

# IHCANTABRIA

## INSTITUTO DE HIDRÁULICA AMBIENTAL DE CANTABRIA

### UNIVERSIDAD DE CANTABRIA

## Situación actual y futuro de la eólica marina

Cátedra  
de Energía



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Santander, 13 de Marzo de 2019

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- Introducción
  - ¿Por qué eólica marina?
  - La energía eólica marina en la actualidad: eólica fija
  - La energía eólica marina del futuro: eólica flotante
  - Retos y oportunidades de la eólica marina
  - ¿Qué hace IHCantabria en eólica marina?
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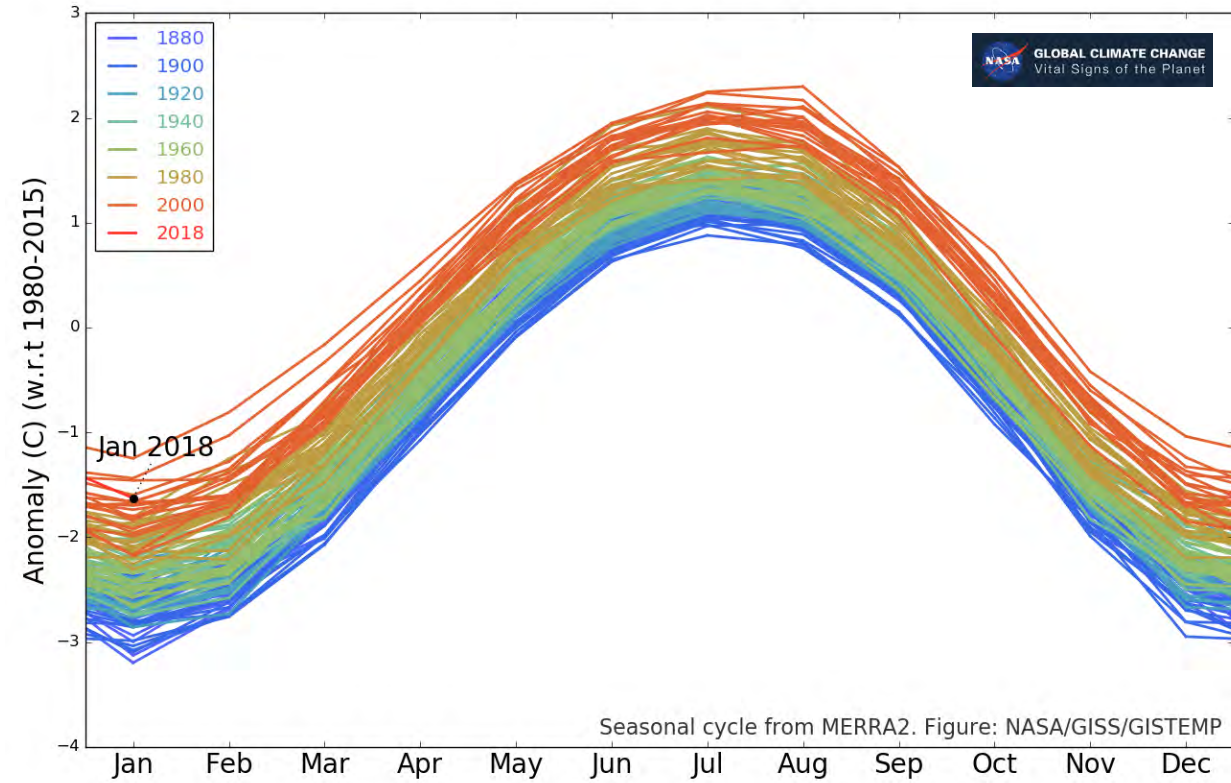
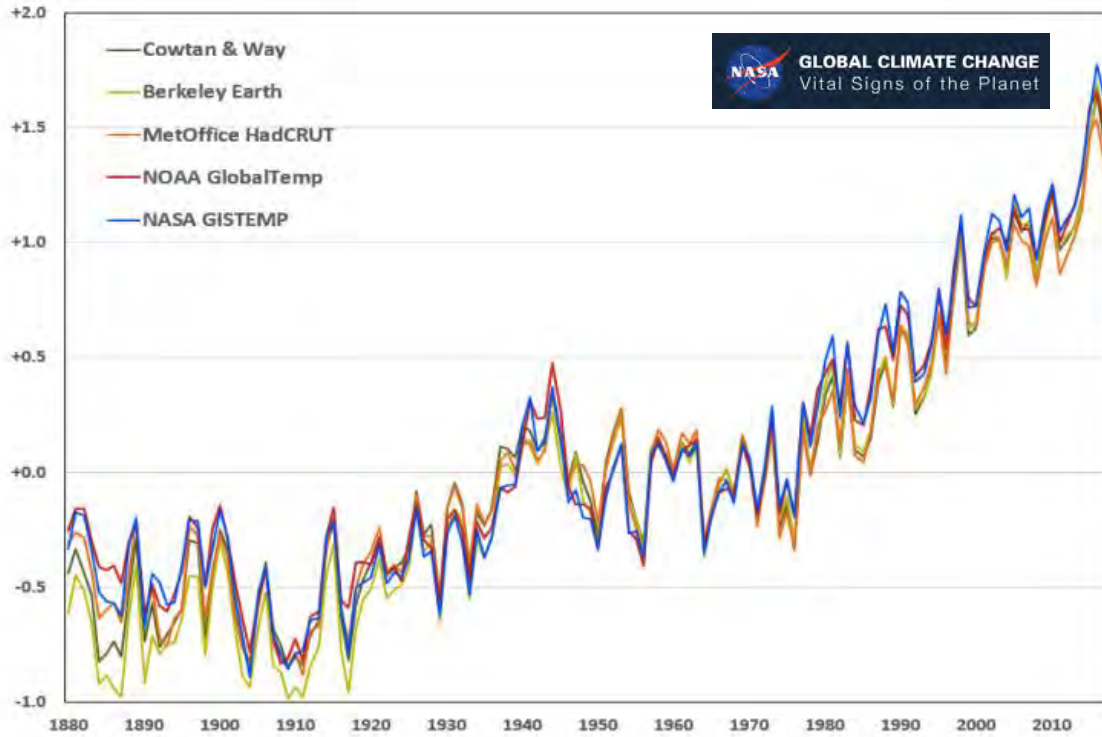
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# Calentamiento Global

