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COST REDUCTION OF FLOATING WIND TECHNOLOGY

COREWIND:

Improving competitiveness of floating offshore wind through cost-reduction

Final event

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

26 April 2023, 10:30-14:00
Copenhagen and Online

Welcome and Introduction

- Welcome to the COREWIND final event!
- For online participants: please mute your microphone. If any technical issue: do not hesitate to write directly in the chat.
- Questions can be asked on Slido. But for the audience in the room, do not hesitate to speak up!

Join at
slido.com
#COREWIND

Agenda

10:45-10:50	**Enabling cost-reduction and increasing performance of floating wind: the COREWIND project**	Jose-Luis Dominguez, IREC
10:50-11:00	**Floating wind: which potential to help achieveing the Green Deal targets?**	Enrico Degiorgis, European Commission, DG RTD
11:00-11:40	**Part 1 - Efficient design and optimisation tools for Floating wind technologies and O&M strategies**	Henrik Bredmose, DTU Valentin Arramounet, INNOSEA Siobhan Doole, JDR Cables Marie Schwarzkopf, RAMBOLL
11:40-11:55	**Time for questions!**	*Moderated by Lizet Ramirez, WindEurope*
11:55-12:05	Coffee Break	

Agenda

12:05-12:35	**Part 2 - Experimential testing, final cost-reduction, life-cycle assessment and roads to exploitation**	Raul Guanche García, FIHAC Victor Ferreira, IREC Bernd Neddermann, UL Solutions
12:35-12:50	**Time for questions!**	*Moderated by Lizet Ramirez, WindEurope*
12:50-13:25	**Similar objectives, different findings? Discussion with AFLOWT and FLOATECH projects**	Jose-Luis Dominguez, IREC Alessandro Bianchini, University of Florence (FLOATECH) Mareike Leimeister, Fraunhofer (AFLOWT) *Moderated by Lizet Ramirez, WindEurope*
13:25-13:30	**What's next for COREWIND solutions?**	Jose-Luis Dominguez, IREC
13:30-14:00	Join us for a networking lunch!	

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

The COREWIND project: in brief

Jose Luis Domínguez García
Head of Power Systems Group
IREC - Institut de Recerca en Energia de Catalunya

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Project information

- Starting Date: **01/09/2019** Ending Date: **28/02/2023** → **31/05/2023**
- Duration: **42 month** → **45 months**

- Project website and social media profiles:

  corewind.eu

  @corewindeu

  https://www.linkedin.com/company/corewind/

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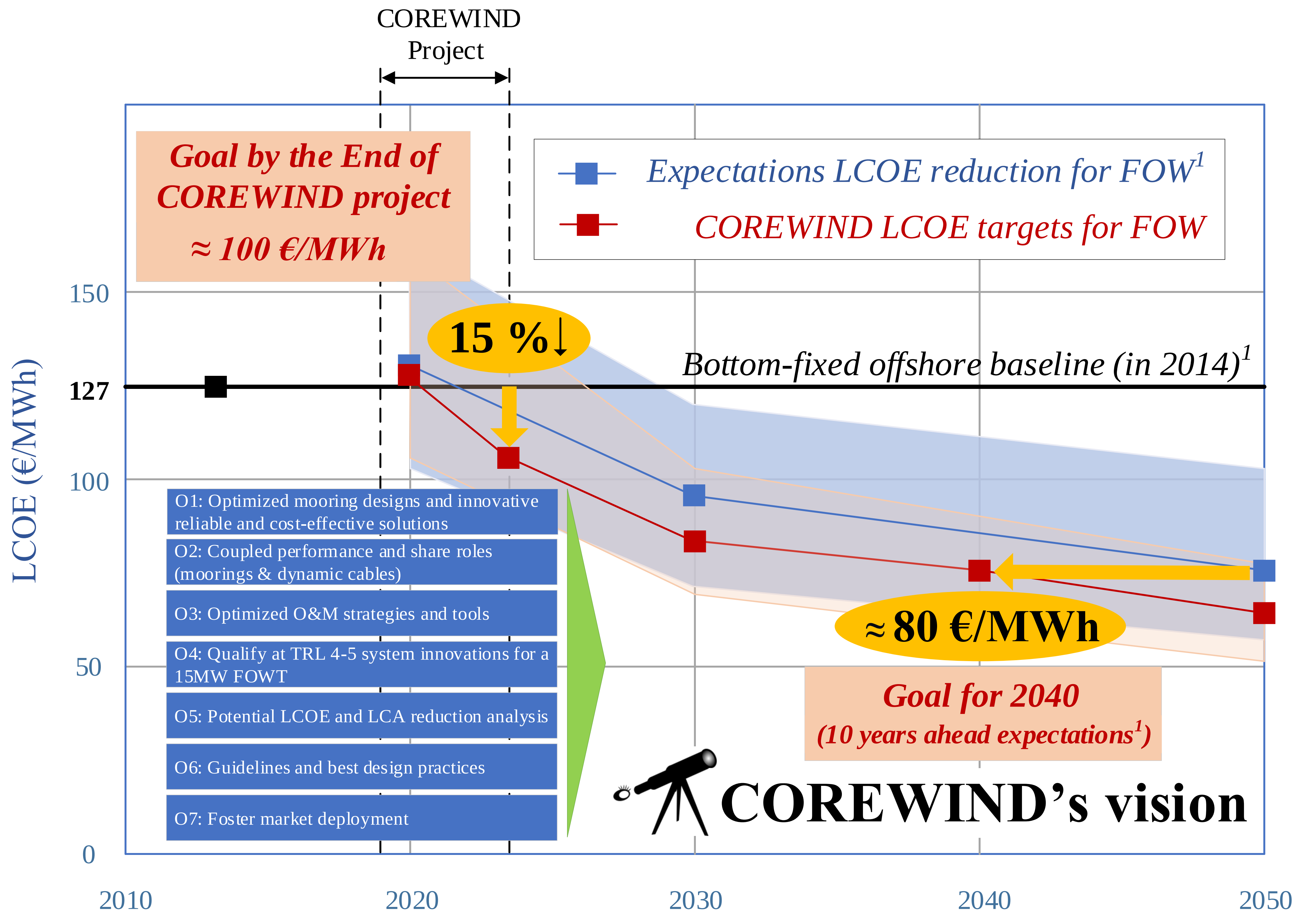
Project introduction

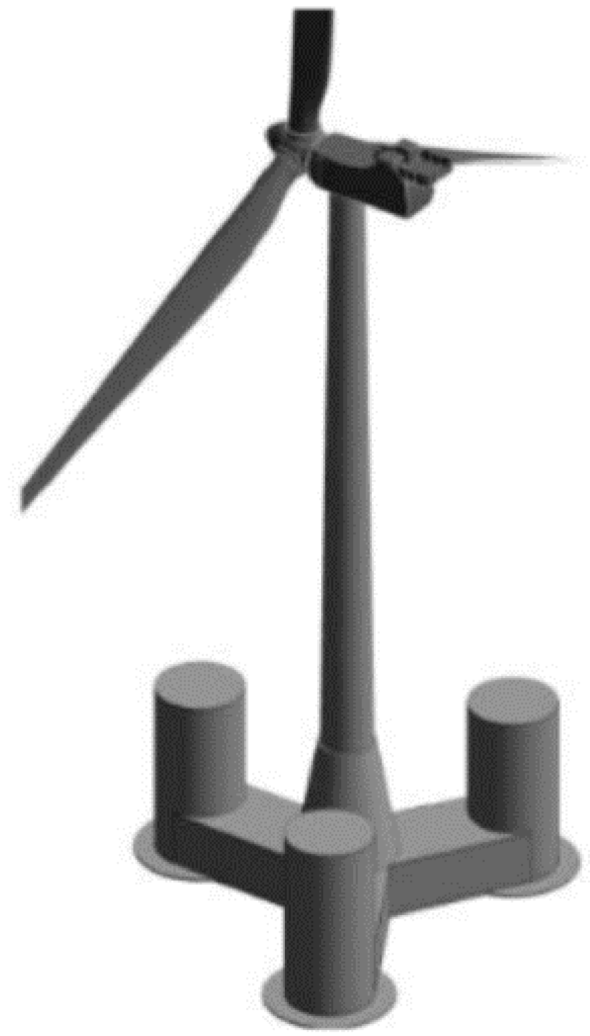
- Provides **disruptive and cost-effective solutions** for floating offshore wind technology, leading to **cost reduction**, by developing **innovative research, modelling and optimisation for floating substructure concepts**.
- Research on the mooring and anchoring systems, power dynamic cables, O&M as well as digitalisation, standardisation and validation.

- Objective: **at least a 15% LCOE reduction** by the end of the project (i.e. 100€/MWh approximately) through disruptive technologies and procedures for floating wind sector; paving the way for achieving future cost objectives earlier (i.e. ≈ 80 €/MWh by 2040, 10 years ahead expectations).

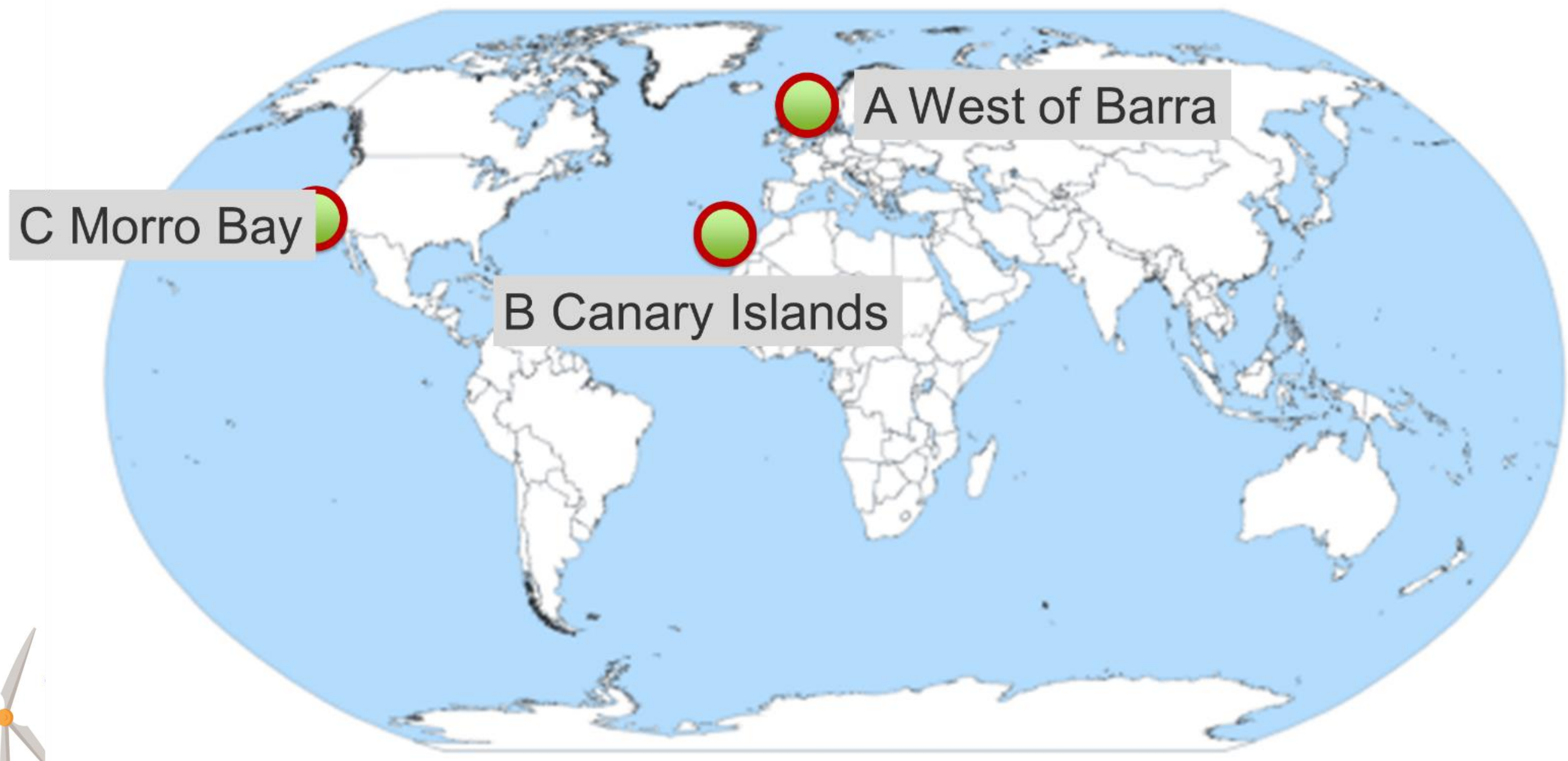


Project introduction

- With special focus on **2 concrete-based floaters**: **WindCrete** and **ActiveFloat**.



- Evaluated in **3 locations:**



	West of Barra	Canary Islands	Morro Bay
Water depth (m)	100	200	870
Distance to shore (km)	20	10	50

Normal Wind Profile	
Height [m]	Speed [m/s]
10	9.50
20	10.16
50	10.97
100	11.58
119	11.74
150	11.95

Normal Wind Profile	
Height [m]	Speed [m/s]
10	9.83
20	10.48
50	11.33
100	11.98
119	12.14
150	12.36

Normal Wind Profile	
Height [m]	Speed [m/s]
10	6.2
20	7.1
50	8.5
100	9.8
119	10.1
150	10.6

Project partners and Advisory board

Third Parties

UC UNIVERSIDAD DE CANTABRIA

ESTEYCO

UL

External Advisory Board

NREL NATIONAL RENEWABLE ENERGY LABORATORY

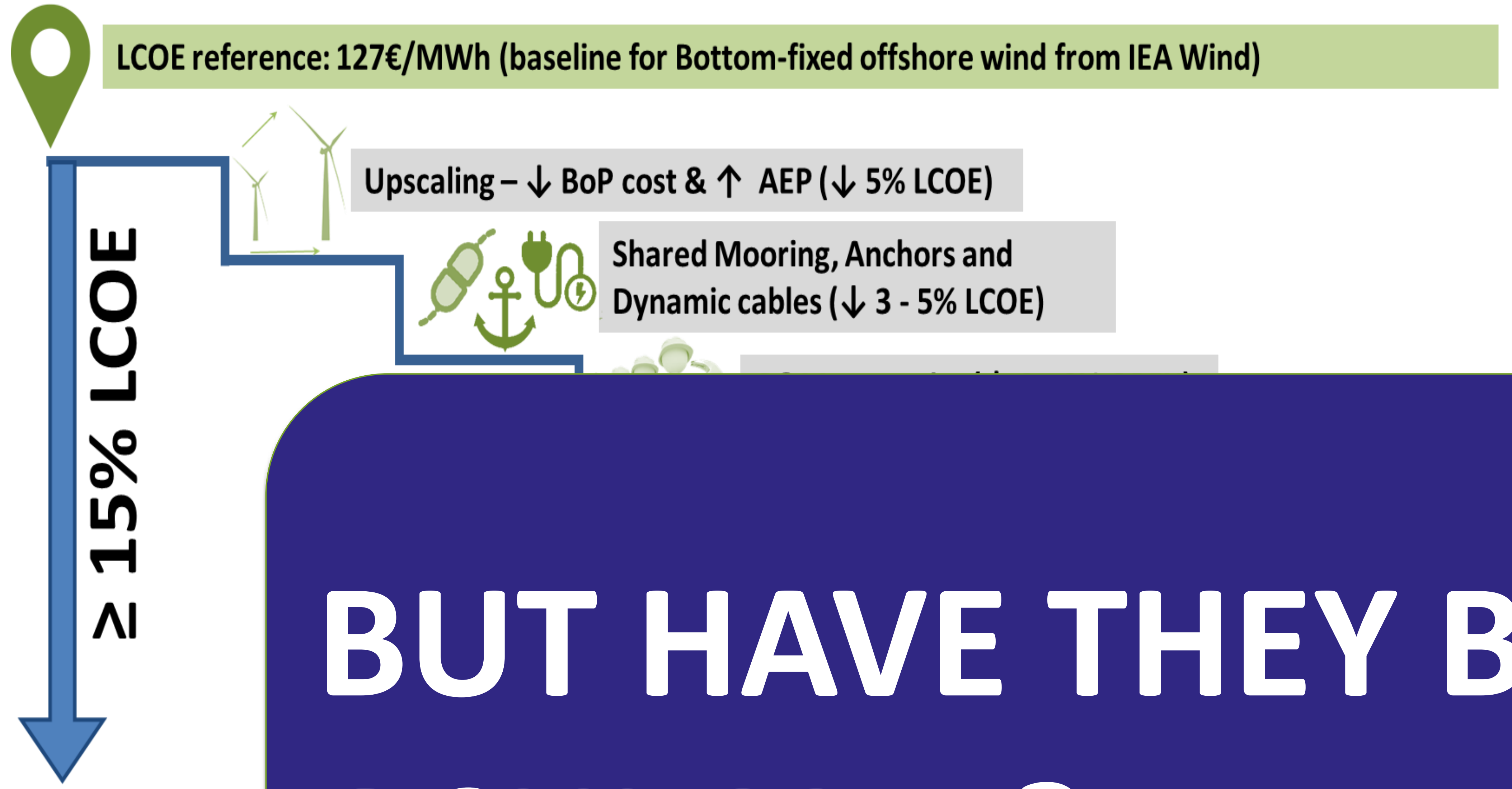
eit European Institute of Innovation & Technology

WINDSY

CARBON TRUST

DEME
Dredging, Environmental & Marine Engineering

Project expected impacts and outcomes



BUT HAVE THEY BEEN ACHIEVED?

- 2 floater (semi-sub & spar) models
- **Design and operation tools:**
  - 1 BIM toolbox for floating wind industry
  - 1 Open and agnostic Digital Twin for floating wind
  - 1 O&M planning and assessment tool
- **Economic tools:**
  - 1 LCOE and LCA calculation tool
  - Floating Wind Farm optimization modules for cost minimization

Where to find our results and outputs

- **Public Deliverables and other reports:**
  - They can be found at: http://corewind.eu/publications/
  - Zenodo platform: https://zenodo.org/communities/corewind/?page=1&size=20 (including scientific articles and papers)

- **Public models (available under different CC licenses):**
https://zenodo.org/communities/corewind/?page=1&size=20
  - UPC-WindCRETE OpenFAST – Grand Canary Island
  - COREWIND - ACTIVEFLOAT OpenFAST model 15 MW FOWT Grand Canary Island site
  - Other locations under analysis if available

- **Scientific publication:** on the COREWIND website.

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Thank you!

For further questions, do not hesitate to contact me:
Jose Luis Domínguez (jldominguez@irec.cat)

Stay tuned and follow us for final news:
Twitter
LinkedIn

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Floating wind: which potential to help achieving the Green Deal targets?

COREWIND project – final event

Copenhagen - 26 April 2023

Enrico Degiorgis
DG Research & Innovation
Clean Planet Directorate
Unit Clean Energy Transition
Policy Officer

Recent EU policy and legislative developments

Net-Zero Industry Act (NZIA)

- Commission proposal for a regulation adopted on 16 March 2023
- Onshore wind and offshore renewables identified among the 8 ‘Strategic Net-Zero Technologies’
- Strategic Net-Zero Technologies:
  - Objective: scale up manufacturing in the EU to provide at least 40% of the EU’s annual deployment needs by 2030
  - Particular support measures (simpler and faster permitting, sustainability and resilience criteria in auctions, possibility to become Strategic Net-Zero Technology project)
- Net-Zero Technologies: One-stop shop, online access to info, faster permitting (12-18 months); Innovation - Regulatory Sandboxes; European Net-Zero Industry Academies

Recent EU policy and legislative developments

Renewable Energy Directive – revision

- Provisional agreement reached between the European Parliament and the Council to **reinforce the EU Renewable Energy Directive** (30 March 2023)
- **EU's binding renewable target for 2030: minimum of 42.5% (up from the current 32%).** With an additional indicative 2.5%
- Indicative target of 5% of new installed renewable energy capacity to be covered by **innovative technologies** at Member State level
- Accelerated permitting procedures, acceleration areas, overriding public interest

Recent EU policy and legislative developments

Critical Raw Materials Act

- Commission proposal for a regulation adopted on 16 March 2023
- List of Critical Raw Materials (CRM) and Strategic Raw Materials (SRM) is defined
- Towards more SRM supply security – 2030 benchmarks
  - EU's extraction capacity cover at least 10% of the EU's SRM consumption
  - EU's processing capacity cover at least 40% of the EU's SRM consumption
  - EU's recycling capacity cover at least 15% of the EU's SRM consumption
- Towards more SRM diversification of supply – 2030 benchmarks
  - Not more than 65% of EU consumption of each SRM should come from a single third country

To incentivise large-scale **recycling of permanent magnets**, the Act sets **requirements on recyclability and recycled** content.

EU countries will take measures to improve the collection of critical raw material-rich waste and ensure its recycling into secondary critical raw materials.

European Commission

Strategic Energy Technology (SET) Plan revamp

Three main **objectives**:

- Support the European Green Deal policies and strategies and make the SET Plan ‘fit for 55’, as well as embedding the approach of REPowerEU;

- Contribute to the ERA policy agenda and reinforce synergies with and between Member States;

- Increase the participation of all countries in SET Plan activities and increase the political visibility of the activities, in order to maximize their impact.

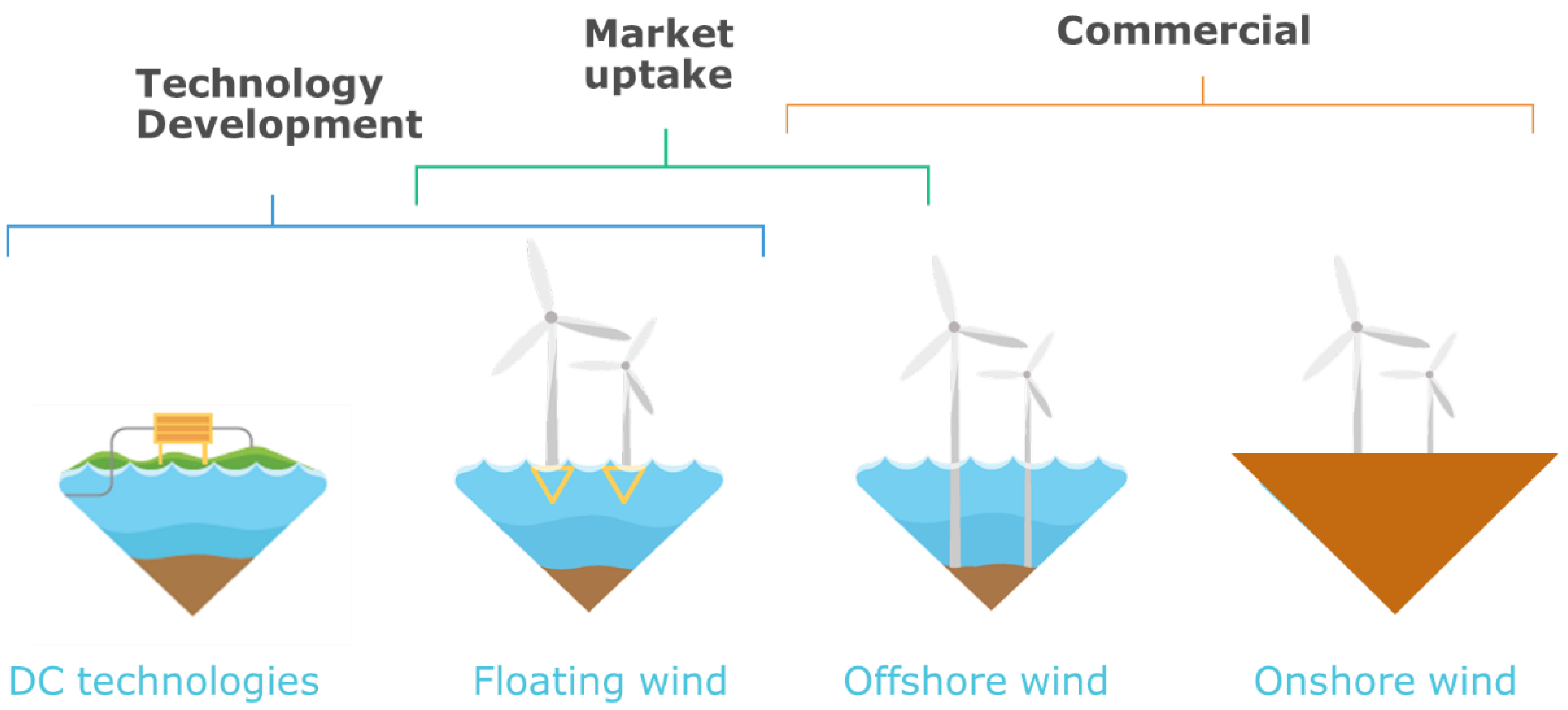
Opportunity to give **more consideration to matters of high priority** in the light of REPowerEU (e.g. hydrogen, materials, circularity, digitalisation, empowerment of citizen and energy storage)

- Wind: Implementation Working Group (IWG) on offshore wind decided to expand its scope to cover both onshore and offshore (February 2023)
  - Terms of reference
  - Targets revision – currenlty ongoing

- Communication of the Commission on SET Plan revamping most likely in **autumn 2023**

- SET Plan Conference (Viladecans – Barcellona - 13-14 November 2023)

Technology readiness level of the main technologies in wind energy



	DC technologies	Floating wind	Offshore wind	Onshore wind
EU	High RES penetration	27 MW	16 GW	174 GW
Global		123 MW	57 GW	780 GW

Source: JRC, 2022

Note: Direct current (DC) technologies are mentioned as they are a key enabler for high offshore RES penetration rates

Projected wind energy capacities – scenarios (1)

Share of total electricity generation (2020): Onshore wind 13.7%; Offshore wind (1.7%); 14% overall in 2021 (385 TWh)

- **EU Offshore Strategy – 19 November 2020**
  - **60 GW by 2030, 300 GW by 2050 (offshore only)**

- **'Fit for 55' package - 14 July 2021**
  - **469 GW by 2030**

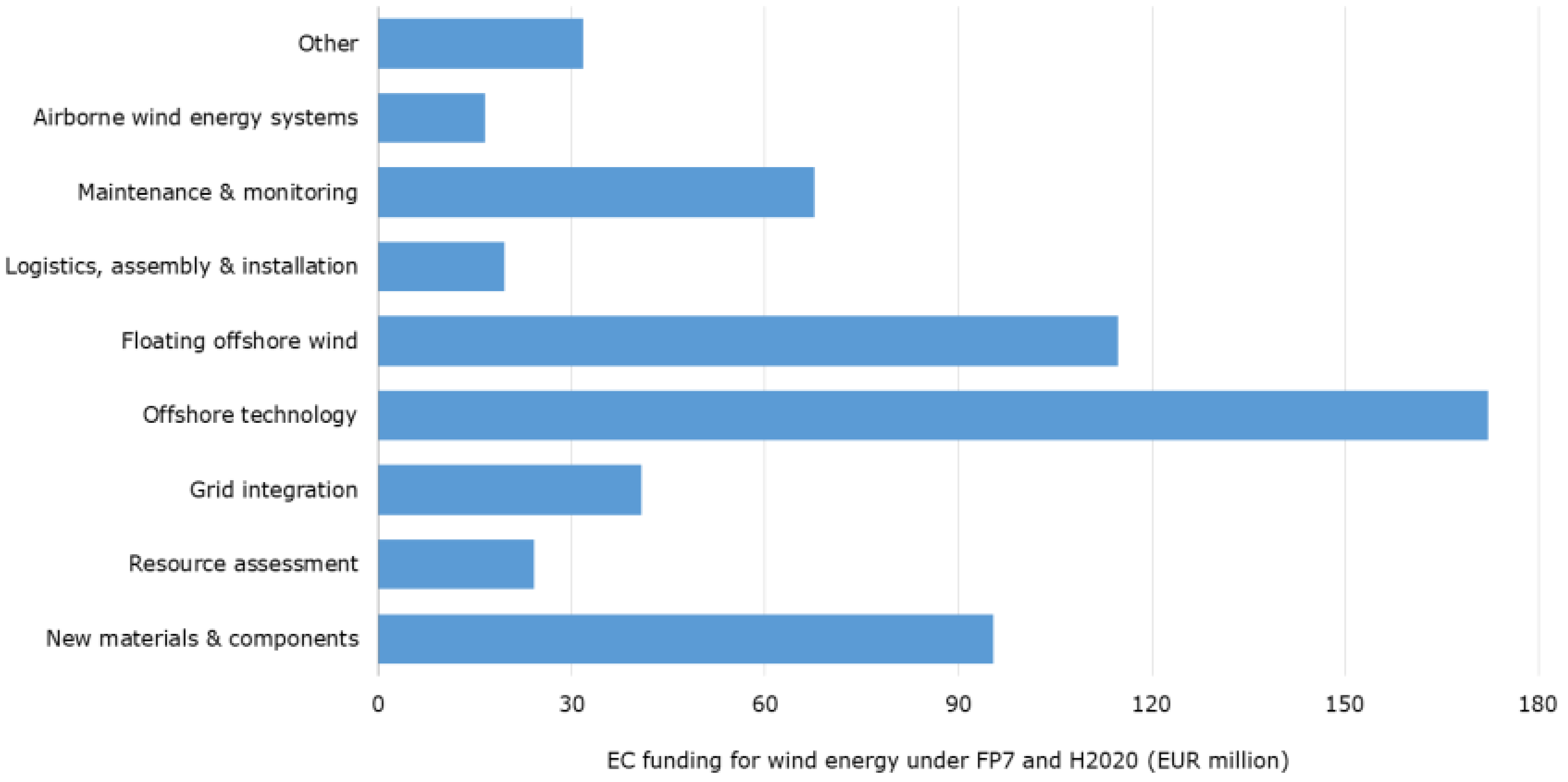
- **REPowerEU Plan – 18 May 2022**
  - With respect to wind energy the REPowerEU Plan proposes an installed capacity of **510 GW by 2030**, an increase by 16% as compared to CTP-MIX scenario

(~ +41 GW/year over the period 2023-2030)

European Commission

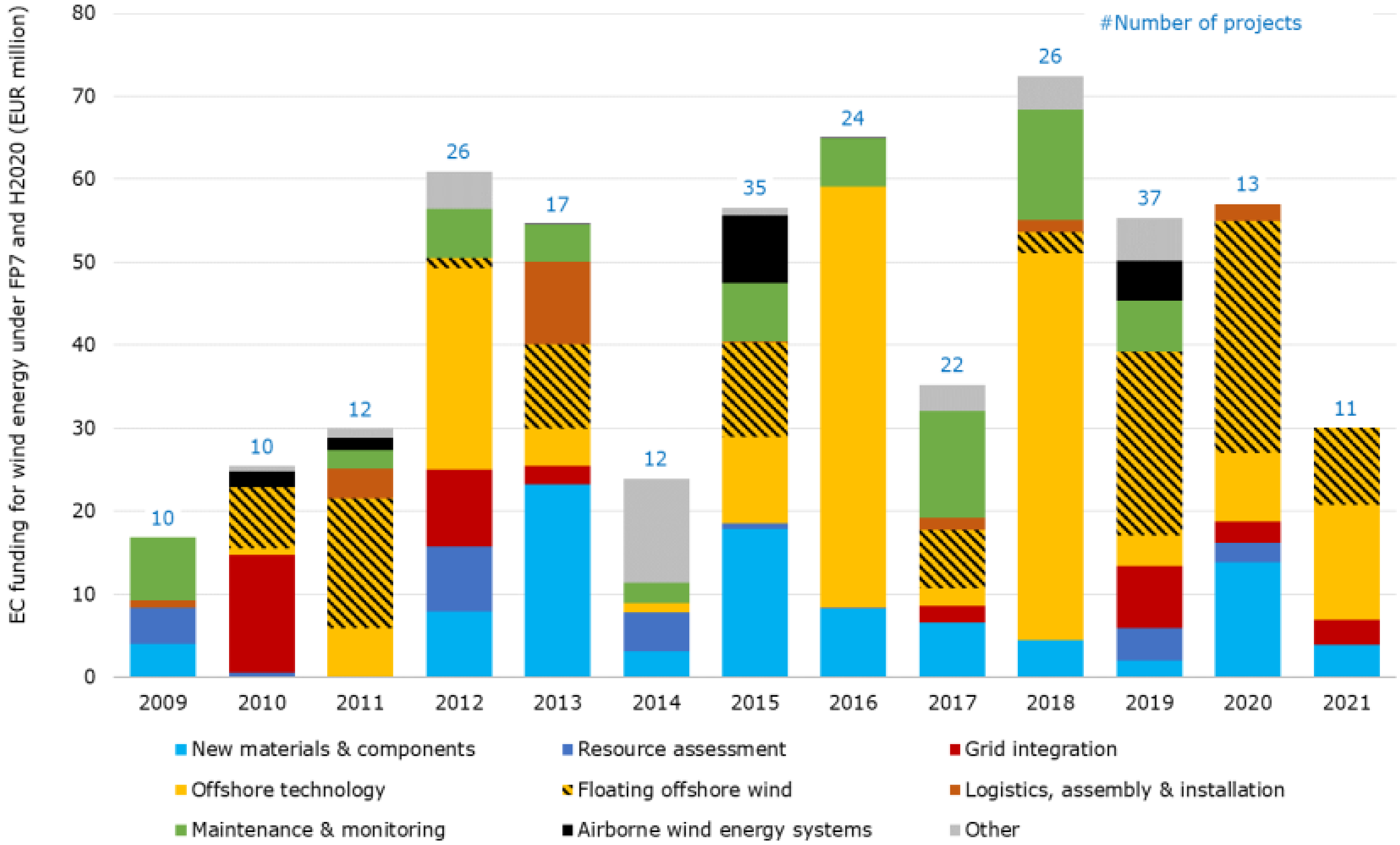
EU R&I funding – wind sector – 2009-2021

Figure 53. EC funding on wind energy R&I priorities in the period 2009 -2021 under FP7 and H2020.



Source: JRC, 2022.

EU R&I funding – wind sector – 2009-2021



Source: JRC, 2022.

European Commission

Horizon Europe – cluster 5 work programme 2023-2024 Wind – related topics (1)

- HORIZON-CL5-2023-D3-01-05 Critical technologies for the offshore wind farm of the Future (18M€ - 6M€/project – call closed on 30.3.23)

- HORIZON-CL5-2023-D3-02-14: Digital twin for forecasting of power production to wind energy demand (12M€ - 6M€/project – call opening: 4.5.23; call closing 5.9.23)

- HORIZON-CL5-2023-D3-02-15: Critical technologies to improve the lifetime, efficient decommissioning and increase the circularity of offshore and onshore wind energy systems (12M€ - 4M€/project – call opening: 4.5.23; call closing 5.9.23)

Search Funding & Tenders (europa.eu)

Horizon Europe – cluster 5 work programme 2023-2024 Wind – related topics (2)

- HORIZON-CL5-2024-D3-02-08: Minimisation of environmental, and optimisation of socio-economic impacts in the deployment, operation and decommissioning of offshore wind farms (10M€ - 5M€/project – call opening: 7.5.24; call closing 5.9.24)

- HORIZON-CL5-2024-D3-02-09: Demonstrations of innovative floating wind concepts (30M€ - 15M€/project – call opening: 7.5.24; call closing 5.9.24)

Horizon Europe – work programme (WP) 2025 and following

- Adoption of the Strategic Plan 2025 – 2027: early 2024

- Work programme 2025:
  - Only urgent needs and continuity of some recurrent actions: early 2024
  - Full WP in early 2025 – including 'politically sensitive' files
  - Topics drafting: likely to start in early 2024 – flexibility needed to consider new College's priorities

- New College of Commissioners: end 2024

Exact procedure and timing still to be fully defined

EU funding for [offshore] renewables

- Horizon Europe Cluster 5
- EU Innovation Council
- LIFE – Clean Energy Transition sub-programme
- European Maritime Fisheries and Aquaculture Fund
- BlueInvest
- Innovation Fund
- Cohesion policy funds
- Connecting Europe Facility - Transport
- Connecting Europe Facility - Energy
- InvestEU Fund
- Modernisation Fund
- Renewable Energy Financing Mechanism

- Overview of EU funding programmes relevant to finance offshore renewable energy projects
- Information about eligible investments
- Previously funded offshore projects
- How different EU programmes can be combined

Innovation Fund: small scale projects call currently open until 19.09.2023
Funding & tenders (europa.eu)

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Accurate design of 15 MW floating wind turbines in farms

Henrik Bredmose

Professor

DTU Wind Energy

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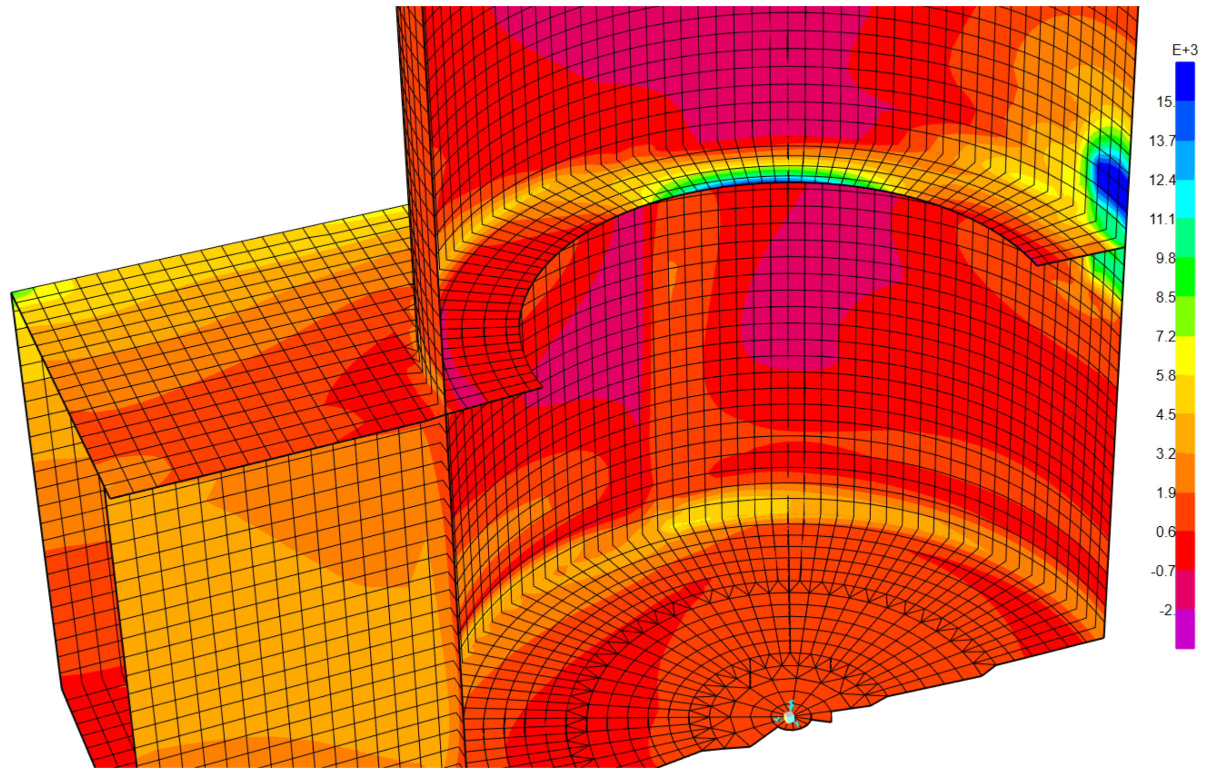
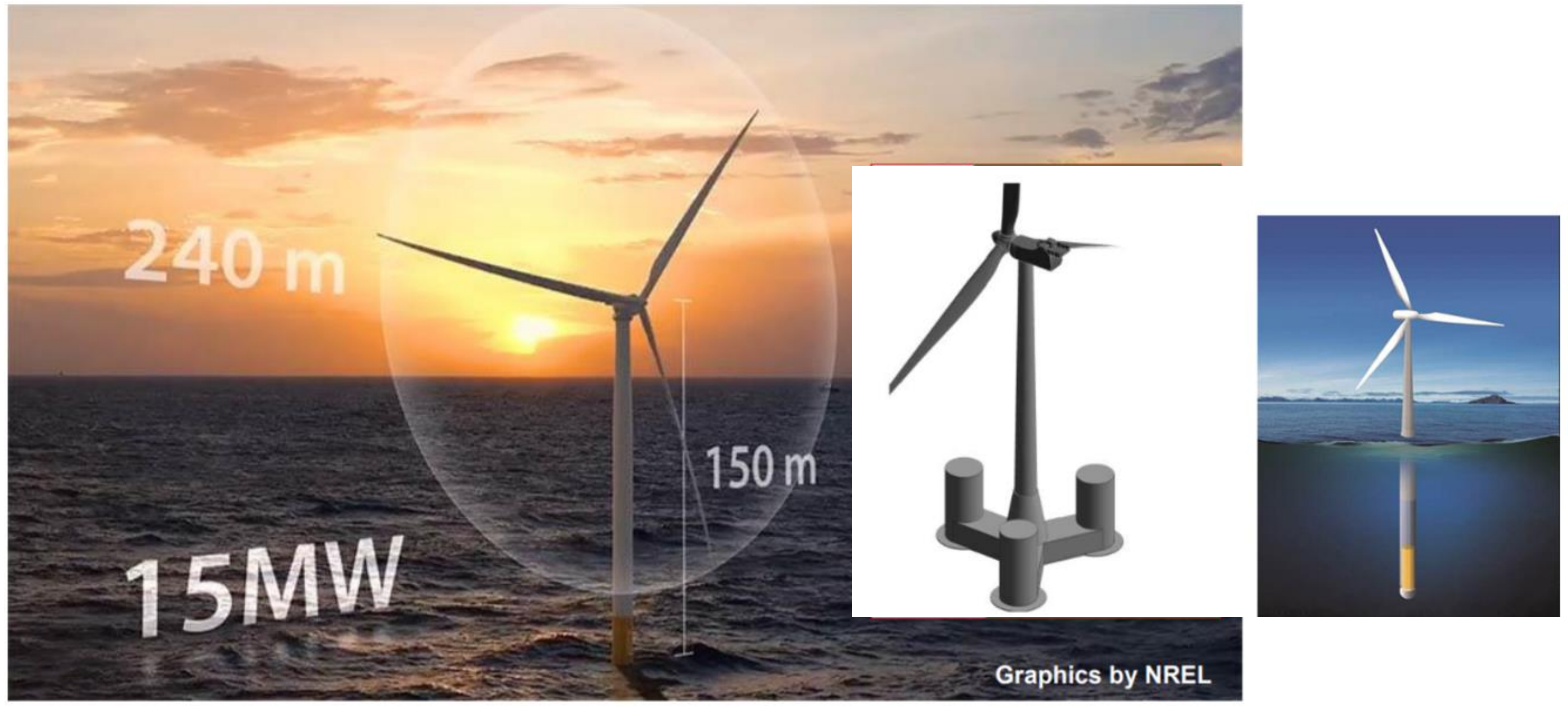
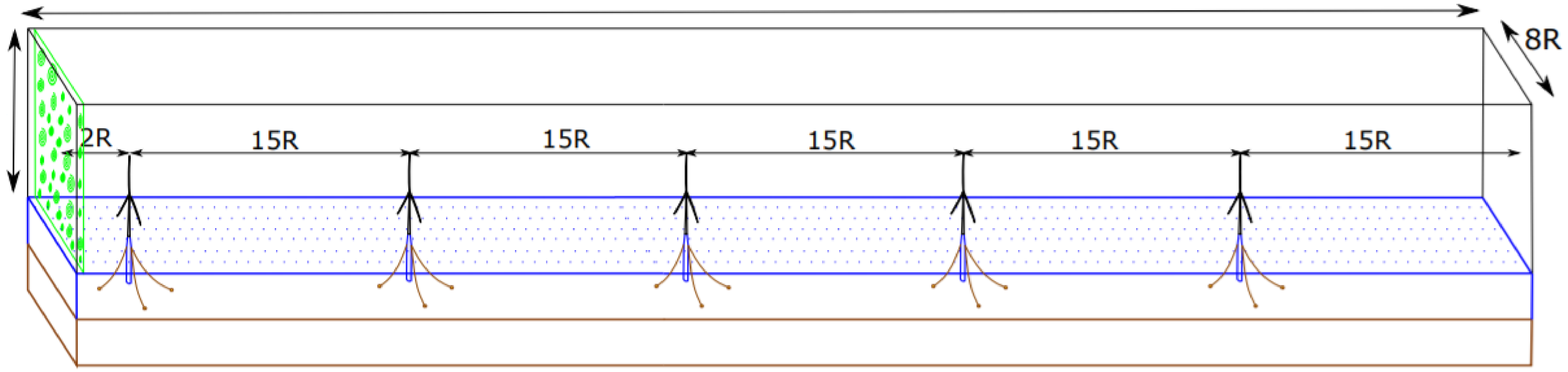
15 MW turbines in farms – Reference material



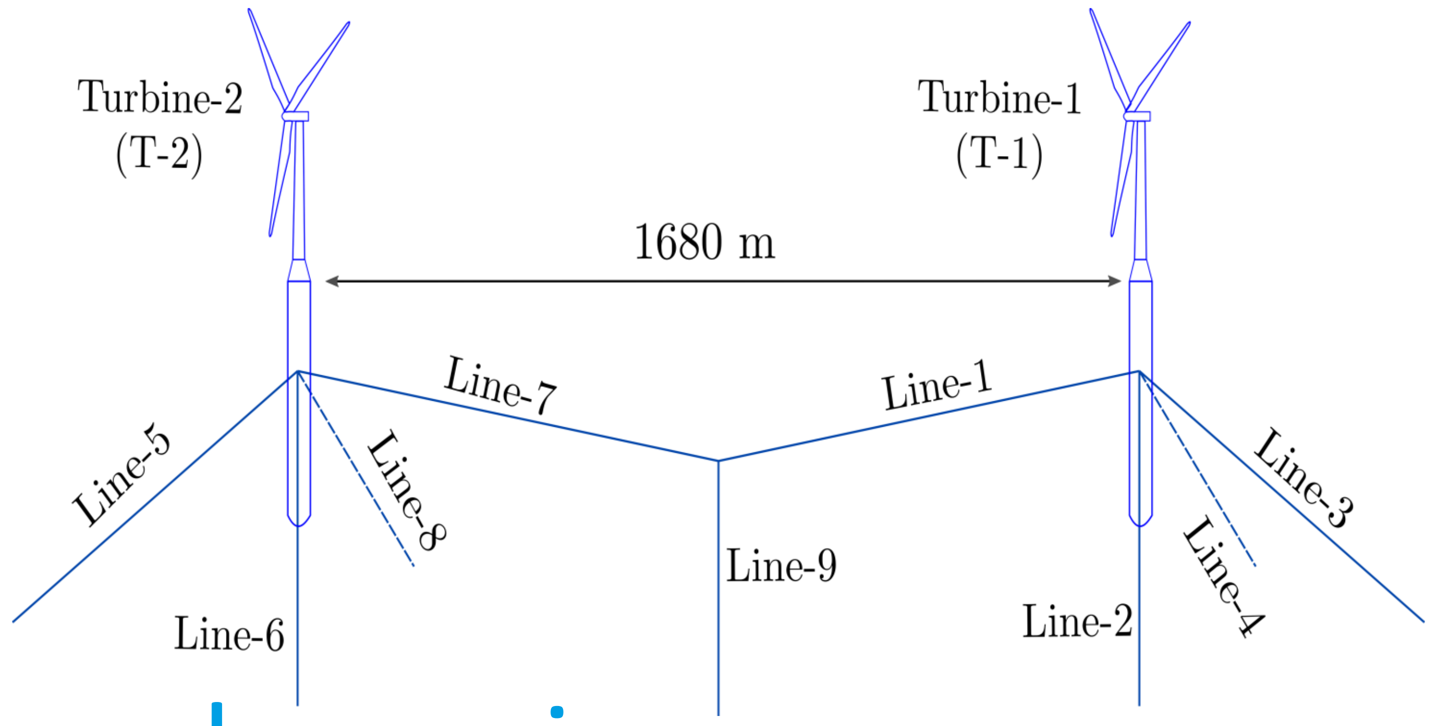
4 Structural floater design



1 Reference floaters 15 MW

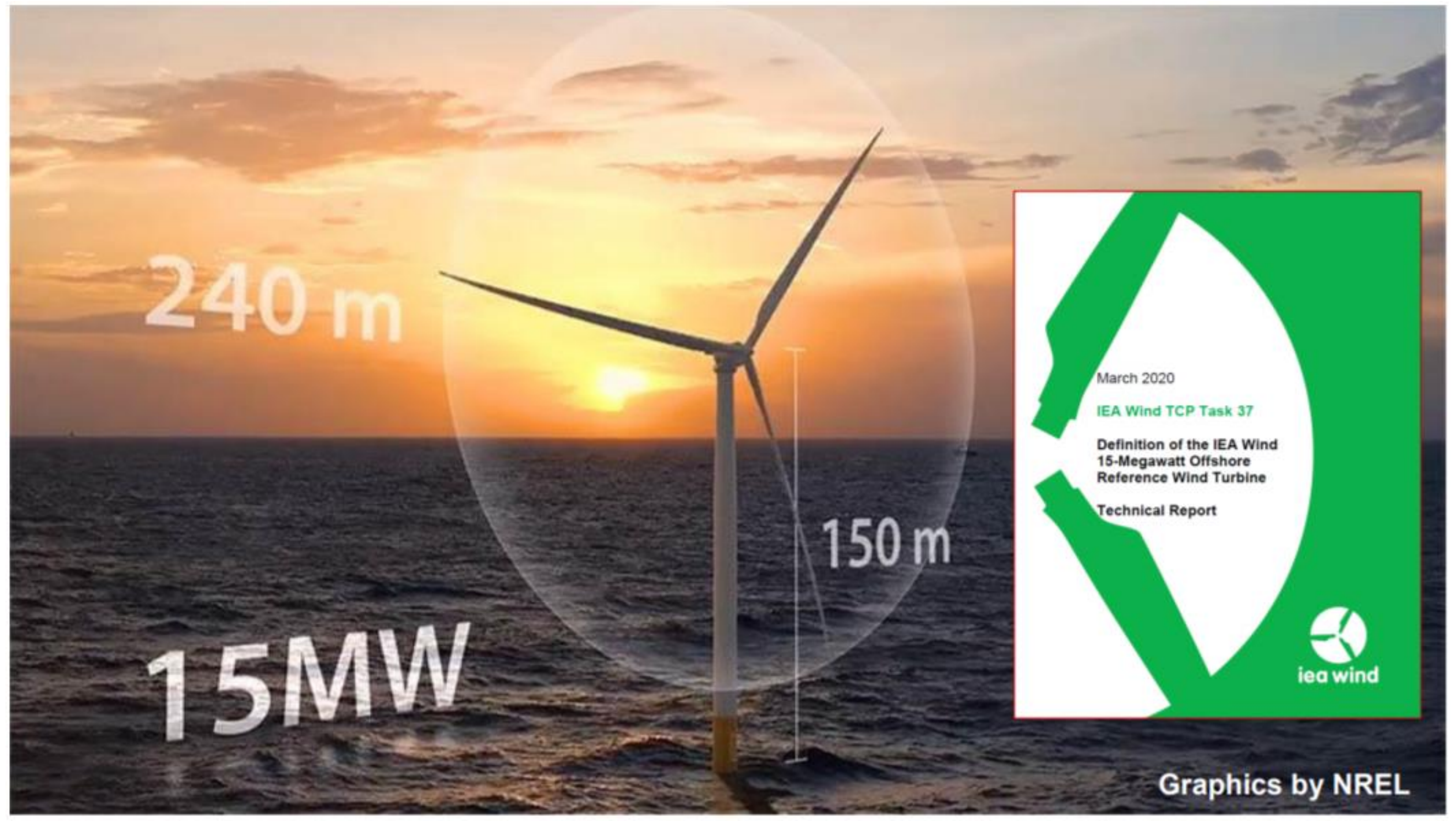


3 Wakes in floating wind farms



2 Shared mooring

1: Two public 15 MW Floaters + 15 MW IEA WIND RWT (2020)



Made by NREL and DTU Wind

IEA WIND 15 MW RWT

Models publicly available at https://github.com/IEAWindTask37/IEA-15-240-RWT

ActiveFloat

Models publicly available at COREWIND H2020 project | Zenodo

WindCrete

Models publicly available at COREWIND H2020 project | Zenodo

1: Two public 15 MW Floaters - Key facts

IEA WIND 15 MW RWT

- 240m rotor diameter
- 150m hub height
- Direct drive

https://github.com/IEAWindTask37/IEA-15-240-RWT

ActiveFloat

- Concrete semisub
- Active ballast system
- Displacement 36.400 tonnes

COREWIND H2020 project | Zenodo

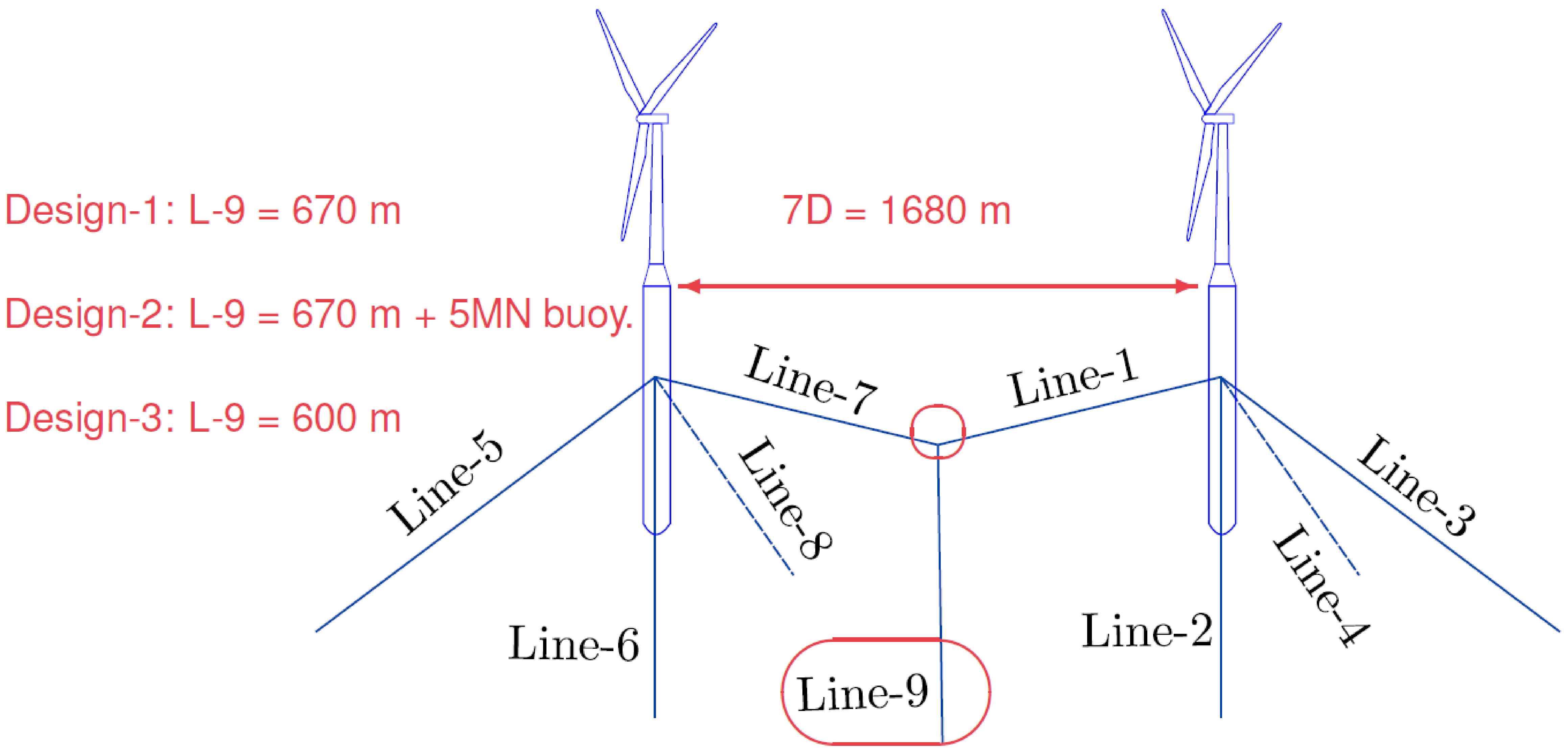
WindCrete

- Concrete spar
- Monolithic structure
- Displacement 40.500 tonnes

COREWIND H2020 project | Zenodo

Gaertner et al (2020)
COREWIND D1.3
Rinker et al (2020)

2: Shared mooring analysis



- Morro Bay site (800 m depth)
- Taut mooring system
- Three design variants with shared anchor+line

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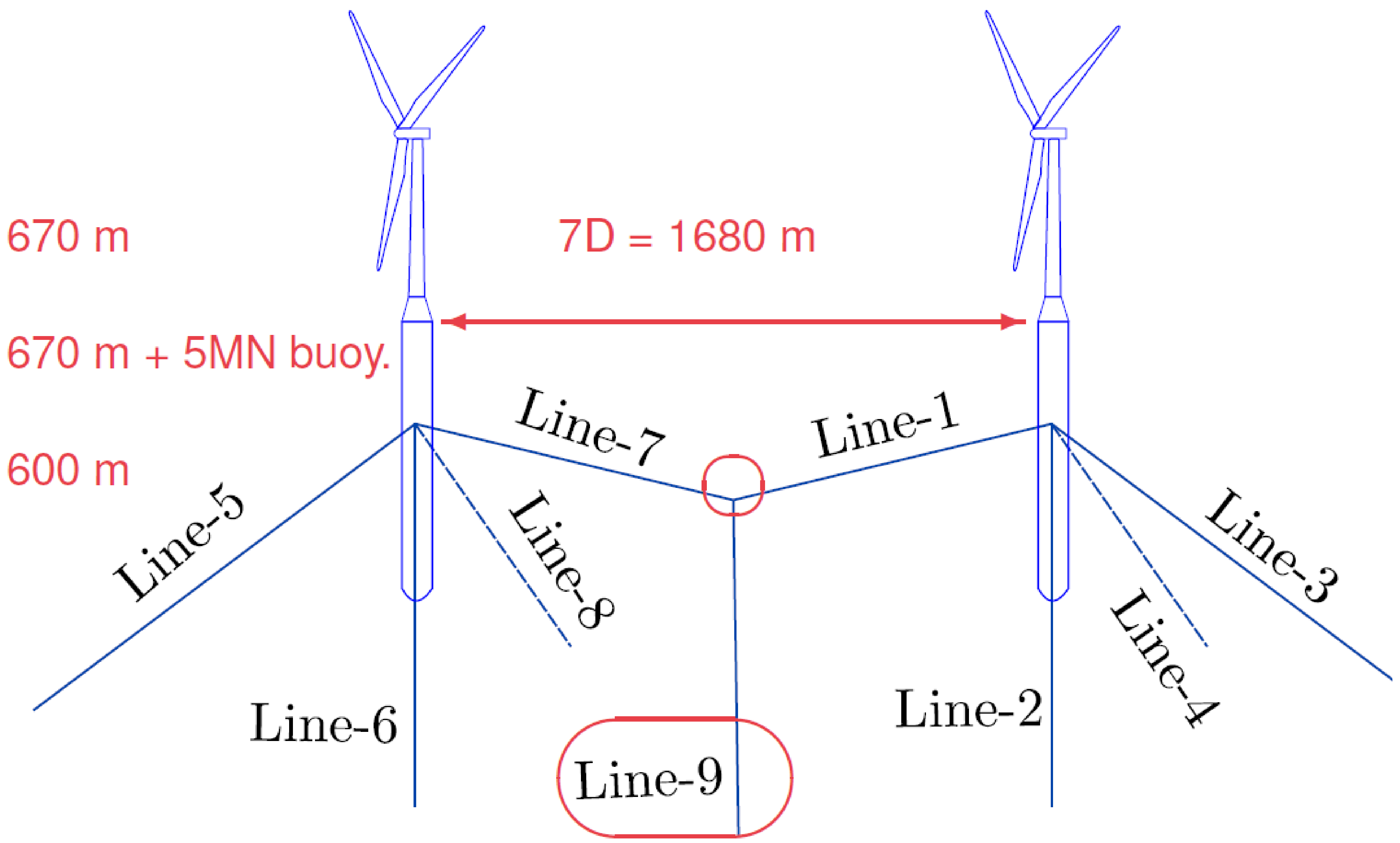
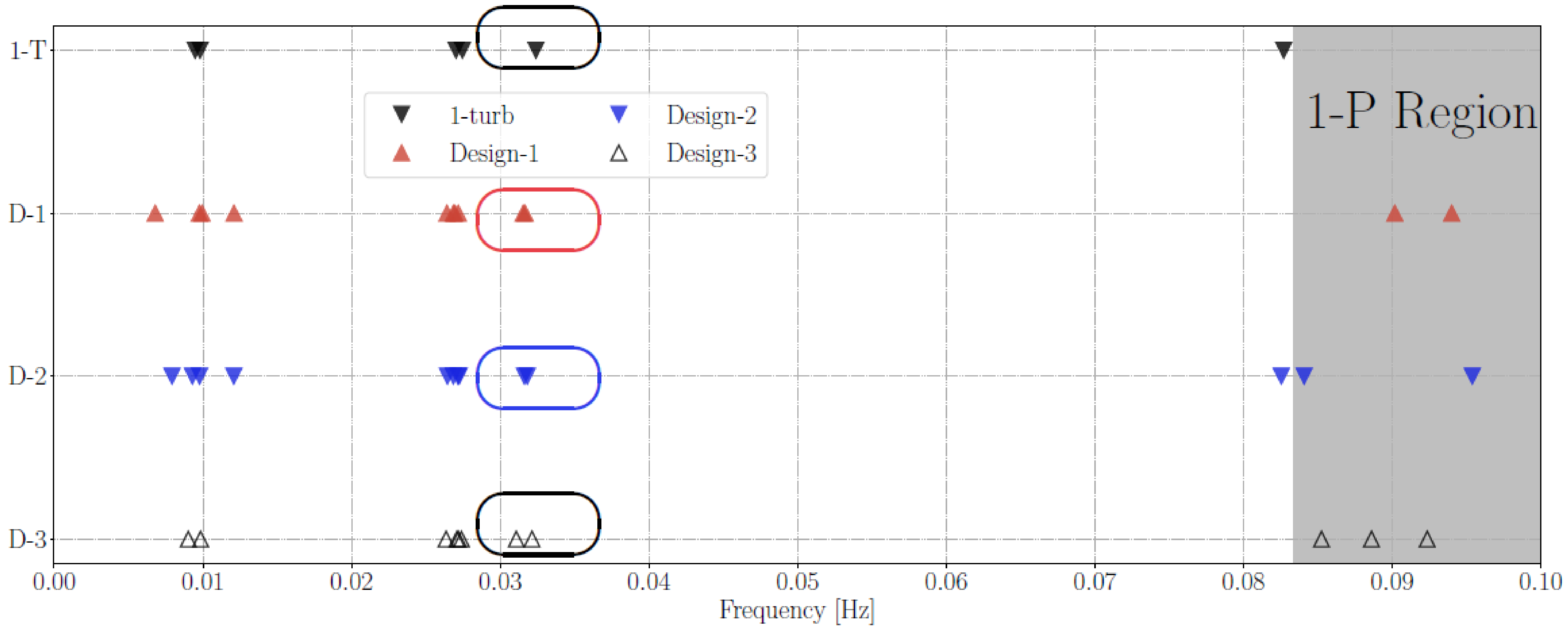
2: Shared mooring analysis



