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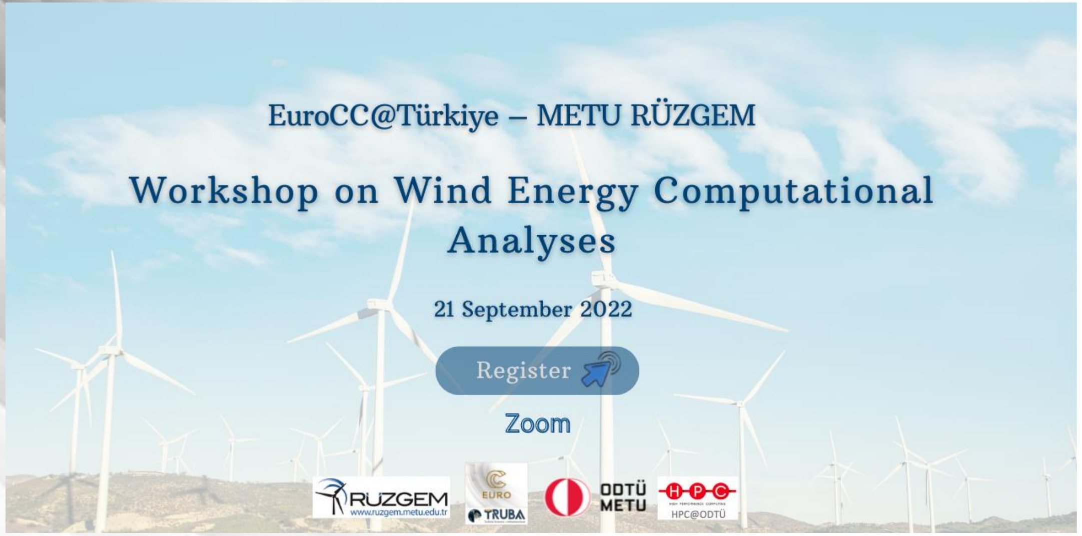
Workshop on Wind Energy Computational Analyses



21 September 2022

EuroCC@Türkiye & METU RUZGEM:
Workshop on Wind Energy Computational Analyses

21 September 2022

09:30 - 10:25	-- Introduction to Wind Turbine Aerodynamics	Assoc. Prof. Dr. Nilay Sezer Uzol
10:25 - 11:20	-- Wind Turbine Airfoil CFD Analyses	Ezgi Orbay Akcengiz
Coffee Break		
11:30 - 12:25	-- Wind Turbine Rotor CFD Analyses	Ali Ata Adam
Lunch Break		
13:15 - 14:10	**-- Introduction to Offshore Wind Turbine Design**	**Assoc. Prof. Dr. Elif Oğuz**
14:10 - 15:05	-- Offshore Wind Turbine Aero & Hydro Analyses	Muhammad Juanda Putra
Coffee Break		
15:15 - 16:10	-- Introduction to Wake Models and Wind Farm Analyses	Ali Ata Adam
16:10 - 17:00	-- Wind Farm CFD Analyses	Hüseyin Can Önel

https://indico.truba.gov.tr/event/94/

Workshop on Wind Energy Computational Analyses

Introduction to Offshore Wind Turbine Design

Elif OĞUZ
Dept. of Civil Engineering, METU
METU RÜZGEM

21 September 2022

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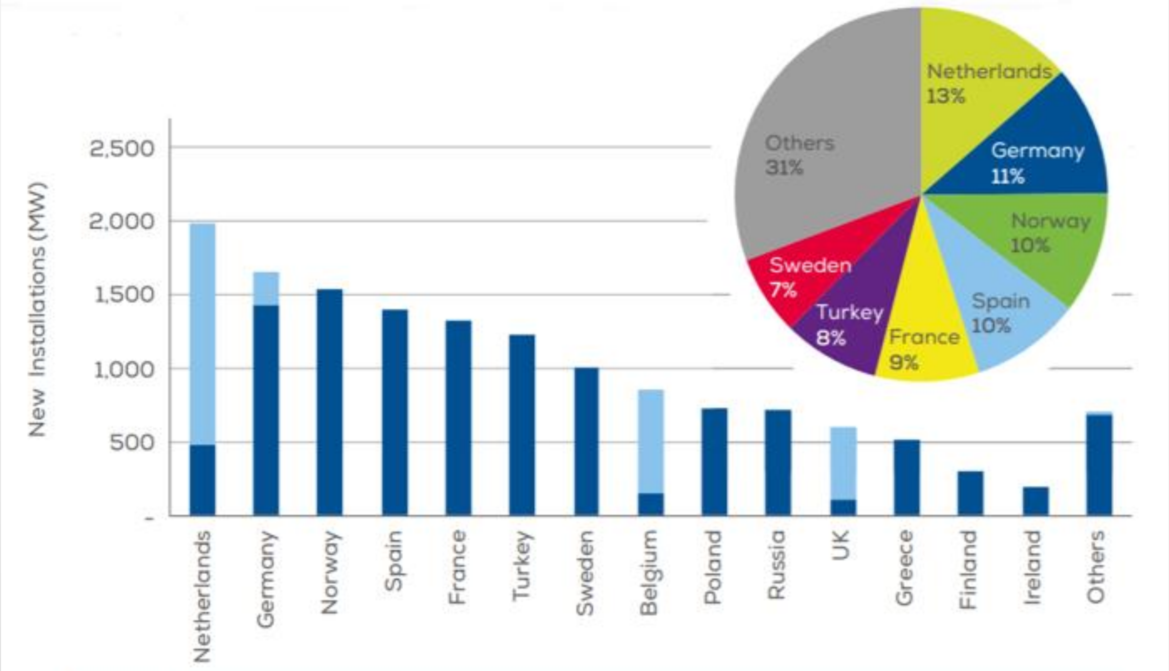
Outline

- Introduction
- Classification of Offshore Wind Turbines
- Numerical Modelling of OWTs
- Recent developments in offshore wind industry

Offshore Wind Turbines

Introduction

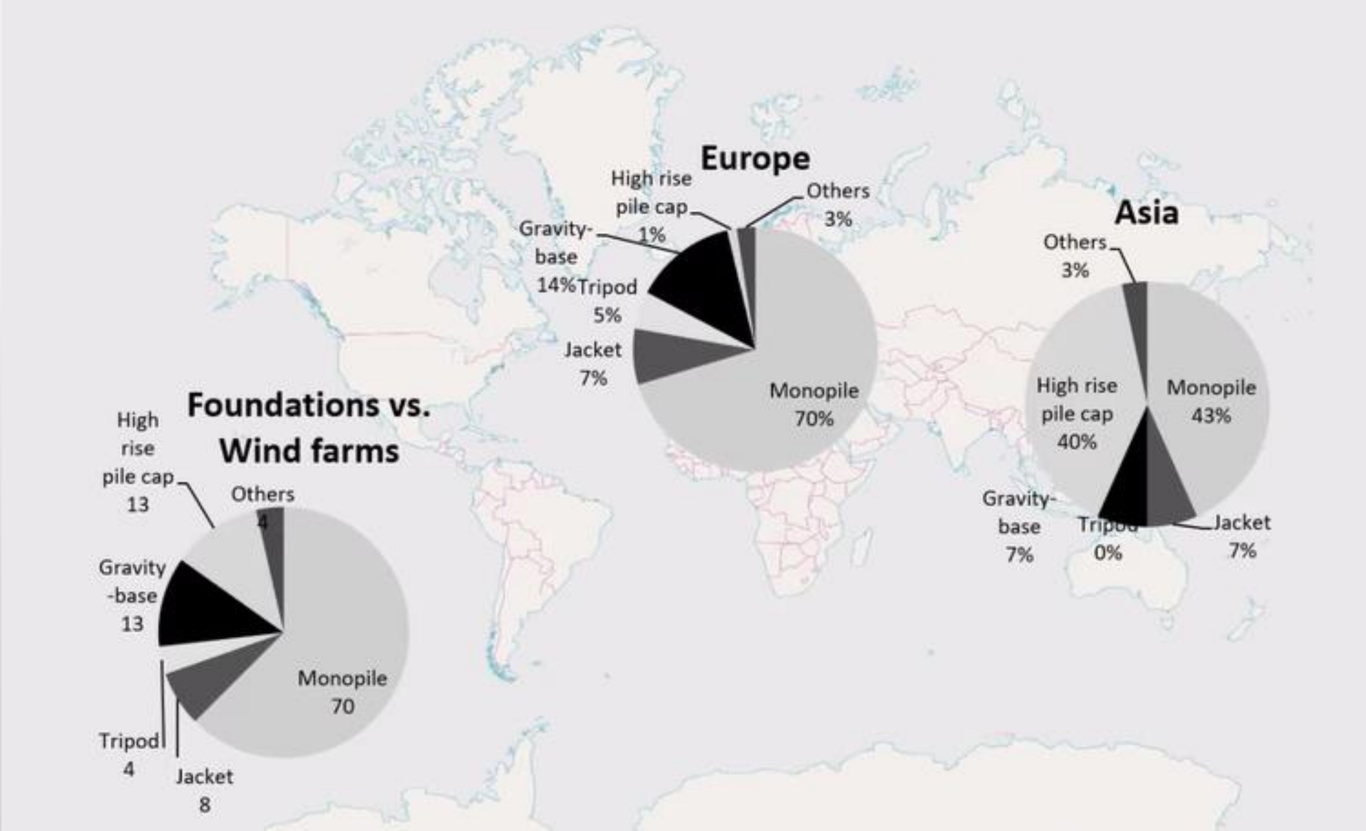
New Onshore and Offshore Installations in Europe in 2020



	Netherlands	Germany	Norway	Spain	France	Turkey	Sweden	Belgium	Poland	Russia	UK	Greece	Finland	Ireland	Others
Offshore	1,493	219	-	-	-	-	-	706	-	-	483	-	-	-	17
Onshore	486	1,431	1,532	1,400	1,318	1,224	1,007	152	731	713	115	517	302	196	688
Total	**1,979**	**1,650**	**1,532**	**1,400**	**1,318**	**1,224**	**1,007**	**858**	**731**	**713**	**598**	**517**	**302**	**196**	**705**

Source: WindEurope

Offshore Wind Farm Foundations worldwide

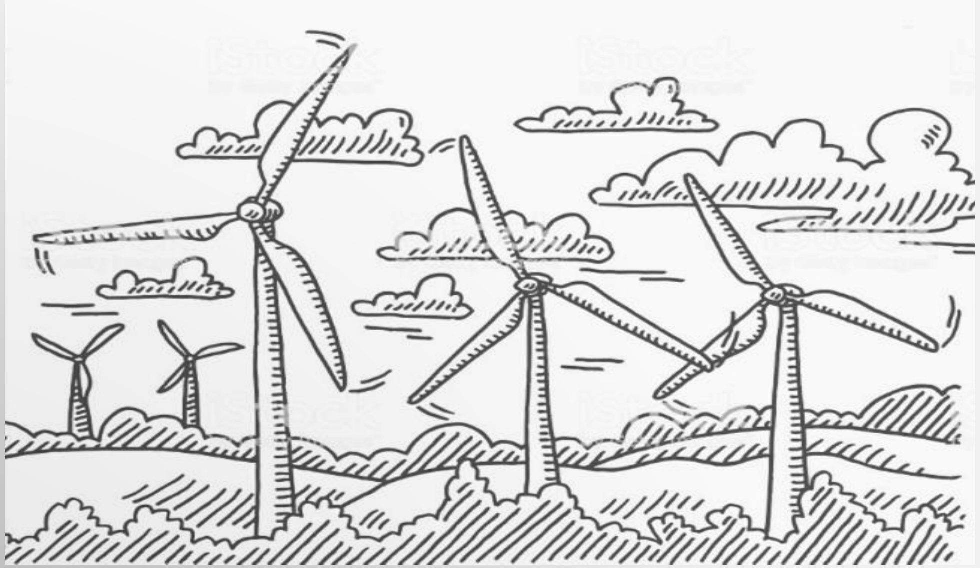


Ref : *Diaz, H. and Guedes Soares, C. (2020). Review of the current status, technology and future trends of offshore wind farms, Ocean Engineering.*

Offshore Wind Turbines

Introduction

Why Offshore Wind.?