## Consenso internacional

GISTEMP Seasonal Cycle since 1880

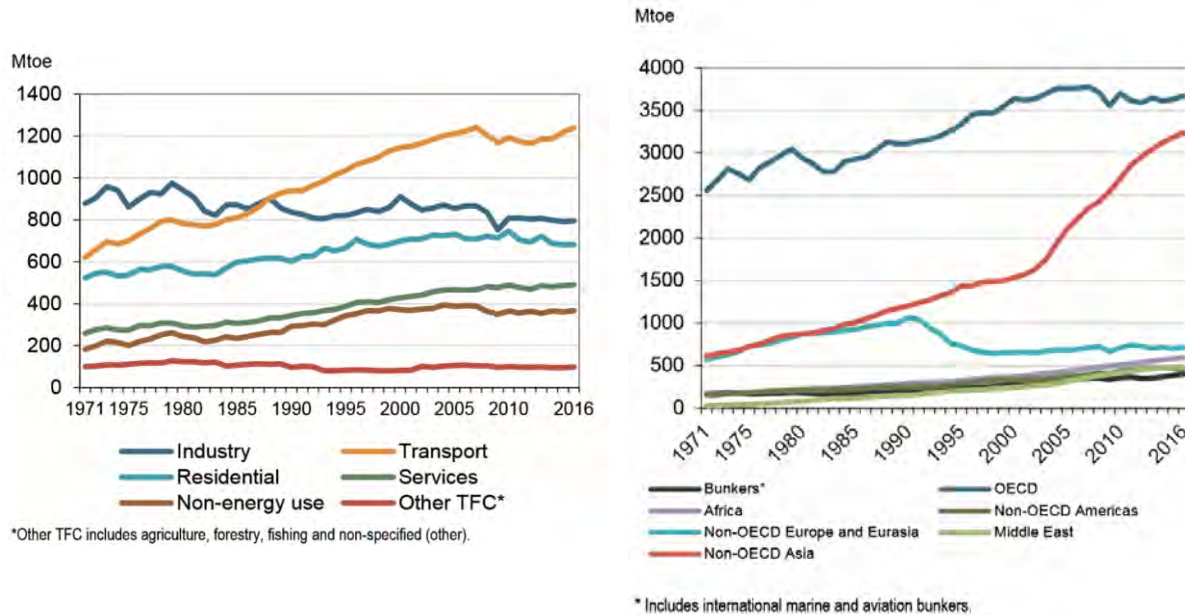


## Calentamiento Global

Consenso internacional

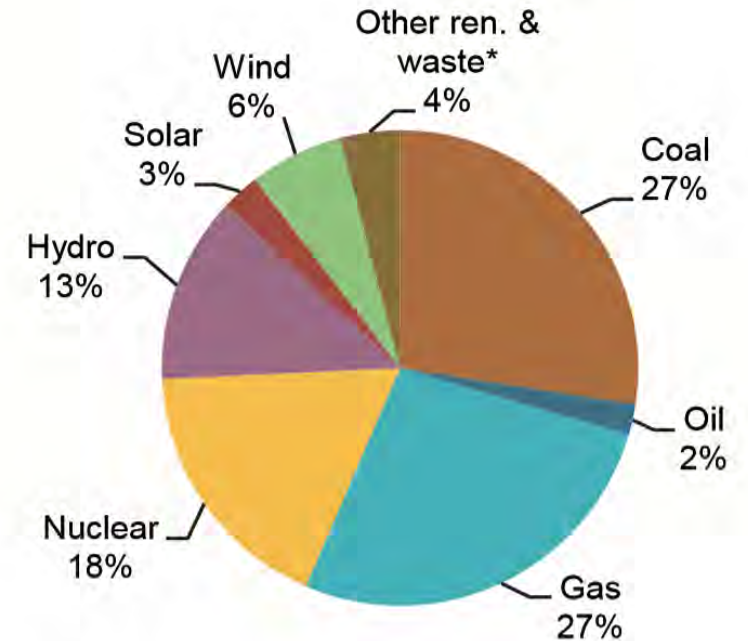
### Consumo energético en la OCDE – 