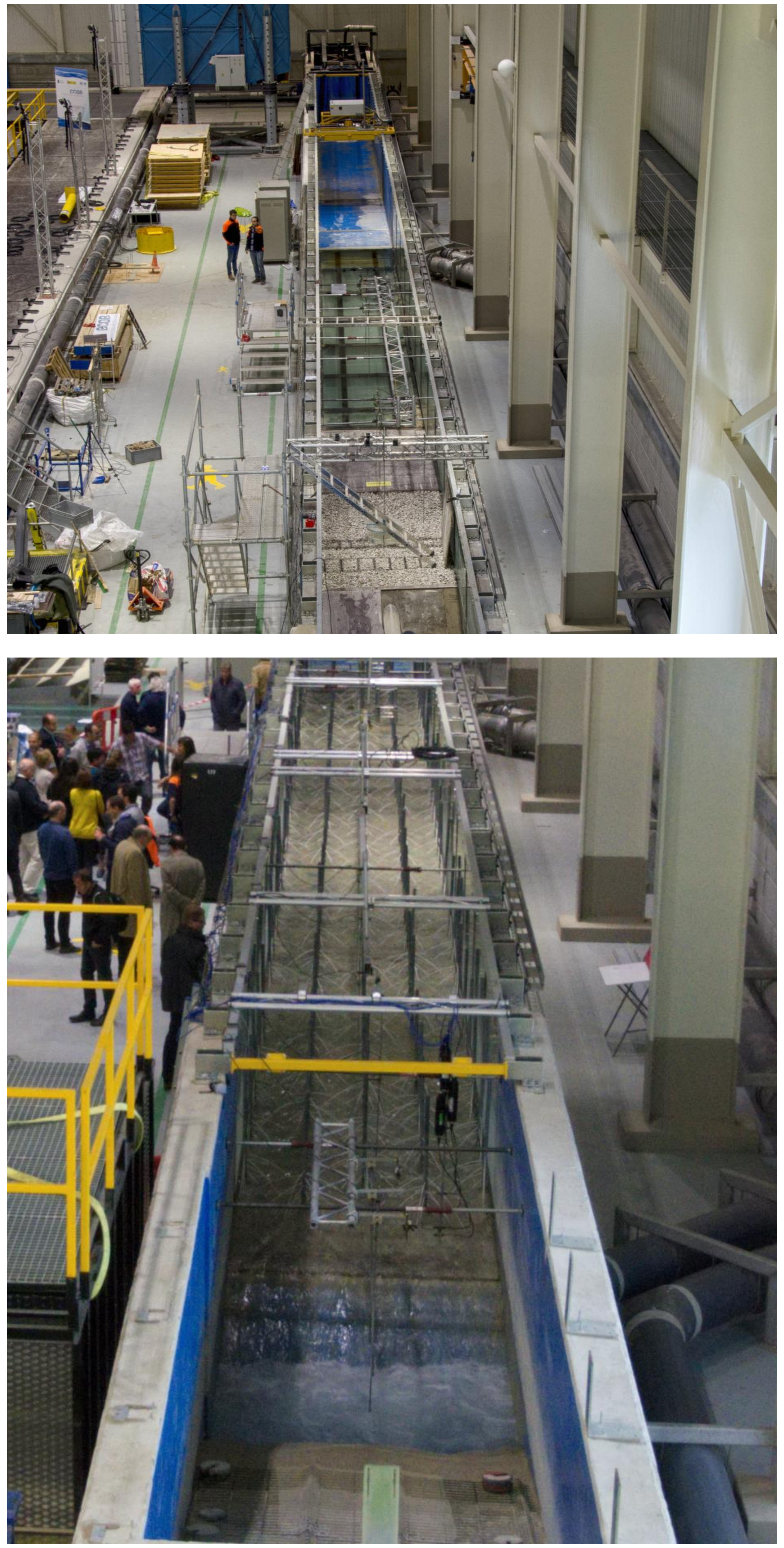
↓

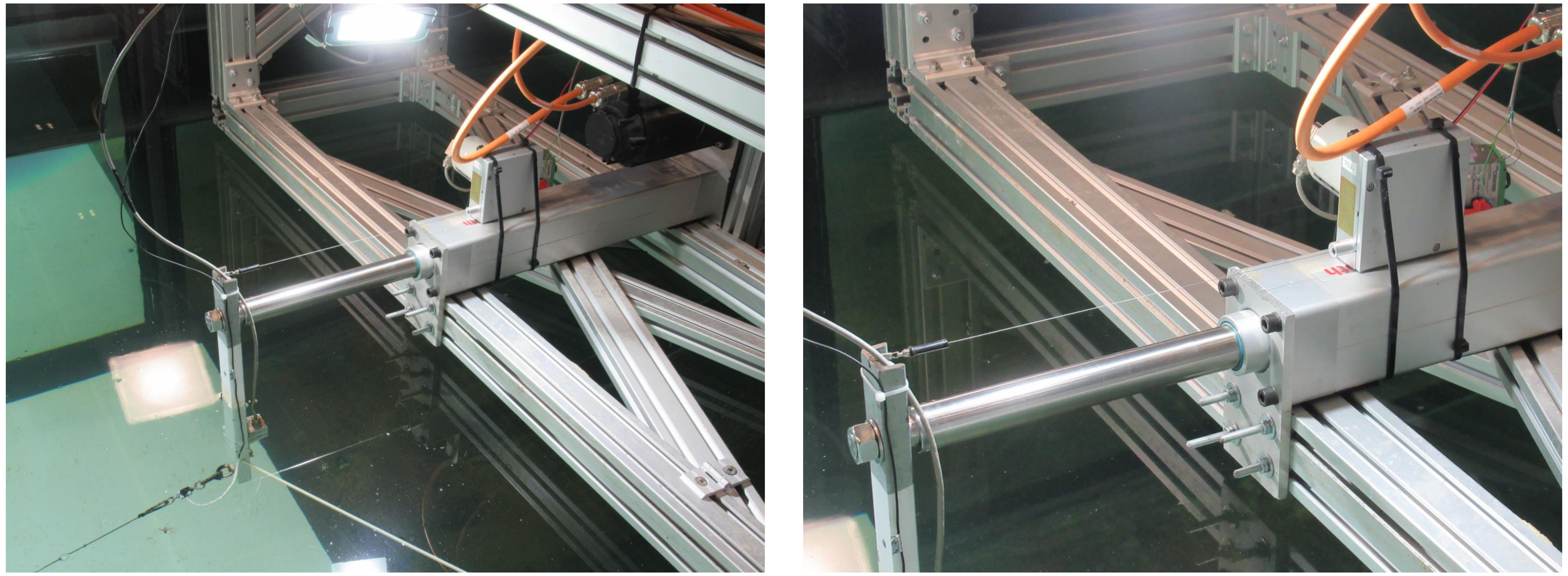
Fairlead surge movements are reproduced by a dedicated **forced oscillation mechanism.**

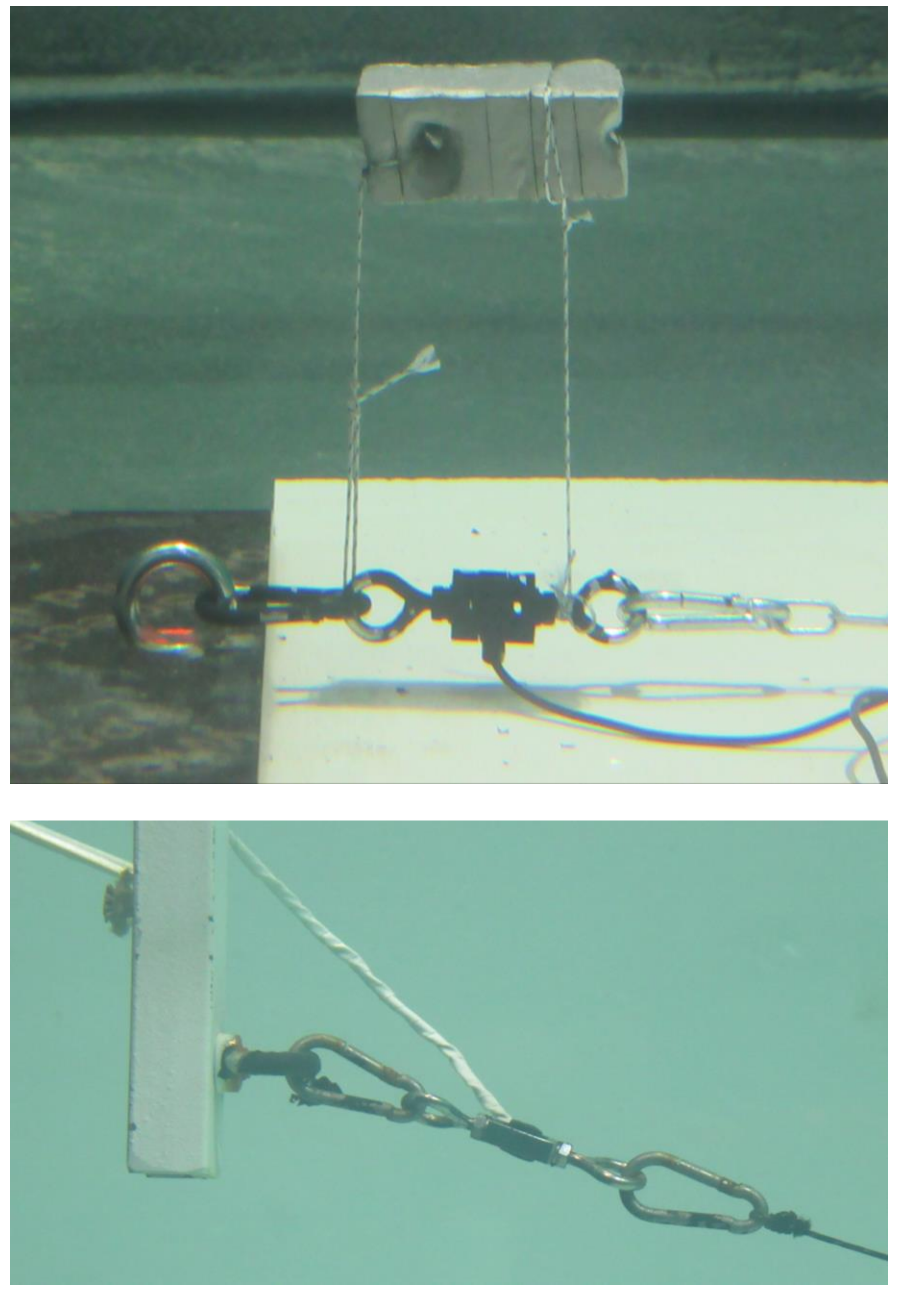
OUTLINE

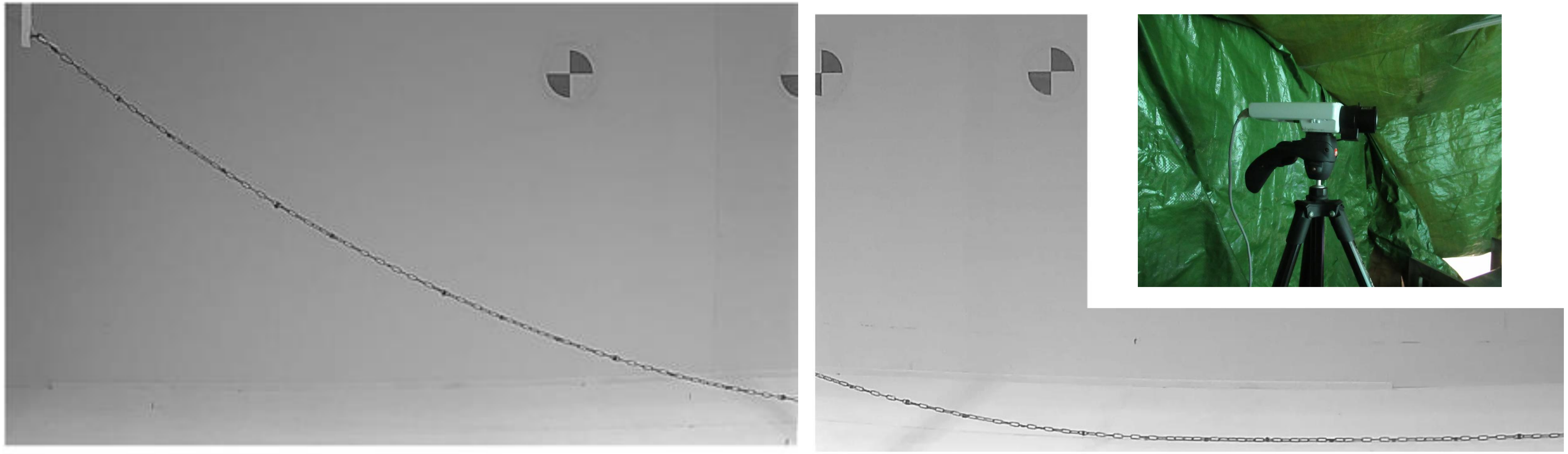
1. Objectives
2. **Experimental approach**
3. Numerical approach
4. Conclusions

Experimental approach $\lambda = 1/75$









More than 400 forced oscillation tests have been conducted, recording simultaneously tensions and novel tracking images.