Offshore Wind Turbines
Introduction

Land based wind turbines

Advantages :
- Cost
- Maintenance
- Grid connection


Disadvantages :
- Noise
- Drawbacks for bird life
- Visual impact
- Lower wind velocities
- Planning approval

Fixed-bottom offshore wind turbines

Advantages :
- Maintenance
- Grid connection

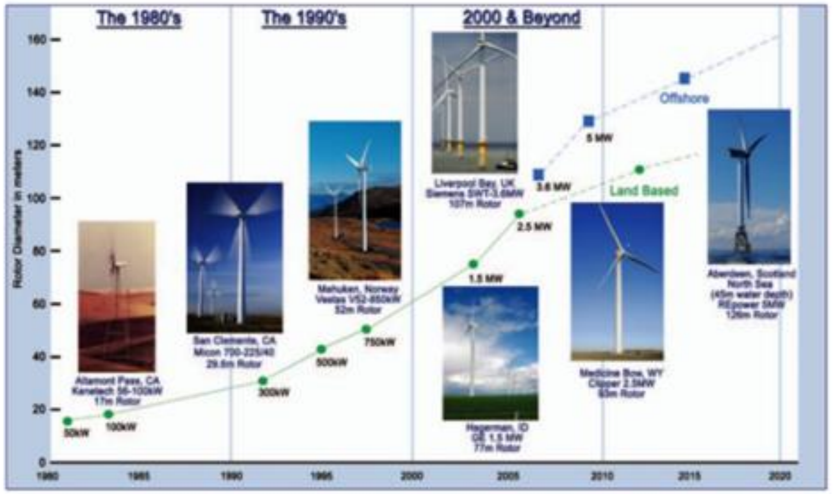
Disadvantages :
- Water depth
- Sea bottom
- Continental shelf
- Expensive for > 50m

Floating offshore wind turbines (FOWTs)

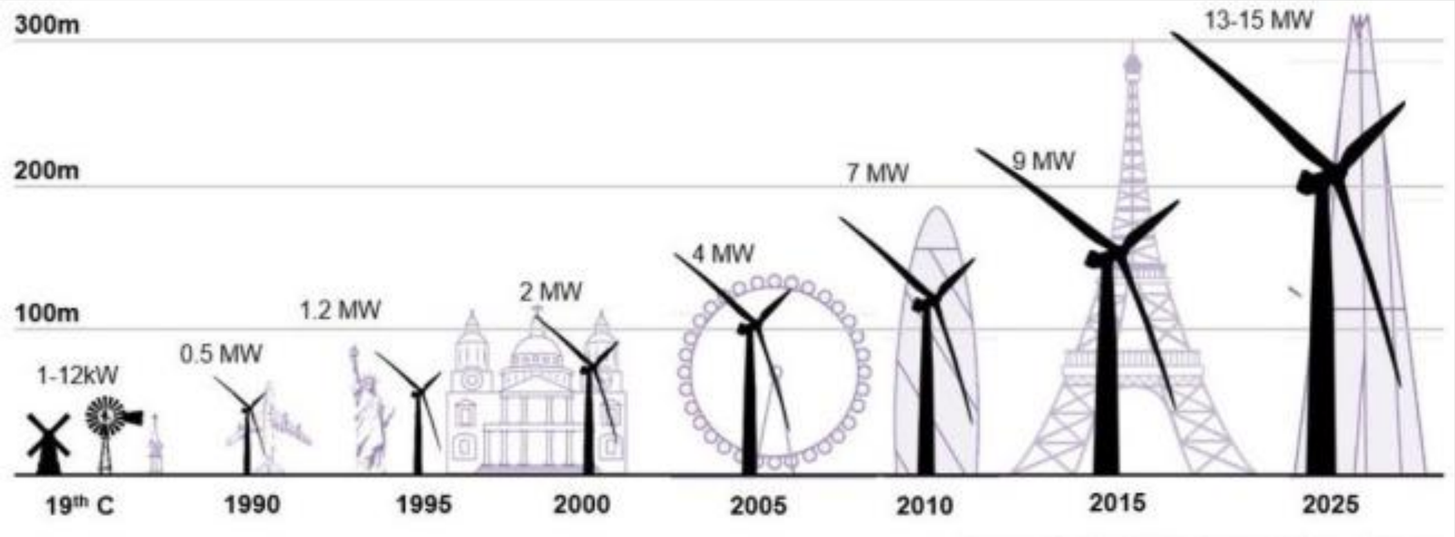
Advantages :
- More stable wind field with higher average velocities
- Increased system efficiency
- Relatively low surface roughness of the ocean → higher wind speeds

Disadvantages :
- Cost
- Maintenance
- Grid connection
- Harsh environment
- Dynamic response

Turbine Capacity



Trends of the wind turbine sizes and capacity
(US Department of Energy)



Offshore Wind Turbines

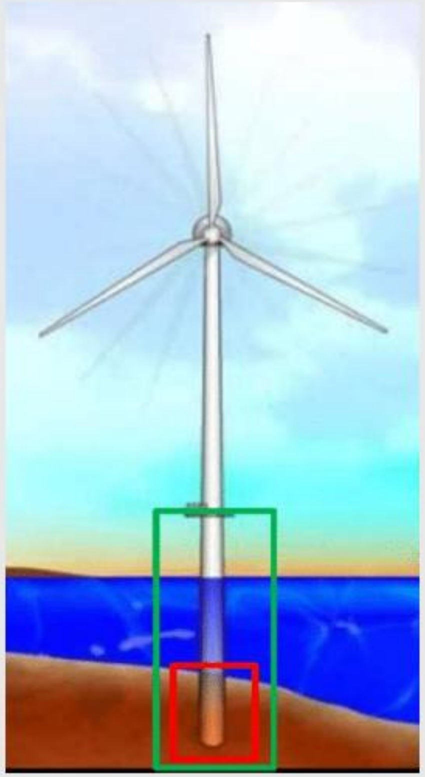
Developments in Offshore Wind Industry

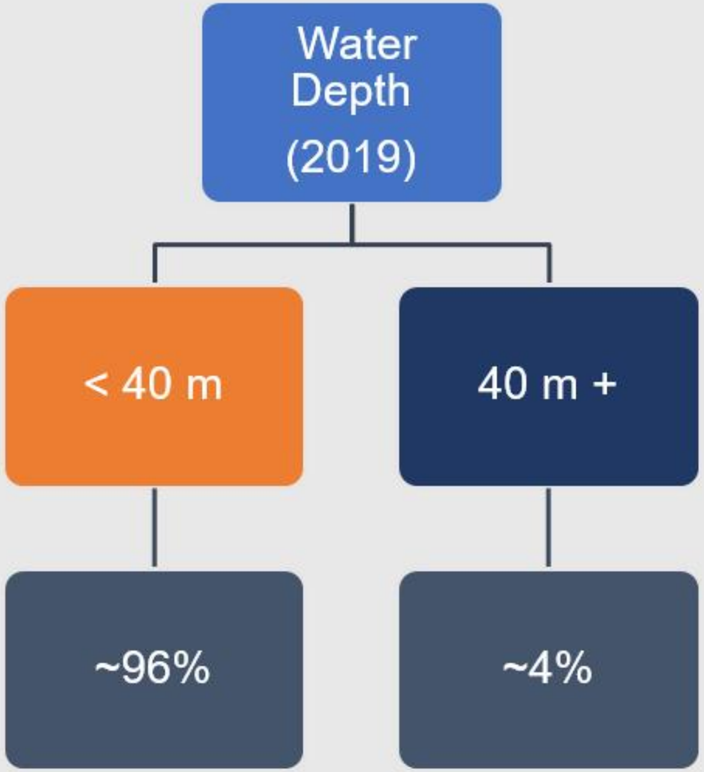
	2013	2019
Average depth	16 m	33 m +100%
Distance to shore	29 km	59 km +103%

Ref. *Uzunoglu, E., Oğuz, E., Soares, C. An Overview of Platform Types Used in Floating Wind Energy. 2nd International Congress on Ship and Marine Technology (GMO-SHIPMAR 2021)*

Offshore Wind Turbines

Developments in Offshore Wind Industry





Ref. *Uzunoglu, E., Oğuz, E., Soares, C. An Overview of Platform Types Used in Floating Wind Energy. 2nd International Congress on Ship and Marine Technology (GMO-SHIPMAR 2021)*

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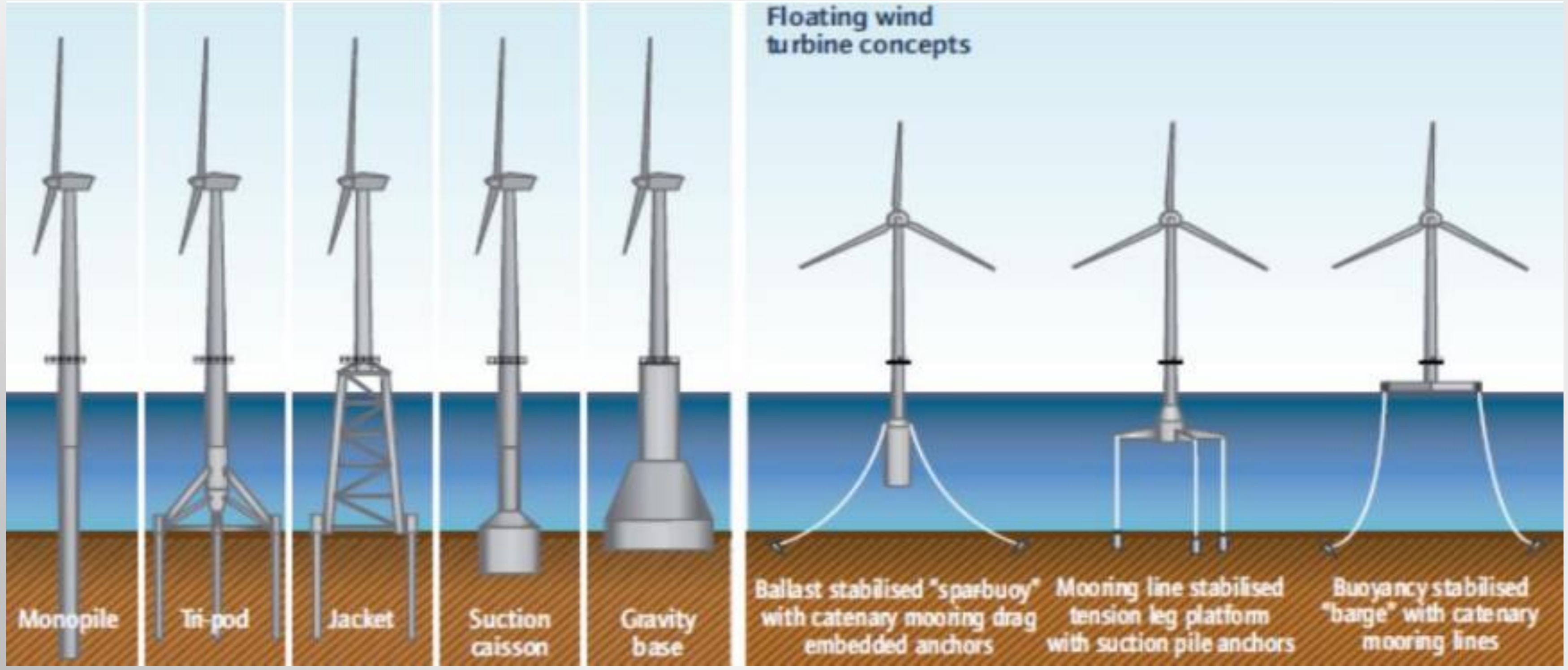
Offshore Wind Turbines

