R & D + I for sustainable development

VII JORNADAS DE MINERÍA Y ENERGÍA

Energía eólica marina flotante: de la investigación al mercado

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UNIVERSIDAD DE CANTABRIA

Torrelavega, 15 de Abril de 2021

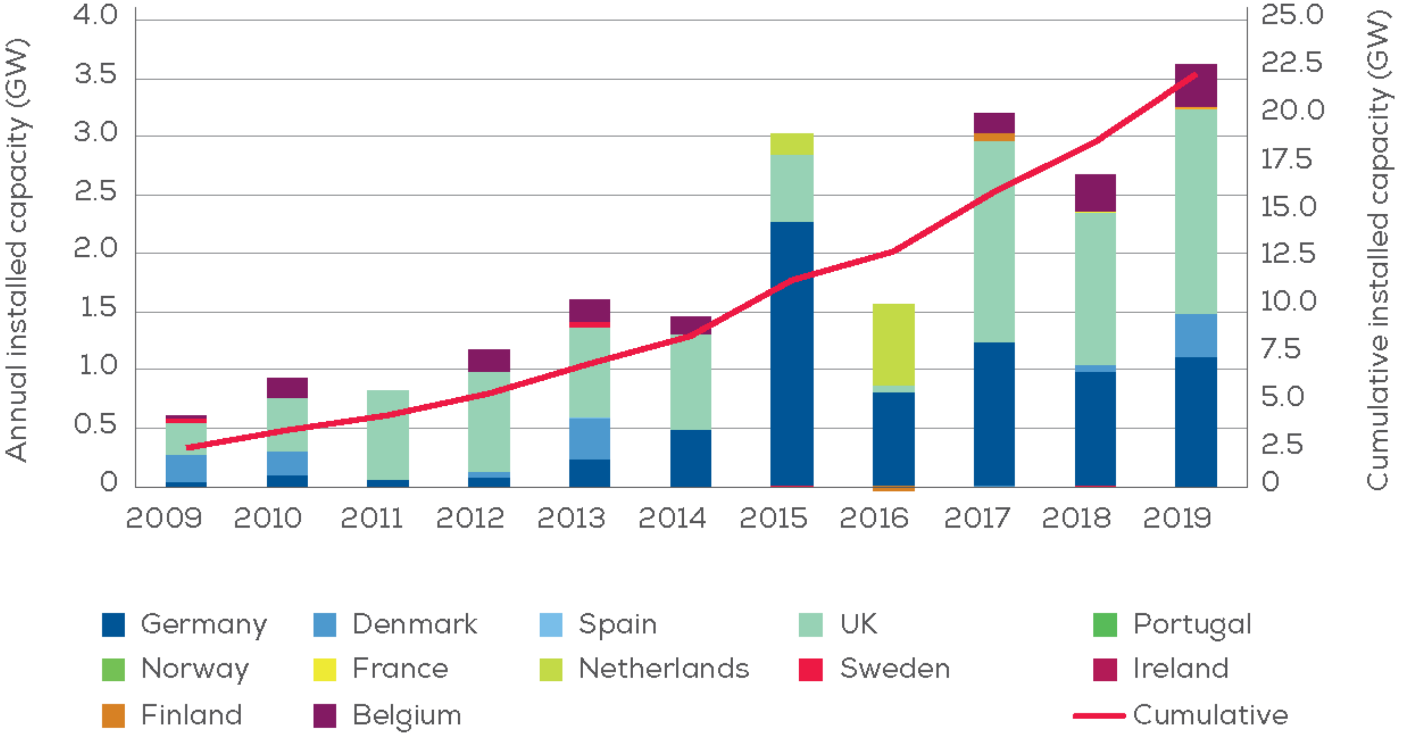
OUTLINE

OFFSHORE WIND

Introduction: Offshore wind in numbers

OFFSHORE WIND IN EUROPE: MARKET GROWTH

- Europe added 3,623 MW net offshore capacity in 2019.
  - 502 new offshore wind turbines connected to the grid, across 10 wind farms.
- Total installed capacity: 22,072 MW. A total of 5,047 grid-connected wind turbines across 12 countries.



Source: WindEurope. [3]

OFFSHORE WIND IN EUROPE: MARKET GROWTH

Economy of scale → Possibility of developing large facilities

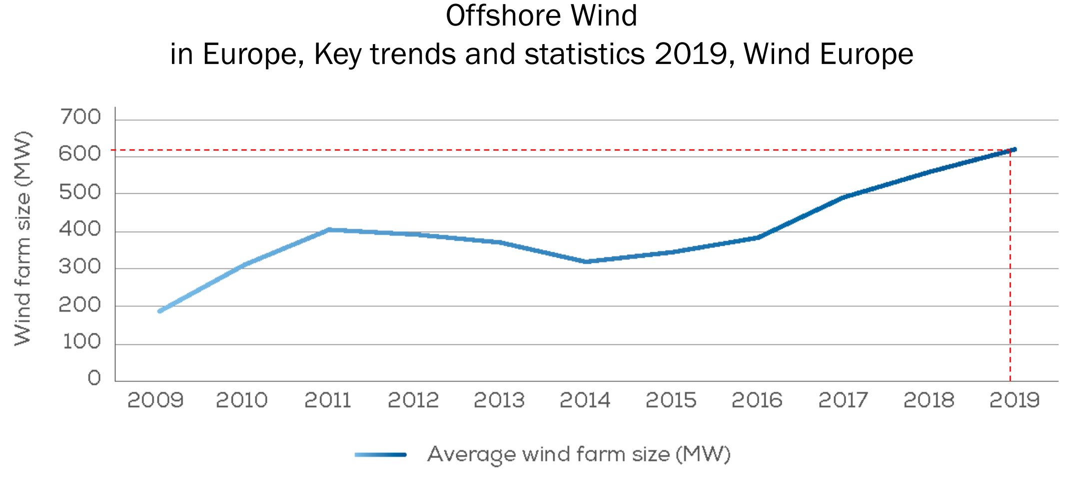
Overview of grid-connected offshore wind power projects at the end of 2019

COUNTRY	WIND FARM	CAPACITY CONNECTED IN 2019 (MW)	NUMBER OF TURBINES CONNECTED	TURBINE MODEL	TYPE OF FOUNDATION	STATUS[3]
UK	Hornsea One	1,218.0	174	SWT-7.0-154 (SGRE)	Monopile	●●●●●
	Beatrice 2	315.0	45	SWT-7.0-154 (SGRE)	Jacket	●●●●●
	East Anglia Offshore Wind 1	231.0	33	SWT-7.0-154 (SGRE)	3-Leg jacket	●●○○○
Germany	EnBW Hohe See	497.0	71	SWT-7.0-154 (SGRE)	Monopile	●●●●●
	Deutsche Bucht	260.4	31	V164-8.4 MW (MHI Vestas)	Monopile	●●●●●
	Merkur Offshore	252.0	42	Haliade 150-6MW (GE)	Monopile	●●●●●
	Trianel Windpark Borkum 2	101.3	16	6.2M152 (Senvion)	Monopile	●●●○○
Denmark	Horns Rev 3	373.5	45	V164-8.3 MW (MHI Vestas)	Monopile	●●●●●
Belgium	Norther	369.6	44	V164-8.4 MW (MHI Vestas)	Monopile	●●●●●
Portugal	Windfloat Atlantic Phase 1	8.4	1	V164-8.4 MW (MHI Vestas)	Semi-sub	●●○○○

3. • < 25% red conectada. • • < 50% red conectada. • • • < 75% red conectada. • • • • < 100% red conectada.

Source: WindEurope. [3]

Average size of commercial offshore wind farm projects in the year (MW)



Source: WindEurope. [3]

The average size in 2019 was **600 MW**

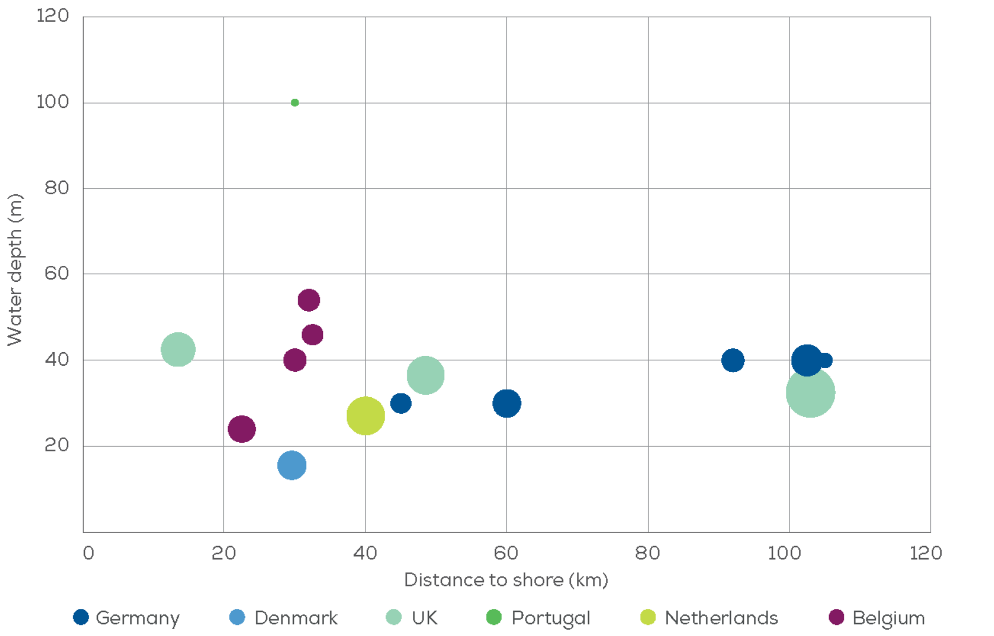
OFFSHORE WIND

Introduction: Offshore wind in numbers

OFFSHORE WIND IN EUROPE: MARKET GROWTH

Average water depth and distance to shore of offshore wind farms under construction during 2019.

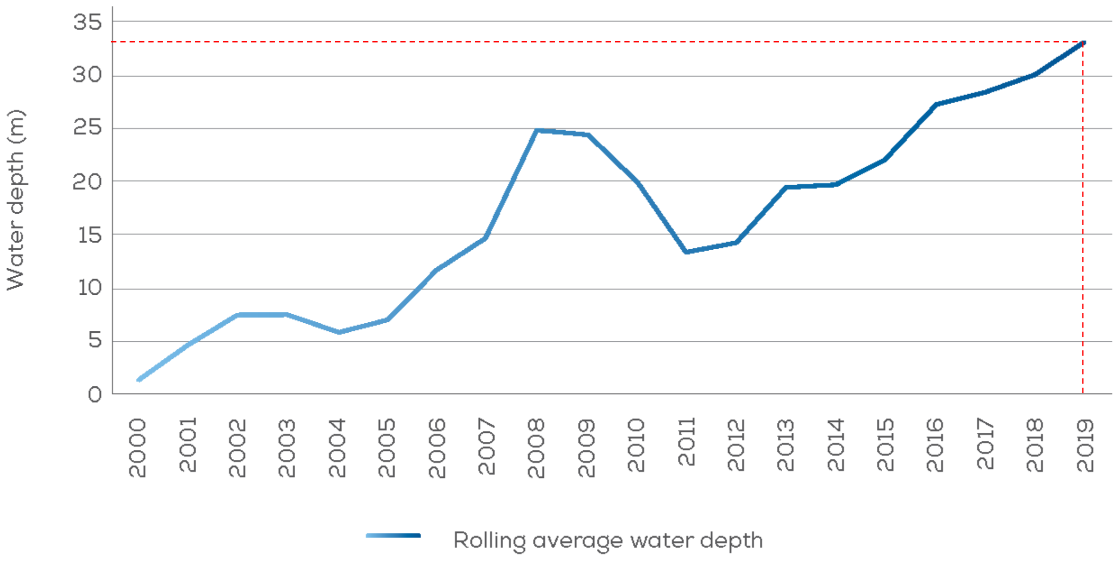
Offshore Wind
in Europe, Key trends and statistics 2019, Wind Europe



Source: WindEurope. [3]

Rolling average water depth of online offshore wind farms

Offshore Wind
in Europe, Key trends and statistics 2019, Wind Europe



Source: WindEurope. [3]

In 2019 the average distance to shore (**59 km**) and water depth (**33 m**) still is increasing

OFFSHORE WIND
Introduction: Offshore wind in numbers

OFFSHORE WIND – FLOATING WIND – GLOBAL OVERVIEW

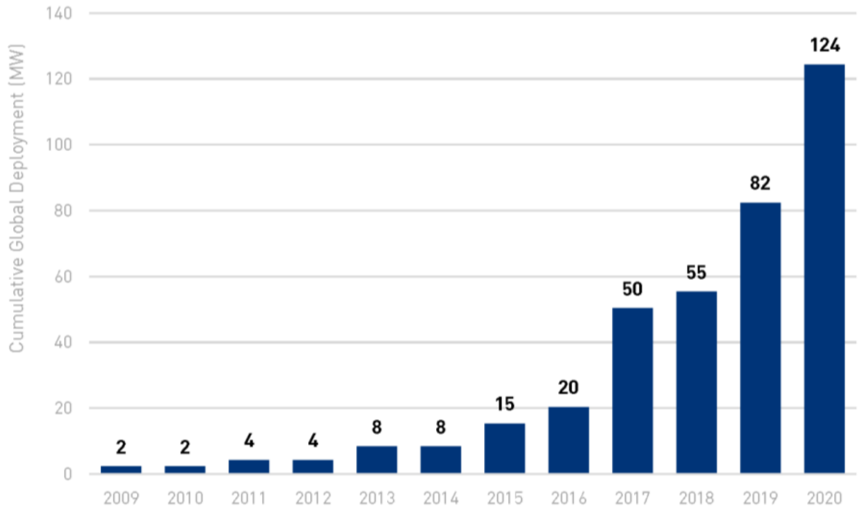
Table 1: Commissioned and in-construction floating wind projects

First power	Country	Project	Total capacity	Turbine rating	Project developer	Technology developer	Concept	Turbine supplier
2009	Norway	Hywind I	2.3MW	2.3MW	Equinor	Equinor	Hywind	Siemens
2011	Portugal	WindFloat Atlantic Phase 1*	2MW	2MW	EDPR, Repsol, Chiyoda, Mitsubishi	Principle Power	WindFloat	Vestas
2013	Japan	Kabashima	2MW	2MW	Toda Corporation	Toda Corporation	Hybrid Spar	Hitachi
2013	Japan	Fukushima FORWARD	2MW	2MW	Marubeni	Mitsui Engineering and Shipbuilding	Semi-Sub	Hitachi
2015	Japan	Fukushima FORWARD**	7MW	7MW	Marubeni	Mitsubishi Heavy Industries	V-Shape Semi-Sub	Mitsubishi
2016	Japan	Fukushima FORWARD	5MW	5MW	Marubeni	Japan Marine United	Advanced Spar	Hitachi
2017	UK	Hywind Pilot Park	30MW	6MW	Equinor	Equinor	Hywind	Siemens
2018	France	FloatGen	2MW	2MW	IDEOL	IDEOL	Damping Pool	Vestas
2018	Japan	IDEOL Kitakyushu Demo	3MW	3MW	IDEOL and Hitachi Zosen	IDEOL	Damping Pool (Steel)	Aerodyn
2019 (2020)	UK	Kincardine***	2MW (50MW)	2MW x1 (9.5MW x5)	Pilot Offshore, Cobra	Principle Power	WindFloat	MHI-Vestas
2019	Norway	TetraSpar demonstration	3.6MW	3.6MW	RWE Renewables, Shell, Steisdal OT	Steisdal Offshore Technologies	TetraSpar	Siemens
2020	Portugal	WindFloat Atlantic 2	25MW	8.3MW	EDPR, ENGIE, Repsol, PPI	Principle Power (PPI)	WindFloat	MHI-Vestas
2020	Spain	DemoSATH	2MW	2MW	Saitec	Saitec	SATH	TBC

** WindFloat 1 decommissioned in 2016. The WindFloat 1 substructure redeployed in the Kincardine pre-commercial project in Scotland.*
*** Mitsubishi 7MW floater is being decommissioned, works started in early May 2020 and scheduled to be completed by Spring 2021.*
**** As yet only Windfloat 1 device (2MW) has been installed and is producing power, remaining 5 devices (48MW) due for commissioning in 2020.*

Source: CARBON TRUST. [1]

- A cumulative total of **73MW of floating offshore wind power has been installed** in countries in Asia and Europe, which will increase to **124MW by the end of 2020.**
- Prototypes installed between 2009 and 2018 **have demonstrated the feasibility of the technology** in single units, paving the way for larger arrays.
- **Europe** has the **largest installed capacity** using floating technology.