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Effect of seabed irregularities on dynamic performance, including snap loading, has been modelled.

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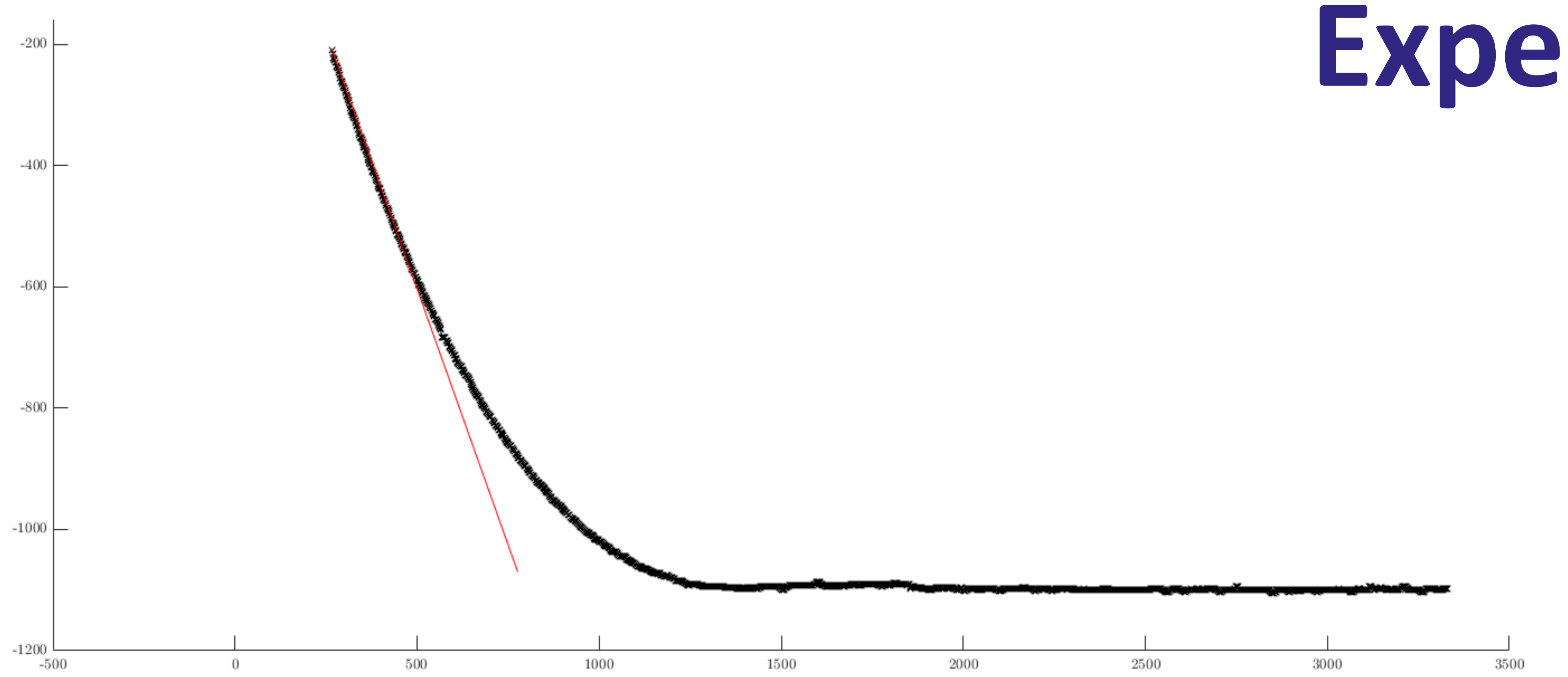
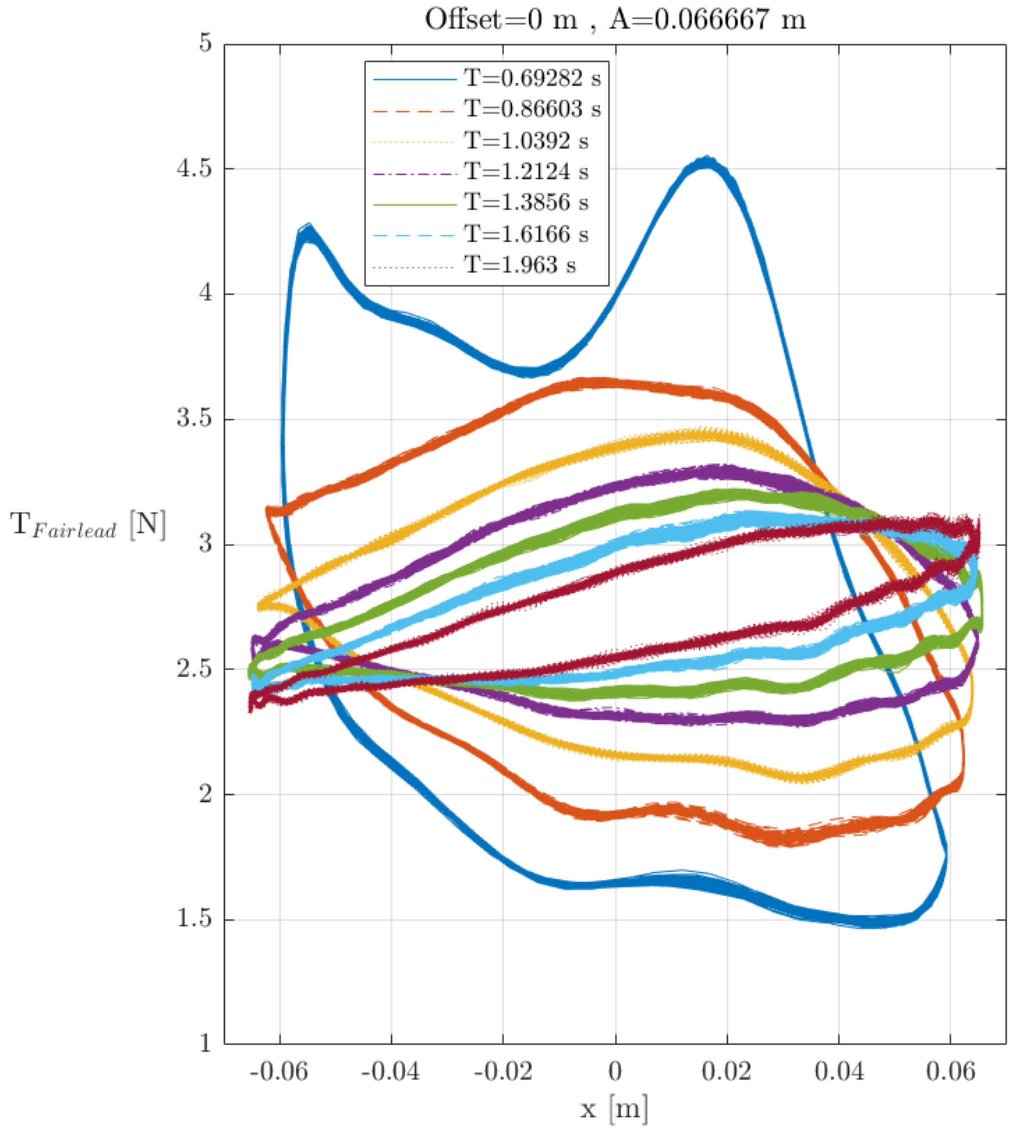
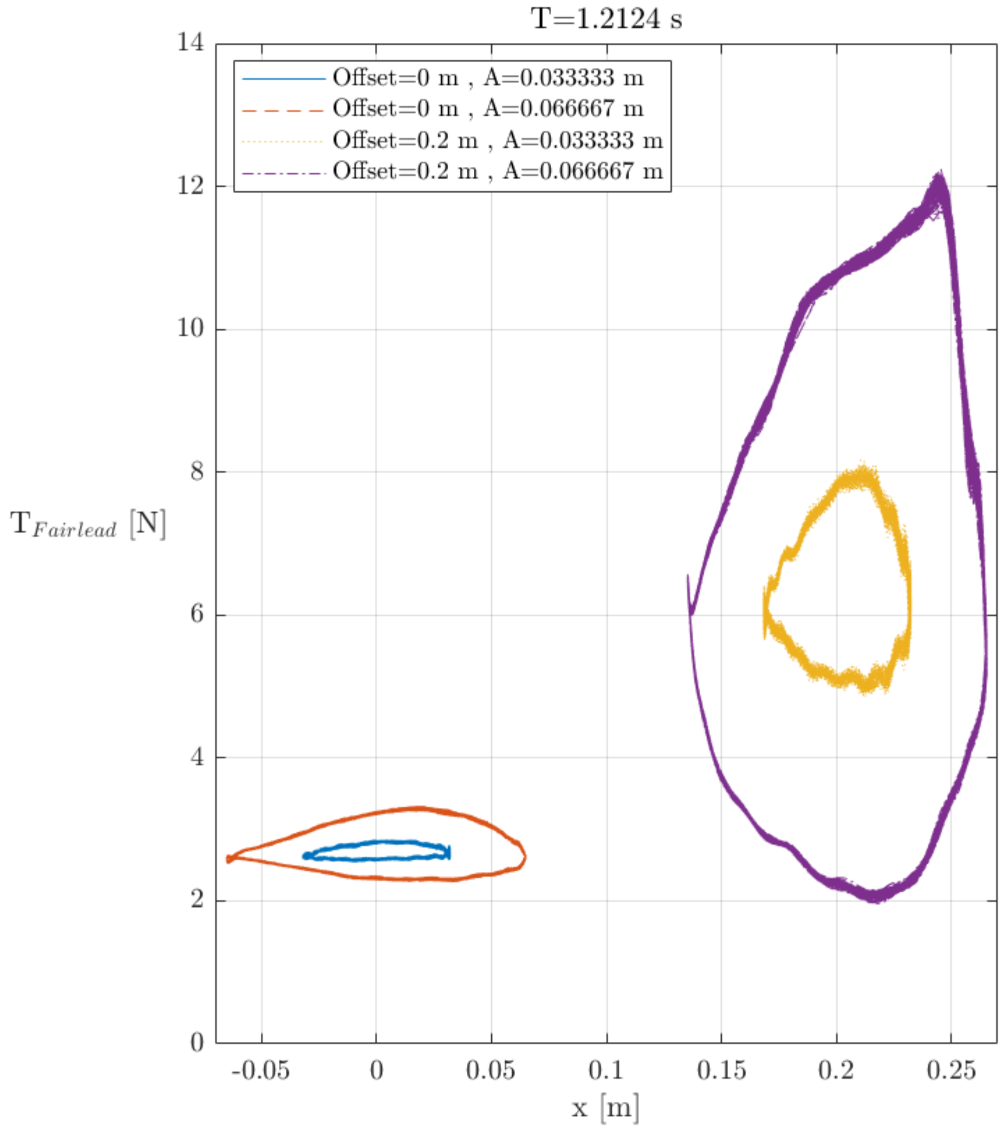
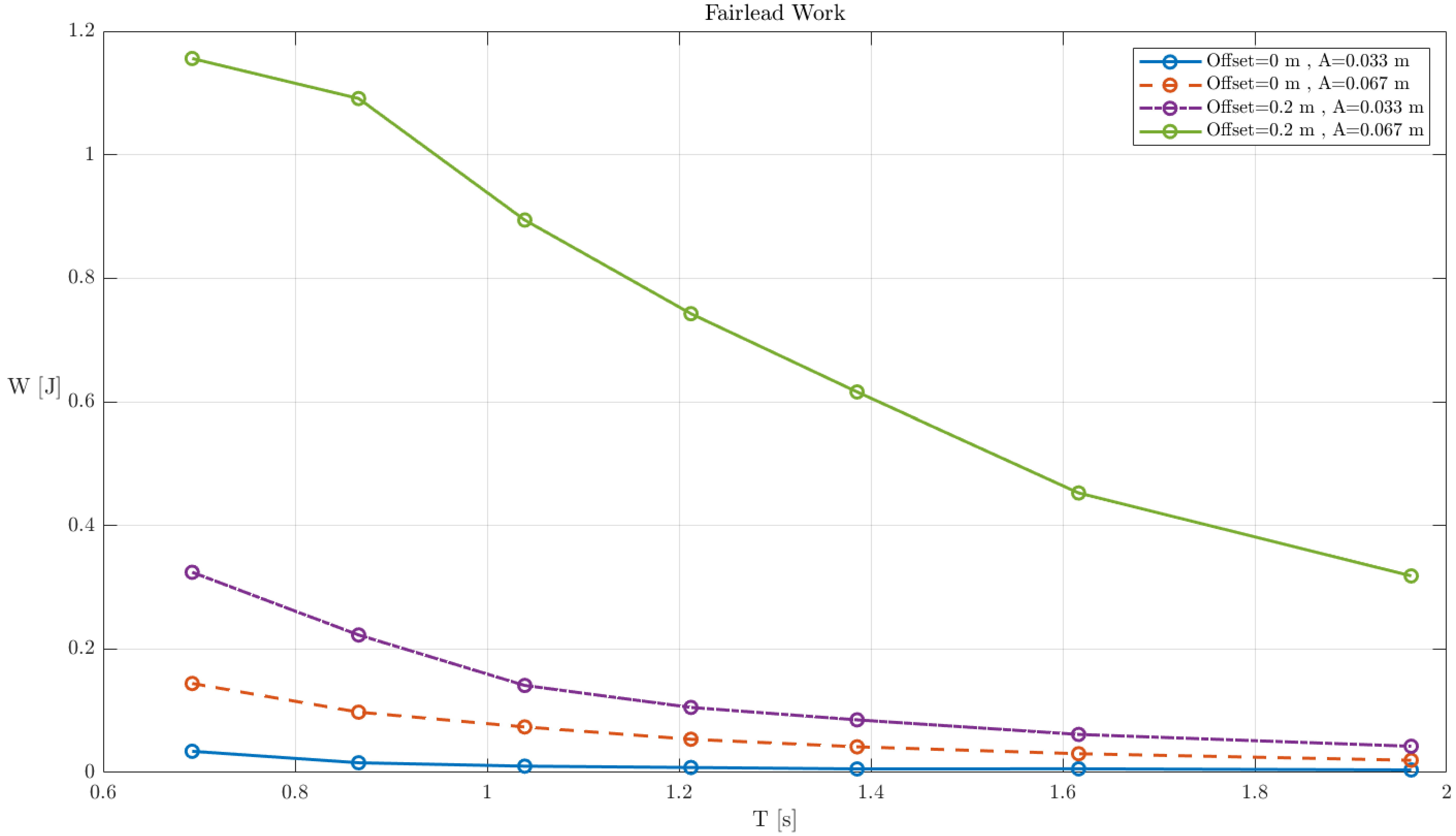
Experimental approach