- *Fixed bottom offshore wind turbines*
- *Floating offshore wind turbines*

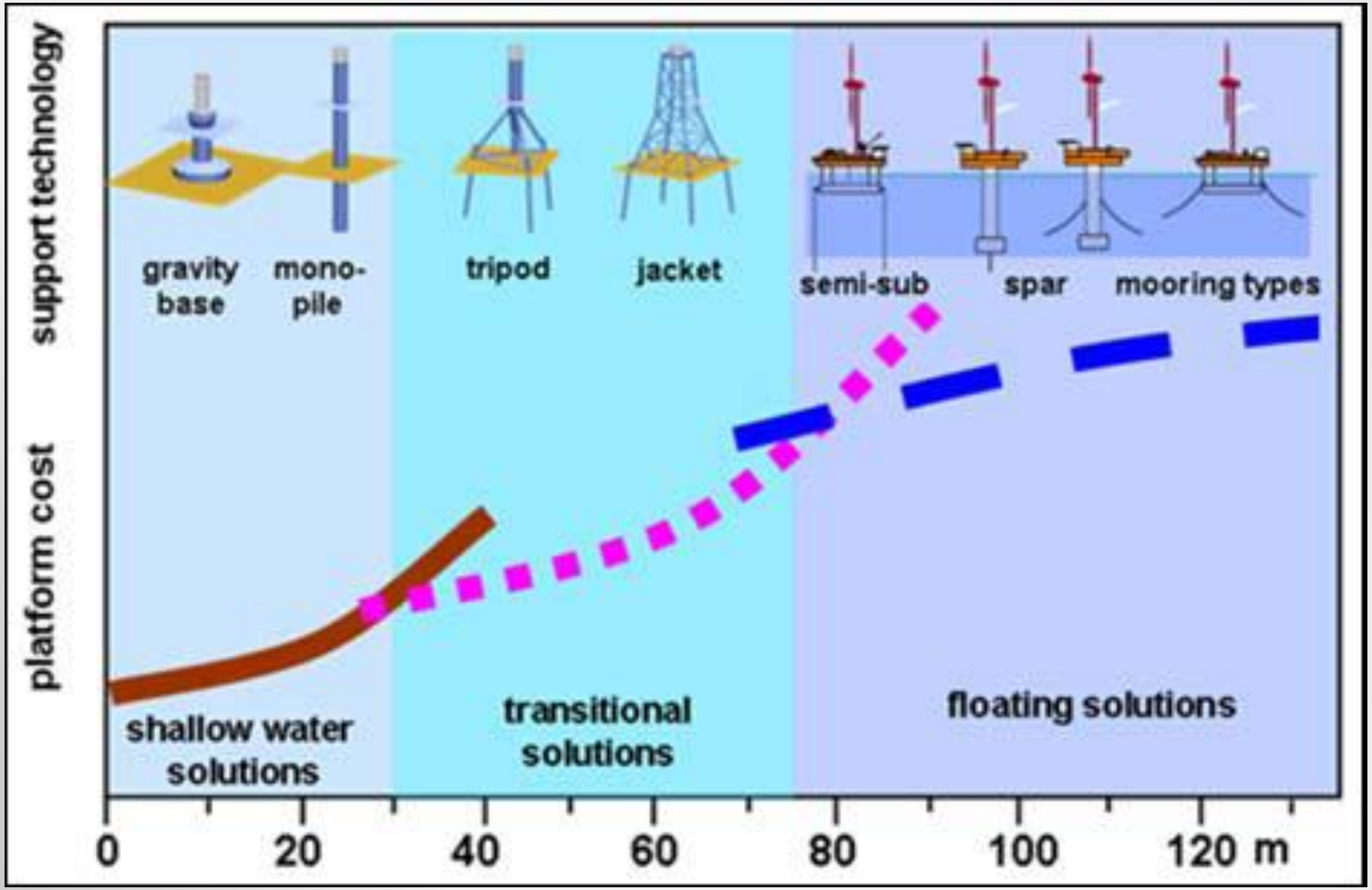
Fixed bottom foundations and floating offshore concepts



Ref. *Edenhofer o. et al, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, 2012 (Cambridge University Press)*

Offshore Wind Turbines

Fixed bottom foundations and floating offshore concepts



Offshore wind

- Offshore oil-and-gas sector
- Onshore turbine technologies

Identification of environmental loads on floating wind turbines

The equation of motion of a floater can be written, in simplified form:

$$F_{aero} + F_{hydro} = (M_a + M)\ddot{x} + (B_v + B_p)\dot{x} + (C_h + C_m)x$$

F_{aero} : the aerodynamic forces

F_{hydro} : hydrodynamic force

M_a : hydrodynamic added mass

M : mass of the structure (i.e., the inertial components).

B_v, B_p : hydrodynamic damping components

where the v subscript represents the viscous component and p is used for the potential damping.

The restoring is provided by the moorings C_m and hydrostatics (C_h)

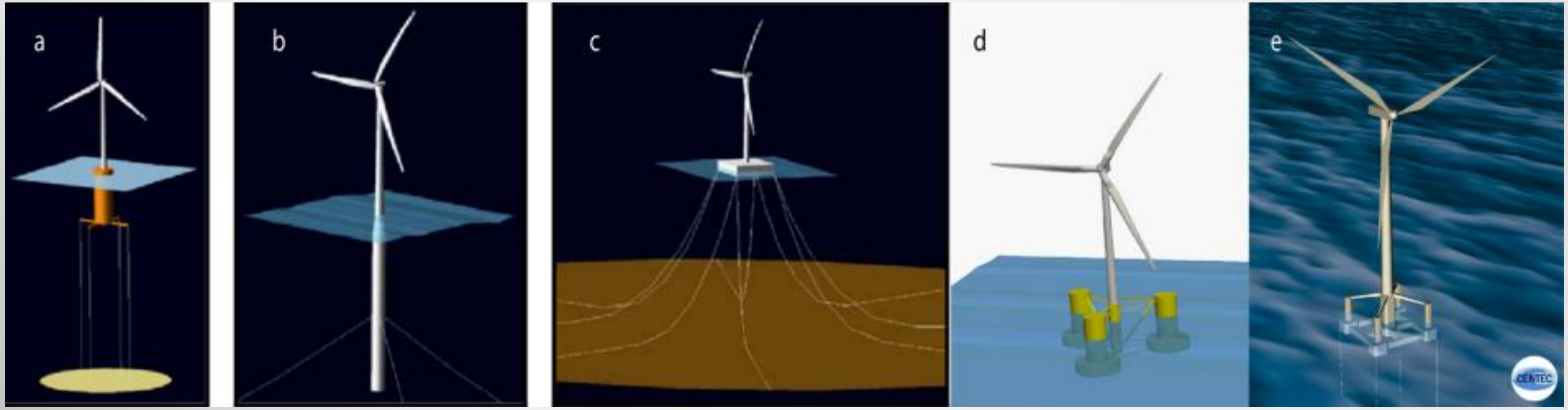
Offshore Floating Wind Turbines (OFWTs)

Platform examples from oil-and-gas. From a to d: semisubmersible, TLP, SPAR, and barge

***Ref.** Uzunoglu, E., Oğuz, E., Soares, C. An Overview of Platform Types Used in Floating Wind Energy. 2nd International Congress on Ship and Marine Technology (GMO-SHIPMAR 2021)*

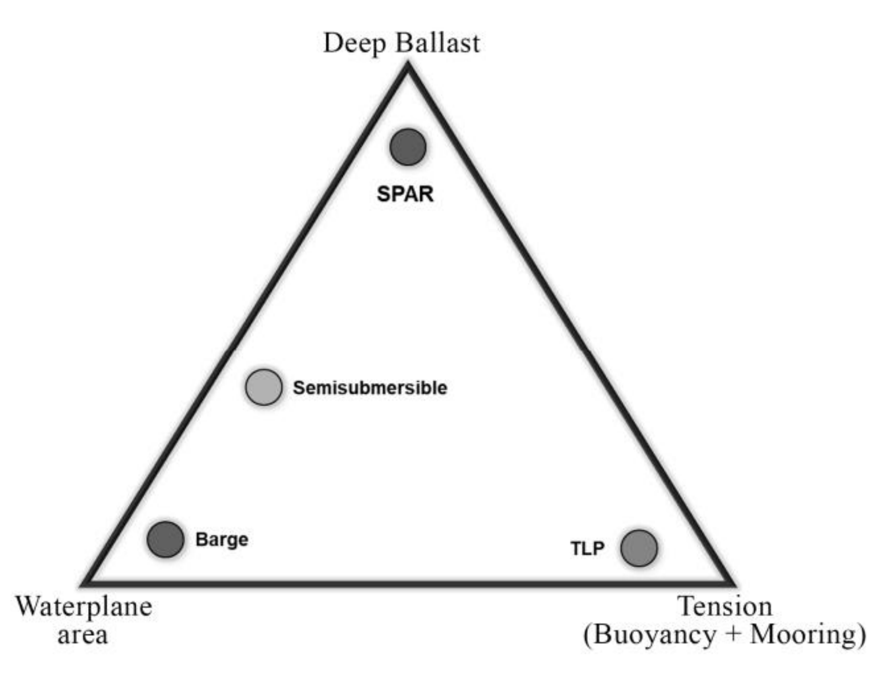
Offshore Floating Wind Turbines (OFWTs)

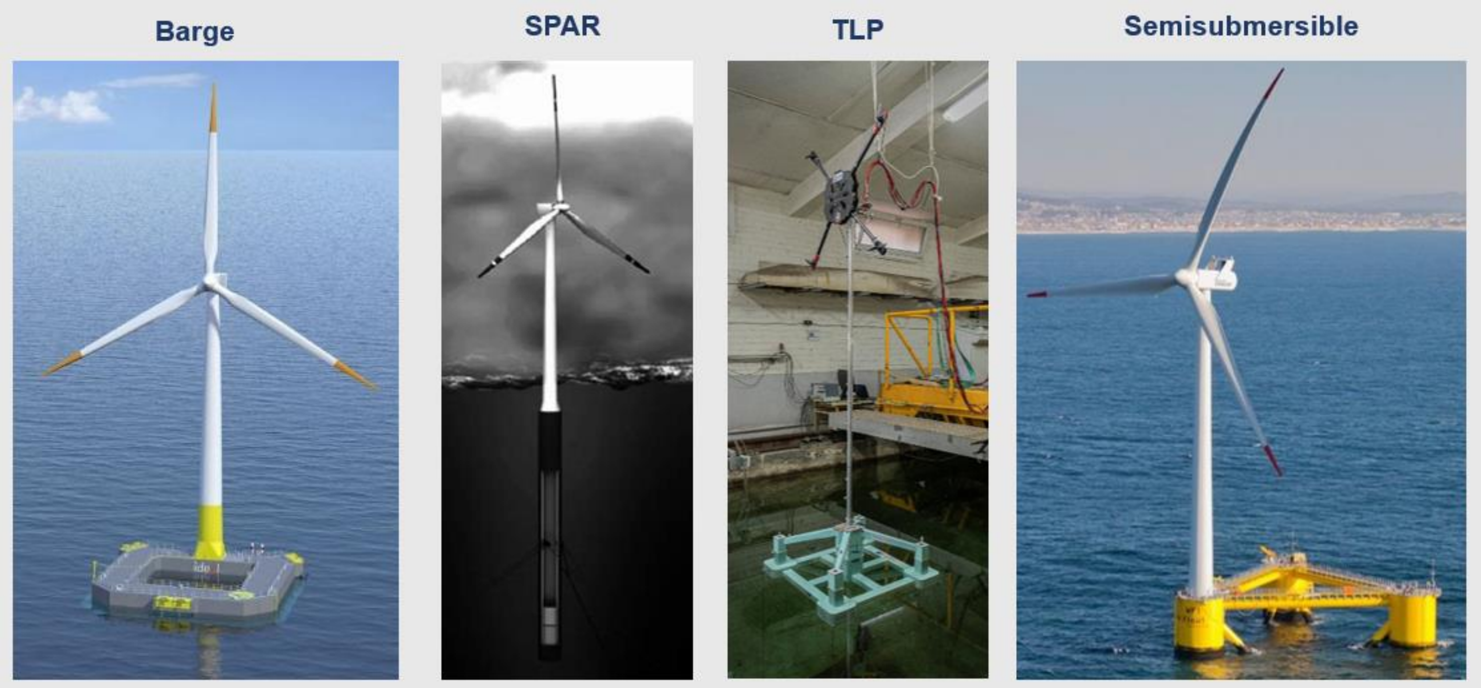
Platform examples from floating wind, the first four figures are from the OC4 Consortium and the 5th design is the CENTEC-TLP



Ref. *Uzunoglu, E., Oğuz, E., Soares, C. An Overview of Platform Types Used in Floating Wind Energy. 2nd International Congress on Ship and Marine Technology (GMO-SHIPMAR 2021)*