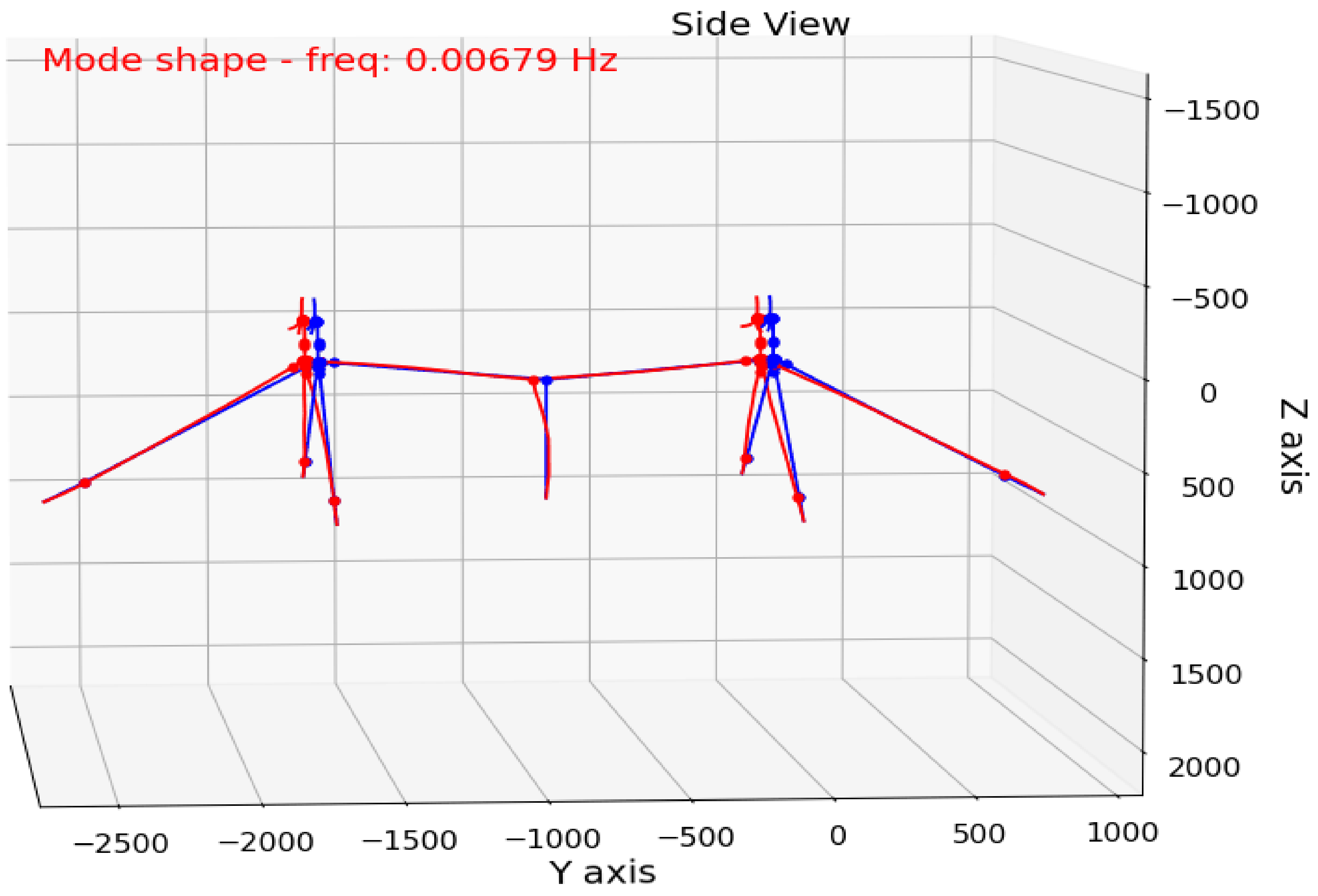


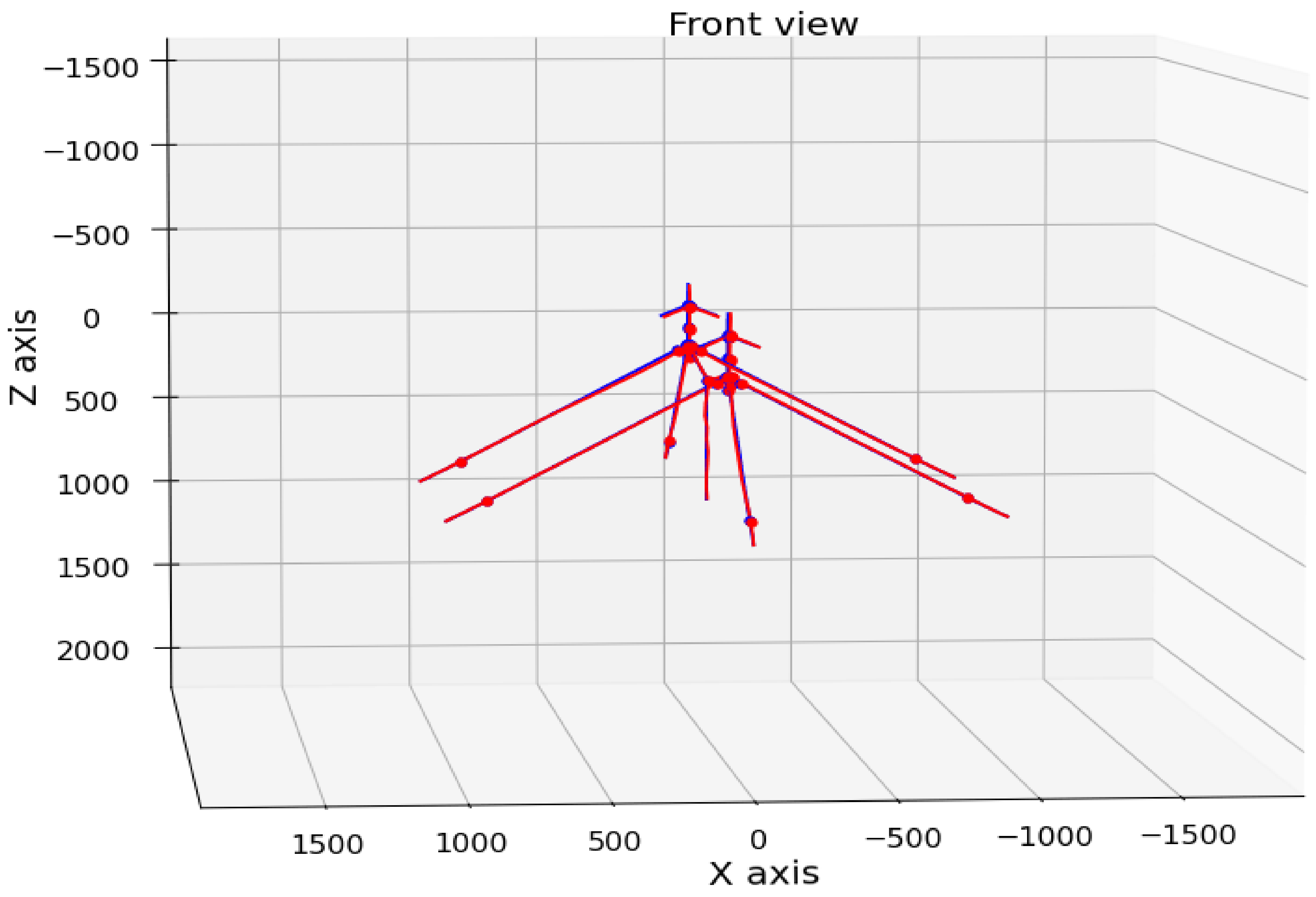
- Morro Bay site (800 m depth)
- Taut mooring system
- Three design variants with shared anchor+line

- Additional natural modes
- Split-up and move of nat freq
- Watch out for 1P region

Gözcü and Bredmose (2022)
COREWIND D1.4

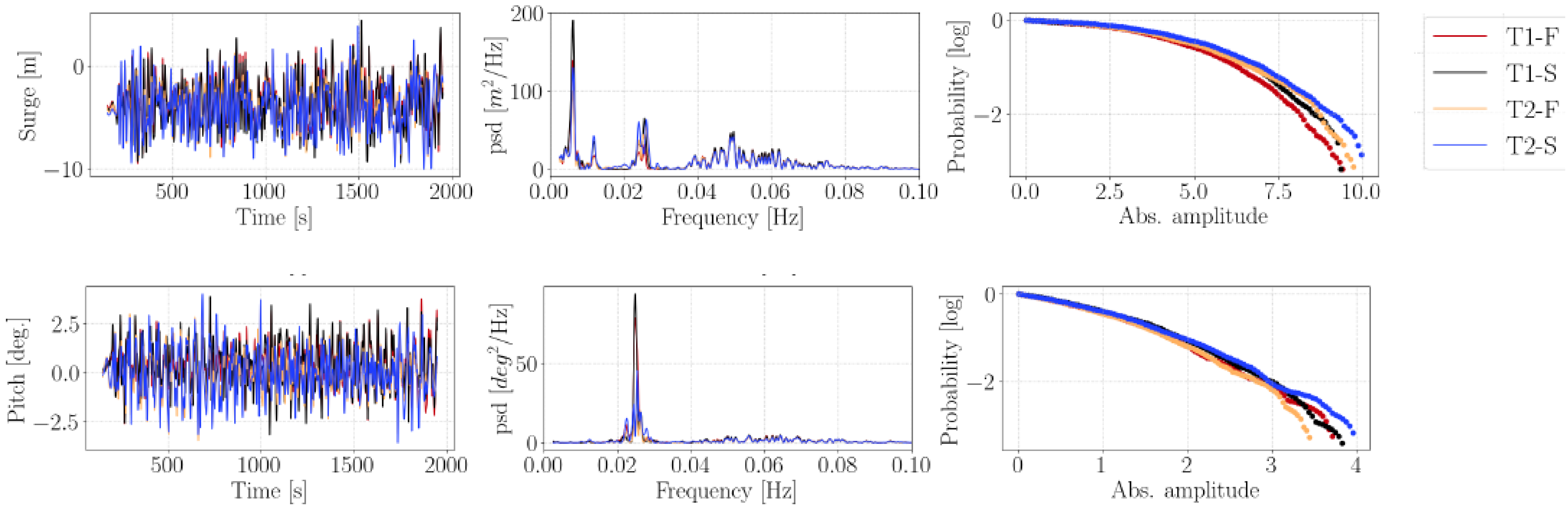
2: Shared mooring – natural modes





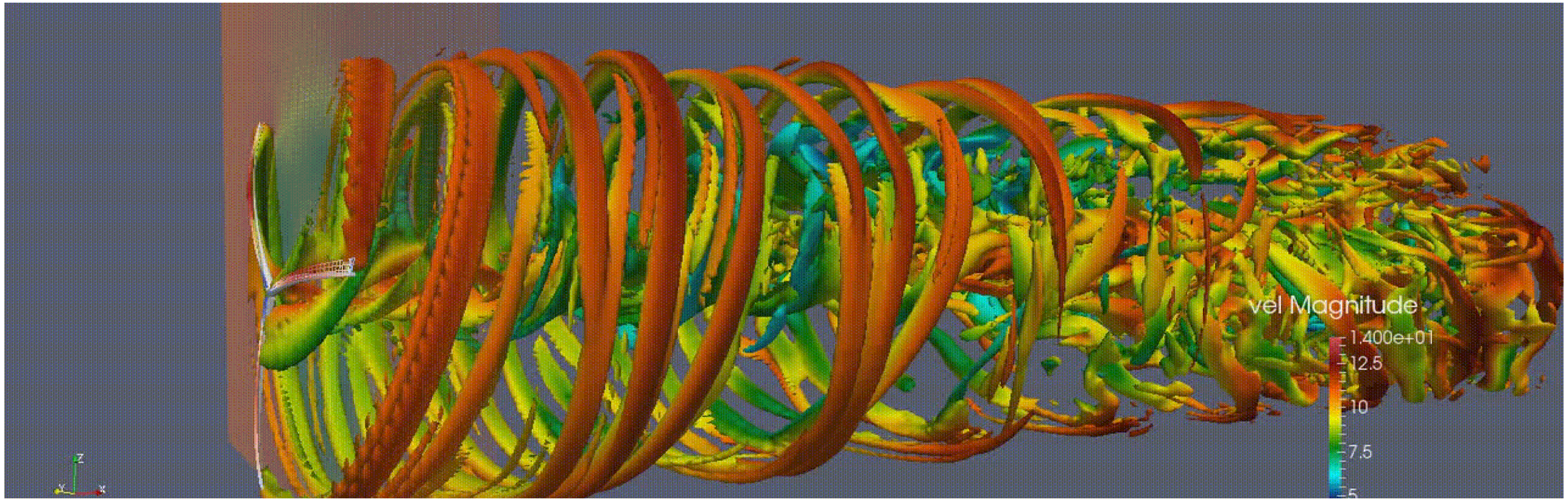
Gözcü and Bredmose (2022)
COREWIND D1.4

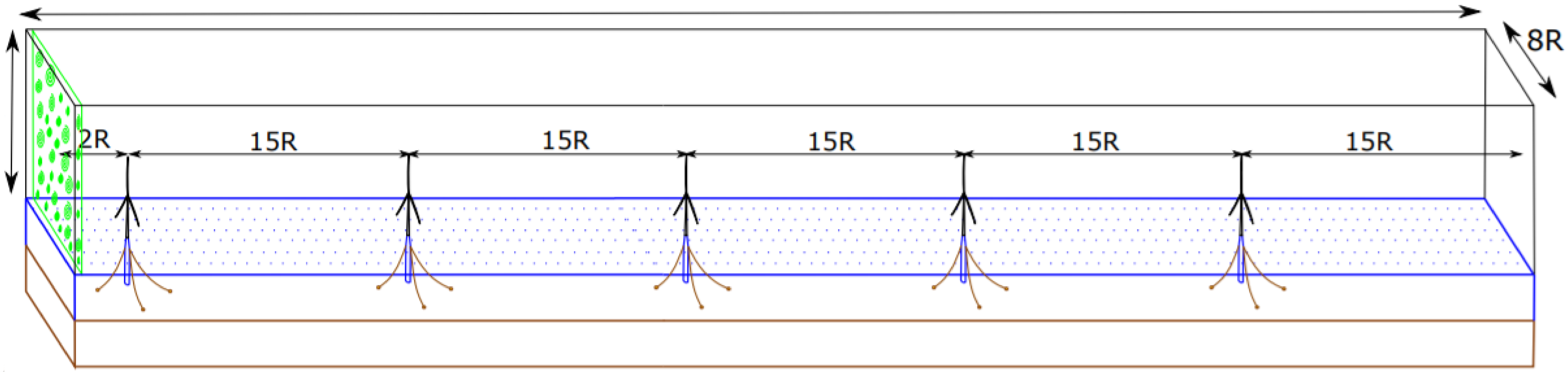
2: Shared mooring – time domain load analysis DLC6.1



- Storm wave case with idled turbines
- Cumulative surge for down-wave turbine
- Second-order wave force effects

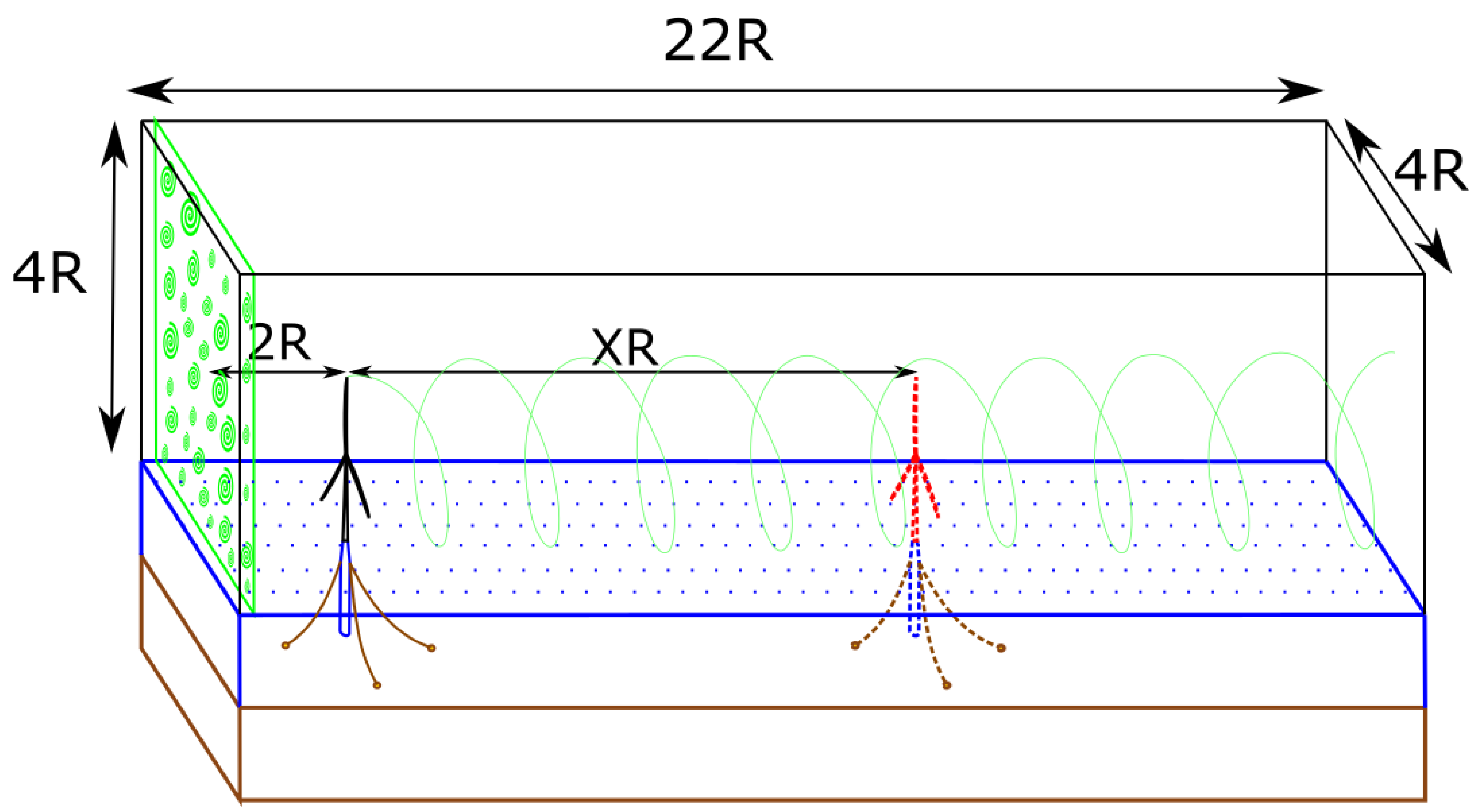
3: Wake recovery and response behind floating turbines

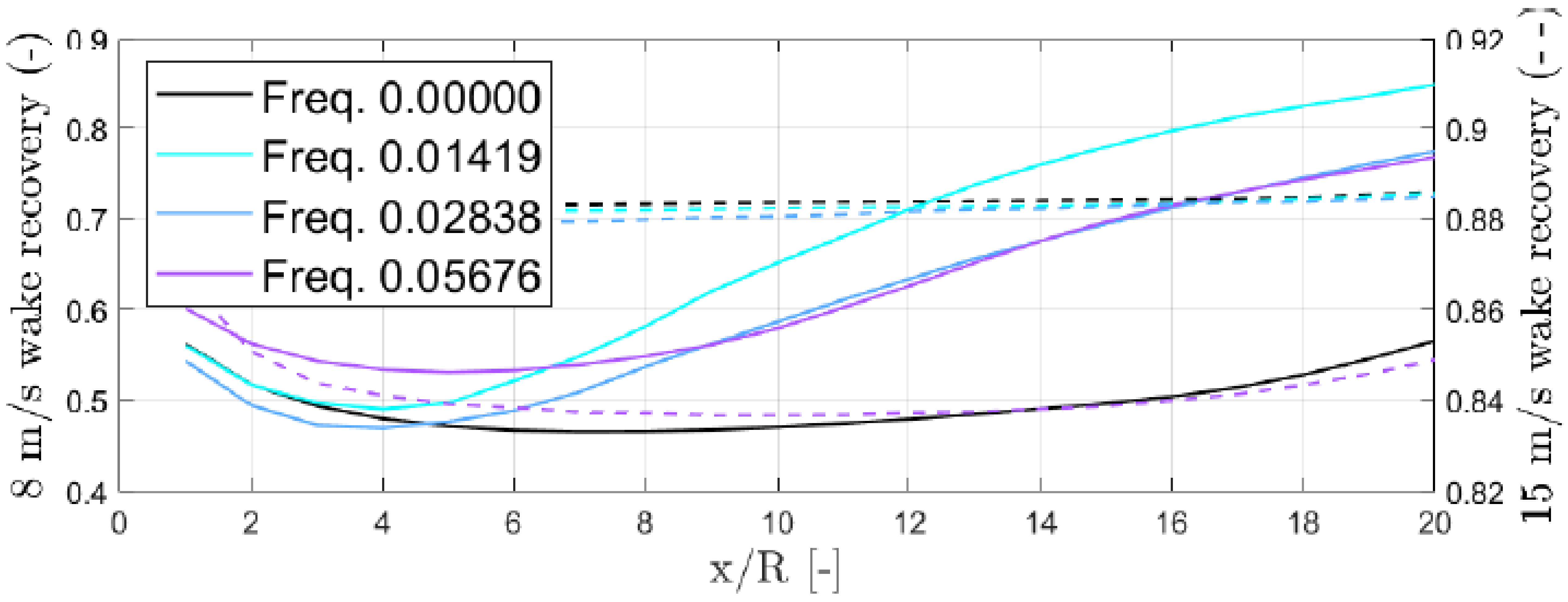




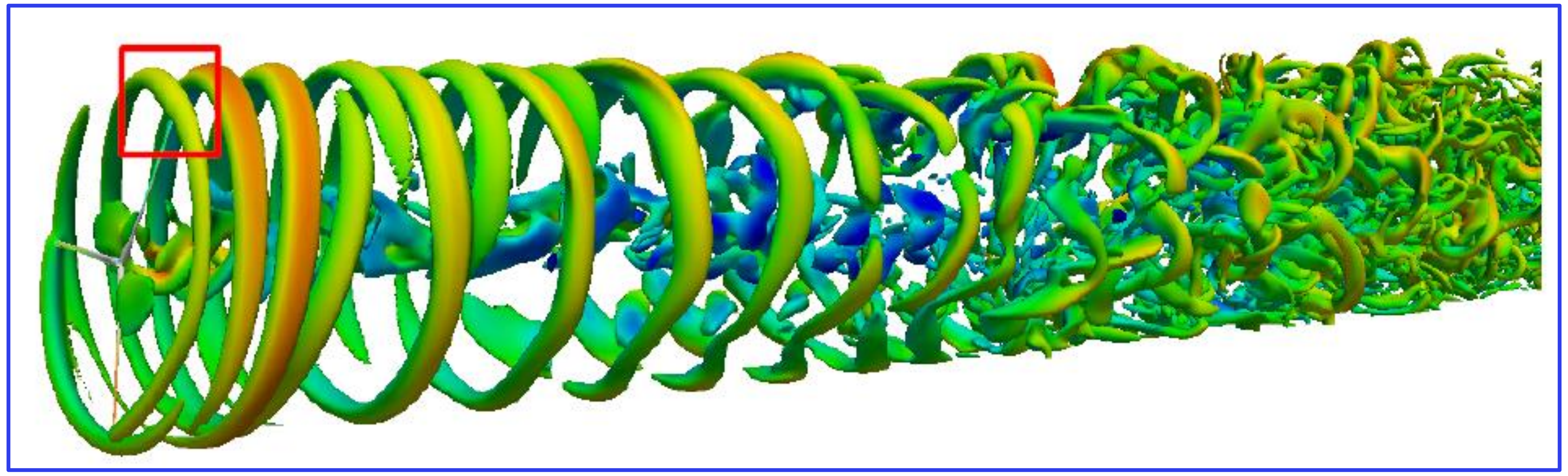
Ramos-García et al (2022a,b)

3: Wakes in floating wind farms: Parametric study



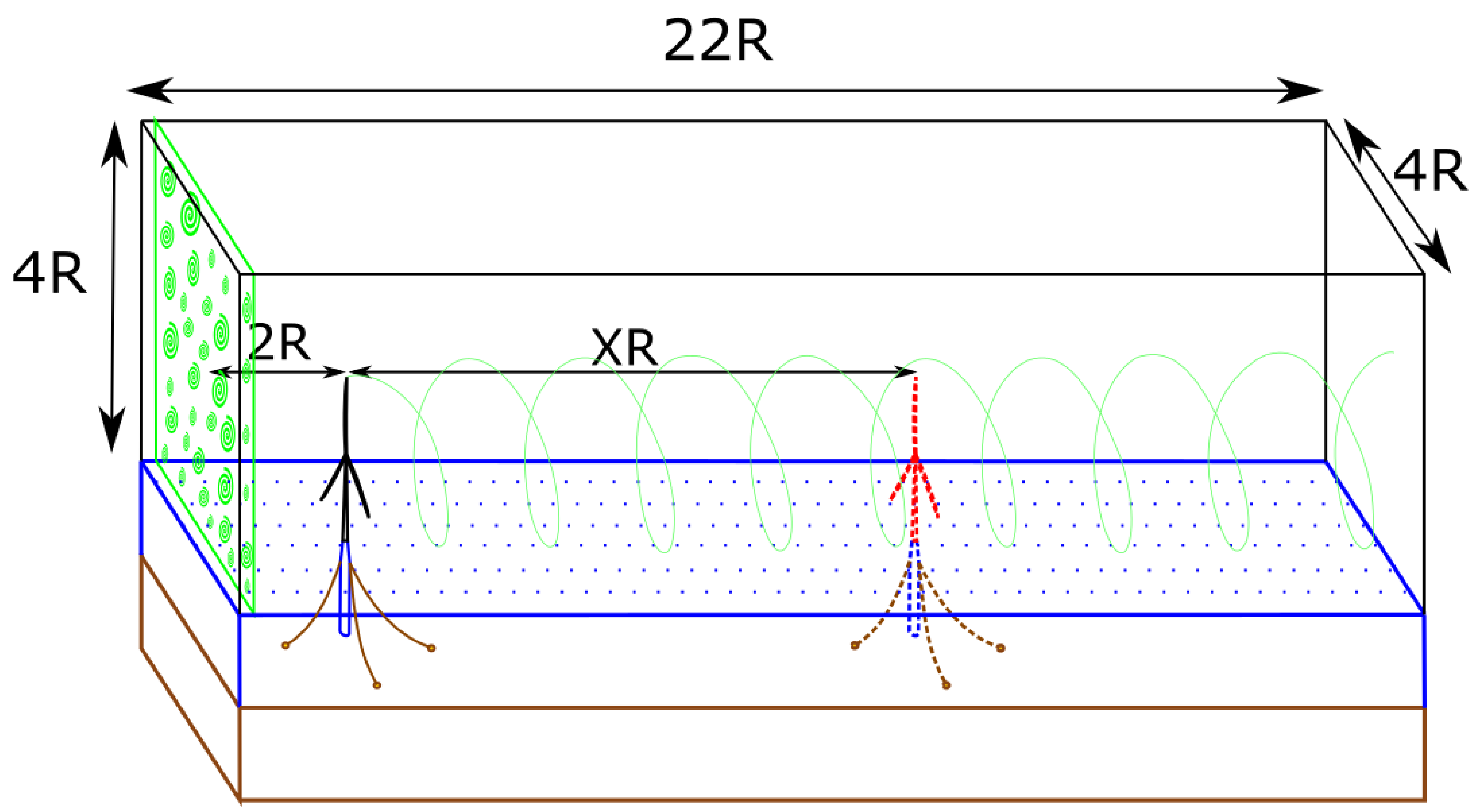


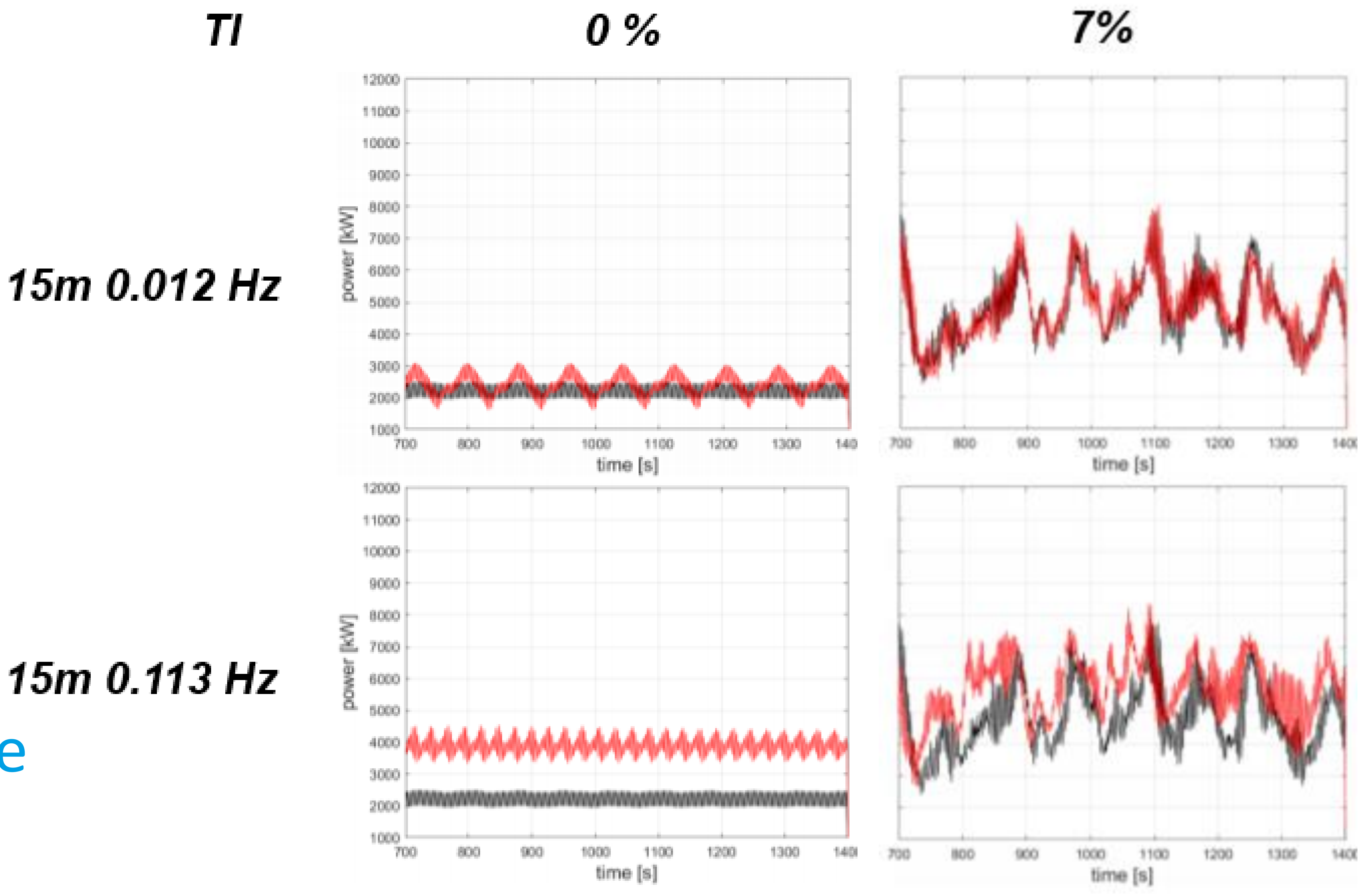
- Effect of floater tilt
- Harmonic pitch motion
- Vary frequency and amplitude
- Non-trivial function of frequency



Ramos-García et al (2022a,b)

3: Wakes in floating wind farms: Power production

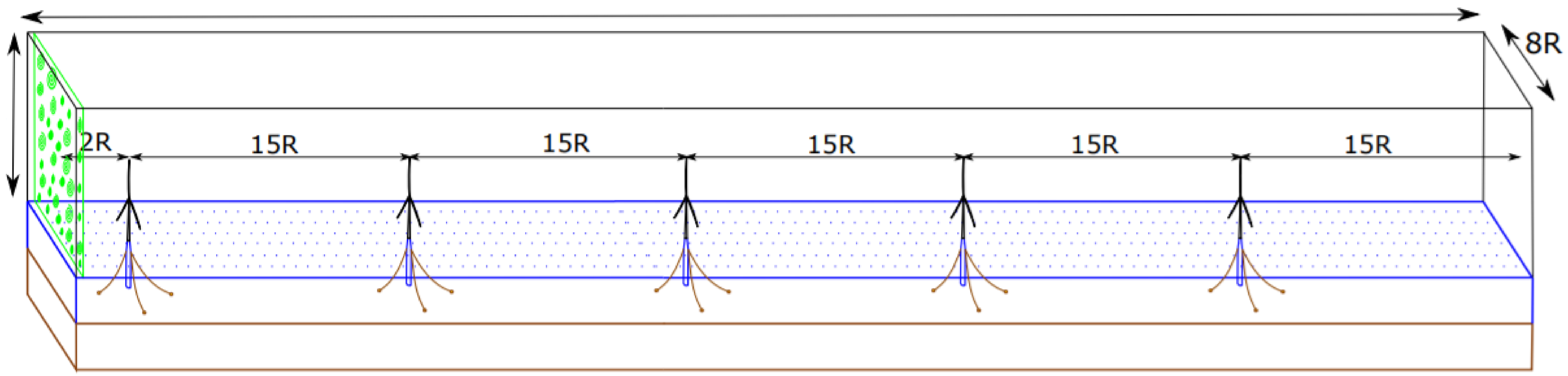




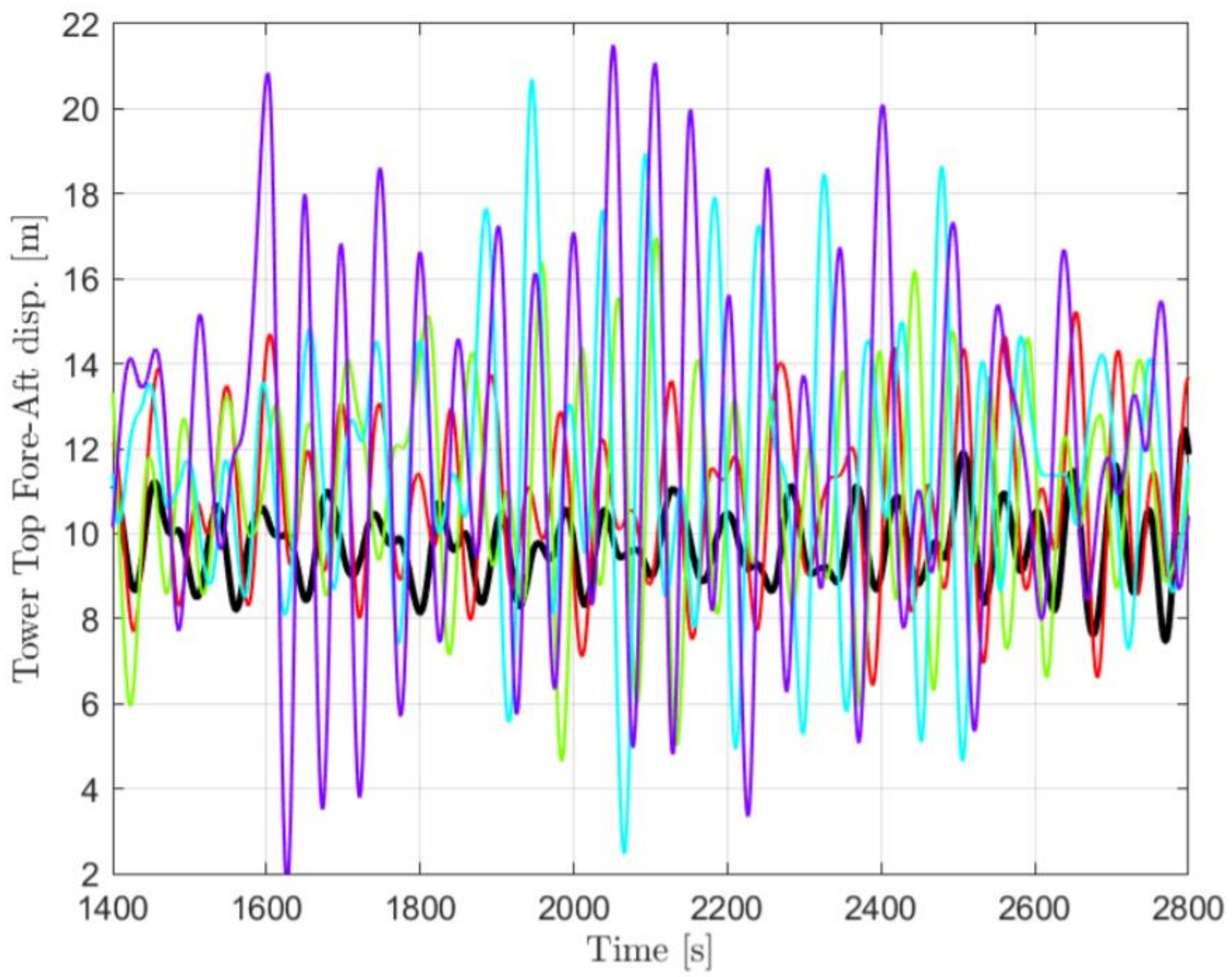
- Zero turbulence: Power of turbine 2 affected by motion of turbine 1
- Realistic turbulence: Effect seen at wave-range frequency

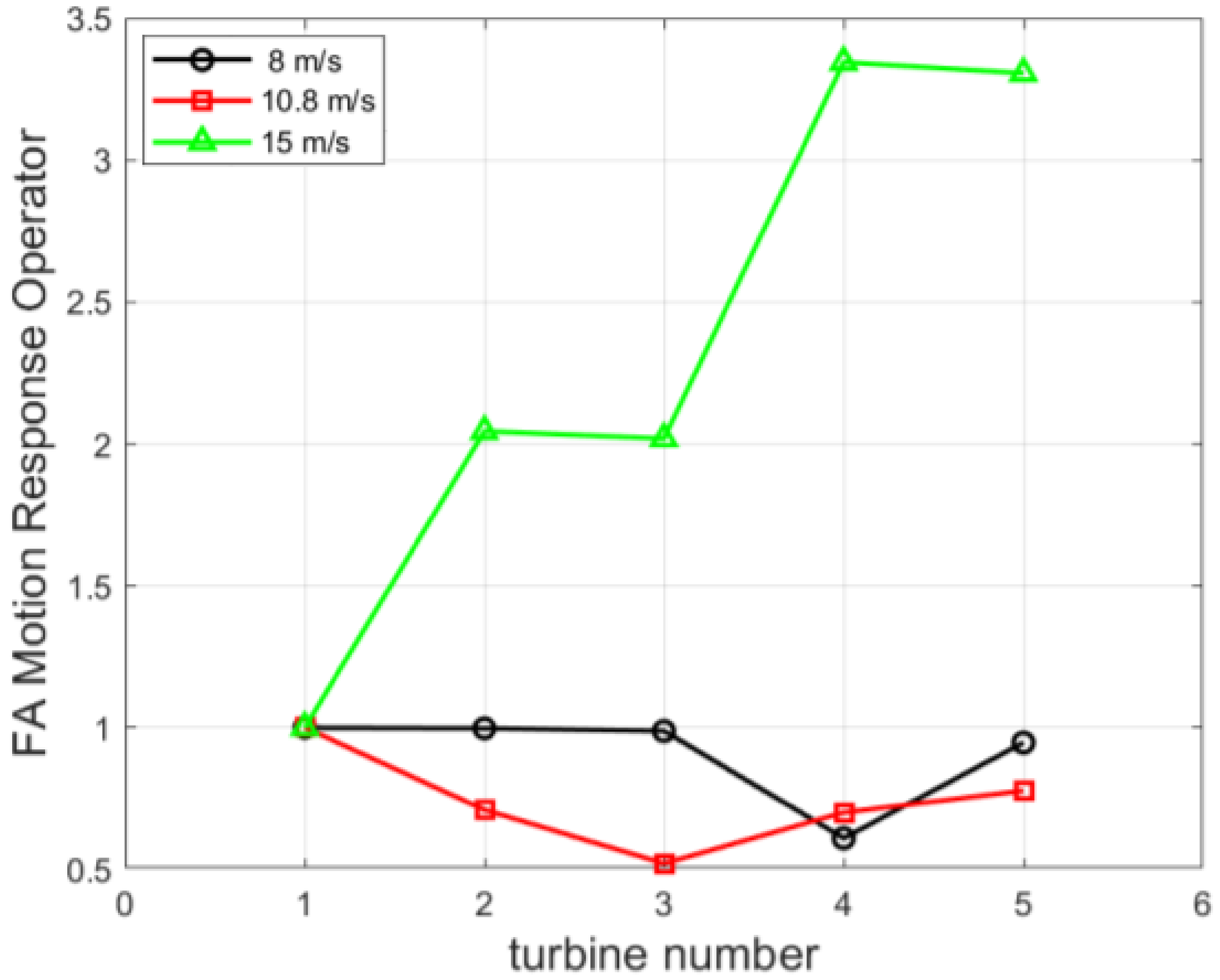
Ramos-García et al (2022a,b)

3: Wakes in floating wind farms: Wake-induced farm resonance



- 5 turbine farm
- 15 m/s



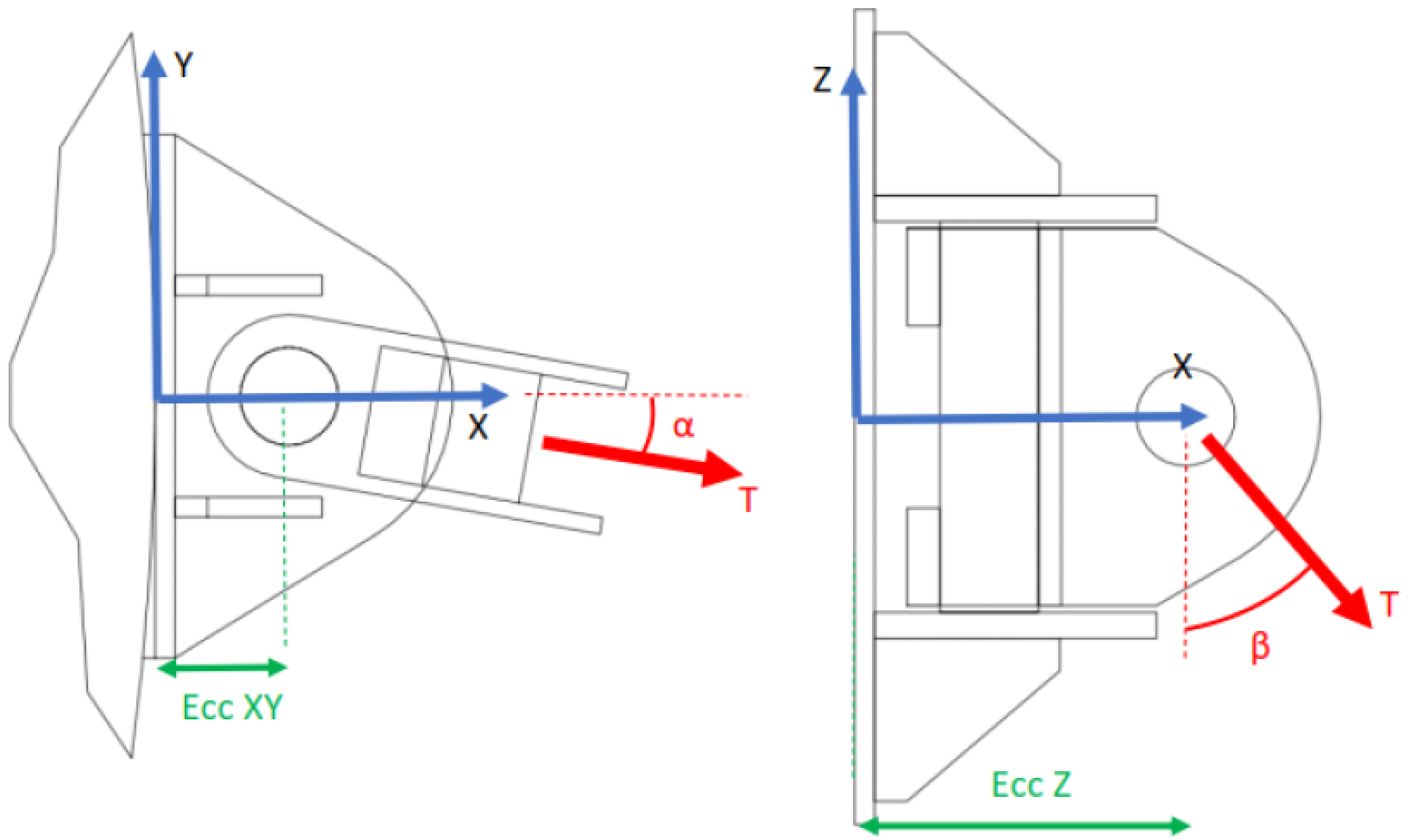


- Fore-aft resonance through wake

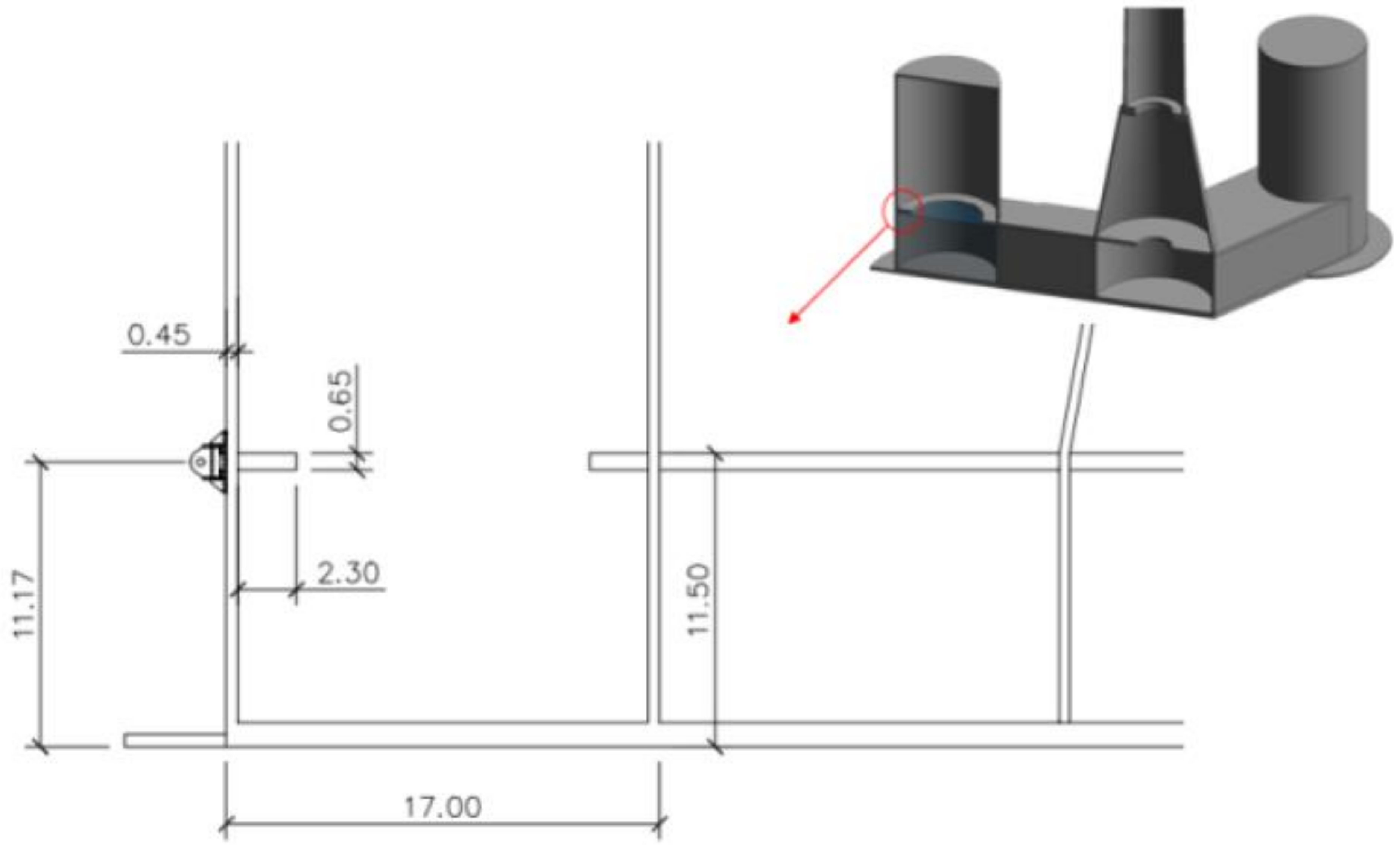
- Not at 8 m/s
- Hence control-related

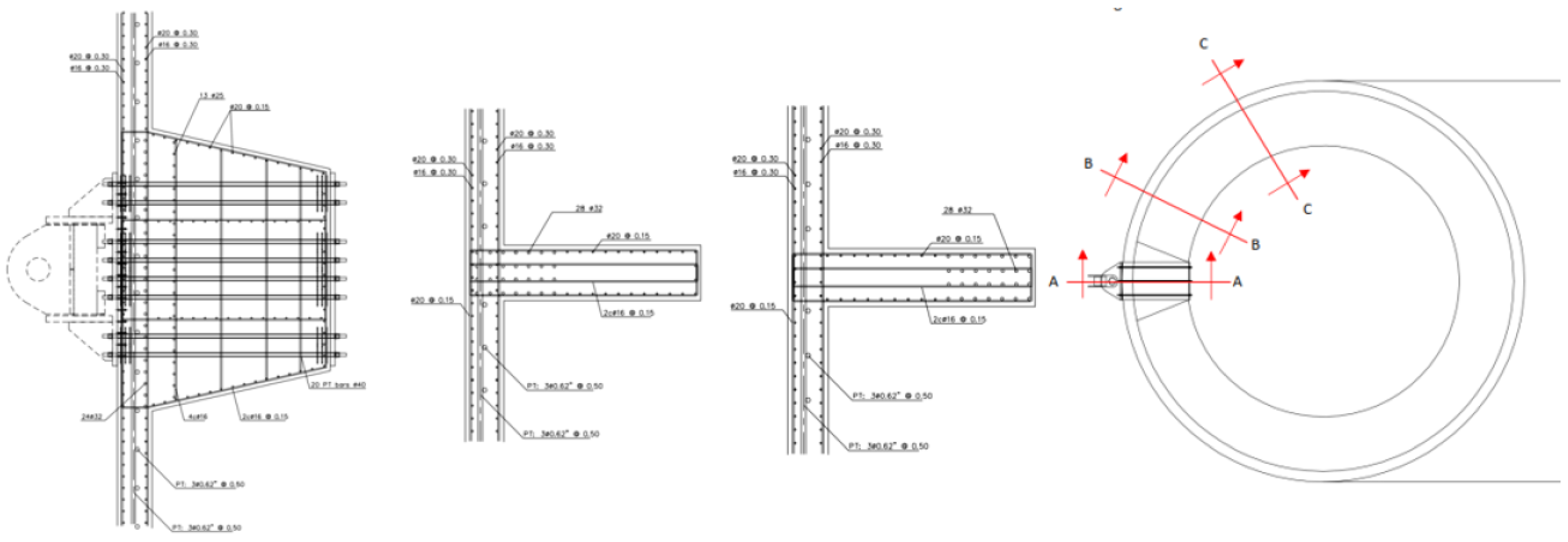
Ramos-García et al (2022a,b)

4: Structural floater design: ActiveFloat mooring connection



- Ring stiffener
- Two degrees of freedom
- Base plate and anchor bolts





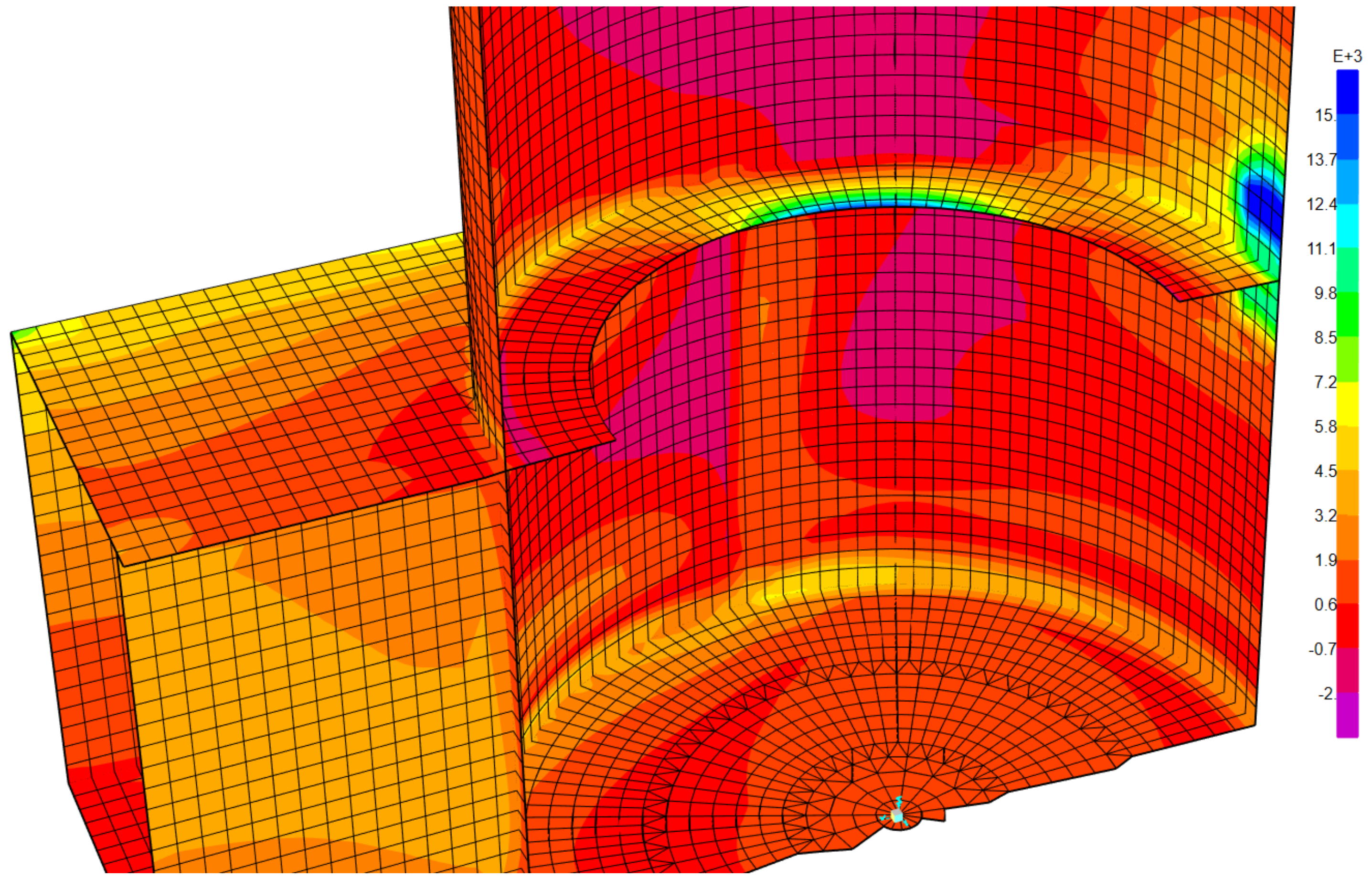
Section A-A

Section B-B

Section C-C

Plan view

4: Structural floater design: ActiveFloat mooring connection



cobra

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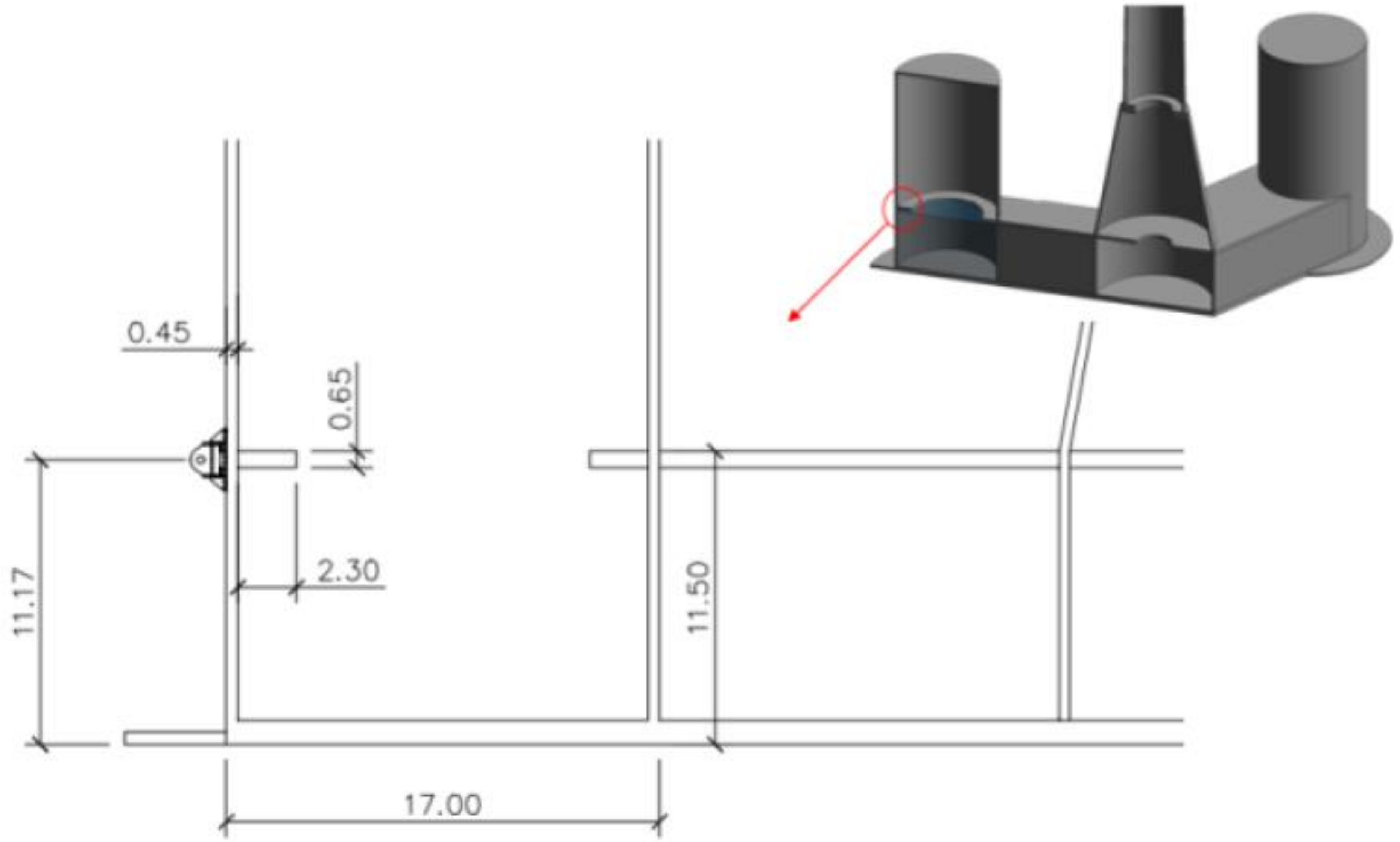
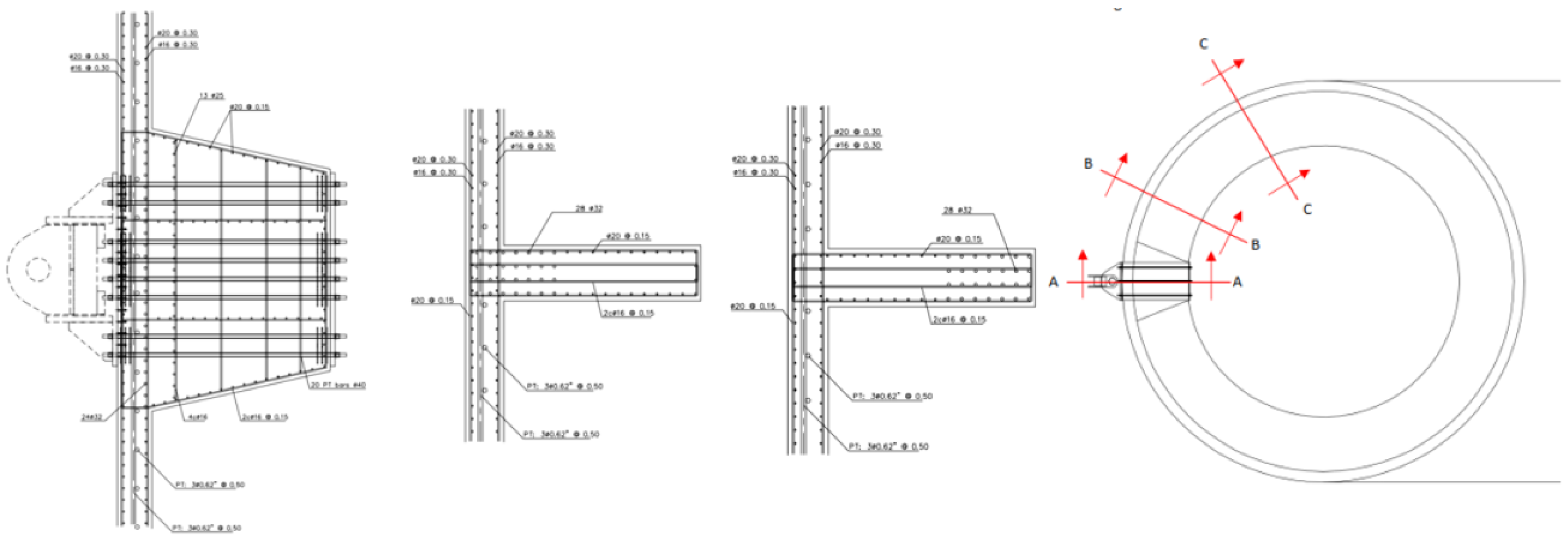


- Stress analysis
- Fatigue
- ULS



Section A-A Section B-B Section C-C Plan view

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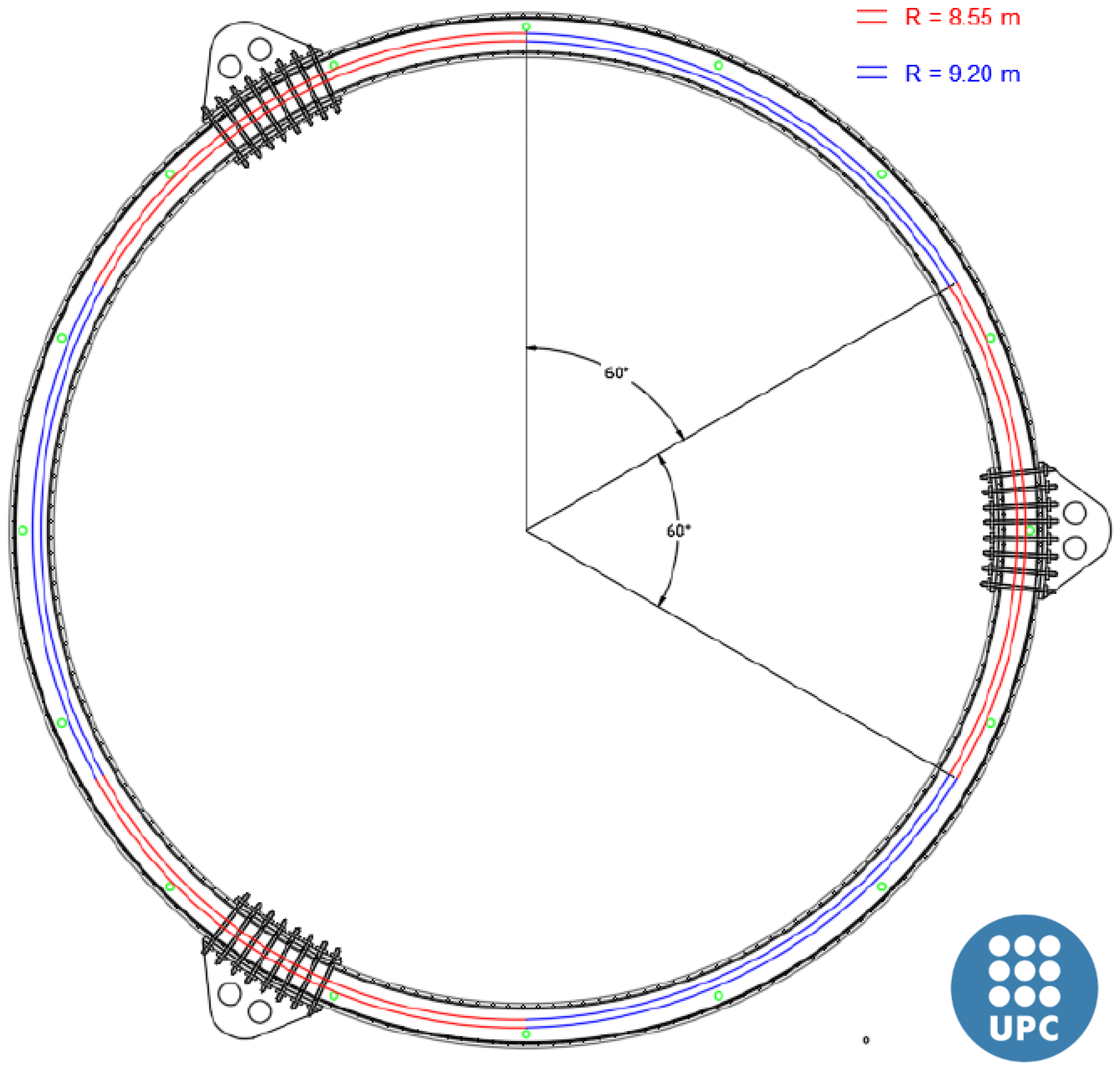
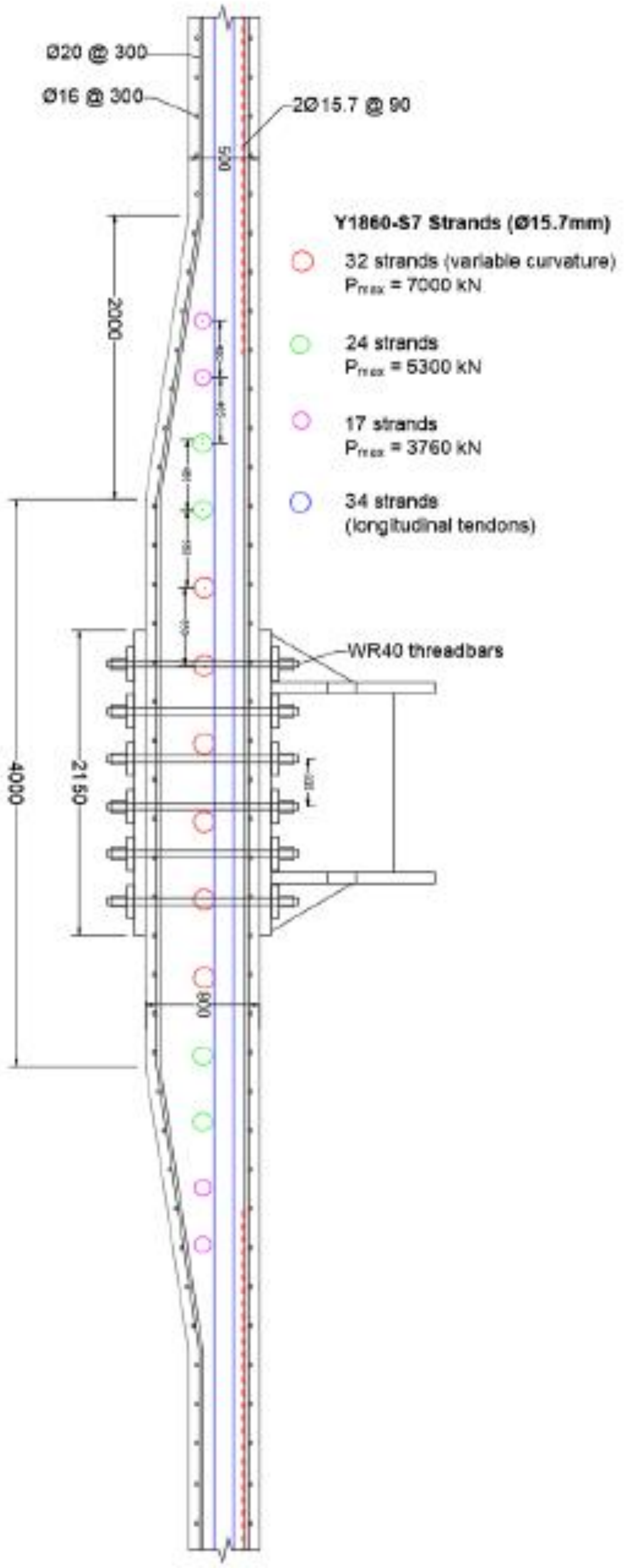
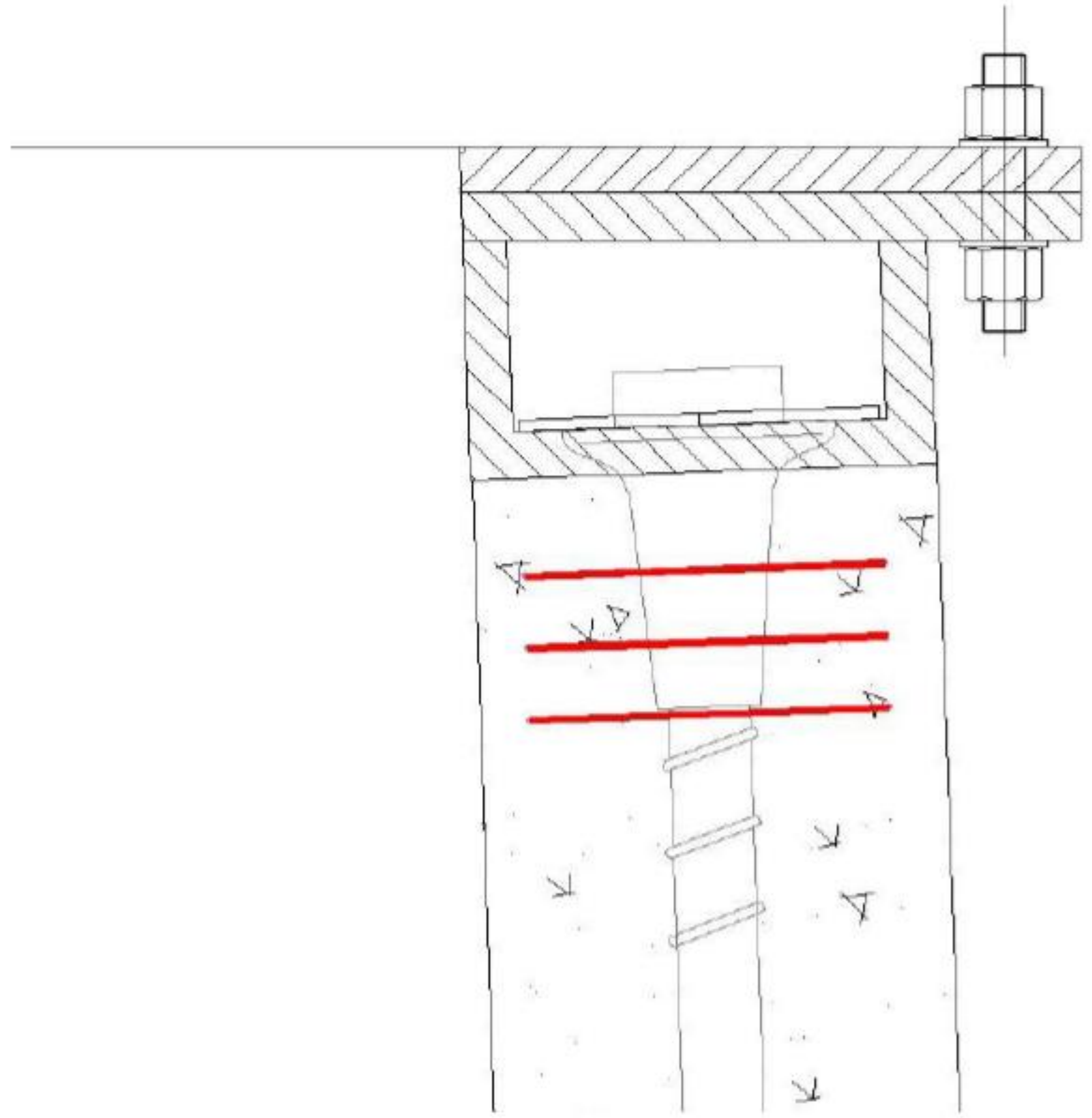
4: Structural floater design - WindCrete