Dynamics of contact on the mooring energy dissipation have been realistically assessed.

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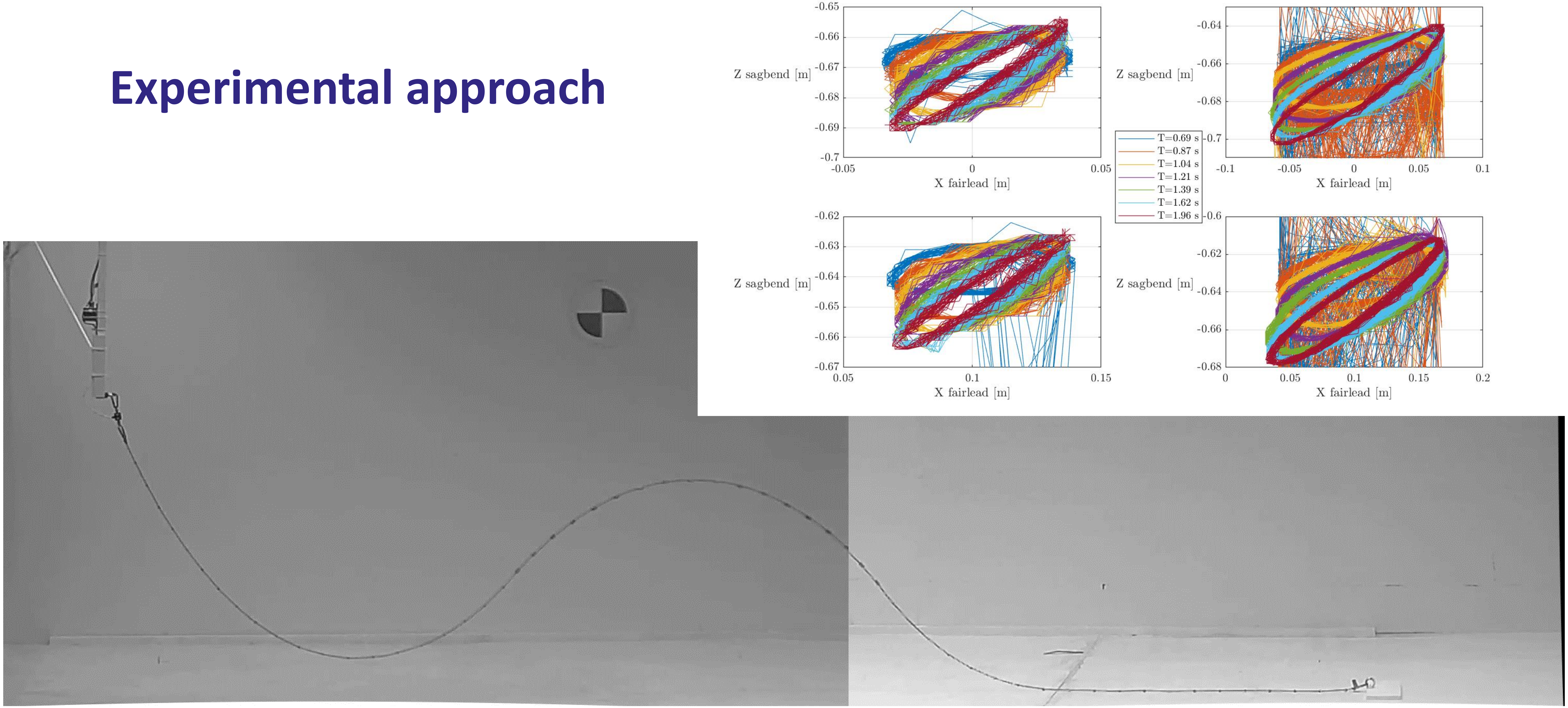
Elastic materials have allowed us to replicate nylon mooring axial stiffness and thus, to study its effect on damping snap loads.

Experimental approach



Elastic materials have also allowed us to replicate dynamic cable bending and hence, to analyse its kinematics.

OUTLINE

1. Objectives
2. Experimental approach
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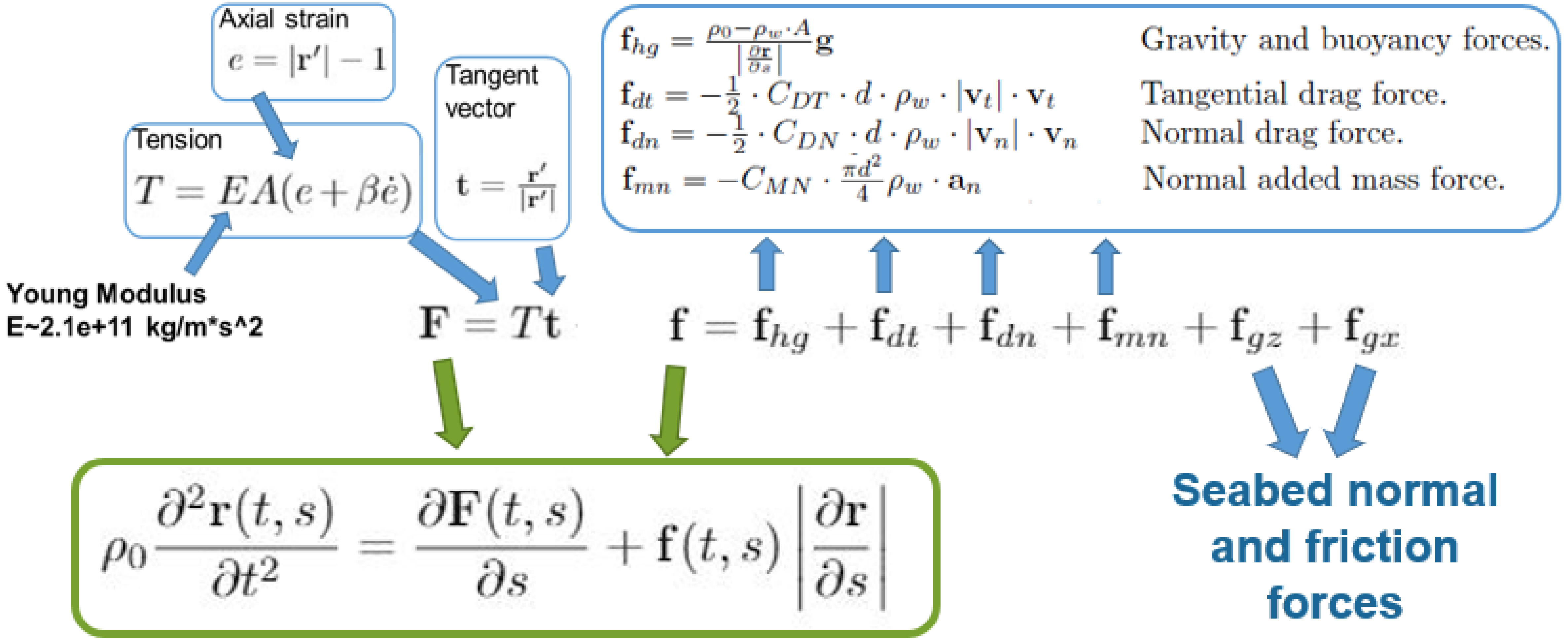
4. Conclusions

Mooring numerical models' calibration and validation

Numerical model description (1/3)

High order finite element method model

Governing equations: Newton Second Law – Non-Linear wave equation



Axial strain
$e = |\mathbf{r}'| - 1$

Tension
$T = EA(e + \beta\dot{e})$

Young Modulus
E~2.1e+11 kg/m*s^2

Tangent vector
$\mathbf{t} = \frac{\mathbf{r}'}{|\mathbf{r}'|}$

$\mathbf{F} = T\mathbf{t}$

$\mathbf{f}_{hg} = \frac{\rho_0 - \rho_w \cdot A}{\left|\frac{\partial \mathbf{r}}{\partial s}\right|}\mathbf{g}$ Gravity and buoyancy forces.

$\mathbf{f}_{dt} = -\frac{1}{2} \cdot C_{DT} \cdot d \cdot \rho_w \cdot |\mathbf{v}_t| \cdot \mathbf{v}_t$ Tangential drag force.

$\mathbf{f}_{dn} = -\frac{1}{2} \cdot C_{DN} \cdot d \cdot \rho_w \cdot |\mathbf{v}_n| \cdot \mathbf{v}_n$ Normal drag force.

$\mathbf{f}_{mn} = -C_{MN} \cdot \frac{\pi d^2}{4}\rho_w \cdot \mathbf{a}_n$ Normal added mass force.