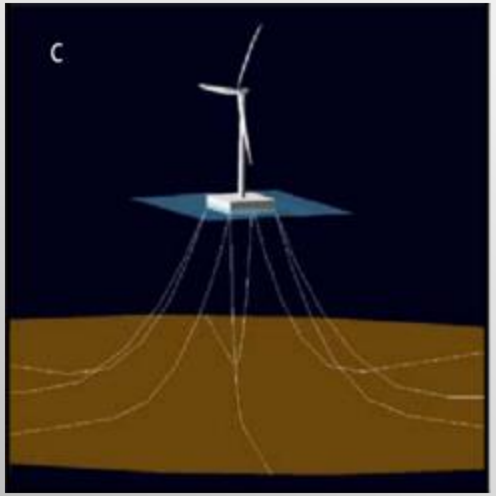
Classification of FOWTs by stabilization methods

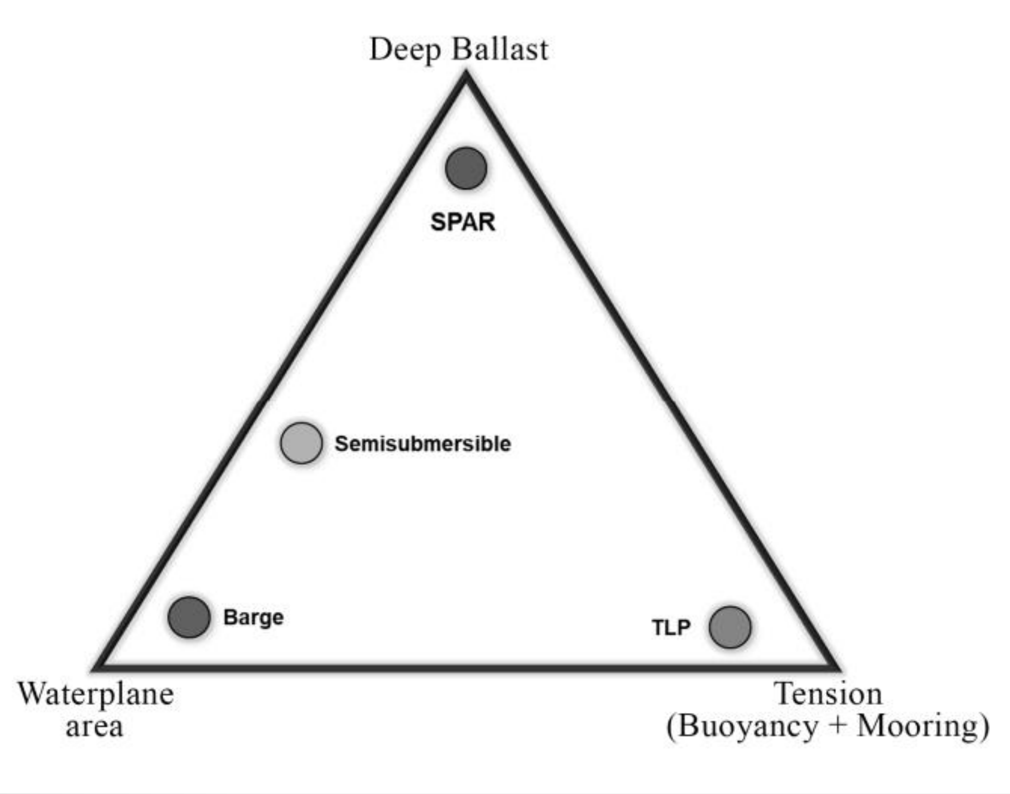




(NREL, 2007)

Waterplane area stabilized platforms

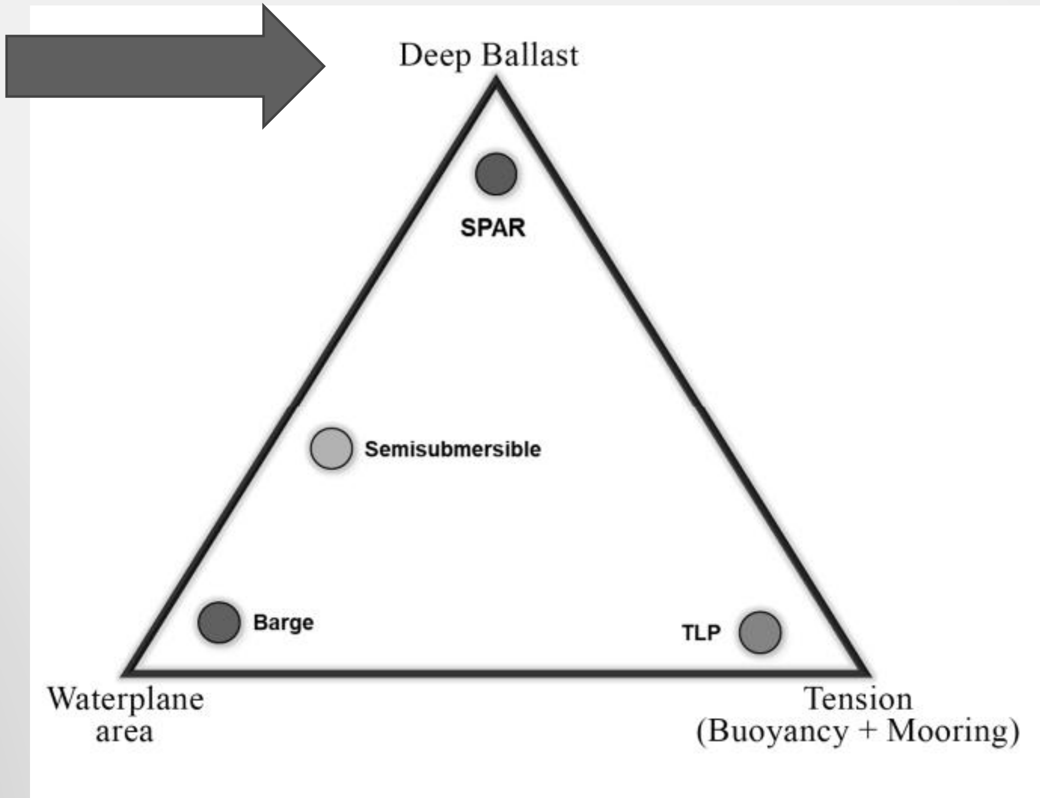




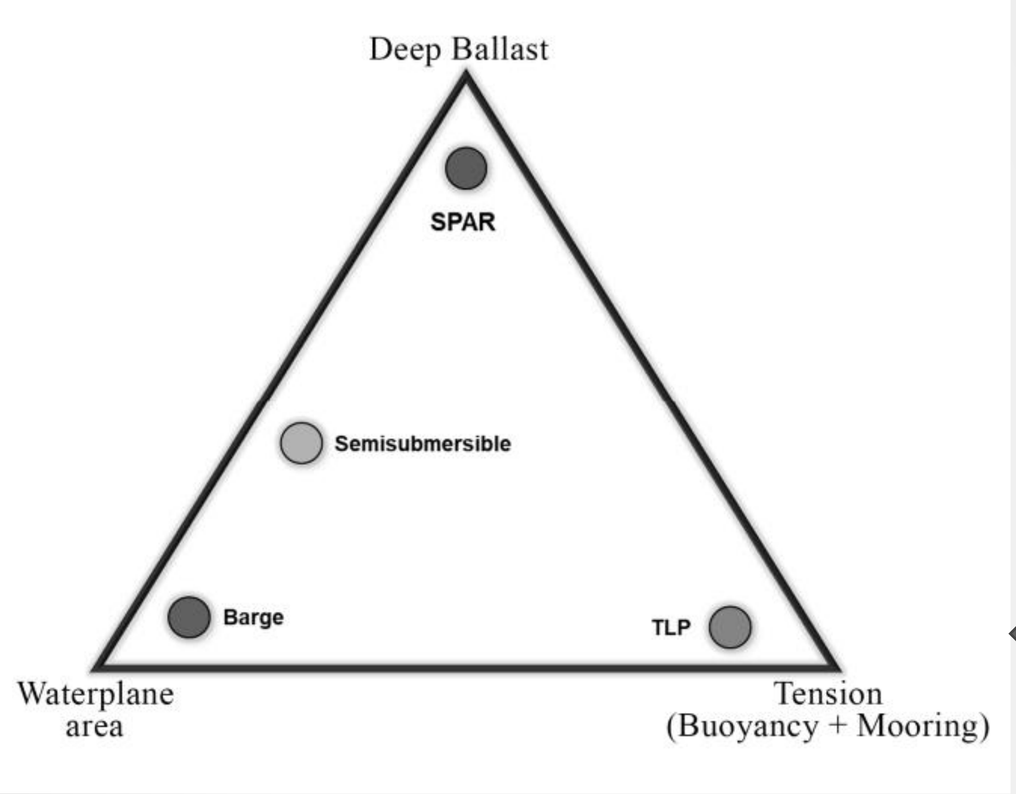
Offshore Wind Turbines

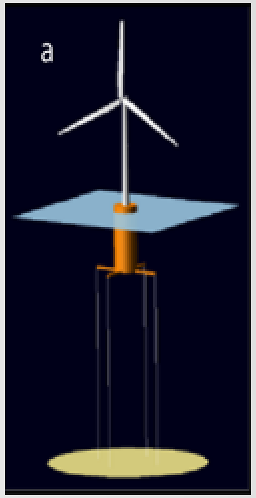
Classification of FOWTs by stabilization methods

Deep draft stabilized platforms



Tension stabilized platforms

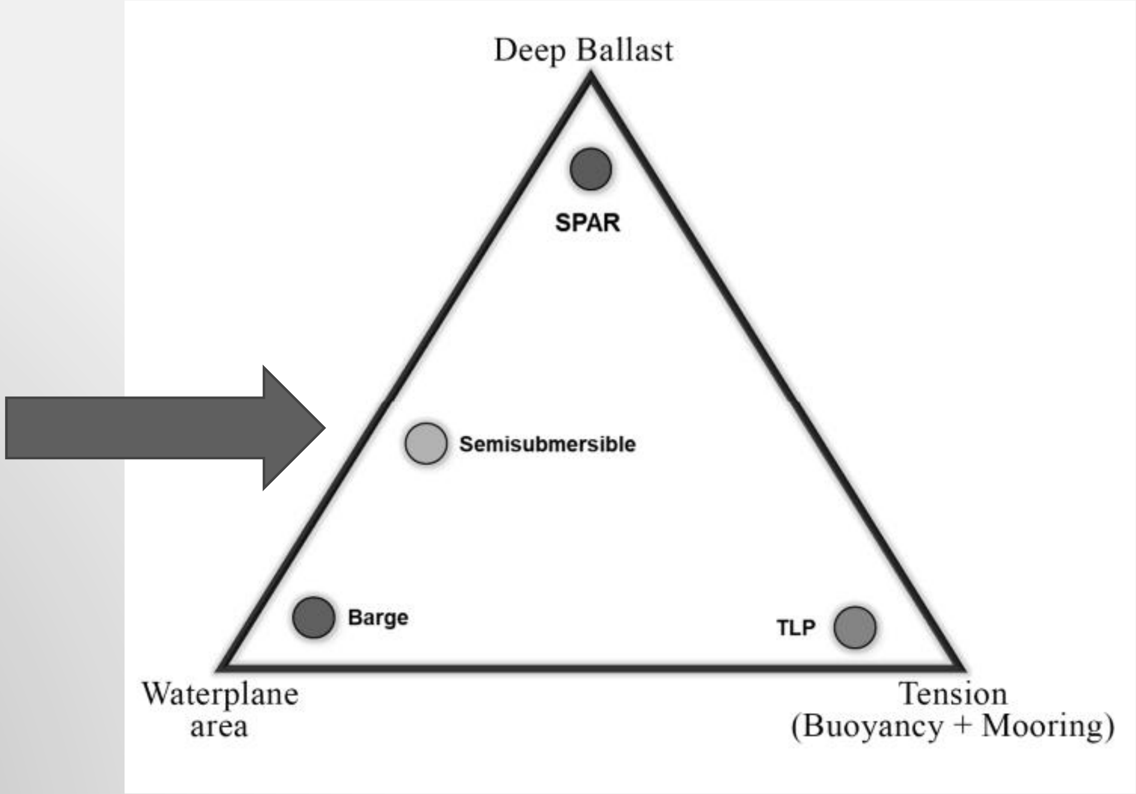




Offshore Wind Turbines

Classification of FOWTs by stabilization methods

Column stabilized units : Semi-submersibles



Resonance characteristics

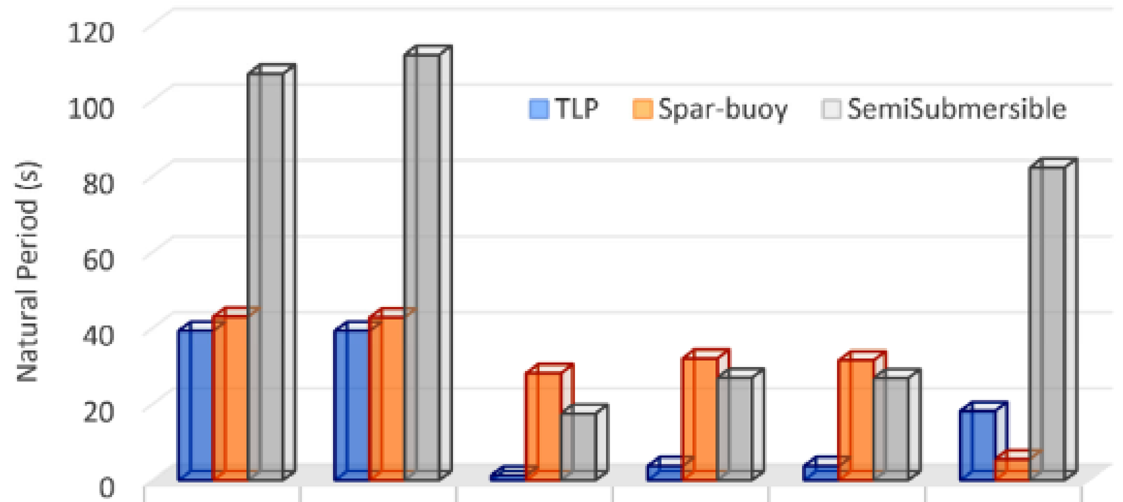
Summary of platfrom stabilization methods and motion characteristics