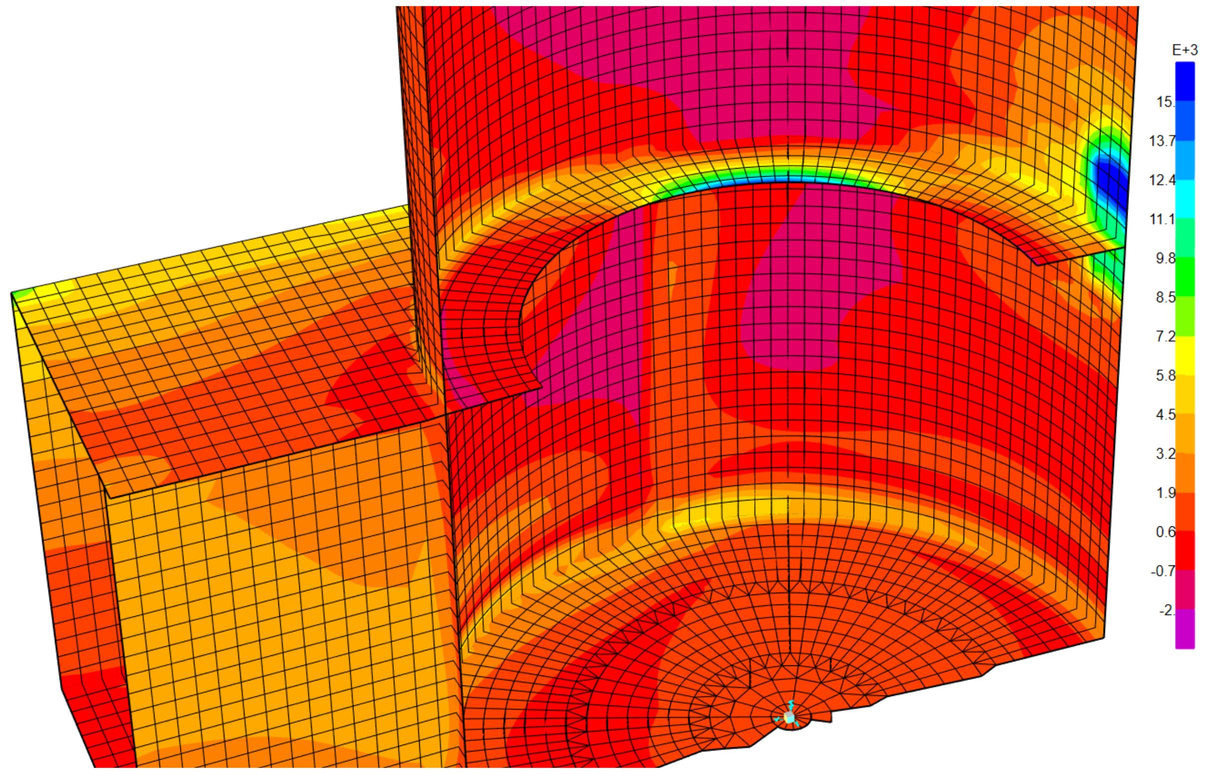
Fair lead connection

- Double fairleads
- Anchor plate
- Post tensioning bars

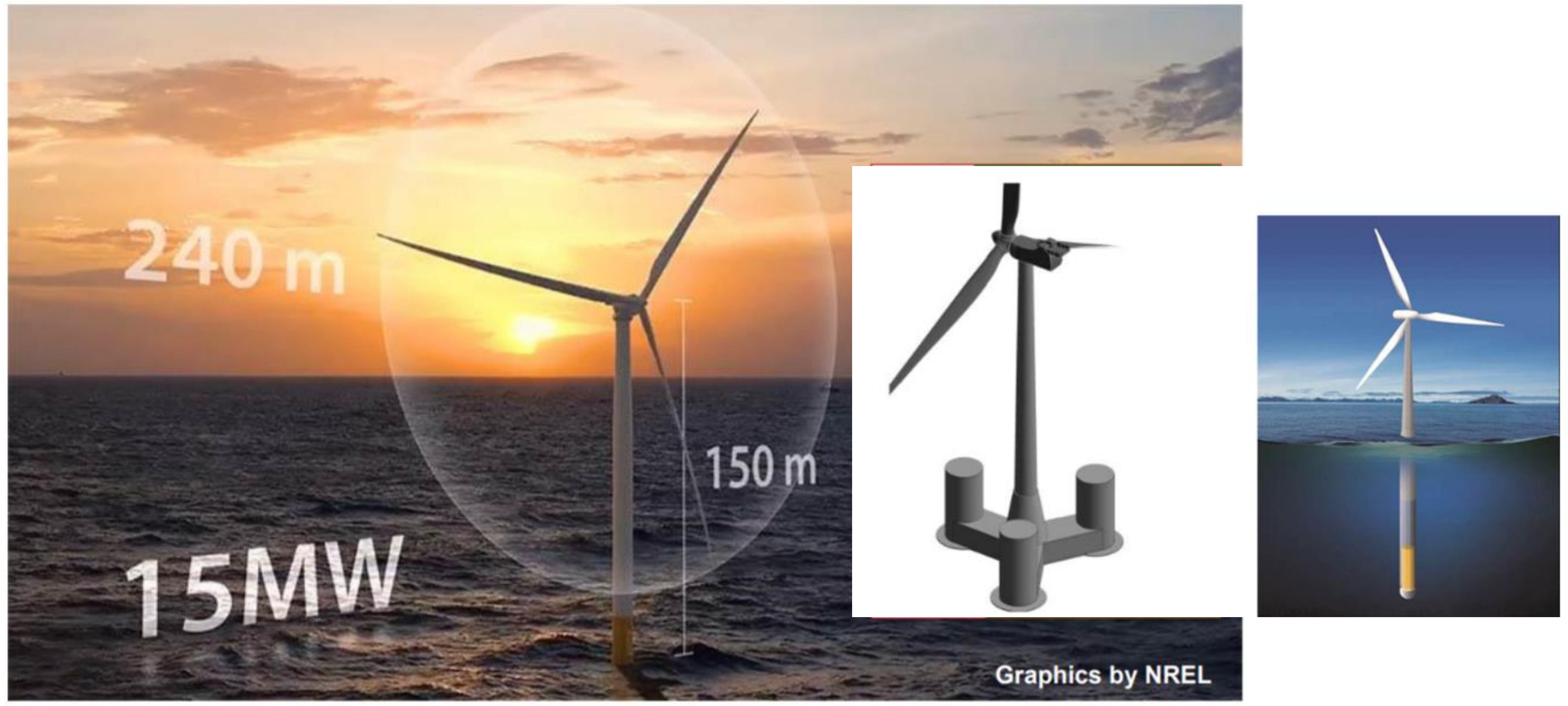
Yaw bearing at tower top

- Concrete tower
- Tendons for compression
- U-shaped steel ring
- Flat plate on top
- Bolted connection

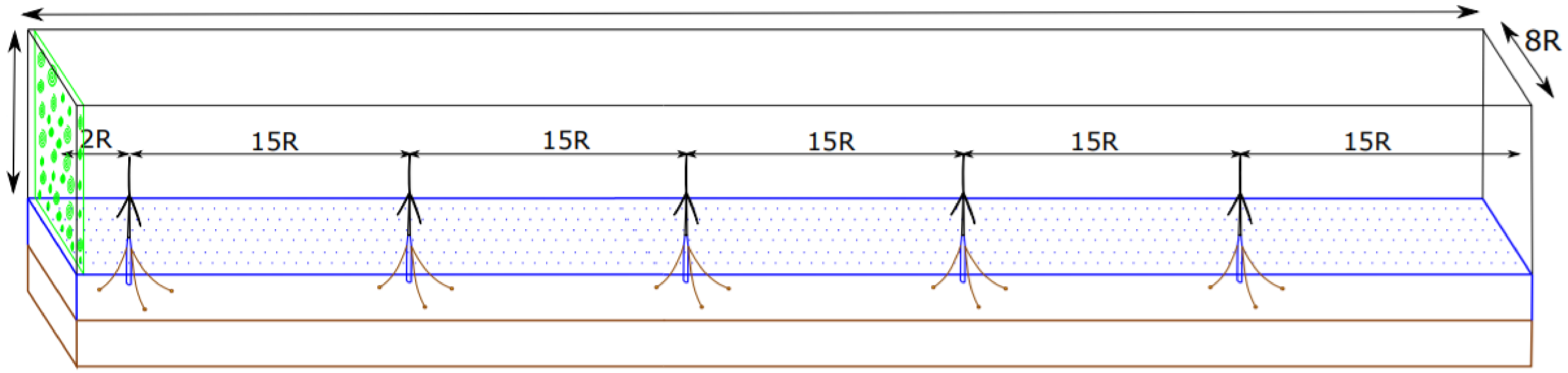
15 MW turbines in farms – Reference material



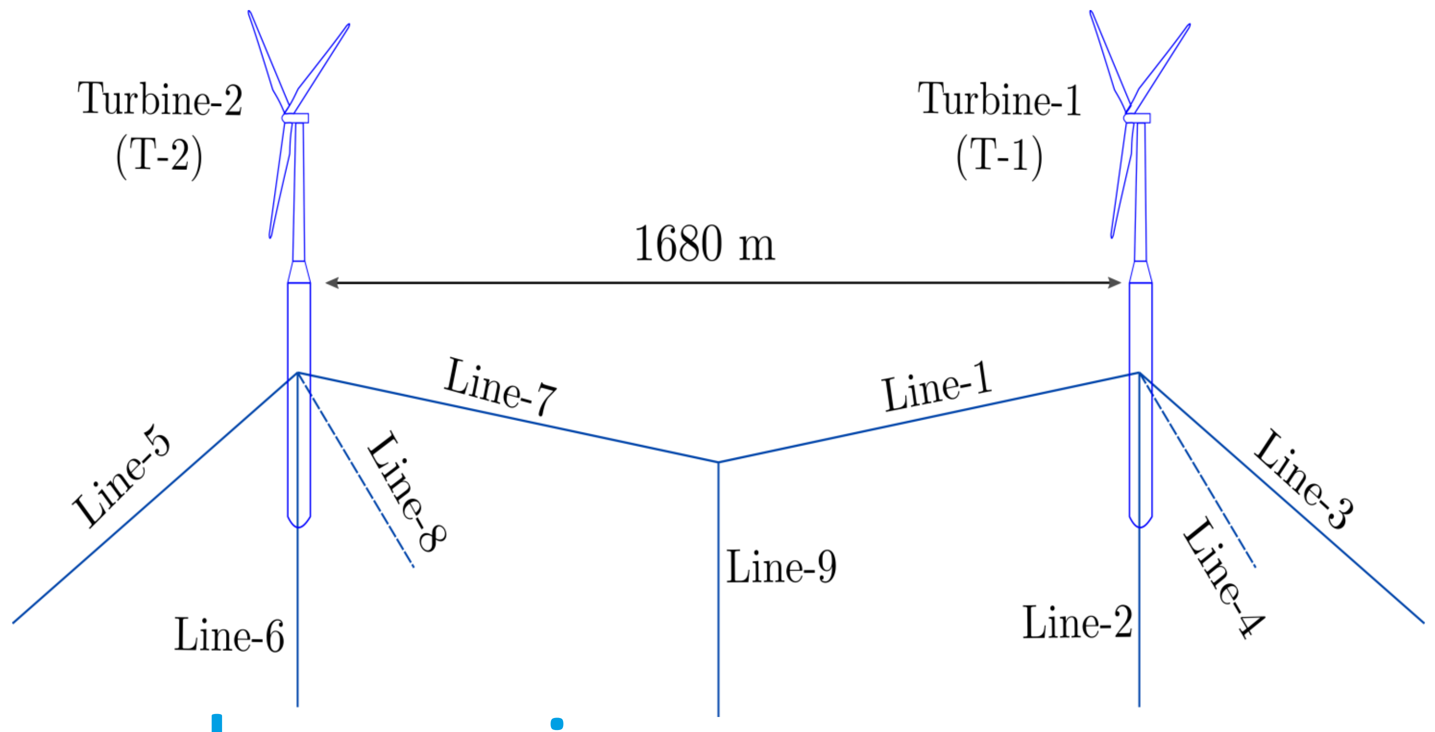
4 Structural floater design



1 Reference floaters 15 MW



3 Wakes in floating wind farms



2 Shared mooring

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Publications – Deliverables and models

- D1.1 ‘Definition of the 15 MW Reference Wind Turbine’ Henrik Bredmose (ed), Jennifer Rinker, Witold Skrzypinski, Frederik Zahle, Fangzhong Meng, Katherine Dykes (DTU), Evan Gaertner, Garrett Barter, Pietro Bertolotti, Latha Sethuraman and Matt Shields (NREL).

- D1.2 ‘Design Basis’ Fernando Vigara, Lara Cerdán, Rubén Durán, Sara Muñoz, Mattias Lynch, Siobhan Doole, Climent Molins, Pau Trubat, Raúl Guanche.

- D1.3 ‘Public design and FAST models of the two 15MW floater-turbine concepts’ Mohammad Youssef Mahfouz, Mohammad Salari, Sergio Hernández, Fernando Vigara, Climent Molins, Pau Trubat, Henrik Bredmose, Antonio Pegalajar-Jurado.

- D1.4 ‘Methods for multiple floaters and dynamic cables at farm level” Ozan Gözcü, Stavros Kontos, Henrik Bredmose, Tom Bailey and Friedemann Borisade. Delivered April 2020.

- D1.5 “Methods for nonlinear wave forcing and wakes” Néstor Ramos-García, Sergio González-Horcas, Antonio Pegalajar-Jurado, Stavros Kontos, Ozan Gözcü, Henrik Bredmose, Umut Özinan, Mohammad Youssef Mahfouz, Alessandro Fontanella, Alan Facchinetti and Marco Belloli. Delivered March 2022.

- D1.6 “Design Recommendations and Impact of Mooring and Dynamic Cables Into Integrated Modelling and Structural Design”, Pau Trubat, Climent Molins, Daniel Alarcon, Friedemann Borisade, Ozan Gözcü , Henrik Bredmose, Ignacio Romero, Diego Sisí, Raúl Guanche, Miguel Somoano, Maxime Chemineau, Siobhan Doole. Delivered March 2023.

- HAWC2 model of 15 MW RWT on Github

- FAST models of site B floater-turbine configurations on Zenodo

Publications – Papers and public reports

Rinker, J., Gaertner, E., Zahle, F., Skrzypiński, W., Abbas, N., **Bredmose, H.**, Barter, G., & Dykes, K. (2020). Comparison of loads from HAWC2 and OpenFAST for the IEA Wind 15 MW Reference Wind Turbine. Journal of Physics: Conference Series, 1618(5)

Gaertner, Evan, Jennifer Rinker, Latha Sethuraman, Frederik Zahle, Benjamin Anderson, Garrett Barter, Nikhar Abbas, Fanzhong Meng, Pietro Bortolotti, Witold Skrzypinski, George Scott, Roland Feil, Henrik Bredmose, Katherine Dykes, Matt Shields, Christopher Allen, and Anthony Viselli. 2020. *Definition of the IEA 15-Megawatt Offshore Reference Wind*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-75698. https://www.nrel.gov/docs/fy20osti/75698.pdf

MY Mahfouz, C Molins, P Trubat, S Hernández, F Vigara, A Pegalajar-Jurado, H Bredmose and M Salari (2021) 'Response of the IEA Wind 15 MW – WindCrete and Activefloat floating wind turbines to wind and second-order waves' (2021) Wind Energy Science **6**(3) pp 867-883

M Y Mahfouz, T Roser, and P W Cheng, "Verification of SIMPACK-MoorDyn coupling using15 MW IEA-Wind reference models Activefloat and WindCrete" (2021) *J. Phys.: Conf. Ser.* **2018** 012024

Ramos-García, N., Kontos, S., Pegalajar-Jurado, A., González Horcas, S., & Bredmose, H. (2022). Investigation of the floating IEA Wind 15 MW RWT using vortex methods Part I: Flow regimes and wake recovery. Wind Energy, 25(3), 468-504. https://doi.org/10.1002/we.2682

Ramos-García, N., González Horcas, S., Pegalajar-Jurado, A., Kontos, S., & Bredmose, H. (2022). Investigation of the floating IEA wind 15-MW RWT using vortex methods Part II: Wake impact on downstream turbines under turbulent inflow. Wind Energy, 25(8), 1434-1463. https://doi.org/10.1002/we.2738

Gözcü, O., Kontos, & Bredmose, H. "Dynamics of two floating wind turbines with shared anchor and mooring lines". Paper for Torque 2022 conference. IOP Journal of Physics: Conference Series Vol. 2265 No. 4 https://doi.org/10.1088/1742-6596/2265/4/042026

Thank you for your attention!

Contact: Henrik Bredmose, hbre@dtu.dk

COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Design and optimisation of station keeping systems

Valentin Arramounet

Technical lead Ocean Engineering team
INNOSEA

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

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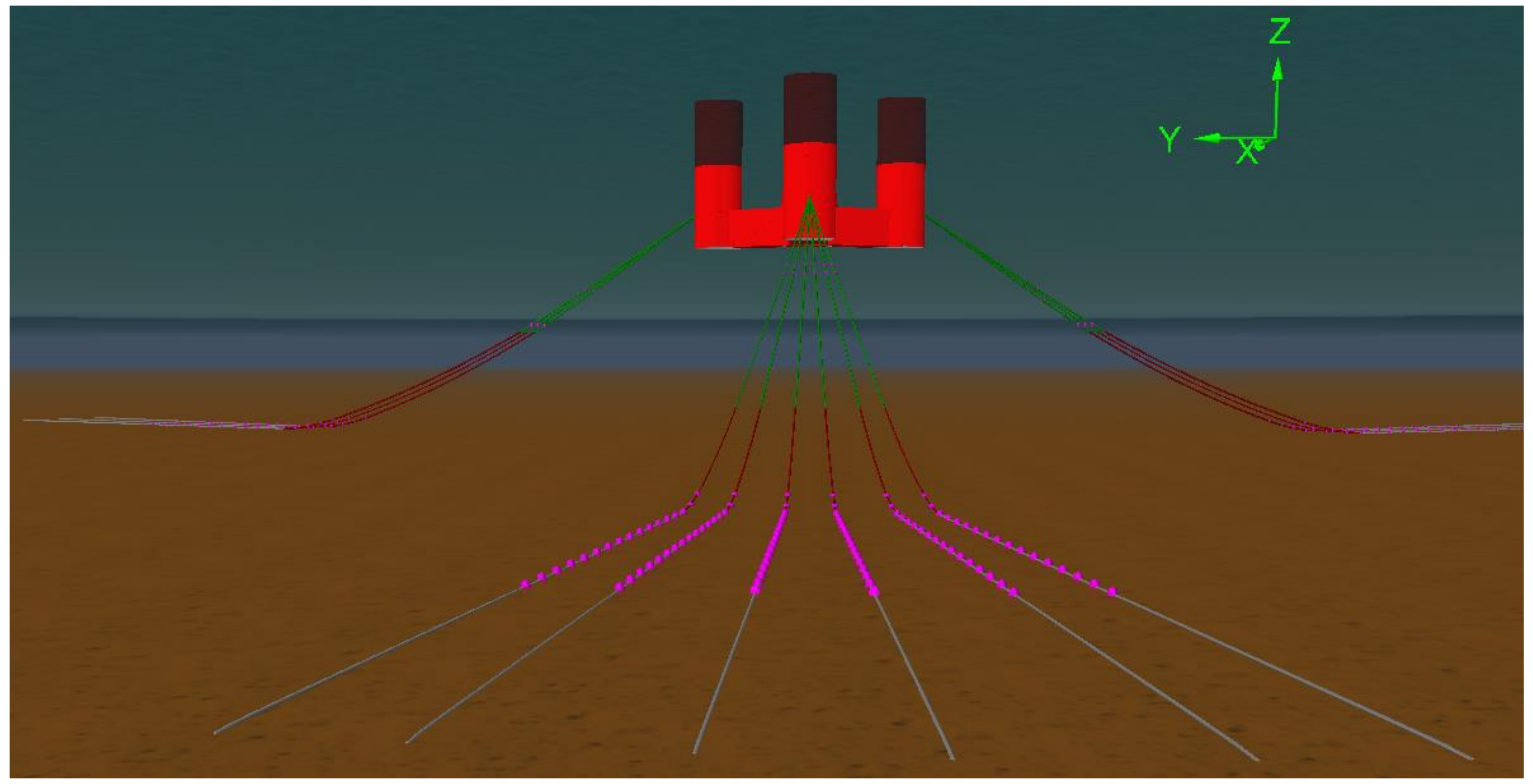
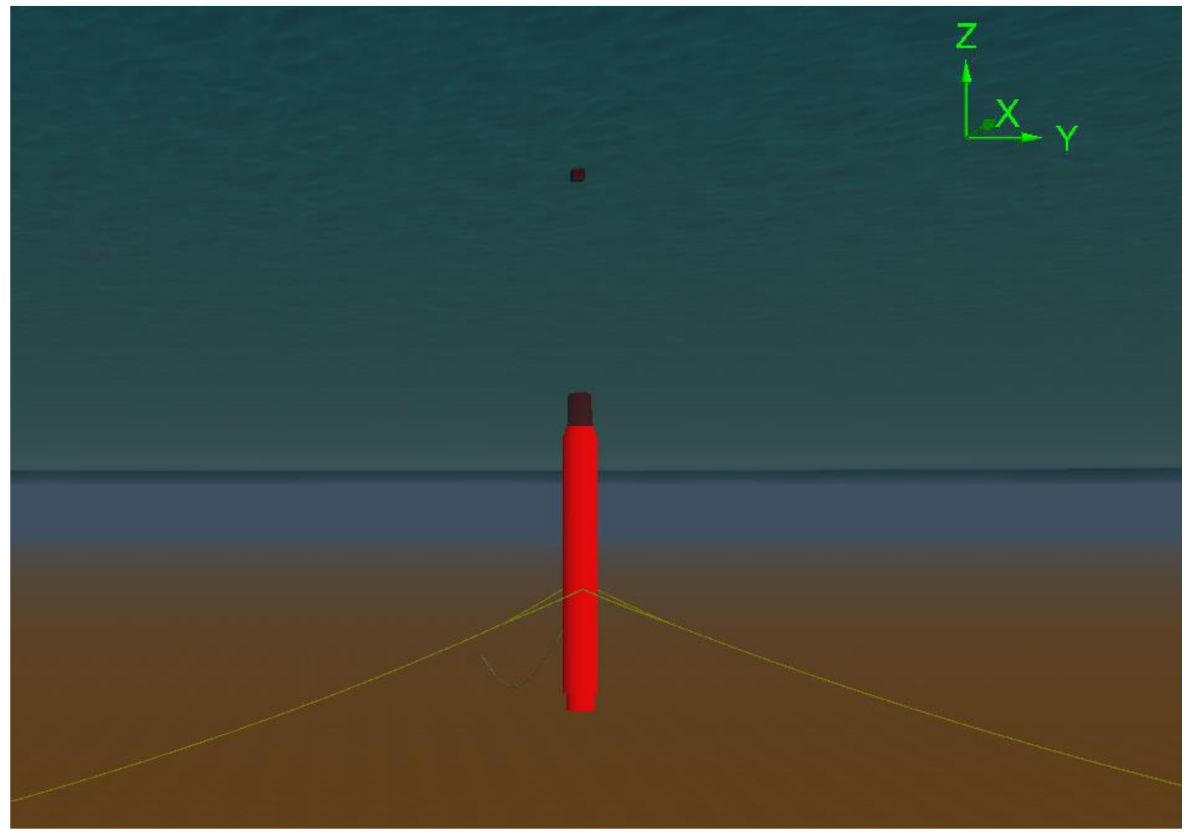
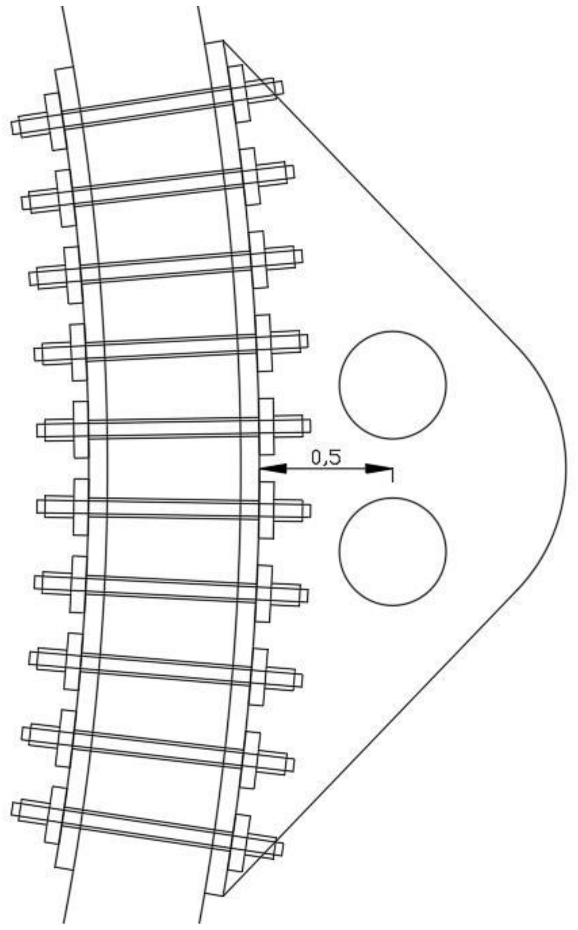
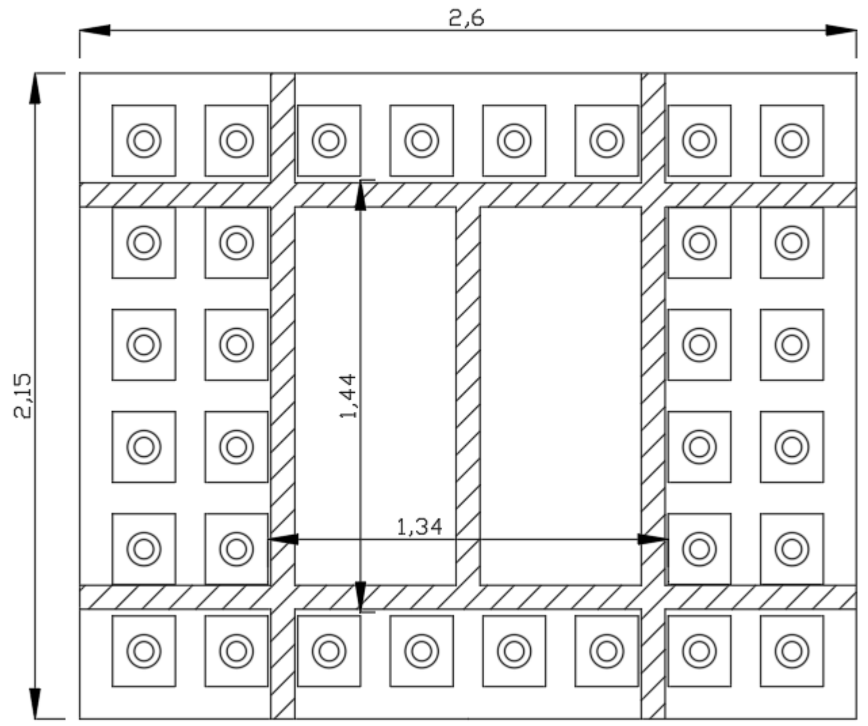
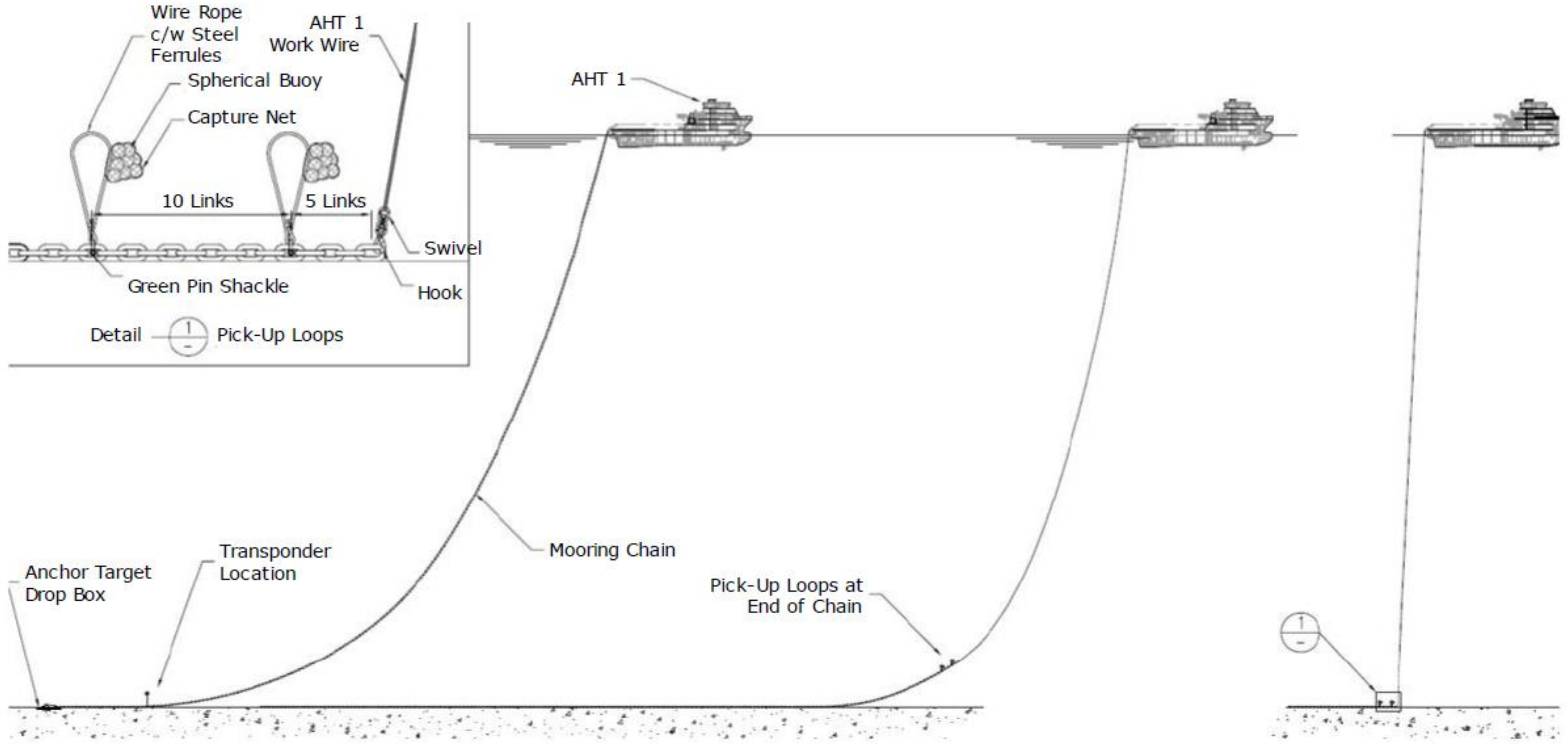
Studied aspects

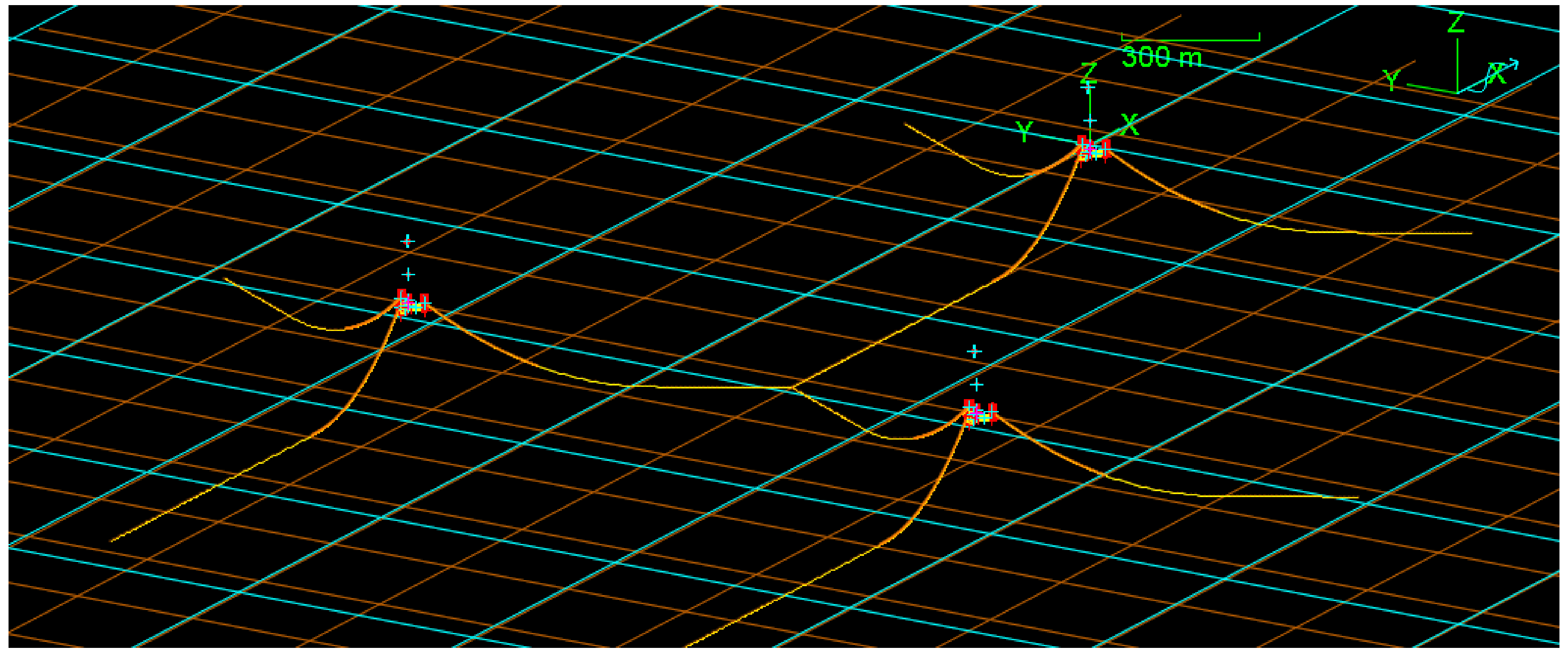


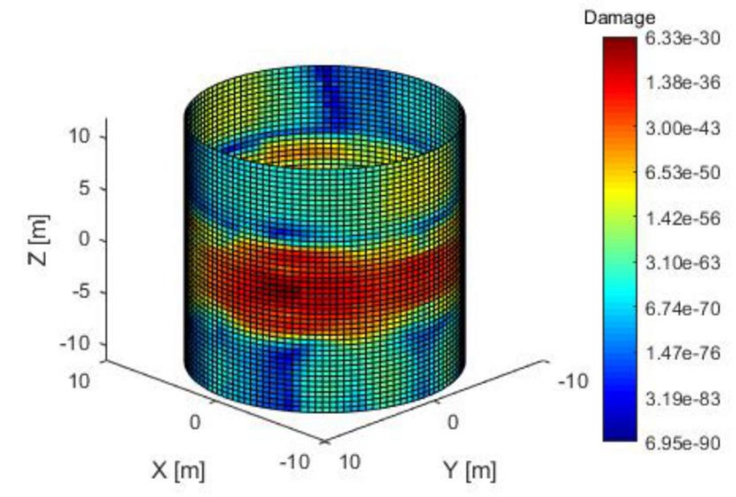












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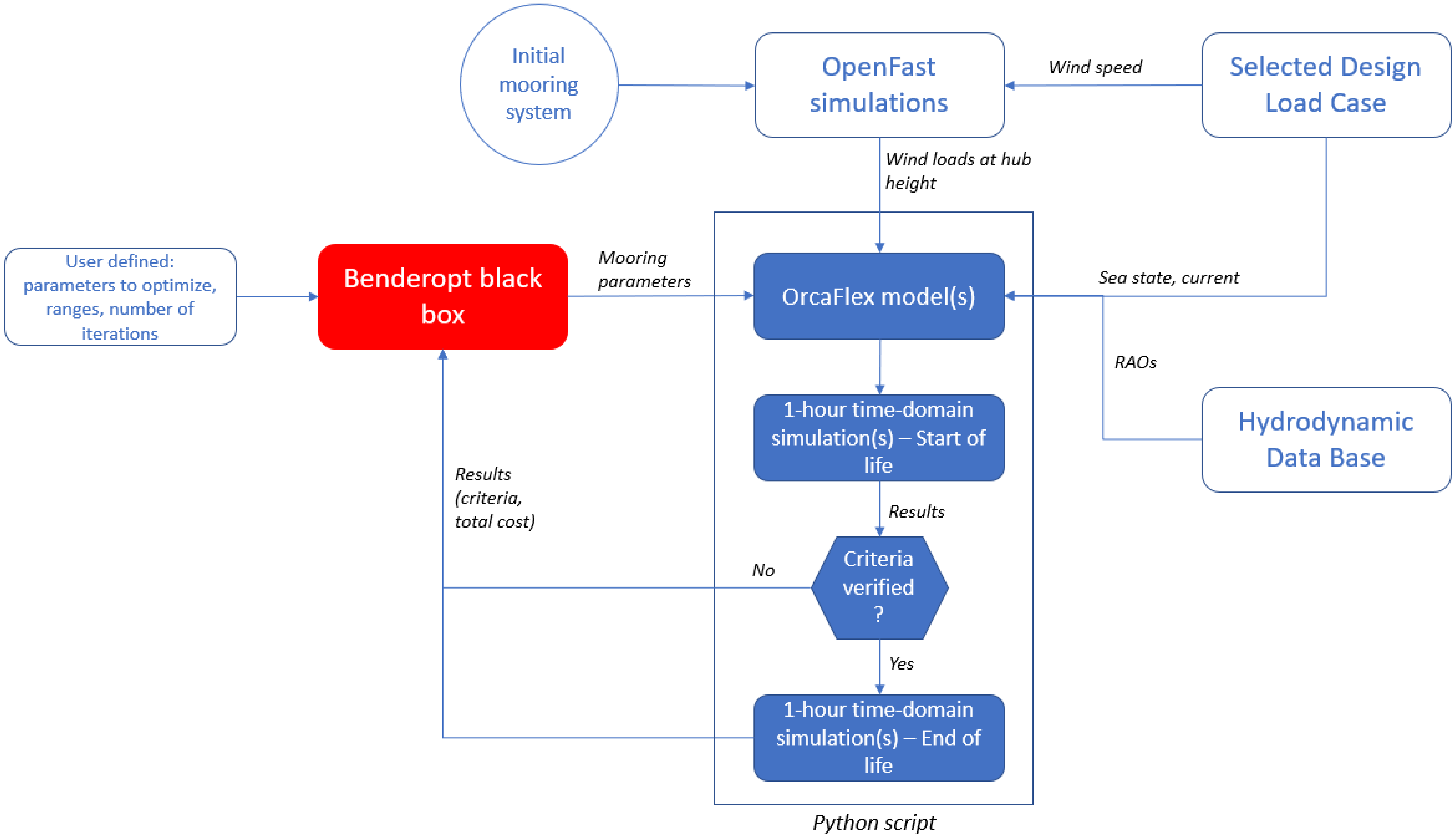
Topics

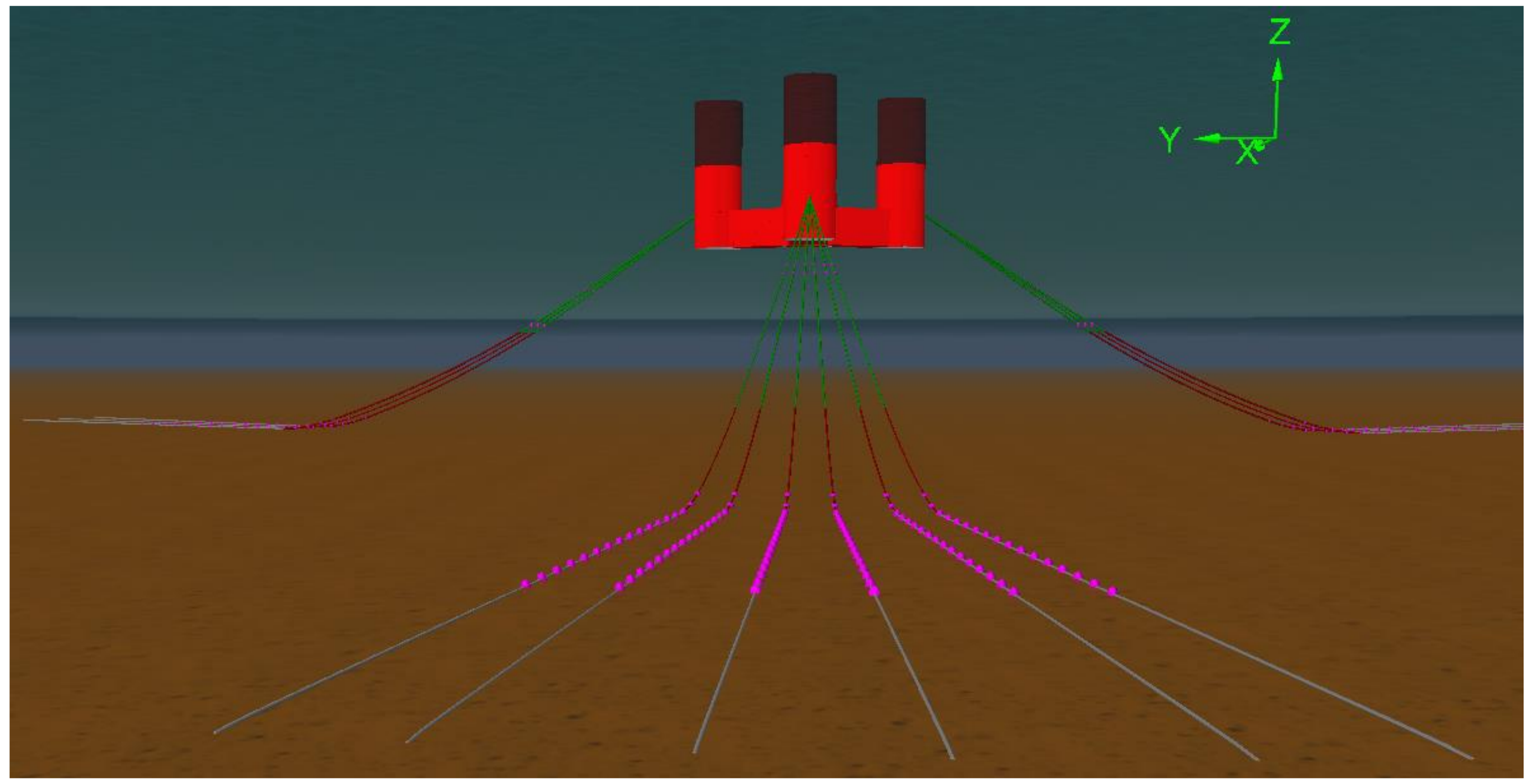
- Mooring design automatize optimization tool
- Mooring design and optimization
- Technological benefits regarding peak loads reduction
- Design at farm level: use of shared anchors, shared mooring lines
- General conclusions

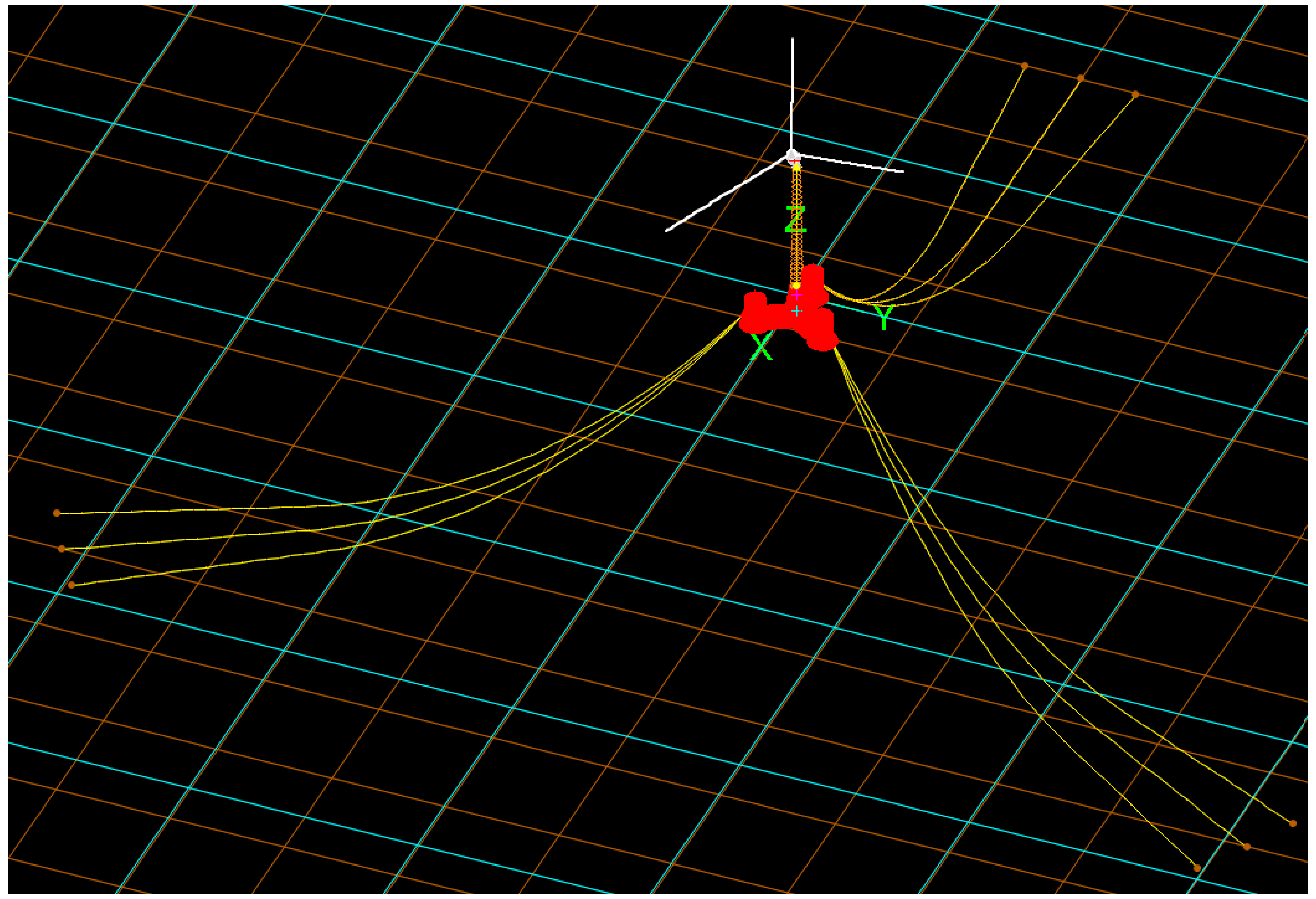
Mooring design automatize optimization tool

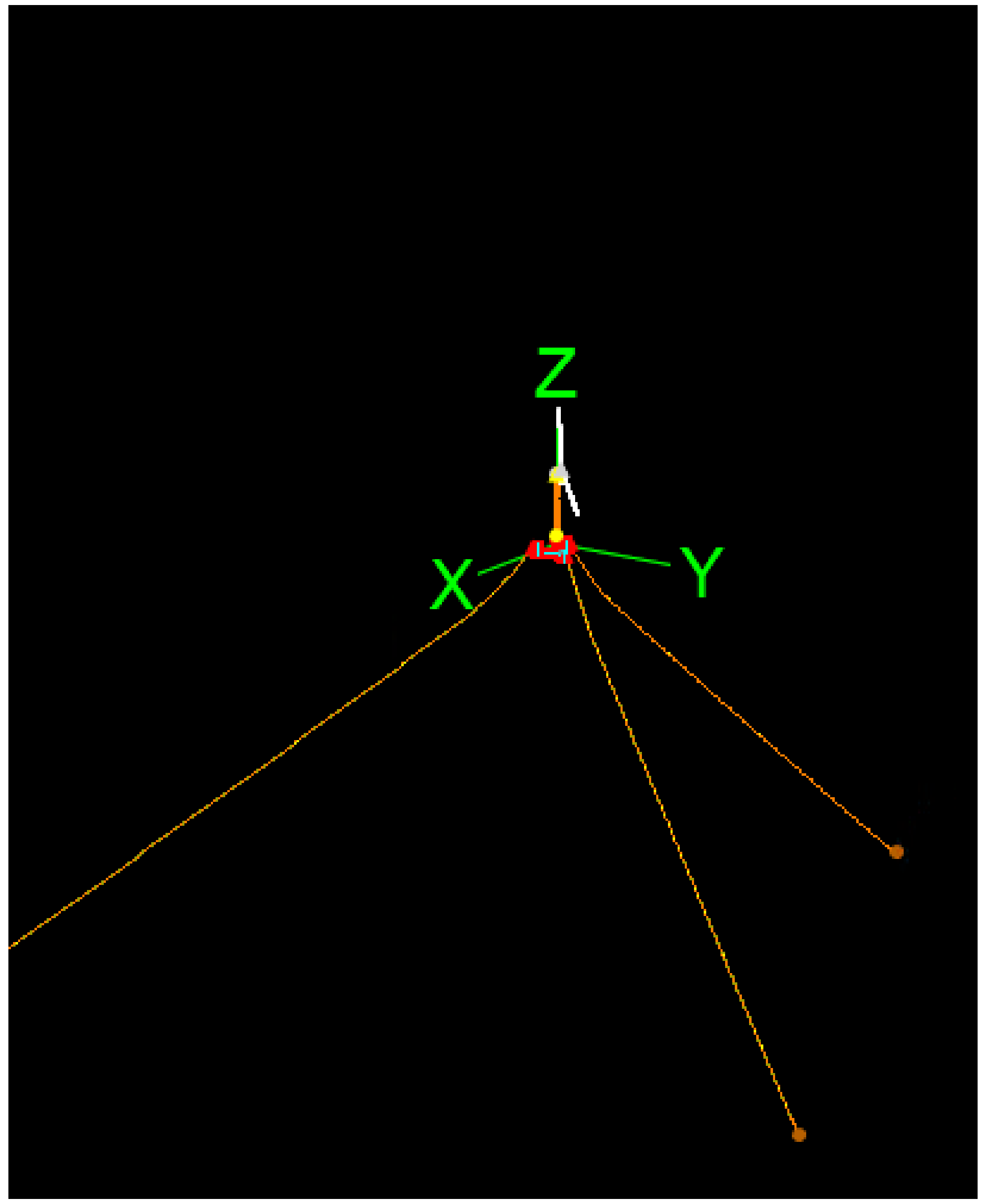
- Automatize mooring design and optimize procurement cost



Mooring design and optimization







- Site A: West of Barra
- Procurement cost 5600 k€

- Site B: Gran Canaria
- Procurement cost 3800 k€

- Site C: Morro Bay
- Procurement cost 1400 k€

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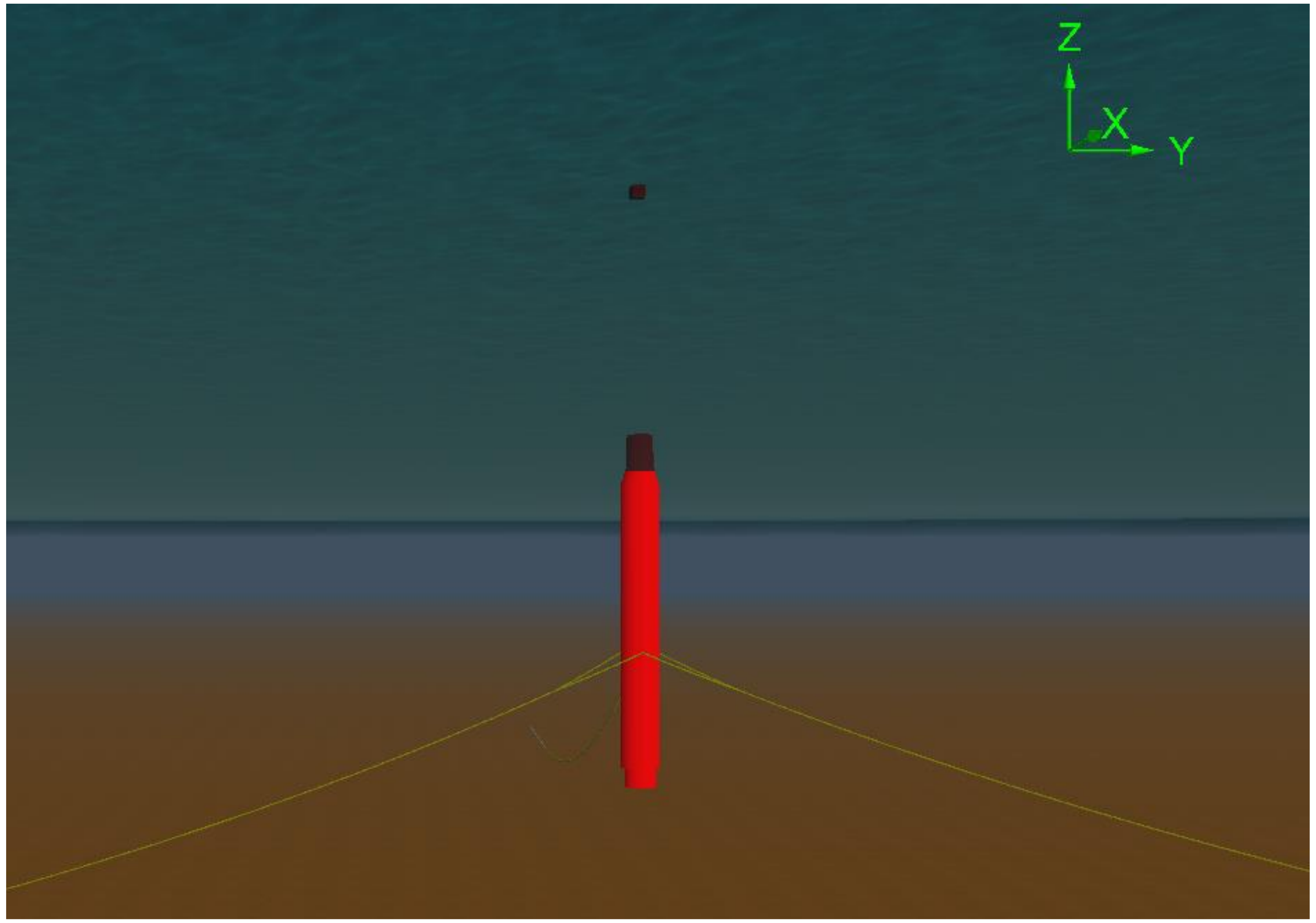
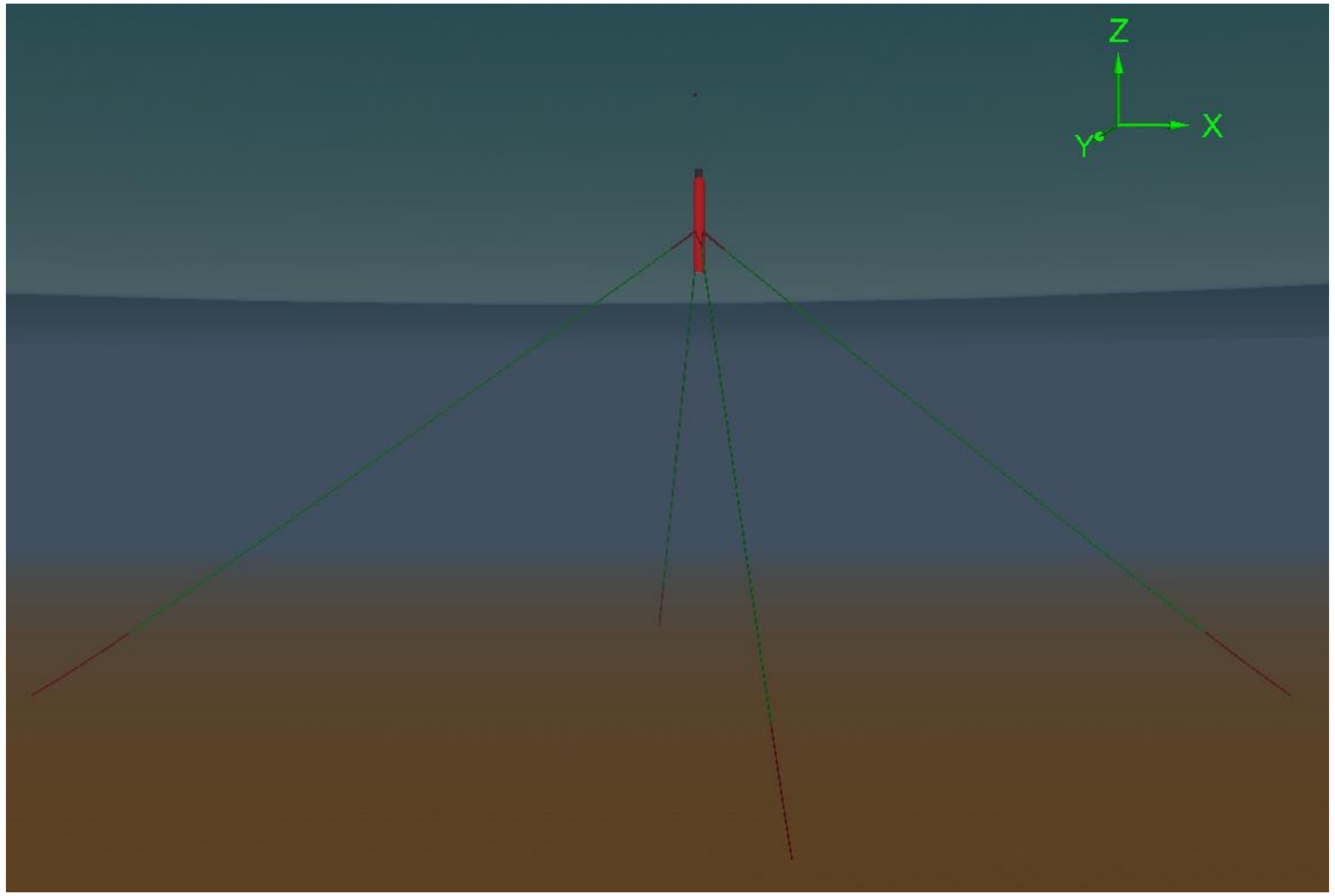
Mooring design and optimization