2017

WORLD ENERGY BALANCES: OVERVIEW (2018 edition) - IEC



### Mix eléctrica en la OCDE – 2017

WORLD ENERGY BALANCES: OVERVIEW (2018 edition) - IEC

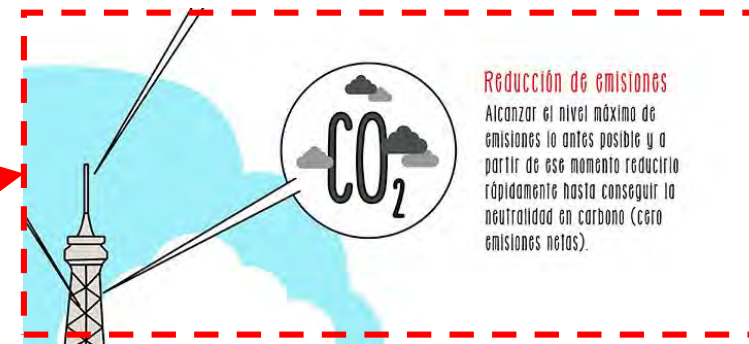
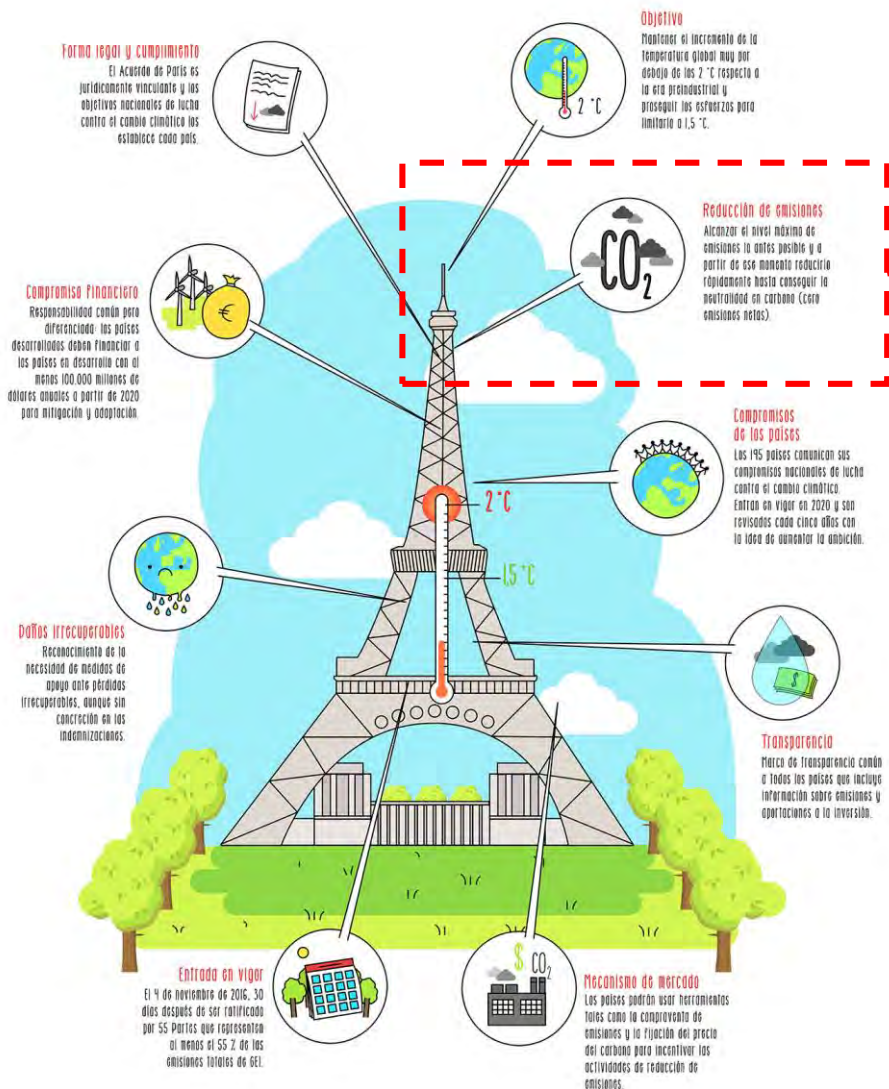