Platform	Stability method	Surge and sway	Heave	Roll and Pitch	Yaw
Barge	Waterplane area	C	C	C	C
SPAR	Deep ballast	C	C	C	C
TLP	Mooring Tension	C	R	R	C
Semisubmersible	Column (Waterplane + Ballast)	C	C	C	C

Offshore Wind Turbines

Resonance Characteristics

The natural frequencies of the DeepCwind Platforms

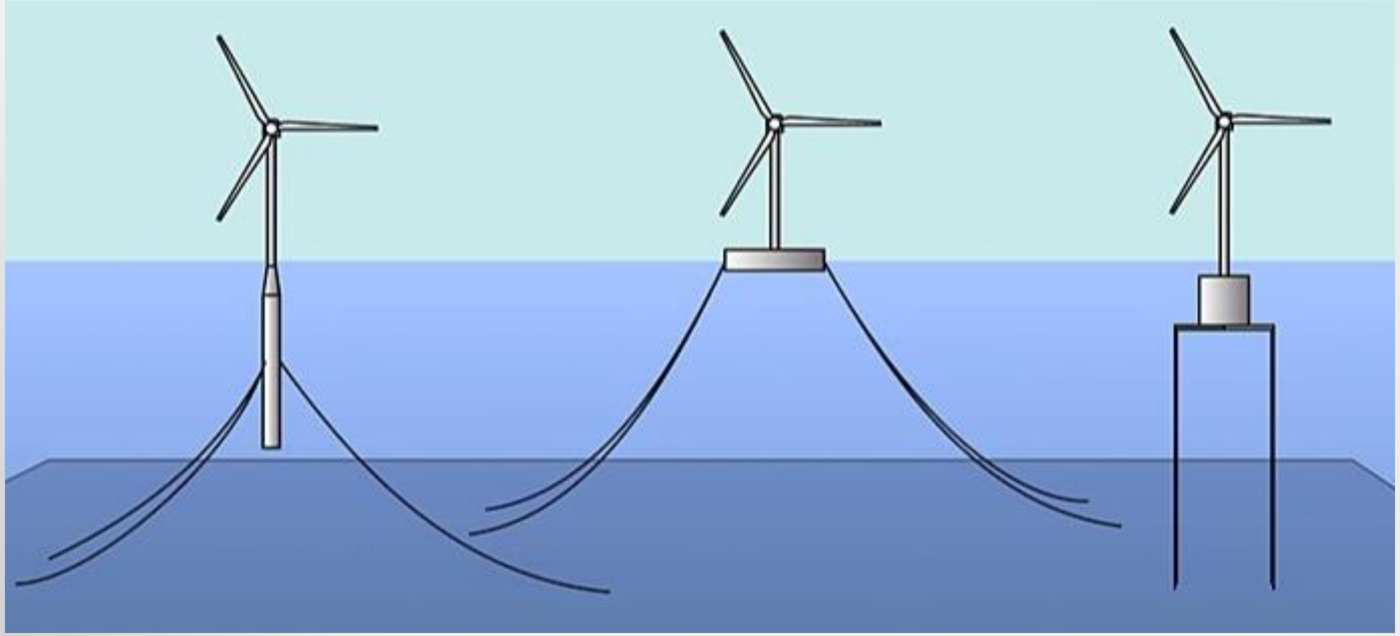


	Surge	Sway	Heave	Roll	Pitch	Yaw
TLP	39.3	39.3	1.25	3.7	3.7	18.2
Spar-buoy	43	42.8	28.1	32	31.5	5.5
SemiSubmersible	107	112	17.5	26.9	26.8	82.3

Ref. B. J. Koo, A. J. Goupee, R. W. Kimball, and K. F. Lambrakos, "Model tests for a floating wind turbine onthree different floaters," in 31st International Conference on Ocean, Offshore and Arctic Engineering (OMAE2012), 2012, pp. OMAE2014-24040 (PDF).

5 – 25 s
wave frequency

Mooring systems used in offshore platforms



Catenary mooring lines

taut mooring lines (tendons)

Ref. *Hall, M., Buckham, B., Crawford, C. «Evaluating the importance of mooring line model fidelity in floating offshore wind turbine simulations, Wind ENergy. (2013).*

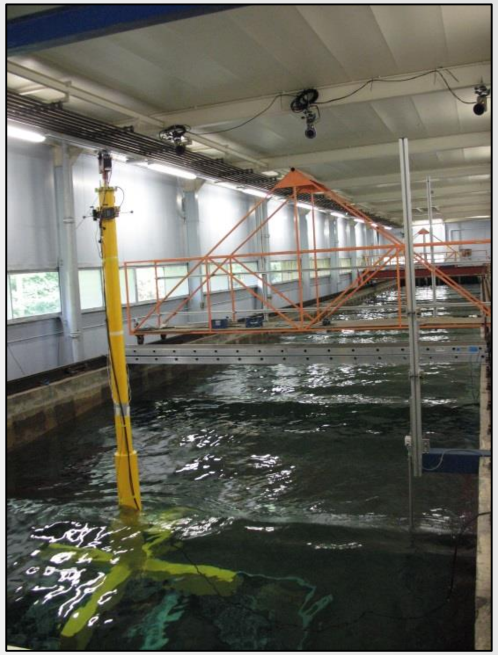
TLPs

- TLPs popular in deep water offshore oil extraction and gaining interest in floating wind energy sectors

- 'Good' dynamic response

- Reduced costs compared to fixed offshore structures

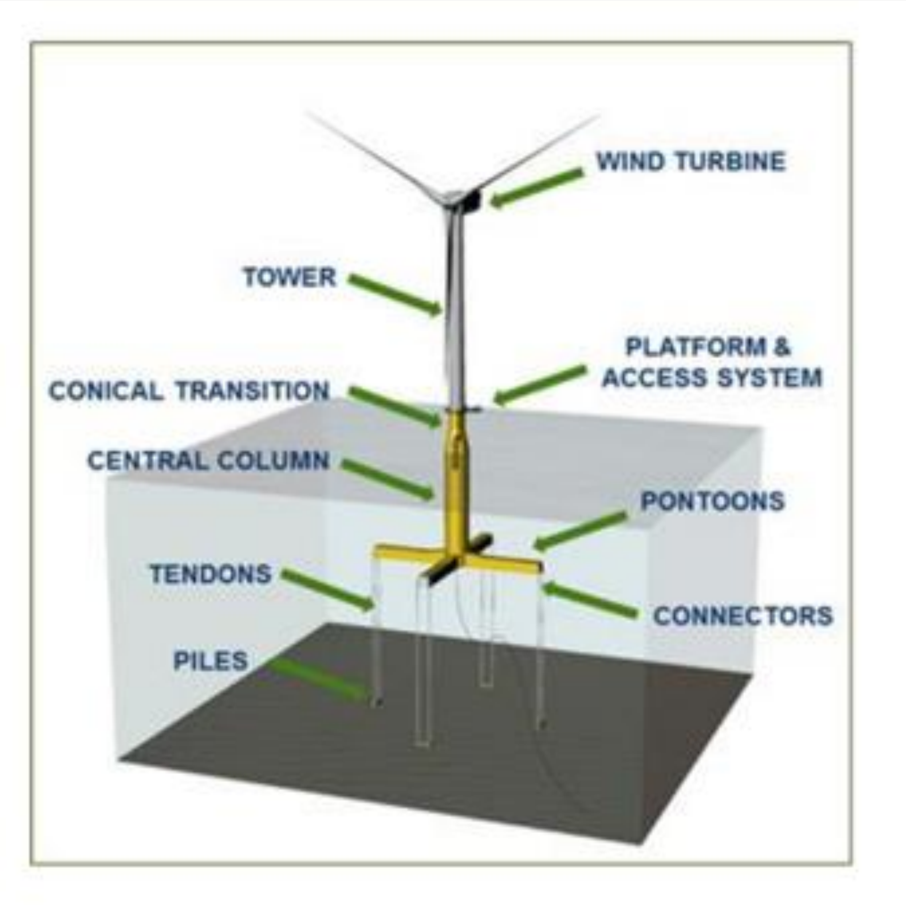
- Challenging topic – adoption of TLPWT in shallow water depth ~70m

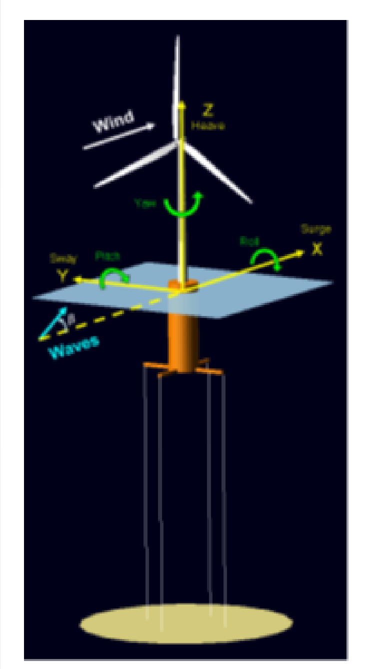


Offshore Wind Turbines

Tension Leg Platform (TLP)