Source: CARBON TRUST. [1]

OFFSHORE WIND
Introduction: Offshore wind in numbers

OFFSHORE WIND – FLOATING WIND – GLOBAL OVERVIEW

Table 3: Industry deployment ambitions to 2040

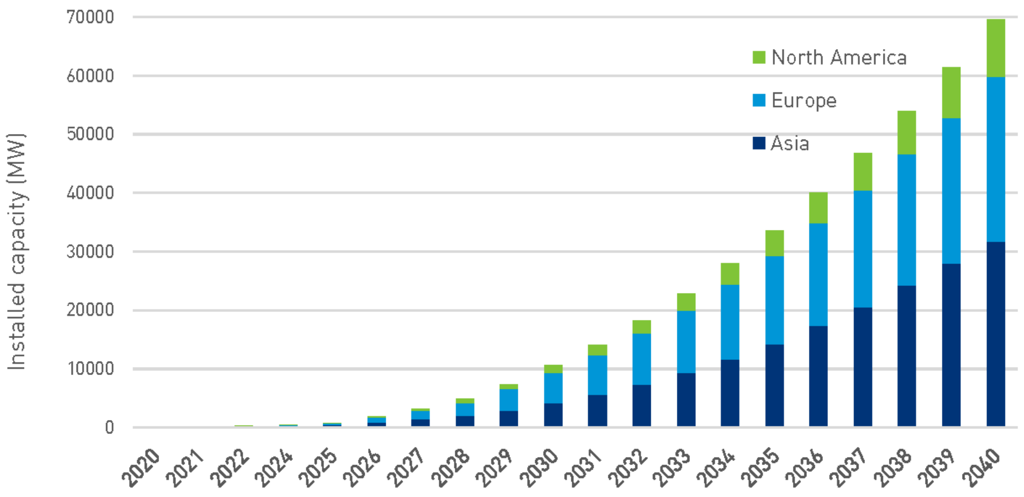
Country	Installed (MW) by end 2020	Expected (MW) 2022	Estimated Deployment (MW) 2025	2030	2035	2040
EUROPE						
UK	80	80	142	1,100	3,800	7,400
France	2	116	116	1,550	5,100	8,900
Other Europe*	31	125	160	2,450	6,200	11,900
Europe (slow)	-	255	296	2,300	6,300	11,000
Europe (expected)	**113**	**320**	**420**	**5,100**	**15,100**	**28,200**
Europe (accelerated)	-	355	449	5,950	21,900	45,600
ASIA						
Japan	12	30	80	930	4,200	11,000
China	0	0	20	495	2,500	7,000
South Korea	0	3	320	1,600	5,000	10,000
Asia (slow)	-	25	210	1,800	5,900	12,900
Asia (expected)	**12**	**33**	**420**	**4,300**	**14,300**	**31,800**
Asia (accelerated)	-	40	520	5,300	21,200	56,200
UNITED STATES						
US (slow)	-	0	0	370	1,500	3,700
US (expected)	**0**	**12**	**12**	**1,270**	**4,300**	**9,800**
US (accelerated)	-	12	12	1,800	6,600	17,500
GLOBAL						
Global (slow)	-	280	511	4,500	13,800	27,800
Global (expected)	**125**	**365**	**848**	**10,750**	**34,000**	**70,300**
Global (accelerated)	-	407	971	13,100	50,100	120,200

Other Europe includes Portugal, Spain, Norway, Greece and Turkey

Source: Carbon Trust. [1]

Commercial projects and market growth to 2040
GLOBAL OVERVIEW

Figure 2: Global floating wind deployment



Source: Carbon Trust. [1]

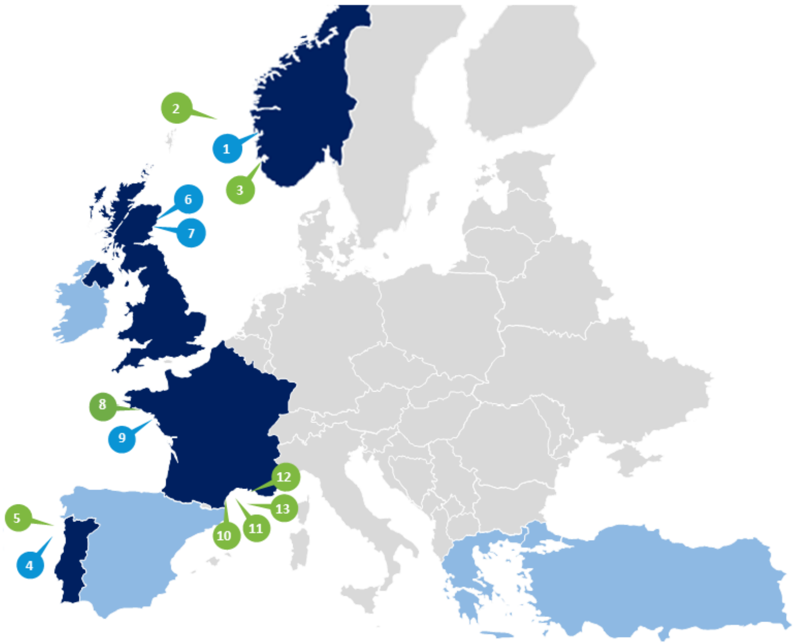
OFFSHORE WIND

Introduction: Offshore wind in numbers

OFFSHORE WIND – FLOATING WIND – GLOBAL OVERVIEW

MARKET PROJECTIONS – 3 KEY REGIONAL MARKETS

Key
Lead markets | Follower markets
● Installed projects | ● Pipeline projects



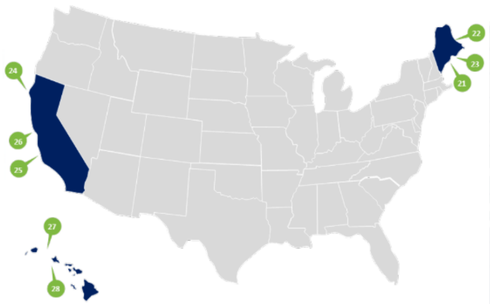
Europe

Project	MW
Norway	
1. Hywind 1	2.3
2. Hywind Tampen	88
3. Tetraspar demo	3.6
Portugal	
4. Windlfoat Atlantic 1*	2
5. Windlfoat Atlantic 2	25
United Kingdom	
6. Hywind Pilot Park	30
7. Kincardine	50
France	
8. Commercial tender (2021)	250
8. (bis) Groix & Belle-Île	28.5
9. FloatGen	2
10. Golfe du Lion	
11. EolMed	30
12. Provence Grand Large	25
13. Commercial tender (2022)	250 x 2

* Windfloat Atlantic 1 now decommissioned

Asia

Project	MW
Japan	
14. Sakiyama	2
15. Fukushima FORWARD: Phase 1	2
16. Fukushima FORWARD: Phase 2	12
17. IDEOL Kitakyshu demo	3
18. Goto City	22
Taiwan	
19. Eolfi Taiwan	500-2000
China	
20. CGN Jieyang	500-3000
South Korea	
21. Shin-Gori Pilot	1
22. Ulsan Prototype	5
23. Donghae Sites	500-1500



United States

Project	MW
Maine	
21. Aqua Ventus I	12
22. Aqua Ventus II	450
23. Aqua Ventus III	450
California	
24. Humbolt Coast	150
25. Morro Bay	700-1000
26. Diablo Canyon	700-1000
Hawaii	
27. Oahu Northwest	400
28. Oahu South	400

Source: Carbon Trust. [1]

OFFSHORE WIND – FLOATING WIND – EUROPEAN OVERVIEW

The following floating projects are currently being developed in Europe

Name	Country	Total Project Capacity	Commissioning Date	Turbine number and capacity	Project developer
TetraSpar Demo	Norway	3.6 MW	2020	1 x 3.6 MW	Shell, RWE, Stiesdal
DemoSATH	Spain	2 MW	2021	1 x 2 MW	RWE, SAITEC
Kincardine	UK	50 MW	2021	5 x 9.5 MW + 1 x 2MW	KOWL, COBRA
EFGL	France	30 MW	2022	3 x 10 MW	Ocean Winds
Groix-Belle-Ile	France	28.5 MW	2022	3 x 9.5 MW	Ferme Eolienne Flottante de Groix & Belle-Île
EolMed	France	28.5 MW	2022	3 x 9.5 MW	EolMed SAS
Provence Grand Large (PGL)	France	24 MW	2022	3 x 8 MW	EDF, Enbridge
AFLOWT	Ireland	6 MW	2022	1 x 6 MW	EMEC, SAIPEM, MARIN, ESB, Frunhofer, CaLiCyA, University College Cork, SEAI
Hywind Tampen	Norway	88 MW	2022	11 x 8 MW	Equinor ASA

Source: Wind Europe. [3]

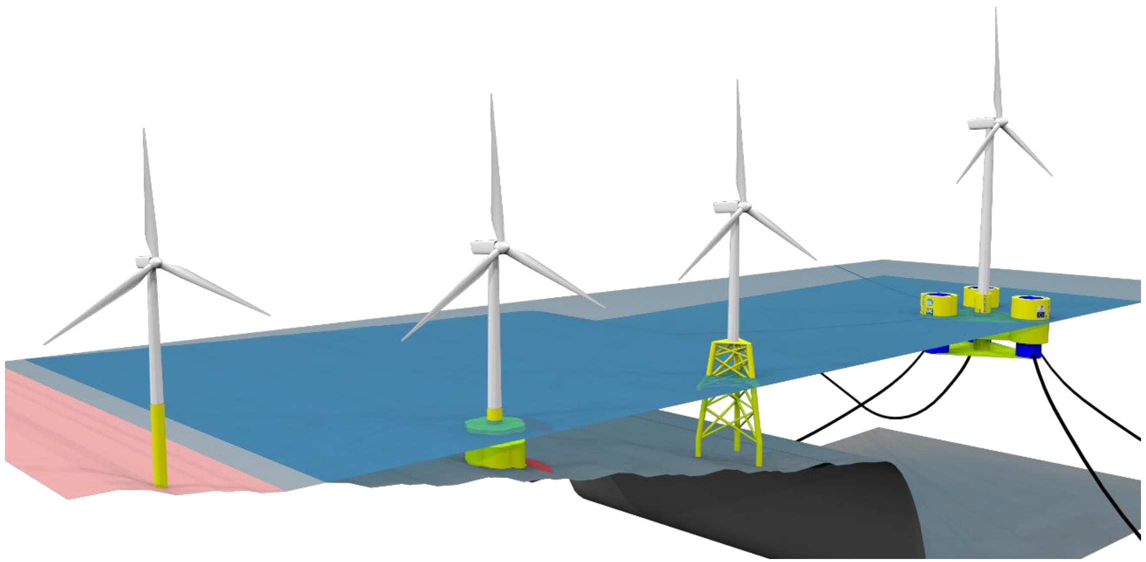
FLOATING OFFSHORE WIND IN EUROPE

- There will be nearly **350 MW** online in **2022** and at least **6 GW** worth of projects that could be commissioned by **2030** if they secure support**,**
- At least **7 countries** in Europe have the ambition to develop floating wind in the **next decade.**
- Europe needs between **100-150 GW of floating wind for reaching climate neutrality.**
- Volumes backed-up with the right policies **will continue to reduce cost to 40-60€/MWh by 2030.**

OFFSHORE WIND

Introduction: Why floating offshore wind?

PROS & CONS



✓ Advantages

- More resource
- Better resource (less turbulence)
- Larger economies of scale (larger facilities)
- Less socio-environmental restrictions

✗ Disadvantages

- Harsh environment
- Technological barriers
- Higher costs
- Higher risks

OFFSHORE WIND

Introduction: Why floating offshore wind?

- Winds are stronger and more consistent further out to sea
- Close to 80% of the world's offshore wind resource potential is in waters deeper than 60 metres
- Floating wind can potentially power 12 million homes in Europe by 2030
- Removing water depth constraints allows us to select the best sites in the world
- Floating wind has a higher capacity factor thanks to better wind further offshore
- Floating wind aims to be competitive with other forms of energy by the year 2030

INDUSTRY PERSPECTIVE

Floating offshore wind in Equinor - equinor.com

Hywind | Saipem

OFFSHORE WIND

Introduction: Why floating offshore wind?

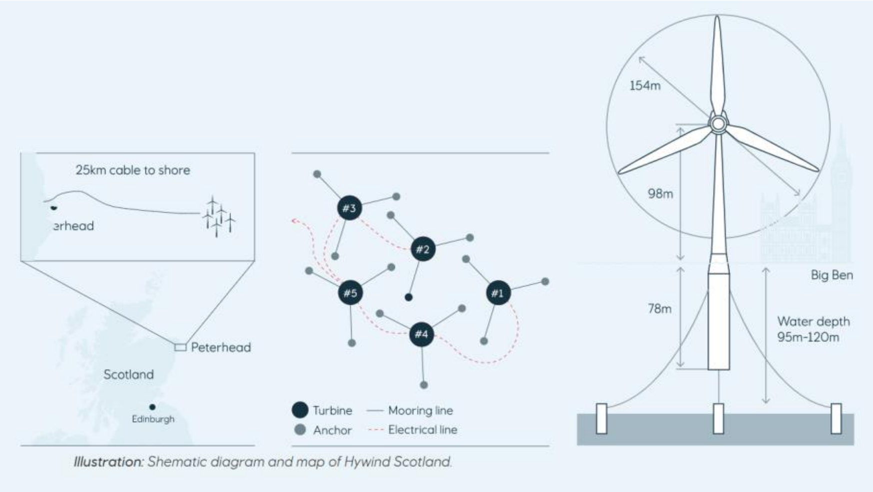
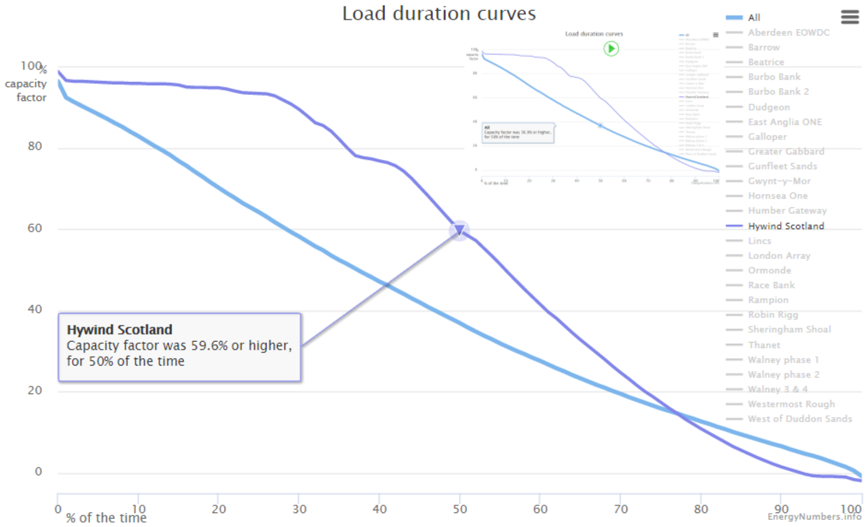
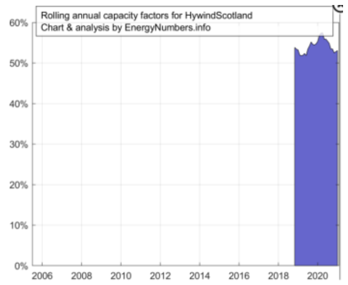


Illustration: Shematic diagram and map of Hywind Scotland.