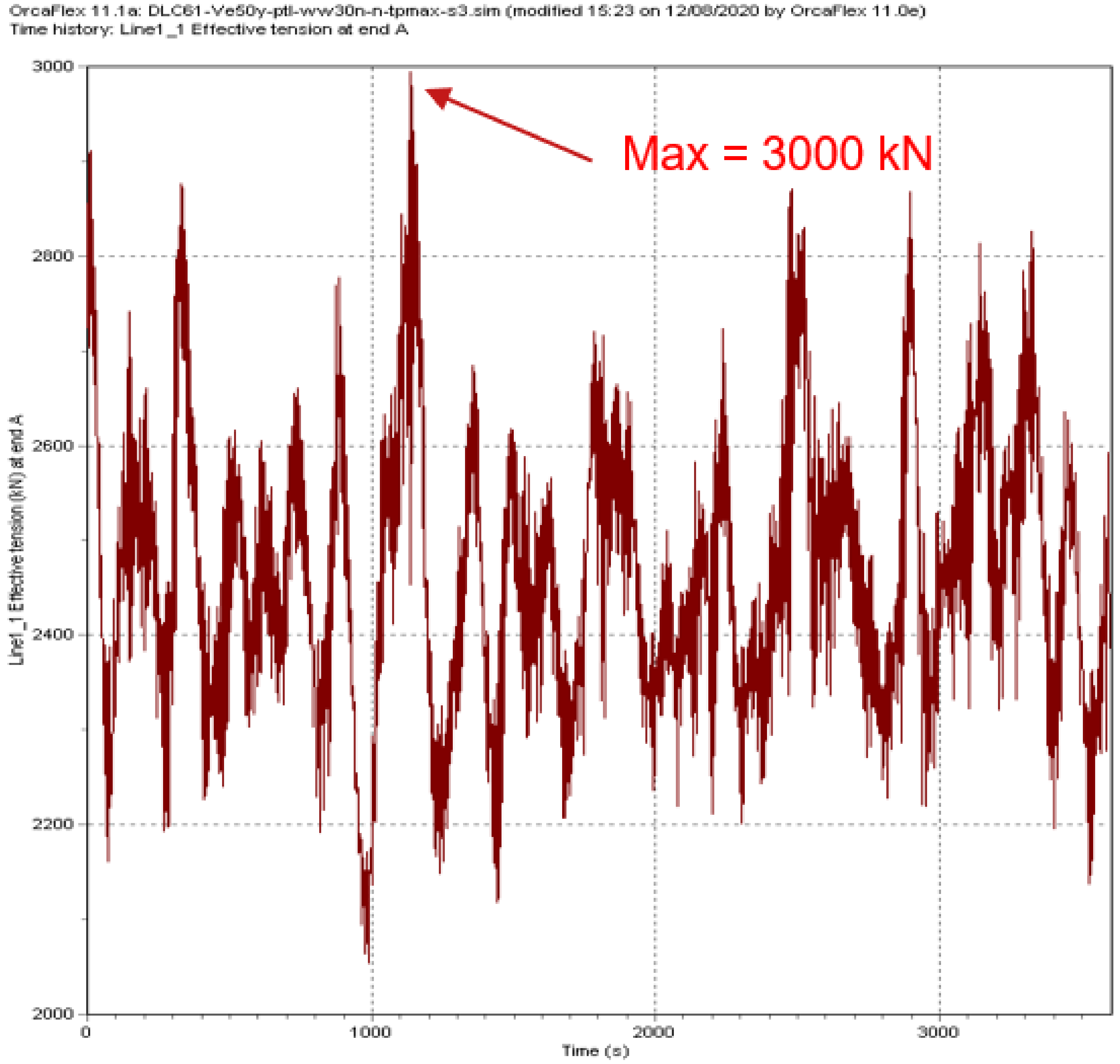




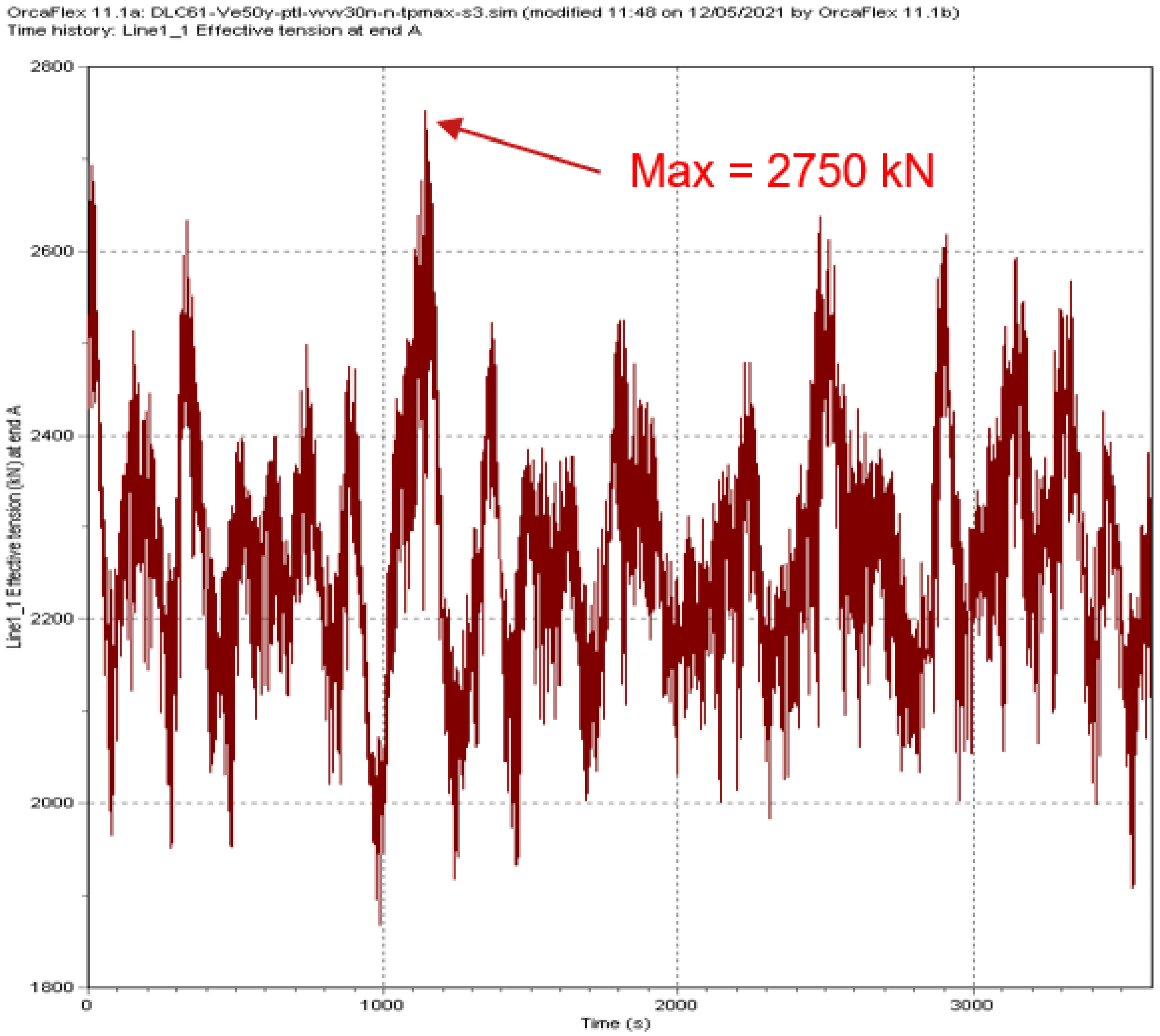
- Site B: Gran Canaria
- Procurement cost 1300 k€

- Site C: Morro Bay
- Procurement cost 1600 k€

Technological benefits regarding peak loads reduction



Effective tension on upwind line at fairlead



Effective tension on upwind line at fairlead

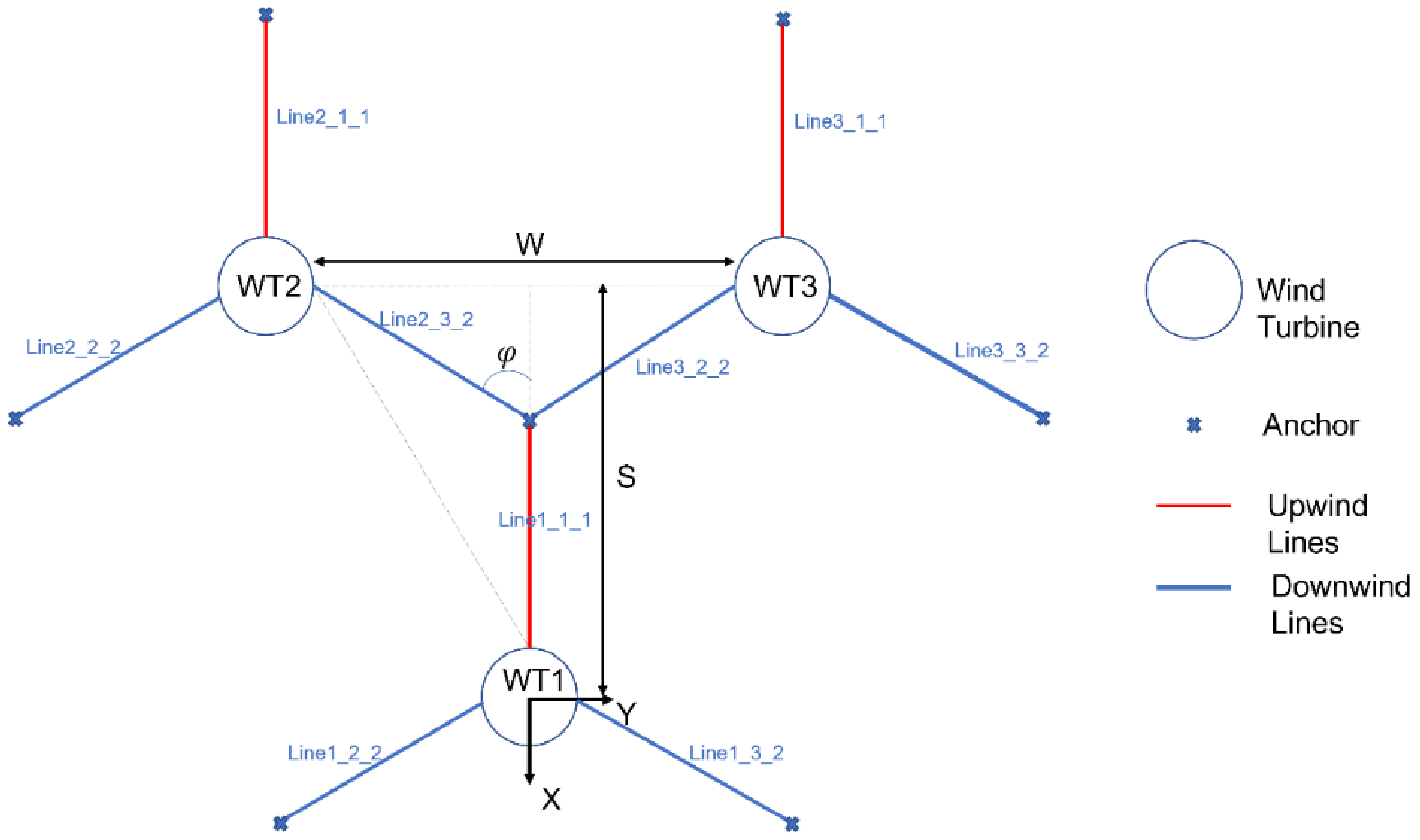
Technological benefits regarding peak loads reduction

Site	Floater	System	Chain cost diference (*)	Synthetic rope cost diference (**)	PLRS cost increase (*)	Peak load reduction (*)	Total cost (k€)	Diference
A - West of Barra	ActiveFloat	1	-26.7%	+0.0%	+38.9%	-32.0%	5651.4	+1.5%
		2	-	-	-	-	-	-
	WindCrete	1	-	-	-	-	-	-
		2	-	-	-	-	-	-
B - Gran Canaria	ActiveFloat	1	-23.2%	-	+11.9%	-28.0%	712.8	-17.6%
		2	-25.2%	-	+20.1%	-24.0%	765.7	-11.5%
	WindCrete	1	-39.7%	-	+12.2%	-47.0%	813.7	-37.1%
		2	-32.6%	-	+13.4%	-45.0%	943.6	-27.1%
C - Morro Bay	ActiveFloat	1	-0.4%	+1.2%	+19.3%	+11.0%	1660.0	+19.8%
		2	+0.9%	+1.9%	+13.1%	+21.0%	2586.2	+16.5%
	WindCrete	1	-4.8%	-17.2%	+16.1%	-2.0%	1529.0	-5.8%
		2	-4.9%	-16.1%	+14.3%	-14.0%	1491.2	-8.1%

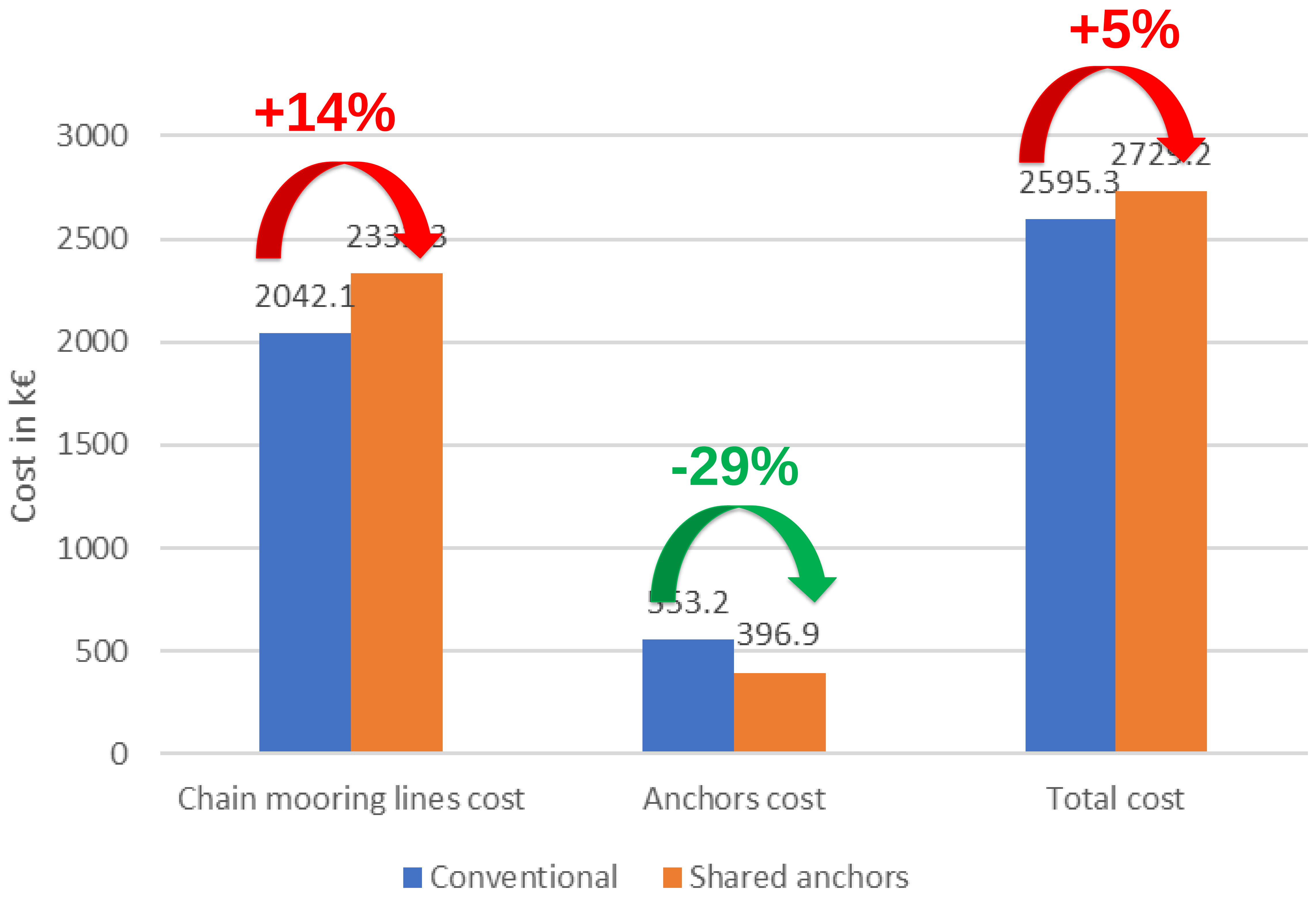
(*) in % of the total cost of the optimized mooring w/o PRLS

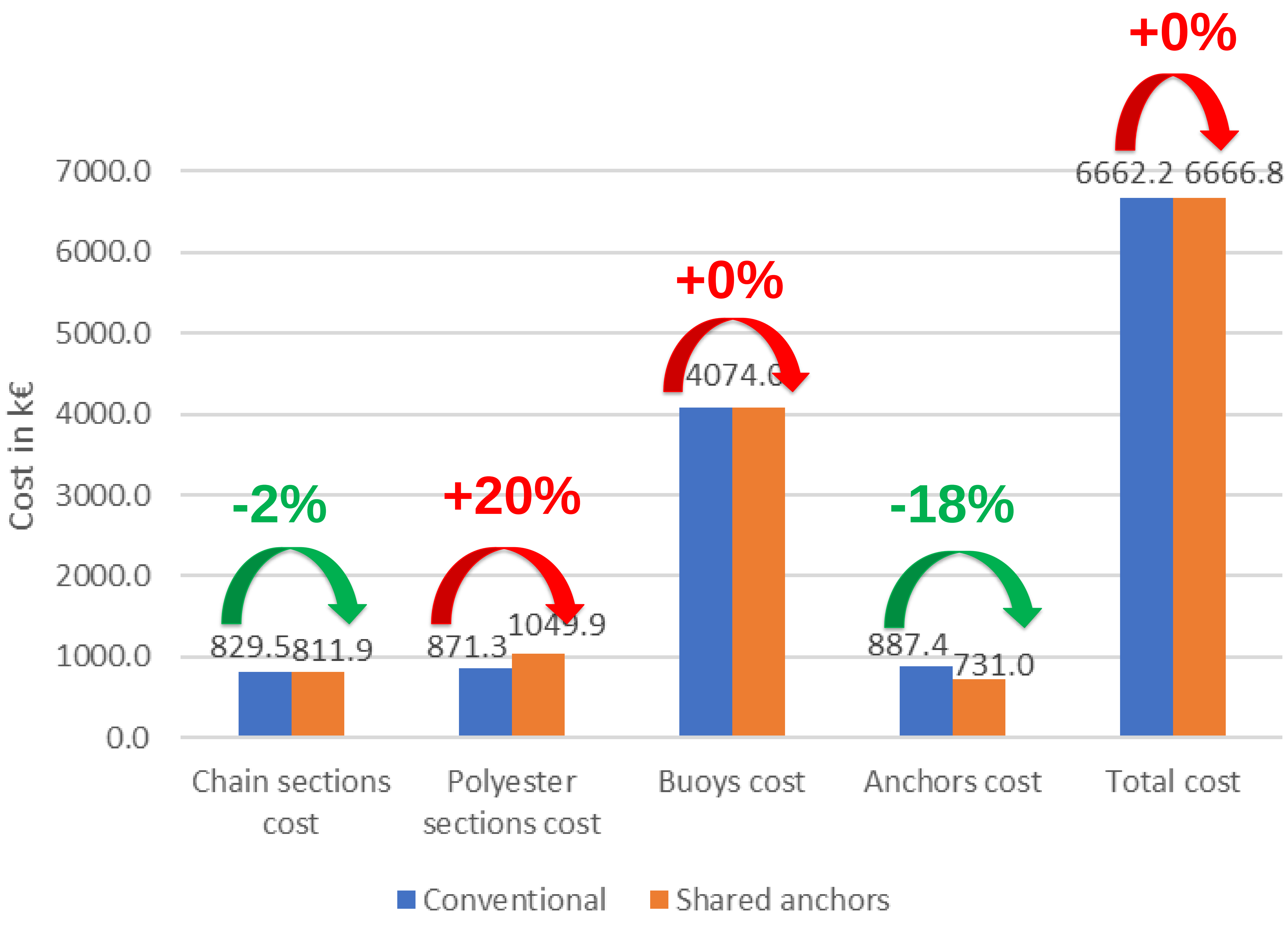
(**) nylon or polyester ropes, in % of cost of the optimized mooring w/o PRLS

Design at farm level: Shared anchors



Design at farm level: Shared anchors





- Site B: Gran Canaria
- ActiveFloat

- Site C: Morro Bay
- ActiveFloat

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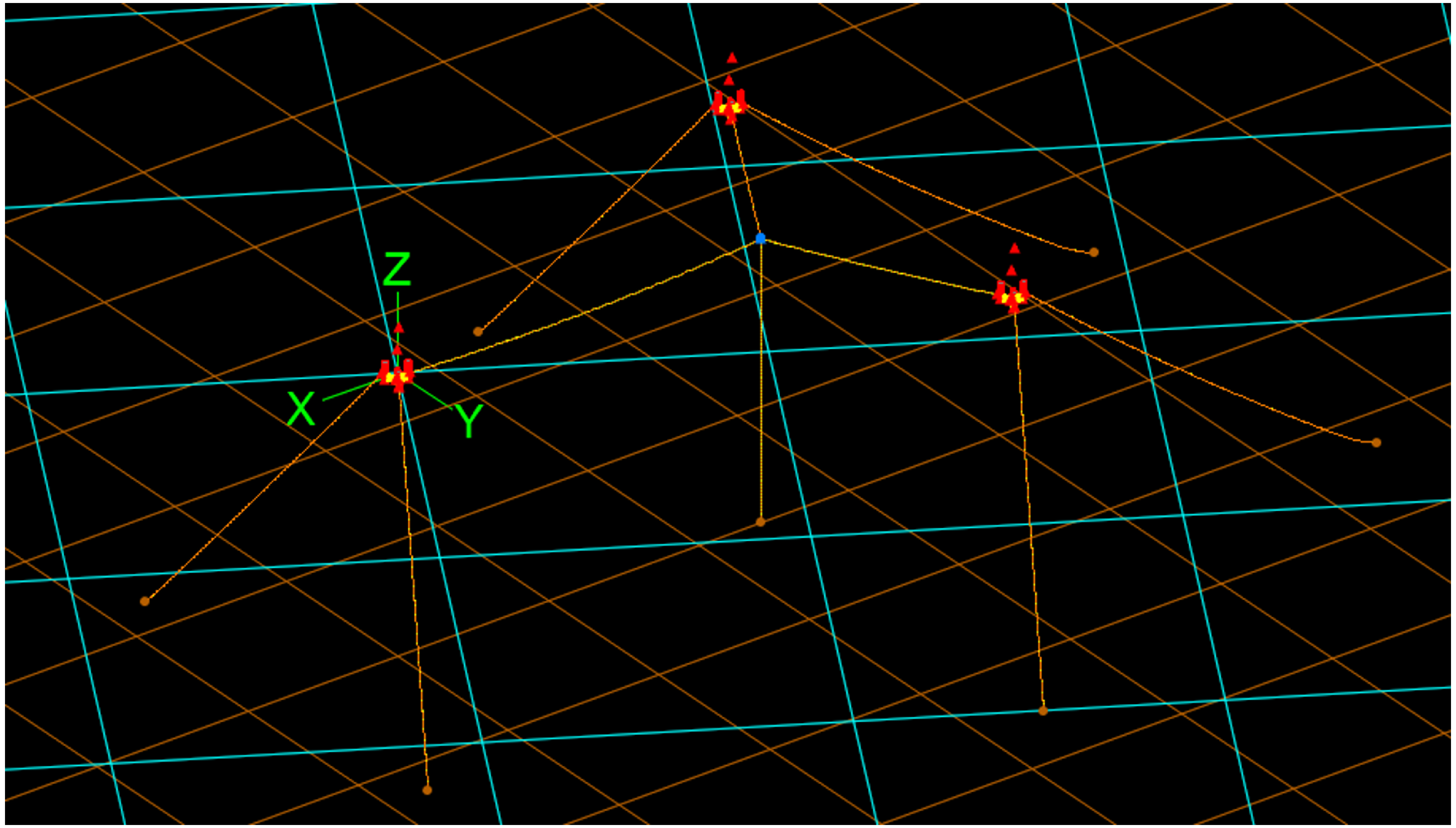
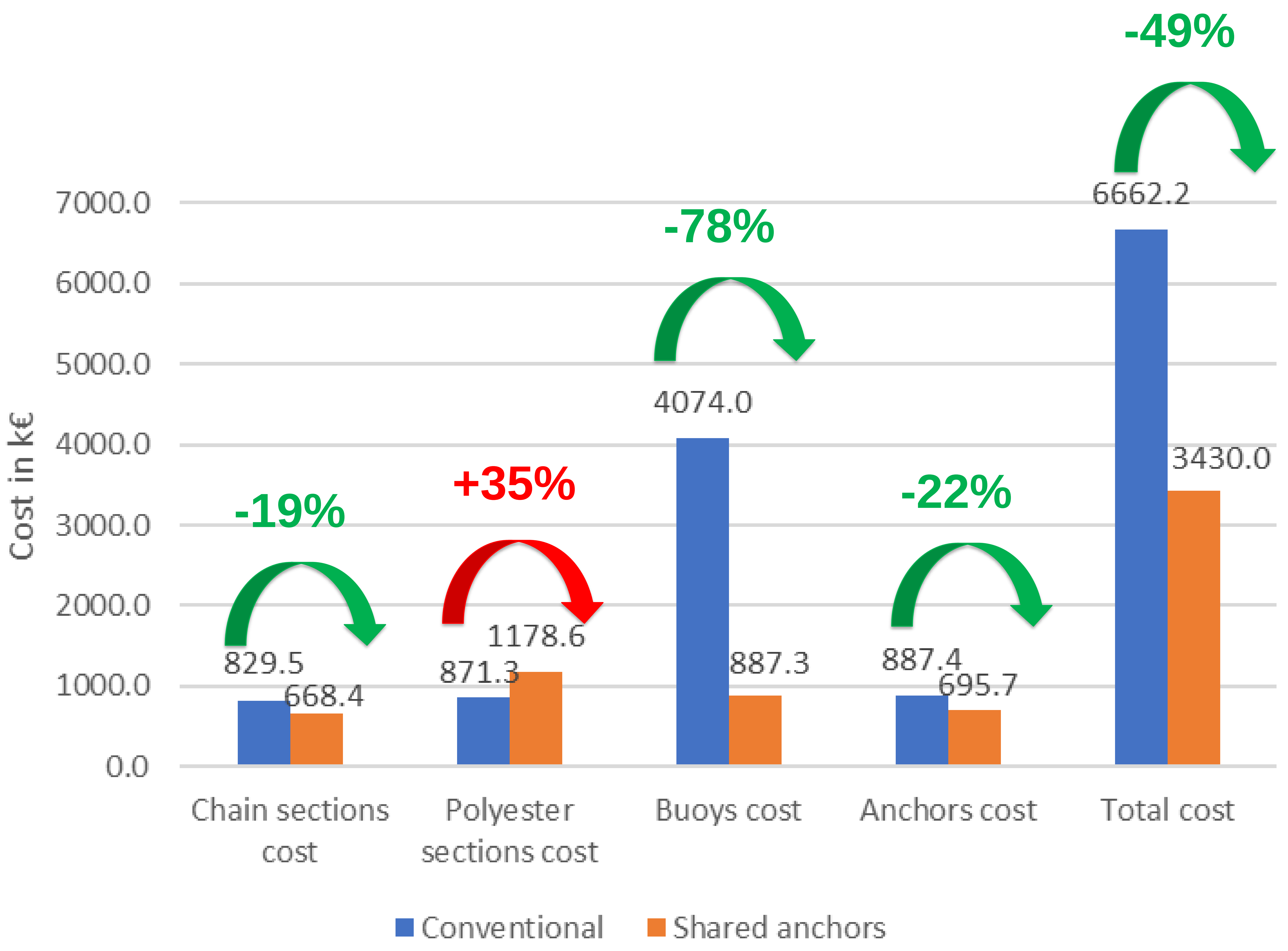
Design at farm level: Shared mooring lines



Design at farm level: Shared mooring lines



General conclusions: Design strategies

- Development of an optimization tool
  - Efficient to optimize systems driven by ULS in most cases
  - Improve the overall strategy (quasi-static, frequency analysis, improve algorithm
  - Add further costs (installation costs)
- Use of modal analysis to get tensions
  - Identify natural frequencies and predict response
- Use of surrogate model for optimization
  - Simplified model
- Use of machine learning to predict design parameters
- Tunning of the controller
  - Encouraging results to reduce fatigue (Kp, Ki and fore-aft velocity)

General conclusions: Mooring and fairleads designs

- Use of peak load reduction systems
  - ➢ Allow to reduce peak loads in the lines, allowing to reduce mooring size. Devices un-competitive for the moment.
- Use of shared anchors and shared mooring lines
  - ➢ Important potential (costs reduction due to line reduction)
- Footprint reduction
  - ➢ Use of clump weight and act on pretension
- Use of synthetic lines instead of chain
  - ➢ Should be investigated further (warning on FLS and modelling strategies)
- Fairlead design
  - ➢ Design based on optimize mooring system

General conclusions: O&M Strategies

- RoE from Oil&Gas industry
  - ➢ Differences:
    - Anchor radius
    - Large number of FOWT
- Increase of potential failure modes
- Balance between decreasing number of lines and increase costs for installation vessels
- Early engagement between installation engineering and foundation/mooring designer is a key to the success

Thank you for your attention!

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valentin.arramounet@innosea.fr

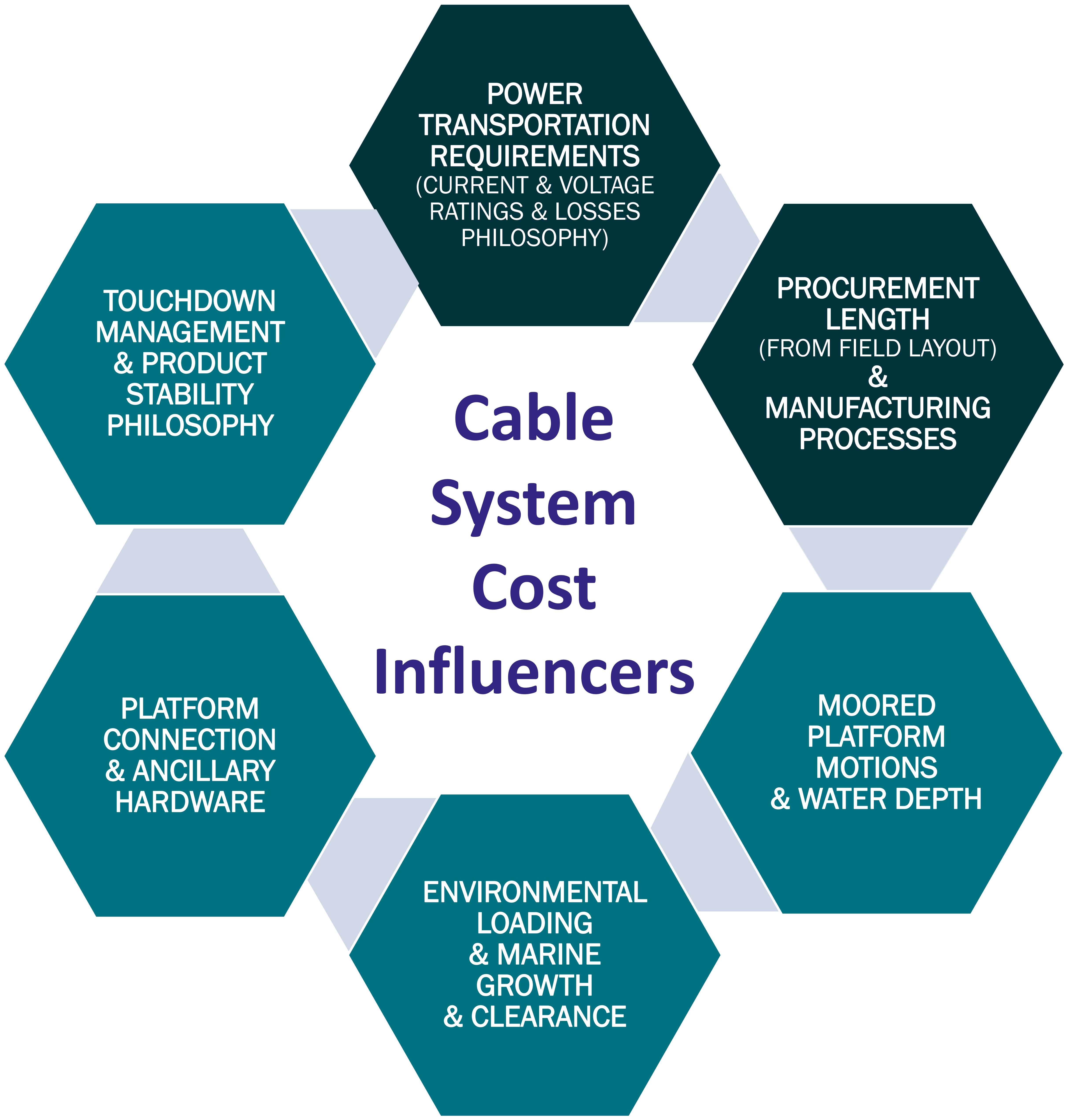
COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Dynamic Cable Design Optimisation

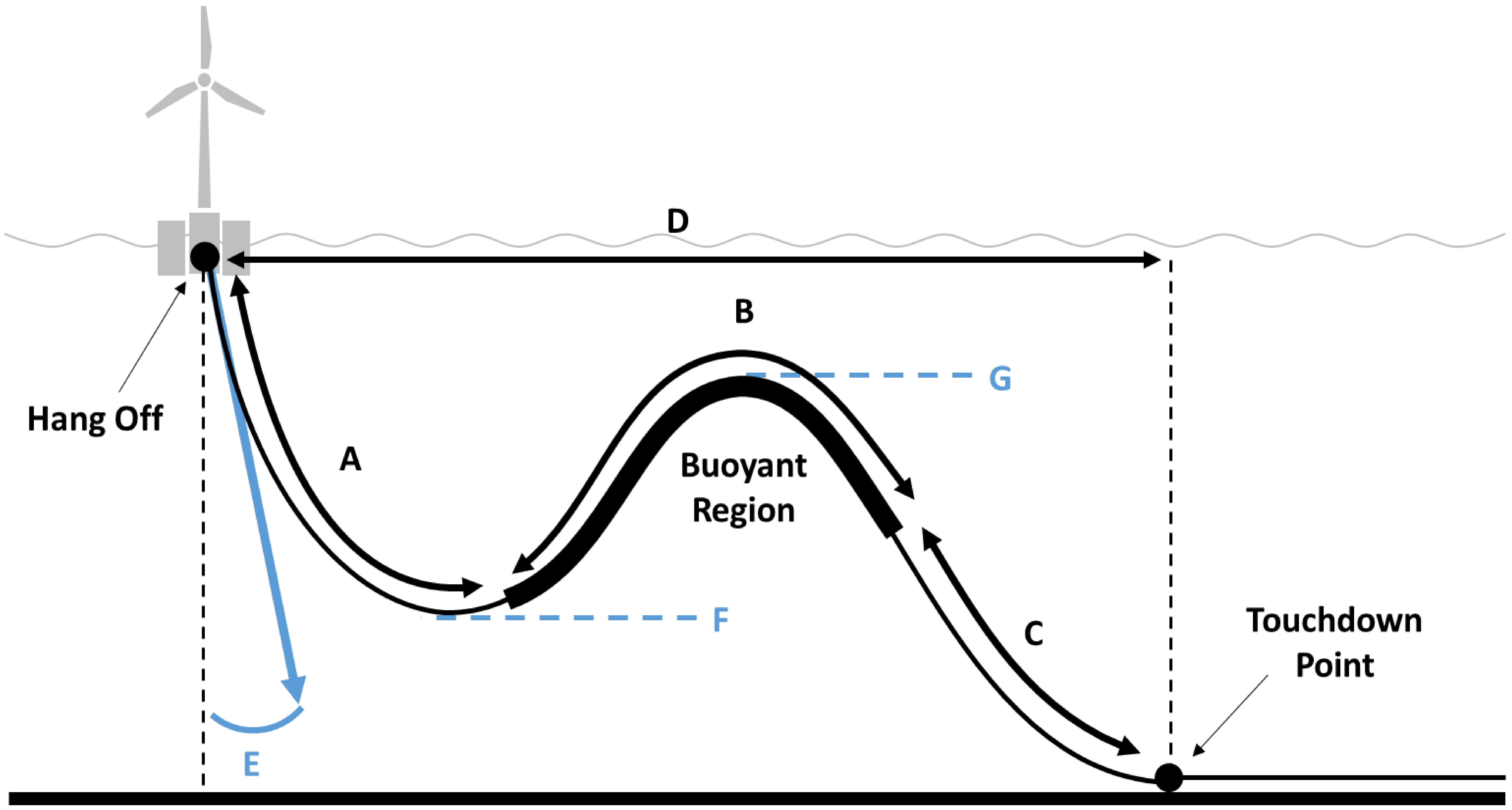
Joseph Allen
Graduate Engineer
JDR Cables

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

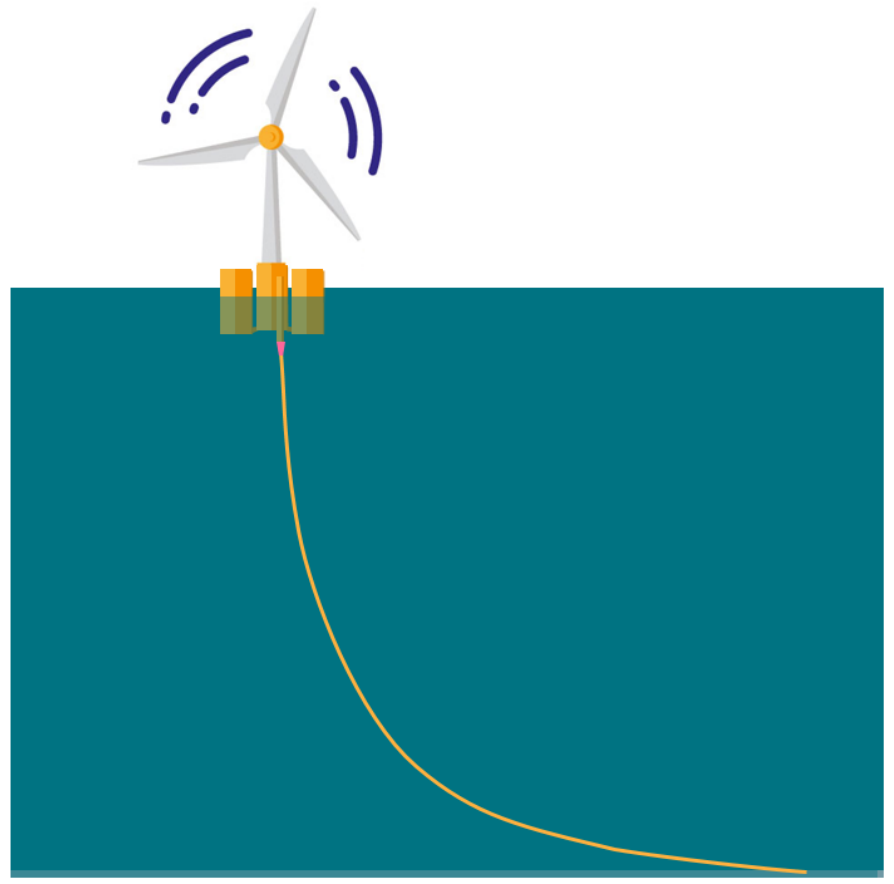
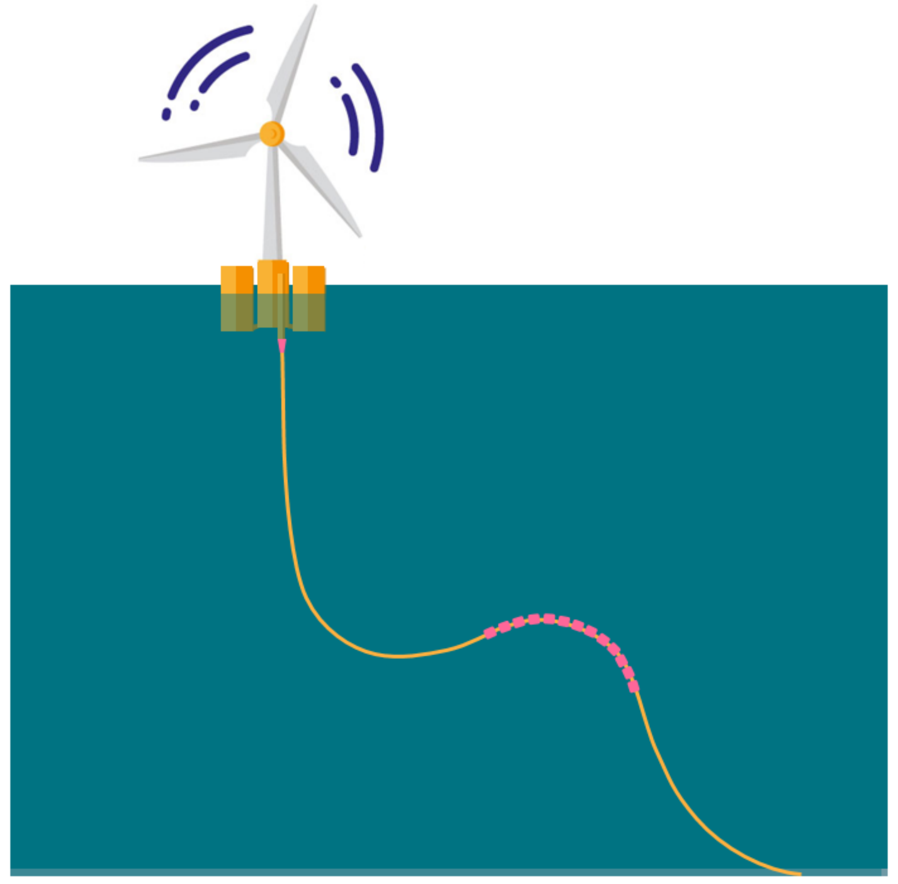
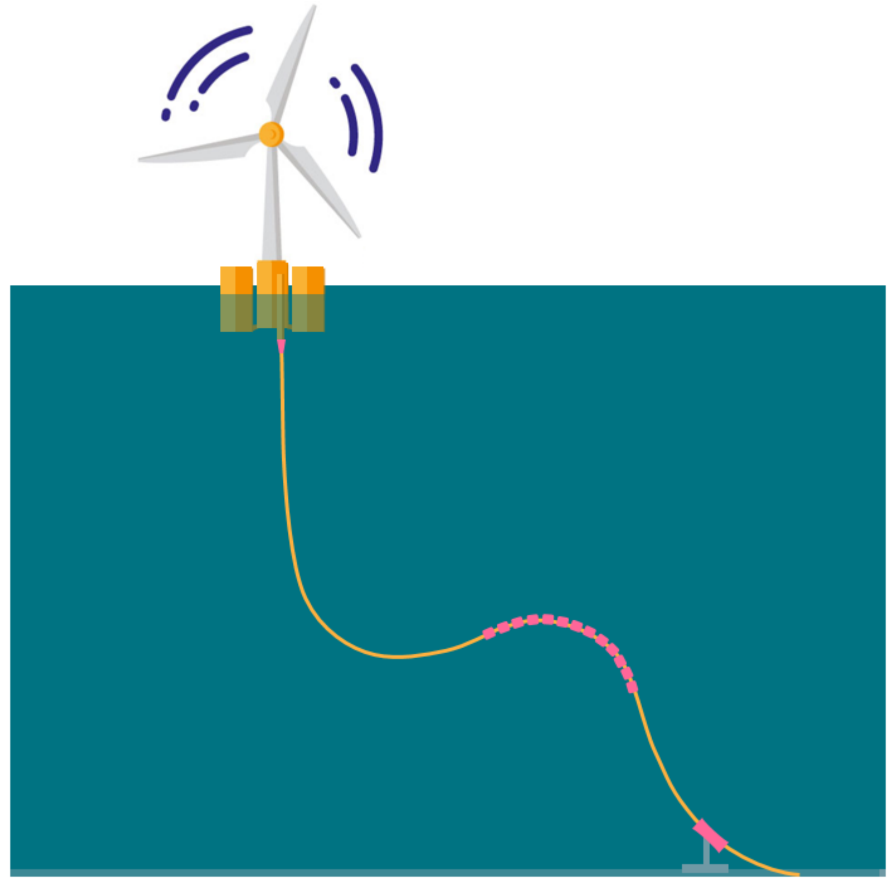
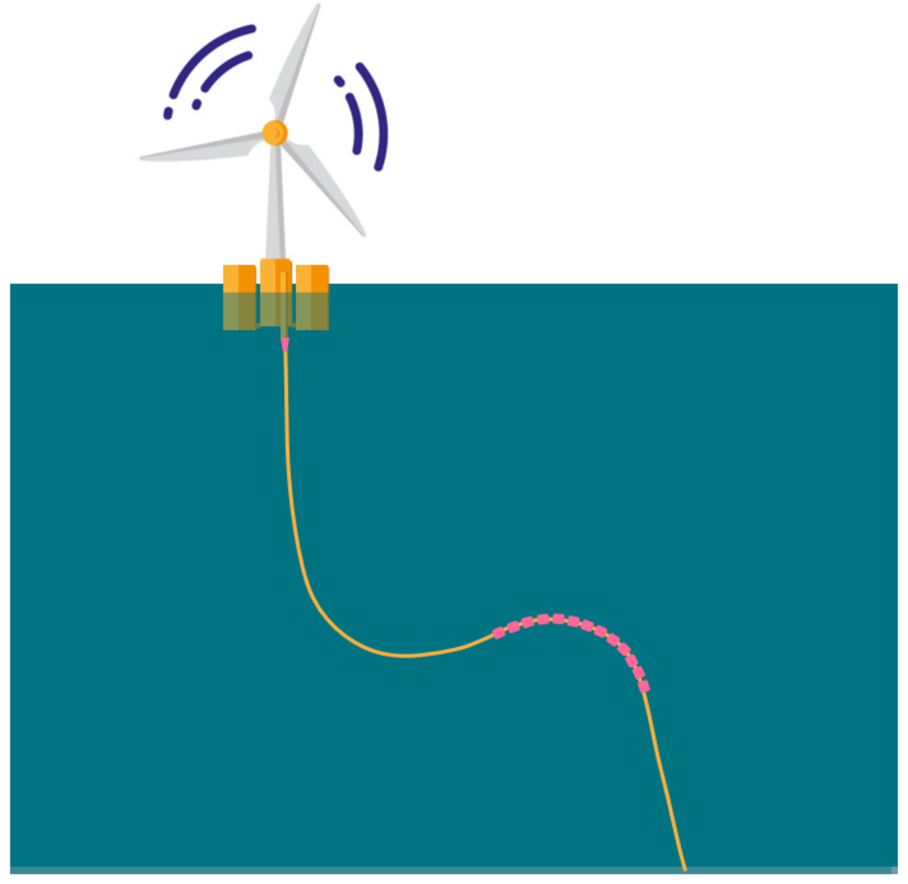
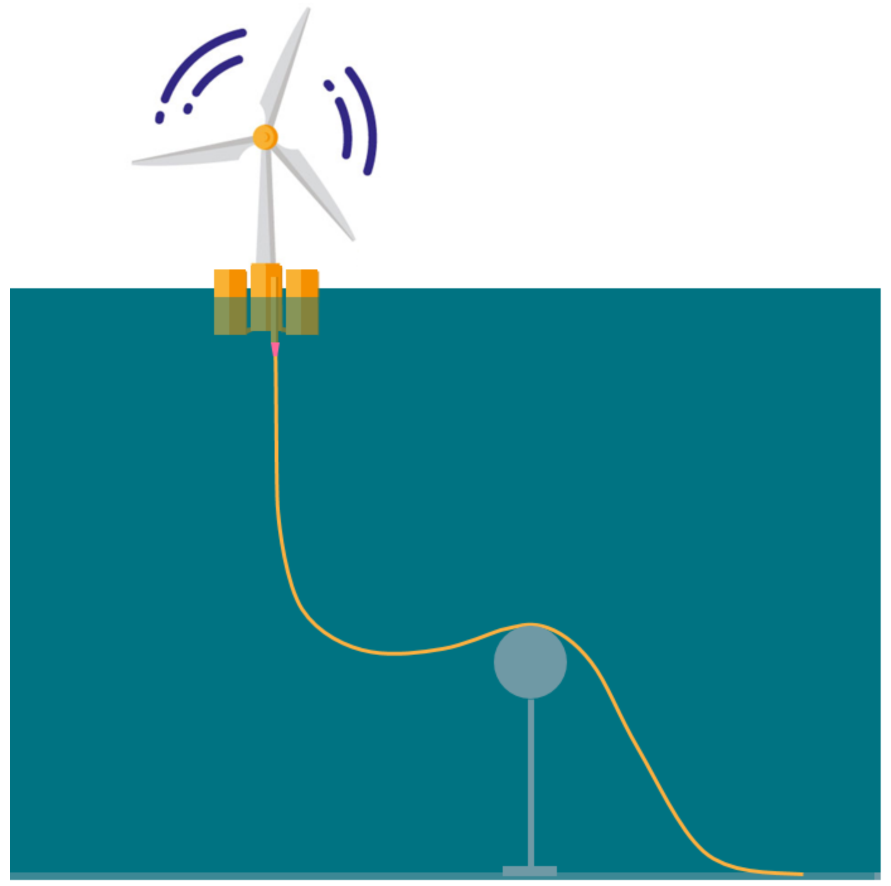

Cable System Cost Influencers
POWER TRANSPORTATION REQUIREMENTS (CURRENT & VOLTAGE RATINGS & LOSSES PHILOSOPHY)
PROCUREMENT LENGTH (FROM FIELD LAYOUT) & MANUFACTURING PROCESSES
MOORED PLATFORM MOTIONS & WATER DEPTH
ENVIRONMENTAL LOADING & MARINE GROWTH & CLEARANCE
PLATFORM CONNECTION & ANCILLARY HARDWARE
TOUCHDOWN MANAGEMENT & PRODUCT STABILITY PHILOSOPHY

Overview of Cable System



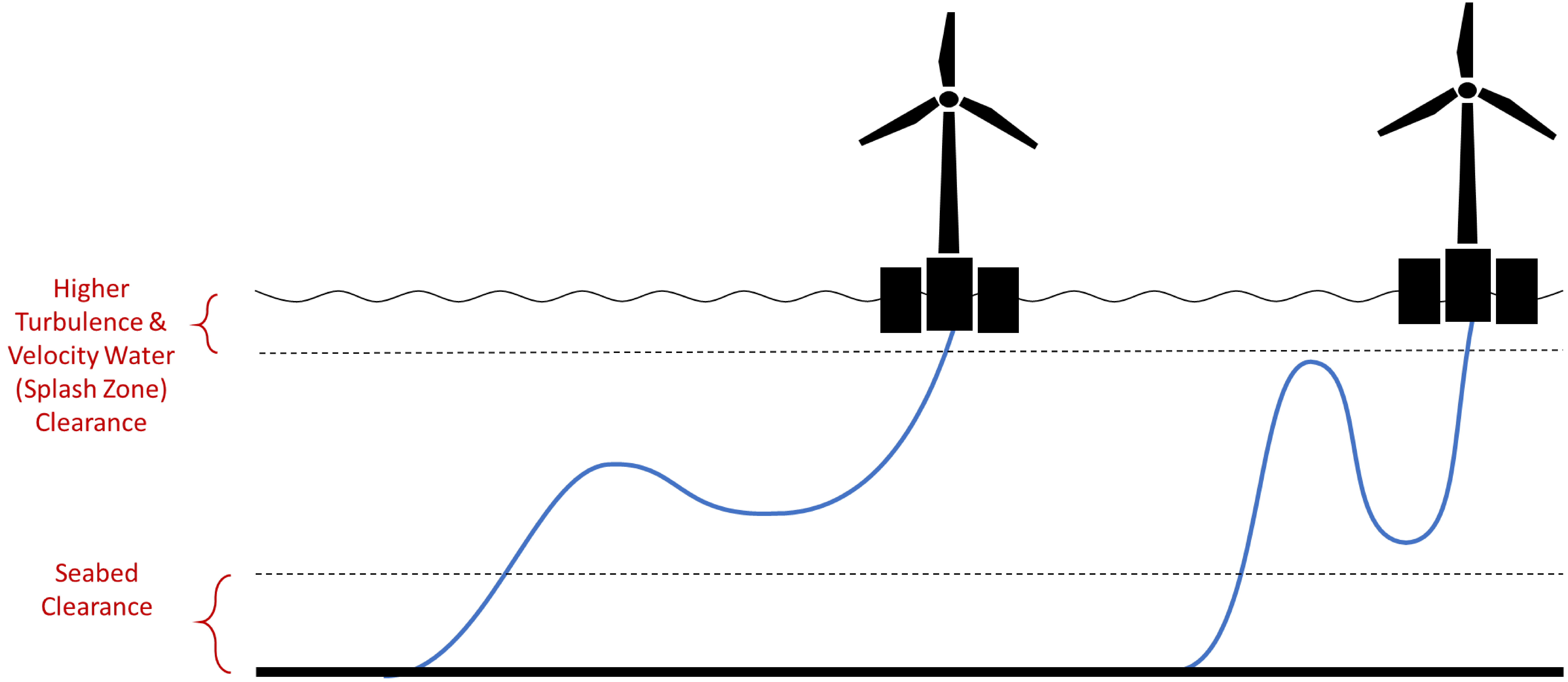
Cable system configuration options for touchdown solutions

LOW COST → HIGH COST

Free Hanging Catenary	Lazy Wave	Tethered Wave	Steep Wave	Lazy S (Mid Water Arch)
				
No/Small platform offsets relative to depth Limited depth based on current qualification limits & tensions	Larger offsets with mild environmental conditions Limited by marine growth for shallow depths and environmental loading	Inclusion of tether to mitigate migration of touchdown point, restrain cable system within allowable movement envelope	Lack of qualified field proven wet-mate technology available for high voltages but may be useful for detachable systems in the future	Recommended for floating platforms to control multiple cable approach, for example several FWT strings approaching an OSS

Key result 1 – Platform Offset influence on Costs

- Total moored platform offset distances have a major influence on the cable length required in the system

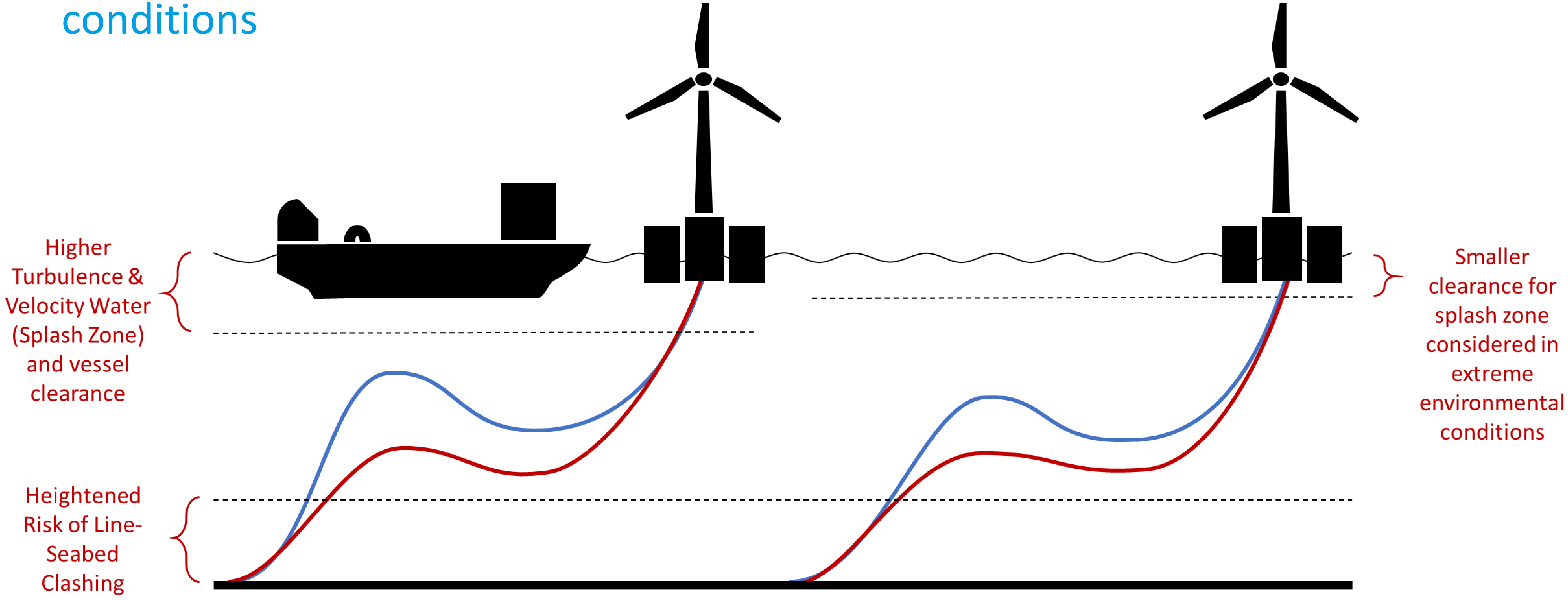


Key result 1 – Platform Offset influence on Costs

- Why do platform offsets matter?
  - ➢ Maximum platform offset dictate cable length required for a pliant system, and therefore the cable length that must be accommodated in the water column when platform shifts to the near condition
  - ➢ This becomes acute in shallower water sites where water column envelope is limited
    - ➢ For platform horizontal offsets greater than 20% of water depth, and vertical offsets greater than 10% of water depth, it becomes increasingly challenging to find a solution
    - ➢ The maximum platform excursions a cabling system may be designed to tolerate may be up to ≈30% of water depth, provided conditions at the surface are not onerous, however costs increase with these large excursions
    - ➢ Limiting platform motion can reduce cable costs significantly so recommend moored platform and cable system are designed iteratively together upfront - study for Site B suggested ≈15% of water depth was optimal for CAPEX reduction

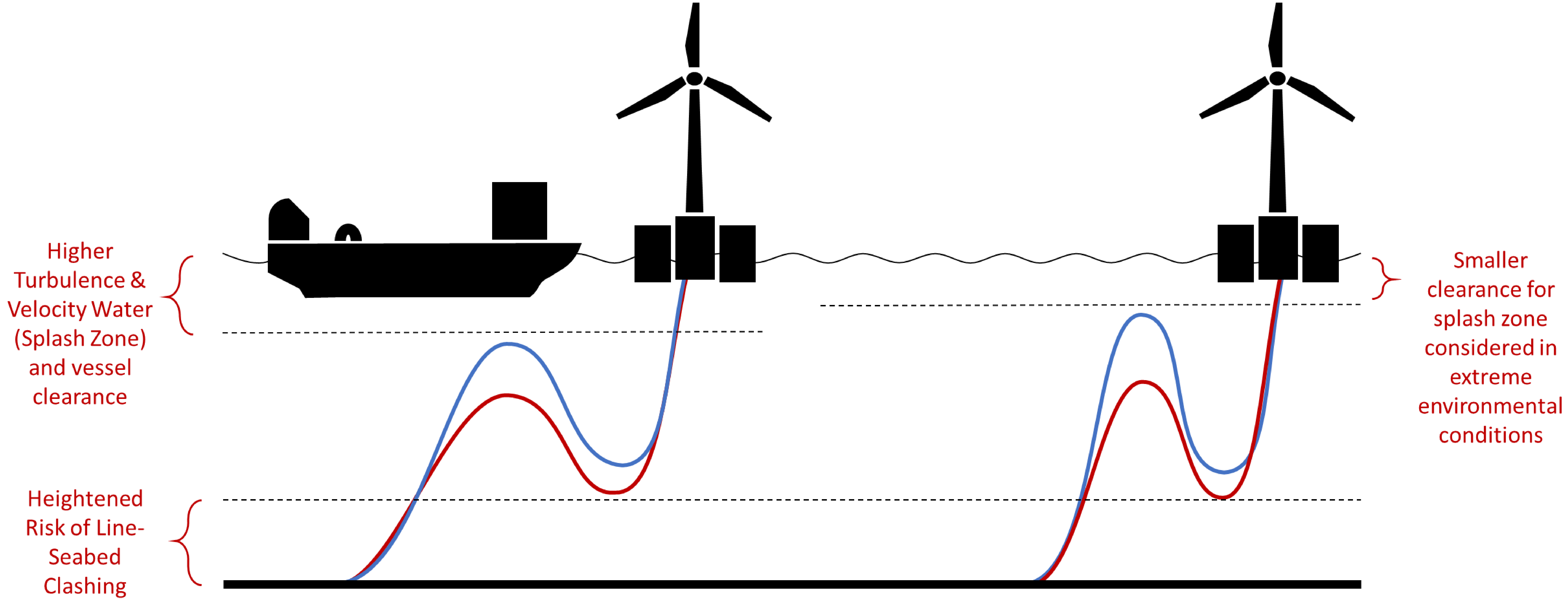
Key result 2 – Marine growth is a critical influencer on Costs

- Far platform offset requires pliant length in both SOL (installed) and EOL (+MG) conditions



Key result 2 – Marine growth is a critical influencer on Costs

- Clearance limits constrain water column available to manage resulting cable length in platform's near offset

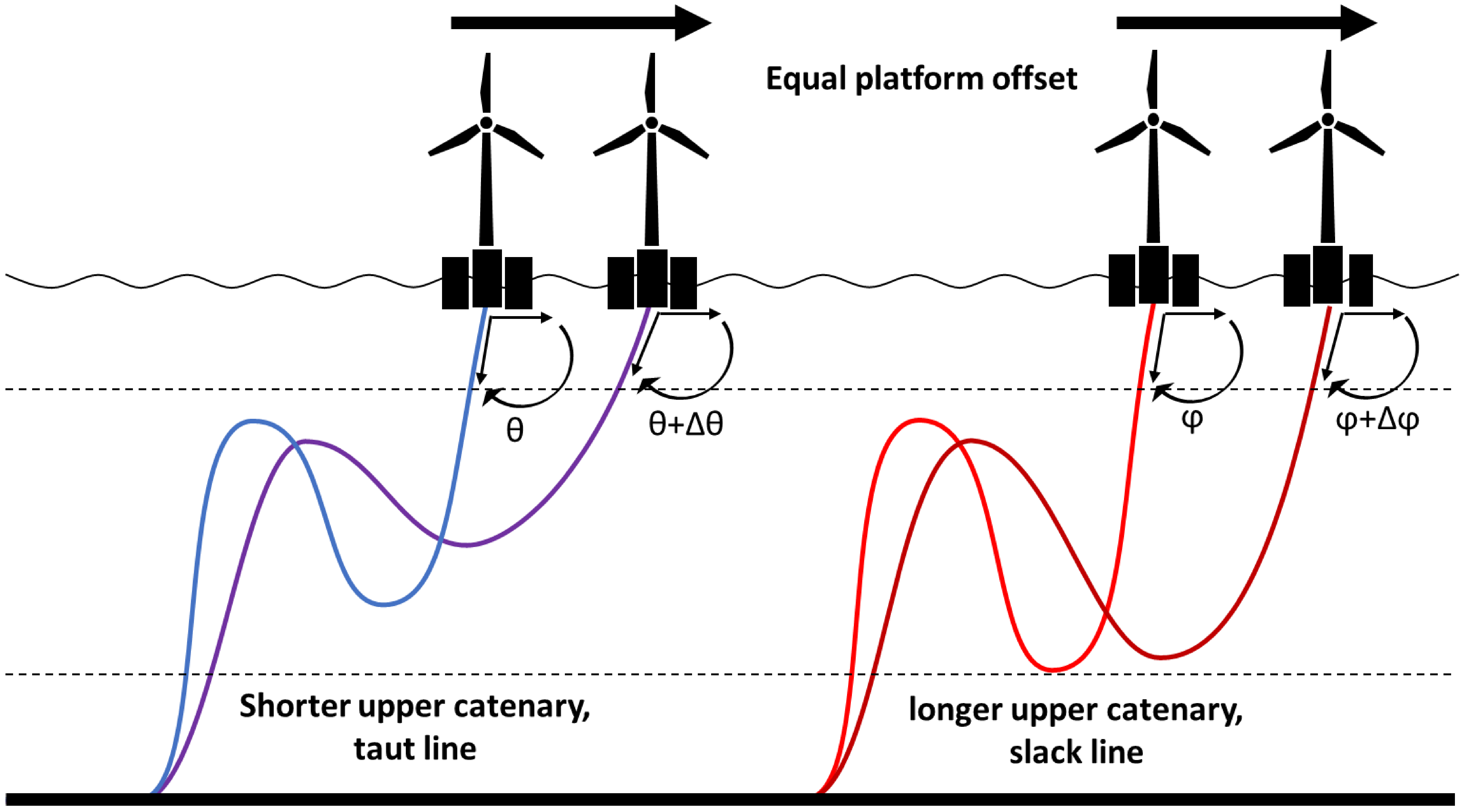


Key result 2– Marine growth is a critical influencer on Costs

- Why do Marine Growth and Clearance limits matter?
  - ➢ Predict marine growth on cable surface as accurately as possible, as conservative assumptions may lead to unnecessary cable & hardware requirements:
    - ➢ May require additional cable length in system to retain pliant wave
    - ➢ High drag can result in greater lateral motion of cable system, which influences platform connection loading and touchdown migration risk and hardware design to mitigate (i.e. tether)
    - ➢ Added weight increases tension to the cable system, increasing risks and cable design requirements
    - ➢ More challenging to fit SOL + EOL cabling within the water column, especially in shallow water where clearance limits are large.
  - ➢ Clearance limits should be reviewed specifically for when vessel may be present (e.g. during some FLS cases, but unlikely to be present during ULS/ALS conditions) to minimize influence on cable system requirements to reduce system costs