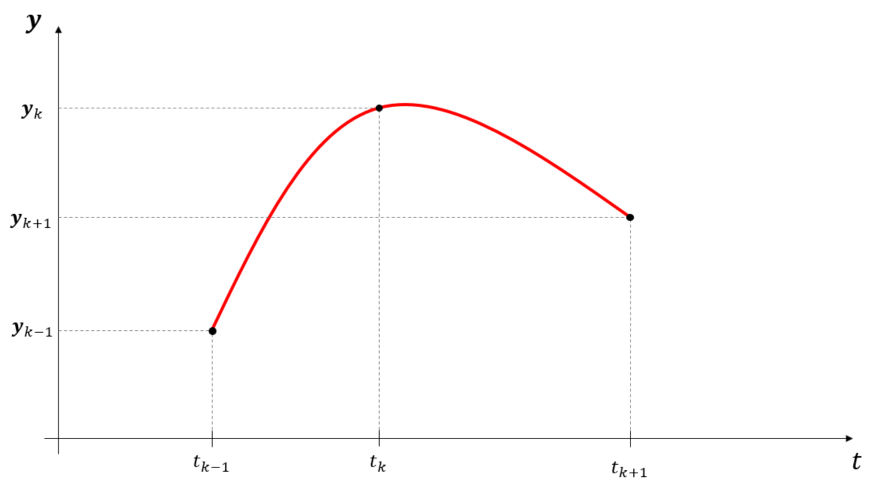
$$\mathbf{f} = \mathbf{f}_{hg} + \mathbf{f}_{dt} + \mathbf{f}_{dn} + \mathbf{f}_{mn} + \mathbf{f}_{gz} + \mathbf{f}_{gx}$$

Seabed normal and friction forces

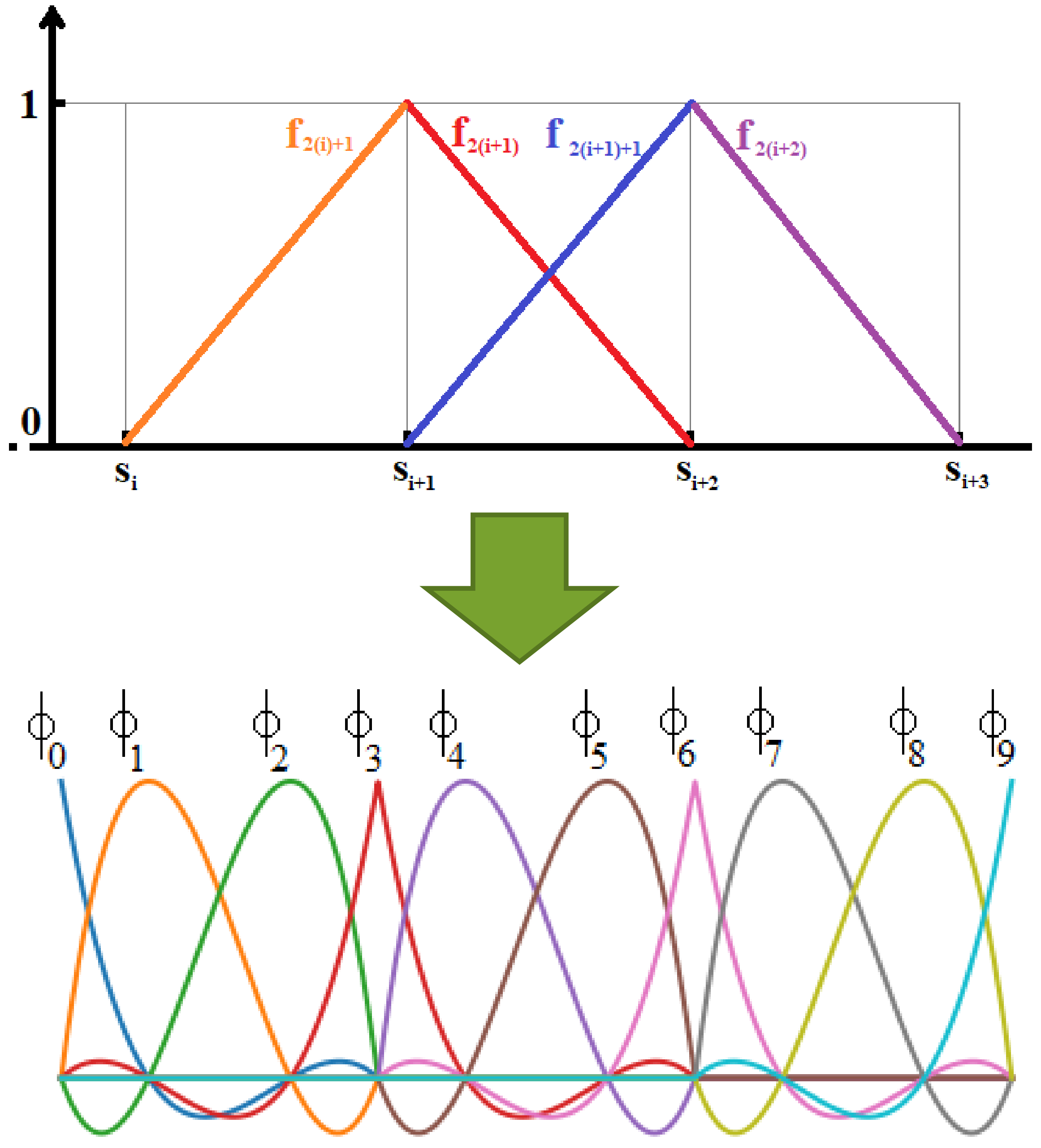
$$\rho_0 \frac{\partial^2 \mathbf{r}(t,s)}{\partial t^2} = \frac{\partial \mathbf{F}(t,s)}{\partial s} + \mathbf{f}(t,s)\left|\frac{\partial \mathbf{r}}{\partial s}\right|$$

Time integration: Implicit second order backward differentiation formula with adaptative time-step.

$$y_{n+2} - \tfrac{4}{3}y_{n+1} + \tfrac{1}{3}y_n = \tfrac{2}{3}hf(t_{n+2}, y_{n+2})$$



Spatial discretization:
Gauss-Lobatto-Lagrange polynomials



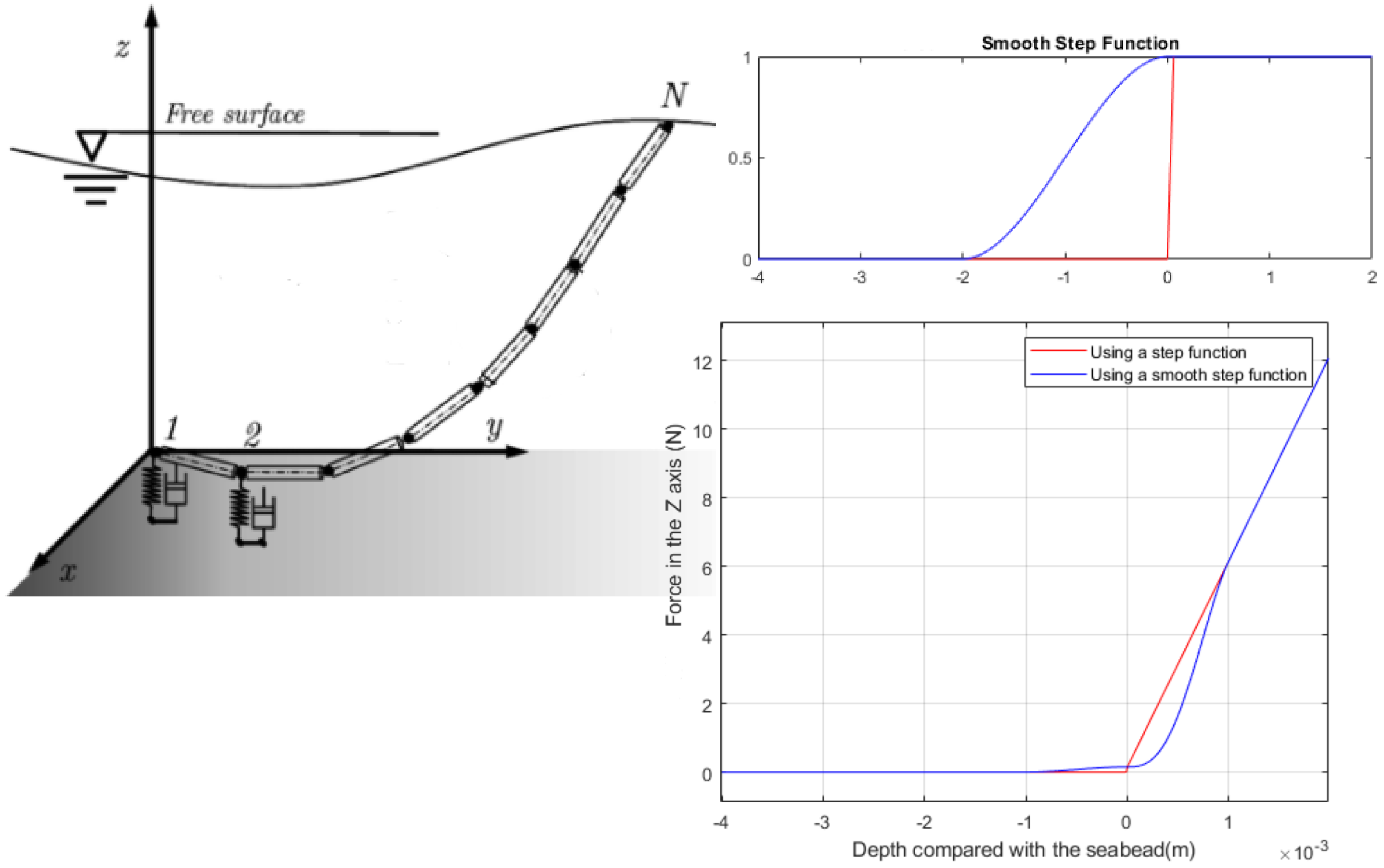
Mooring numerical models' calibration and validation

Numerical model description (2/3)

Seabed normal and friction forces model

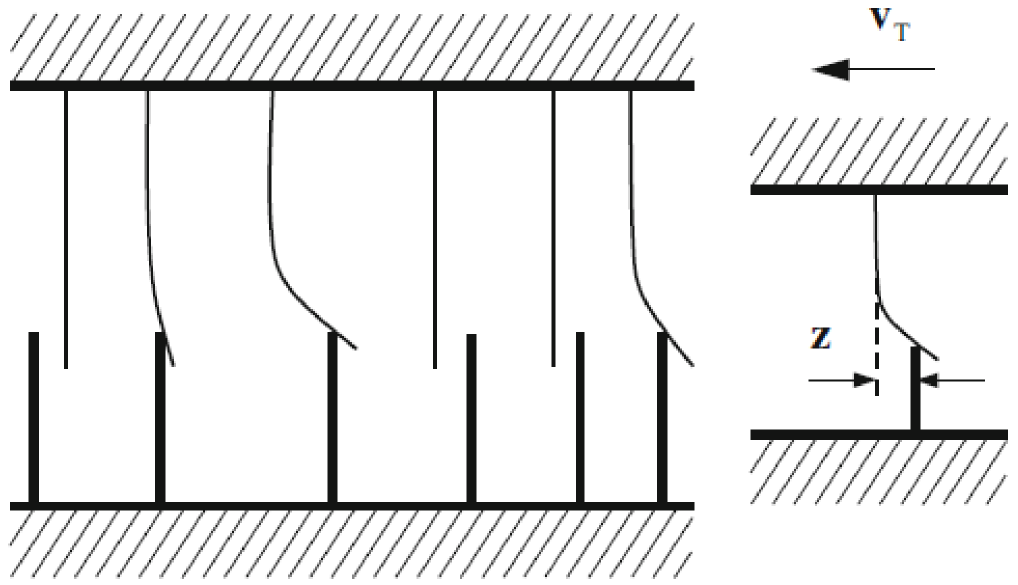
Normal forces model: Damped spring model with smoothing.

$$G_{\hat{z}} = \left(K_G d_c (z_G - r_{\hat{z}}) - 2\xi_G \sqrt{K_G \gamma_0 d_c}\, max(\dot{r}_{\hat{z}}, 0) \right) \hat{z}$$



Palm et al. An hp-adaptive discontinuous Galerkin method for modelling snap loads in mooring cables. Ocean Engineering. 2017.