UK offshore wind capacity factors – Energy Numbers

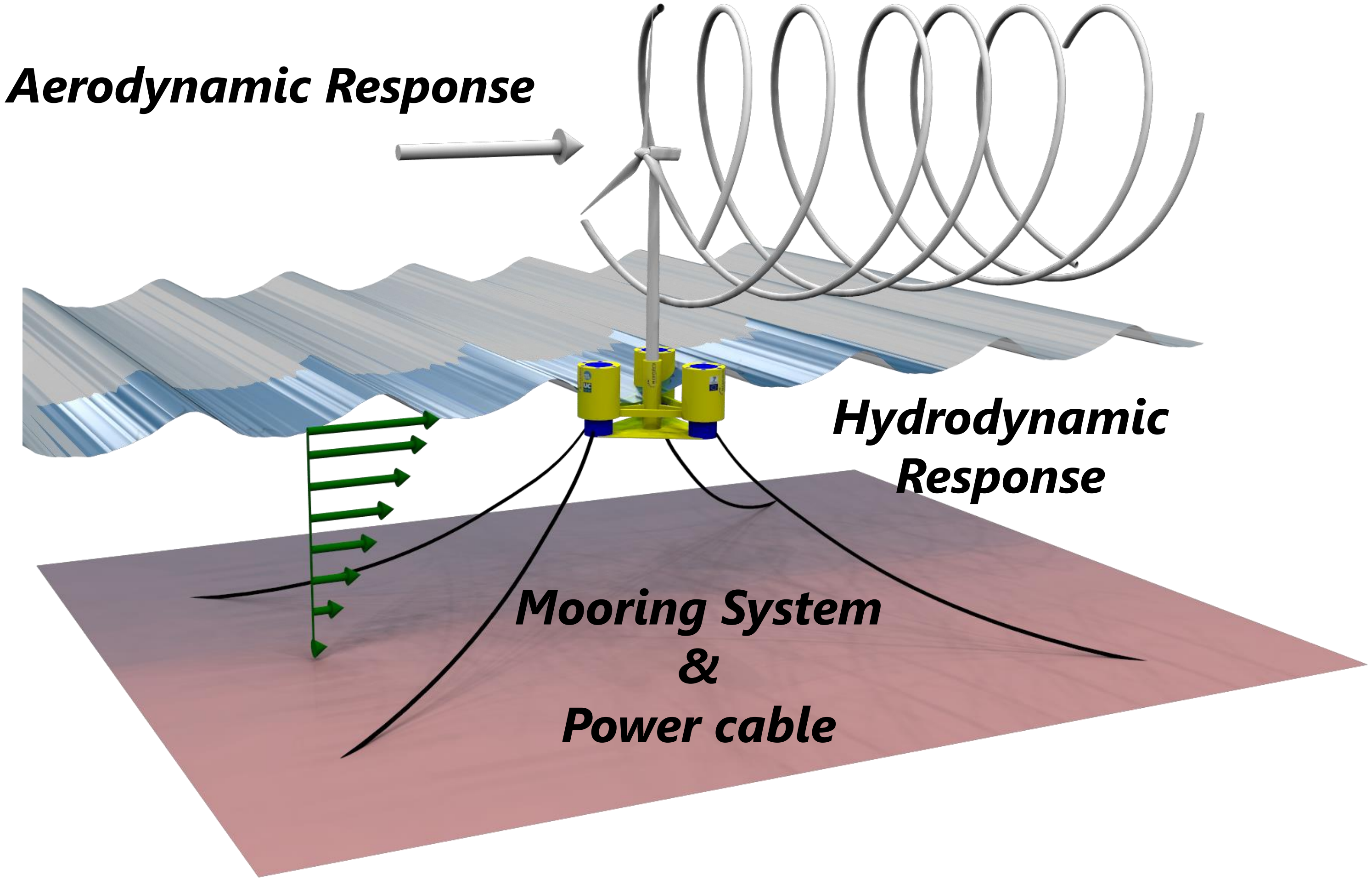
All numbers are to the end of 2020. Analysis by EnergyNumbers.info. Raw data from Ofgem and Elexon	Latest rolling 12-month capacity factor	Life capacity factor	Age (y)	Installed capacity (MW_p)	Total elec. gen. (GWh)	Power per unit area spanned (W/m^2)
Total	46.9%	39.7%	.	10,426	184,198	2.2
Hywind Scotland	53.1%	53.6%	3.2	30	458	1.1

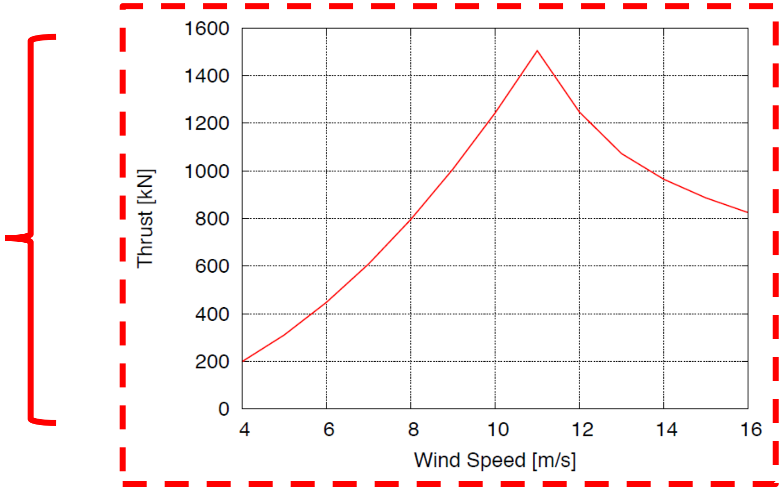


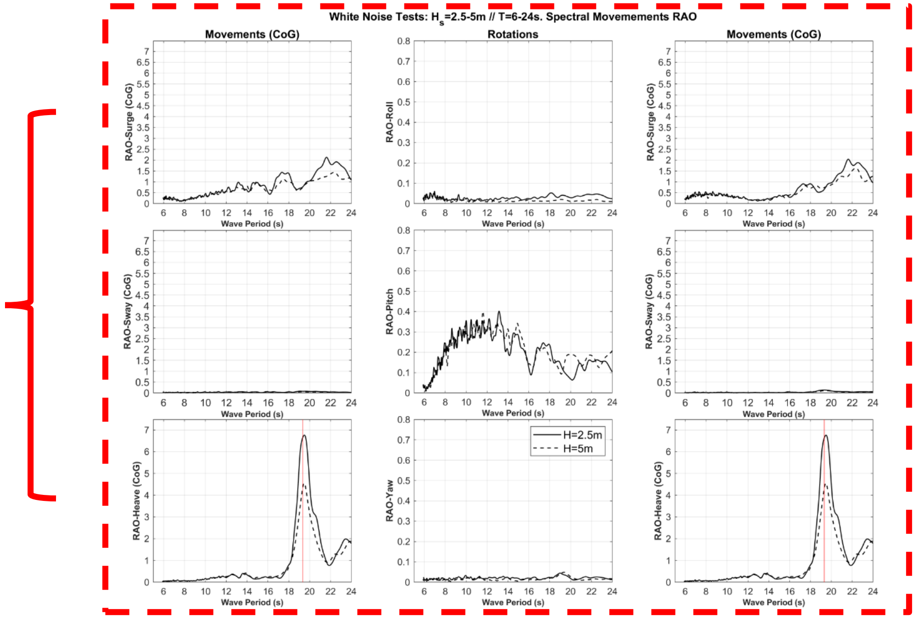
OFFSHORE WIND

Introduction: The problem

- FOWT = support + RNA
- Support = tower + floater + station keeping
- Station keeping = mooring + anchoring

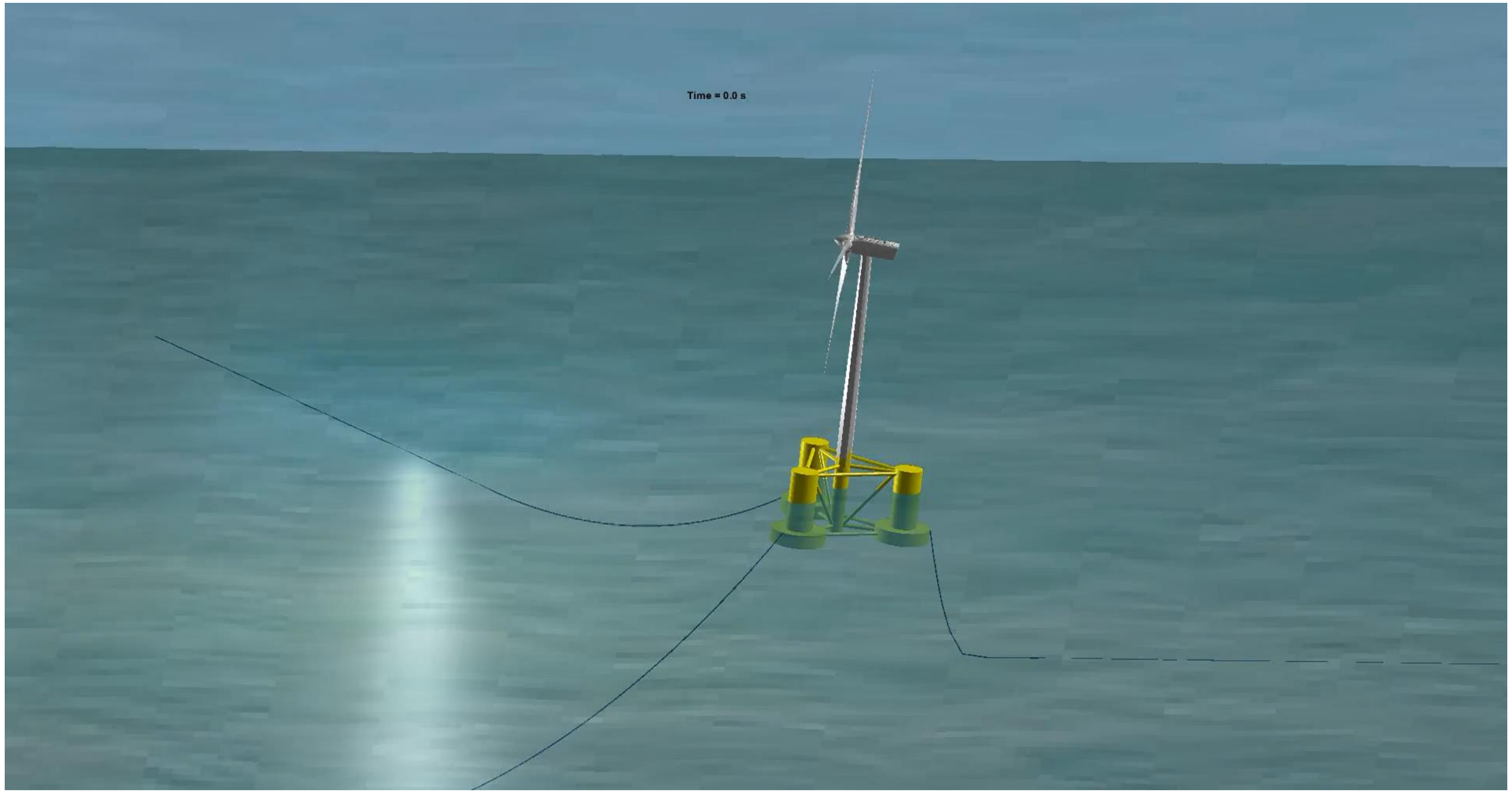


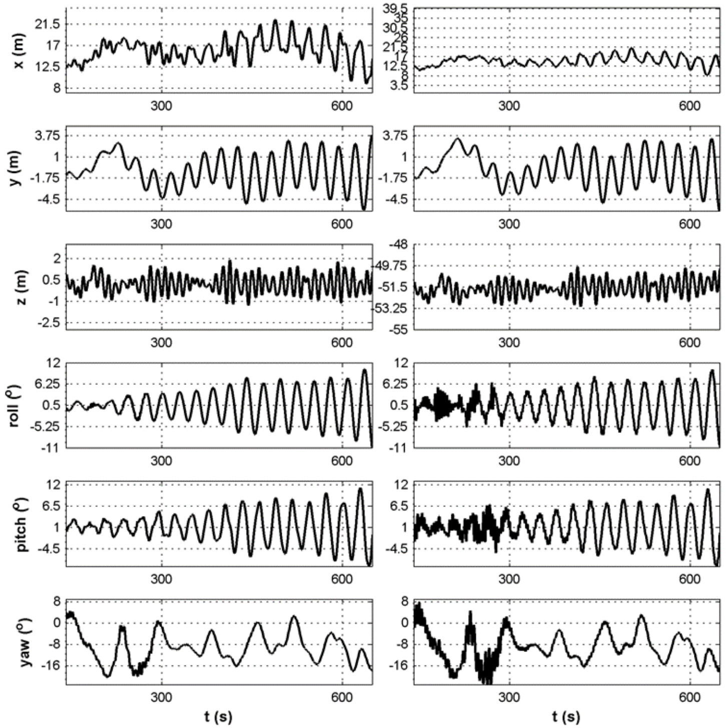




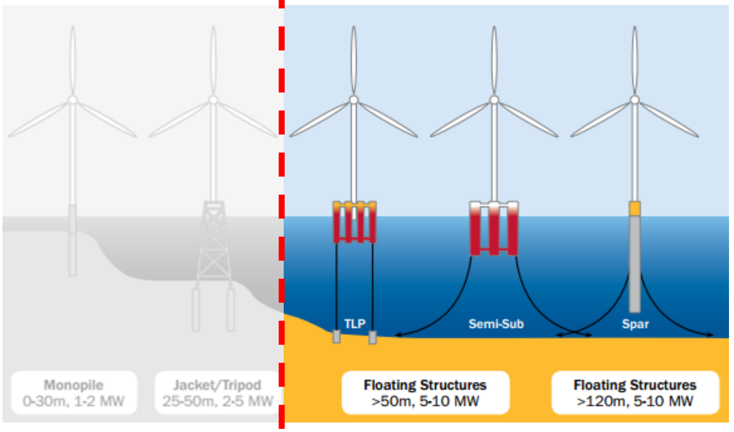
OFFSHORE WIND

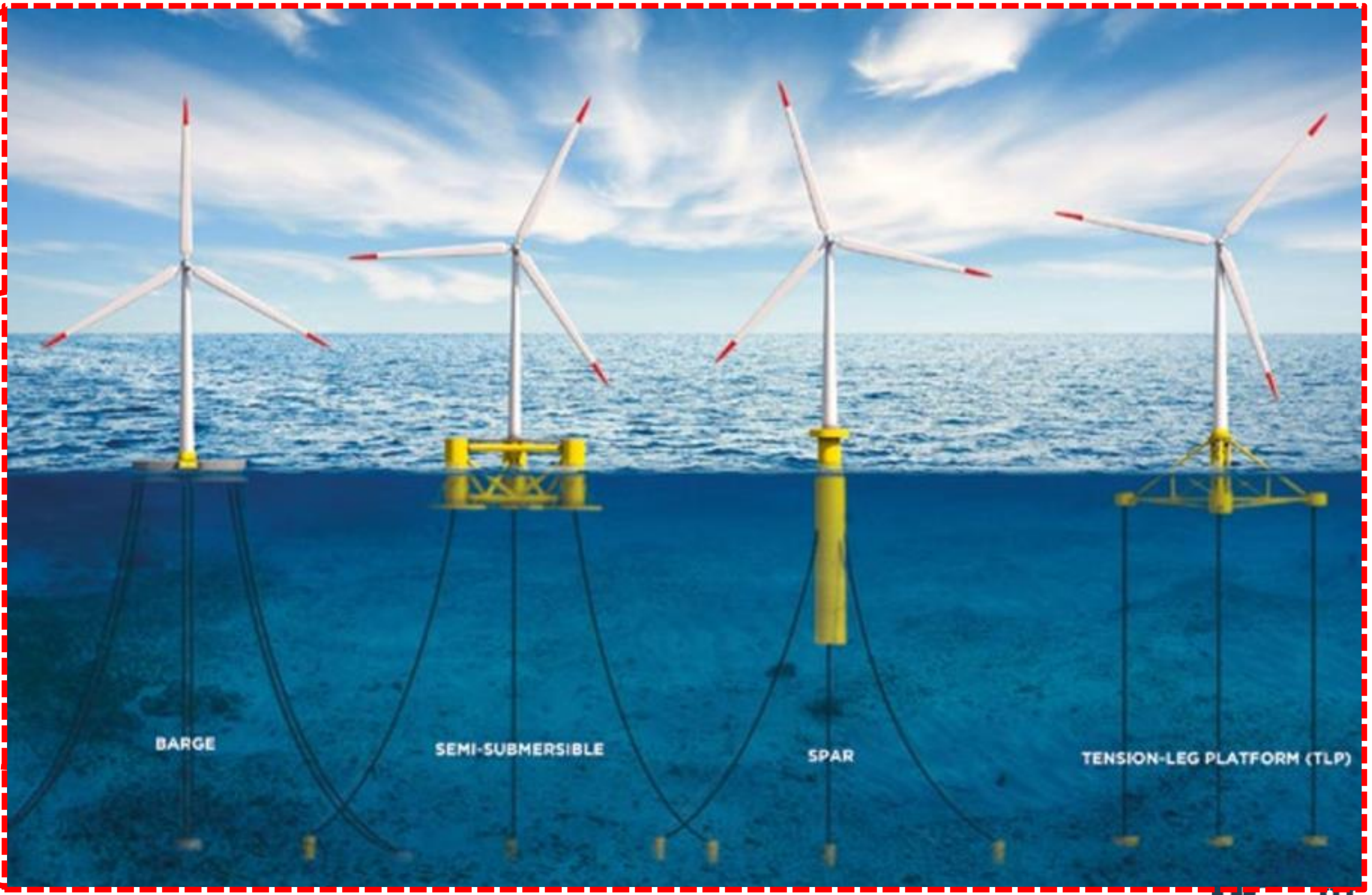
Introduction: The problem





OFFSHORE WIND
Introduction: The floating concept





Floating structures – State of the art
Offshore O&G Structures

Four primary industry recognized solutions

Proven, Functional, Scalable, Adaptable worldwide.