\*Includes geothermal, tide, biofuels, all waste and heat.



# Acuerdo de París

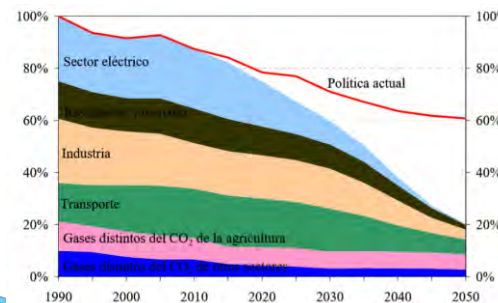
# Introducción



## Marco sobre clima y energía para 2030

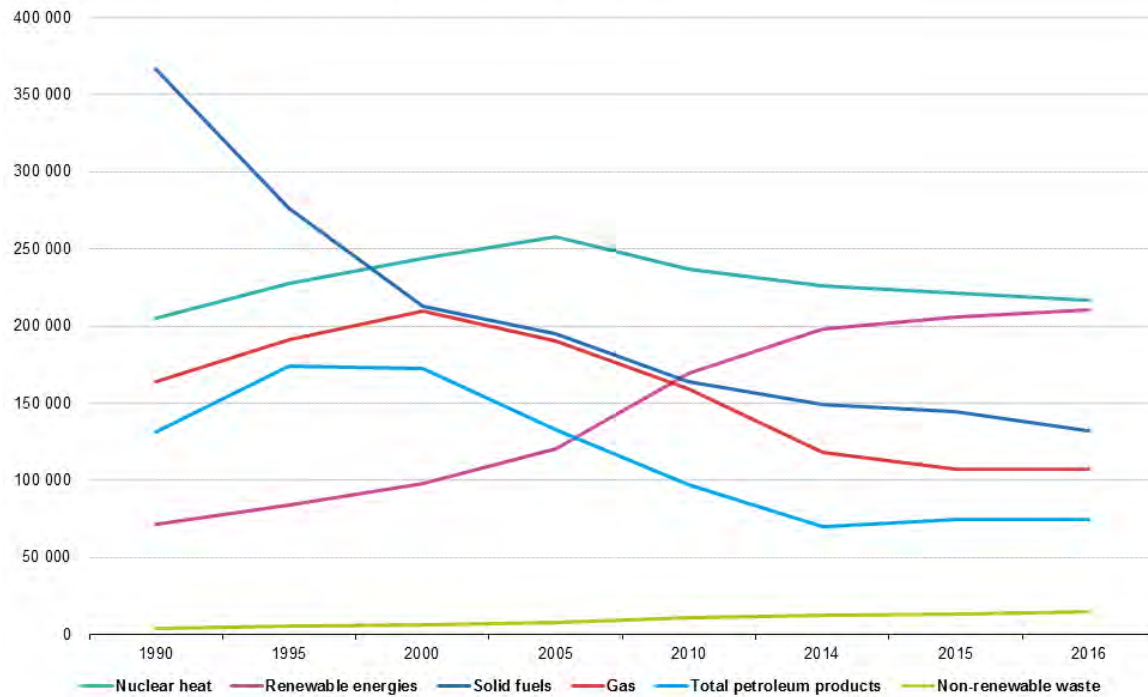
[https://ec.europa.eu/clima/policies/strategies/2030\\_es](https://ec.europa.eu/clima/policies/strategies/2030_es)