Friction model: Stick-slip (combines static and dynamic friction)



$$f_f^{stiction} = -\mathrm{sgn}(\Delta)(1-\beta)\mu_\Delta(v,\Delta) f_n$$

$$f_f^{sliding} = -\mathrm{sgn}(v)\mu_v(v) f_n$$

State	Slip	Stick
v	$\lvert v \rvert > v_t$	$0 \le \lvert v \rvert \le v_t$
β	1.0	$step(\lvert v \rvert, -v_t, -1.0, v_t, 1.0)$
μ_Δ	0.0	$step(\lvert \Delta \rvert, -\Delta_{max}, -\mu_t, \Delta_{max}, \mu_t)$
μ_v	μ_t	$step(\lvert v \rvert, -v_t, -\mu_t, v_t, \mu_t)$
f_f	$f_f^{sliding}$	$f_f^{sliding} + f_f^{stiction}$

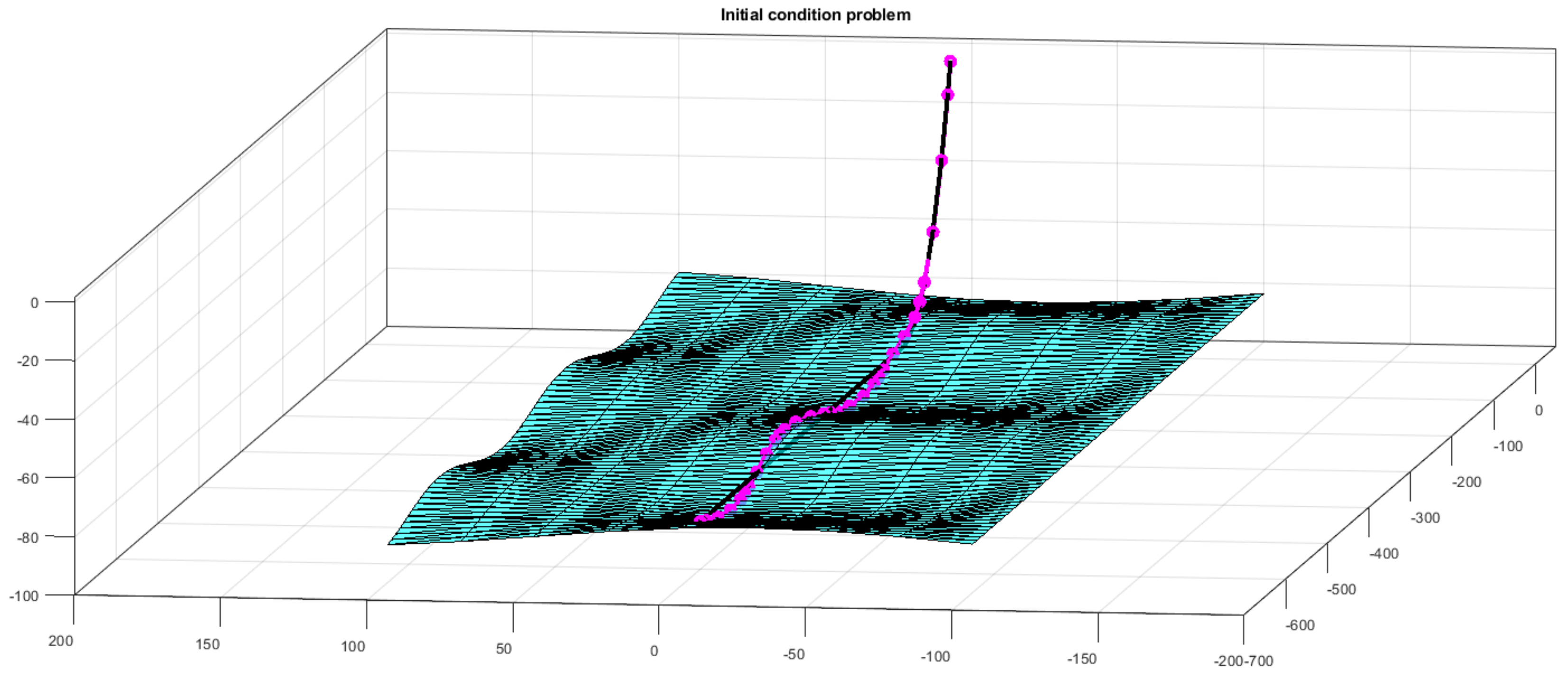
Cha et al. Stick-slip algorithm in a tangential contact force model for multi-body system dynamics. Journal of Mech. Science and Tech. 2011.

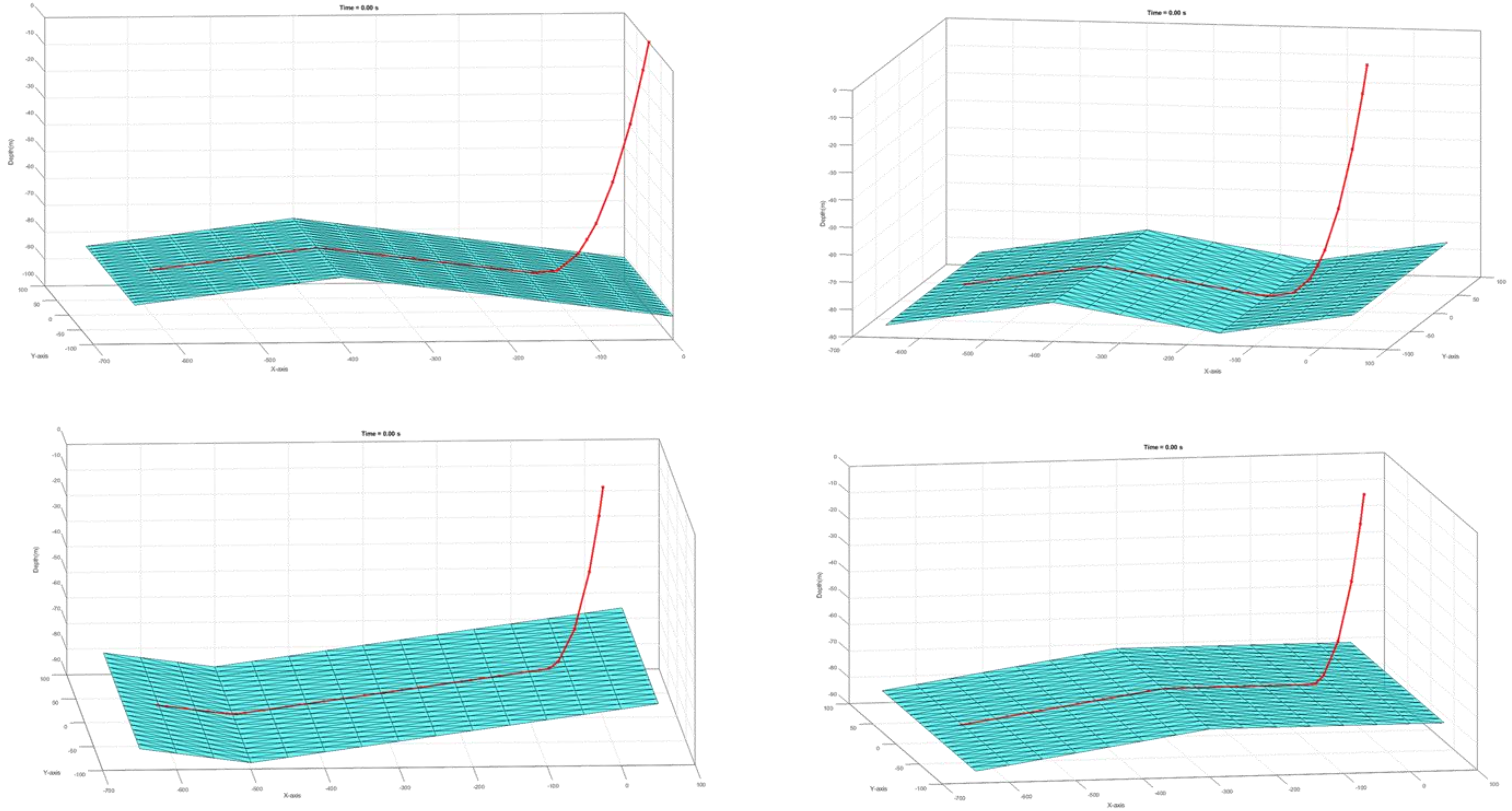
Mooring numerical models' calibration and validation

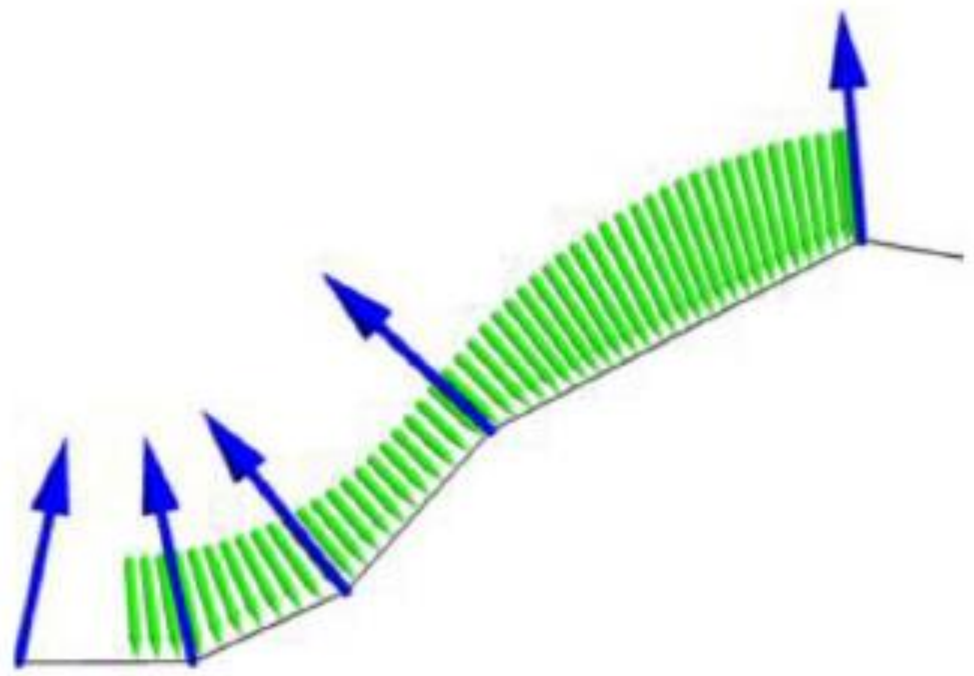
Numerical model description (3/3)

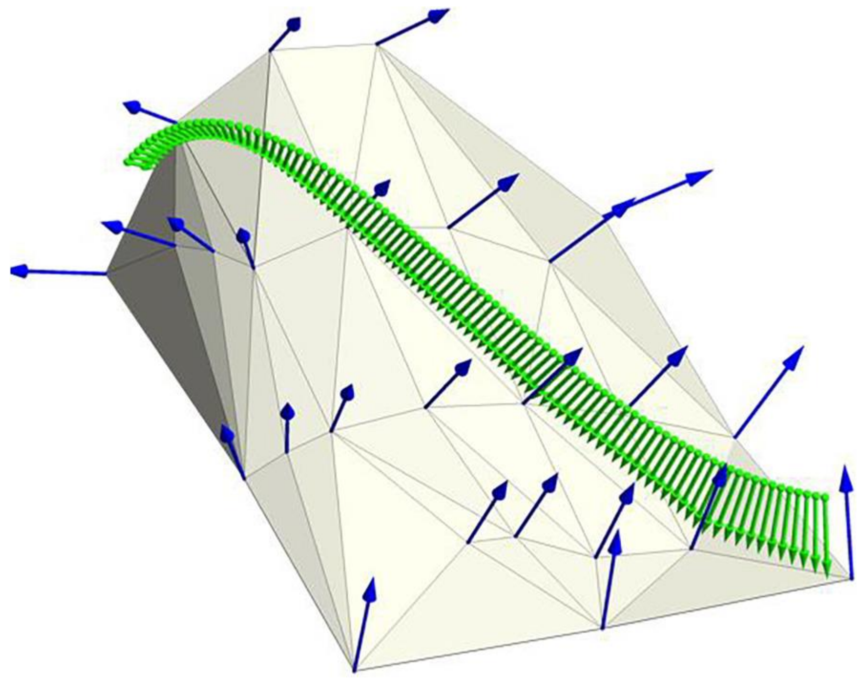
Projection into complex bathymetry

- Projection into a triangulated surface.
- Normal vectors are computed at the nodes and interpolated with parametric coordinates.
- Line nodes are projected into all triangles (first the closest ones).
- Penetration depth and normal vector are used in the ground normal and friction forces expressions.