Basic components of a TLP

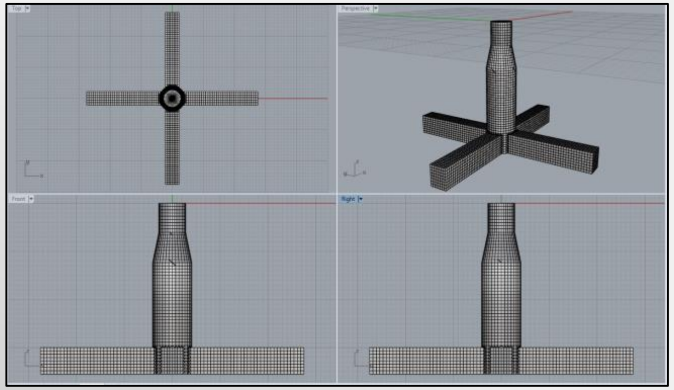




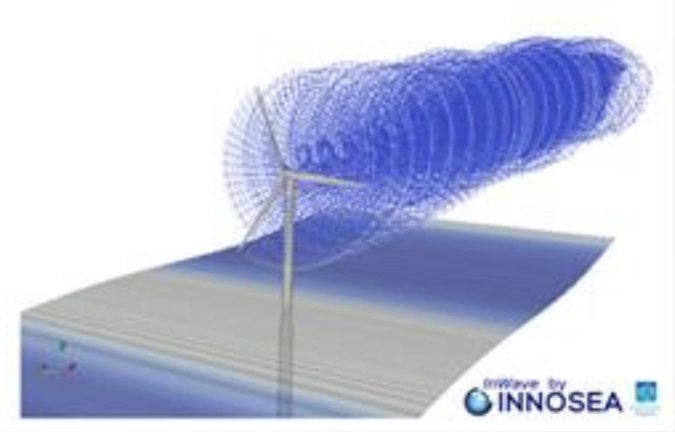
Offshore Wind Turbines

Numerical modelling of an OFWT

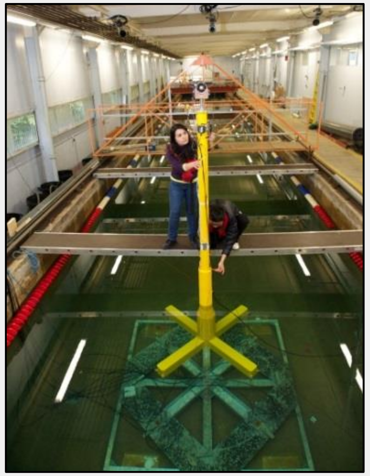
Numerical Modelling of FOWTs



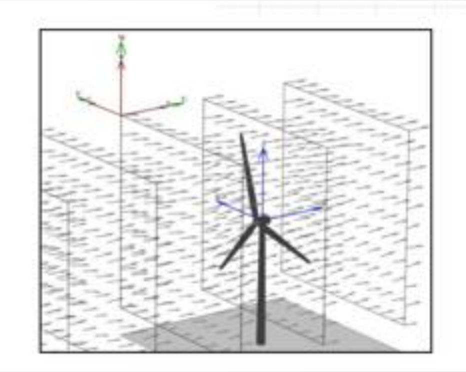
Hydrodynamic modelling of a FOWT (Oguz et al. 2018)



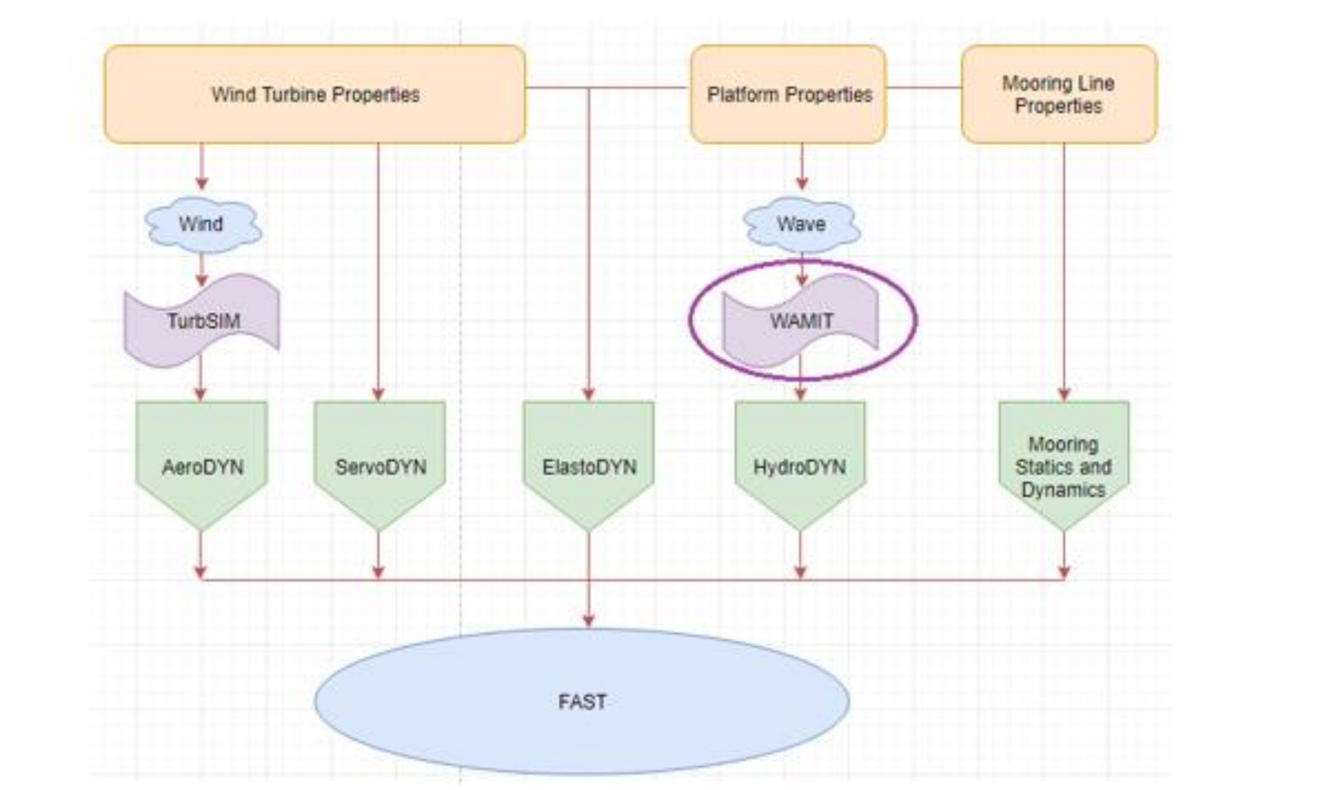
Aeordynamic modelling of a FOWT (Leroy et al. 2019)



Experimental study (Oguz et al. 2018)



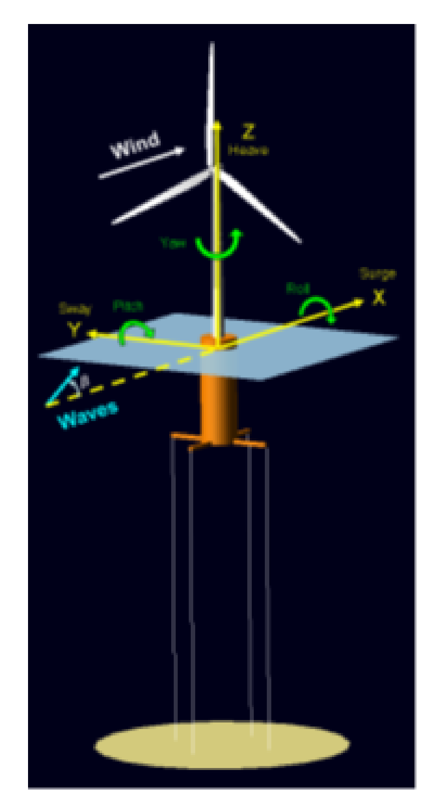
Coupled analysis of an Offshore Floating Wind Turbine – FAST / OpenFAST



Hydrodynamic modelling of an OFWT

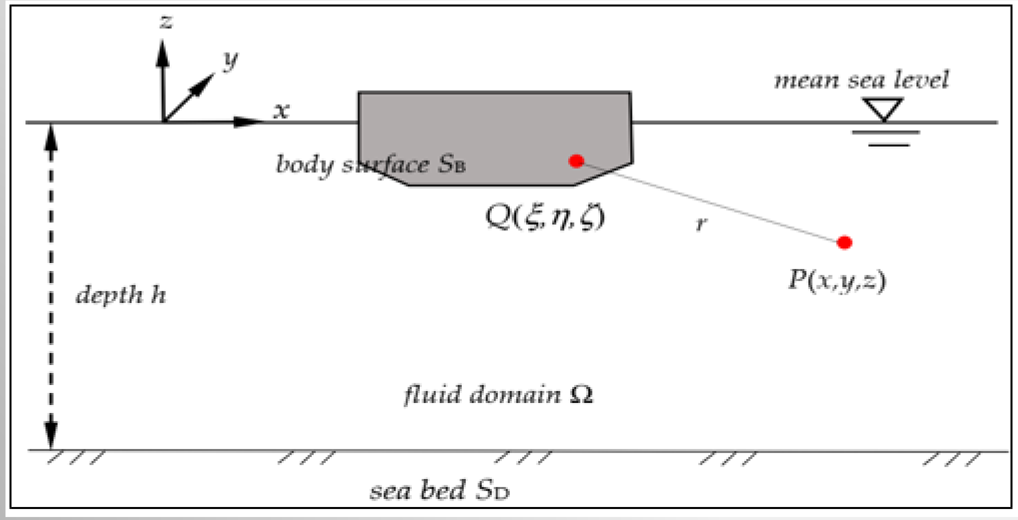
Hydrodynamic solvers and their Characteristics (Penalba et al., 2017)

BEM solver	Frequency domain	Time-domain	Open source	Usage (%)
WAMIT	+	-	-	80.5
NEMOH	+	-	+	19.5
AQWA	+	-	-	22.0
Aquaplus	+	-	-	9.8
ACHIL3D	-	+	-	4.9
WADAM	+	-	-	7.3
HAMS	+	-	+	NA

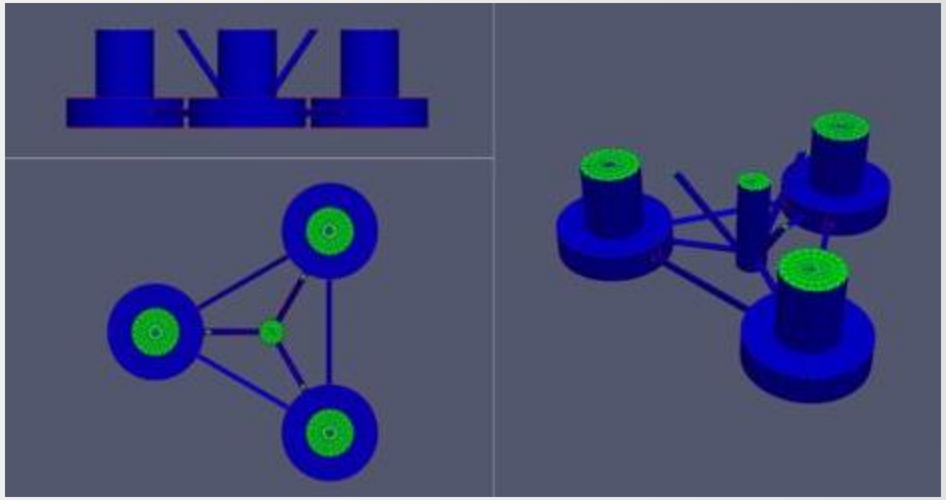


Hydrodynamic Analysis of Marine Structures (HAMS)

- Open-source code
- Developed by Liu
- Panel method. Based on potential flow theory.
- Built-in WAMIT_MeshTran.exe
- Output is in WAMIT's format (can be used in HydroDyn)



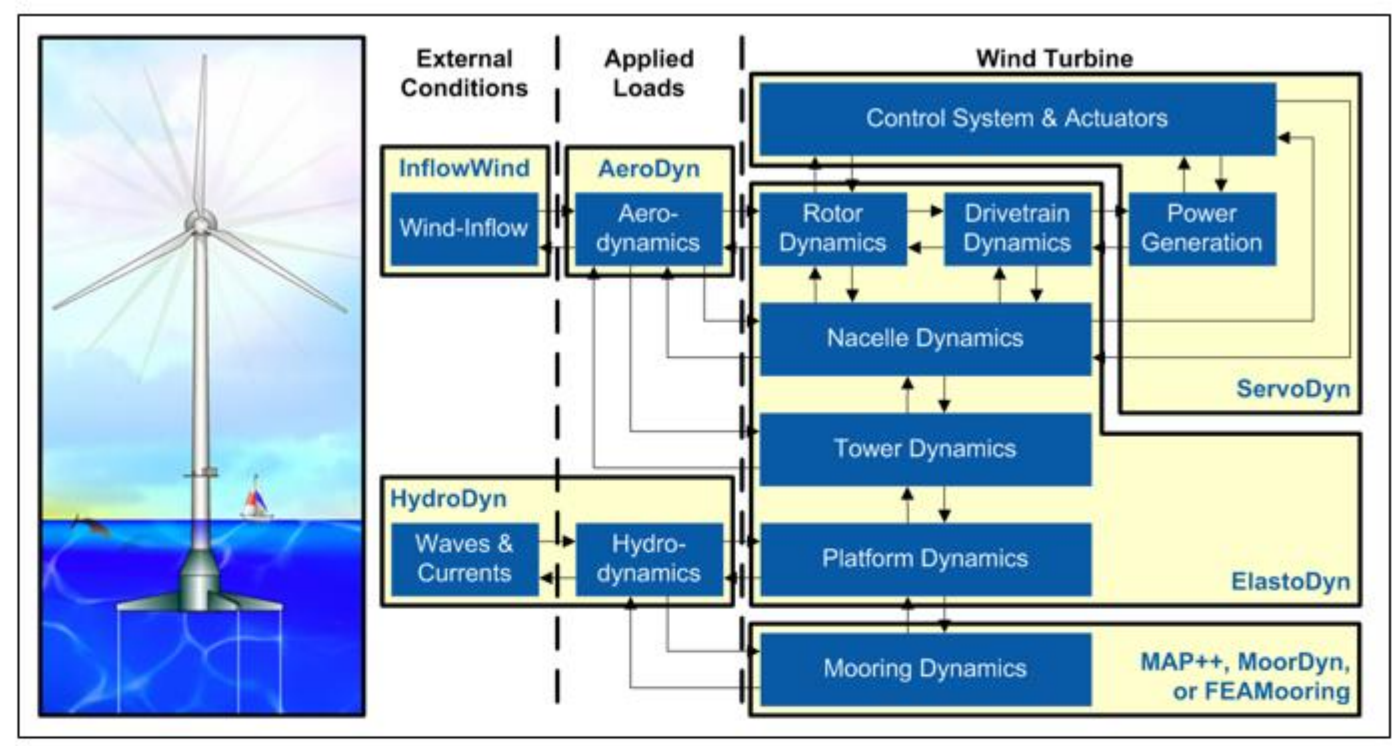
Coordinate system used in HAMS (Liu, 2019)