Key result 3 – Cable Connection to the platform

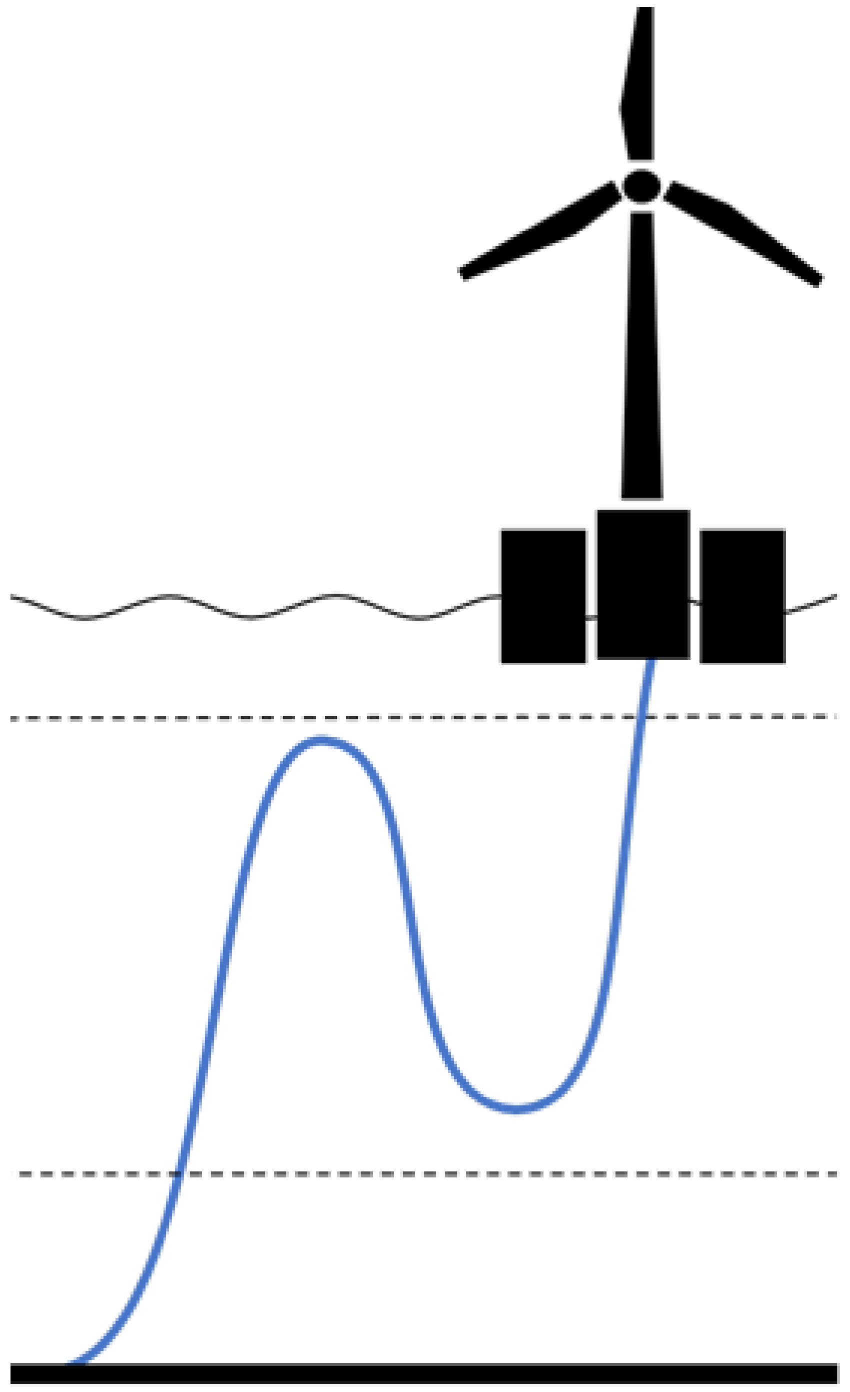
- Where platform motion is dominant (over wave and current influence), optimising configuration through exit angle studies (supported by buoyancy module adaptation) can lead to greater cost reduction of overall bending hardware

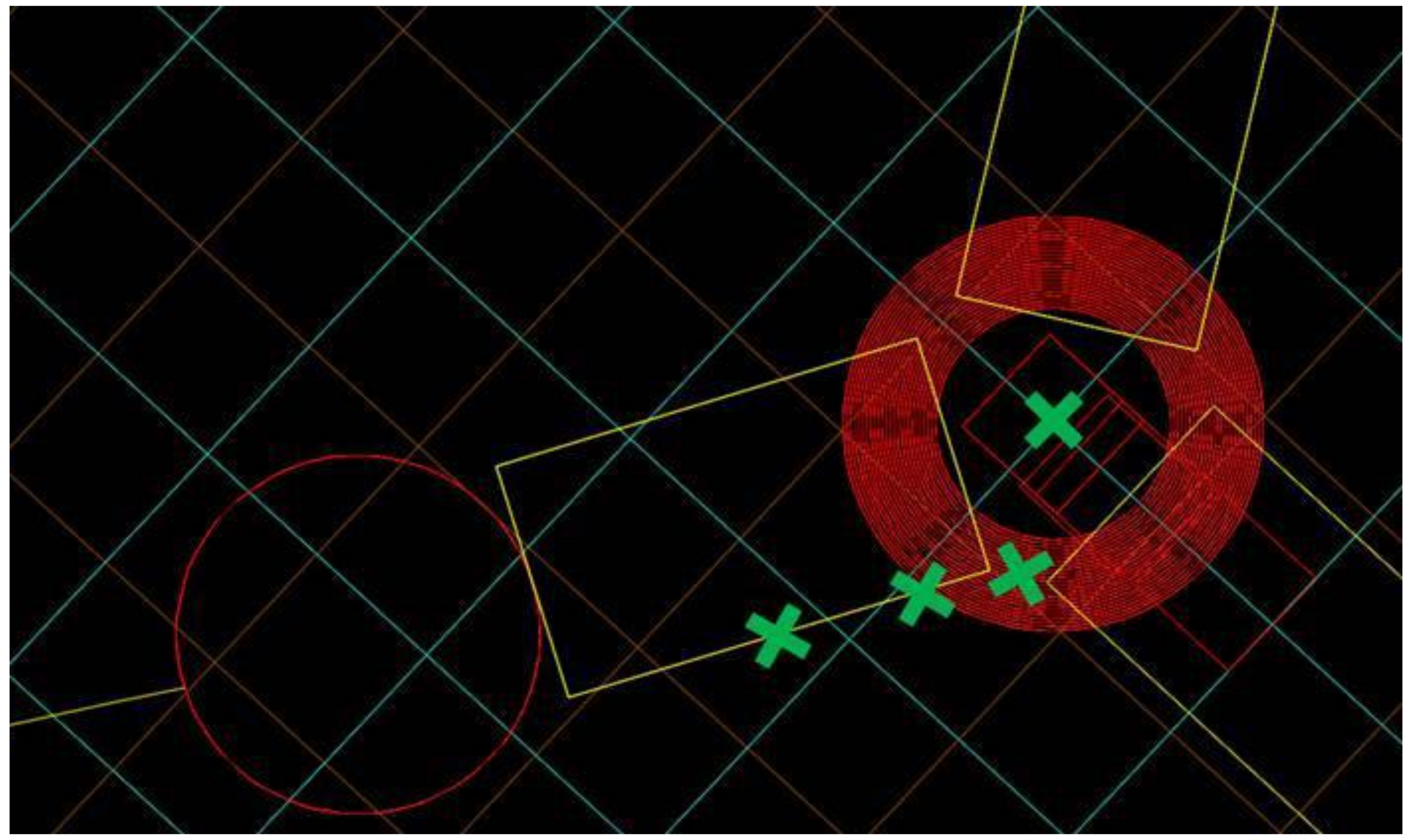


$\Delta\theta > \Delta\varphi$

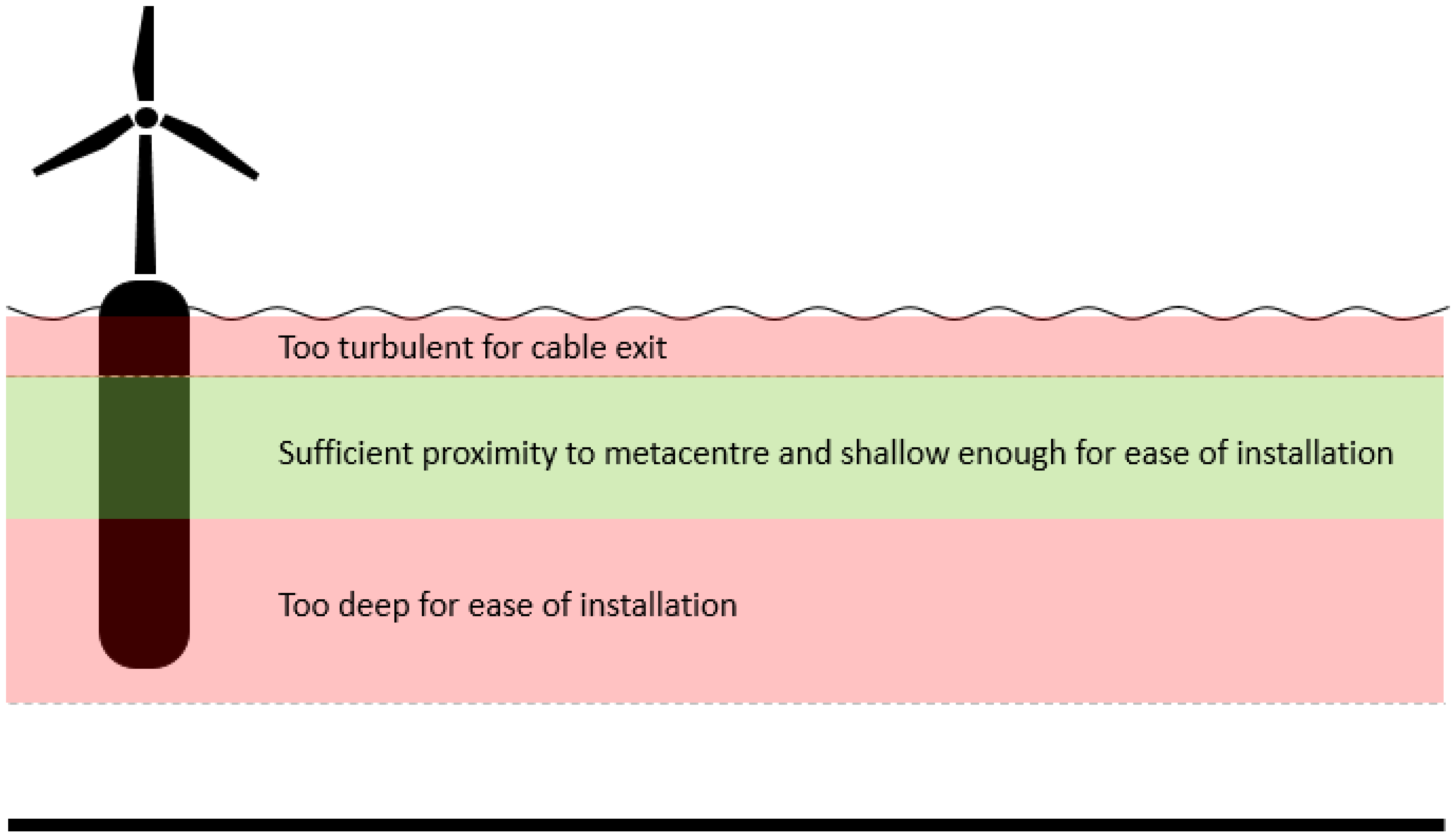
Key result 3 – Cable Connection to the platform

- Connection point for platform minimize motion induced in the cable, but should be considered with installation plans





Consider ease of installation access, planned and emergency disconnection philosophy for hardware design requirements, and minimising motion imparted into the cabling system to increase fatigue life and reduce cable design requirements



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Key result 4 – Hardware Optimisation studies

- Detailed sensitivities to review and develop buoyancy designs with suppliers can reduce costs of hardware

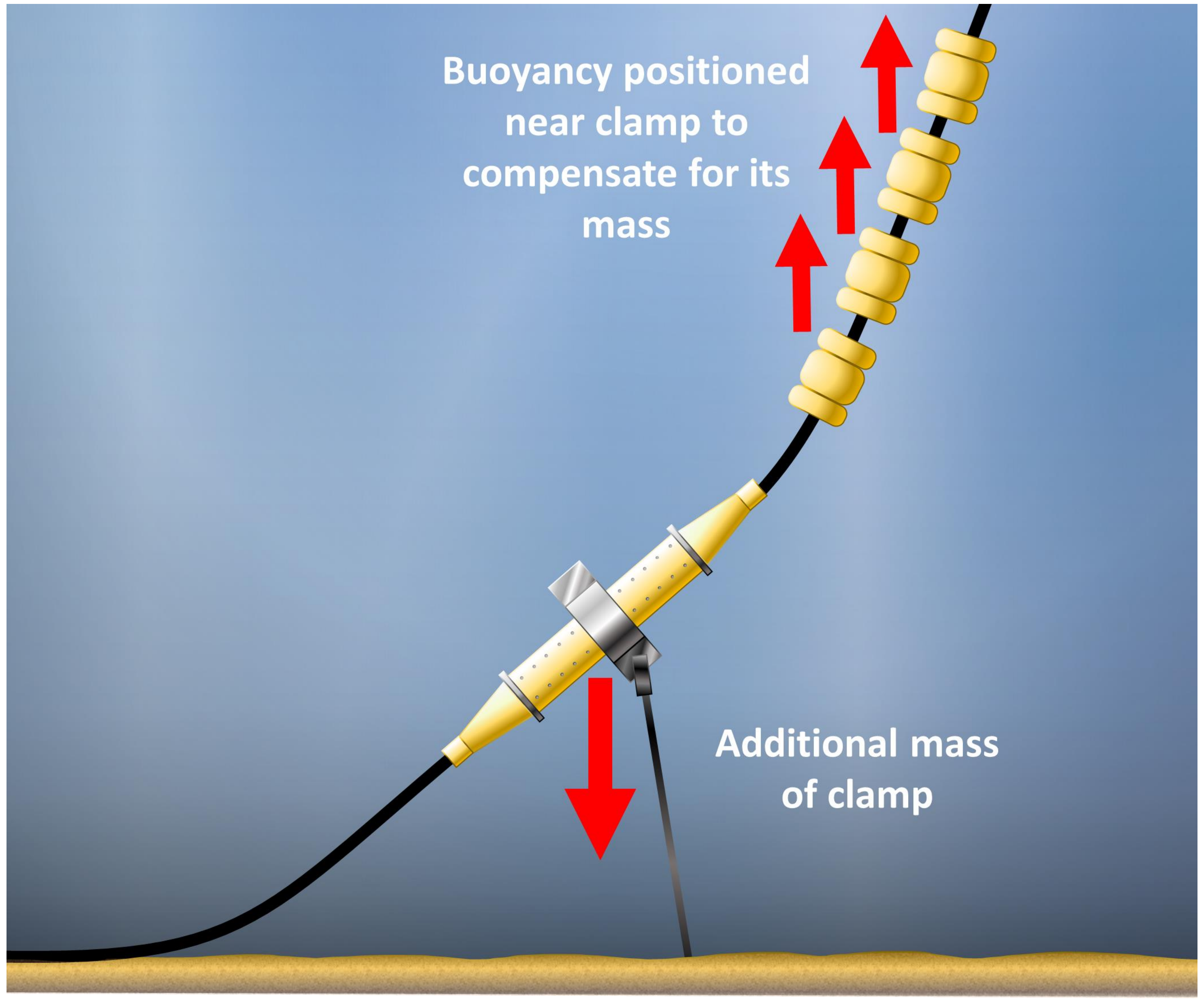
- Buoyancy spacing optimisation studies can reduce costs of hardware

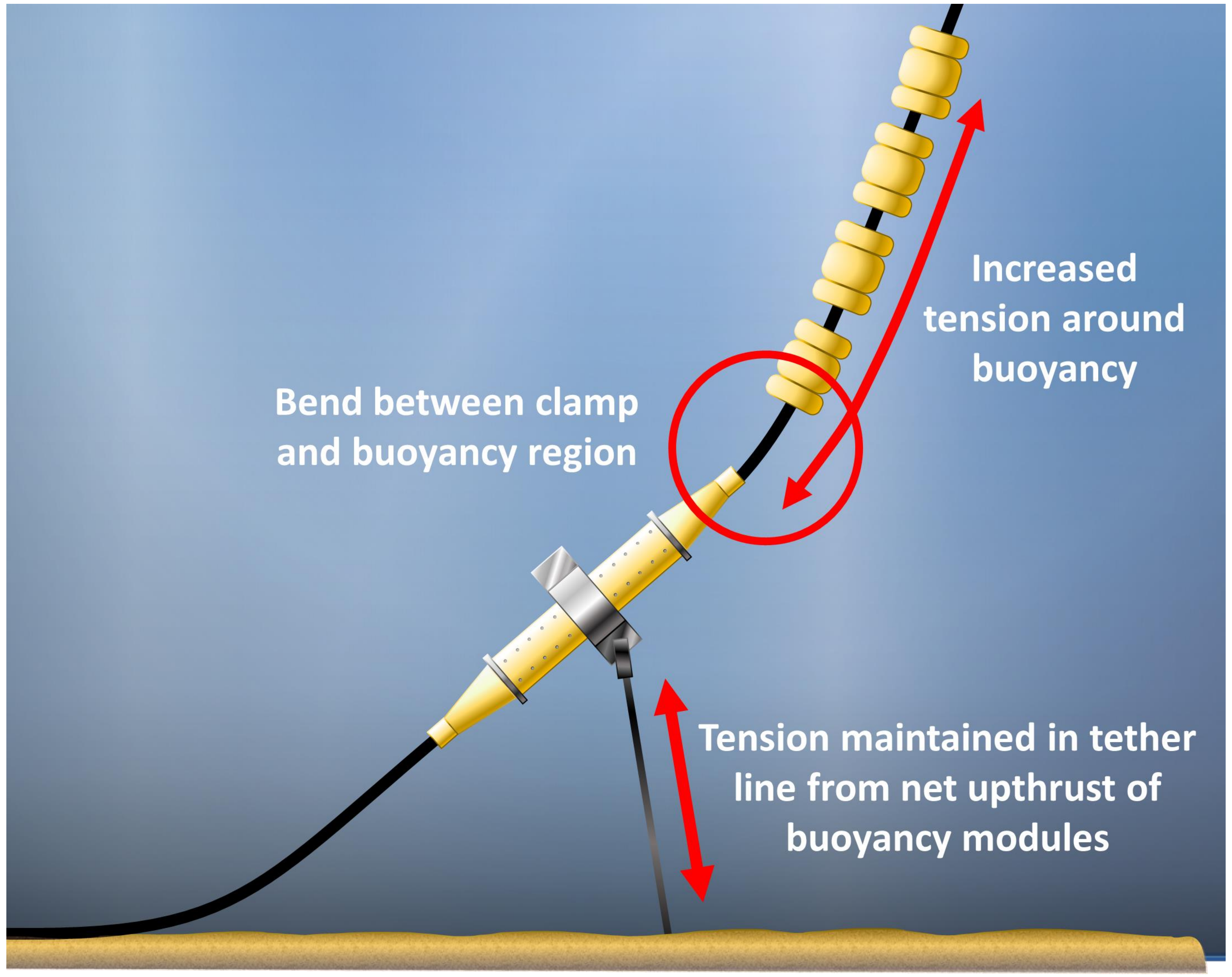
- Tether clamp and buoyancy module joint optimisation studies can reduce hardware costs of both types of hardware

- Multiple designs of buoyancy modules can reduce overall costs of hardware if positioning is optimised

Key result 4 – Optimisation studies (buoyancy, etc)

- Buoyancy and tether solutions should be developed together to optimise and reduce costs of hardware requirements on the system and avoid exceeding cable limits





Conclusion

- Significant cost reduction seen for dynamic cable configurations which consider:
  - Accurate marine growth specified relative to water depth
  - Limited moored offsets relative to water depth
  - Seabed and Sea surface clearance levels bespoke to FLS and ULS conditions
  - Careful consideration of cable connection position vs. connection/disconnection requirements
  - Detailed upfront optimisation studies for hardware interaction, standardisation and reduction of requirements

- Next steps / Topics that could be further investigated:
  - ➢ Non-touchdown solutions for deeper water applications
  - ➢ Non-standard shallow water solutions for larger platform offsets
  - ➢ More detailed evaluations of turbine reaction on platform motion influencing imparted motion into cable system and associated fatigue

Thank you for your attention!

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Optimization of floating offshore wind O&M strategies and installation techniques

Marie-Antoinette Schwarzkopf
Senior Consultant
RAMBOLL

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

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Work Package 4: Optimization of floating offshore wind O&M strategies and installation techniques

Objectives

I. Identification of floating-wind-specific O&M requirements w.r.t. access and major component exchange strategies, workability and other technological aspects.

II. Development of floating-wind specific O&M strategies and of a cost and availability model

III. Assessment of the cost reduction potential through optimized floater-specific O&M strategies and technological innovations, such as condition monitoring to support the maintenance strategy.

IREC Institut de Recerca en Energia de Catalunya Catalonia Institute for Energy Research
DTU
INNOSEA Marine Energy Engineering
JDR TFKable Group
RAMBOLL
IH cantabria INSTITUTO DE HIDRÁULICA AMBIENTAL
UPC
equinor
cobra
Universität Stuttgart

Key Results

- Operation and Maintenance Strategy Development and Optimization
- Comparison of major component exchange strategies
- Effect of structural health monitoring technologies on OPEX
- Installation strategy, duration, and weather windows

Operation and Maintenance Strategy Development and Optimization

Aim: Site and marine spread specific strategy optimisation and OPEX modelling

Preliminary Studies

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

Optimisation

Time-based OPEX modelling & Strategy Optimization

Outcomes and Recommendations

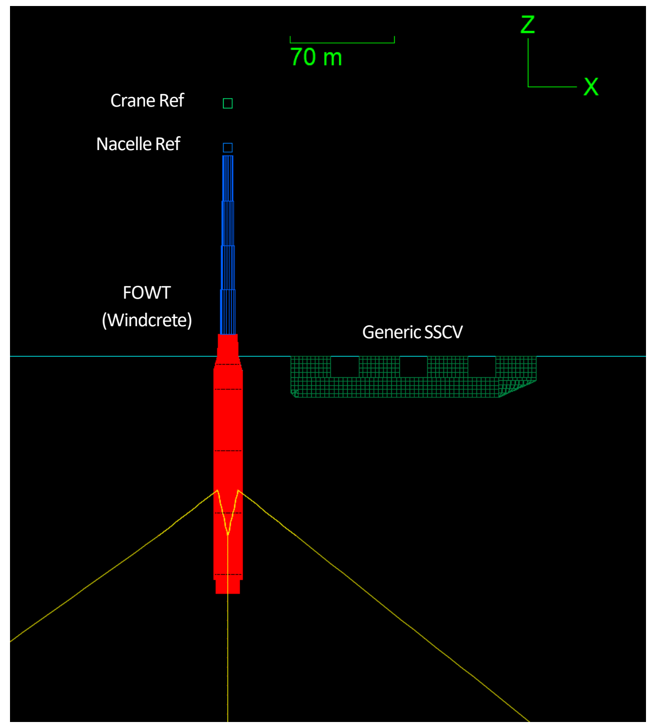
Optimized Resources, OPEX and Availability

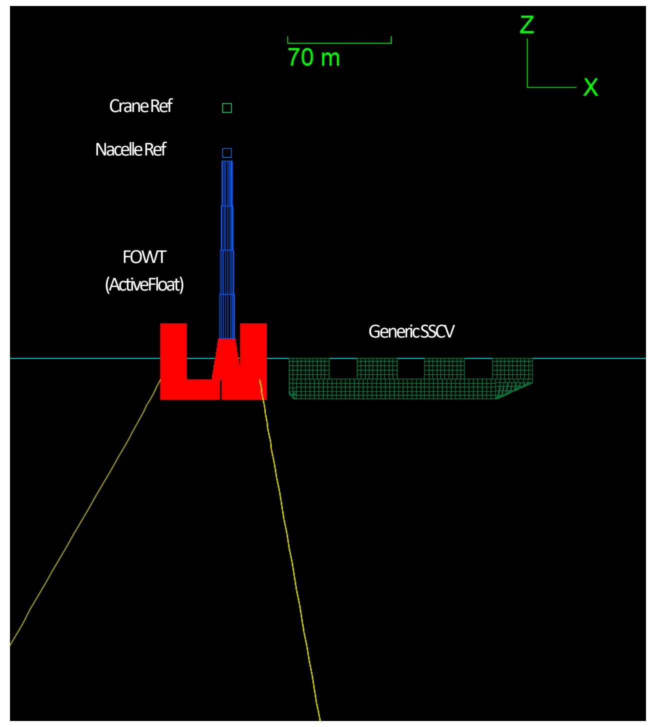
Model Assumptions:
Resource costs, distances, fuel consumption, vessel fleet composition, reliability parameters, durations, weather prediction, availabilities, durations, …

Operation and Maintenance Strategy Development and Optimization

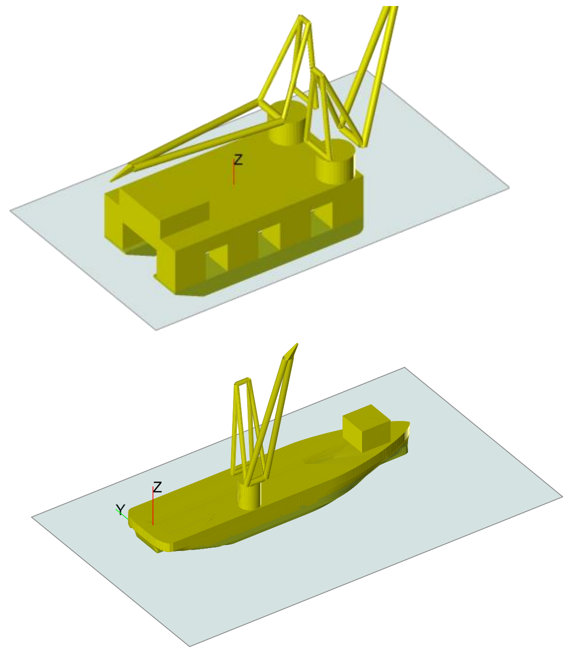
Floating-to-Floating (F2F) Scenario:

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





Generic heavy lift vessels: semi-sub & monohull

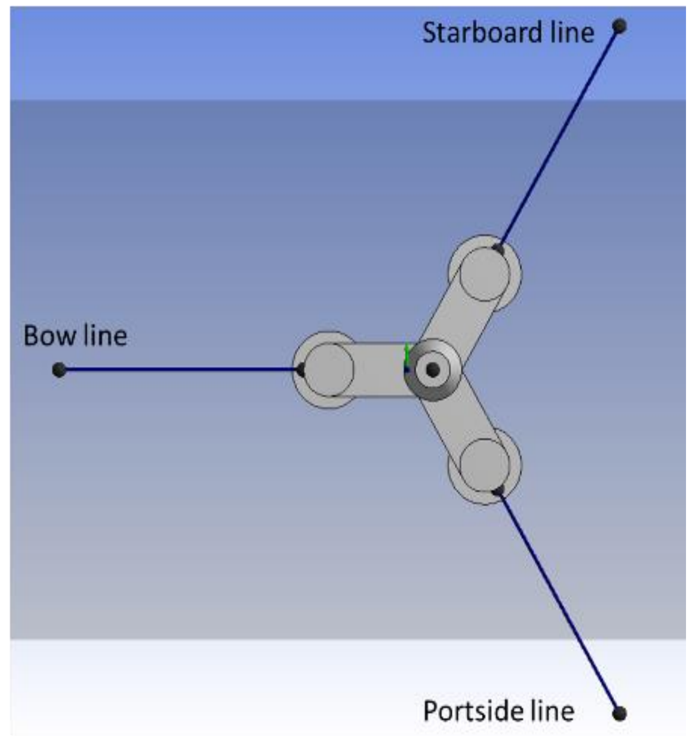


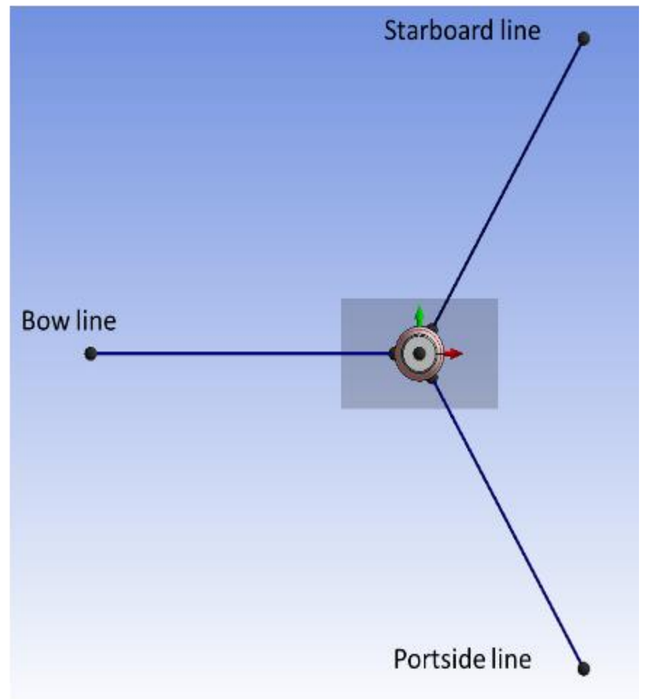
Results: Operational limits based on relative motions and compensation requirements (relative vertical velocity)

Operational conditions		Hs							
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
TP	0-2								
	2-4								
	4-6								
	6-8								
	8-10								
	10-12								
	12-14								
	14-16								
	16-18								
	18-20								
	20-22								
	22-24								

Tow-In Scenario:

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



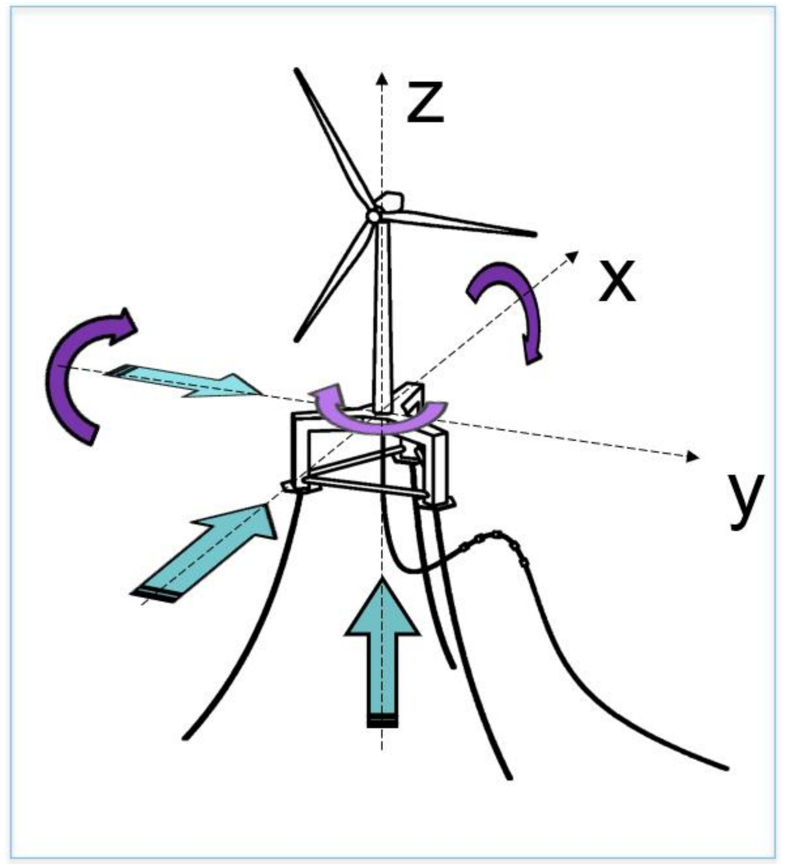


Results: Operational limits based on motion criteria

Operational conditions		Hs							
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
TP	0-2								
	2-4								
	4-6								
	6-8								
	8-10								
	10-12								
	12-14								
	14-16								
	16-18								
	18-20								
	20-22								
	22-24								

Operation and Maintenance Strategy Development and Optimization

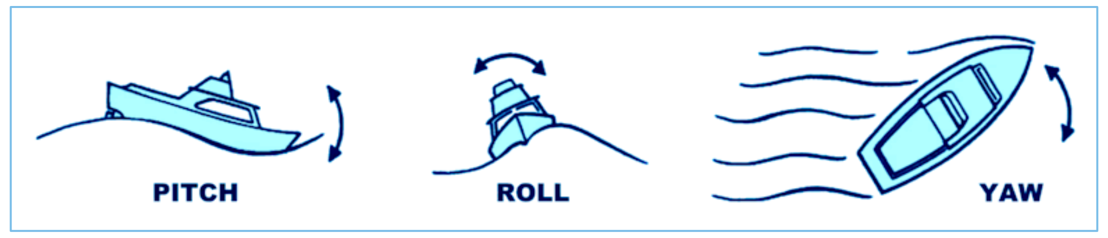
Workability and Transportability:



Source: Schwarzkopf 2018, RWTH University

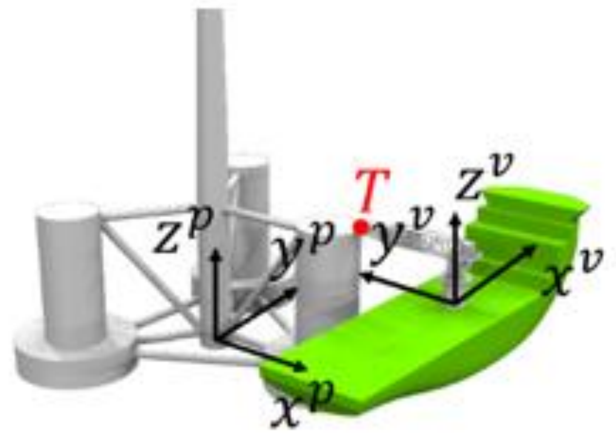
Approach: Post-processing of motion signal to assess its effect on Human Comfort (e.g. sea-sickness)

Results: Transportability and Workability limits on the vessel and Floater

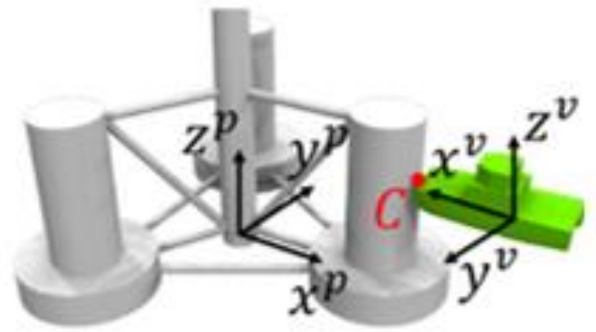


Source: https://mechanicalelements.com/trailer-attitude-pitch-yaw-roll/

Accessibility for CTV and SOV:



Approach: Frequency domain post-processing of coupled RAO signal for different sea states



Results: Operational limits based on motion criteria

Accessibility of CTV

Operational conditions		Hs							
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
TP	0-2								
	2-4								
	4-6								
	6-8								
	8-10								
	10-12								
	12-14								
	14-16								
	16-18								
	18-20								
	20-22								
	22-24								

Comparison of major component exchange strategies

Tow-to-port

Source: Principle Power

Floating-to-Floating

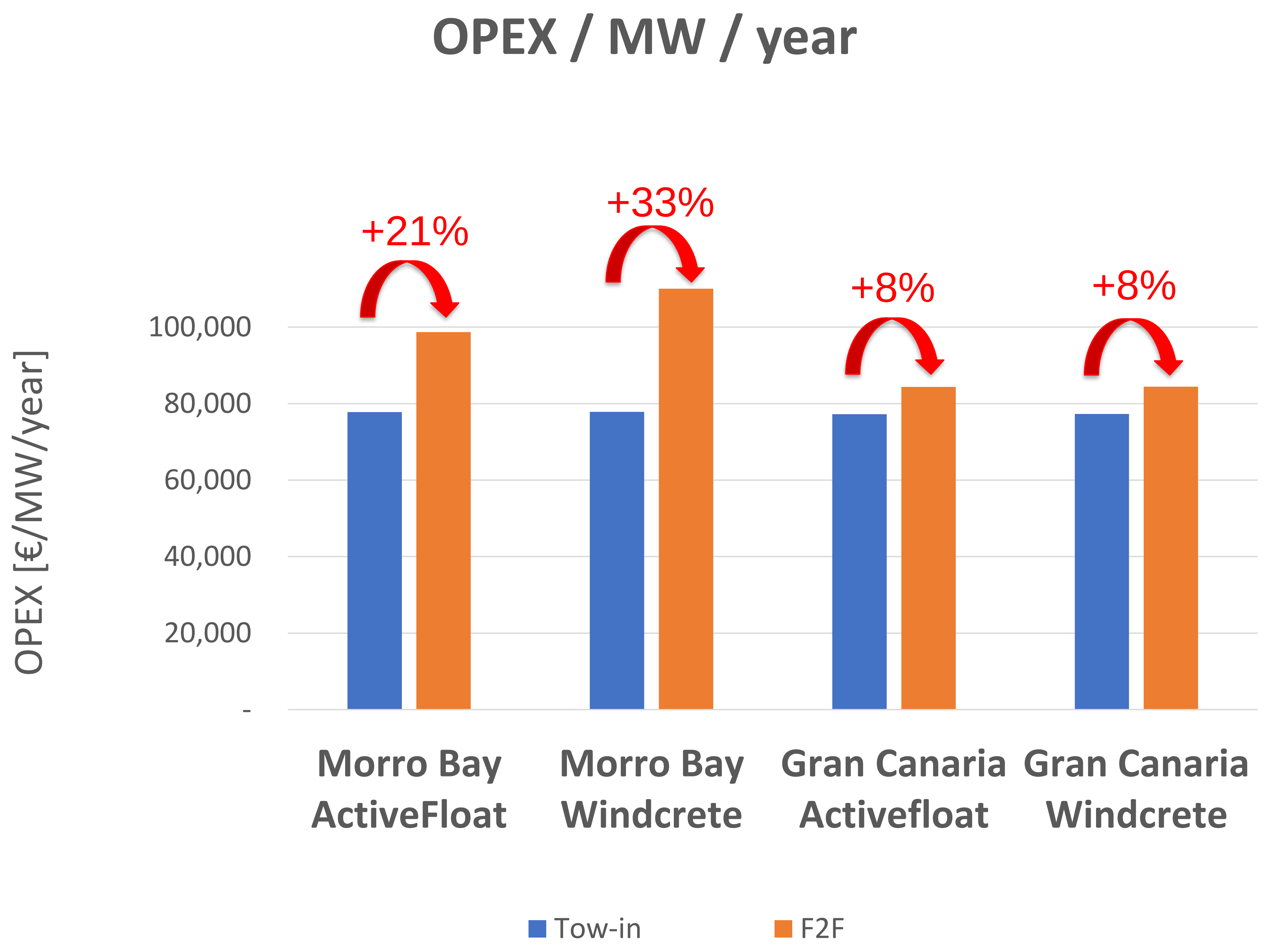
Source: Heerema

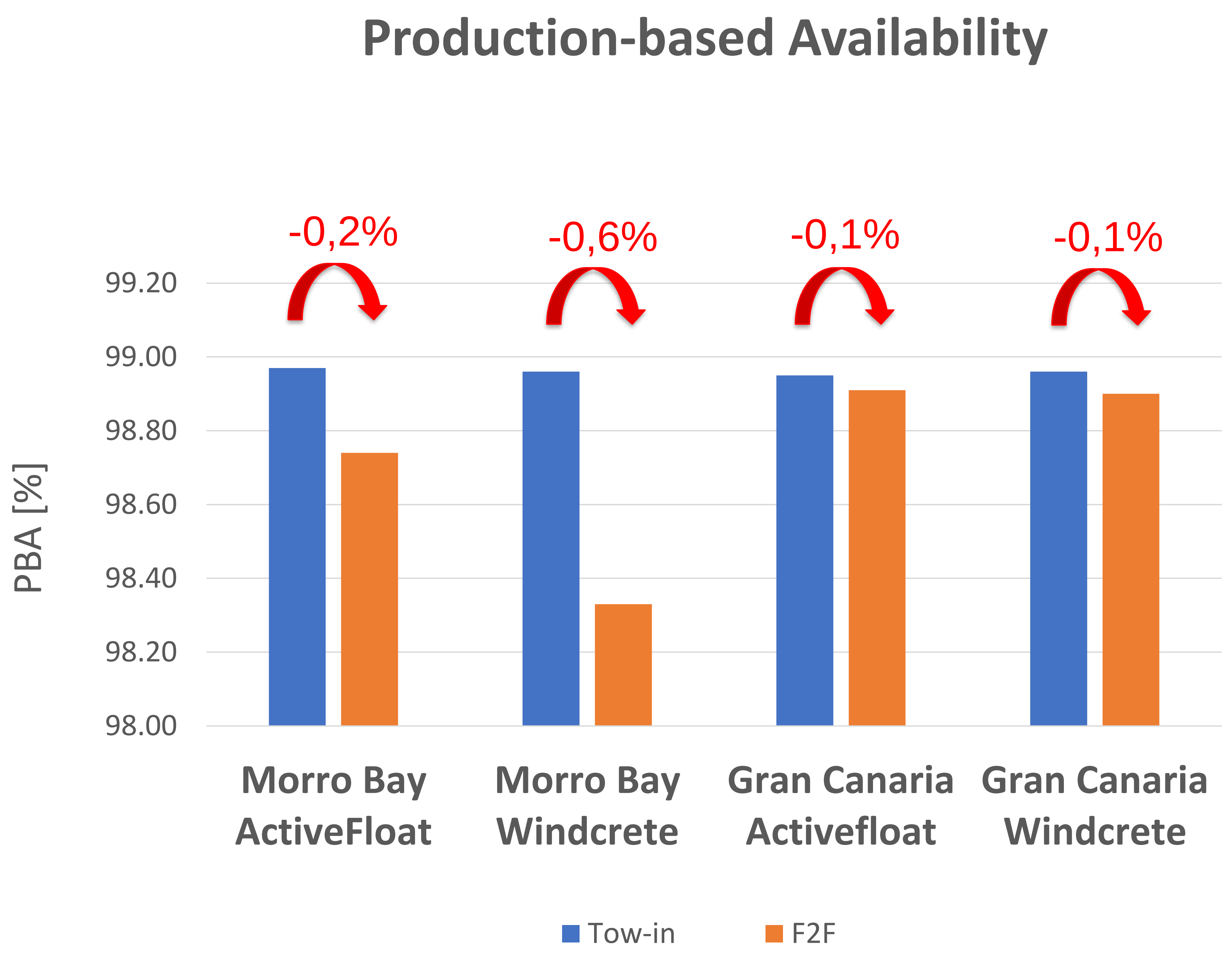
Self-hoisting/ mounted Crane

Source: Liftra A.S.

Comparison of major component exchange strategies

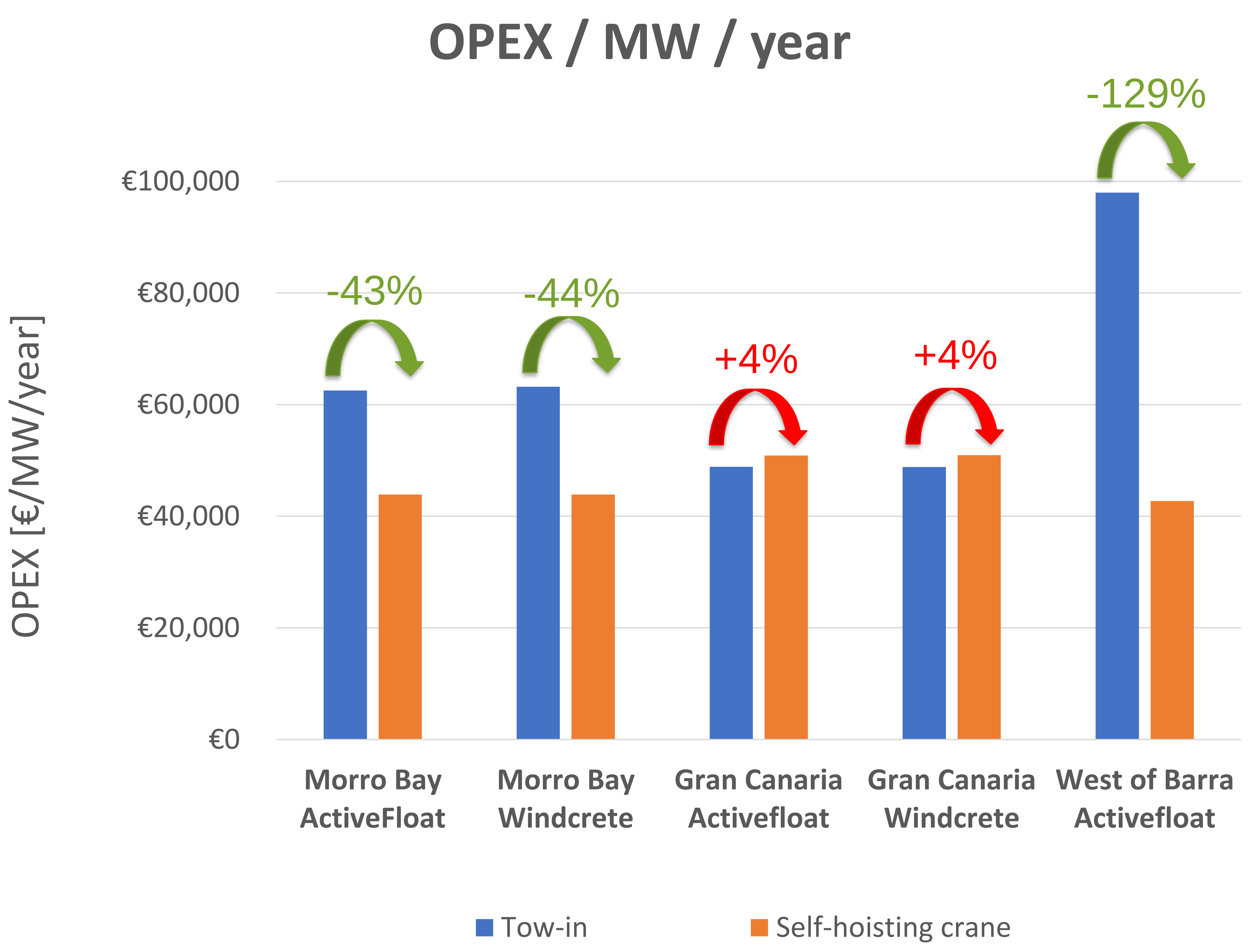
Aim: Comparison of the **Floater Tow-In** to harbour to the in-situ component exchange with a **Floating Crane Vessel**

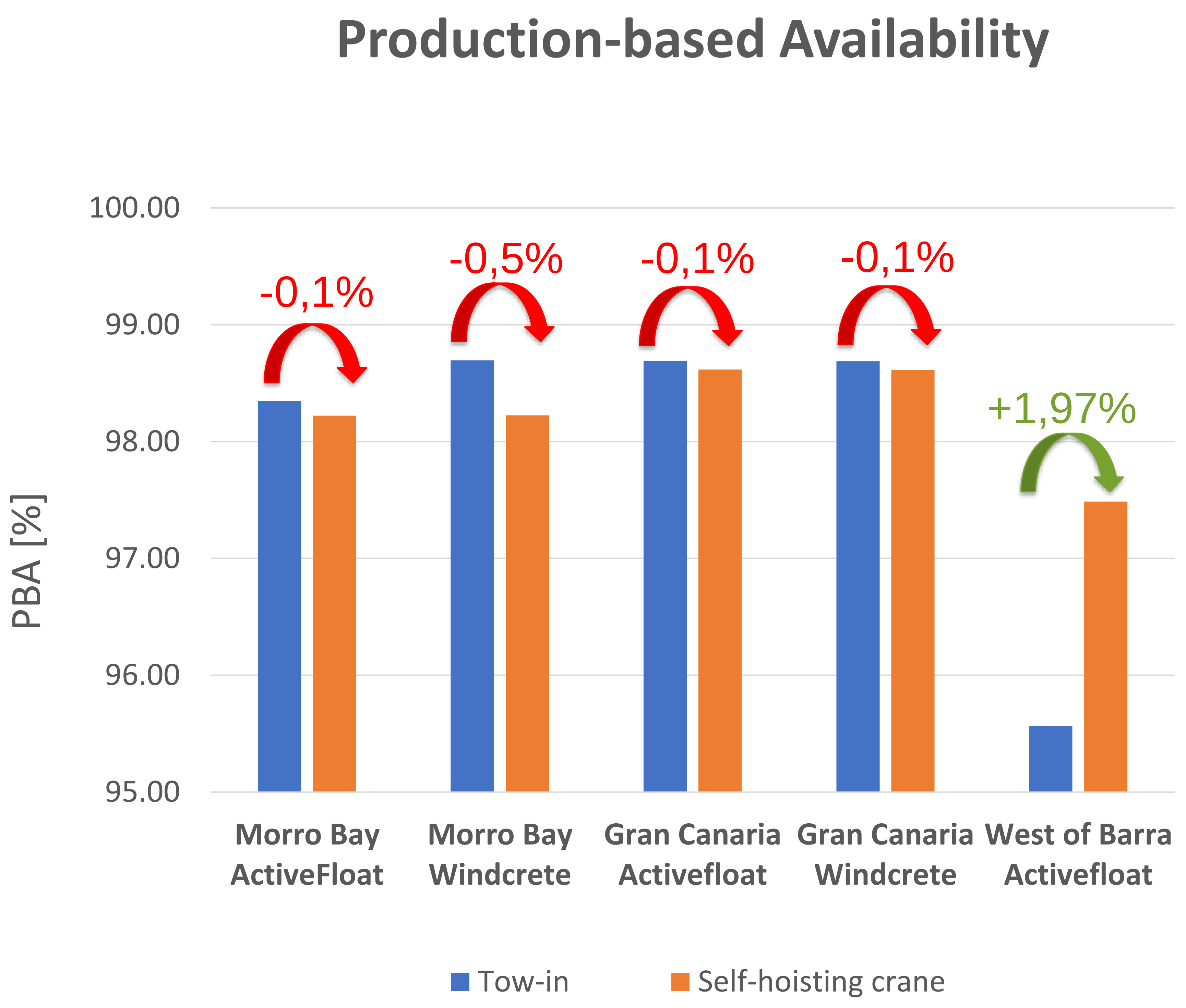




Comparison of major component exchange strategies

Aim: Comparison of the **Floater Tow-In** to harbour to the in-situ component exchange with a **Self-Hoisting Crane**





Comparison of major component exchange strategies

- **Major Cost driver** for F2F are **dayrates and mobilisation costs** of the floating crane vessels, thus vessel price fluctuation could change the outcome of the study

- As the durations of the operations were similar for tow-in and in-situ solutions, the **self-hoisting crane** did not prove more efficient under favorable weather conditions, however in harsher conditions the **tow-in operation** was significantly hindered, allowing the self-hoisting crane to prove a potential to reduce downtime and costs

Effect of structural health monitoring technologies on OPEX

Assumptions on the SHM system

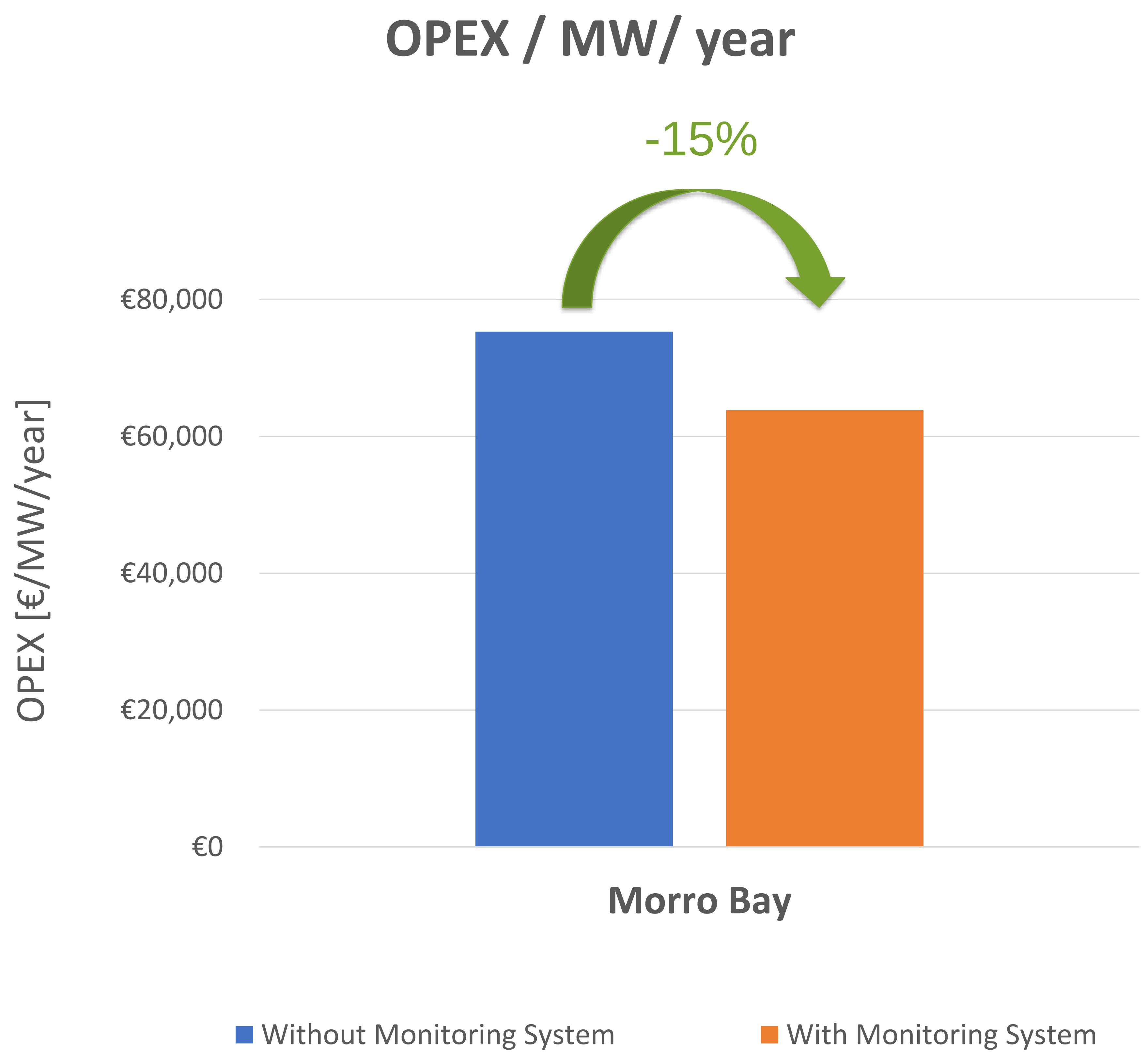
- Alarm is triggered for
  - Mooring line dislocation and twist
  - Mooring line breakage
  - Anchor dislocation
  - Anchor loss
- "ideal" functioning of the system
- System downtime has been neglected

Effect of SHM on O&M Phase

- Knowledge gain on the status of the asset
- Interval between maintenance activities can be reduced (risk-based approach)
- The timely detection and proper calibration of technologies enable prompt action on alarms indicating potential failures, preventing functional failure from occurring.
- Long vessel lead times will be reduced due to early failure detection
- Lower vessel prices for due to longer planning time of marine interventions

Effect of structural health monitoring technologies on OPEX

- Quantification of the effect of SHM systems on the O&M phase

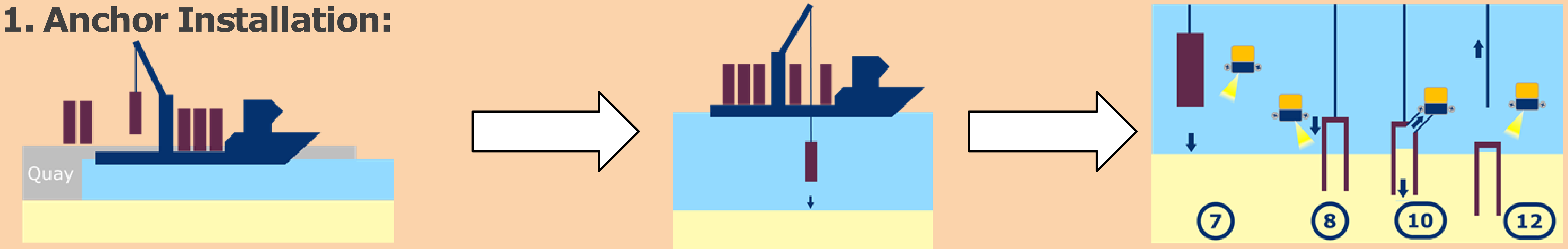


- The monitoring of the station keeping system allowed a reduction of 15% (11.500 €/MW/year) of the OPEX in the studied scenario.

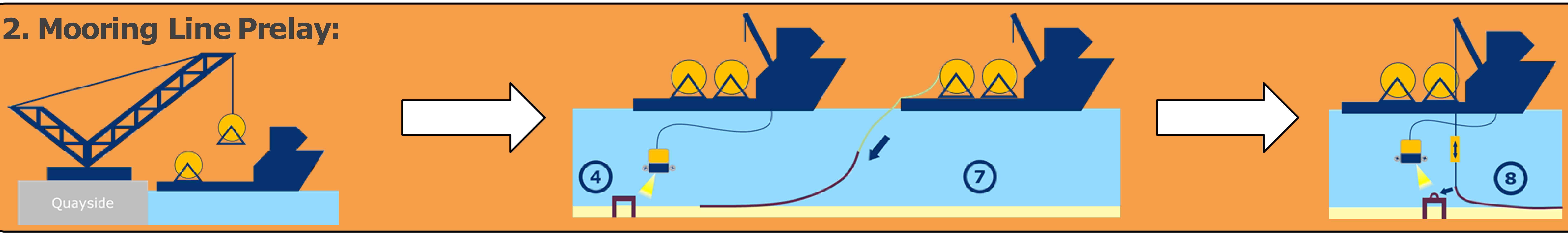
Installation strategy, duration, and weather windows

- Work Breakdown was iteratively optimized to reduce weather downtime and increase workability
- Operational limits and vessel requirements were established through detailed calculations

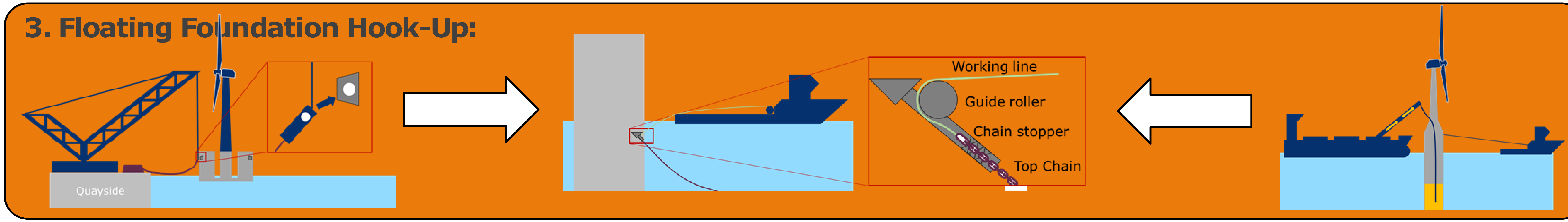
1. Anchor Installation:



2. Mooring Line Prelay:



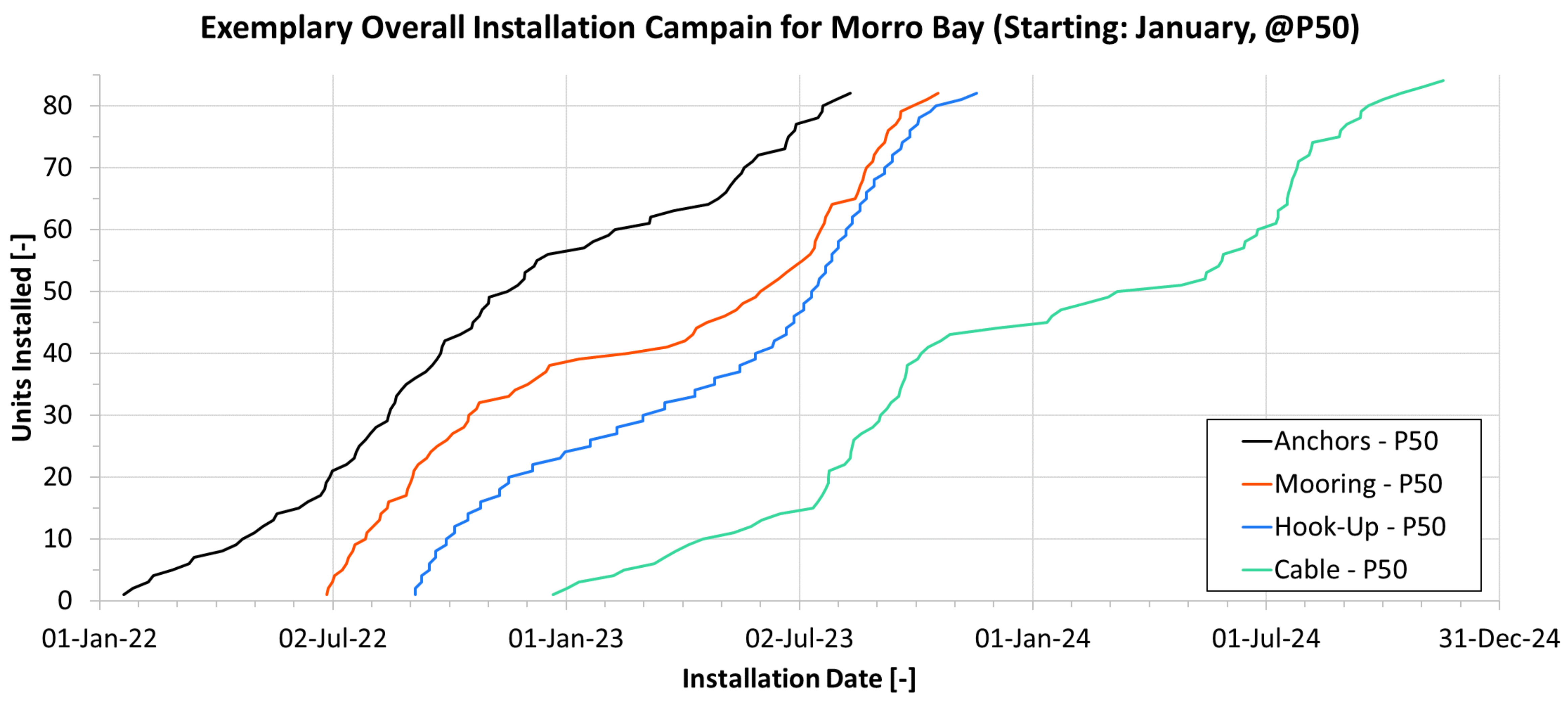
3. Floating Foundation Hook-Up:



4. Power Cable Installation (IAC and EXC)

Installation results

➢ Challenging weather conditions (swell, Hs) leading to lower workabilities compared to Western Europe and APAC with weather downtime compared to campaign duration of ~60 – 80%



Overall Campaign	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Workability: P10	42%	41%	42%	47%	53%	56%	70%	77%	72%	65%	48%	46%
Workability: P30	33%	32%	31%	38%	44%	47%	64%	70%	64%	53%	40%	32%
Workability: P50	26%	24%	24%	30%	35%	40%	58%	63%	58%	44%	31%	23%
Workability: P70	17%	14%	16%	22%	27%	33%	53%	56%	52%	36%	22%	17%
Workability: P90	7%	1%	3%	9%	12%	21%	32%	43%	40%	23%	7%	6%

➢ Critical marine operations:
Anchor installation and hook-up less impacted by bad weather than the mooring pre-lay and cable installation

Conclusion

- Seasonal varying metocean conditions highly impacted the weather downtime at Morro Bay emphasising the importance of accurate metocean data for all sites and passages for reliable calculations.
  - Affecting Installation, Accessibility, Major Component exchange, and day-to-day maintenance.
- The accessibility limits of the vessel turned out to be more decisive than the workability limits for the technicians on the 15 MW wind turbine
- No clear strategy preference for major repairs: offshore onsite vs. tow-in to be evaluated in case-to-case studies
- Trend towards risk-based inspections and extrapolation of findings to wind turbine clusters

Thank you for your attention!

Contact:

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Senior Consultant at Ramboll Deutschland GmbH

Time for questions!