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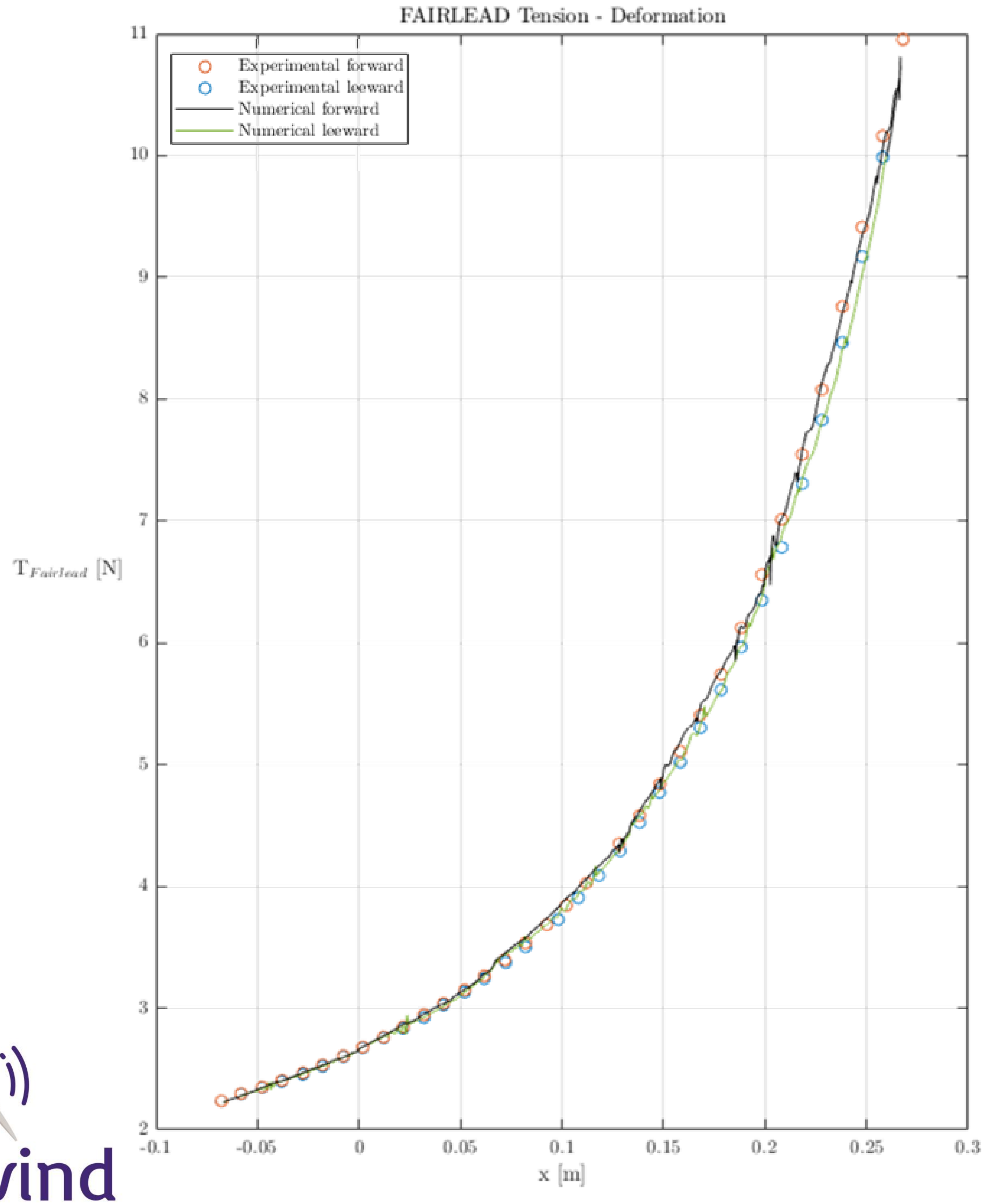
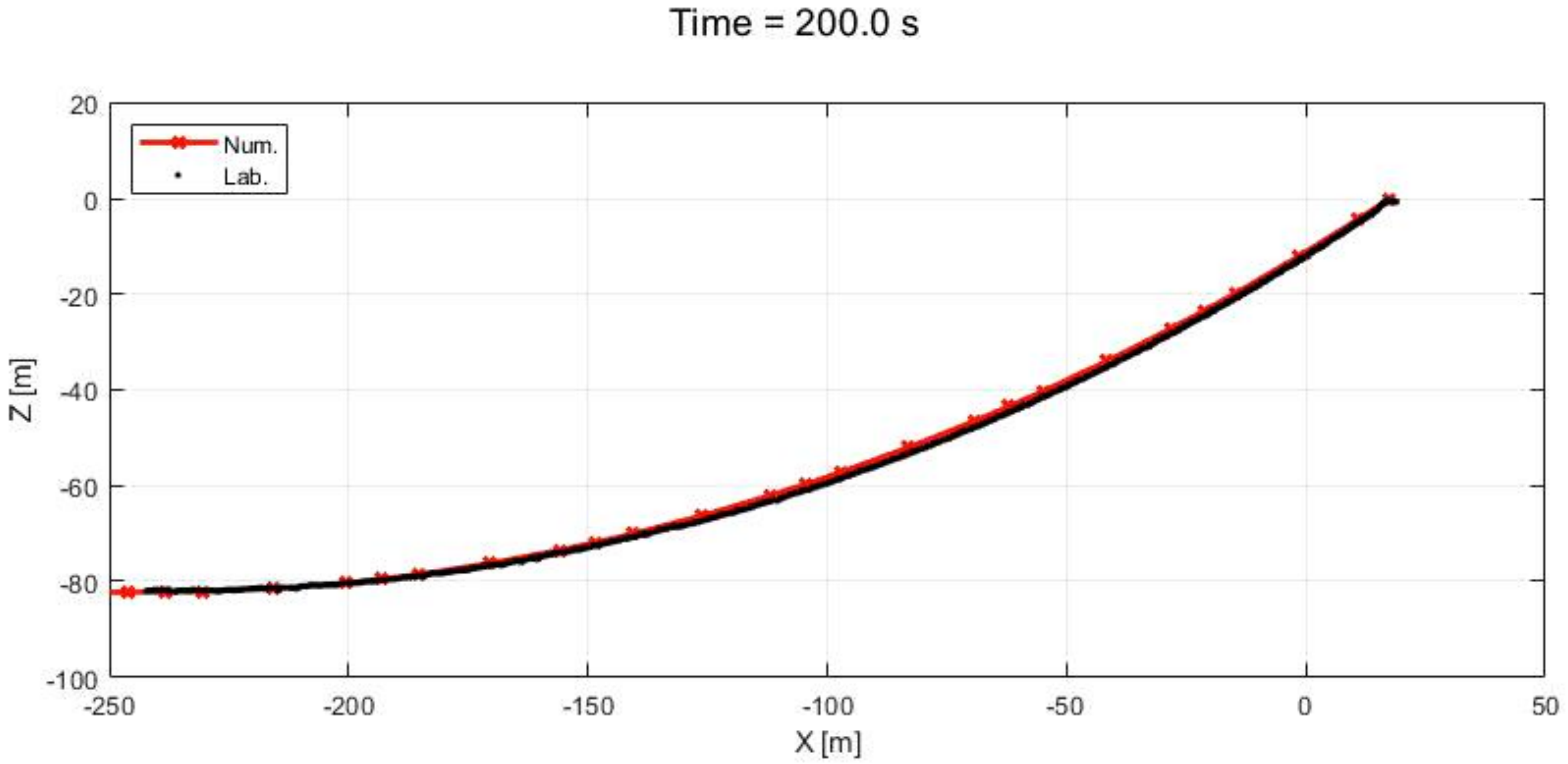
Orazi et al. A novel algorithm for a continuous and fast 3D projection of points on triangulated surfaces for CAM/CAD/CAE applications. Journal of King Saud University - Computer and Information Sciences. 2020.

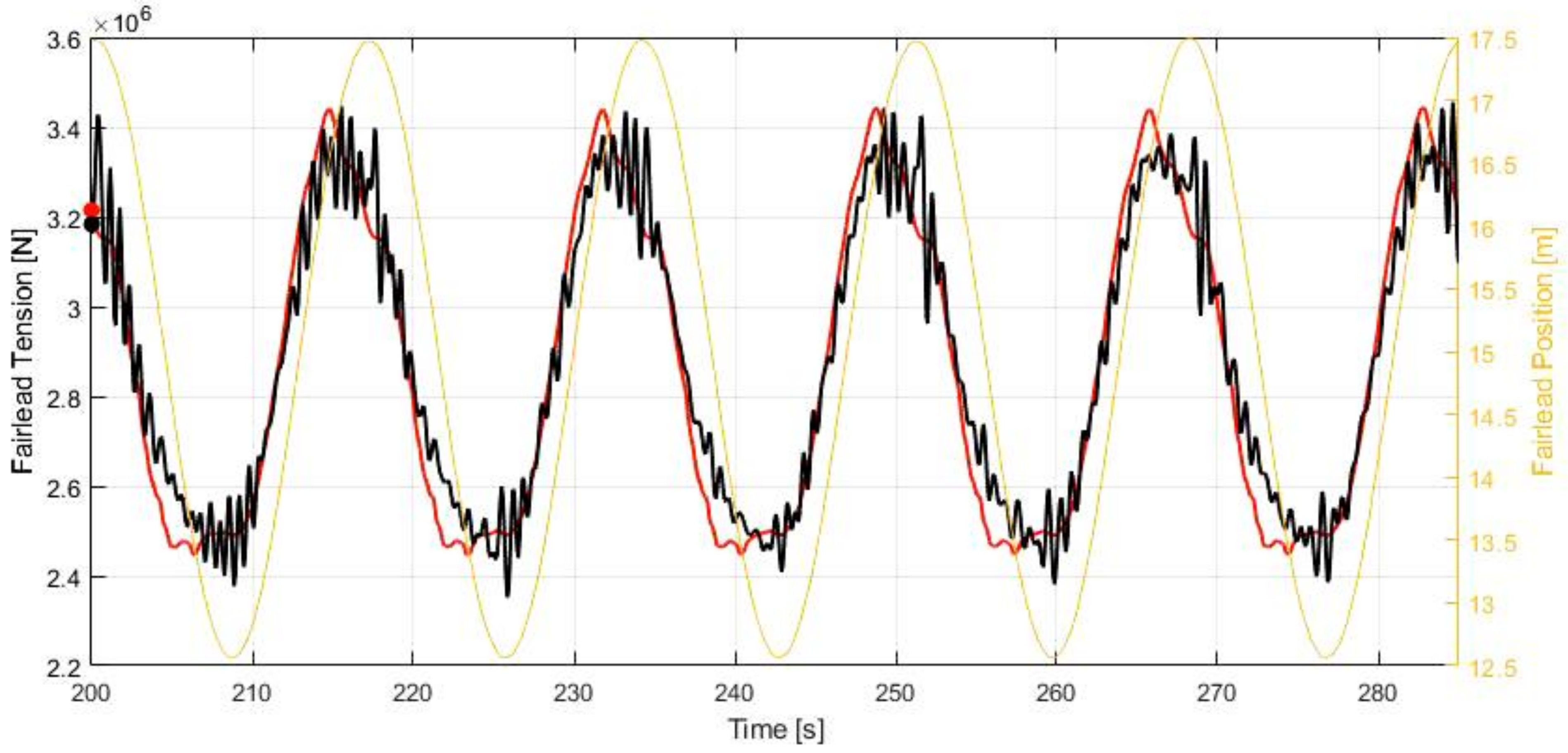
Mooring numerical models' calibration and validation