Example of mesh trans. result for HAMS

OpenFAST (Fatigue, Aerodynamic, Stucture, Turbulent)

•Open-source code developed by NREL
•Non-linear time-domain simulator for structure, aerodynamics, hydrodynamics, control, and servo.
•Well validated against:
•2.3 MW Siemens WT on SPAR
•Laboratory experiment
•Other codes (e.g. OC4)



Flowchart of modeling in FAST (Jonkman, 2016)

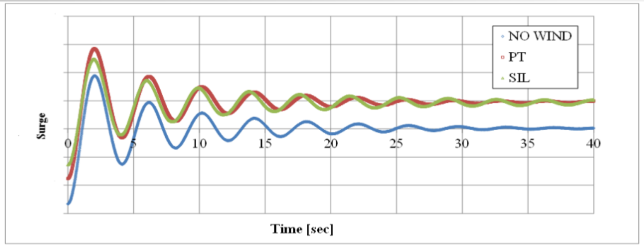
Hydrodynamic performance analysis of FOWTs

1. Free Oscillation Tests

- To identify the resonance region
- Compare physical behaviour with the numerical model

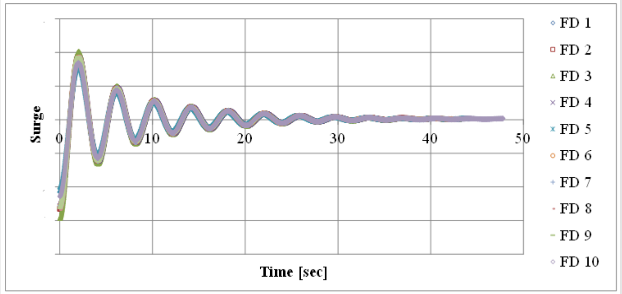
Description of Free Decay Tests

	Experiment [sec]	Numerical [sec]
Surge (no wind)	24.376	22.475
Surge (PT w_s=11.4m/s)	24.344	22.468
Surge (SIL w_s=11.4m/s)	24.649	22.355
Heave (no wind)	1.40	1.057
Pitch (no wind)	2.56	2.522



Effect of wind on Surge Free Oscillation Tests

Free Oscillation Test in Surge



Repeatability of Free Oscillation Test in Surge (no wind)

Hydrodynamic performance analysis of FOWTs

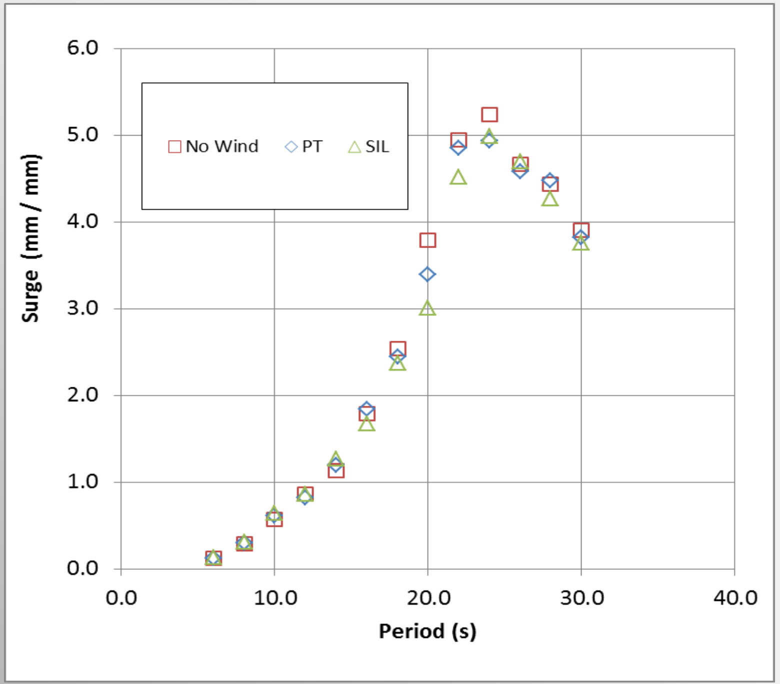
2. Regular Wave Tests

- To characterise the dynamic behaviour of the system
- Offer insight into its underlying physics
- Tests were designed to obtain the platform motion Response Amplitude Operators (RAOs) and tendon tension transfer functions.

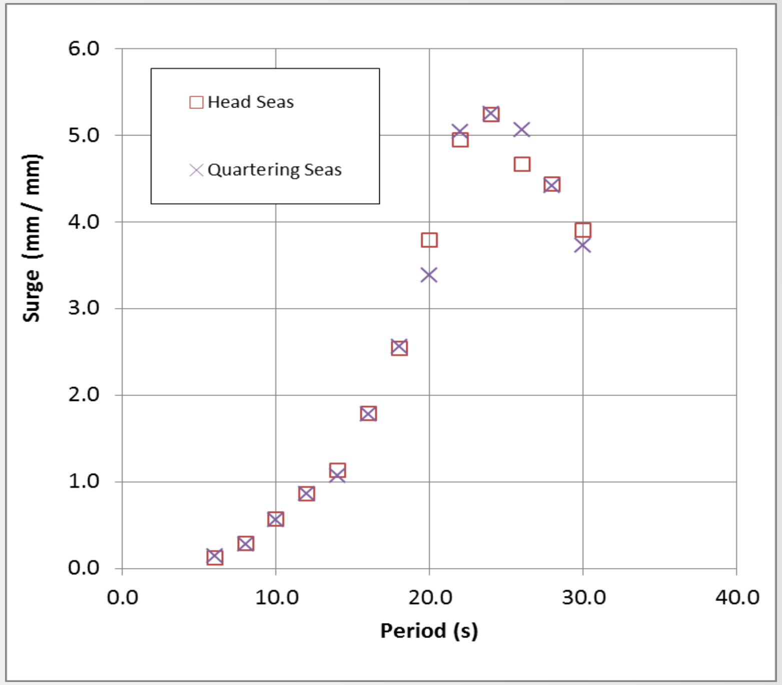
Overview of regular wave test matrix

Configuration	Wave/Wind heading(deg)	Wind condition
1	0º/0º	No wind
2	0º/0º	Software in the loop
3	0º/0º	Predefined Thrust
4	45º/0º	No wind

Impact of wind and wave heading angle on surge

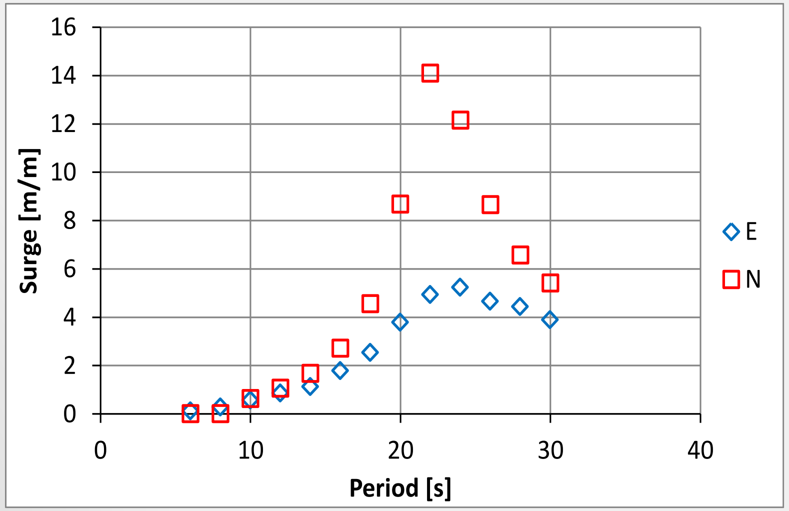


Surge RAOs for three different wind models



Surge RAOs for two different wave headings

Experiment/Numerical motions for 0/0 no wind condition



Comparison of surge motion

Offshore Wind Turbines

Performance analysis of FOWTs

3. Irregular Wave Tests

- to characterise the motion responses and tendon loadings of the platform under realistic environmental conditions

Configuration	Wave/Wind heading(deg)	Experiment	Numerical	
		Turbulent	Turbulent	Constant
1	0º/0º	+	+	+
2	0º/45º	+		
3	0º/225º	+	+	+
4	45º/0º	+	+	[illegible]
5	45º/45º	+		[illegible]
6	45º/-45º	+		[illegible]
7	45º/225º	+		[illegible]

Sea State	H_s (m)	T_p (s)	Mean Wind Speed(m/s)
N1	4.55	9.00	11.40
N2	1.50	6.61	11.40
N3	8.46	10.13	38.76*
N4	0.75	5.44	6.05
N5	1.25	6.36	9.18
N6	1.75	6.86	12.80
N7	2.75	7.80	16.80
N8	6.00	10.28	25.00

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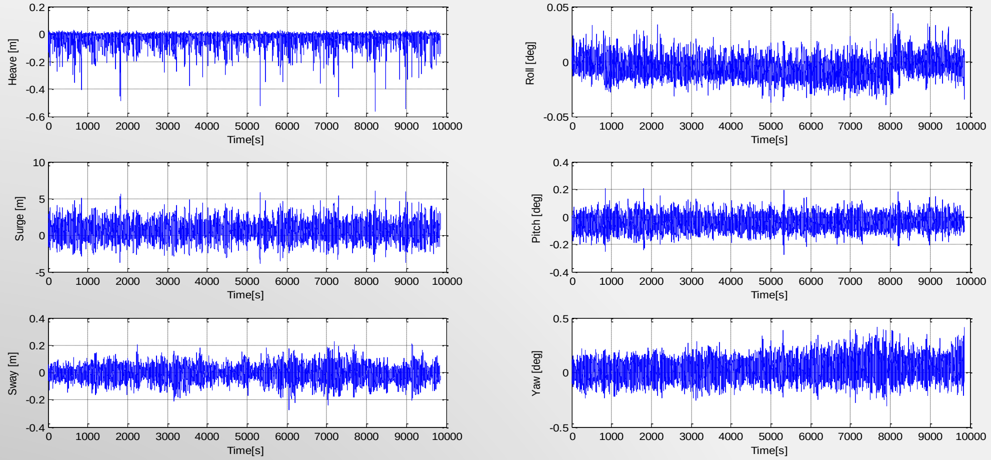
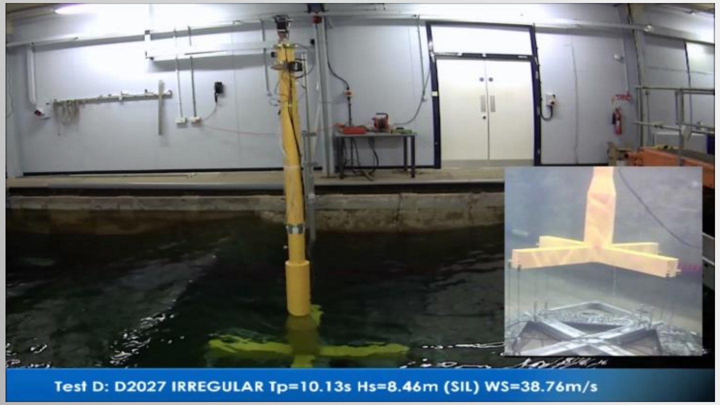
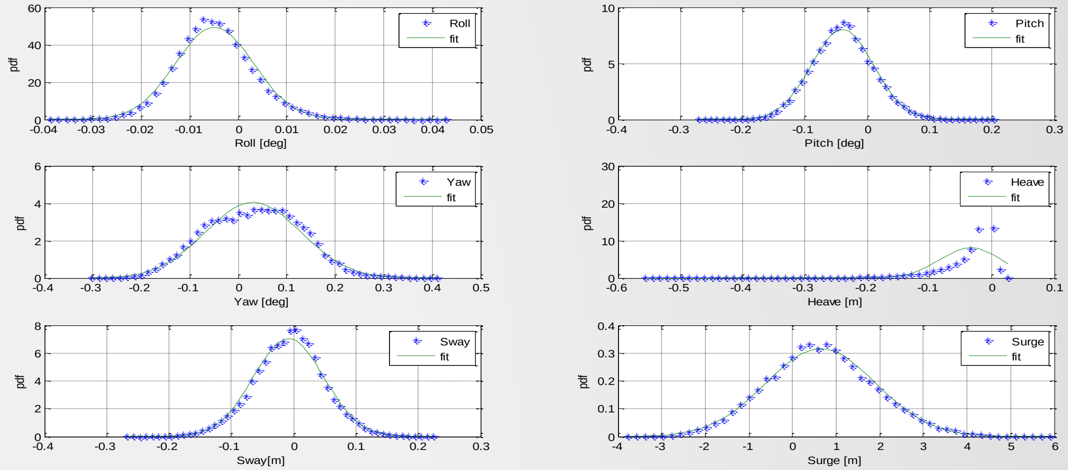
Irregular wave test: motion analysis of storm condition