Spar

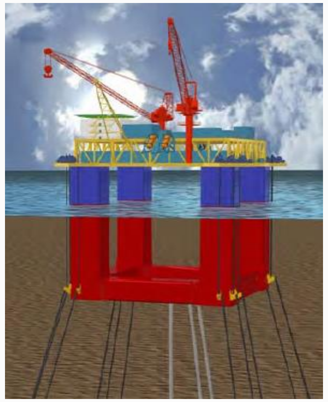
(10.000 ft ~3000 m)
Hollow cylinder, with extra weight in the bottom; Lateral anchoring system.

Primary control load:
Hull Configuration.

Semi-Submersibles

(9.000 ft ~ 2700 m)
Deck supported by columns, connected underwater by pontoons. Lateral mooring system.

Primary control load:
Hull Configuration.



Tension Leg Platforms

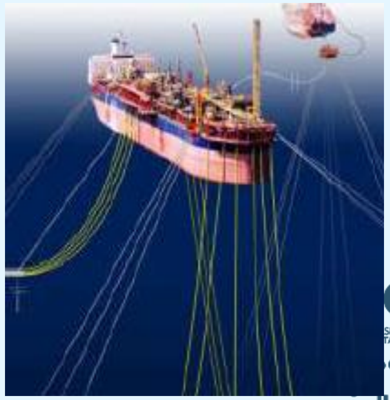
(6.000 ft ~1800 m)
Floating hull tethered by steel tendons.

Primary control load:
Mooring System

Ship –Shape (FPSO)

(10.000 ft ~3000 m)
Mooring systems connected to a "turret" mounted to the hull; freely rotation.

Primary control load:
Hull Configuration



Source: Floatec, 2010.

OFFSHORE WIND

Introduction: The floating concept

FLOATING WIND TYPOLOGY REVIEW – SEMI-SUBMERGIBLE TECHNOLOGY

- A semi-submersible is a free-surface buoyancy-stabilised structure with relatively shallow draft.
- It is a versatile structure thanks to its relatively low draft and flexibility to different site conditions.
- Generally, it is a heavy structure with a relatively high steel mass and manufacturing complexity due to the many welded connections.
- There are emerging and very promising solutions based on concrete.

WINDFLOAT – Semi-Sub Technology

OFFSHORE WIND

Introduction: The floating concept

FLOATING WIND TYPOLOGY REVIEW – SPAR TECHNOLOGY

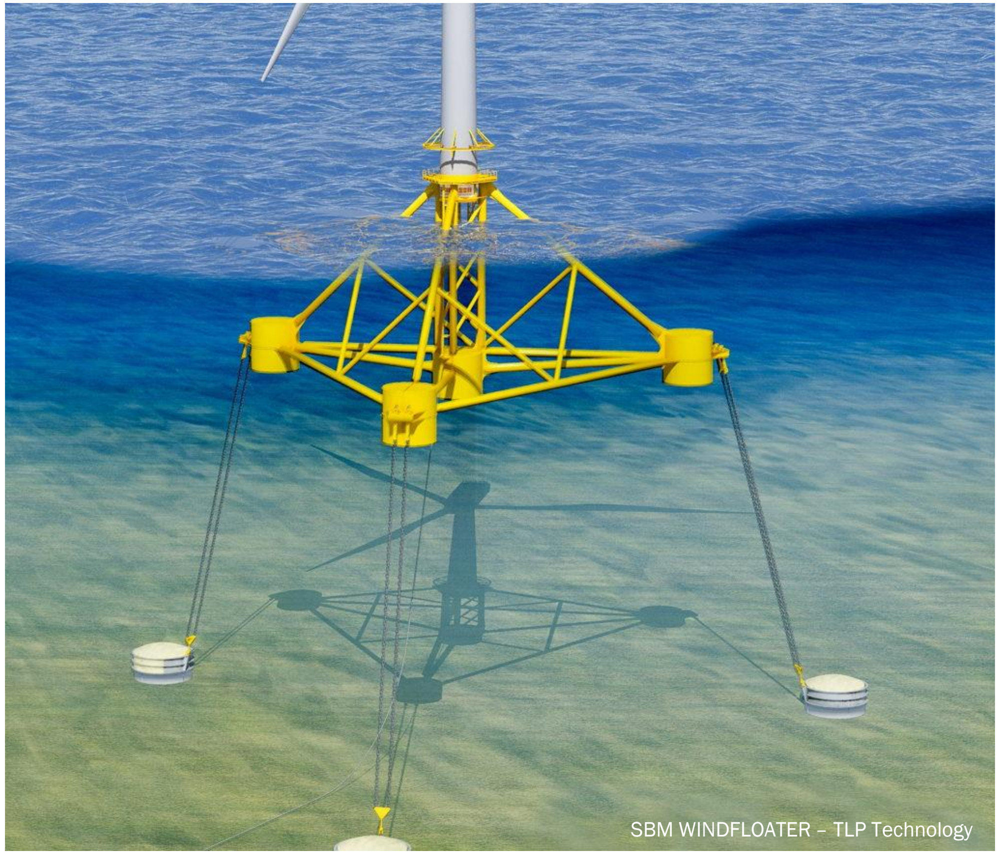
- The spar is a ballast-stabilised structure with relatively large draft.
- It uses simple, well-proven technology with inherently stable design that exhibits high inertial resistance to pitch and roll motions.
- The spar will face challenges due to its large draft requirements for the operational site, but also in terms of assembly sites and transportation routes.
- The spar technology is dominated by steel, but there are solutions based on concrete like Windcrete.

HYWIND – Spar Technology

Introduction: The floating concept

FLOATING WIND TYPOLOGY REVIEW – TENSION LEG PLATFORM (TLP)

- The tension leg platform is a tension-stabilised structure with relatively shallow structural draft and limited motions during operation.
- The tension leg enables low structural weight of the substructure, and thus lower material costs.
- However, mooring tendons can present higher operational risk in case of mooring failure and add requirements with regard to soil conditions at site.
- Regarding with the materials used to manufacture this kind of concepts, they are mostly built in steel, but there are composite structures made of concrete and steel like GICON technology.


SBM WINDFLOATER – TLP Technology

Introduction: The floating concept

FLOATING WIND TYPOLOGY REVIEW – BARGES TECHNOLOGY

- Barges are the shallowest draft of all the floating foundation types.
- This is an advantage for installing the turbine alongside a quay at a shallow draft ports.
- However, this designs usually show larger motions due to waves, which can demand more advanced mooring systems.
- Some barge designs include a moonpool to suppress wave-induced loading (i.e. IDEOL).
- With regards to the base materials used within this technology, both materials, steel and concrete, are being used to develop this kind of concepts.

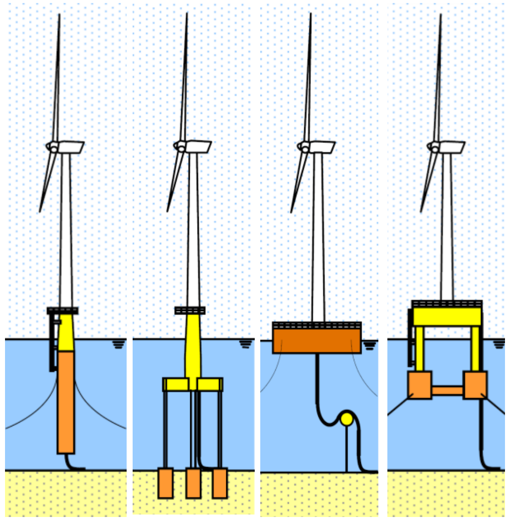
BLUESATH – Barge Technology

OFFSHORE WIND
Introduction: The floating concept

Floating structures – State of the art
Offshore O&G Structures

Fit For Purpose Design of Deepwater Support Structures:

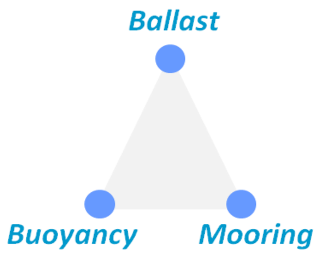
Optimize the Structural Configuration ensuring Robustness, Cost and Performance Efficiency, and thus meeting Financial Targets.



Source: Upwind Project, 2010.

	TLP	SPAR	BARGUE
Pitch Stability	Mooring	Ballast	Buoyancy
Natural Periods	(+) Avantage	(0) Neutral	(-) Disvantage
Coupled Motion	+	0	-
Wave Sensitivity	0	+	-
Turbine Weight	0	-	+
Moorings	+	-	-
Anchors	-	+	+
Construction	-	-	+
O&M	+	0	-

Source: Upwind Project, 2010.



*In practice, floating concepts are **hybrid** designs that gain static stability from all three methods, although generally relying on one primary source for stability.*

SPAR
- Stable Design, Lowest Risk
- Simple and Inexpensive
- Catenary or Taut Mooring
- High Mass, Deflection and Heel Angles.
- For very High Depths

TLP
- Most Stable (low roll and pitch).
- Site – Constrained. High depth.
- Expensive taut mooring.
- Prone to fatigue loading.
- Sensitive to yaw load.

BARGUE / TRIFLOATER / SEMI-SUB
- Most Flexible.
- Easily Mass Produced.
- Catenary or Taut mooring
- High heel angles
- Dry-docking possible

OUTLINE

01

INTRODUCTION TO OFFSHORE WIND

- Offshore wind in numbers
- Why offshore wind?
- The problem
- The floating concept

02

AN INNOAVATIVE INDUSTRY

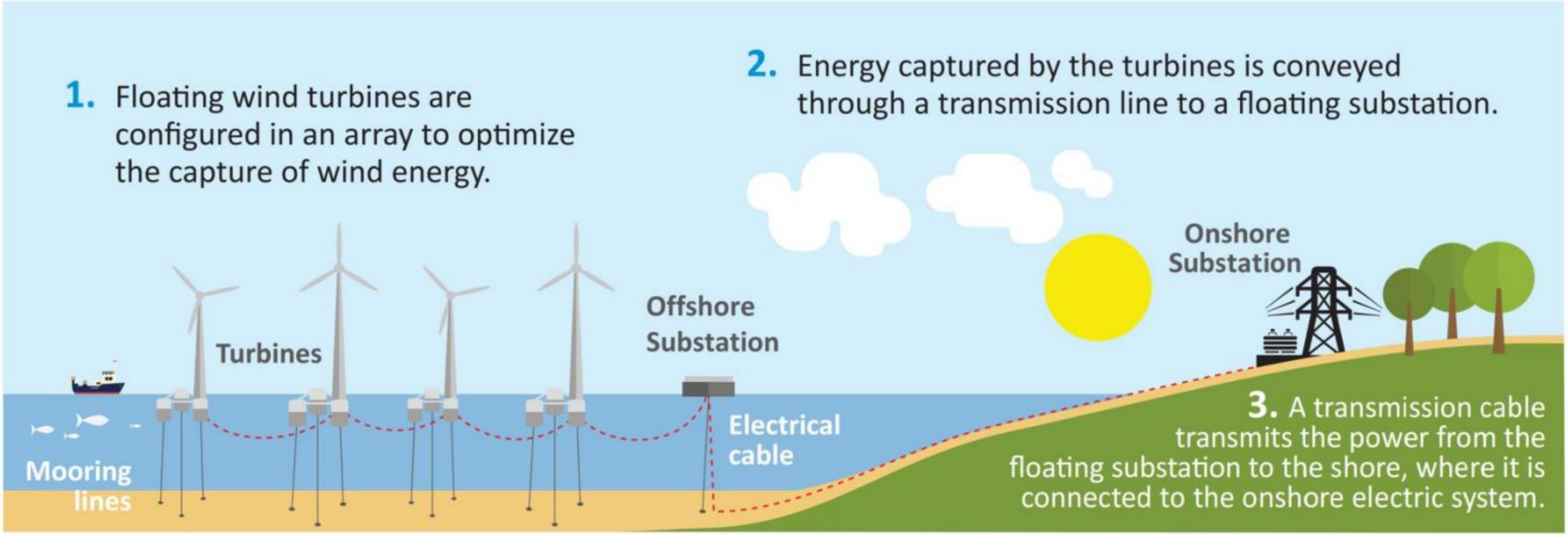
- The floating wind farm
- Technical barrier
- The Floater
- Station Keeping
- Materials
- Key numbers

03

FLOATING OFFSHORE WIND AT IHCANTABRIA

- Floating offshore wind in Spain
- IHCantabria

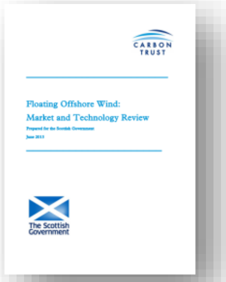
OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: The floating wind farm



[Life Cycle Assessment of Greenhouse Gas Emissions for Floating Offshore Wind Energy in California (pnnl.gov)]

Keywords: Efficiency, Reliability, Durability, Standardization/Industrialization, …
Weather dependency, Marine Environment, Floating …

OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: The floating wind farm



Floating Offshore Wind - Market & Technology Review_FINAL (storage.googleapis.com)

Prioritisation of key technical barriers

Technical challenge	Cost reduction potential	Urgency	IP sensitivity
Platform size & weight	2.7	2.4	2.8
Installation procedures	2.5	2.2	1.8
Port-side O&M (major repair procedures)	2.3	2.2	1.0
Floating substations/transformer modules	2.3	2.0	2.0
Advanced control systems for floating WTGs	2.2	2.2	2.6
Mooring design & installation	2.2	2.1	2.4
Anchor design & installation	2.1	2.1	2.0
Advanced tank testing facilities	2.0	2.1	1.7
Wind farm operation (wake effects, yield, AEP)	1.9	2.1	1.0
Advanced modelling tools	1.9	2.5	2.0
High voltage dynamic cables	1.8	2.1	1.6
Bespoke standards for floating wind	1.8	2.0	1.0
Environmental impact	1.4	2.1	1.0