‘All chain’ tension-deformation



‘All chain’ regular test





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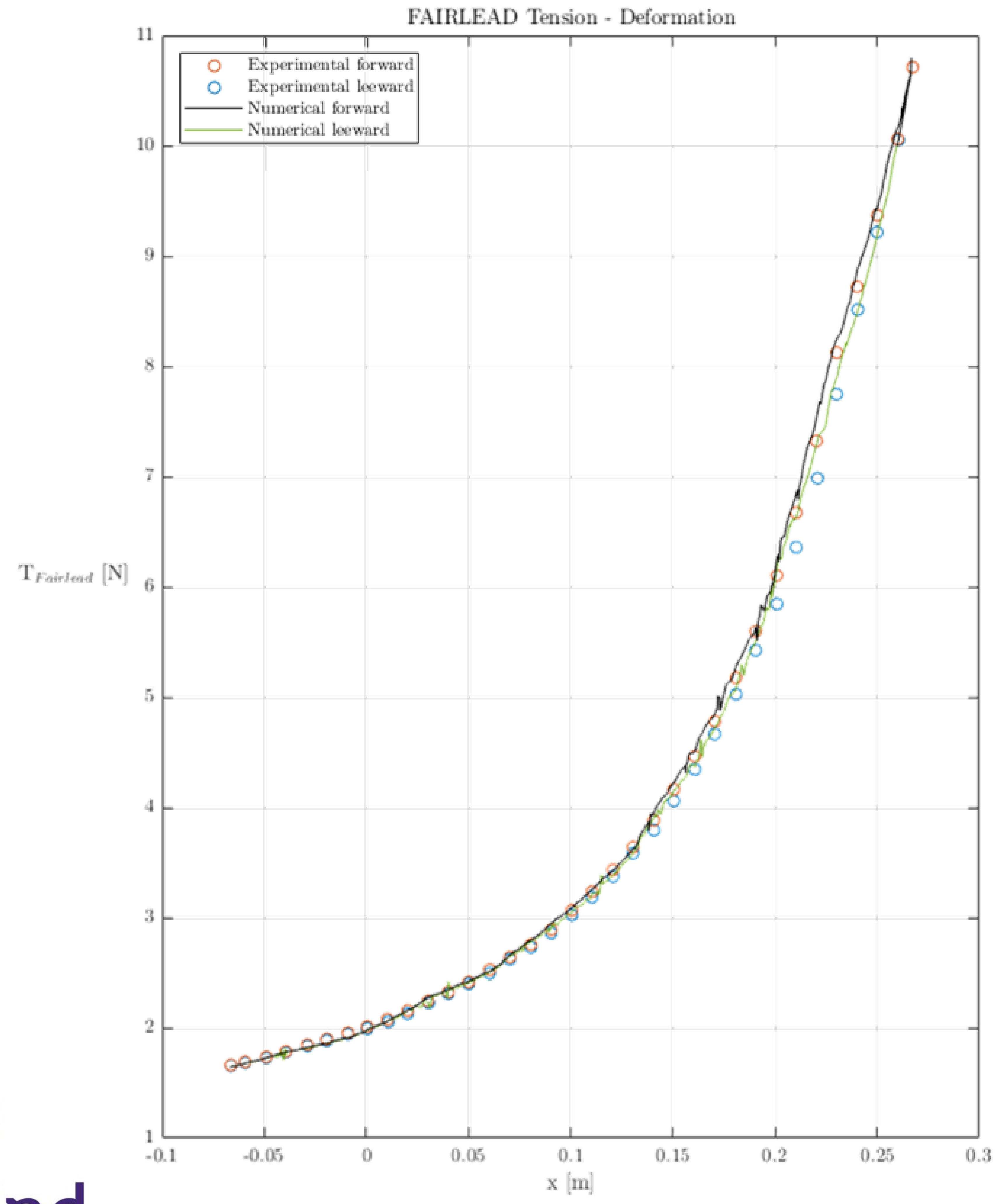
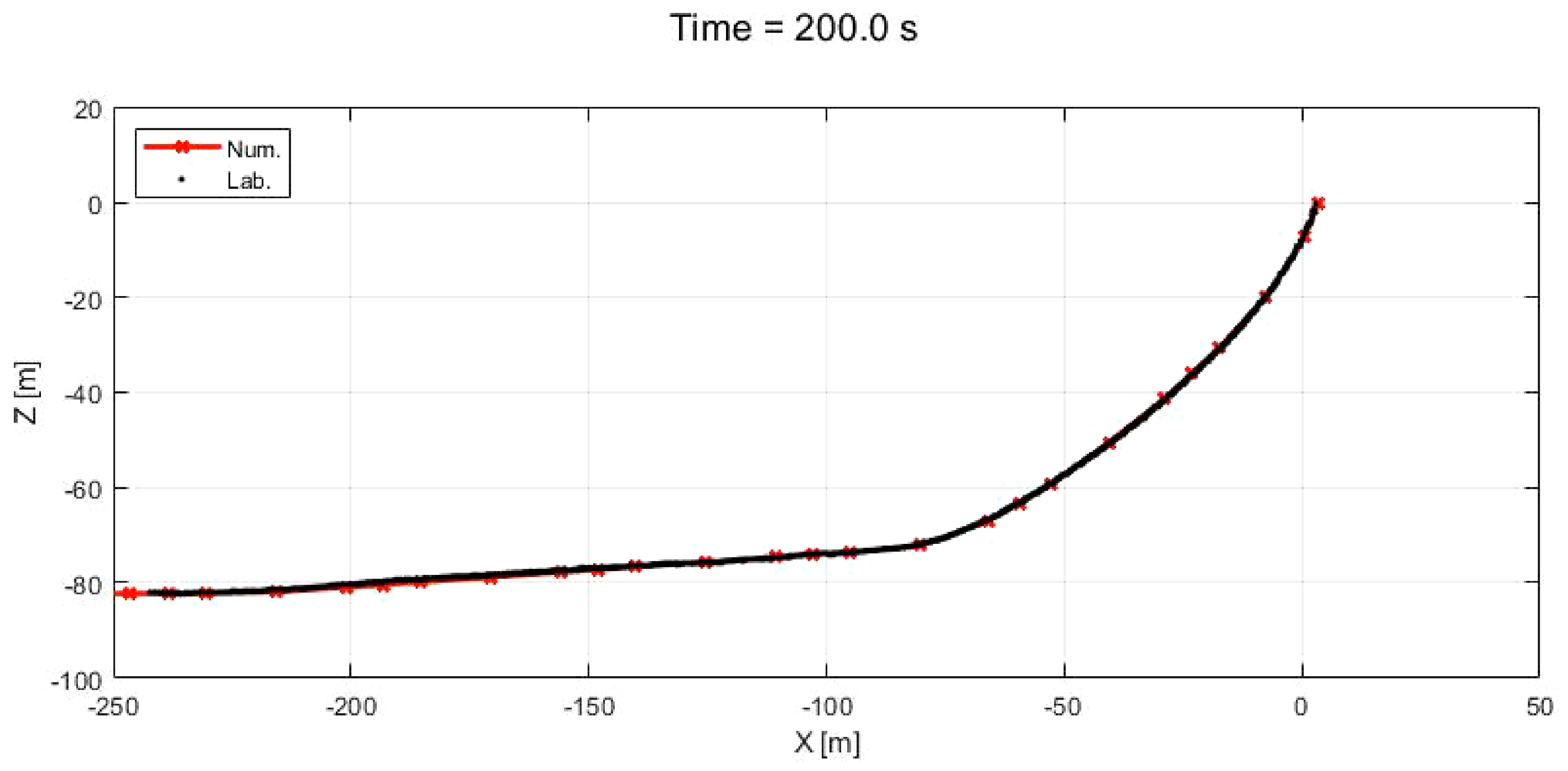
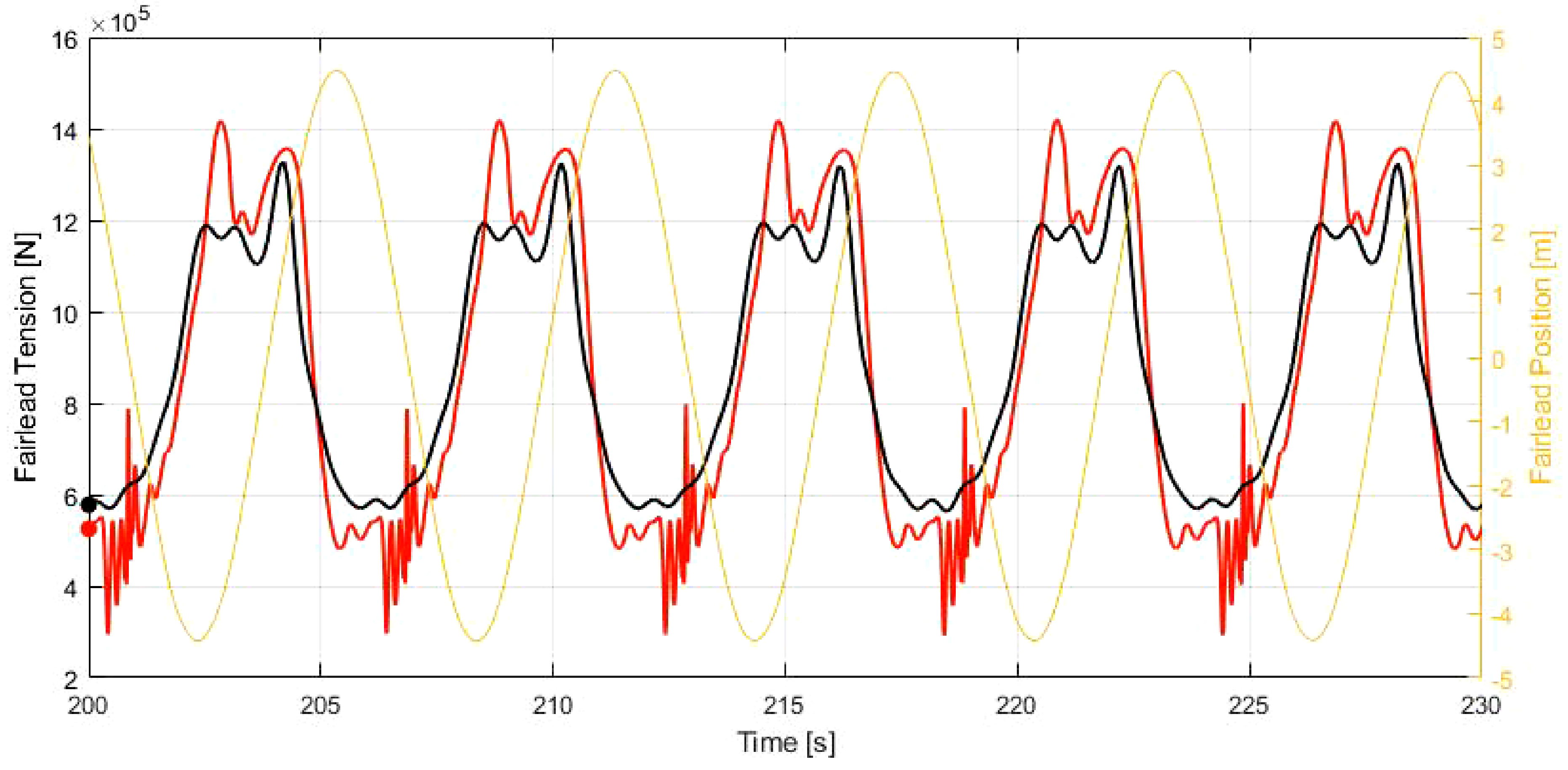
Mooring numerical models' calibration and validation

‘All chain’ tension-deformation with sloped seabed



‘All chain’ regular test with sloped seabed





OUTLINE

1. Objectives
2. Experimental approach
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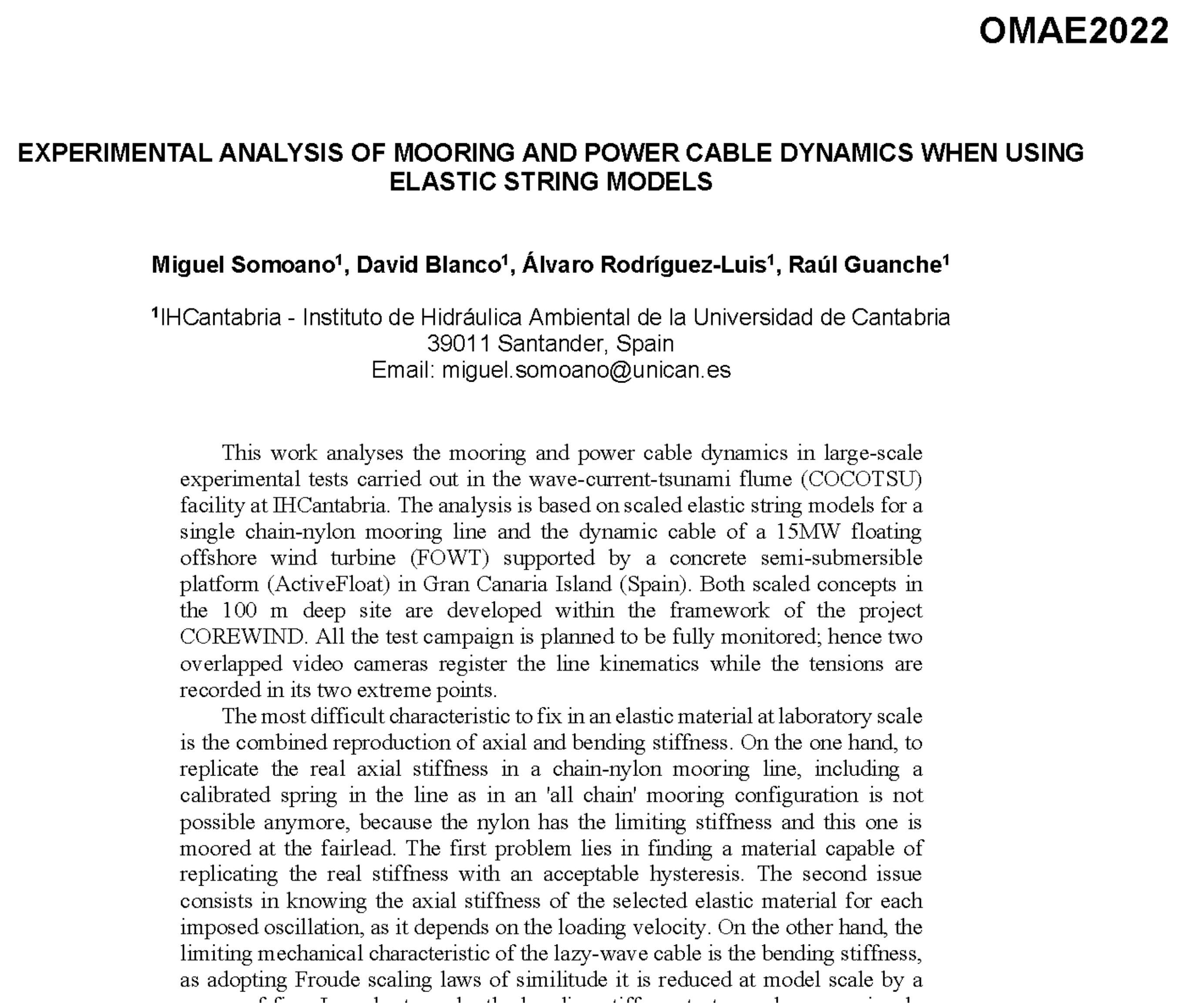
Conclusions

1) A new experimental methodology for tracking the position of any point of the tested line was developed.
2) Variable axial stiffness and bending axial stiffness was experimentally reproduced, using and characterizing elastic materials.
3) Complex bathymetries were used and the importance of considering seafloor irregularities was shown.
4) A mooring lines numerical model capable of considering advanced seafloor interaction models was calibrated and validated.