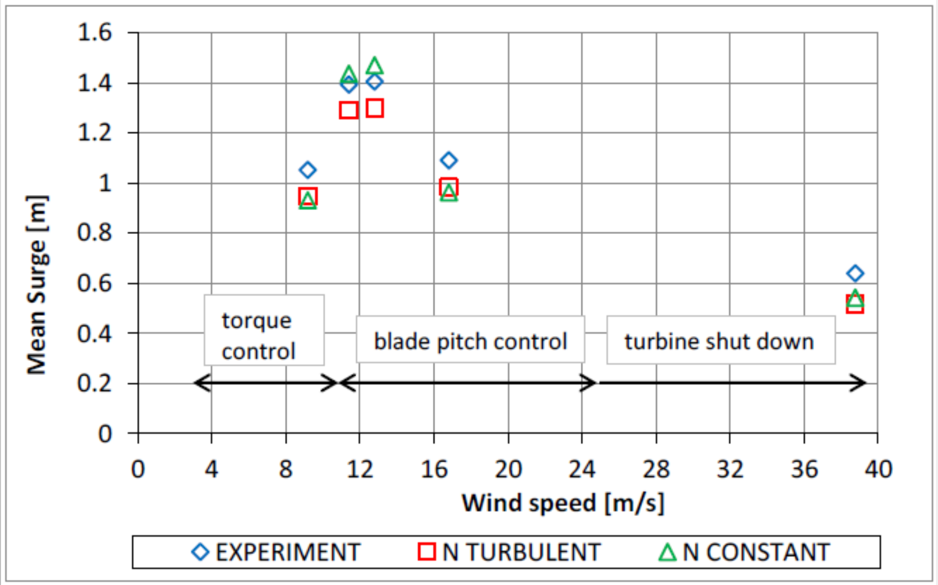


- FOWT drifts downwind and reaches equilibrium at 0.64m
- Apart from surge and pitch all other motions are small even for this extreme case
- Apart from heave all pdf's show good agreement with standard Gaussian distribution

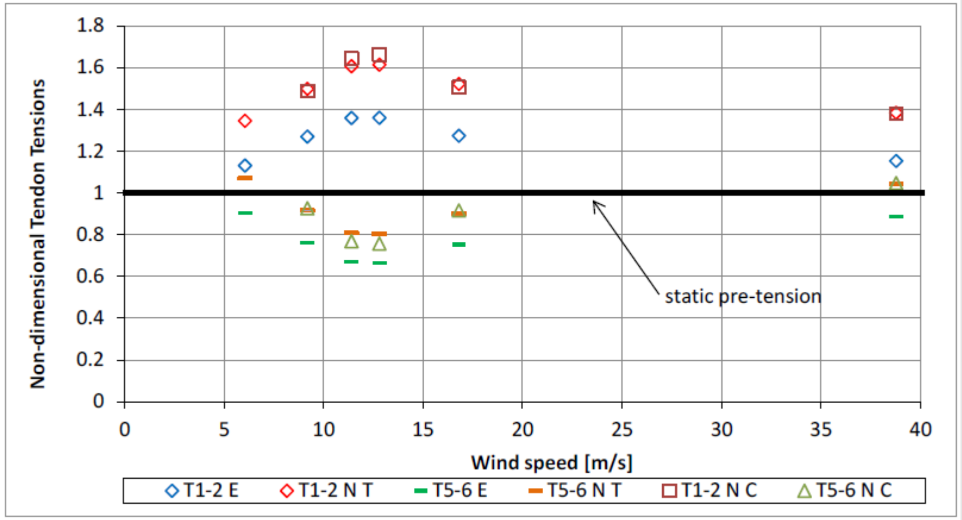


PDFs of 6 DOF motions

Irregular wave test: motion analysis of storm condition



Mean value of surge motion wave 0° wind 0°

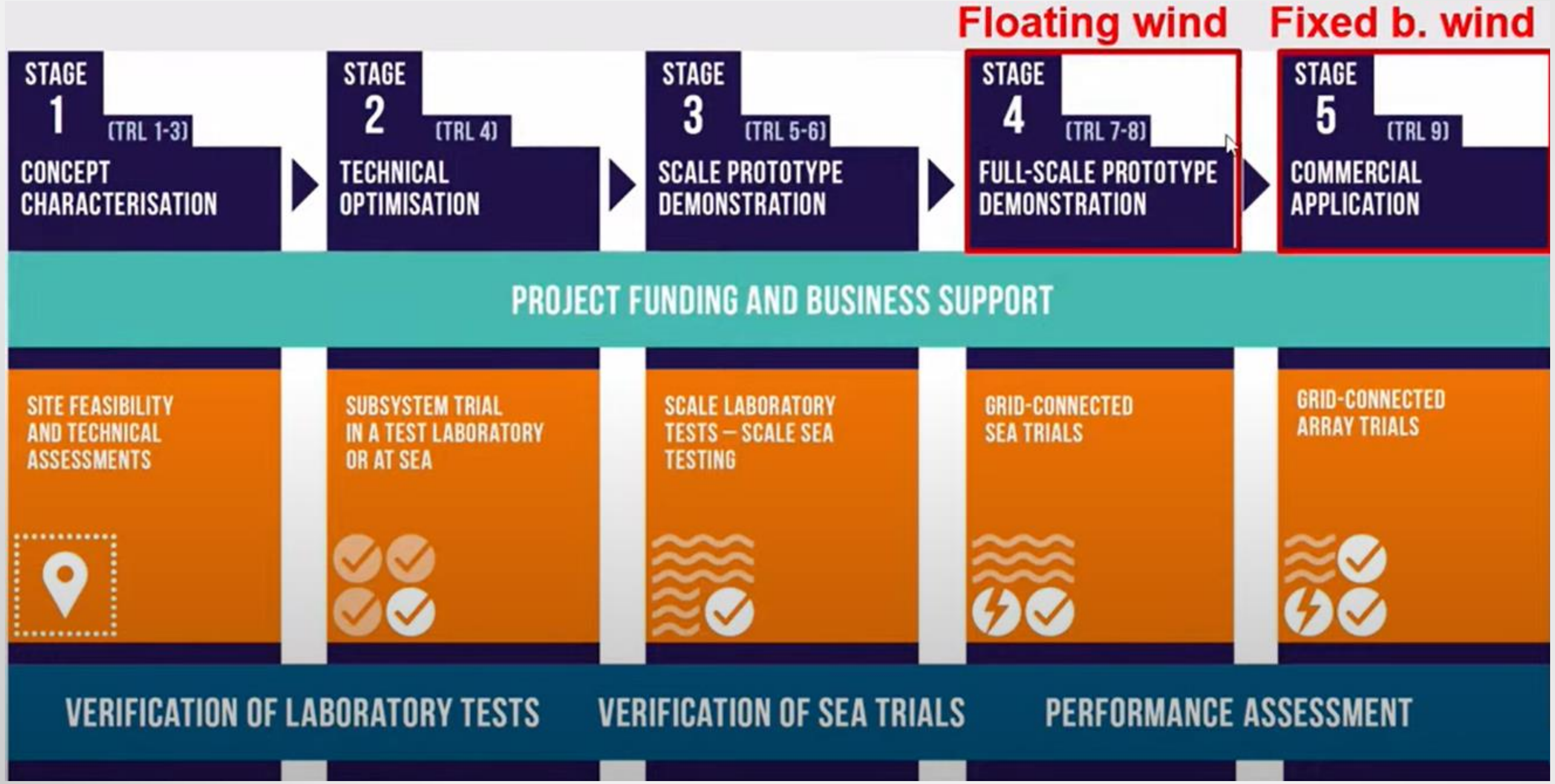


Mean tension values for front and back tendons

Offshore Wind Turbines

Commercialization of wind turbines

Technology Readiness Levels (TRLs)



Ref. GWEC 2016

- **Fixed bottom offshore wind** applications are **commercially approved**
- **Floating offshore wind** is at an **earlier developmental stage**

Offshore Wind Turbines

Recent developments in offshore industry

Important Progress : Offshore Floating Wind Turbines

- A number of full scale floating wind turbines are currently in operation
- Pilot floating wind farms have now been operating for several years
- Commercial wind farms are currently being developed
- Although scarce, data on wind turbine loads measured at sea are available for certain projects
- Modelling techniques have progressed both numerically and in physical testing
- But there remains uncertainties in the dynamics of floating wind turbines

Kincardine farm after completion (top left), the Hywind Scotland farm in operation (right) and the TetraSpar (bottom left)

Ref. *A. Kolios, K-H. Kim, C-H. Cheng, E. Oguz, P.G. Morato, F. Ralph, C. Fang, C. Ji, M. Le Boulluec, T. Choisnet, L. Greco, T. Utsunomiya, K. Rezanejad, C. Rawson, J-M. Rodrigues. Offshore Renewable Energy (2022).*

Important Findings : Offshore Floating Wind Turbines

- High fidelity integrated numerical simulation tools were developed and are now being validated by full scale field deployment of floating wind turbines.
- Hybrid formulations coupling simplified rotor aerodynamics models with CFD hydrodynamic models are continuously investigated.
- Aerodynamic load predictions with good levels of accuracy and low computational burden are of great interest for the preliminary design of FOWTs.
- CFD studies of the coupled aerodynamic-hydrodynamic response of a floating offshore wind turbine are typically addressed under the assumptions of rigid bodies for the parts interacting with the CFD mesh.
- A good trade-off among accuracy of simulation, CPU time demand and out-of-the-box functionality is nowadays represented by potential flow methods.

Ref. *A. Kolios, K-H. Kim, C-H. Cheng, E. Oguz, P.G. Morato, F. Ralph, C. Fang, C. Ji, M. Le Boulluec, T. Choisnet, L. Greco, T. Utsunomiya, K. Rezanejad, C. Rawson, J-M. Rodrigues. Offshore Renewable Energy (2022).*

Offshore Wind Targets and Challenges

- Improving the design and layout of offshore wind farms
- Increasing reliability, accessibility and efficiency of offshore wind turbines
- Design of special purpose vessels for installation and access
- Optimising the maintenance, assembly and installation of offshore turbines and their substructures
- Development of energy storage systems for grid management to allow high levels of wind power in the electricity system
- Development of spatial planning

Workshop on Wind Energy Computational Analyses

Offshore Wind Turbine Aerodynamic and Hydrodynamic Analyses by using OpenFAST

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