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

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

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COST REDUCTION OF
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FOWT Experimental testing: lowering engineering risks towards a full commercial scenario

Raul Guanche
R&D Group Manager Offshore Engineering and Ocean Energy
IH Cantabria

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:
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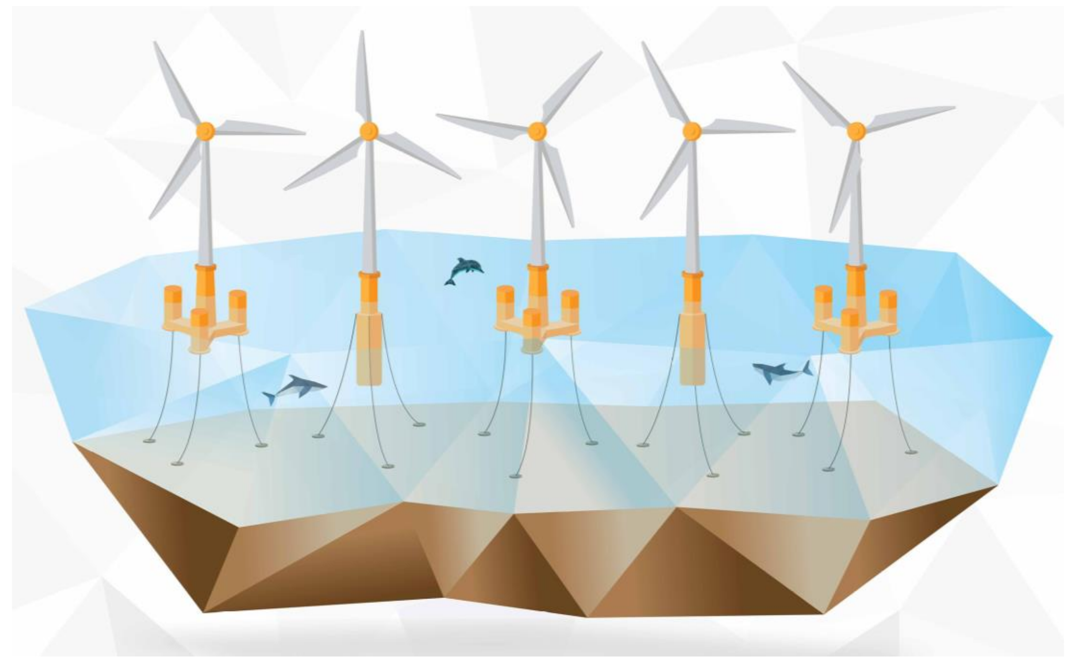
Objectives



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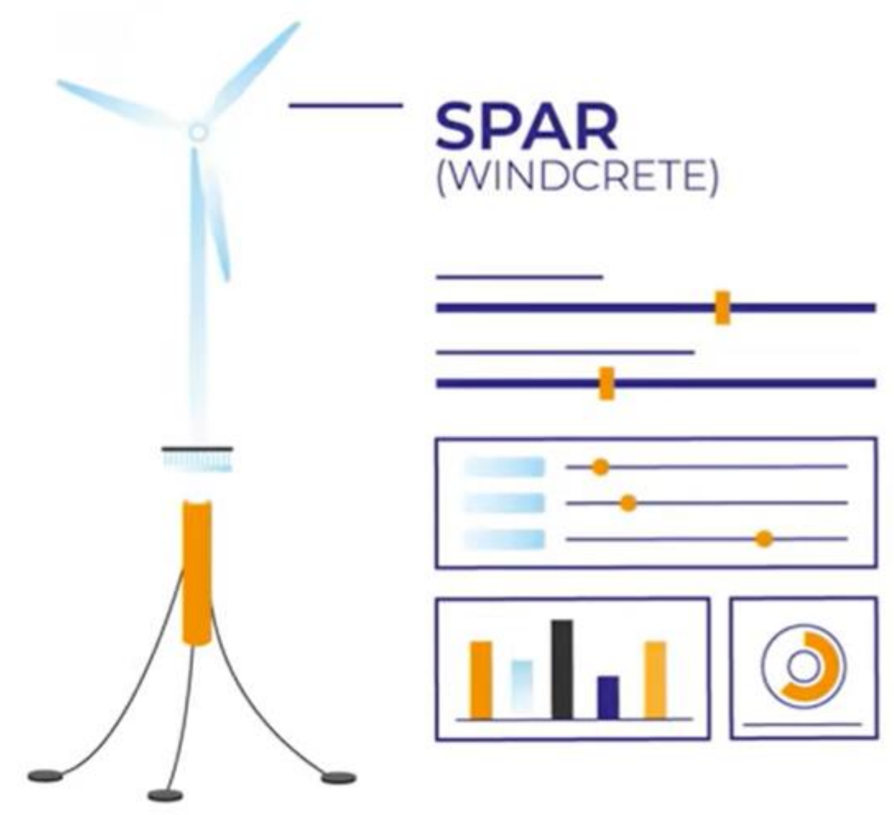

corewind Innovations

Floater + Mooring + Power Cable + Wind Turbine

- **Objectives :**

✓ **To deepen into coupled testing techniques** to evaluate wind-turbine control impact.

✓ **To understand mooring and power cable dynamics** under different loading conditions.

✓ **To validate innovations proposed** by **COREWIND** project.

✓ **To generate opensource experimental benchmarking database** leverage the development of coupled numerical models

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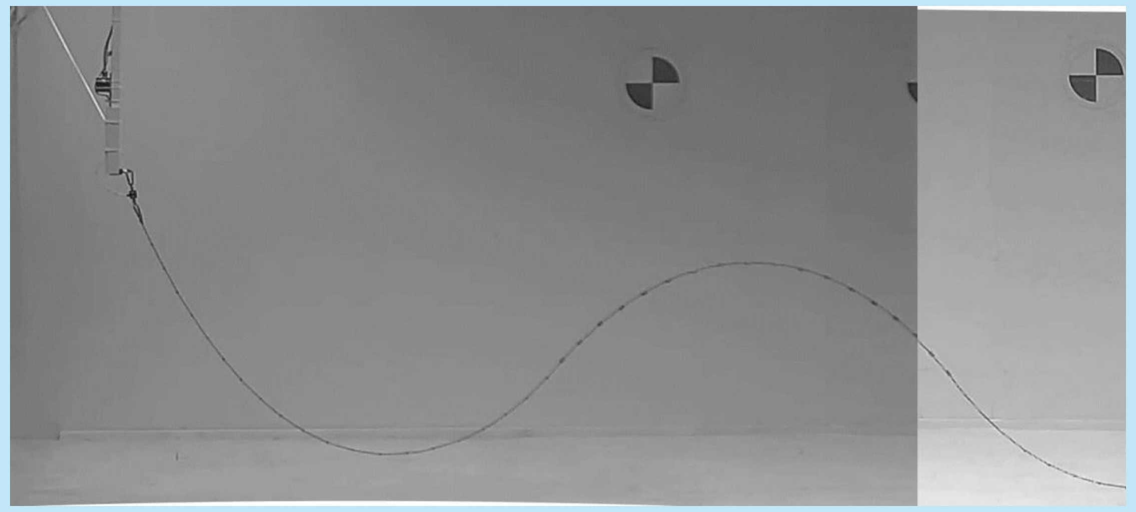
Testing facilities

Mooring and cable performance

Large scale wave flume



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INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

Marine Corrosion Test Site

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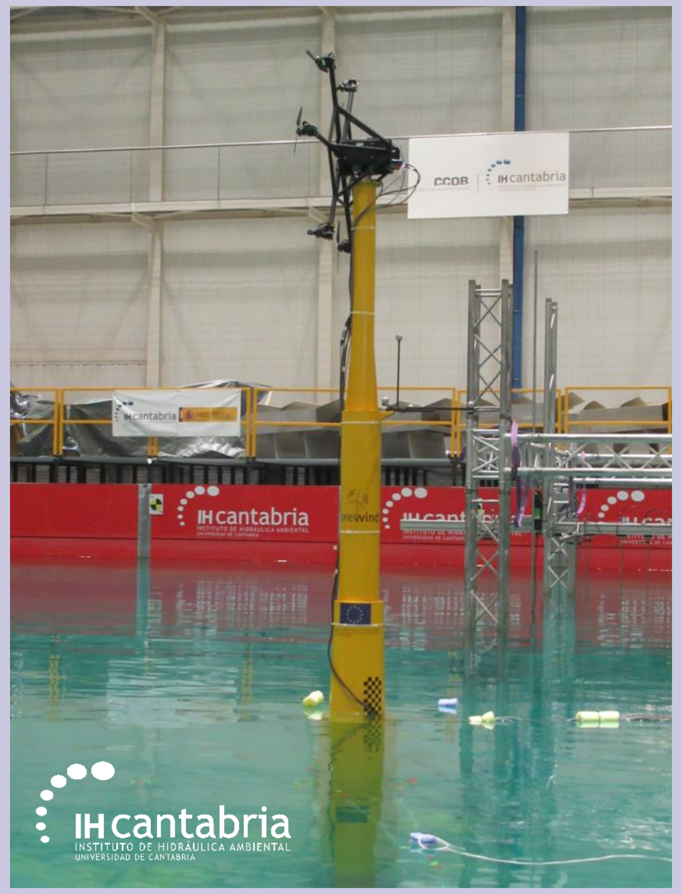
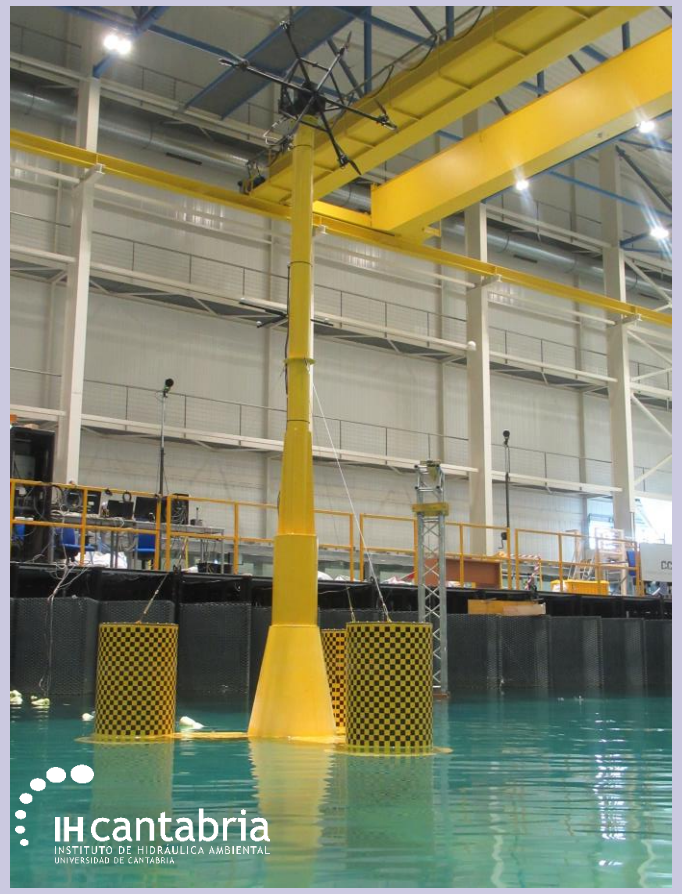
MCTS
EL BOCAL
DARE TO INNOVATE

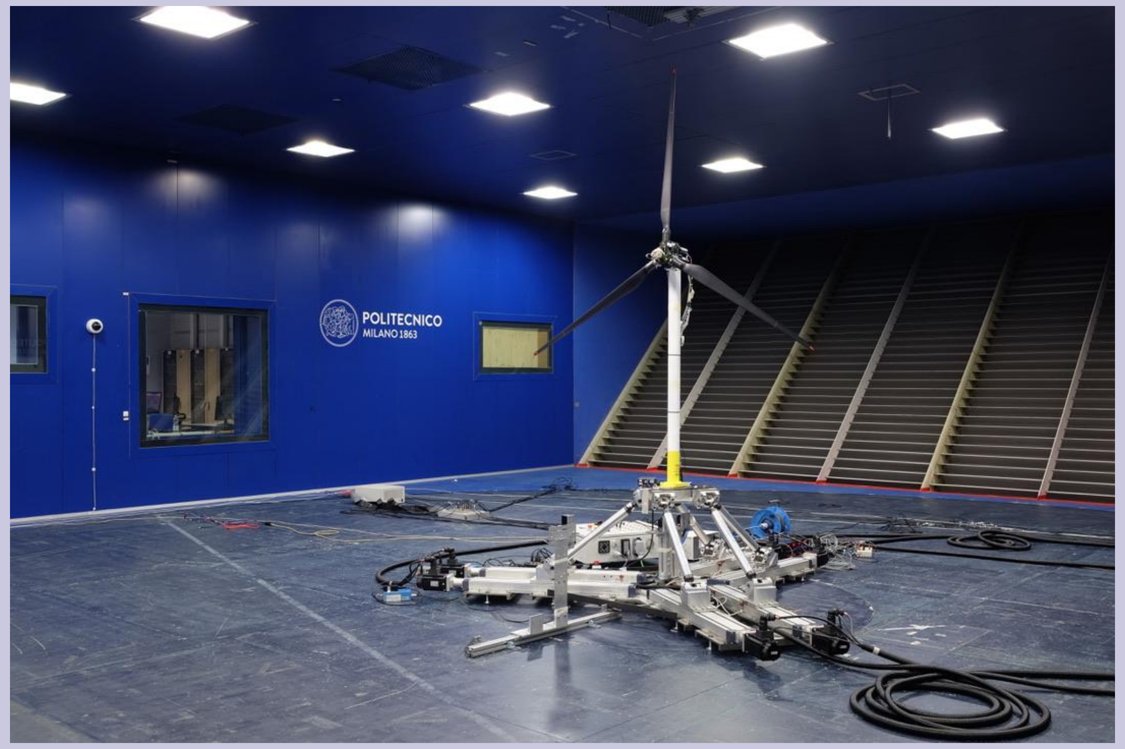
Coupled FOWT dynamics

Large scale wave basin





Large scale wind tunnel



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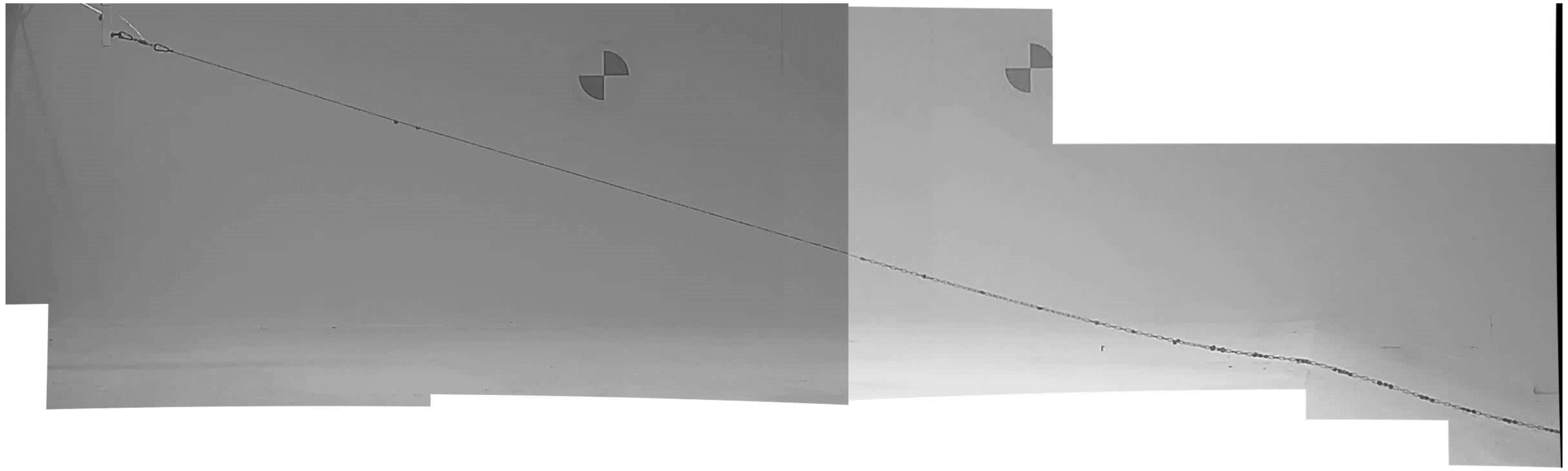
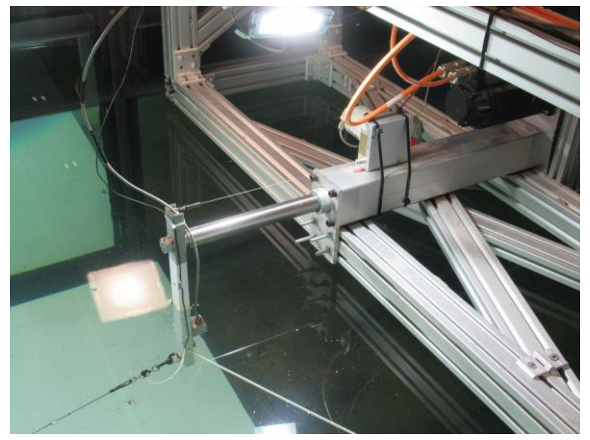
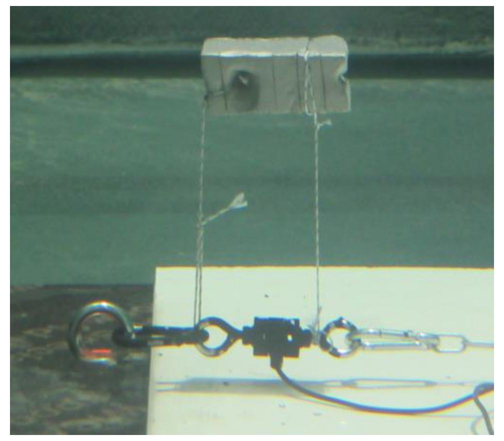
Mooring and power export cable dynamics

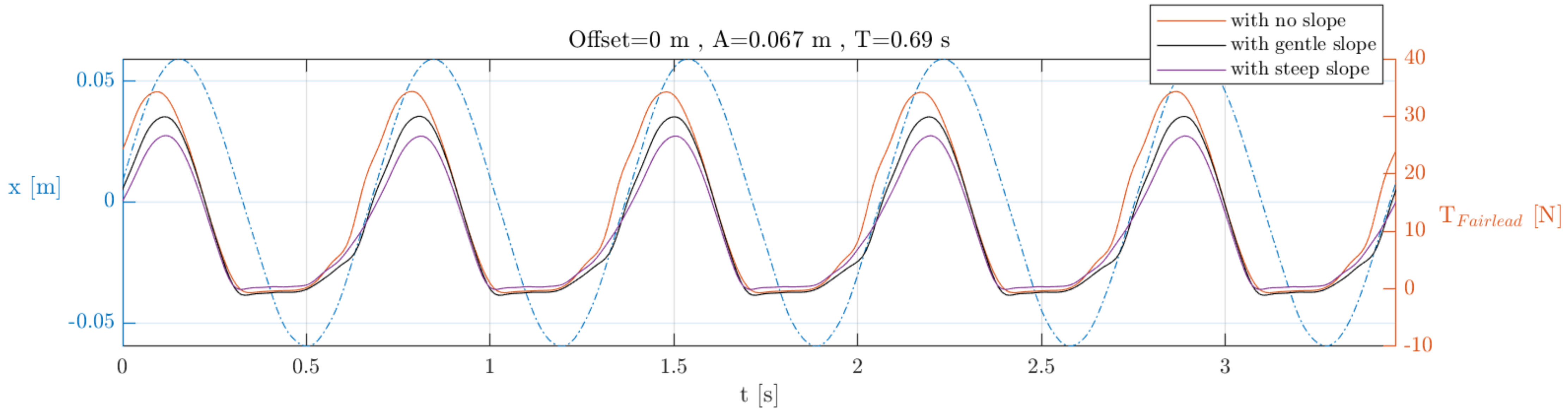


+400 forced oscillation tests have been conducted, recording simultaneously tensions and novel tracking images.

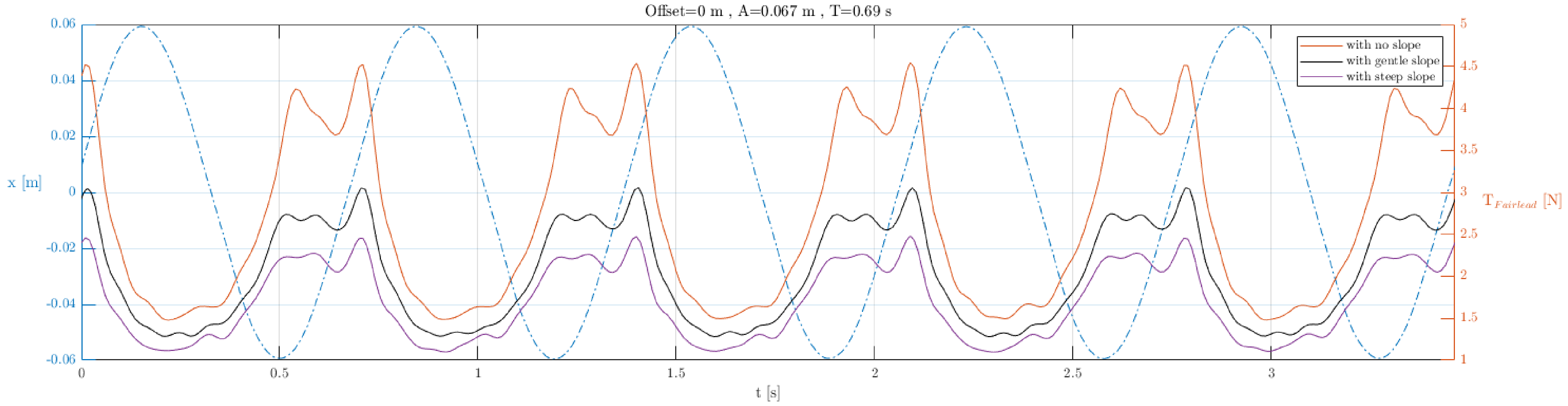




Elastic materials have allowed us to replicate **nylon mooring axial stiffness and cable axial-bending stiffness**.



Elastic mooring line



Conventional catenary mooring line

Importance of elasticity over mooring line extreme peak loads:

- Elastic mooring lines evidenced quasi-static performance in comparison with the highly nonlinear dynamics of conventional catenary lines.

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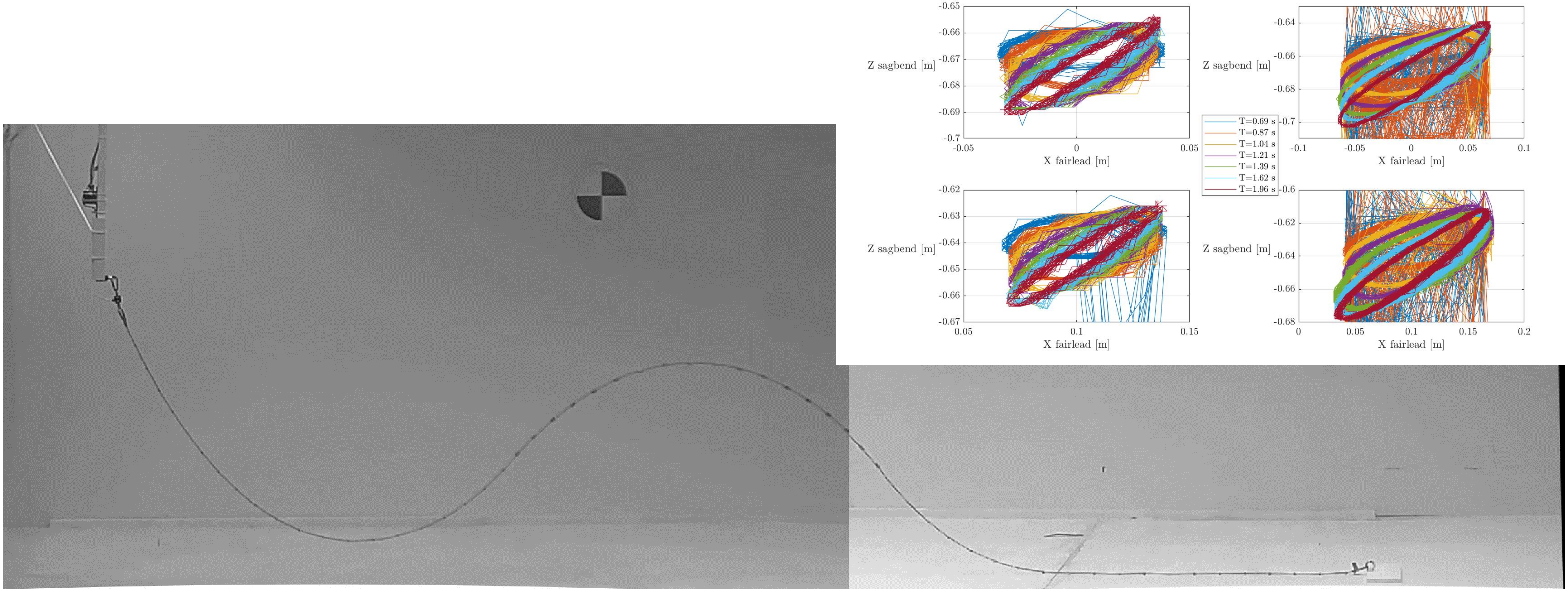
Mooring and dynamic cable experimental analysis



Barriers faced:
- Cable mechanical properties
- Cable layout

Outcomes
- Detailed power dynamic database
- Lazy wave dynamics under realistic fairlead movements

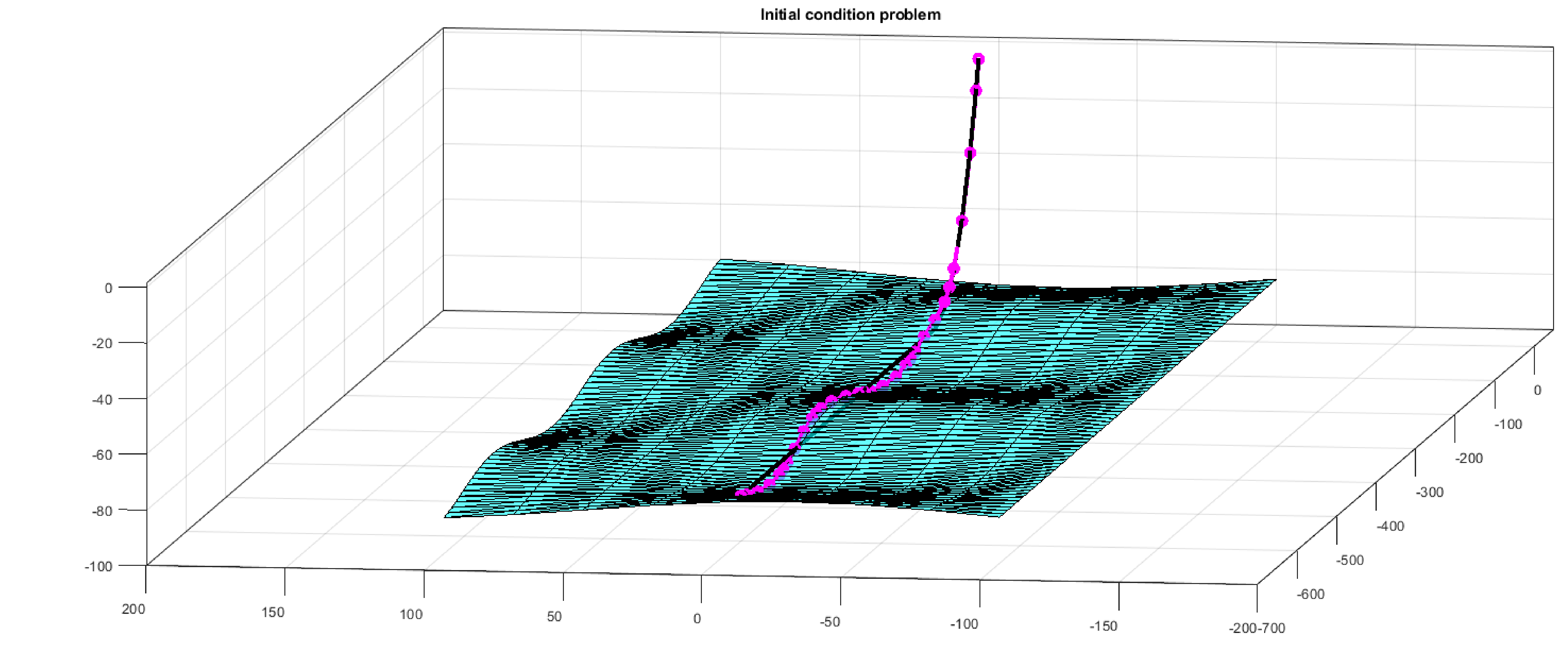
Mooring and dynamic cable experimental analysis: KEY OUTCOMES

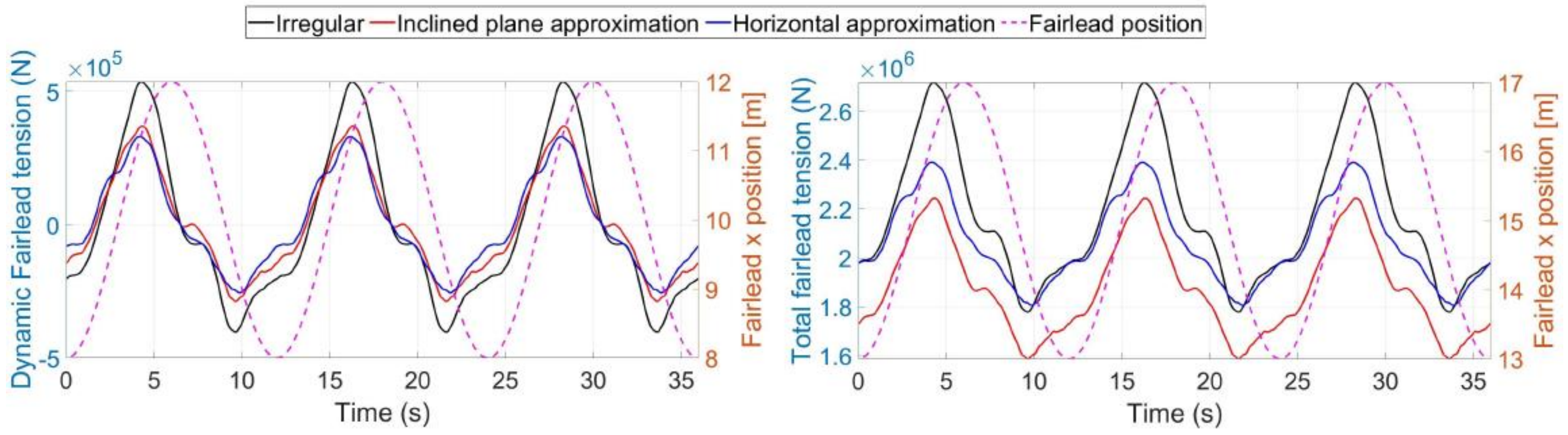
a) **Improved understanding of chain-nylon mooring lines** and power cables dynamic behavior can optimize floating offshore wind structures.

b) Identification of mooring snap loads in chain-nylon mooring lines evidencing the damping effects over the peak mooring line loads

c) **Development of methodology for reproducing bending stiffness in cables** can be applied to other components of floating offshore wind structures: +25 materials have been characterized!

d) Generation of **an open source benchmarking database** for numerical modeling calibration and validation.





Importance of irregular bathymetry over mooring line loads estimation (all chain case):

- In a quasistatic performance, the maximum load observed does not change from flat bathymetry to irregular bathymetry.
- The contact point with the sea bottom have an strong influence over dynamic/snaping loads

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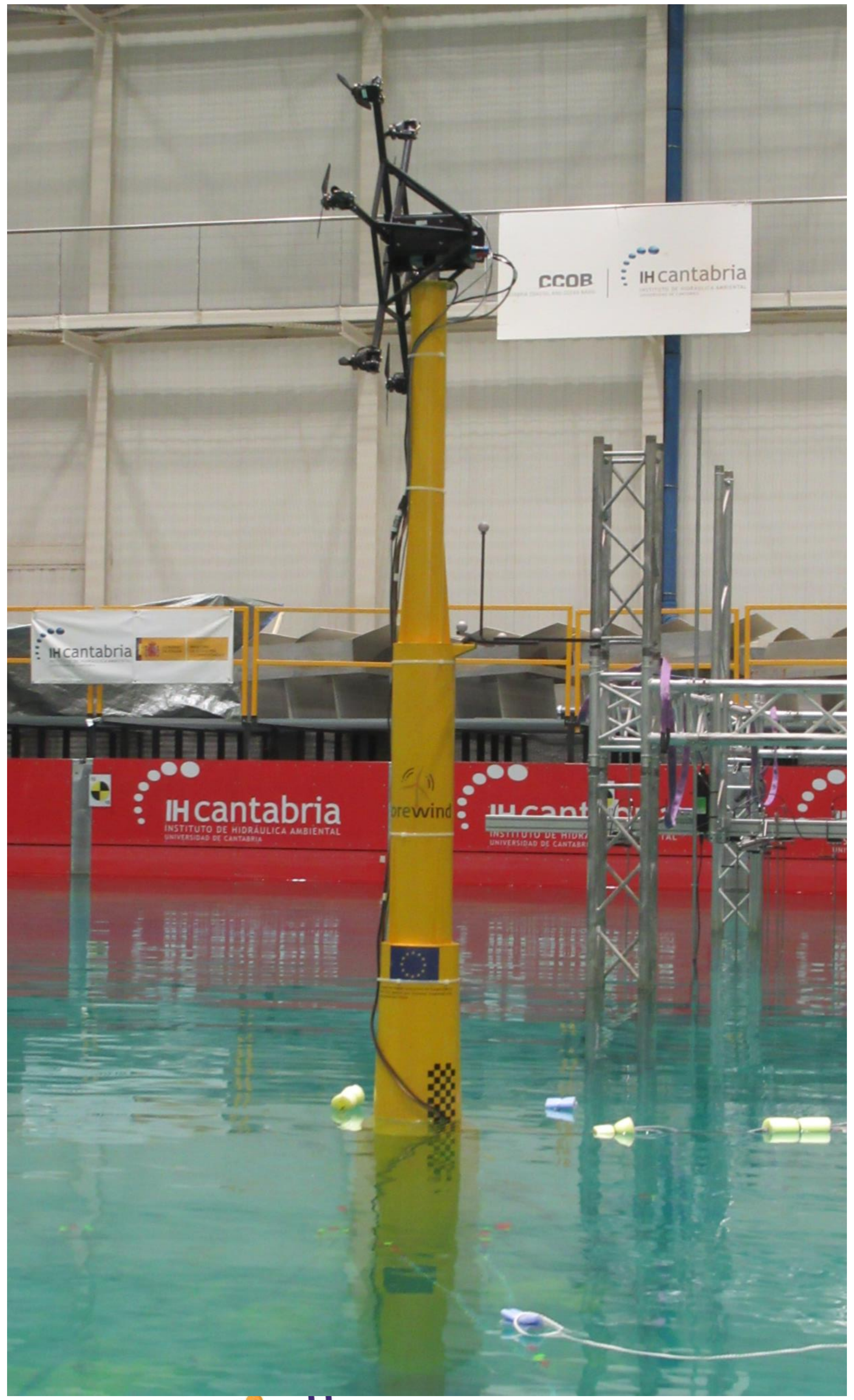
Coupled FOWT dynamics

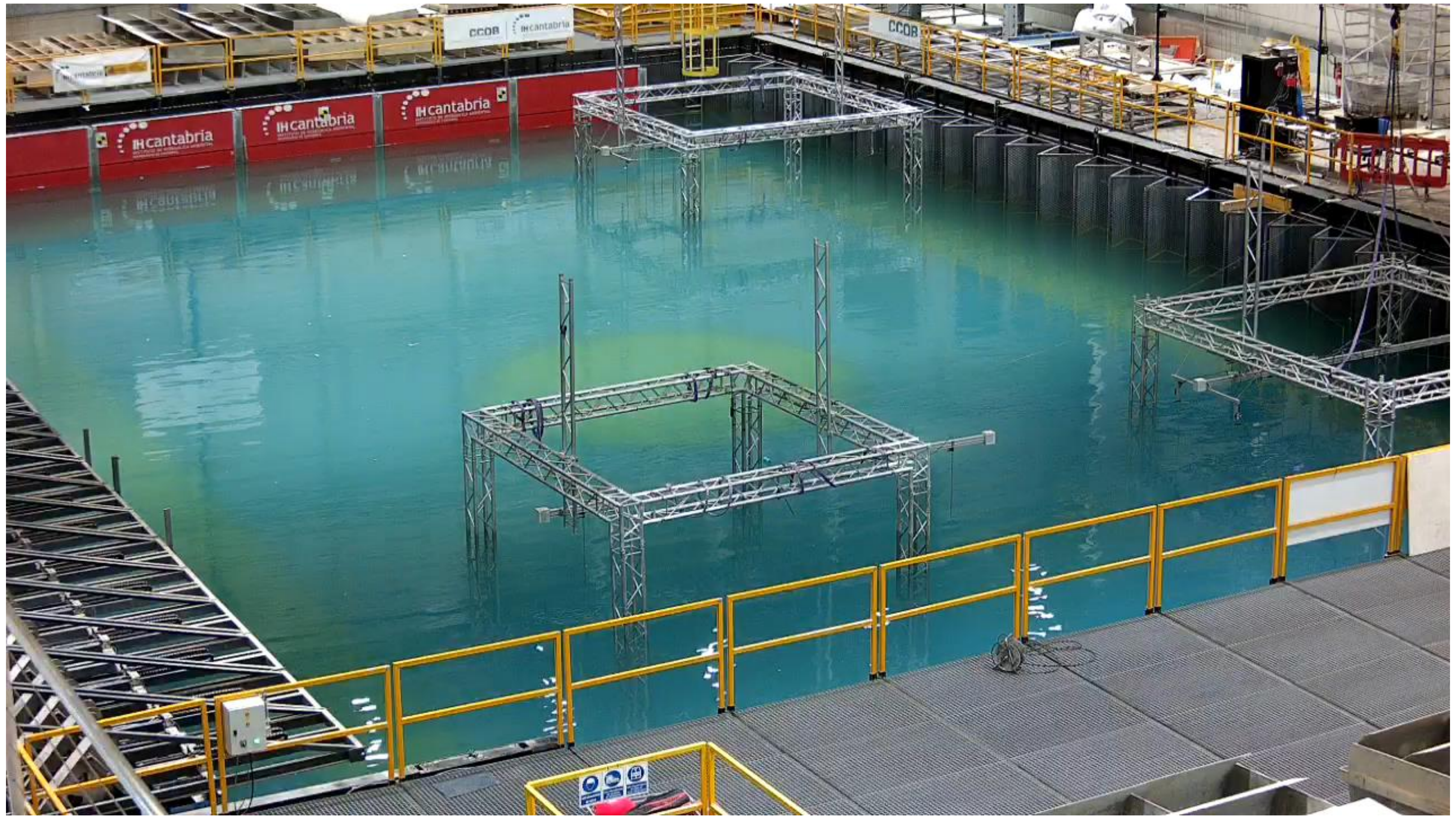
WINDCRETE



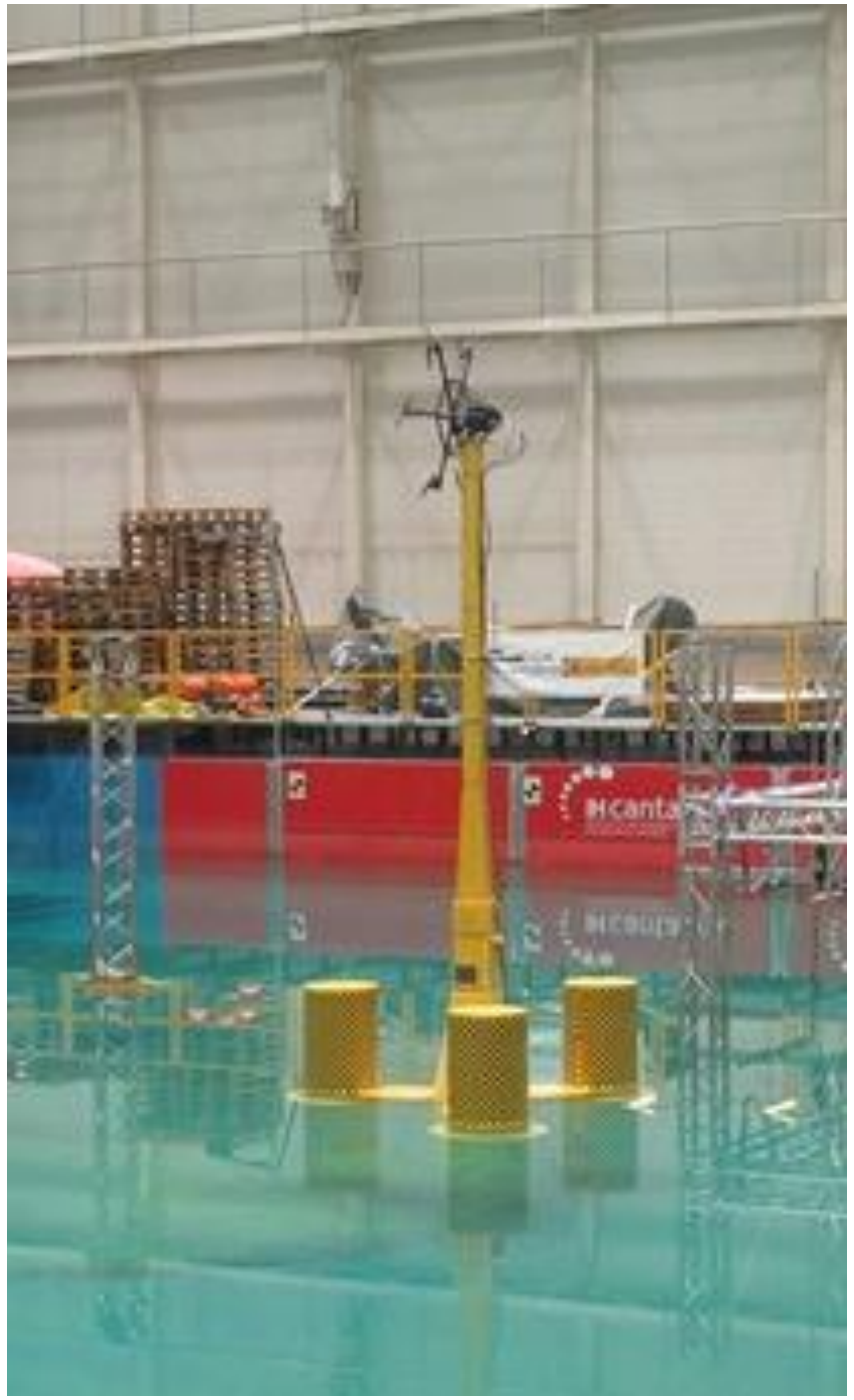
WINDCRETE test requirements and plan → Scale 1/55

ACTIVEFLOAT test requirements and plan → Scale 1/40

+135 tests has been carried out



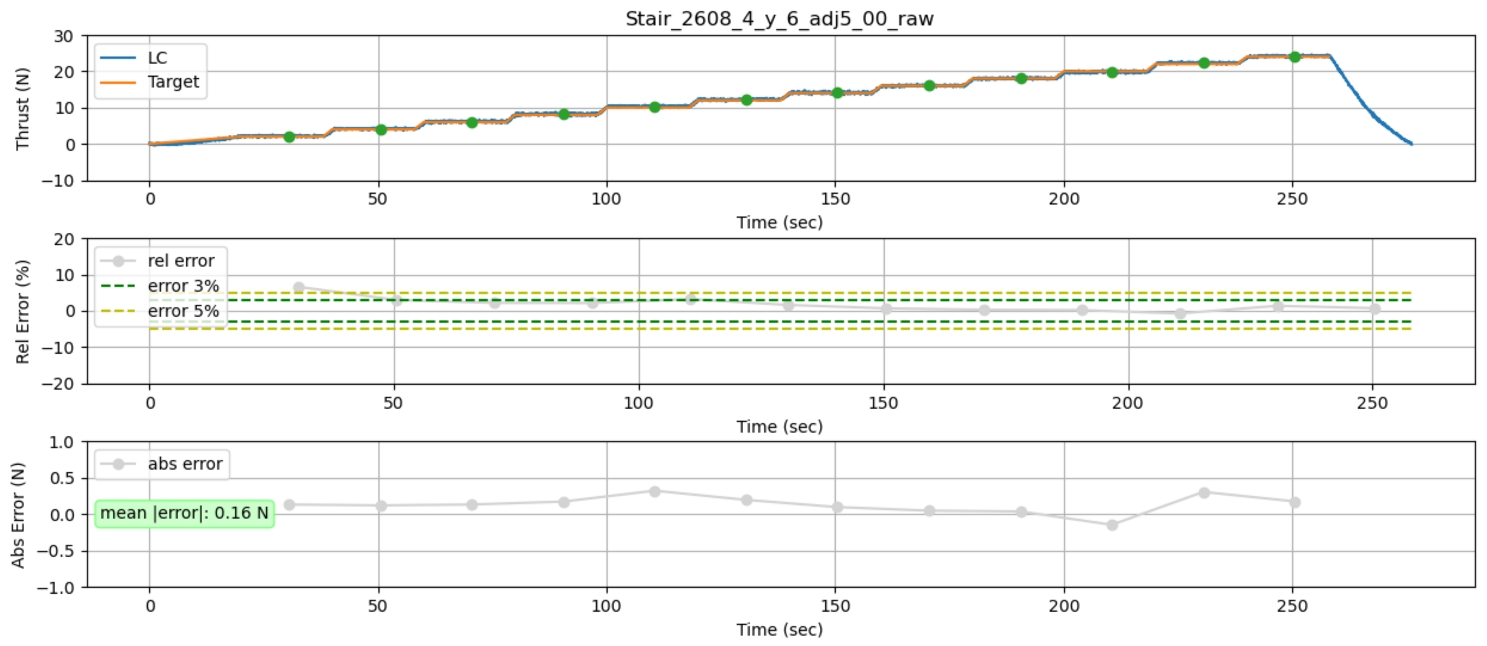
ACTIVEFLOAT



Coupled FOWT dynamics: Hardware in the loop methodology

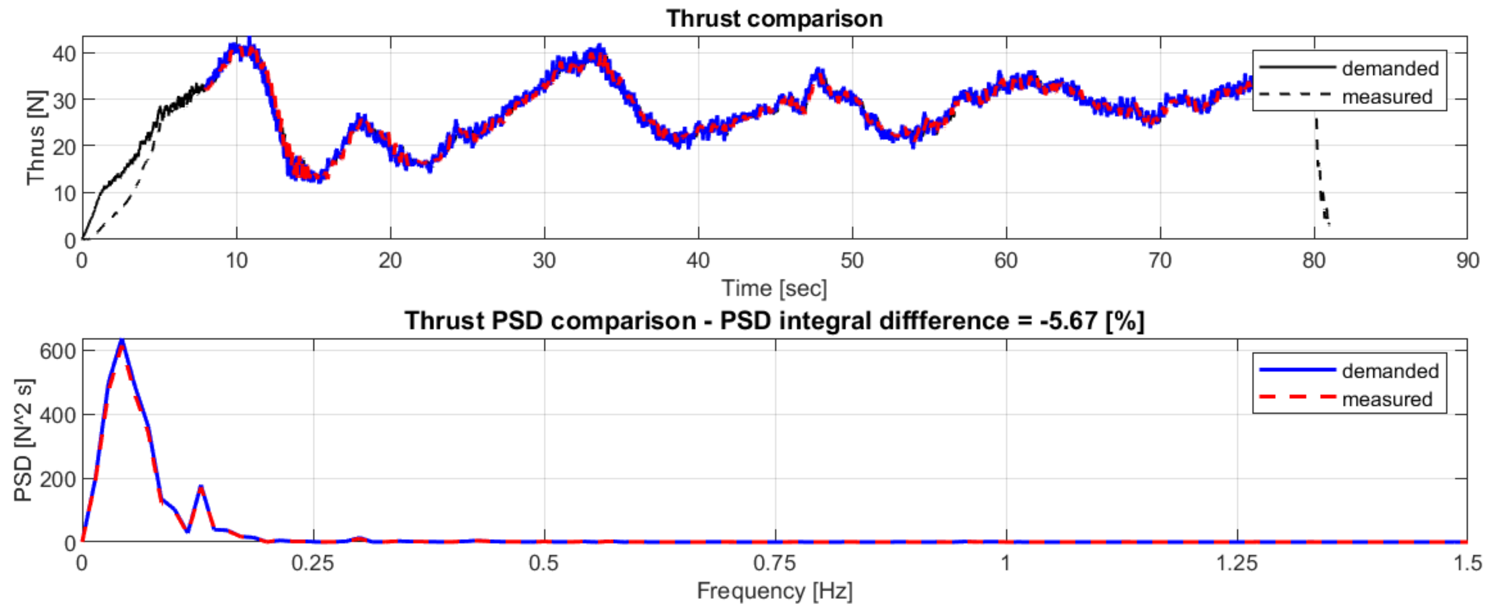
Wind turbine simulation

- Trust mean error: 0.16 N (< 3% of target Thrust)



Wind turbine simulation

- Turbulent wind : Error < 6% wind energy spectra



Fully coupled system:

Wind+Waves+Currents
Hydrodynamics + Turbine performance

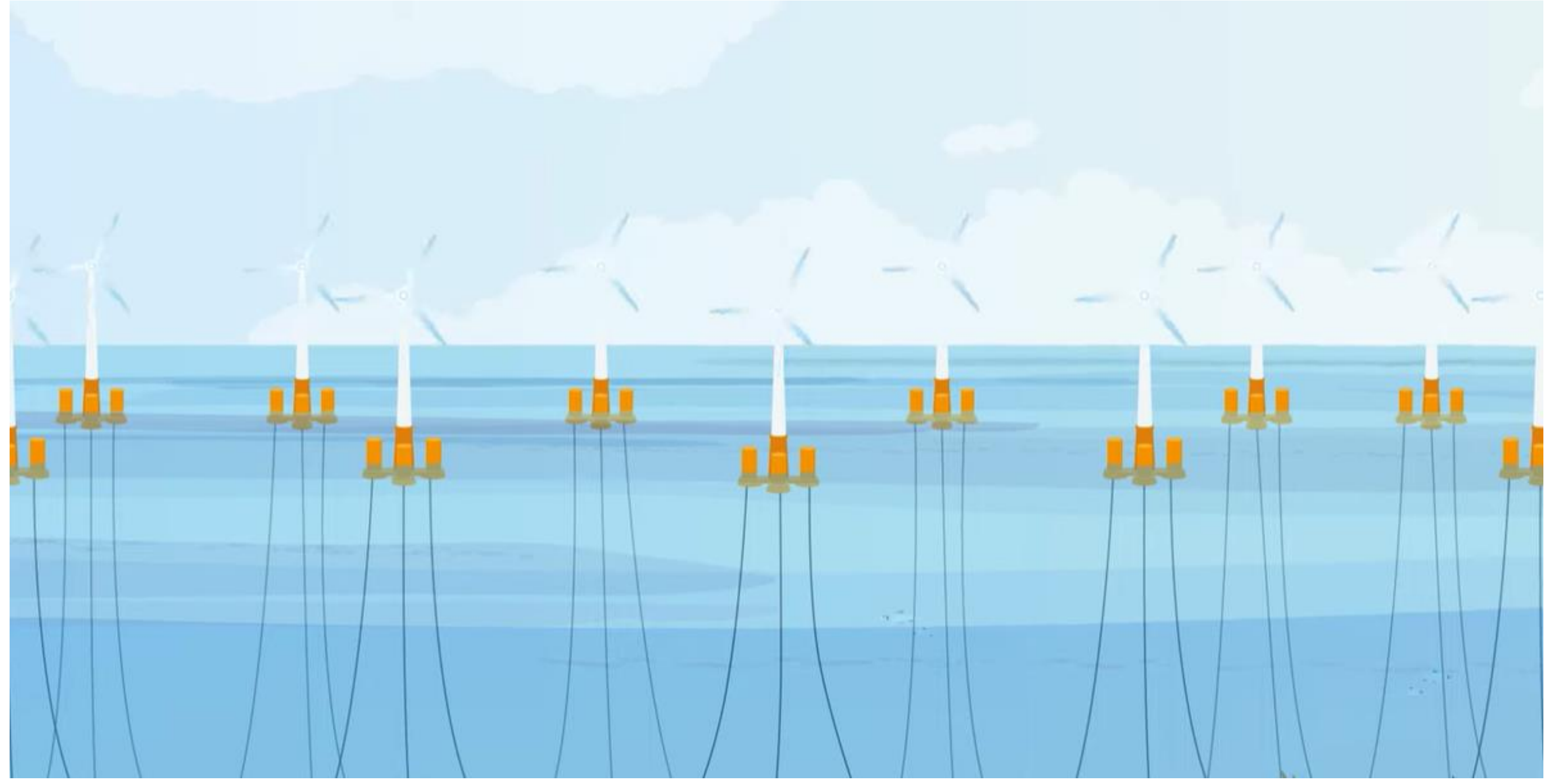
Coupled FOWT dynamics: WINDCRETE

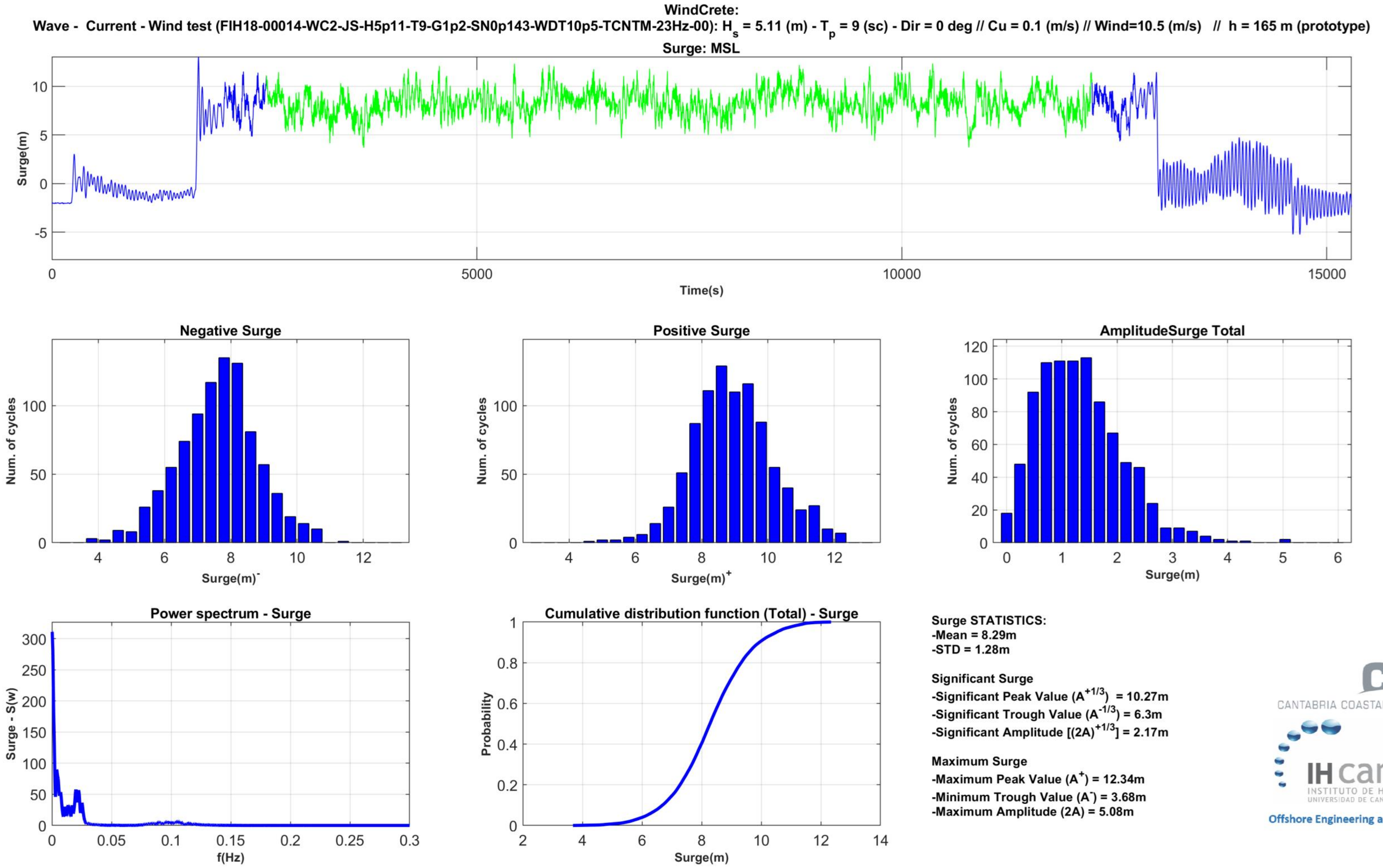
Irregular wave, currents and wind test – Hs 5.11 m Tp 9.0 sec – cu 0.143 m/s – WS 10.5 m/s

	unit	mean	min	max
surge	m	8.29	3.68	12.34
Sway	m	1.38	-7.88	10.68
heave	m	-2.06	-3.07	-1.15
roll	deg	0.45	-0.95	1.64
pitch	deg	4.39	2.18	6.34
yaw	deg	1.07	0.42	1.63
Acc X	m/s^2	0.00	-1.48	1.74
Acc Y	m/s^2	0.00	-0.65	0.70
Acc Z	m/s^2	0.00	-0.15	0.14

Coupled FOWT dynamics: WindCrete

Limit for	Acceptance Crit.	WINDCRETE
OPERATION		
Yaw (10 min. max)	<15º	1.65º ✓
Yaw (10 min. std)	<3º	0.15º ✓
Pitch (max.)	[-10.0º, +10.0º]	6.73º ✓
Pitch (10 min. average)	[-5.0º, +5.0º]	3.93º ✓
Roll (max.)	[-5.0º, +5.0º]	1.49º ✓
IDLING CONDITION		
Pitch (10 min. average)	[-5º, +5º]	4.38º ✓
Pitch (10 min. max)	[-15º, +15º]	6.33º ✓
ACCELERATIONS LIMITS		
Operation (acc. XY / acc. Z)	2.94 m/s2 (0.3 g)	0.98 m/s2 ✓
Survival (acc. XY / acc. Z)	4.41 m/s2 (0.45g)	1.74 m/s2 ✓





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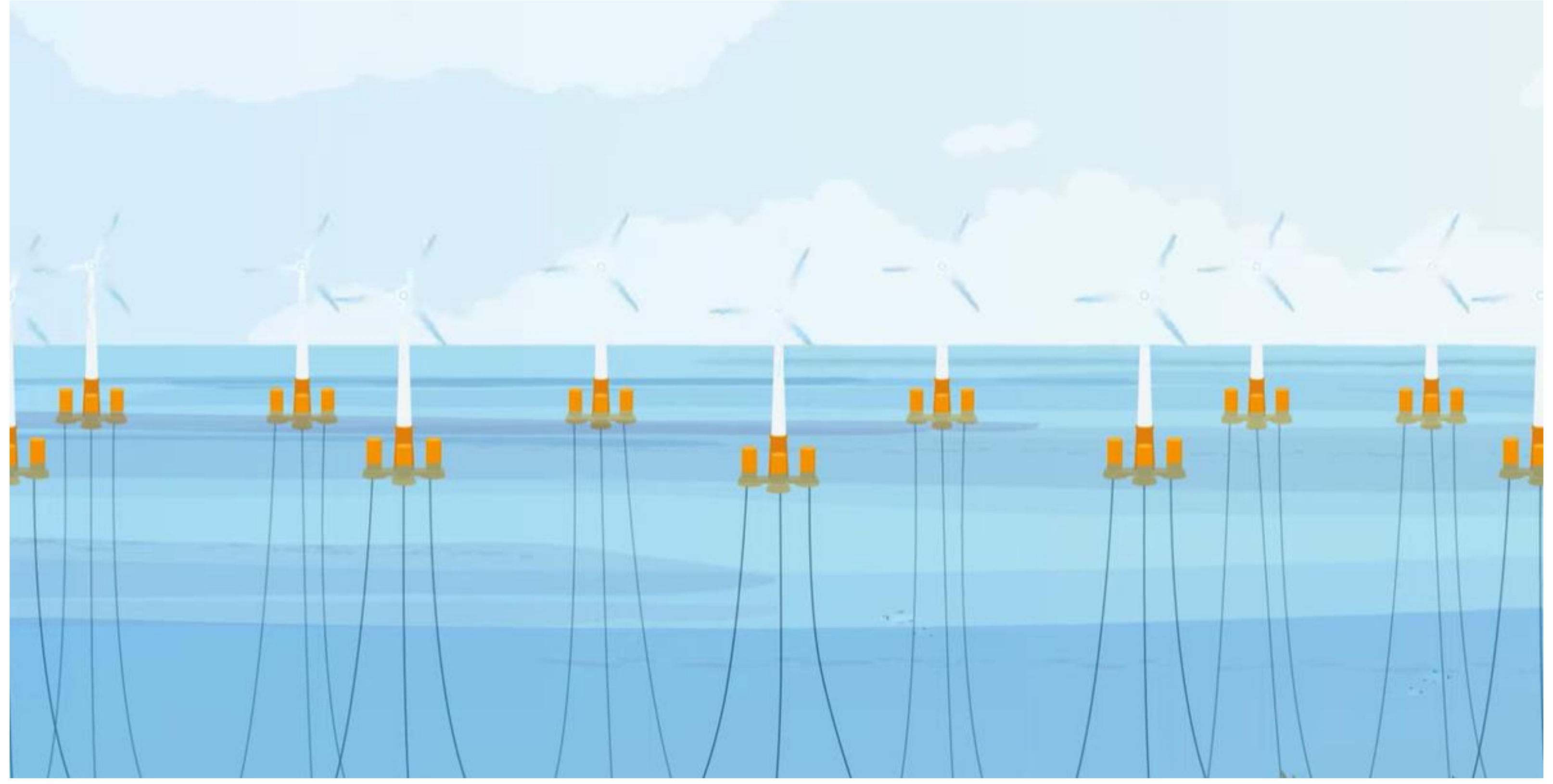
Coupled FOWT dynamics: ACTIVEFLOAT

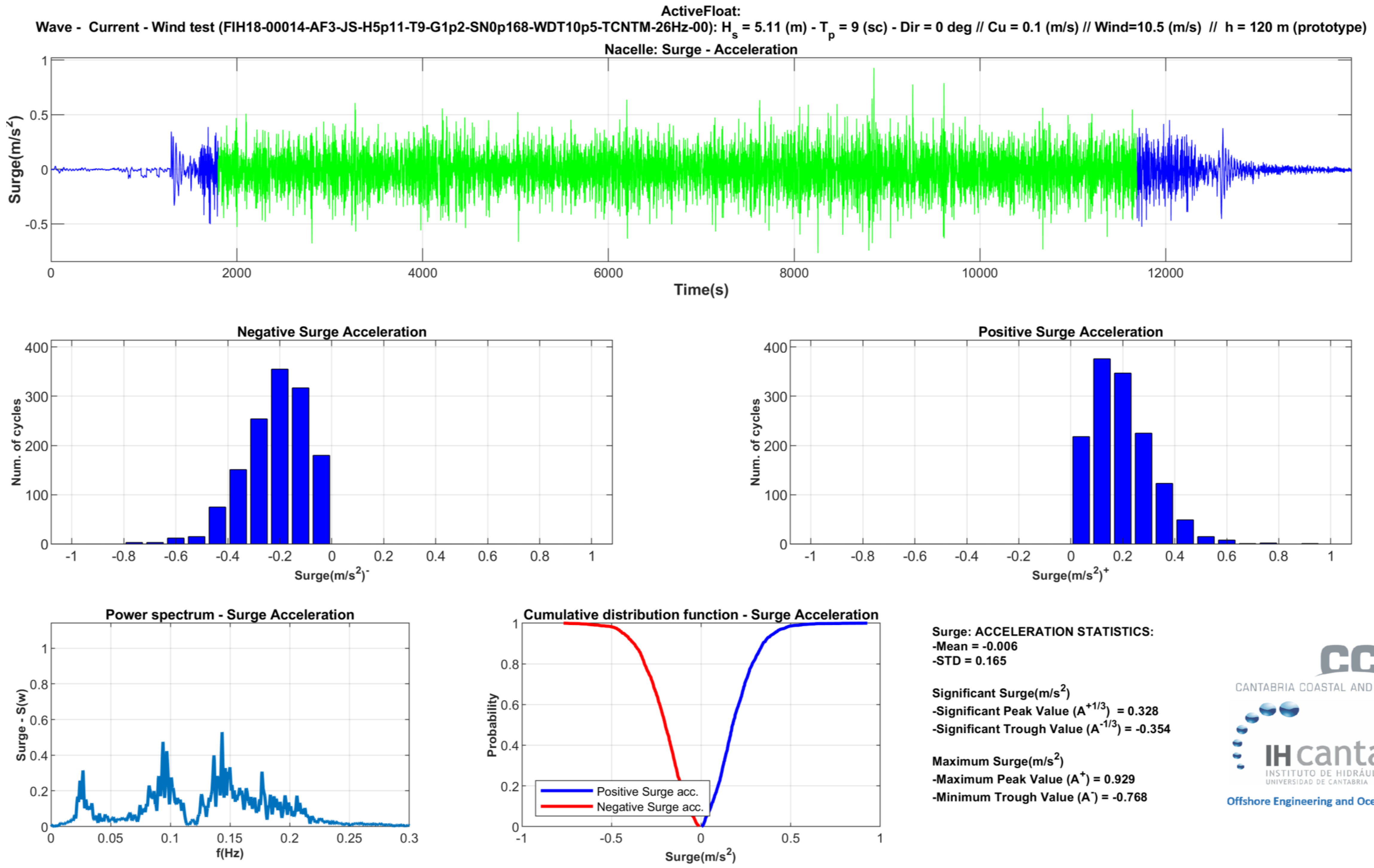
Irregular wave, currents and wind test – Hs 5.11 m Tp 9.0 sec – cu 0.168 m/s – WS 10.5 m/s

	unit	mean	min	max
surge	m	39.27	33.25	46.94
Sway	m	3.27	-14.49	21.97
heave	m	0.25	-1.24	1.84
roll	deg	0.54	-0.20	1.28
pitch	deg	-1.45	-5.43	2.06
yaw	deg	1.22	-6.70	9.87
Acc X	m/s^2	0.00	-0.77	0.93
Acc Y	m/s^2	0.00	-0.41	0.50
Acc Z	m/s^2	0.00	-0.58	0.45

Coupled FOWT dynamics: ACTIVEFLOAT

Limit for	Acceptance Crit.	ACTIVEFLOAT
OPERATION		
Yaw (10 min. max)	<15º	12.52º ✓
Yaw (10 min. std)	<3º	2.74º ✓
Pitch (max.)	[-10.0º, +10.0º]	-8.03º ✓
Pitch (10 min. average)	[-5.0º, +5.0º]	-2.12º ✓
Roll (max.)	[-5.0º, +5.0º]	0.99º ✓
IDLING CONDITION		
Pitch (10 min. average)	[-5º, +5º]	-1.45º ✓
Pitch (10 min. max)	[-15º, +15º]	-5.43º ✓
ACCELERATIONS LIMITS		
Operation (acc. XY / acc. Z)	2.94 m/s2 (0.3 g)	0.89 m/s2 ✓
Survival (acc. XY / acc. Z)	4.41 m/s2 (0.45g)	0.93 m/s2 ✓