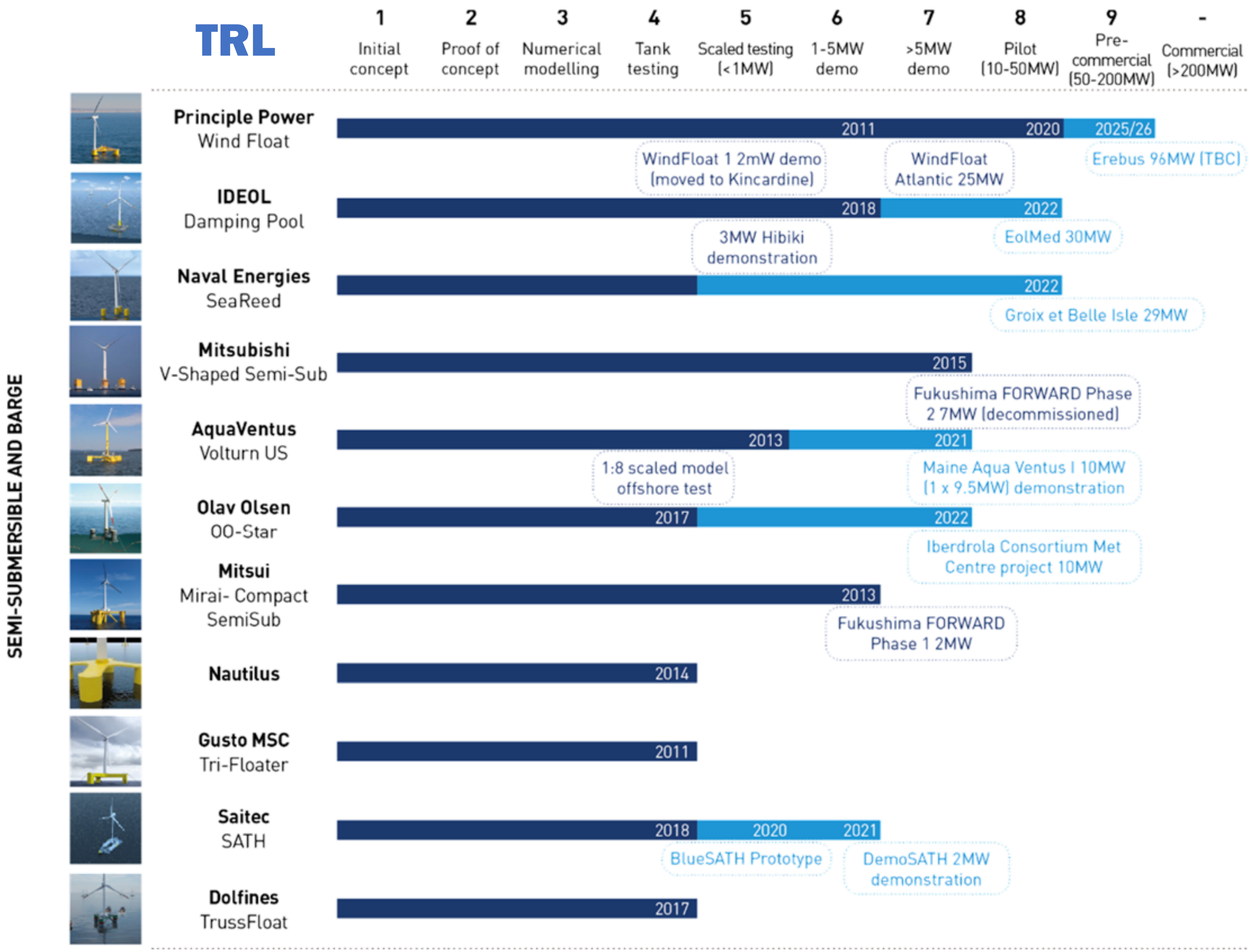
Impact: 1-3 (High=3; Med=2; Low=1)
Criticality/Barrier: High - Low

R&D Opportunities

Technology focus area	Detail	Cost reduction	Urgency	IP Sensitivity
Installation optimisation	> Faster installation > Reduce sensitivity to met-ocean conditions > Maximise onshore/port-side operations > Reduce vessel requirements	2.5	2.2	1.8
O&M – major repairs	> Technical viability and cost benefit of port-side versus offshore repairs of major components	2.3	2.2	1.0
Substations / transformer modules	> Develop optimal solutions for transformer platforms (single substation; distributed transformer modules)	2.3	2.0	2.0
Mooring & anchoring systems	> Understanding loads and limitations > Advanced materials for moorings (lightweight, low cost) > Ensure lifetime asset integrity for minimum 25 years > Optimise installation process > Solutions for 50-100m water depths	2.1	2.1	2.0
Wind farm operation (wake effects, yield, power output)	> Understand floater motion and impact on wake effects in floating wind arrays, in regard to both wind farm yield and fatigue > Combine with efforts to develop advanced design modelling tools and advanced control systems	1.9	2.1	1.0
Integrated modelling tools	> Developing advanced modelling software to accurately simulate coupled behaviour of floating wind systems	1.9	2.5	2.0
	> Offshore demonstrations and tank testing can be used to validate the accuracy of the modelling tools			
Electrical cables	> Develop and qualify high voltage dynamic cables	1.8	2.1	1.6
Standards and best practice guidance	> Develop a bespoke set of industry standards and guidelines for floating wind devices > Identify opportunities for component standardisation	1.8	2.0	1.0
Environmental impact	> Impact of floating wind structures on the seabed, marine mammals, and local fishing activities	1.4	2.1	1.0

OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: The floater

STATUS OF FLOATERS DESIGN IN 2020 (1/2)

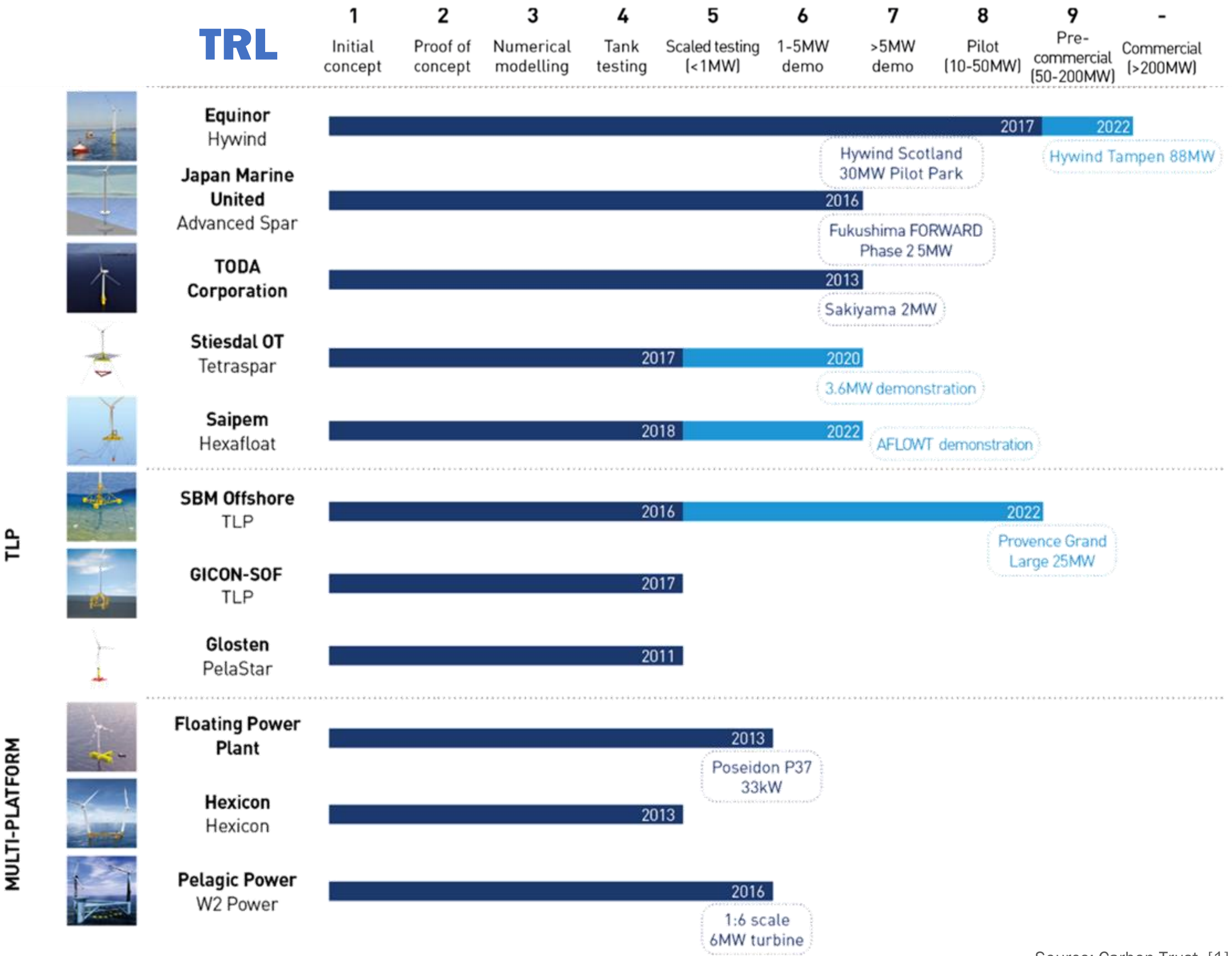


Source: Carbon Trust. [1]

- There are approximately 40 different floating wind concepts at various stages of development.
- Almost all the developments are focused on the floaters.
- The majority of the turbines are conventional horizontal axis turbines, as provided by the major offshore wind turbine suppliers.
- While a large number have successfully completed tank testing, the progression to full-scale demonstration has proved more elusive, largely due to the step change in investment required.

OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: The floater

STATUS OF FLOATERS DESIGN IN 2020 (2/2)



Source: Carbon Trust. [1]

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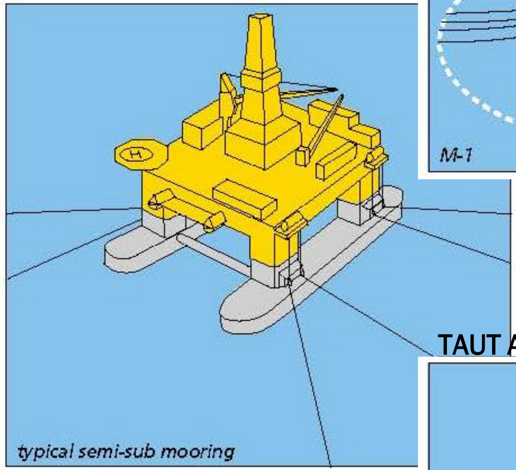
OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: Station keeping

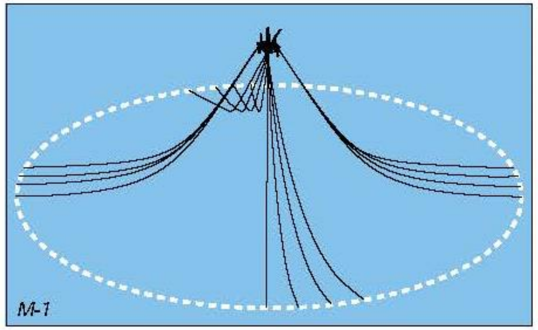
FLOATING WIND TYPOLOGY – STATION KEEPING SOLUTIONS – MOORING ARRANGEMENT

➢ 3 Main solutions:

SPREAD MOORING SOLUTIONS

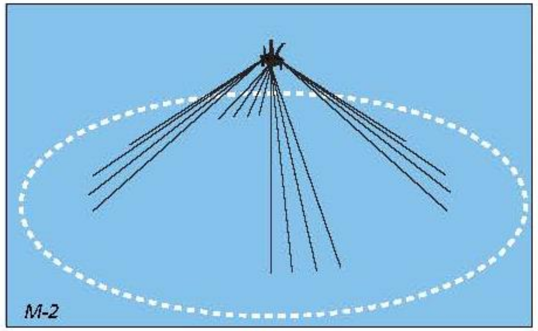


CATENATY MOORING SYSTEM



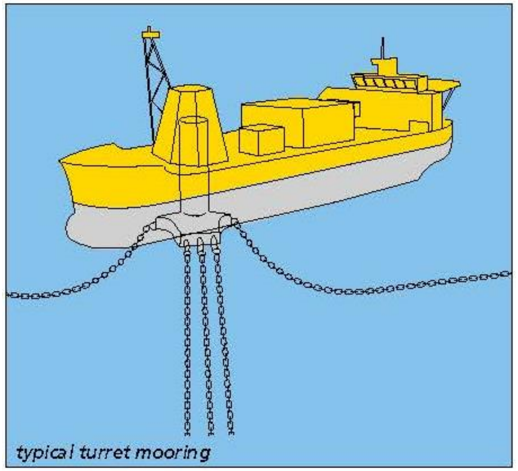
- Chain
- Wire Rope
- Drag Embedment Anchor

TAUT AND SEMI-TAUT MOORING SYSTEM



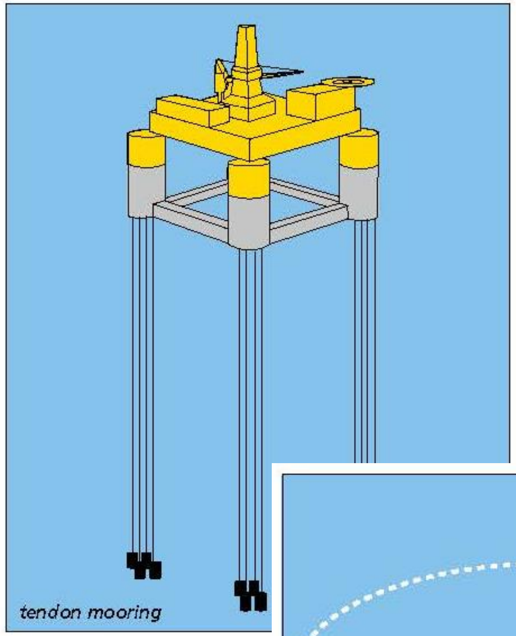
- Synthetic Rope
- Wire Rope
- Vertical Loaded Anchor (VLA)

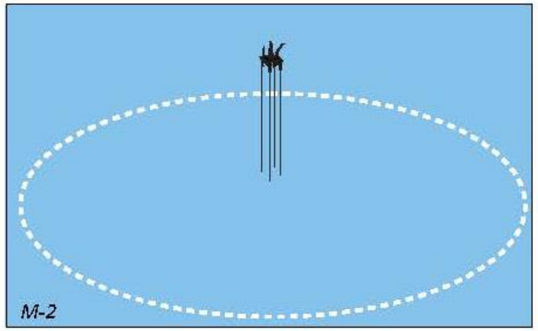
TURRET SOLUTIONS



- Generally used on Barge floating platforms in more harsh environments.
- Multiple mooring lines are used,
- The Barge is able to rotate around the turret to obtain an optimal orientation relative to the prevailing weather conditions.

TENSION LEG SOLUTION



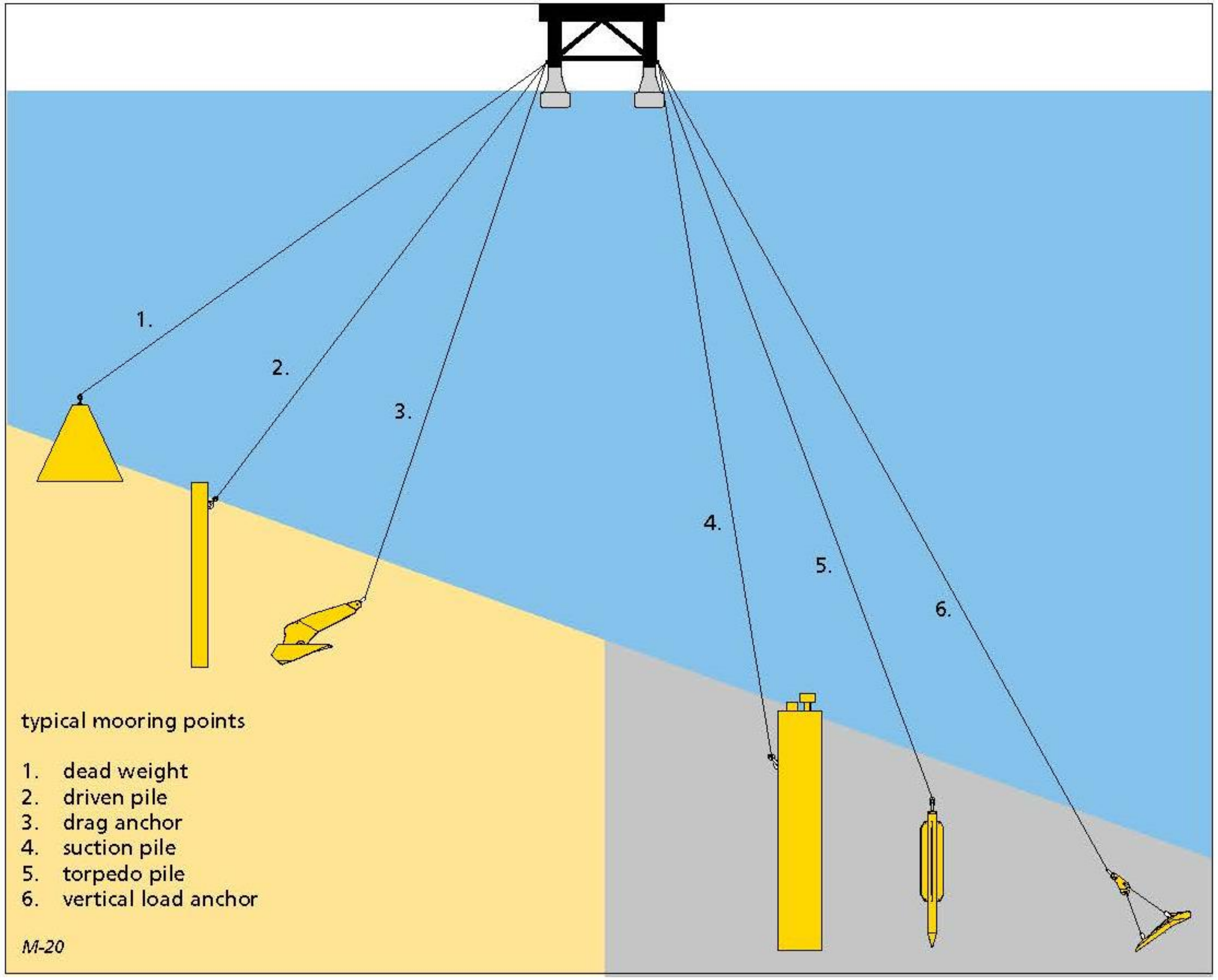


- Very Hight Deep Water
- Suction Anchor
- Vertical Loaded Gravity Anchors

Source: Vryhof. [5]

OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: Station keeping

FLOATING WIND TYPOLOGY – STATION KEEPING SOLUTIONS – ANCHORING



Source: Vryhof. [5]

Most common anchors:

- Deadweight anchor (1)
- Drag embedment anchor (mainly against horizontal load) (3)
- Anchor piles:
  - Driven pile (2)
  - Suction pile (4)
  - Torpedo pile (5)
- Vertical load anchor (6)

OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: Materials

FLOATING WIND TYPOLOGY REVIEW – 2 MAIN MATERIALS OF CONSTRUCTION: STEEL & CONCRETE

Offshore Steel Structures


Bollsta Dolphin - Semisub

ADVANTAGES FOR STEEL HULLS:

- *Fabrication in Existing Shipyards*
- *Potentially Lower First Cost for One Hull*
- *Traditional Engineering*
- *Traditional Construction*
- *More Steel Fabricators are Available*
- *More Steel Designers are Available*
- *Prestressing Not Required*

Steel is the most common material used for offshore construction

Advantages of steel structures

Fabrication in Existing Shipyards

High supply of specialized shipyards → *Cost Reduction*

Traditional Engineering & Construction

Standardized processes
Specialized staff
Production efficiency
→ *Cost Reduction*

More Steel Fabricators & Designer

High supply to develop technology.