Conclusions

This WP of the CoreWIND project has returned satisfactory results that led to the elaboration of two publications.



OMAE2022

EXPERIMENTAL ANALYSIS OF MOORING AND POWER CABLE DYNAMICS WHEN USING ELASTIC STRING MODELS

Miguel Somoano[1], David Blanco[1], Álvaro Rodríguez-Luis[1], Raúl Guanche[1]

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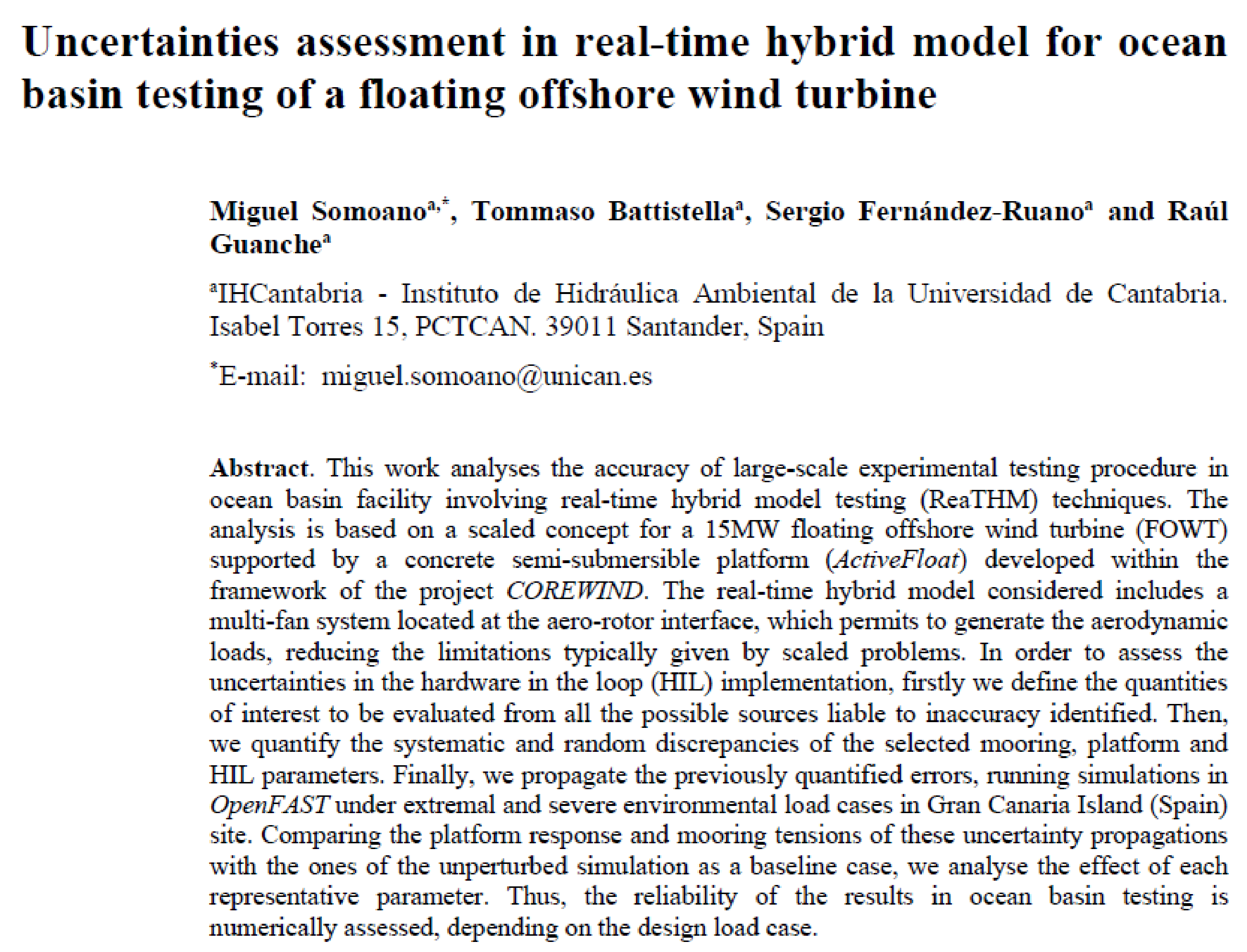
Email: miguel.somoano@unican.es

This work analyses the mooring and power cable dynamics in large-scale experimental tests carried out in the wave-current-tsunami flume (COCOTSU) facility at IHCantabria. The analysis is based on scaled elastic string models for a single chain-nylon mooring line and the dynamic cable of a 15MW floating offshore wind turbine (FOWT) supported by a concrete semi-submersible platform (ActiveFloat) in Gran Canaria Island (Spain). Both scaled concepts in the 100 m deep site are developed within the framework of the project COREWIND. All the test campaign is planned to be fully monitored; hence two overlapped video cameras register the line kinematics while the tensions are recorded in its two extreme points.

The most difficult characteristic to fix in an elastic material at laboratory scale is the combined reproduction of axial and bending stiffness. On the one hand, to replicate the real axial stiffness in a chain-nylon mooring line, including a calibrated spring in the line as in an 'all chain' mooring configuration is not possible anymore, because the nylon has the limiting stiffness and this one is moored at the fairlead. The first problem lies in finding a material capable of replicating the real stiffness with an acceptable hysteresis. The second issue consists in knowing the axial stiffness of the selected elastic material for each imposed oscillation, as it depends on the loading velocity. On the other hand, the limiting mechanical characteristic of the lazy-wave cable is the bending stiffness, as adopting Froude scaling laws of similitude it is reduced at model scale by a



Uncertainties assessment in real-time hybrid model for ocean basin testing of a floating offshore wind turbine

Miguel Somoano[a,*], Tommaso Battistella[a], Sergio Fernández-Ruano[a] and Raúl Guanche[a]

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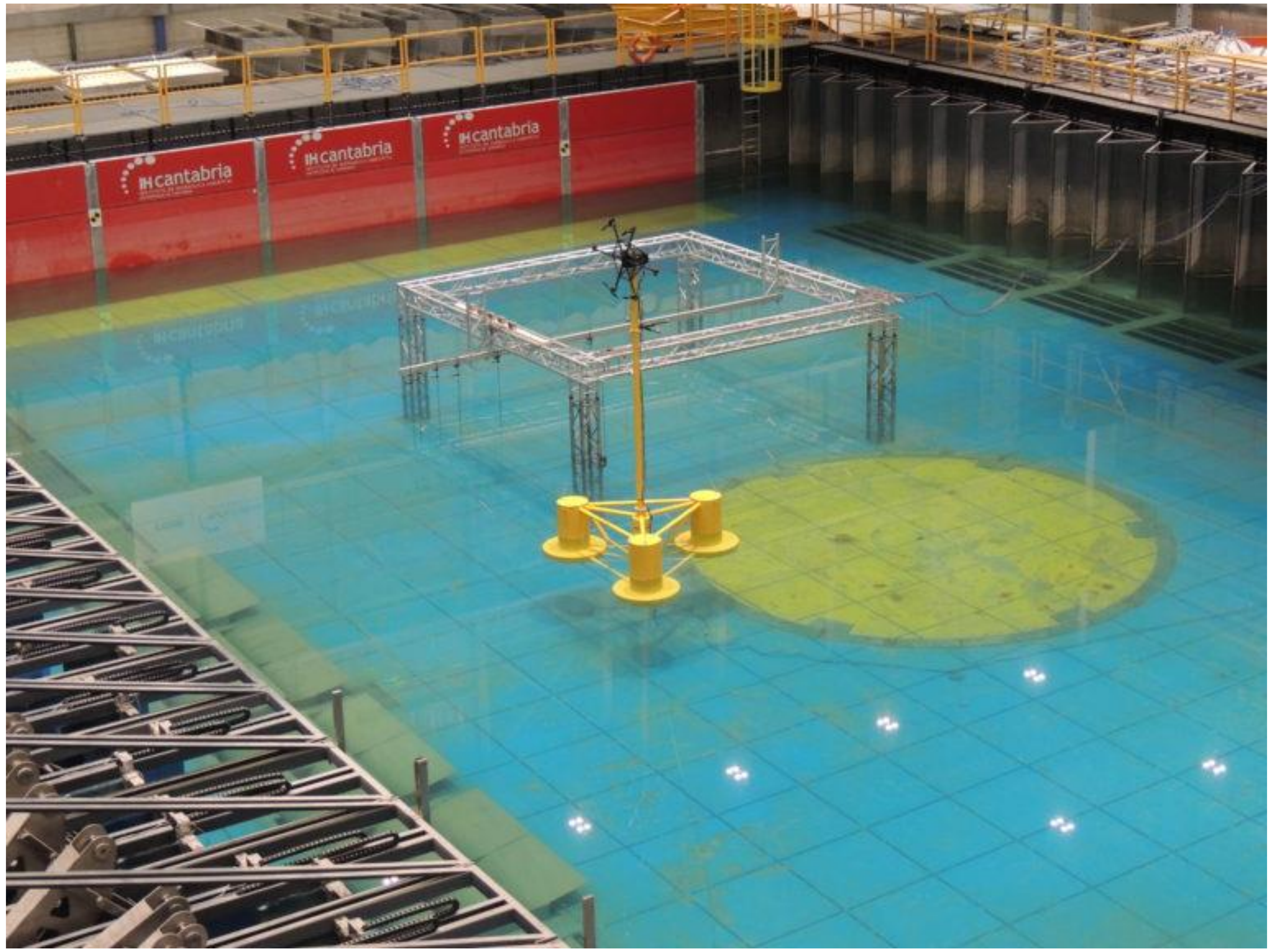
Abstract. This work analyses the accuracy of large-scale experimental testing procedure in ocean basin facility involving real-time hybrid model testing (ReaTHM) techniques. The analysis is based on a scaled concept for a 15MW floating offshore wind turbine (FOWT) supported by a concrete semi-submersible platform (*ActiveFloat*) developed within the framework of the project *COREWIND*. The real-time hybrid model considered includes a multi-fan system located at the aero-rotor interface, which permits to generate the aerodynamic loads, reducing the limitations typically given by scaled problems. In order to assess the uncertainties in the hardware in the loop (HIL) implementation, firstly we define the quantities of interest to be evaluated from all the possible sources liable to inaccuracy identified. Then, we quantify the systematic and random discrepancies of the selected mooring, platform and HIL parameters. Finally, we propagate the previously quantified errors, running simulations in *OpenFAST* under extremal and severe environmental load cases in Gran Canaria Island (Spain) site. Comparing the platform response and mooring tensions of these uncertainty propagations with the ones of the unperturbed simulation as a baseline case, we analyse the effect of each representative parameter. Thus, the reliability of the results in ocean basin testing is numerically assessed, depending on the design load case.

Conference paper OMAE 20022: 41st International Conference on Ocean, Offshore & Arctic Engineering, is **ongoing**

Conference paper IOP Conf. Series: Journal of Physics EERA DeepWind'2021, 18th Deep Sea Offshore Wind R&D Conference

Future steps



Fully coupled experimental test program including the simulation of the wind turbine control strategy from two points of view, will be implemented at both wave basin and wind tunnel.

Importance of the non-linearities in the hydrodynamics, aerodynamics and mooring system.

Thanks for your attention

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

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Disclaimer:

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 815083.

Project details:

Duration:
1 Sep 2019 - 28 Feb 2023
Grant agreement:
No: 815083