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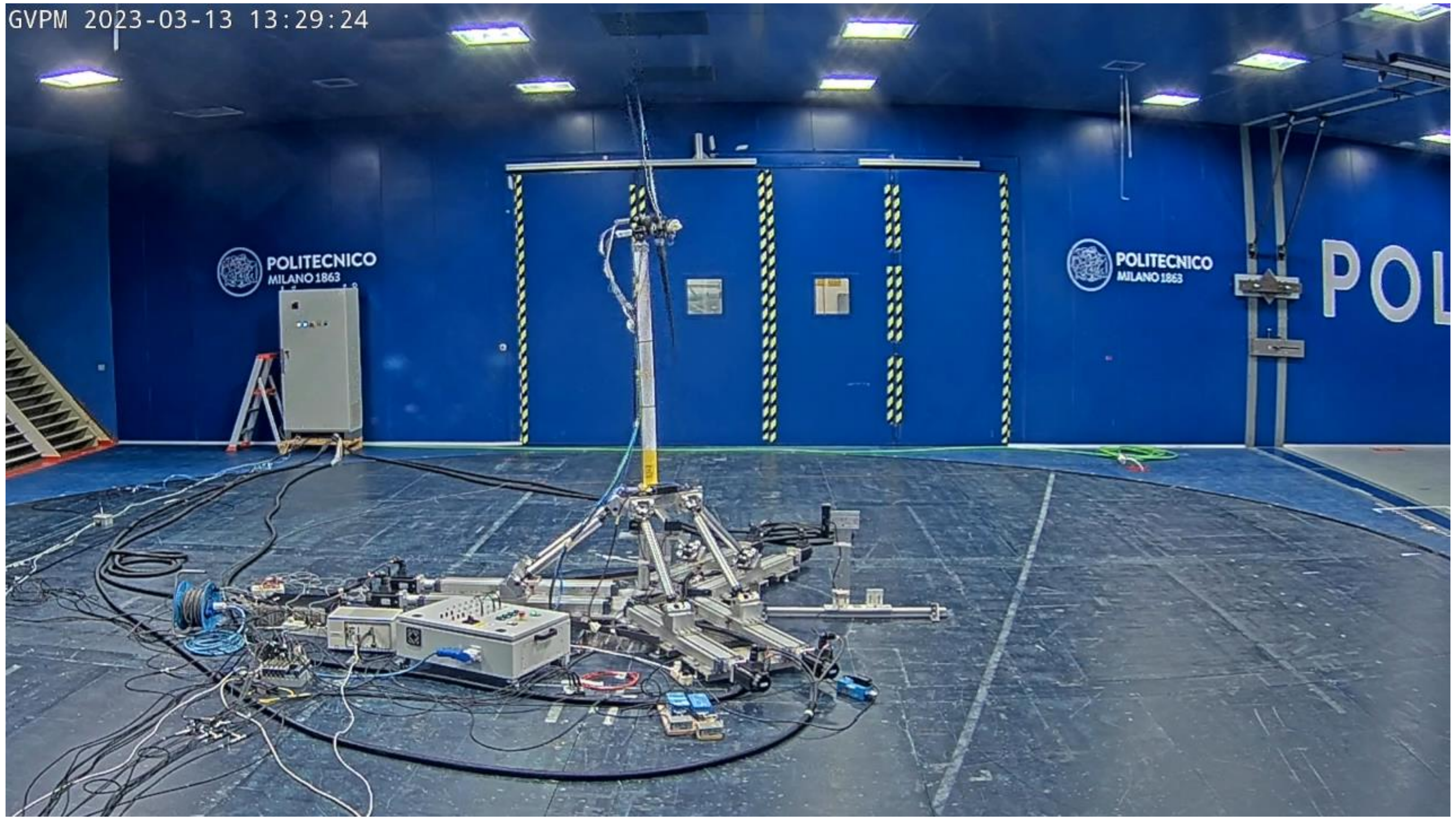
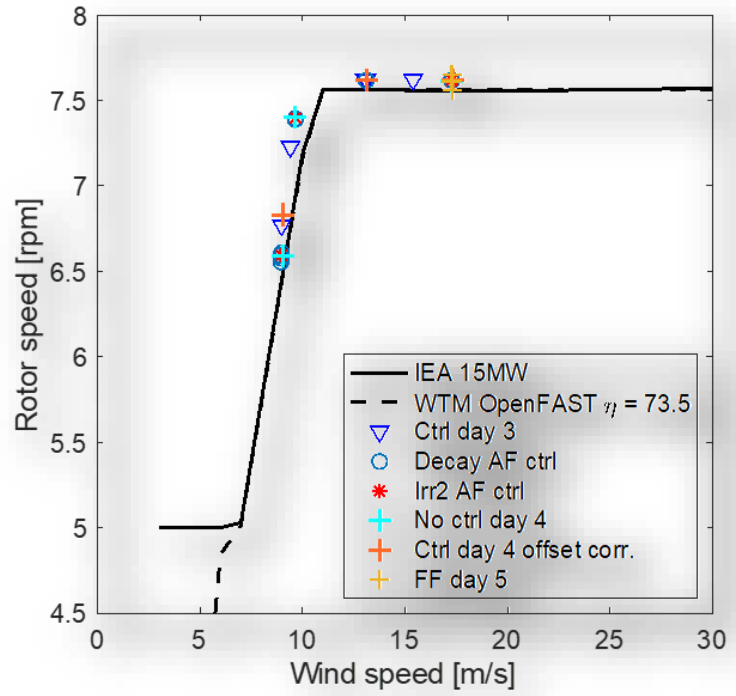
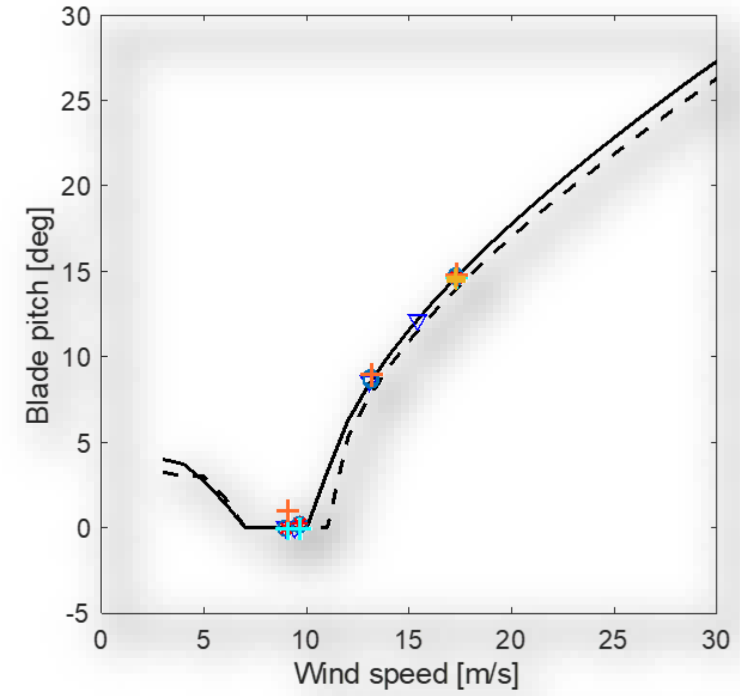
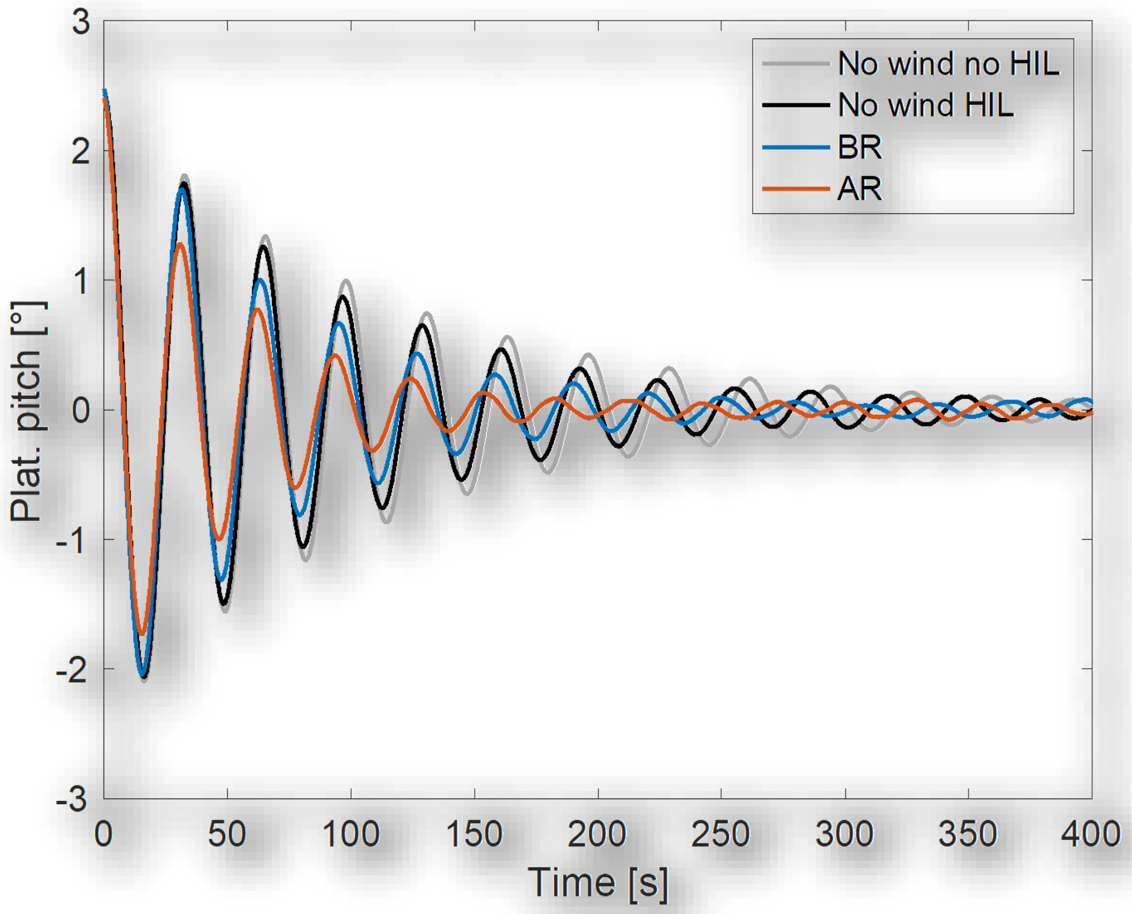
Coupled FOWT dynamics: Wind tunnel tests – Hardware in the loop

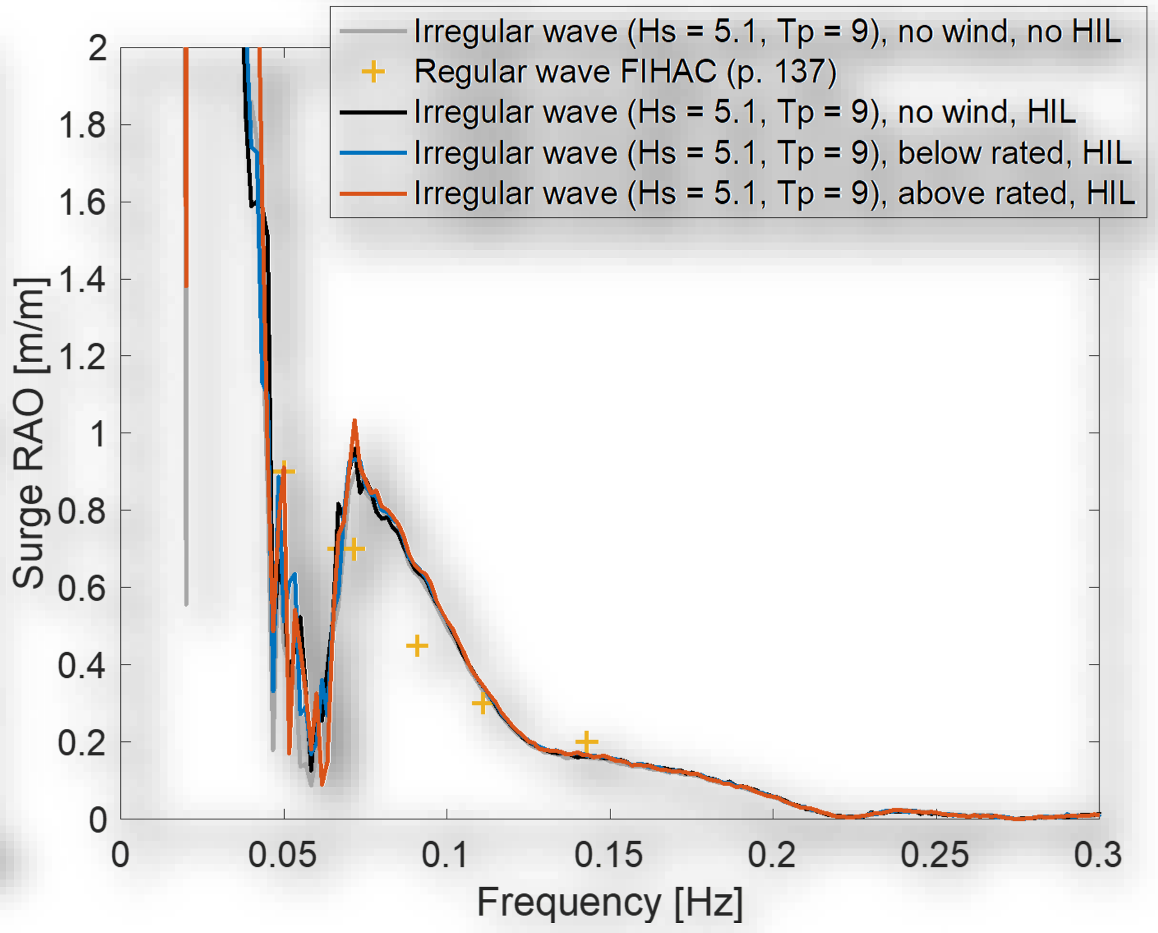
- Scale model of the IEA 15MW
- Blade aerodynamic design to match thrust of the reference turbine
- Reference Open Source Controller (ROSCO)











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<tr><th>U [m/s]</th><th>T_n [s]</th><th>ξ [-]</th><th>T_n [s]</th><th>ξ [-]</th></tr>
<tr><td>–</td><td>32.98</td><td>3.73</td><td rowspan="2">32.50</td><td rowspan="2">3.43</td></tr>
<tr><td>–</td><td>30.95</td><td>4.27</td></tr>
<tr><td>BR</td><td>30.20</td><td>5.69</td><td></td><td></td></tr>
<tr><td>AR</td><td>29.33</td><td>7.45</td><td></td><td></td></tr>
</table>

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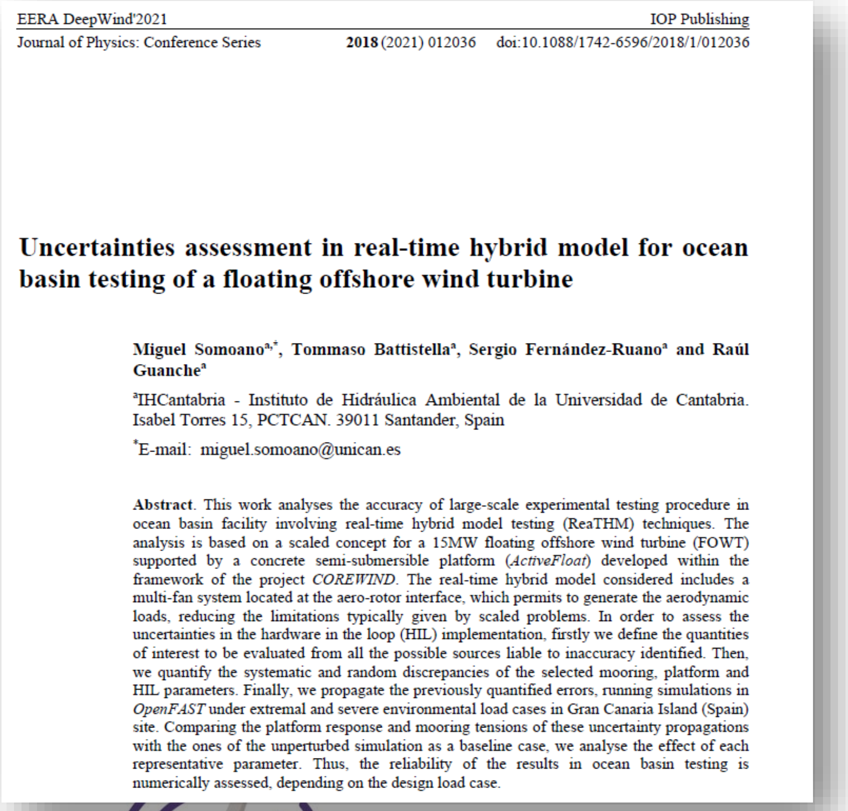
Conclusions

Thanks to the **COREWIND** project:

- ✓ A set of innovations dealing with floater, mooring and power export cable have been validated experimentally
- ✓ Testing methodologies have been leveraged to reduce uncertainties and enhance FOWT designs
- ✓ Hi-detail experimental databases are available for numerical modeling calibration and validation leading towards reduced extrapolation uncertainties.


EERA DeepWind'2021 IOP Publishing
Journal of Physics: Conference Series 2018 (2021) 012036 doi:10.1088/1742-6596/2018/1/012036

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

Miguel Somoano, Tommaso Battistella, Sergio Fernández-Ruano and Raúl Guanche

IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria. Isabel Torres 15, PCTCAN. 39011 Santander, Spain

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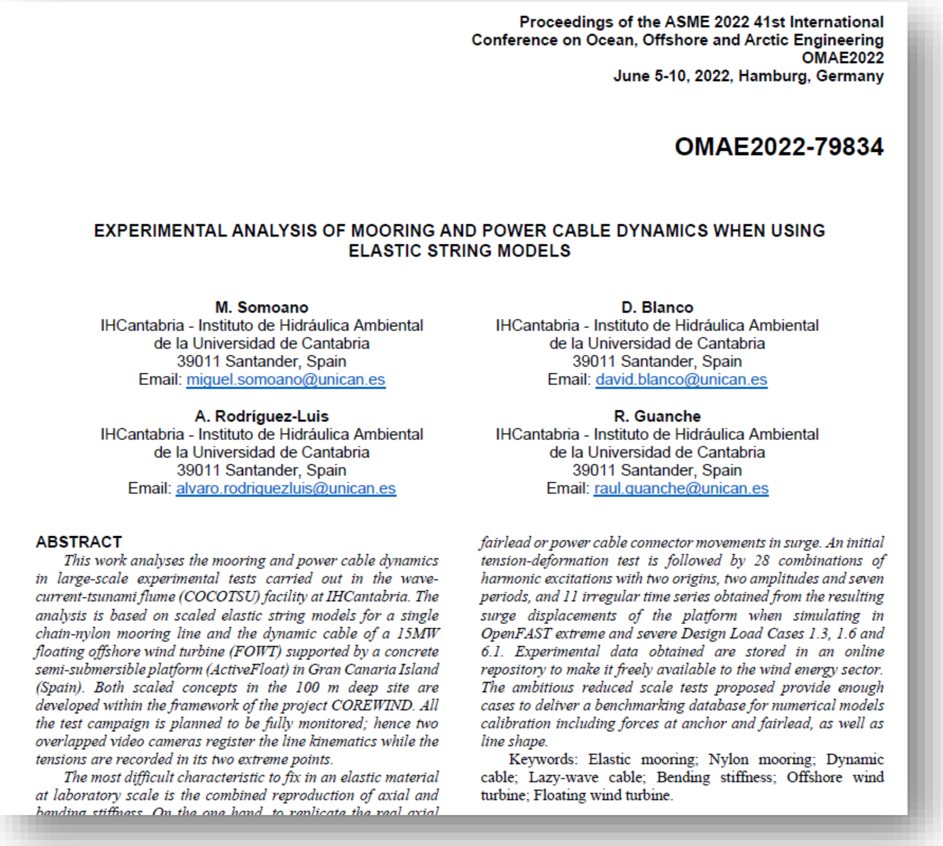

Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering
OMAE2022
June 5-10, 2022, Hamburg, Germany

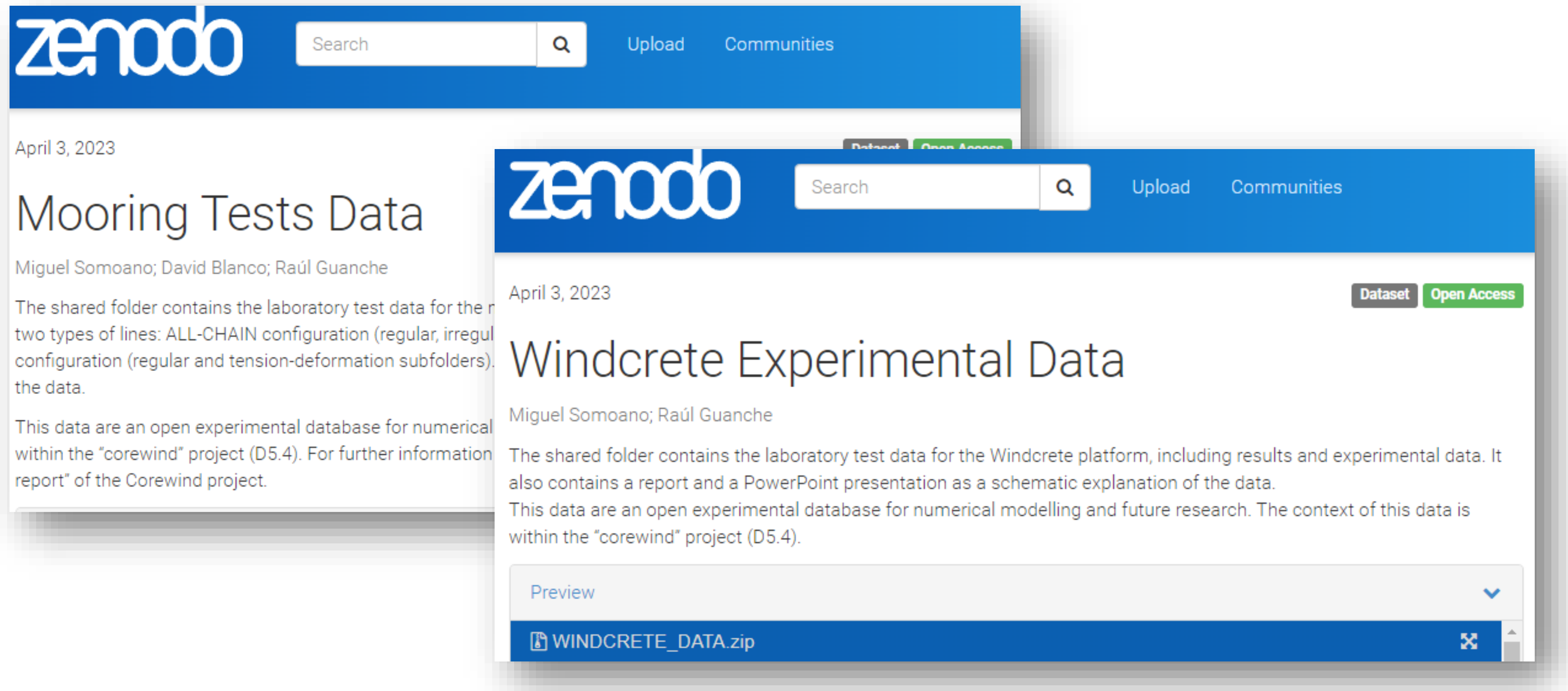
OMAE2022-79834

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

M. Somoano, D. Blanco, A. Rodriguez-Luis, R. Guanche
IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria
39011 Santander, Spain


Ocean Engineering

Simulation of mooring Lines in complex bathymetries using a finite element method



More info:

https://zenodo.org/record/7794406#.ZDVMC3ZByUI
https://zenodo.org/record/7794289#.ZDVMAnZByUI

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Thank you for your attention!

Contact: raul.guanche@unican.es

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Insight into LCOE and LCA analysis of concrete-based floating substructures

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

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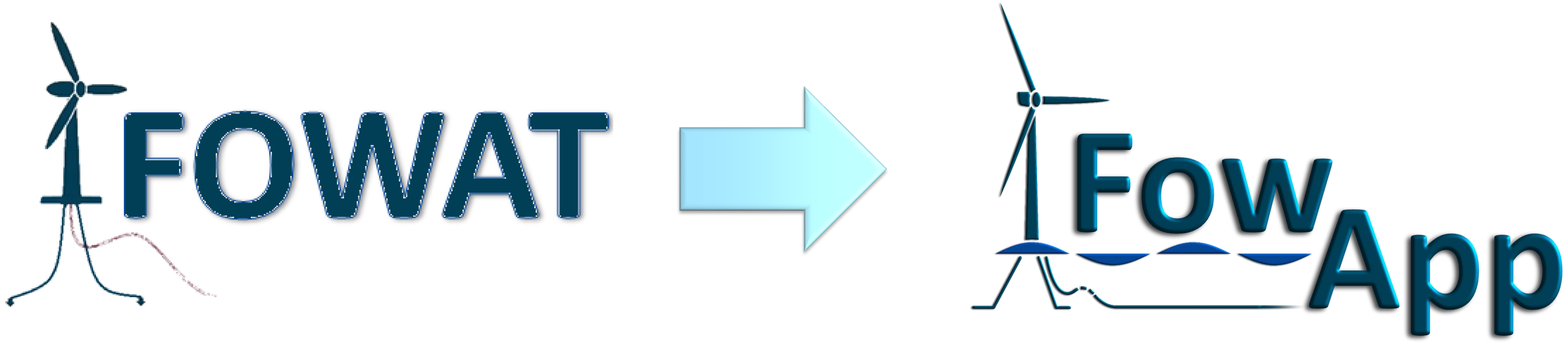
Outline

- LCOE analysis and Life Cycle Assessment (LCA)
- Reference scenarios
- Developments carried out to upgrade FowApp
- LCOE and LCA baseline results
- Innovations and optimisations for cost reduction
- Optimised LCOE and LCA results
- Main outcomes
- Beyond COREWIND

LCOE Analysis & Life Cycle Assessment (LCA)

As part of the research of the project, enhancement of an existing tool called FOWAT was carried out. FOWAT was developed in the LIFES 50+ project to perform an LCOE analysis and simplified LCA. To this end, outputs from other technical developments through the project were considered, based on a holistic and comprehensive approach, to obtain estimated LCOE and LCA results integrated into the new tool for distinct concrete-based floating substructure scenarios, different met-ocean conditions and different locations. In addition, the potential LCOE reductions achieved by considering economies of scale is considered.

- Methodological framework development
- Preliminary LCOE and LCA estimations of reference scenarios
- CAPEX, OPEX and LCOE review after optimisation for cost-reduction scenarios



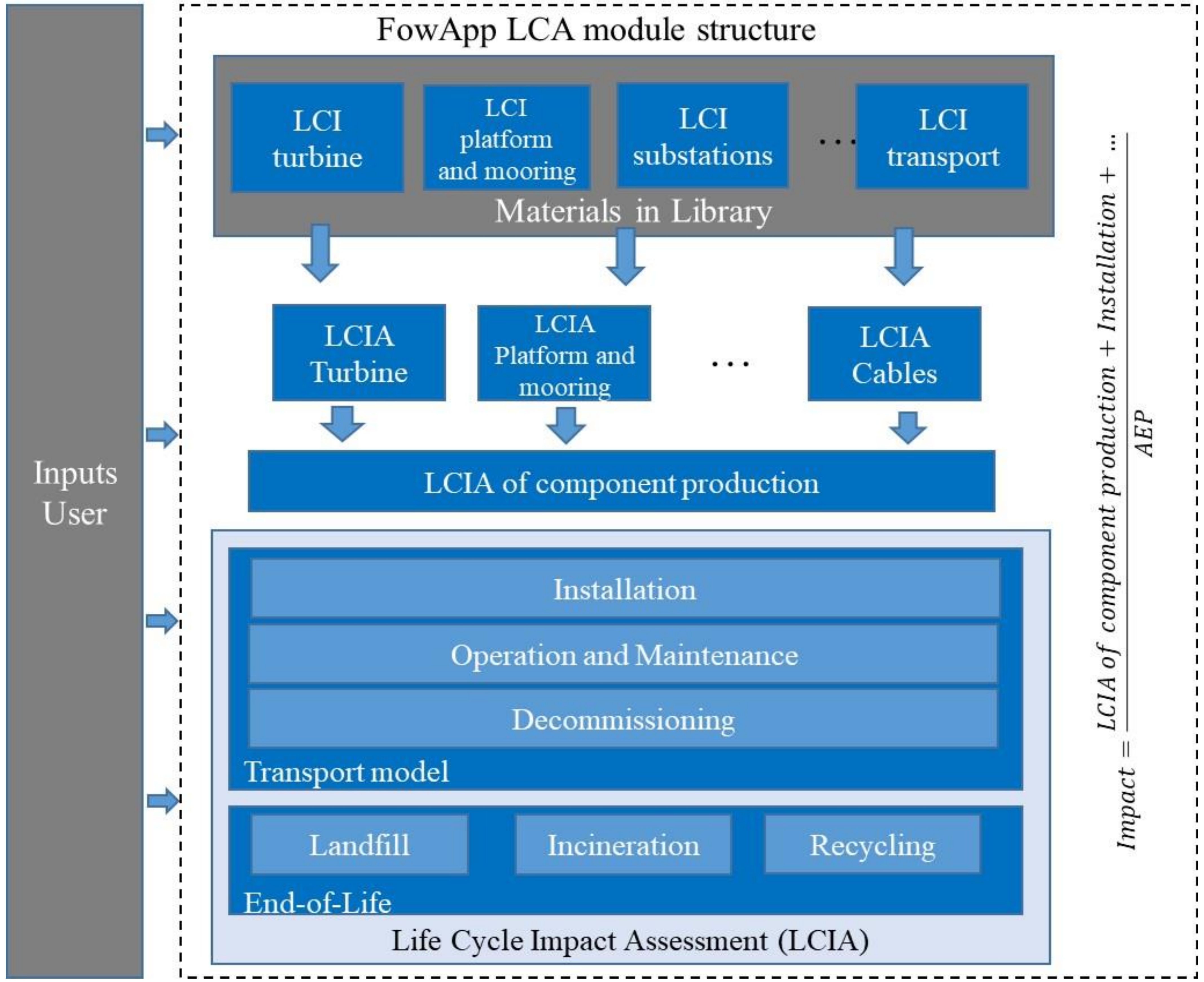
Reference scenarios

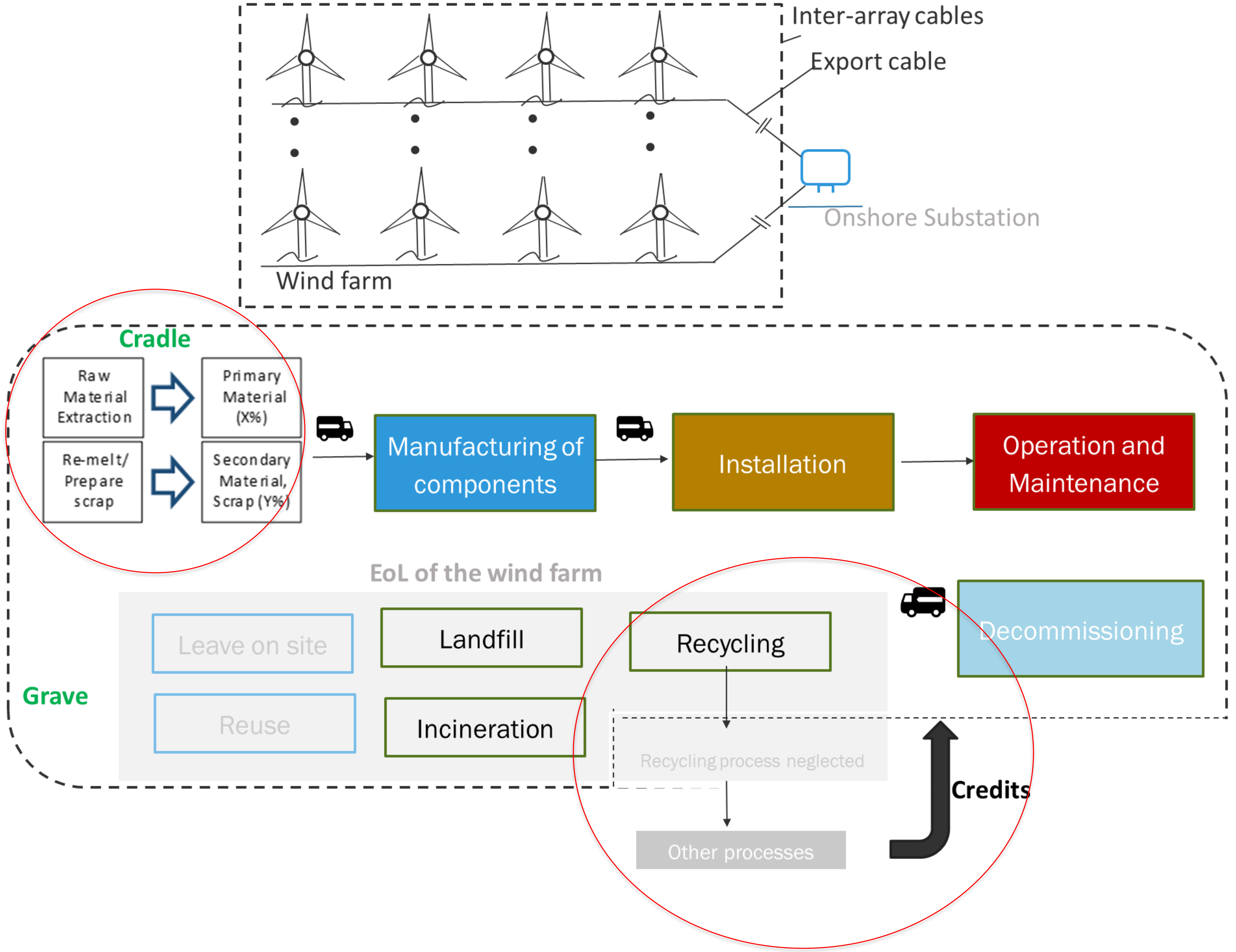
Scenario	Location	Capacity	Grid connection
1A	W of Barra	60 MW (4 WT)	Single string to onshore substation
2A		300 MW (20 WT)	5 strings to offshore substation, plus export cable to onshore substation
3A		1200 MW (80 WT)	16 total strings to 2 offshore substations, plus export cables to onshore substation
4A & 4W	SE of Gran Canaria	60 MW (4 WT)	Single string to onshore substation
5A & 5W		300 MW (20 WT)	5 strings to onshore substation
6A & 6W*		1200 MW (80 WT)	16 total strings to 2 offshore substations, plus export cables to onshore substation
7A & 7W	Morro Bay	60 MW (4 WT)	Single string to onshore substation
8A & 8W		300 MW (20 WT)	5 strings to offshore substation, plus export cable to onshore substation
9A & 9W		1200 MW (80 WT)	16 total strings to 2 offshore substations, plus export cables to onshore substation

A: ActiveFloat, W: WindCrete, WT: wind turbine, (*): scenarios not fully analysed due to low power demand in the region and limited area with depths below 1000 m

Developments carried out to upgrade FowApp

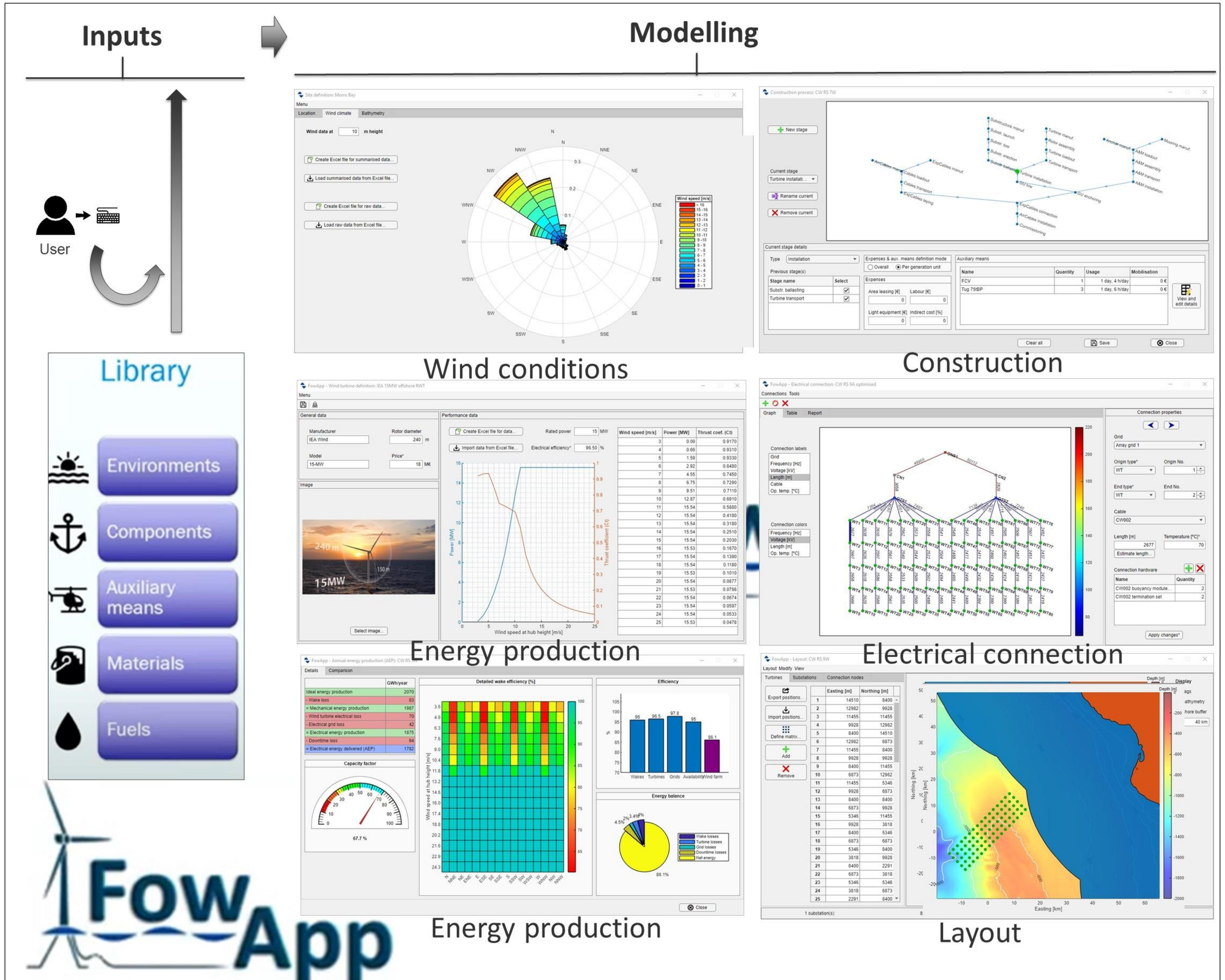
- A new more comprehensive LCA model to find the floating wind technology with circular economy principles





Developments carried out to upgrade FowApp

- A new and friendly interface for the user to introduce data and upgrade the LCOE model

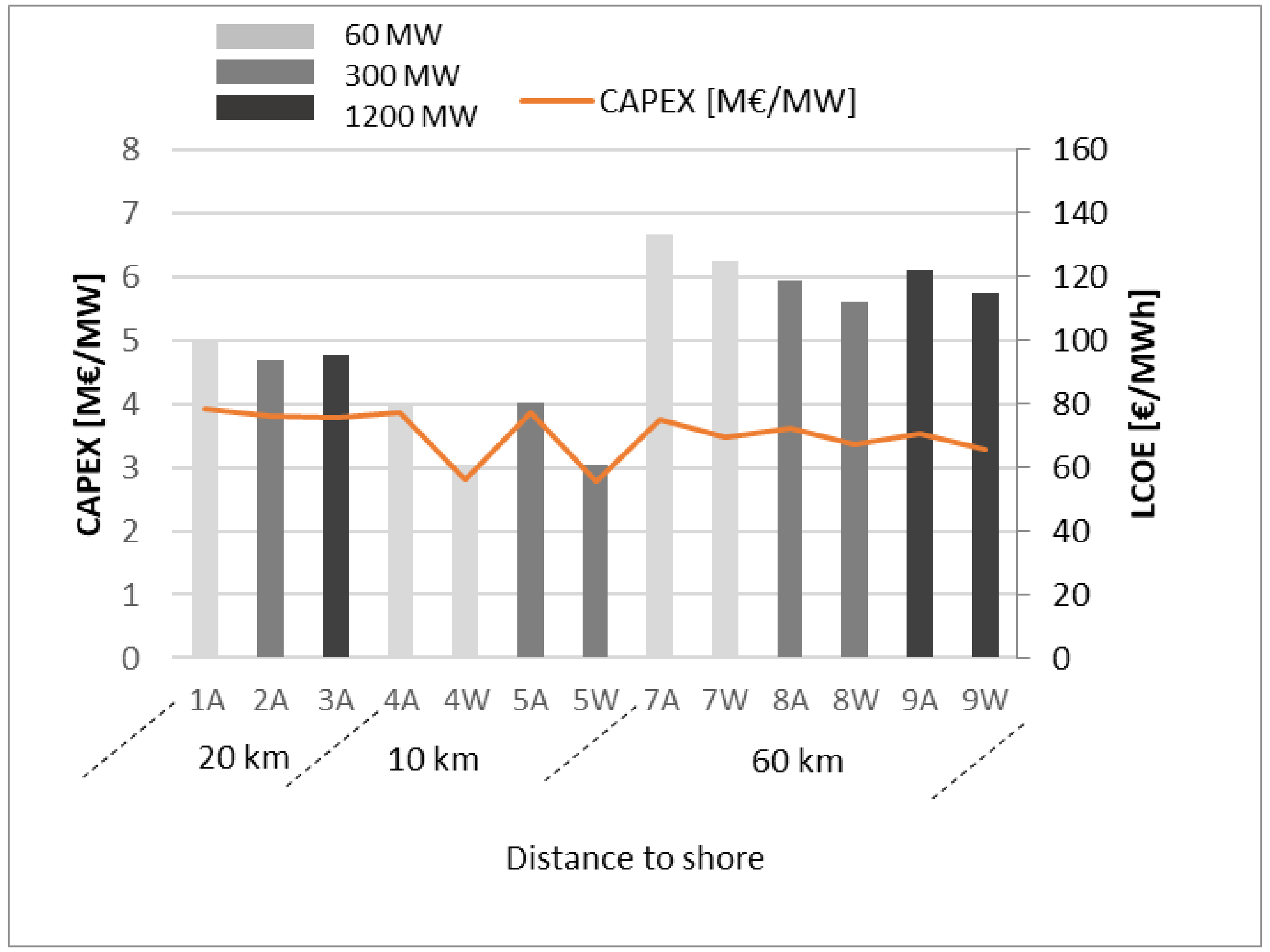


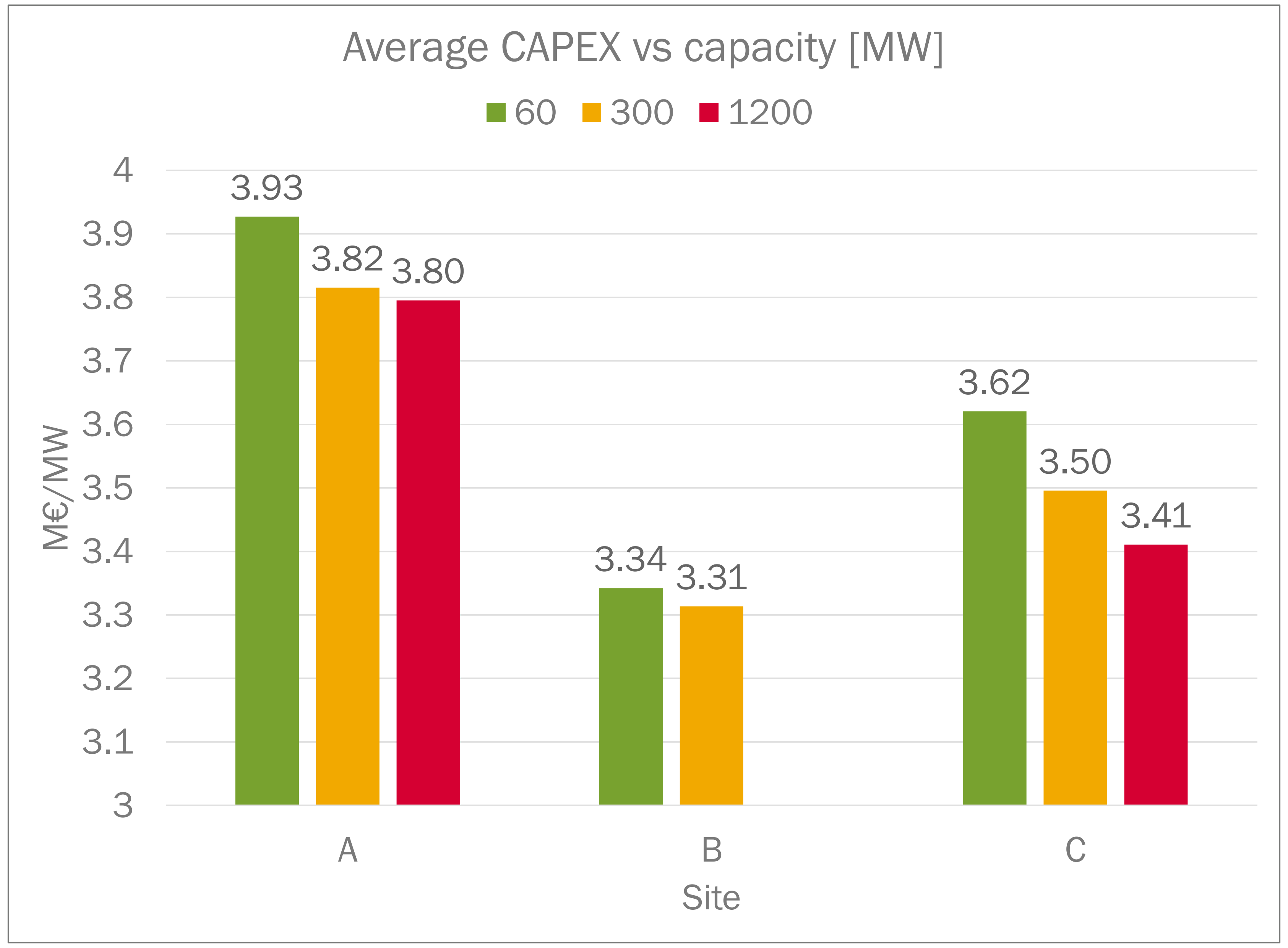
Developing FowApp as a new desktop application with the following features:

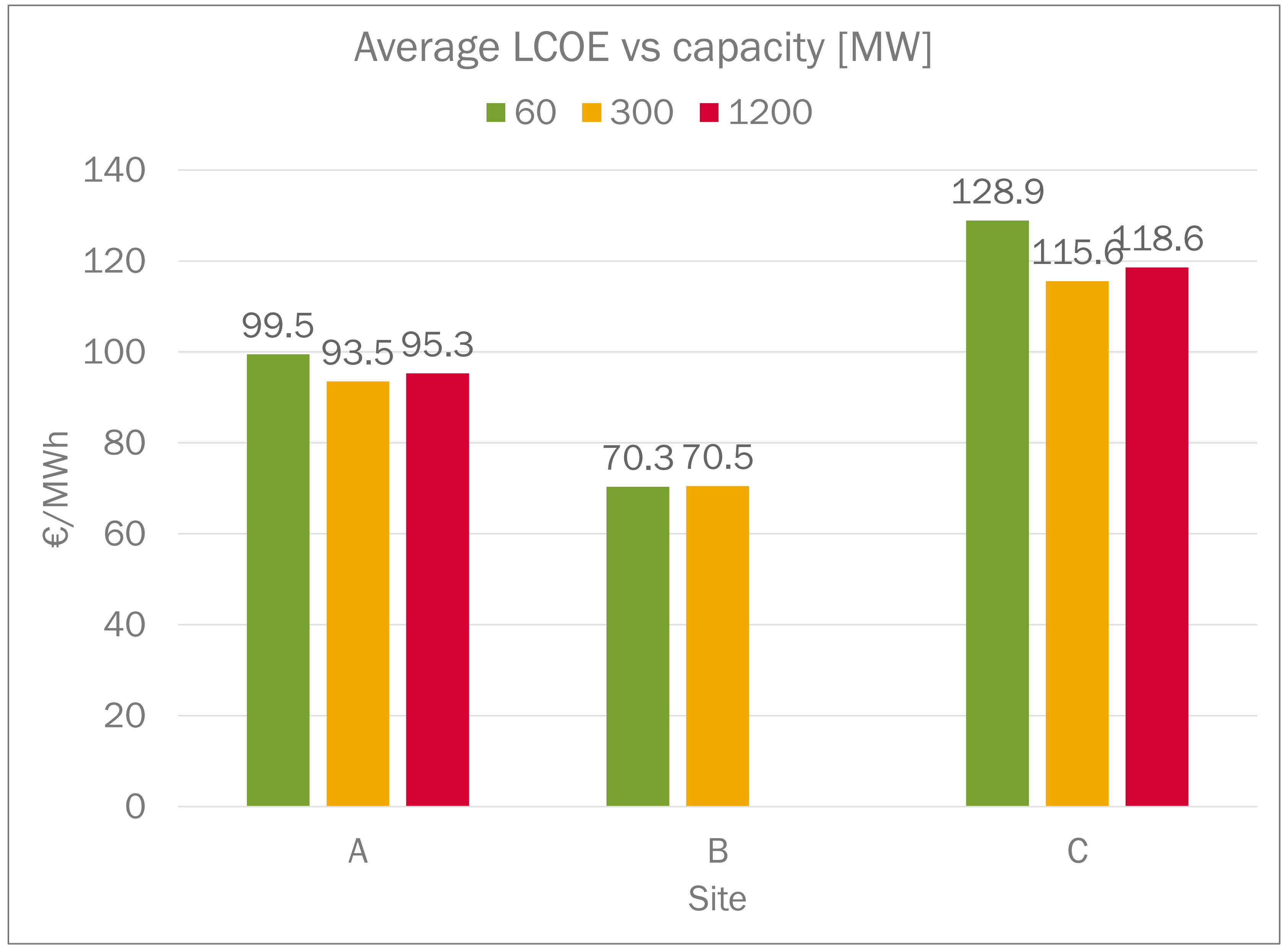
- Built from scratch for the floating wind industry
- Import/export capabilities
- Integrated calculations
- Detailed Annual Energy Production calculation
- Economic analysis, including LCOE calculation
- Full LCA cradle-to-Grave approach

Baseline LCOE and LCA results

- LCOE results







- The average LCOE of the 15 reference scenarios studied is 99.7 €/MWh
- The main drivers of the LCOE are the AEP and the CAPEX
- The OPEX and DECEX have smaller impacts due to the discount rate used: 10%

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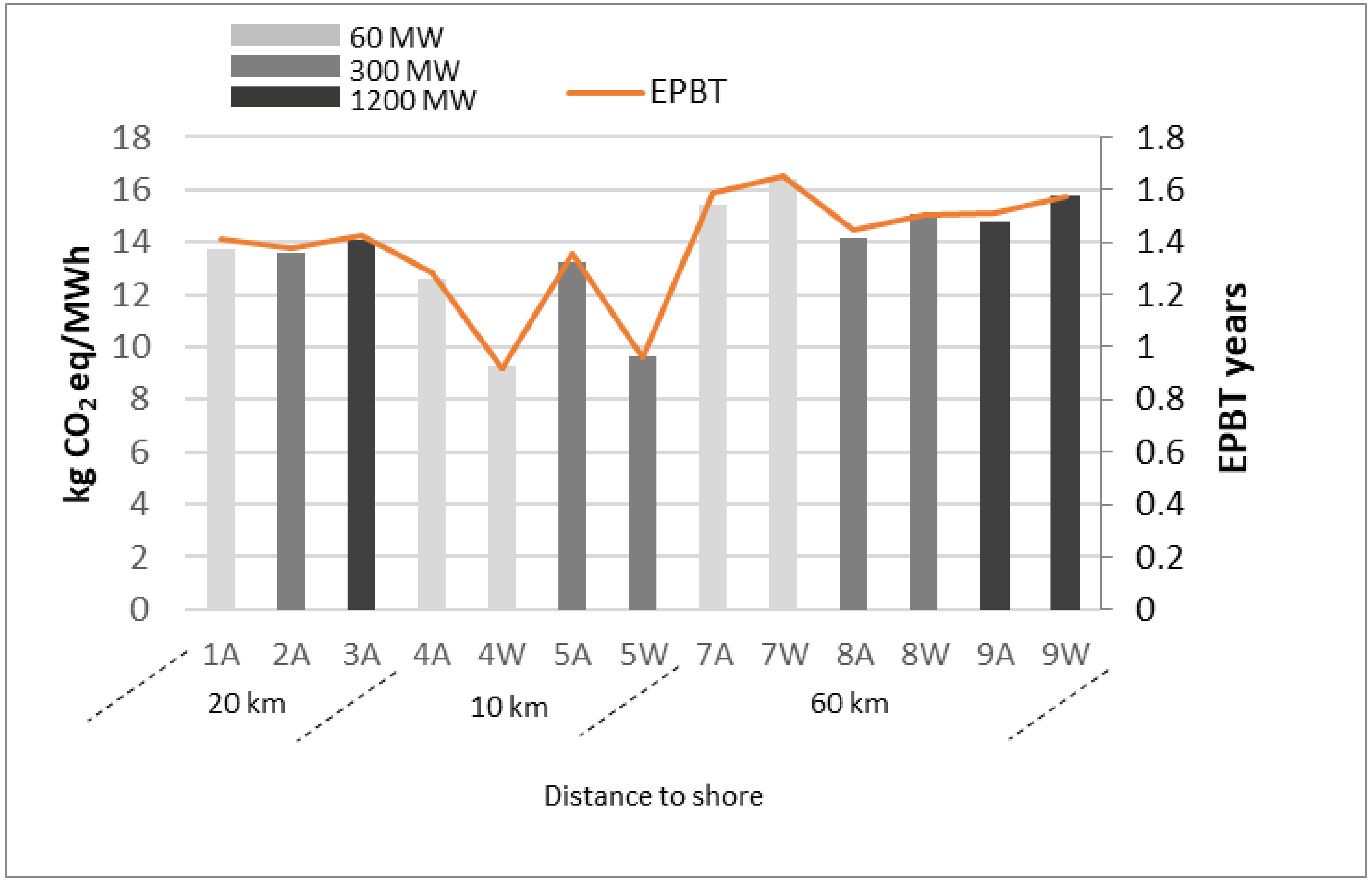
Baseline LCOE and LCA results

- LCA results in the carbon footprint indicator



- ➢ The environmental results depend on each scenario, impact categories analysed and scenarios
- ➢ Let's see the GHG emissions

CO_2 eq emissions
<< 20 gCO_2 eq/kWh

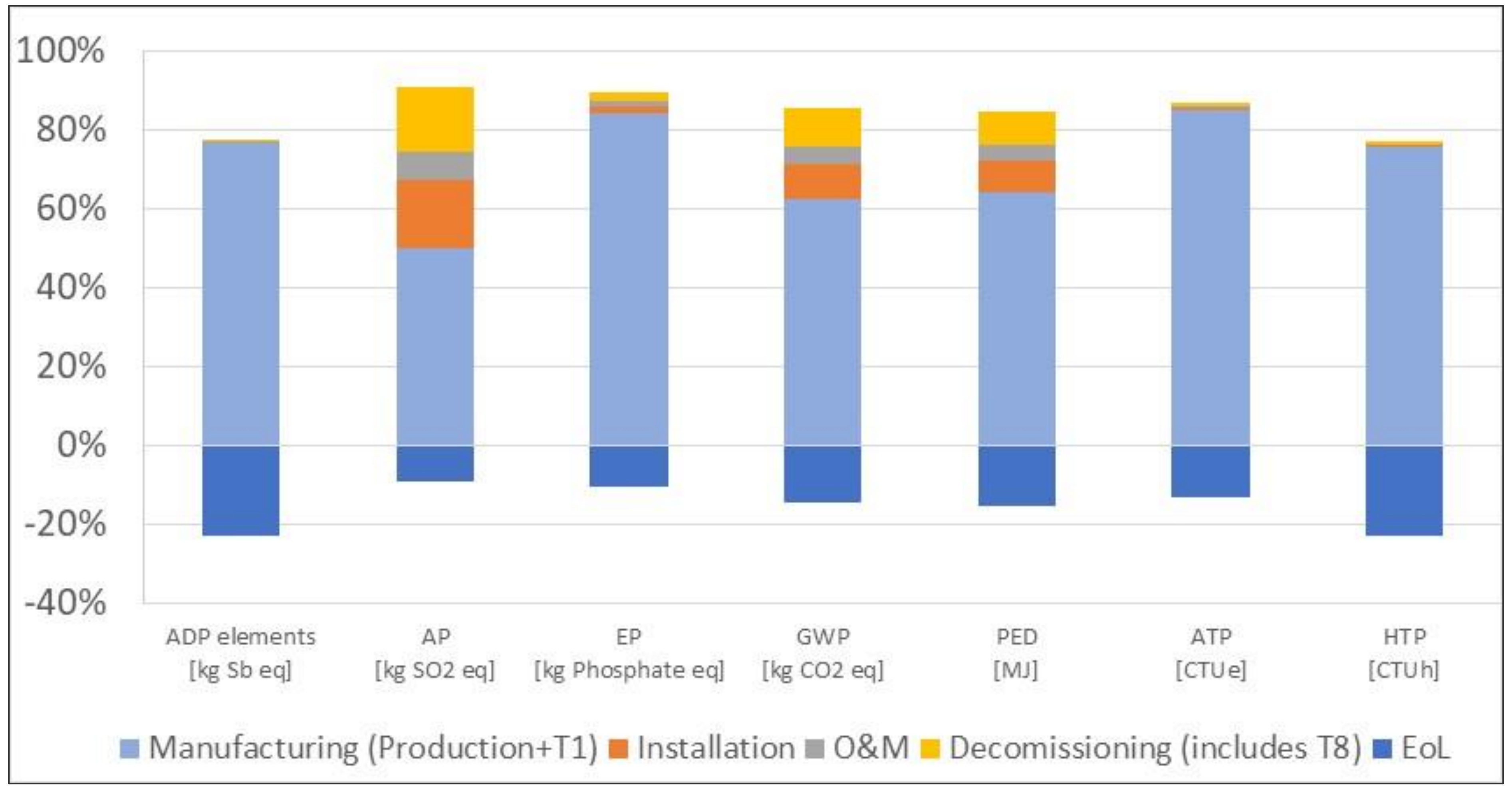
- ➢ The EPBT (Energy Payback Time) is the time required to generate as much energy as is consumed during the production and lifetime operation of the system

EPBT ranges 0.9 – 1.7 years

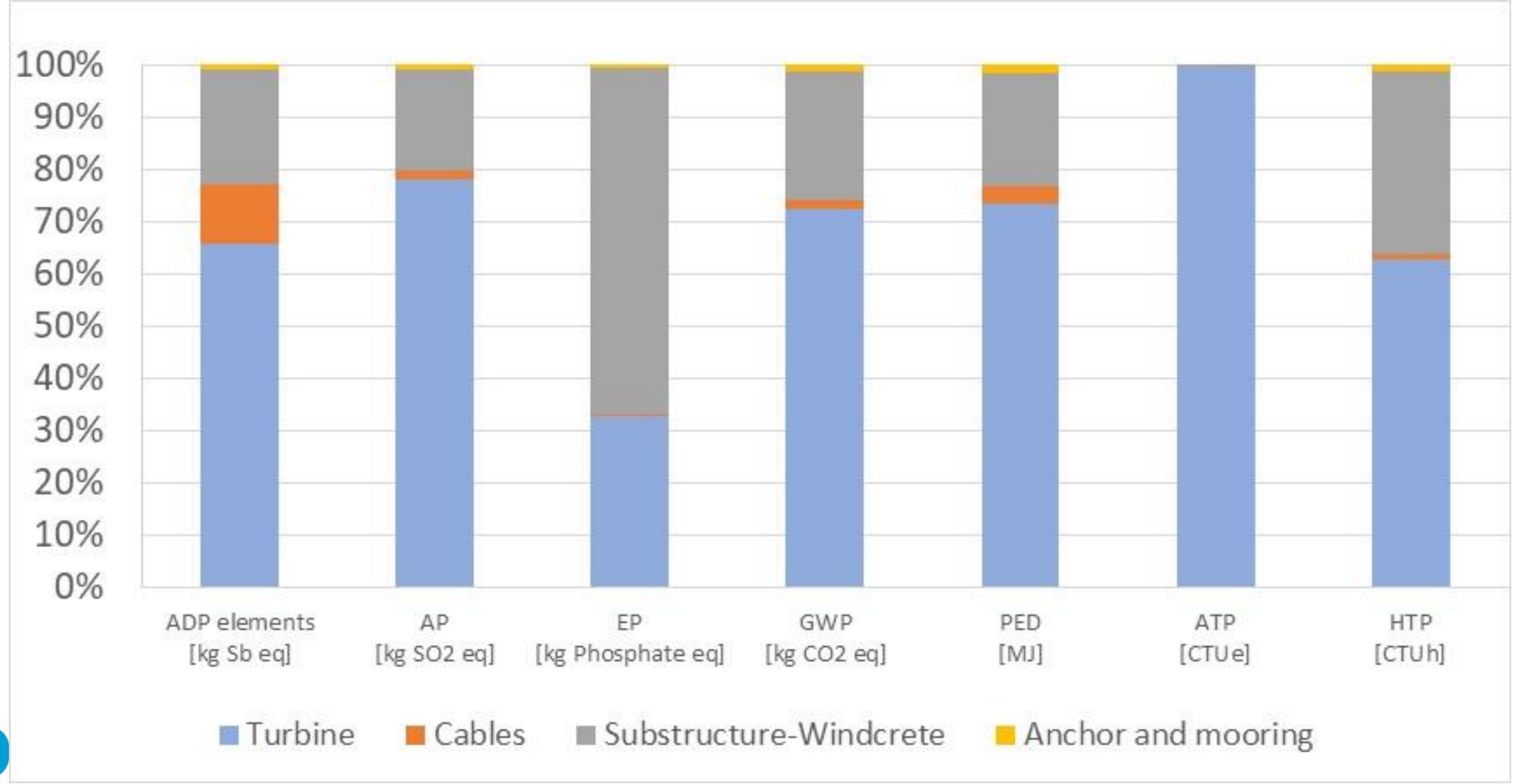
Baseline LCOE and LCA results

- Results by life cycle stages for Gran Canaria (scenario 5W as an example)

Overall Life Cycle Results



Manufacturing stage



Substructure manufacturing by materials

Impact category	Slag	Unreinforced concrete	Steel	Energy for manufacturing	TOTAL
ADP elements [kg Sb eq/MWh]	8.08E-07	3.67E-06	8.95E-06	2.25E-11	1.34E-05
AP [kg SO_2 eq/MWh]	4.90E-04	7.42E-04	4.08E-03	1.30E-07	5.31E-03
EP [kg PO4 eq/MWh]	1.41E-02	2.90E-04	2.52E-03	1.53E-08	1.69E-02
GWP [kg CO_2 eq/MWh]	**6.97E-02**	**3.81E-01**	**1.00E+00**	**6.66E-05**	**1.45E+00**
PED [MJ/MWh]	2.78E+00	2.14E+00	1.52E+01	1.74E-03	2.01E+01
ATP [CTUe/MWh]	3.07E-04	1.30E-04	6.61E-04	1.14E-07	1.10E-03
HTP [CTUh/MWh]	2.32E-12	5.63E-12	1.59E-10	1.05E-14	1.67E-10

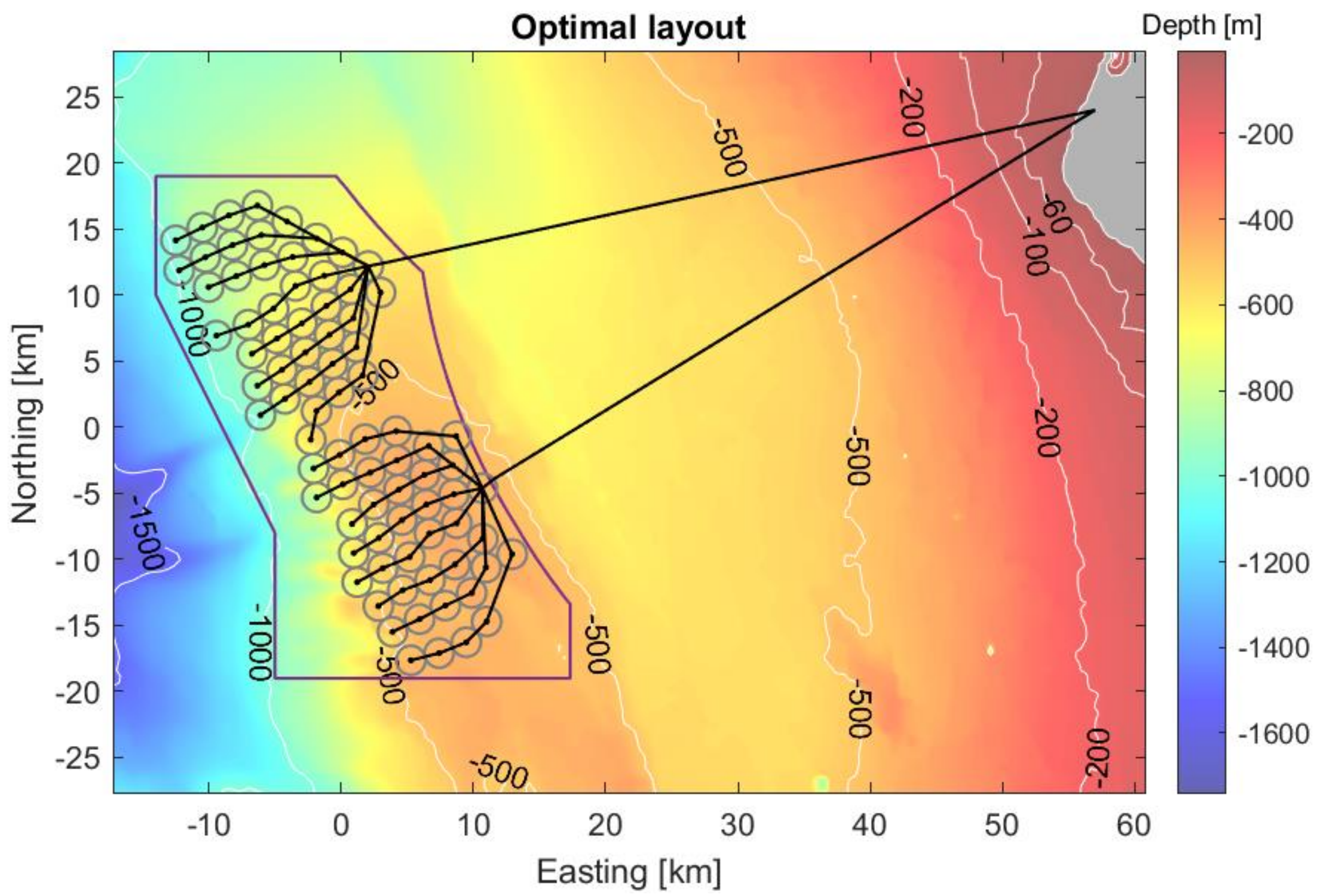
- ➢ Manufacturing is the dominant stage in the environmental overall LCA results
- ➢ EoL stage brings benefits due to recycling credits in all environmental impact categories studied
- ➢ The turbine has a greater impact than the floating substructure in almost all impact categories during the manufacturing stage, hence the importance to use concrete
- ➢ Green steel should be used instead of steel in the substructure to reduce its impact since steel has the highest impact

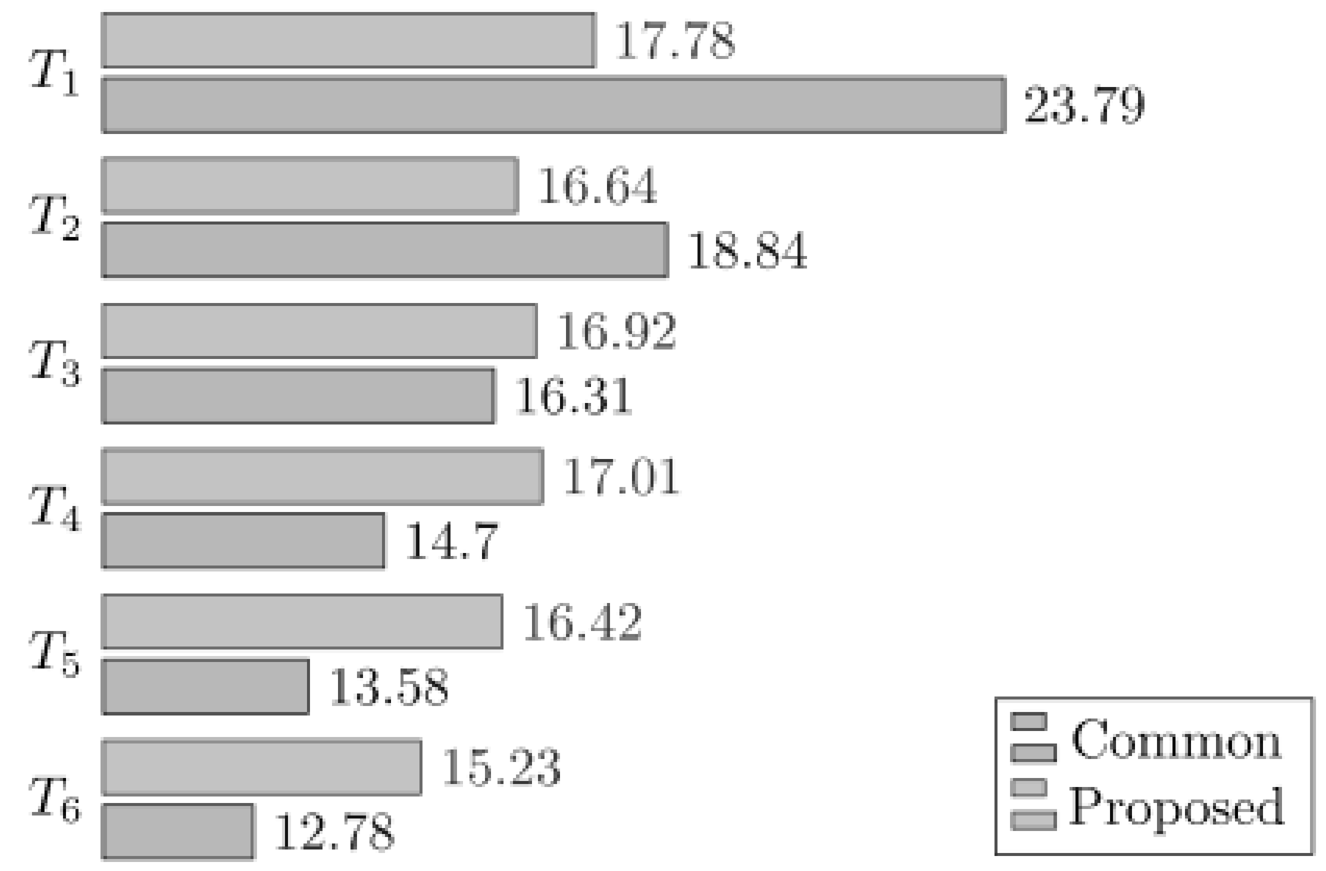
Innovations and optimisations for cost reduction

- Workshops and Surveys to identify Cost Reduction Opportunities (main outcomes)

	Main remarks from survey	Main remarks from workshop
Foundations	➢ Concrete foundations are more easily scalable than steel ones and size and weight do not seem to be a limitation for upscaling their designs. ➢ While developers and suppliers believe that concrete foundations last for 40-50 years, consultancies and certification bodies consider their lifetime to be 25 years	➢ There is not much information available about energy consumption for manufacturing foundations, but one source suggests that energy usage is more than 100 kWh/ton and 10 l/ton for a concrete semi-submersible ➢ It's difficult to quantify the cost advantages of concrete foundations over steel ones, but qualitatively, concrete foundations require less increase for a large turbine compared to steel and can have a longer lifetime
Mooring and anchor system	➢ Deepwater mooring systems have different technical challenges, but the most influential for the LCOE are installation and O&M strategy. Experts believe that manufacturing capabilities could be a bottleneck	➢ The selection of anchors largely depends on the seabed. ➢ Designing shared mooring lines is not straightforward because the maximum load works in a main direction. This means that some lines need to be able to stand higher loads and more fatigue over their lifetime
Dynamic Cables (Electrical system and installation)	➢ Deepwater dynamic cables pose different technical challenges, but the most impactful for the LCOE is designed at the wind farm level. Experts are most concerned about the lack of dynamic export cables	➢ 66 kV is a good rating for inter-array but for export, a voltage higher than 132 kV might be a requirement. ➢ In terms of failure, participants agree that inter-array is more likely to fail than export cable.