Windfloat –Steel Hull

OFFSHORE WIND
AN INNOAVATIVE INDUSTRY: Materials

FLOATING WIND TYPOLOGY – 2 MAIN MATERIALS OF CONSTRUCTION: STEEL & CONCRETE

Offshore Concrete Structures

Offshore concrete structures have been in use successfully for about 40 years.

Troll B (1995). SemiSub

Floating offshore structures have become rather attractive within the last three decades.

Advantages of offshore concrete structures

Lower fabrication costs

Economy of materials
Faster and more cost effective to construct
→ *Lower fabrication costs*

- The fabrication costs **saving is at least a 16%** compared to that of steel.

Lower maintenance costs

High resistance to abrasion
Non corrosion effects over hull
No painting required
Less downtime for repair and maintenance
Repair and restoration can be done afloat
Excellent resistance to impact loads
→ *Lower maintenance costs*

Damping Pool. Ideol

ADVANTAGES FOR CONCRETE HULLS:

- *Lower prices*
- *Well-known performance*
- *Long experience in the marine environment*
- *Industrialize*
- *Low maintenance*

Other key qualitative parameters for cost of concrete structure

- Local availability of labour and materials
- Design basic requirements
- Construction schedule. Construction time is related to simplicity and concrete volume.

R & D + i for sustainable development

OUTLINE

01

INTRODUCTION TO OFFSHORE WIND

- Offshore wind in numbers
- Why offshore wind?
- The problem
- The floating concept

02

AN INNOAVATIVE INDUSTRY

- The floating wind farm
- Technical barrier
- The Floater
- Station Keeping
- Materials
- Key numbers

03

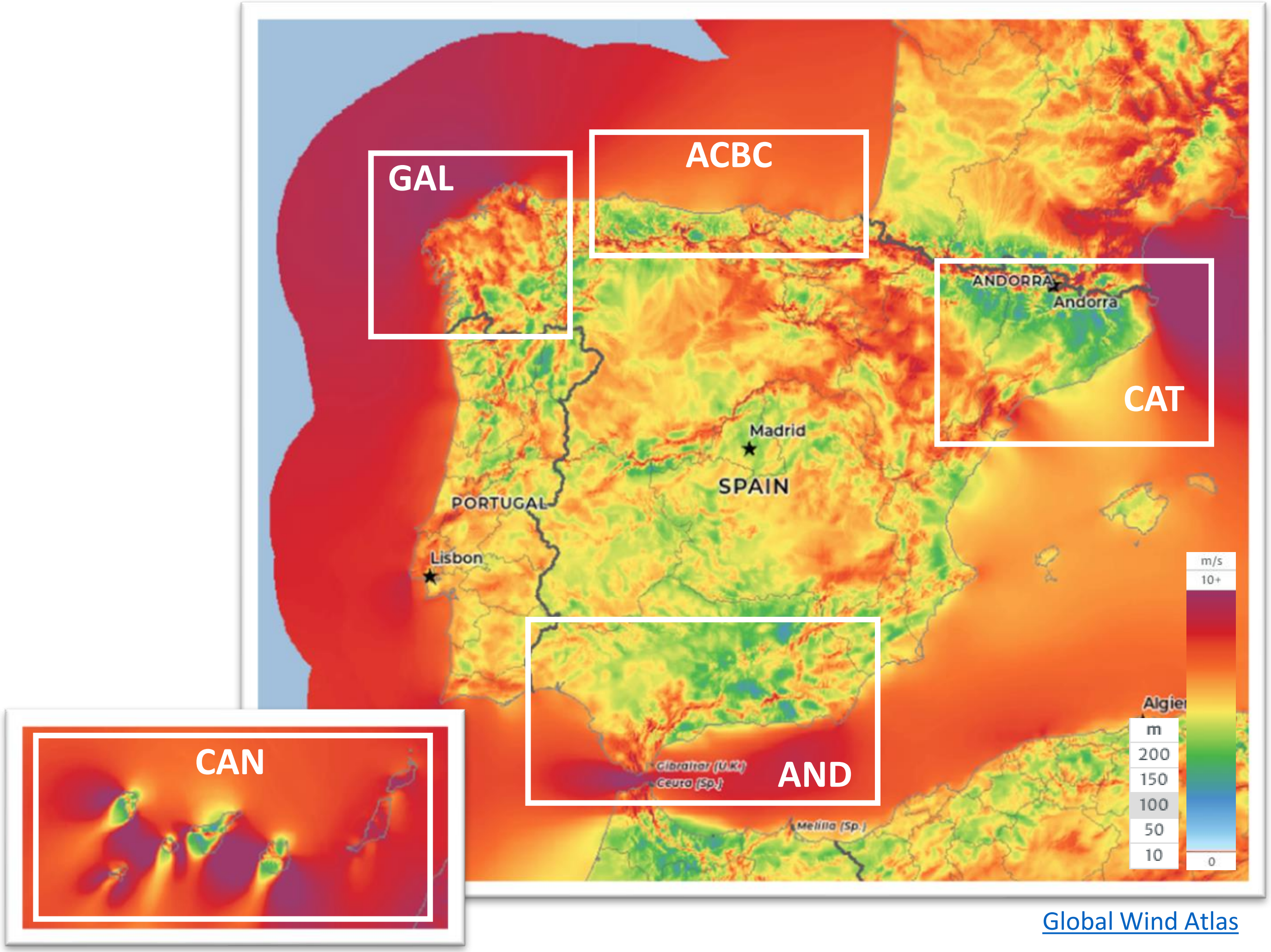
FLOATING OFFSHORE WIND AT IHCANTABRIA

- Floating offshore wind in Spain
- IHCantabria

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

OFFSHORE WIND IN EUROPE: MARKET GROWTH – FLOATING WIND

➢ Opportunities for floating wind – OFFSHORE WIND AREAS



Global Wind Atlas

➢ 5 regions have been identified in Spanish waters and are promoted by the national government

- **Canary islands** (CAN)
- **Galicia** (GAL)
- **Asturias-Cantabria-Basque Country** (ACBC)
- **Andalucía** (AND)
- **Catalonia** (Can)

➢ **Marine spatial planning. Interaction with orher marine uses:** Protected areas, Fisheries, Aquaculture, Sea Transport, Airports, …

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

➢ Opportunities for floating wind – OFFSHORE WIND AREAS

Canary Islands have attracted the most interest on Spanish market.

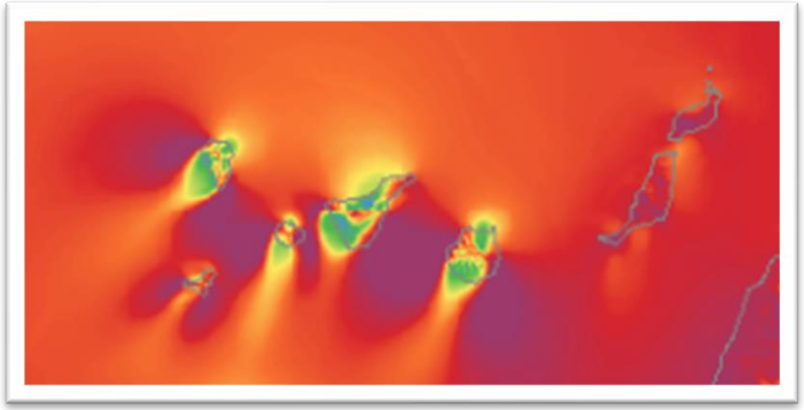
Reasons to be optimistic (+) :
- Best wind resource in Spain with high speed and continuous wind
- Insularity causes a higher cost of electricity which is paid by the Spanish State
- Positive vision of OW as job creator for high unemployed Canary Islands
- Regional Objective 300 MW 2025

Reasons to be less optimistic (-) :
- Limited demand and power to be supplied
- Reduced supply chain
- Massive competition between developers

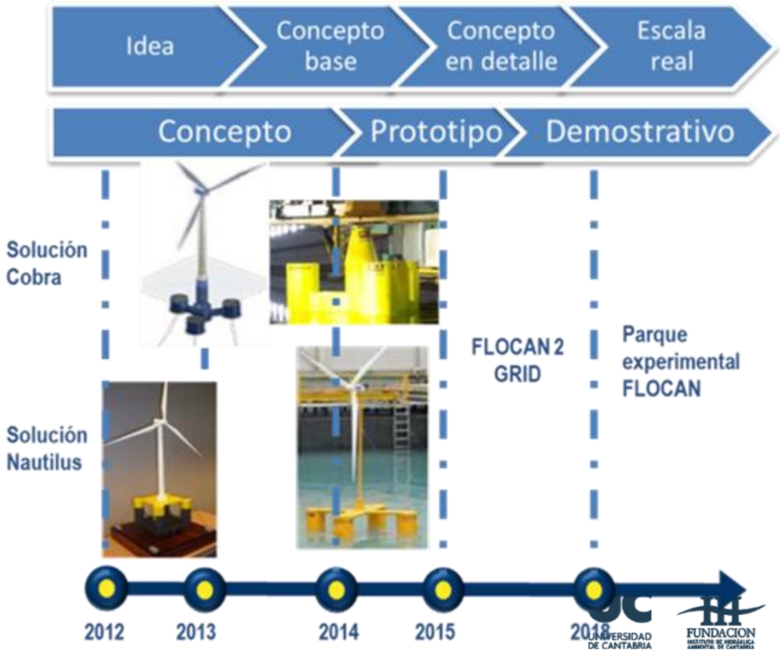
Source: Spanish Offshore Wind Status. Saitec Offshore Technologies. November 2020.

Estimation of potential (ITC) (depths<500m)

Island	Off-shore wind area	Off-shore wind power	Wave energy area
Gran Canaria	500 km²	250 MW	50 km²
Tenerife	50 km²	25 MW	128 km²
Lanzarote	180 km²	90 MW	66 km²
Fuerteventura	250 km²	125 MW	150 km²
La Gomera	70 km²	35 MW	26 km²
La Palma	0 km²	0 MW	0 km
El Hierro	30 km²	15 MW	18 km²



FLOCAN TO GRID



https://www.grupocobra.com/en/proyecto-innovacion/flocan-to-grid/

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

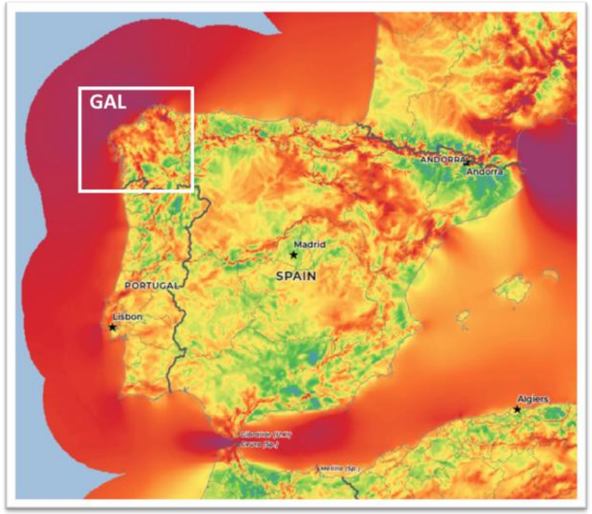
➢ Opportunities for floating wind – OFFSHORE WIND AREAS

Galicia is already Spanish leader in Onshore Wind.

Reasons to be optimistic (+) :
- Best wind resource in the peninsula with high speed
- Supply chain available and betting on floating wind (Navantia & Port of A Coruña)
- Positive vision of OW as job creator for high unemployed Galicia

Reasons to be less optimistic (-) :
- Fisheries high importance in Galicia
- Many protected areas
- Very harsh environment

Source: Spanish Offshore Wind Status. Saitec Offshore Technologies. November 2020.



GREENALIA STARTS THE DEVELOPMENT OF SPAIN`S FIRST FLOATING OFFSHORE WIND FARM IN GRAN CANARIA

02/06/20 - Wind

The company GREENALIA is launching its first Floating Offshore Wind Project in Gran Canaria by filing its project & environmental planning application. The project Parque Eólico GOFIO is a 50 MW offshore wind farm located in the South East of the Gran Canaria Island, in front of the municipality of San Bartolomé de Tirajana and in close proximity to the port of Arinaga.

The power plant is formed by four 12,5 MW offshore wind turbines on top of floating foundations and will deliver the energy produced by the use of submarine cables. The project is located in one of the areas with highest wind resource in Europe as it has been highlighted in several energy reports.

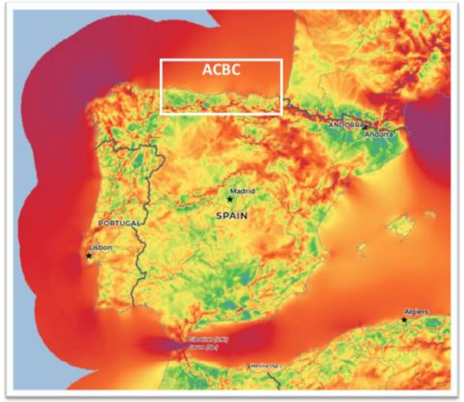
In this way, GREENALIA (based in Galicia, Spain) is endorsing its committment on developing green energy projects as part of the New Green Deal and subsequently wants to be a key part of the descarbonization process both in Spain and Europe. The same way, GREENALIA wants to diversify its energy portfolio by adding on of the most promising Renewable Energy sources to it, as offshore wind is surely the source with the biggest growth rate in the World in the last decade, but also with a vast development potential throughout the World´s Seas and Oceans

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

R & D + i for sustainable development

➢ Opportunities for floating wind – OFFSHORE WIND AREAS

Asturias-Cantabria-Basque Country.



Asturias
- Coal plants going off
- New jobs creation opportunity
- Supply chain (Windar, Port of Avilés..)

Cantabria
- Interest on Marine Energies (IH Cantabria & Clusters)
- New jobs creation opportunity

Basque Country (Autonomous Region):
- Powerful Offshore wind supply chain
- High density area limited onshore & PV ->Decarbonisation through offshore wind
- Industrial Hub
- Limited wind (-)

Source: Spanish Offshore Wind Status. Saitec Offshore Technologies. November 2020.


Economía | Mercados Empresas Autónomos Trabajo Vivienda Fiscalidad Banca

ÚLTIMA HORA En directo: última hora sobre la evolución de la pandemia en Asturias

EdP estudia construir un parque eólico marino y flotante frente a la costa asturiana

La compañía ha informado de su interés al Principado, aunque el proyecto aún está en fase embrionaria, y también investiga la posibilidad de producir hidrógeno en las térmicas

www.elcomercio.es, Dec. 2019


IDERMAR FLOATING MET MAST III (Source: IHCantabria)


Instalan en el Abra de El Sardinero la primera turbina eólica flotante

El prototipo, de la empresa Saitec, generará energía renovable con capacidad de abastecer a 15.000 hogares

Botadura de la boya experimental de Saitec. / DANIEL PEDRIZA

www.eldiariomontanes.es, Aug. 2020

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

➢ Opportunities for floating wind – OFFSHORE WIND AREAS

Andalusia has a very long Coast.

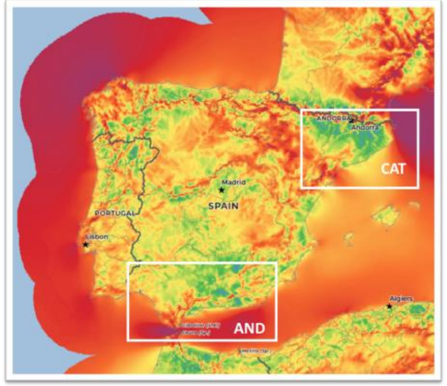
Reasons to be optimistic (+) :
- Good wind resource in certain areas
- Supply chain available and betting on floating wind (Navantia)
- Positive vision of OW as job creator for high unemployed Andalusia

Reasons to be less optimistic (-) :
- Mediterranean sea massive traffic
- Requirements to avoid visual impact
- Many protected areas

Catalonia has limited areas of good wind speed.

- Near the Ebro Delta (really complicated due to environmental concerns)
- Near the French border

Source: Spanish Offshore Wind Status. Saitec Offshore Technologies. November 2020.



ENERGIAS RENOVABLES

Regresa con fuerza la ubicación en el Estrecho de parques eólico-marinos

- La previsión de un cambio normativo en 2021 del decreto de 2007 abre la puerta a una nueva regulación de molinos en la costa española
- Empresas consultoras de renovables destacan en Cádiz el potencial del puerto gaditano como plataforma logística para el desarrollo de estas inversiones

Vista de uno de los complejos eólico-marinos en el Mar del Norte - LA VOZ

0

Javier Rodríguez

CÁDIZ - Actualizado:10/06/2020 21:11h

GUARDAR

Se buscan nuevos negocios y nuevas estrategias en la Bahía de Cádiz para su desarrollo económico. Así **Cádiz-Port**, que agrupa a un sector

www.lavozdigital.es, Jun. 2020

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

ARCHIME 3 Technology

GENERAL INFORMATION AND STATUS

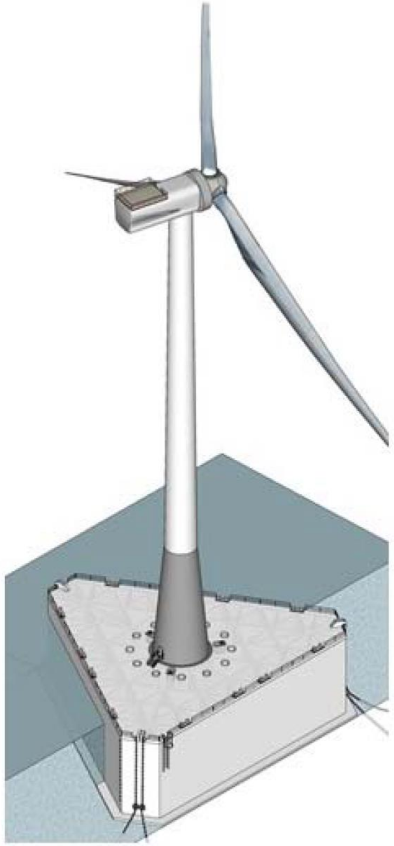
Design Name	ARCHIME 3
Designer	BERIDI – Berenguer Ingenieros
Designer Country	Spain
TRL	
Wind Turbine	10 MW
Projects	-
Possible Projects	-

FLOATER

Technology	Barge
Material	Concrete
Minimum Water Depth Service	-
No. Columns	
Tons/MW Est.	
Total Weight (Incl. Ballast)	
Ballast Weight	
Floater Length	
Floater Width	
Structure Height	
Draft	

MOORING SYSTEM

System	
No. Lines	
Typical Anchor Type	



Source: BERIDI

SPANISH MOST RELEVANT TECHNOLOGY INITIATIVES

Data from 12-2020

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

R & D + i for sustainable development

BlueSATH Technology

GENERAL INFORMATION AND STATUS

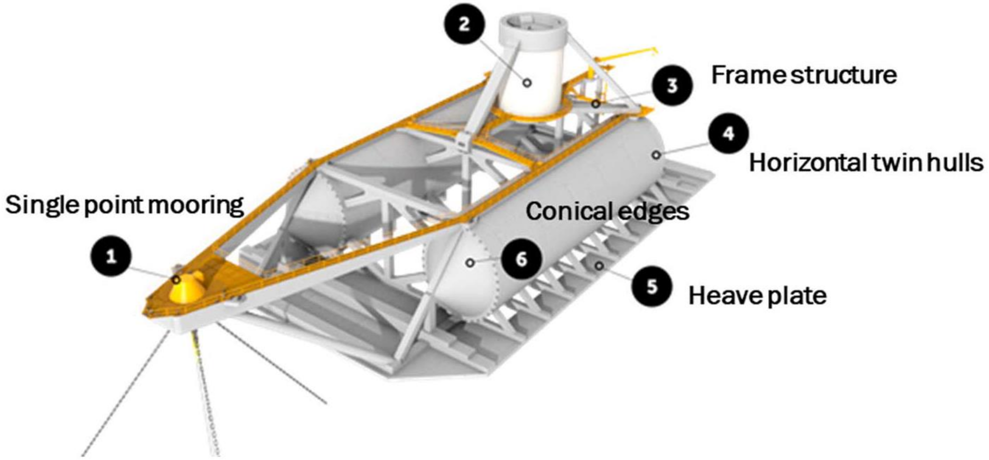
Design Name
Designer
Designer Country
TRL
Wind Turbine
Projects
Possible Projects

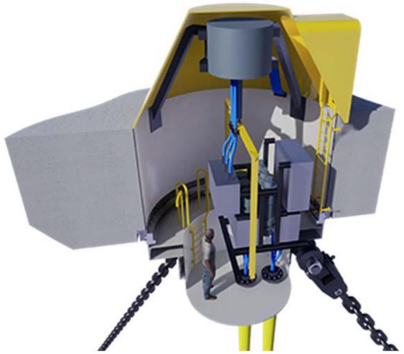
FLOATER

Technology
Material
Minimum Water Depth Service
No. Columns
Tons/MW Est.
Total Weight (Incl. Ballast)
Ballast Weight
Floater Length
Floater Width
Structure Height
Draft

MOORING SYSTEM

System
No. Lines
Typical Anchor Type





SPANISH MOST RELEVANT TECHNOLOGY INITIATIVES

Data from 12-2020

Source: SAITEC OT

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

R & D + i for sustainable development

W2Power Technology

GENERAL INFORMATION AND STATUS

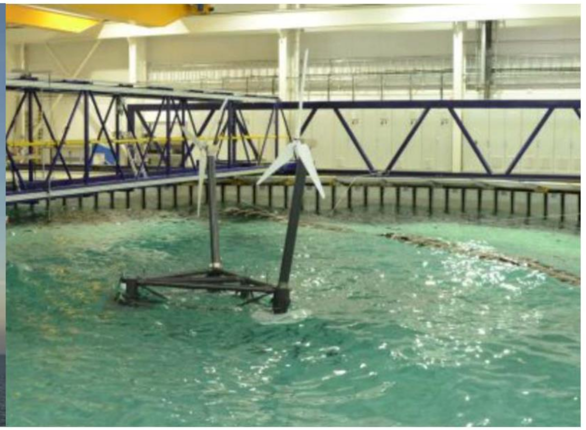
Design Name
Designer
Designer Country
TRL
Wind Turbine
Projects
Possible Projects

FLOATER

Technology
Material
Minimum Water Depth Service
No. Columns
Tons/MW Est.
Total Weight (Incl. Ballast)
Ballast Weight
Floater Length
Floater Width
Structure Height
Draft

MOORING SYSTEM

System
No. Lines
Typical Anchor Type



SPANISH MOST RELEVANT TECHNOLOGY INITIATIVES

Data from 12-2020

Source: Enerocean

R & D + i for sustainable development

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

X1Wind Technology

GENERAL INFORMATION AND STATUS

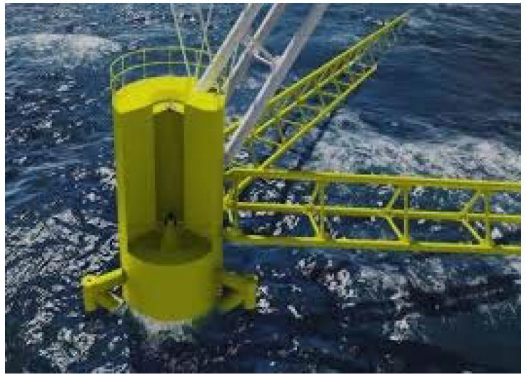
Design Name
Designer
Designer Country
TRL
Wind Turbine
Projects ›ject (Canary Islands)
Possible Projects

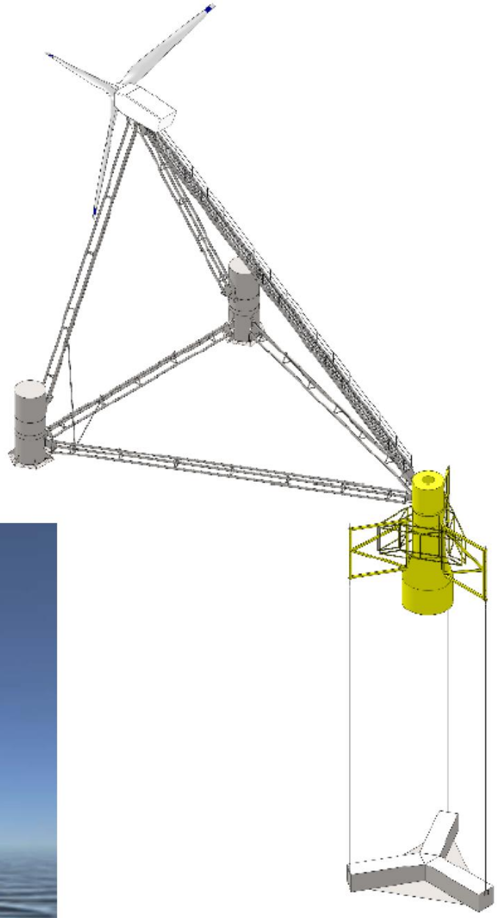
FLOATER

Technology
Material
Minimum Water Depth Service
No. Columns
Tons/MW Est.
Total Weight (Incl. Ballast)
Ballast Weight
Floater Length
Floater Width
Structure Height
Draft

MOORING SYSTEM

System
No. Lines
Typical Anchor Type





SPANISH MOST RELEVANT TECHNOLOGY INITIATIVES

Source: X1Wind

R & D + i for sustainable development

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- Materials
- Key numbers

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OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA: Spain

R & D + i for sustainable development

21.982 m²
BUILT

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD
GOBIERNO de CANTABRIA
Unión Europea
Fondo Europeo de Desarrollo Regional

IHcantabria
INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

OFFSHORE WIND

FLOATING OFFSHORE WIND AT IHCANTABRIA

R & D + I for sustainable development

1 *Hydrodynamic Analysis*

Laboratory and numerical analysis (frequency and time domain analysis):

- Movements (6DOF).
- Accelerations.

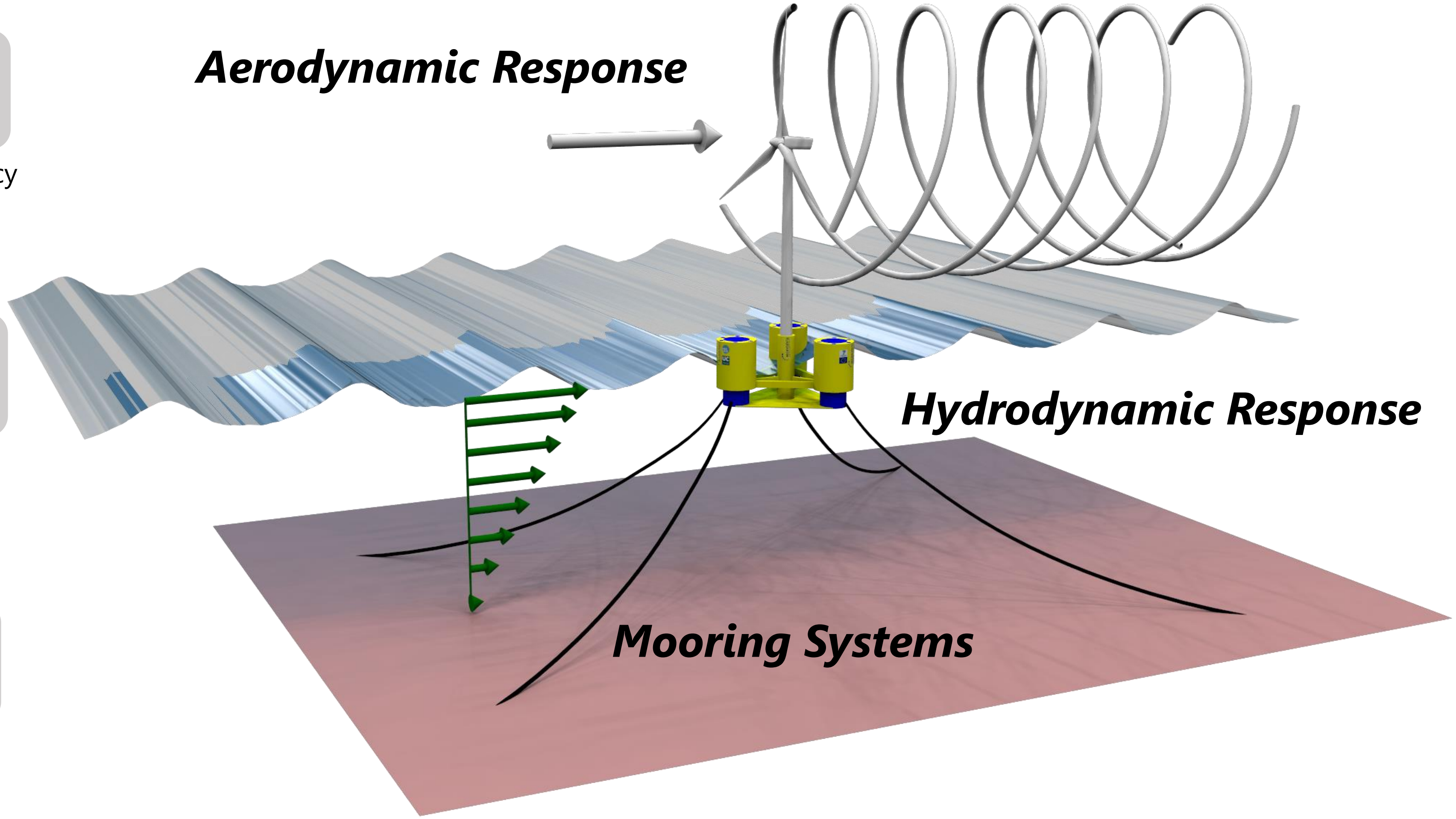
2 *Aerodynamic Response*

Simulation by:

- ***Numerically*** through *In house Model* and Fast.
- ***Laboratory*** *Multi-fan System.*

3 *Mooring Analysis*

- Loads Evaluation.
- Design.
- *Optimization*



Design, Validation and Certification of mooring system for floating structures: Hybrid Methodology

Numerical Modelling

Non-Coupled Analysis

a) ***Pre-Design of mooring systems***

Simulation of mooring line system (forced oscillations)

a.1 **Static Approach**

a.2 **Quasi-static Approach**

Numerical Modelling

Coupled Analysis

b) ***Design of mooring systems***

Simulation of mooring lines and floating structures

b.1 **Quasi static Approach**

b.2 **Dynamic Approach**

Physical Modelling

c) ***Design and Validation of the mooring system***

Non-Coupled Analysis

Coupled Analysis

c.1 **Simulation of mooring line system (forced oscillations)**

c.2 **Mooring Lines Floating Structures**

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA

IH Cantabria has developed different strategies to reproduce the wind turbine loads