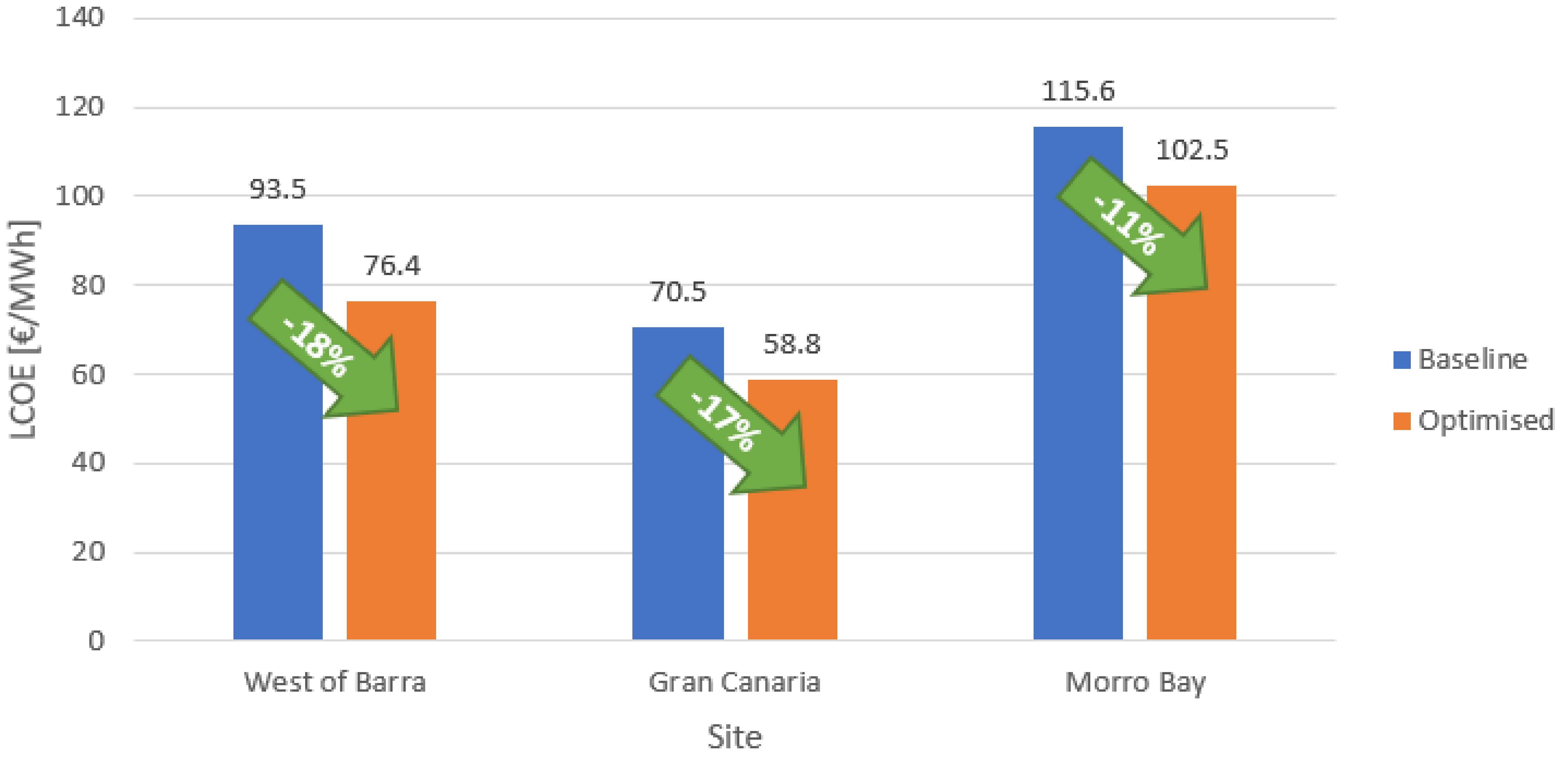
- Main innovations and optimisations
  - Layout optimisation
  - WindCrete reuse
  - Station system peak load reduction
  - Improved maintenance strategies
  - Windfarm control for life extension

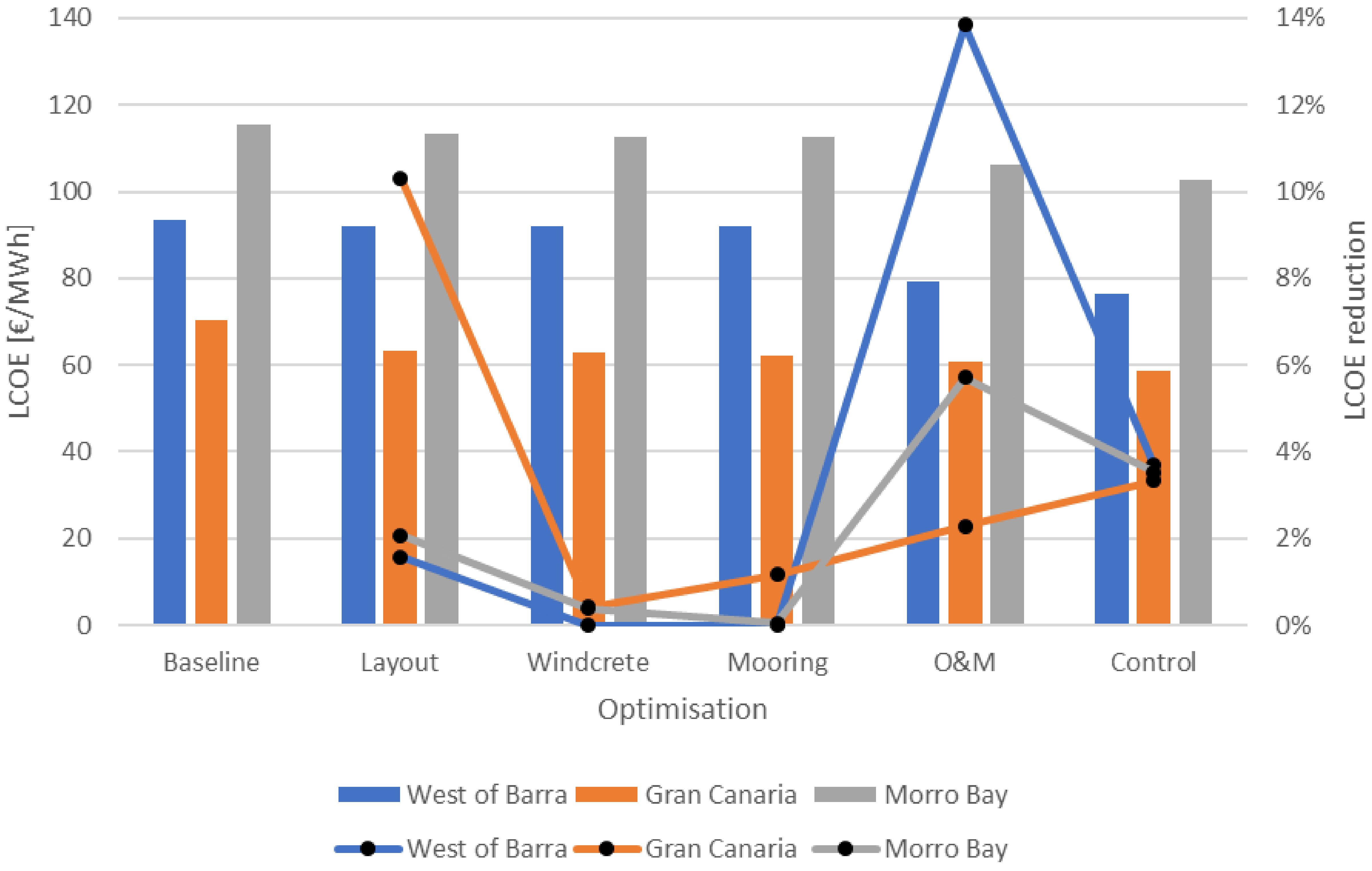




Optimised LCOE and LCA results

- LCOE results





Optimised LCOE and LCA results

- LCA results

5.0% Energy payback time reduction
=> 1.32 years

18.2% Energy return on investment increase
=> 22.0

15.2% Global warming potential reduction
=> 11.6 kg CO_2 eq./MWh

14.9% Primary energy demand reduction
=> 170 MJ/MWh

15.3% Acidification potential reduction
=> 0.0424 kg SO_2 eq./MWh

11.4% Aquatic toxicity potential reduction
=> 0.193 CTUe/MWh

Main outcomes

- Highlights:
  - The average LCOE of reference scenarios studied is 99.7 €/MWh, that went down to 86.6 €/MWh after optimisation
  - The LCOE optimisation leaded in some cases to a reduction of the energy yield due to the purchasing costs
  - The layout optimisation and the maintenance improvements had the highest effect on the LCOE reduction
  - All scenarios are below 20 gCO_2 eq/kWh (average of 11 gCO_2 eq/kWh)
  - Optimising the LCOE resulted in significant reduction of the environmental impacts

- Next steps / Topics that could be further investigated:
  - Developing new materials for blades that can withstand harsh marine environments, reduce maintenance cost, be reusables and recyclable
  - Improving turbine designs to increase efficiency and reduce costs
  - Design new technologies for monitoring and controlling wind turbines remotely
  - Developing new installation techniques that can reduce costs and minimize environmental impact, such as pre-assembly of floating foundation and turbine which could cut installation costs by up to 50%
  - Continuously optimizing the layout design of floating offshore wind farms to maximize energy efficiency over a year
  - Analyse technical, statistical, organizational or market factors to establish the main parameters that influence the economies of scale of floating wind farms

Beyond COREWIND

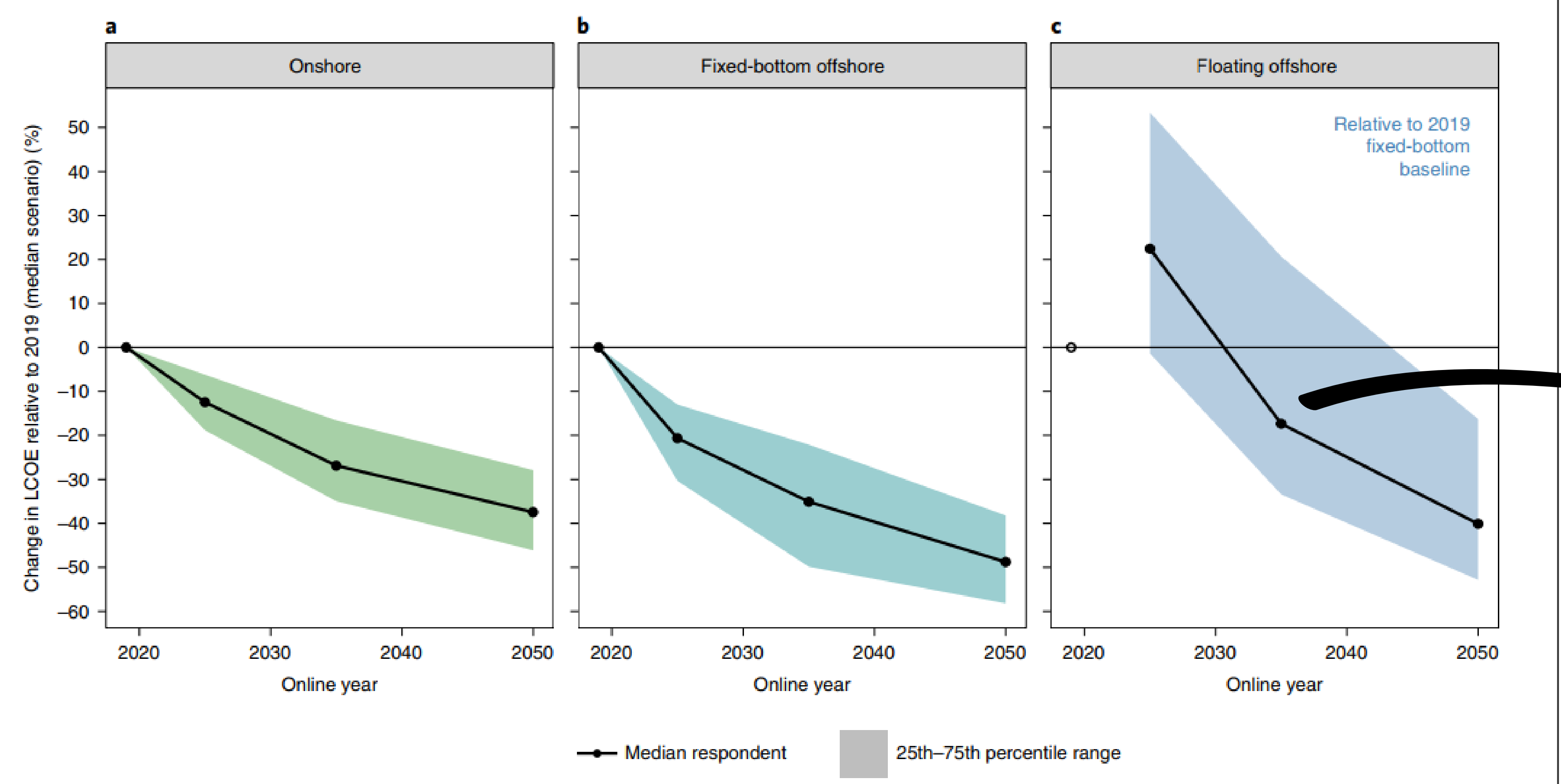
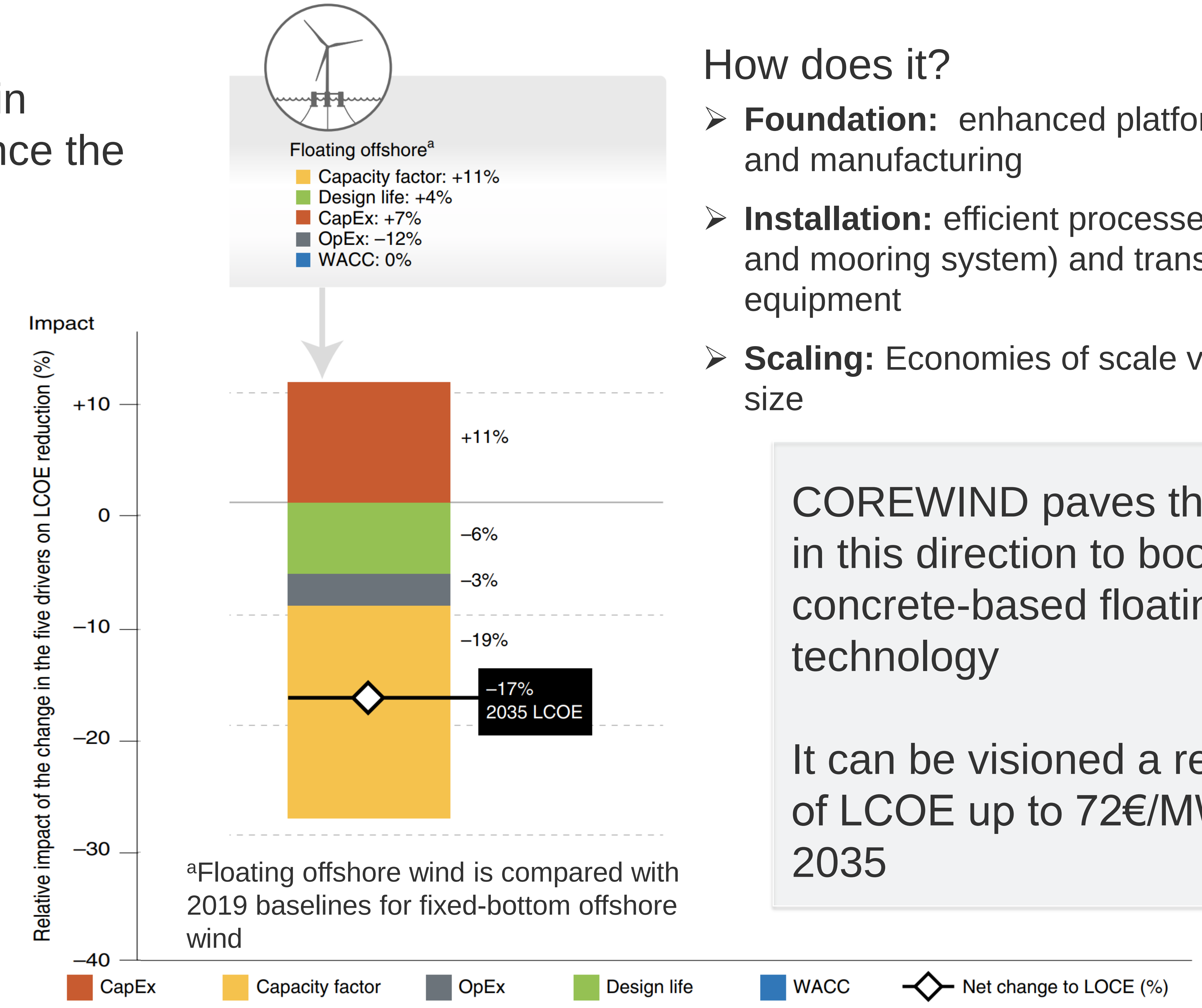


Fig. 2 | Expected LCOE changes in the median scenario in percentage terms relative to 2019 baseline values. a–c, From the 2020 elicitation, the medians of expert responses in terms of percentage LCOE reductions are shown by the lines/markers, and the shaded areas represent the 25th–75th percentile ranges of all responses for the median scenario. Panels show results for onshore (**a**), fixed-bottom offshore (**b**) and floating offshore (**c**) wind. Floating offshore wind changes are compared with expert-specific 2019 baselines for fixed-bottom offshore wind, depicted in the figure as the empty circle; given the nascent state of floating offshore wind, experts predict that LCOE in 2025 will be higher than 2019 fixed-bottom costs.

These are the main factors that influence the LCOE reduction



[a]Floating offshore wind is compared with 2019 baselines for fixed-bottom offshore wind

How does it?

- **Foundation:** enhanced platform design and manufacturing
- **Installation:** efficient processes (cables and mooring system) and transport equipment
- **Scaling:** Economies of scale via project size

COREWIND paves the way in this direction to boost concrete-based floating wind technology

It can be visioned a reduction of LCOE up to 72€/MWh in 2035

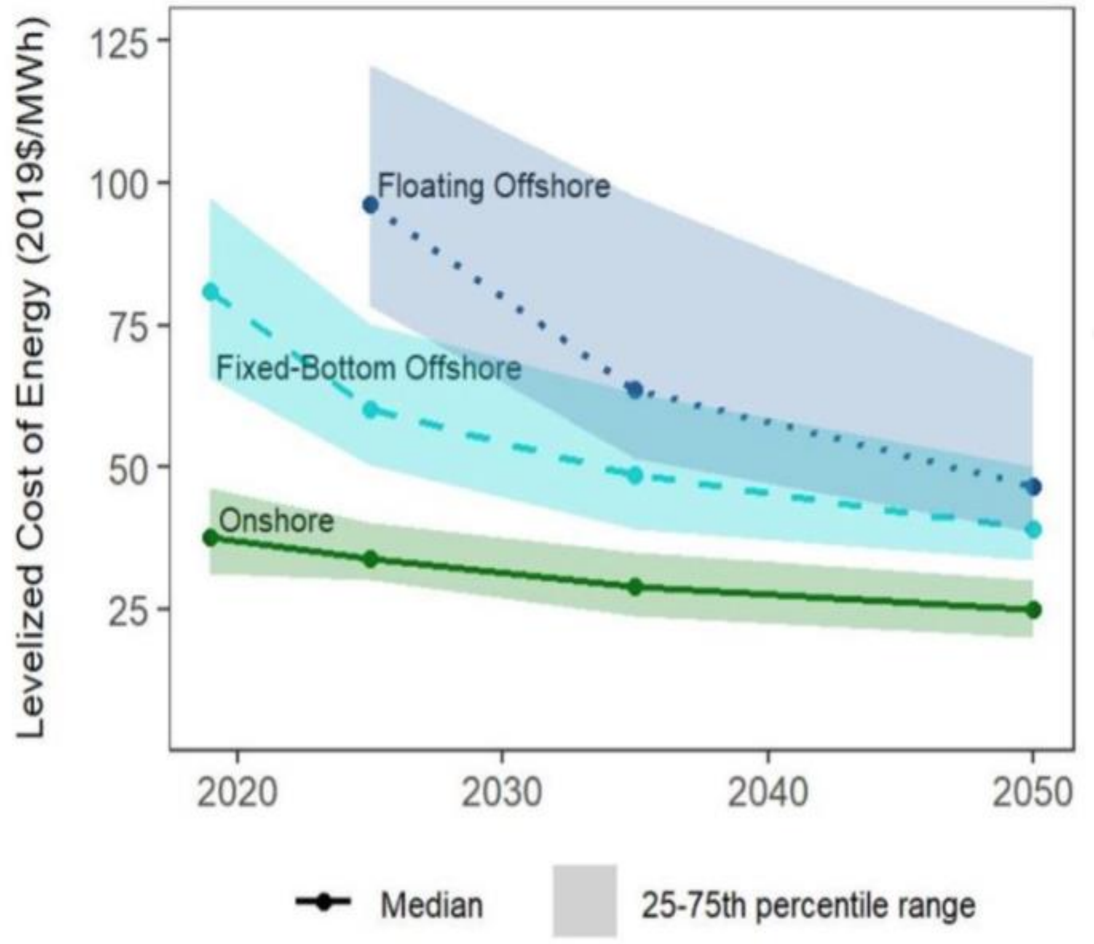


Figure 1. Experts anticipate substantial cost reductions for onshore, fixed-bottom offshore, and floating offshore wind power, but there is considerable uncertainty in those future costs. (Credit: Berkeley Lab)

COREWIND
2022
87€/MWh

COREWIND comes forward with the low-cost scenario expected in 2025, which reflects what might be possible with greatly enhanced research, development and innovation

FowApp is a practical and holistic tool that can be used to analyse LCOE and conduct LCA to give engineers and decision-makers insights into floating offshore wind farms

Source: Expert elicitation survey predicts 37% to 49% declines in wind energy costs by 2050, Ryan et al, Nature Energy, volume 6, pages555–565 (2021) https://doi.org/10.1038/s41560-021-00810-z

Thank you for your attention!

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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Development needs, Market status and exploitable results

Bernd Neddermann
Senior Project Engineer
UL DEWI

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

Introduction

- Market assessment for floating offshore wind
- Exploitable results were identified and recommendations for commercialization have been developed
- The following key results will be presented:
  - Development needs
  - Market status
  - Exploitable results

Development needs

Objectives and activities

- Development needs have been identified from a holistic view, considering
  - **Design practice**
  - **Manufacturing and pre-assembling**
  - **Transport and installation**
  - **Operation and maintenance**
- Focus on wind turbine, floater, mooring/anchoring and dynamic cables
- Analysis is based on information from COREWIND experts and a review of publications

Development needs

Design practice

- **General:** Optimized integrated designs
  Long-lasting design
- **Wind turbine:** Advanced control systems
- **Floater:** Fail-safe floater design solutions
- **Mooring/Anchoring:** Floating-specific load characteristics
  Optimized combined/shared moorings
- **Dynamic cables:** Optimization in terms of maximum excursion limits and bending stress
  Consider protection on seabed and loading at connection point

Development needs

Manufacturing and pre-assembling

- Standardization and capacity for manufacturing/assembly

Transport and Installation (T&I)

- Customized T&I equipment and additional installation assets
- Solutions for work between multiple floating objects and for deep-water installation

Operation and Maintenance (O&M)

- Innovative concepts for large component replacements
- Cost and time efficient methods for O&M strategy with tow-in to harbor for repair

Market status

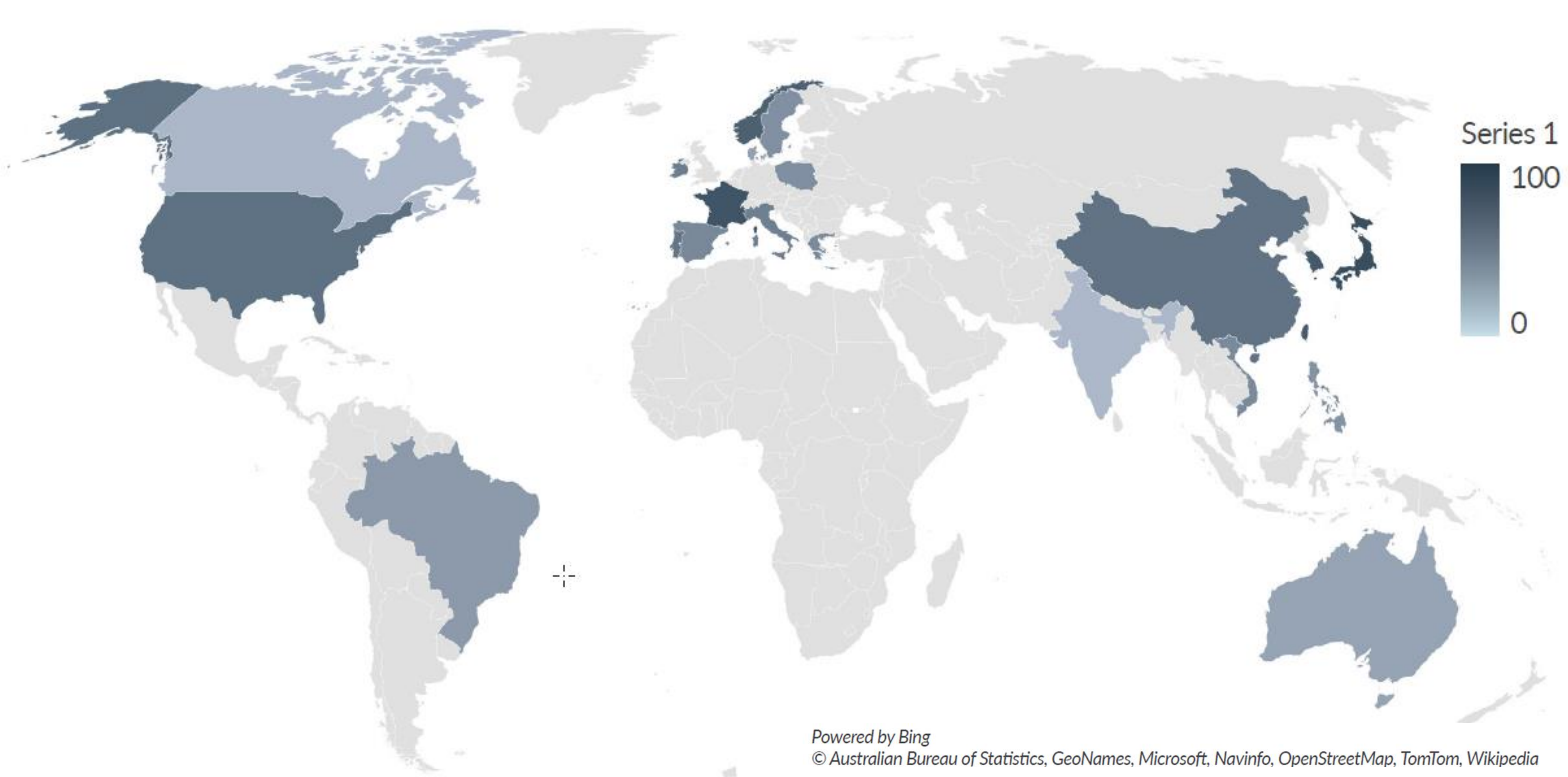
Objectives and activities

- Floating offshore wind market
- Current commercial offerings
- Potential in main global markets
- Analysis is based on a review of publications

Market status

- To date, 190 MW of floating offshore wind capacity in operation
- Floating offshore wind turbine (FOWT) prototypes/pilot projects in the U.K., Norway, Portugal, France and in Japan and Mainland China
- A shift to semi-submersible floaters can be observed
- More than 80 floater concepts under development
- Huge investments from energy and oil companies
- First commercial-scale floating wind projects under development
- 60% (USA) to 80% (Europe, Japan) of wind resources in deep waters can be used by FOWT
- Potential also for green hydrogen production and for power supply of oil and gas platforms

Market status



Near-term floating wind markets 2022-2030

EUROPE

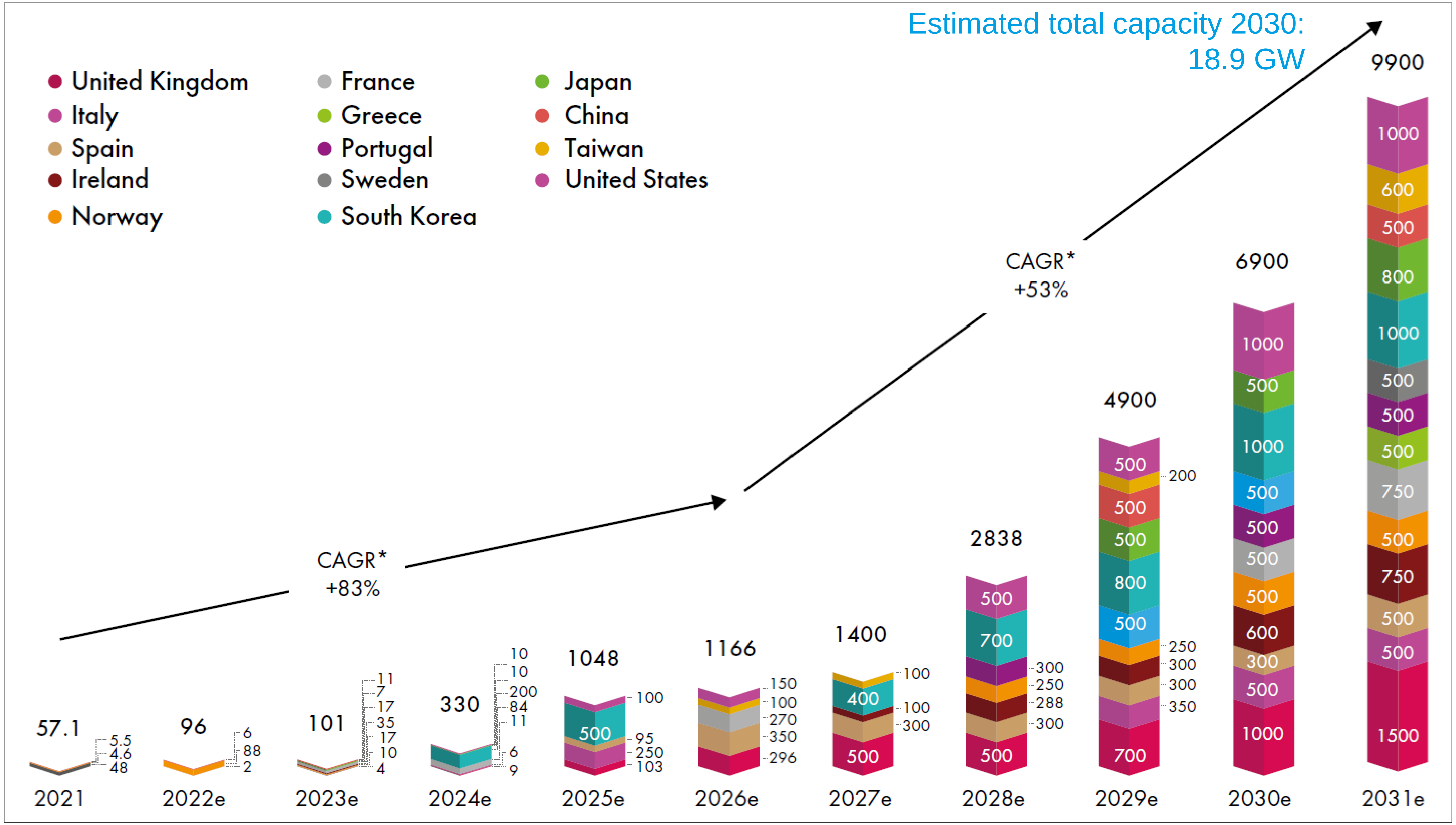
- Norway
- U.K.
- Ireland
- Poland
- France
- Portugal
- Spain

ASIA

- Greater China
- Japan
- South Korea

Source: Floating Offshore Wind International Market Opportunities – FOW CoE/OWC, 06/2022

Market status



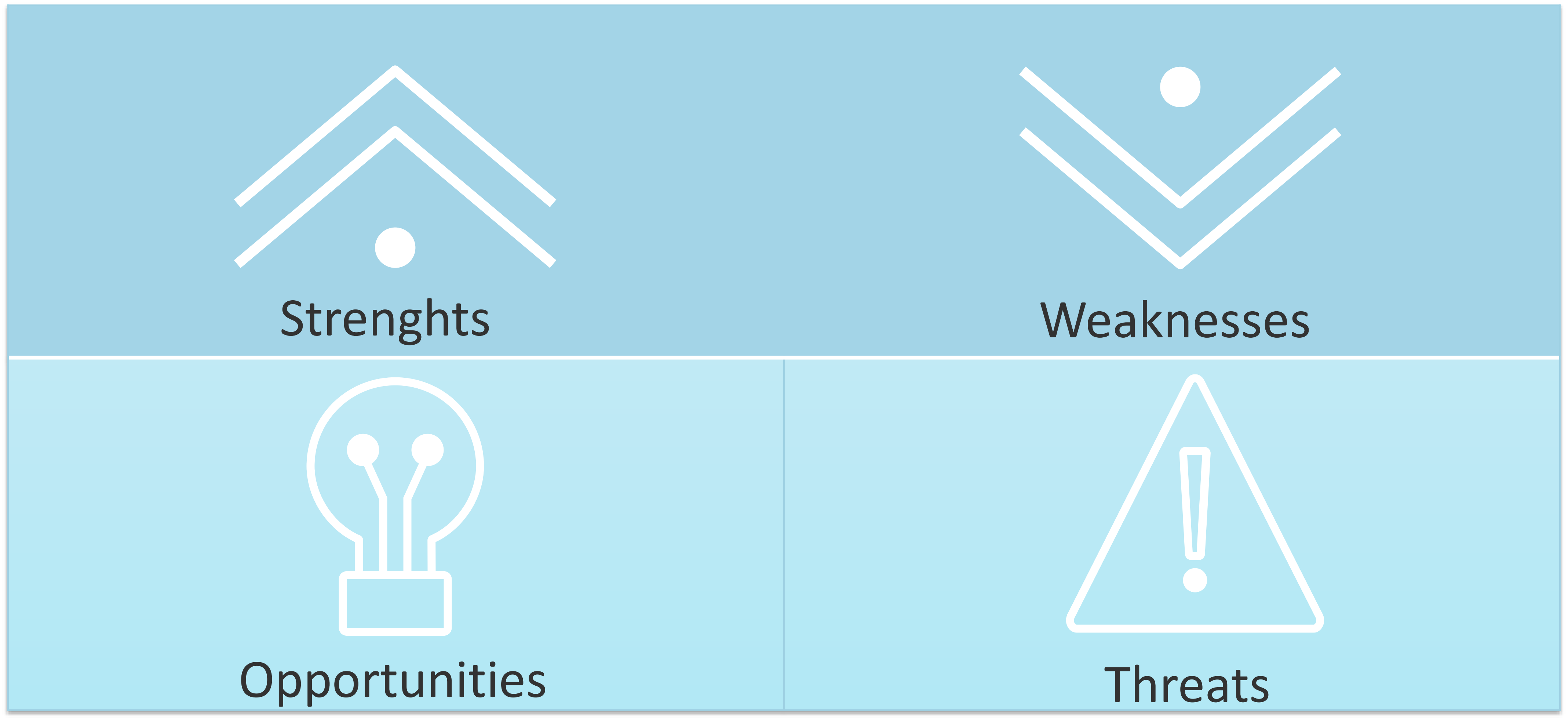
*Compound Annual Growth Rate

Source: Global Offshore Wind Report 2022, GWEC 06/2022

Exploitable results

Objectives and activities

- Exploitable results were identified
- Recommendations for commercialization have been developed
- Analysis is based on information from COREWIND partners



SWOT analysis

Exploitable results

Categories for Exploitable Results (ER)

- Products
- Processes
- Knowledge and intellectual property (IP)
- Services
- Other

Exploitable results

#	Type of ER	Exploitable Result
1	Product /Service	FOWAPP
2	Product	DigitalTwin for FOWT
3	Product	Optimized mooring design – WindCrete
4	Product	Optimized mooring design – ActiveFloat
5	Product	WindCrete 15MW
6	Product	ACTIVEFLOAT floating structure
7	Product/ Software Feature	HAWC2 software new modelling capability: Floating Wind Farm Modeling
8	Product/Software	Open-Source Software
9	Product/Software	Software
10	Service	O&M planning and strategy tool
11	Service	Refinement of certification process for FOWT
12	Service	Improved testing concept for FOWT
13	Service	BIM model
14	Knowledge & IP	Floating Turbine wake Investigation
15	Knowledge & IP	Floating wind turbine Installation Modeling

#	Type of ER	Exploitable Result
16	Knowledge & IP	Limits of heavy-lift maintenance, large component exchange
17	IP	Innovative shared mooring system
18	Product	1st campaign of experimental tests related to mooring and cable dynamics in COCOTSU flume
19	Product	2nd campaign of experimental tests related to integrated FOWT in Cantabrian Coastal and Ocean Basin and in Wind Tunnel
20	Service	Best practices and testing recommendations for experimental modelling of mooring and cable dynamics for FOWT
21	Service	Layout optimization algorithm
22	Product	Shared mooring lines and anchors
23	Product	Peak load reduction systems
24	Service	Mooring optimization code
25	Service	Monitoring system ROI

FOWAPP = Floating offshore wind assessment App
HAWC2 = Horizontal axis wind turbine simulation code 2nd generation
COCOTSU = Wave-current-tsunami-flume

Exploitable results

- 13 Products – e.g., FowApp for Levelized Cost of Energy (LCOE) and Life Cycle Assessment (LCA) calculations
- 8 Services – e.g., O&M planning and strategy tool
- 4 Knowledge and IP – e.g., floating wind turbine installation modeling
- Product strategy and go-to-market-plan have been developed for selected ERs

Go-to-market plan

Conclusion

- A market assessment for floating offshore wind turbines is presented, including
  - **Review of standards**
  - **Design practice recommendations**
  - **Development needs**
  - **Current FOWT projects and commercial offerings**
  - **Potential in global markets**
  - **Opportunities and threats**
- 25 Exploitable Results were identified and recommendations for commercialization have been developed
- Publications are available on the COREWIND website

Thank you for your attention!

Contact: Bernd.Neddermann@UL.com
info@corewind.eu

Time for questions!

Join at
slido.com
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COST REDUCTION OF
FLOATING WIND TECHNOLOGY

Panel discussion: Similar objectives, different findings? Discussion with AFLOWT and FLOATECH projects

Disclaimer:

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Project details:

Duration:
1 Sep 2019 - 28 Feb 2023
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Panel discussion: Similar objectives, different findings? Discussion with AFLOWT and FLOATECH projects

Moderated by:

Lizet Ramirez
Senior Analyst
WindEurope

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Speakers:

Mareike Leimeister
Research Associate
Fraunhofer IWES

Interreg
EUROPEAN UNION
North-West Europe
AFLOWT
European Regional Development Fund

Alessandro Bianchini
Assistant Professor
Università degli Studi di Firenze

FLOATECH

Jose Luis Domínguez García
Head of Power Systems Group
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Interreg
EUROPEAN UNION
North-West Europe
AFLOWT
European Regional Development Fund

Accelerating market uptake of
FLoating
Offshore
Wind
Technology

EMEC
THE EUROPEAN MARINE ENERGY CENTRE LTD

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

ESB Energy for generations

MaREI Energy · Climate · Marine

UCC

Fraunhofer IWES

MARIN

FEBUS OPTICS

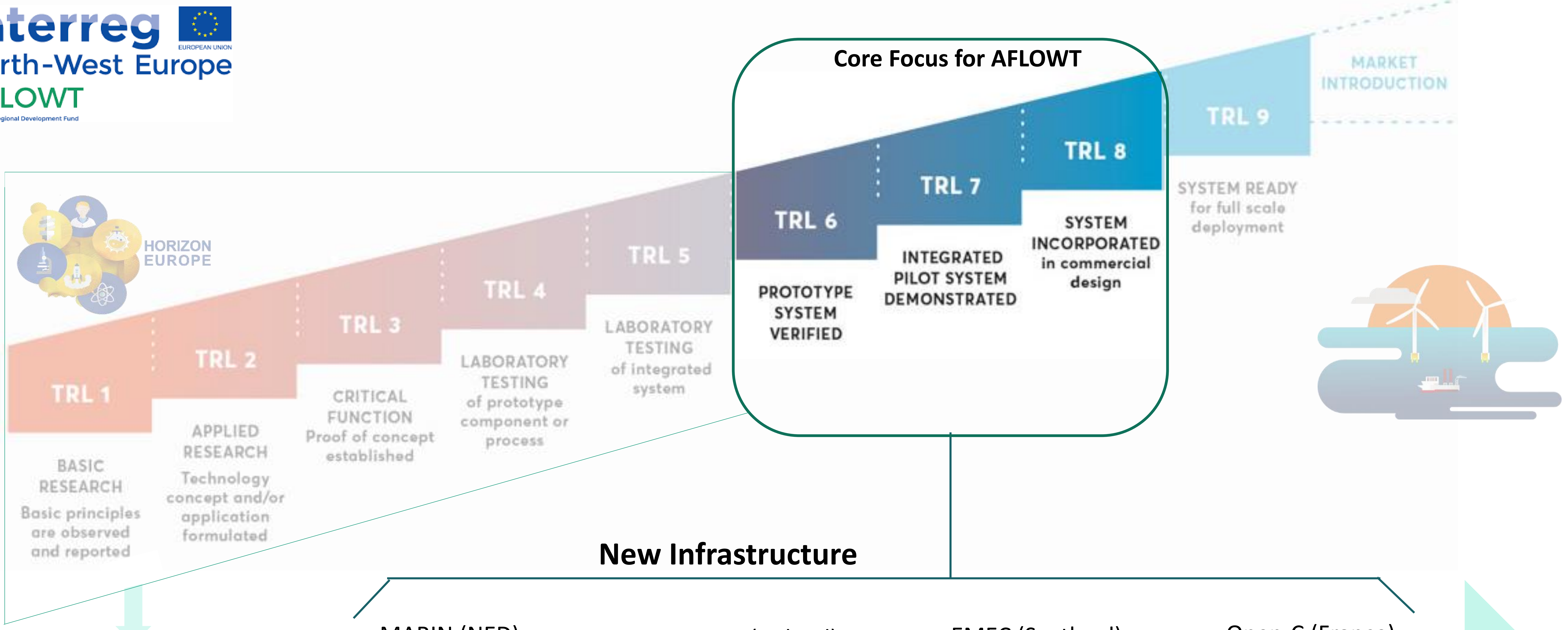
ALICYA Cable Life Cycle Assurance

SAIPEM

FONDATION OPEN-C

Fraunhofer IWES

Interreg North-West Europe
AFLOWT
European Regional Development Fund



New Infrastructure

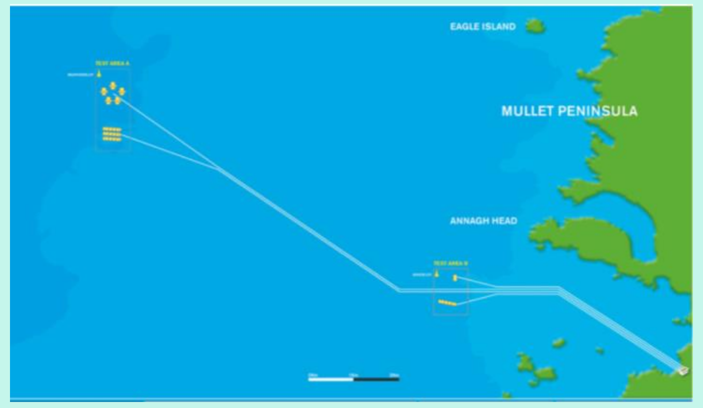
Existing partner linked facilities:

ECN test tank – model scale
UCC test tank – model scale
EMEC scale test sites - components
EMEC Billia Croo – subsystems
IWES – onshore testing at all scales

MARIN (NED)

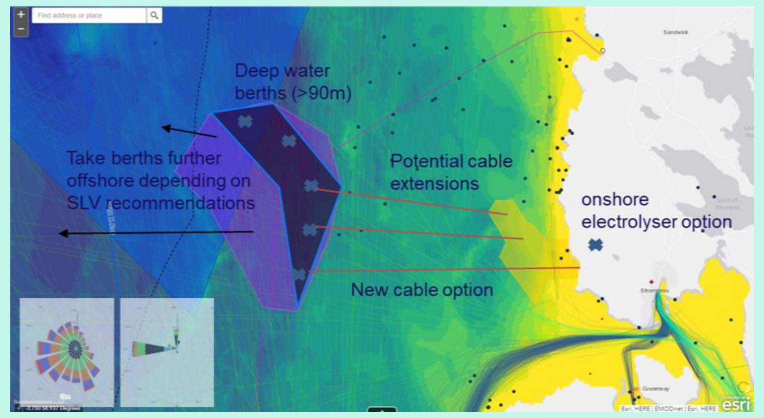
- Large scale model testing
- Onshore test basin upgrade
- Test setup for 15MW+ concepts
- Existing infrastructure upgraded

AMETS (Ireland)



- Full scale high energy site
- Onshore construction phase
- 10MW+
- 8.5km2

EMEC (Scotland)



- Full scale medium energy site
- In design phase
- Up to 100 MW (Hybrid)
- 22km2

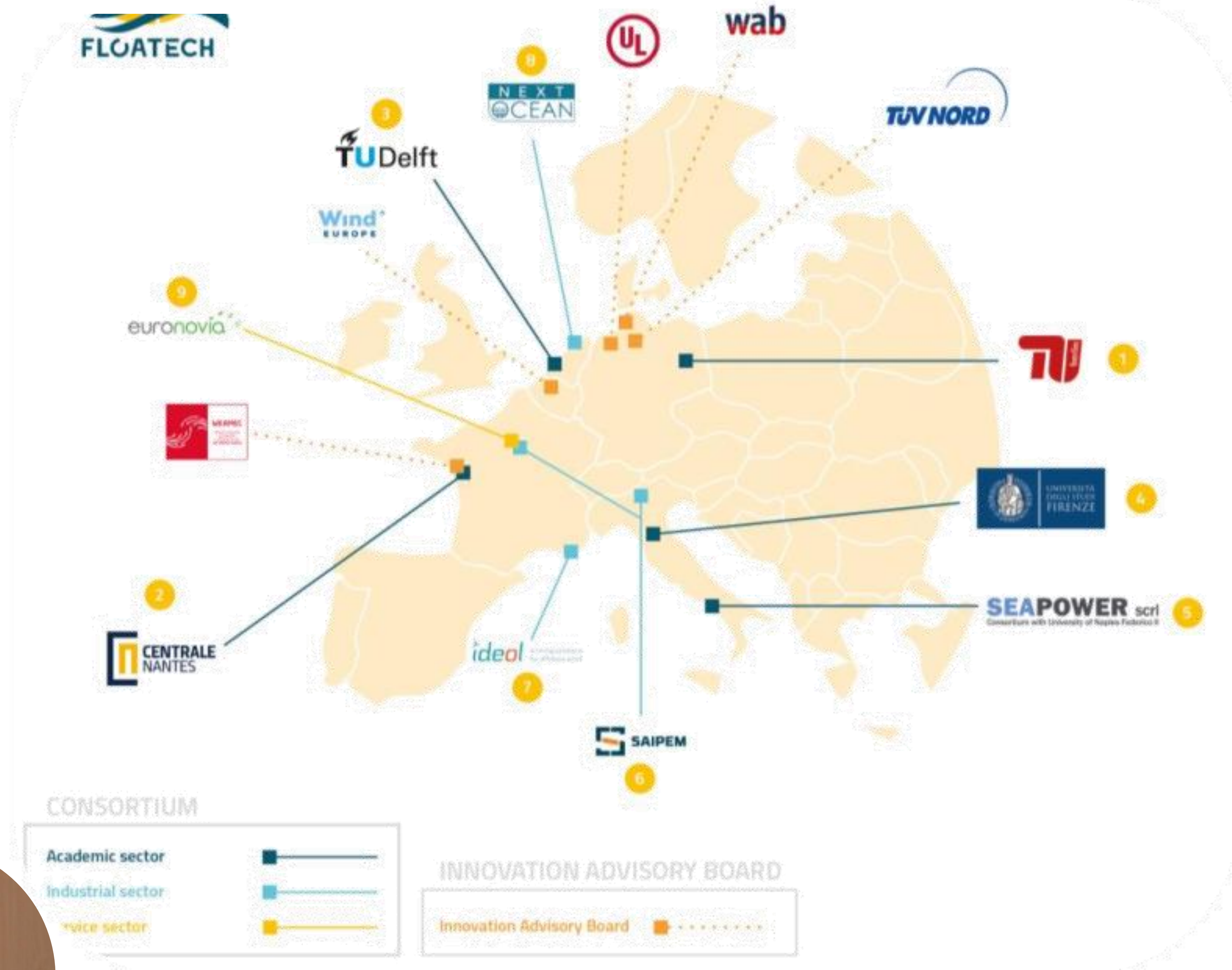
Open-C (France)

- Full scale low energy site
- In permitting phase
- 10MW+
- 1.7km2

Fraunhofer IWES

FLOATECH overview

- EU H2020 funding scheme
- RIA – total budget of 4 M€
- 9 partners
  - 4 from academia
  - 4 from wind industry
  - 1 organizational partner
- Advisory board with 5 highly-reputed companies of the sector
- Project coordinator:
  - Prof. Christian Navid Nayeri (TU Berlin)

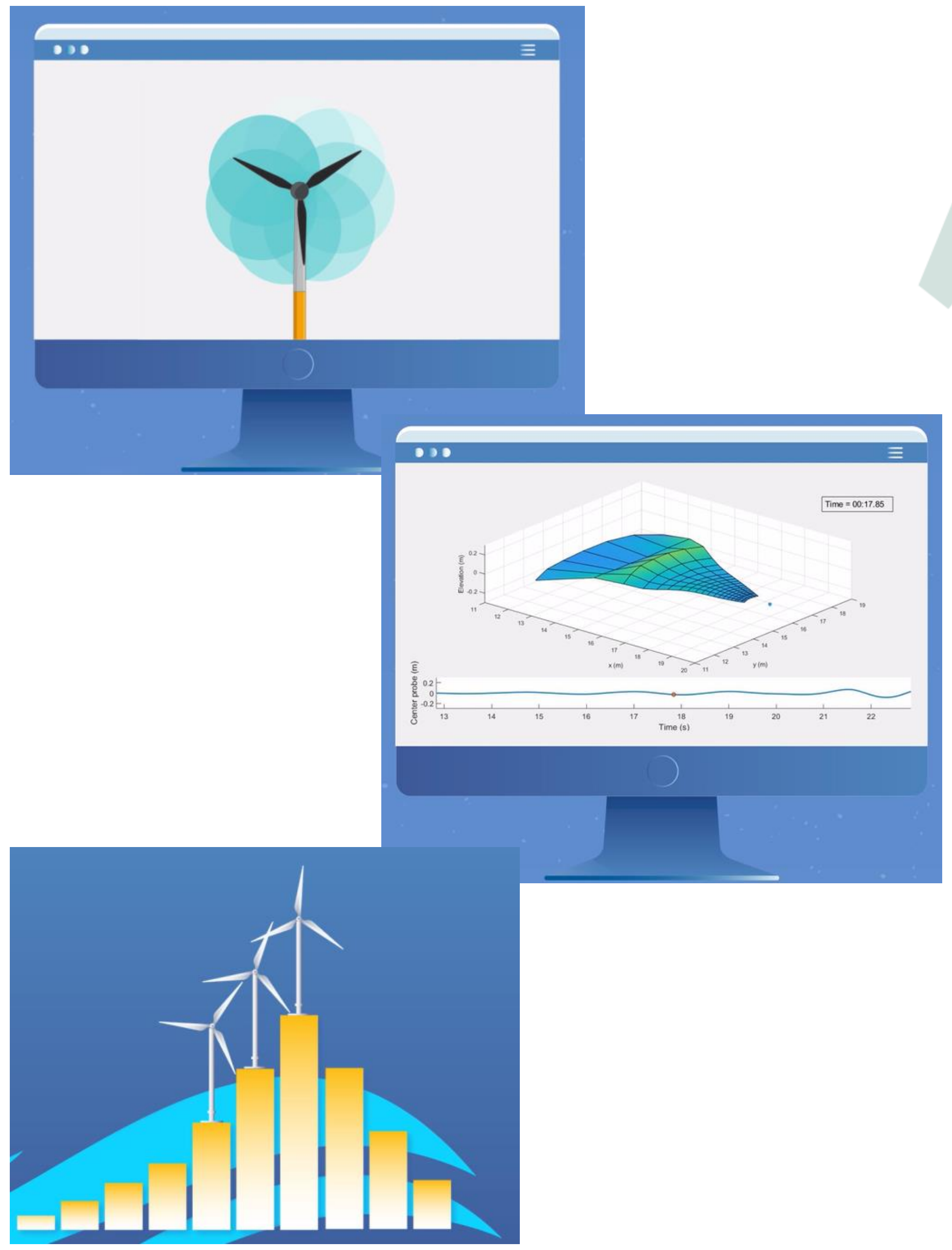


Mission

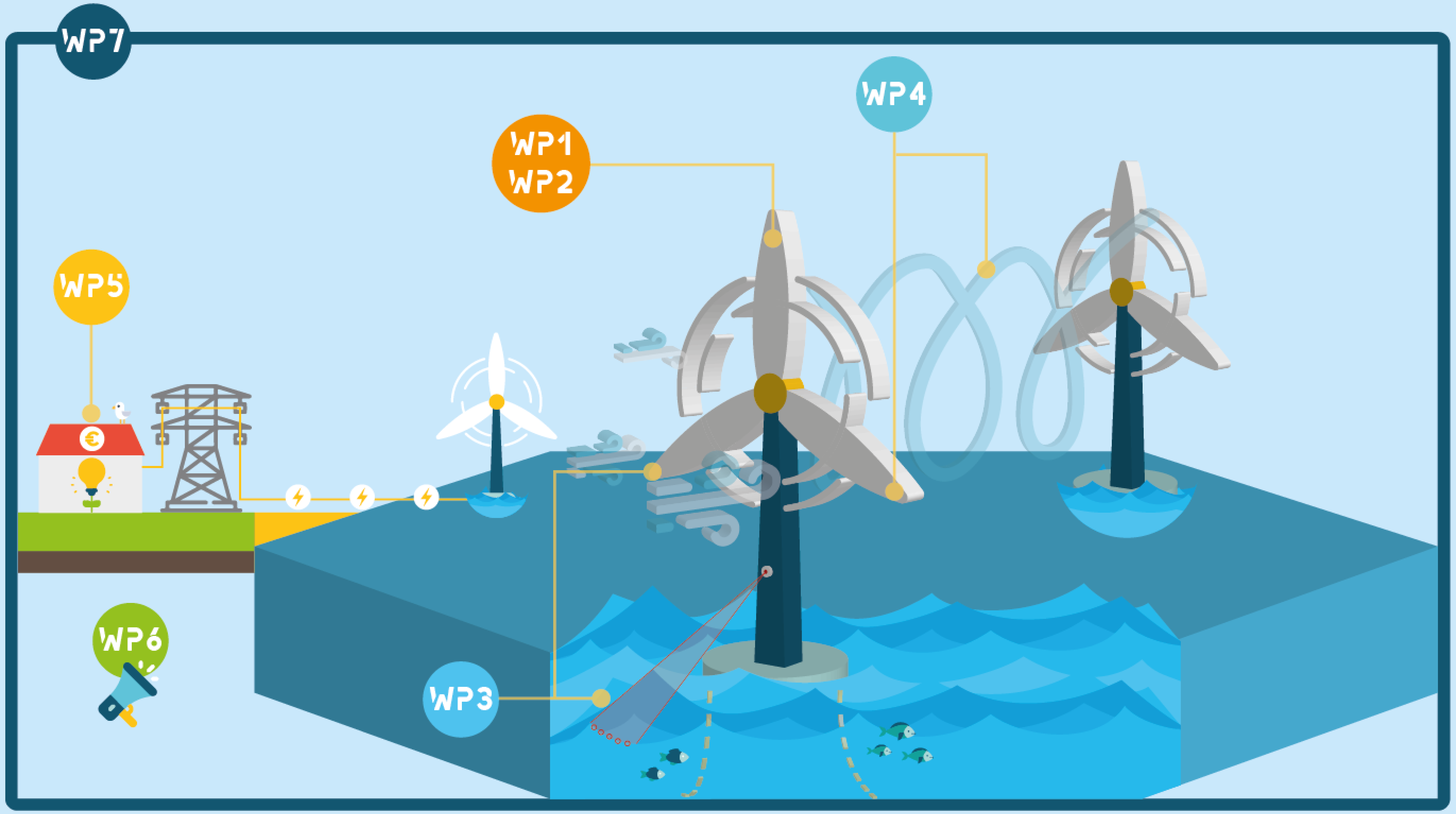
- FLOATECH «*aims to develop* ***advanced technologies*** *and* ***design tools*** *to increase the level of maturity and improve the cost competiveness of FOWT technology*»

- This will be pursued by means of **5 main actions**

  1. get a better insight into the *aerodynamics and hydrodynamics of FOWTs*
  2. model and reduce uncertainties in the design process through *advanced simulation tools*, mainly *open source*
  3. explore *new concepts and techniques* through experiments and simulations
  4. increase the future *market value of floating wind energy*
  5. reducing *LCOE*



Project structure



WP1	WP2	WP3	WP4	WP5	WP6	WP7
Development of QBlade-Ocean	Quantification of uncertainty reduction gained through QBlade-Ocean	Feed forward wave-based control	Active Wake Mixing for floating wind farm	LCOE and market value evaluation of proposed technologies and scale up	Dissemination, Communication & Exploitation	Project Management

COST REDUCTION OF
FLOATING WIND TECHNOLOGY

What's next? Possible future for COREWIND solutions

Jose Luis Domínguez García

Head of Power Systems Group
IREC - Institut de Recerca en Energia de Catalunya

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Closing remarks

- Scan the QR code to find all the results of the COREWIND project
- Any question? Contact us at: info@corewind.eu
- And follow us on social media!
  - @corewindeu
  - COREWIND

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COST REDUCTION OF
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Time for a picture!

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Join us for a networking lunch!

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