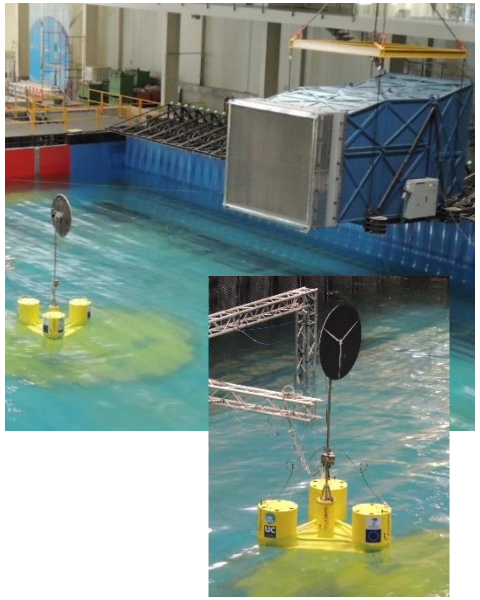
Static lines and cables
2010-2014

System pulley with suspended weights

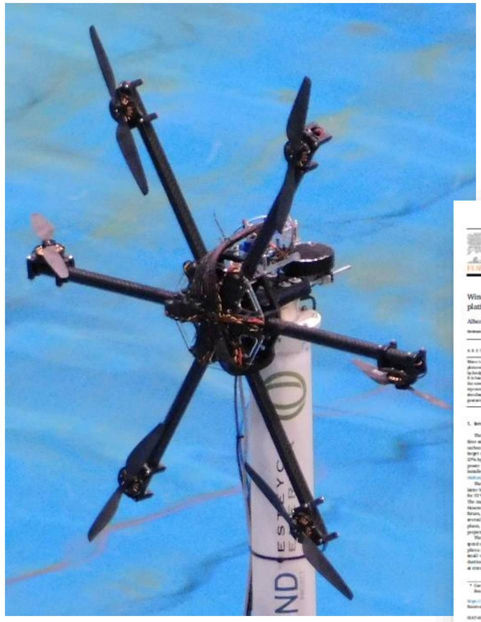
Drag Disk
2013-2015

In house multi-fan wind generator (medium and small scale)

Commercial Wind Generator (GEVI) (large scale)



Multi-fan system: Software in the Loop (SIL)
2016-2020



Pat. ES2632187B1

OFFSHORE WIND
FLOATING OFFSHORE WIND AT IHCANTABRIA

Offshore wind O&M drivers:
Hydrodynamics + Metocean

- **Metocean conditions** rules the crew transfer
- **Fluid–vessel–structure** → Marine operation **risks**
- **Farm Downtime** vs Operation & Maintenance

MPI Dulcinea transfers technicians off D4 at Sheringham Shoal Offshore Wind Farm
https://www.youtube.com/watch?v=Y-IdwS6scEk&t=136s

Metocean conditions → O&M Logistics ← Marine operations
- Personnel transfer
- Sea transport

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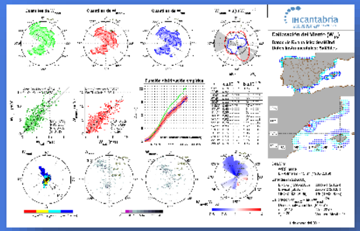
CHALLENGES

- Optimize **availability**
- Facilitate **the decision-making** during personnel transfer operations
- Improve **personnel safety** access (marine operations)
- Optimize transport **vessel/boatlanding selection**

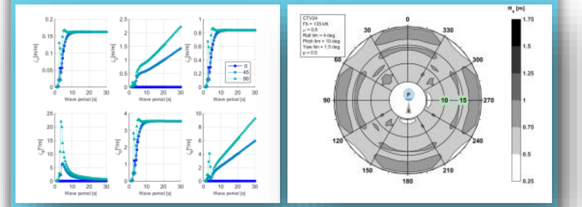
OBJECTIVES

To develop an integrated tool to simulate the marine operations associated to O&M logistics from a long-term perspective

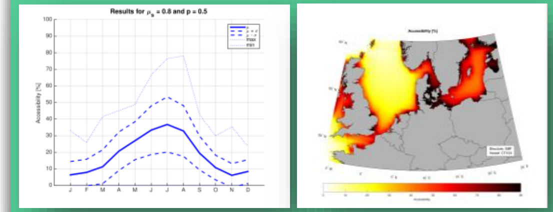
01
Metocean conditions assessment
- Hindcast data
- Forecast data (future works)



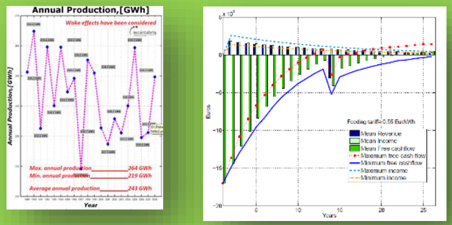
02
Multi-body Hydrodynamics
-Access simulator-



03
O&M Simulator
- Transport model
- Accessibility algorithm
- Fault/reparation model



04
Farm Simulator
- Production model
- Cost model



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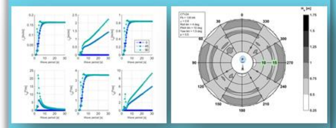
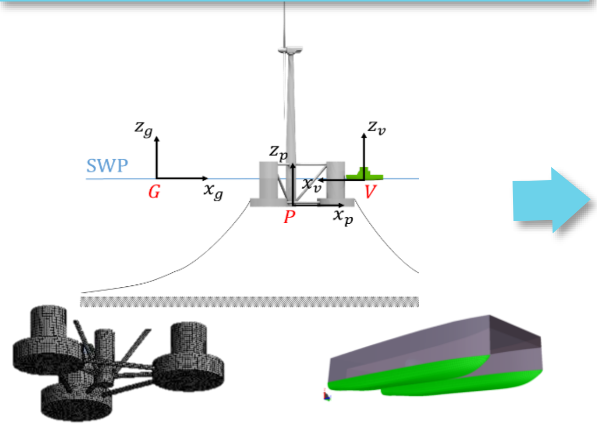
R & D + I for sustainable development

Guanche, R., Martini, M., Jurado, A., Losada, I.J., (2016) Walk-to-work accessibility assessment for floating offshore wind turbines, Ocean Engineering

02
Multi-body Hydrodynamics
-Access simulator-



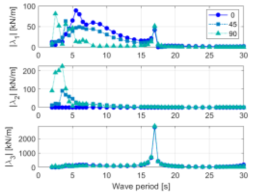
Multibody simulation
NEMOH: Open source code to get hydrodynamic response in the frequency domain



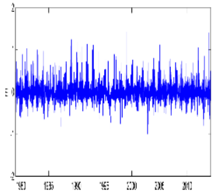
Platform (fixed or floating)   Vessel (CTV or SOV)

Coupled system RAO
Frequency domain response of both bodies according to the wave heading angle

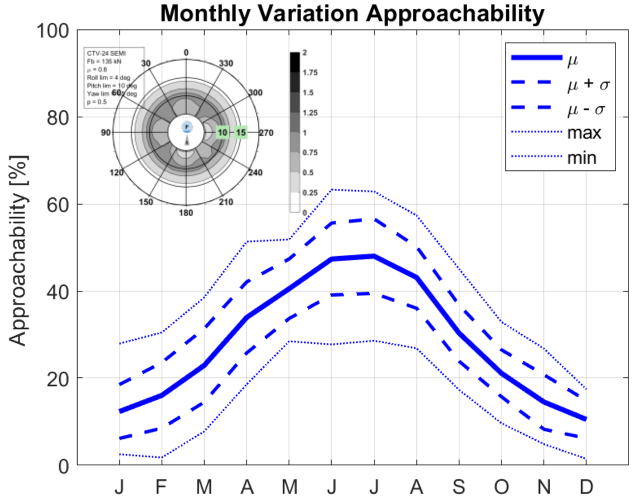
RAOs



Metocean time series (wave, wind)



Accessibility
- Accessibility polar diagram of limiting wave height depending on wave periods and wave headings.
- Statistical results of accessibility for any
- Accessibility atlas.



Results:
- Thorntonbank III
- Zeebrugge Port
- 5MW Semisub
- CTV 24m

W2W strategy: step up to access ladder by CTV (no gangway)

- Hypothesis considered: O&M technicians walk from the vessel to the boatlanding **if and only if** :
  1. There is no-slide condition between both bodies (no relative motion).
  2. There are small relative rotations (thresholds defined by the user).

W2W strategy: SOV with an auto compensated gangway

- Hypothesis considered: gangway tip is infinitely close to the transition piece, allowing O&M technicians to walk to the platform **if and only if**:
  1. Relative motions between the gangway tip and the platform are within operational compensation limits of the gangway.

OFFSHORE WIND

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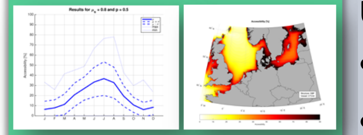
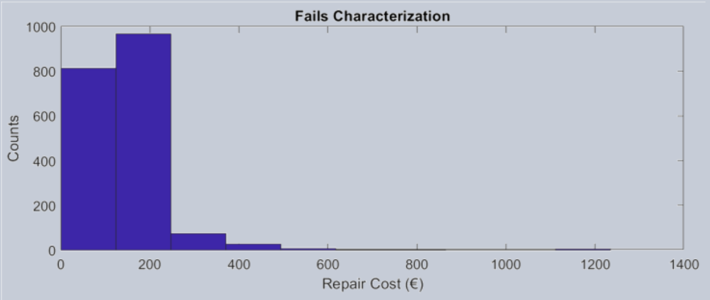
03

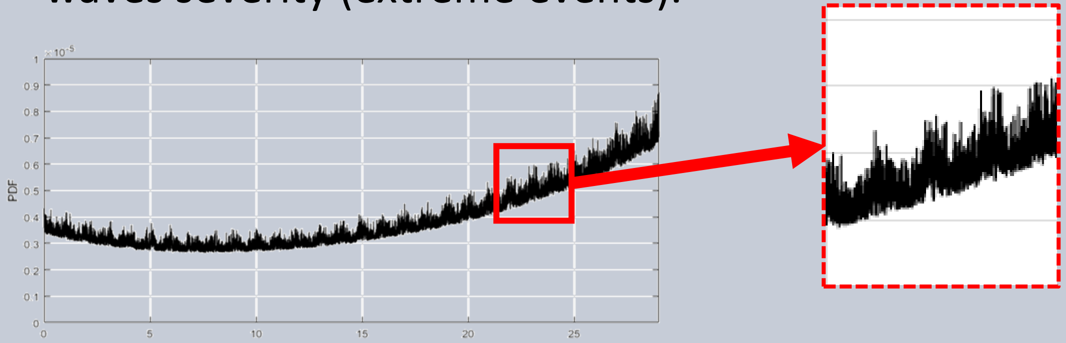
O&M Simulator
- Transport model
- Fault model
- Accesibility algorithm

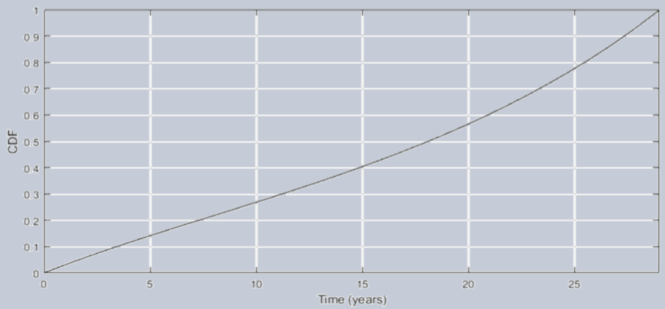


Ingeteam O&M experience has been used to create a database including:
- **Failure rates** per component
- **Repair time** per component
- **Repair cost** per component



Life-time faults distribution:
- Bath-curve: Extra probability at early years (**defective equipment**) and late years (**wear out faults**)
- Met-ocean influence: Extra probability due to wind and waves severity (extreme events).





1604 types of faults characterized by:
- Failure rate
- Reparation time
- Cost

01 Vessel availability → 02 Weather Window (Transportation) (Personnel Transfer) → 03 Reparation time

Farm Intelligence

- **Aggregation** of small failures
- **Night/day** transportation+reparation optimization
- Ad-hoc **reparation protocol** per component

…

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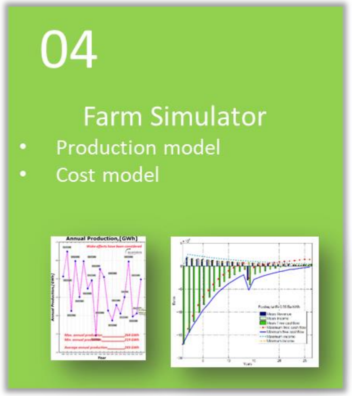
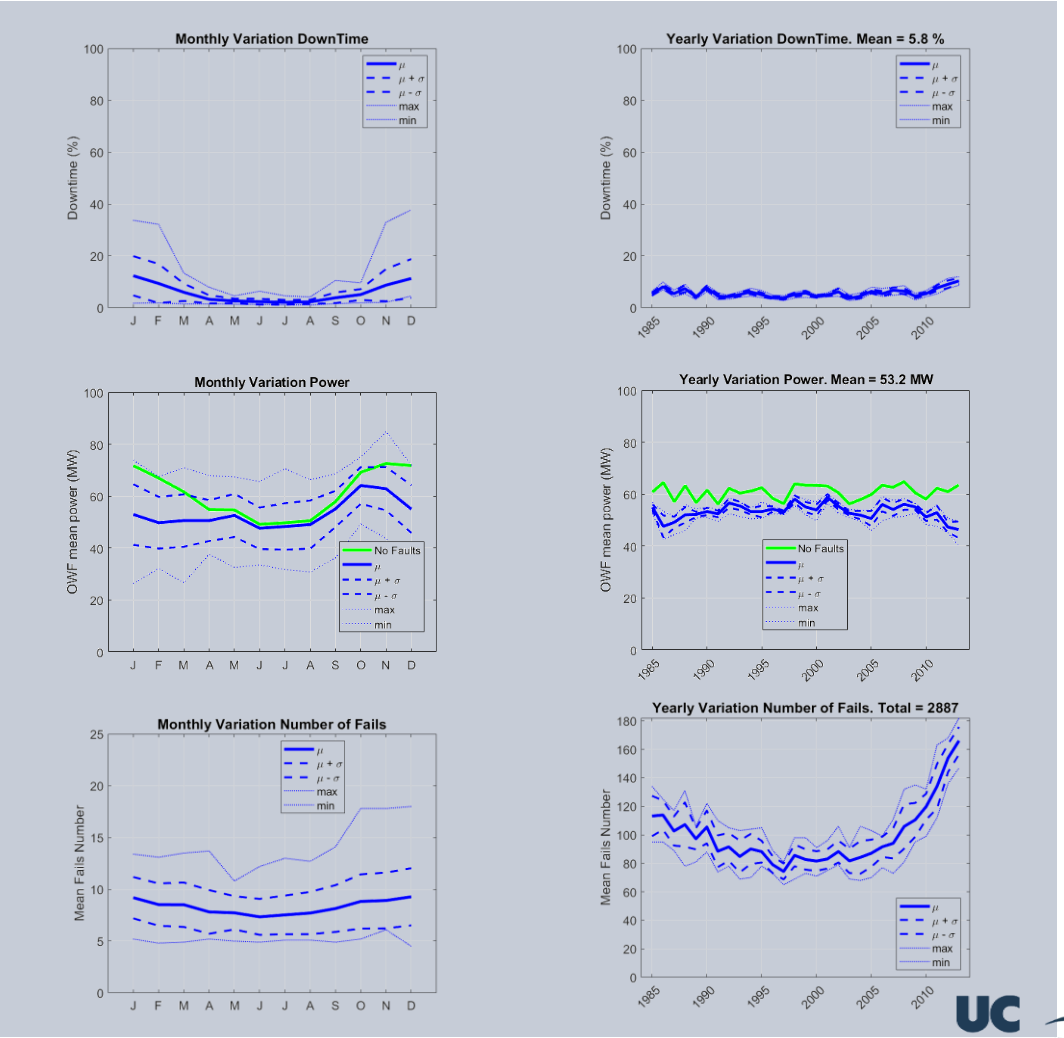


The farm simulator provides long-term information to perform a statistical analysis, of:

- Downtime
- Energy production
- Number of fails
- Reparation costs
- Reparation time
- Number of vessel trips



VII JORNADAS DE MINERÍA Y ENERGÍA

Energía eólica marina flotante: de la investigación al mercado

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IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria

Torrelavega, 15 de Abril de 2021

R & D + I for sustainable development