- Al menos 40% de reducción de las **emisiones de gases de efecto invernadero** (en relación con los niveles de 1990)
- Al menos 27% de cuota de **energías renovables**
- Al menos 27% de mejora de la **eficiencia energética**.



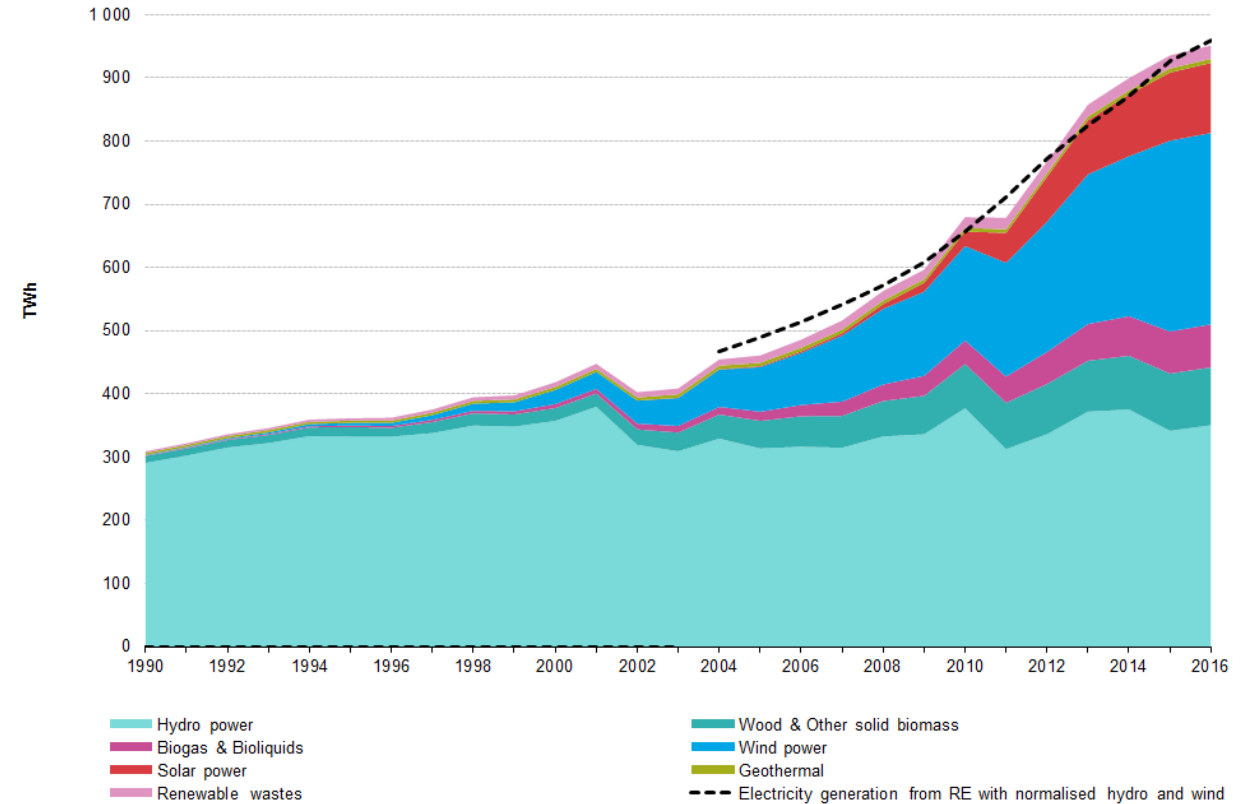
La transición hacia una economía hipocarbónica competitiva supone que la UE debe prepararse para reducir sus emisiones internas un 80 % de aquí a 2050 respecto a 1990

Primary energy production by fuel, EU-28, in selected years, 1990-2016 (ktoe)



Source: Eurostat (online data code: nrg\_110a)

eurostat



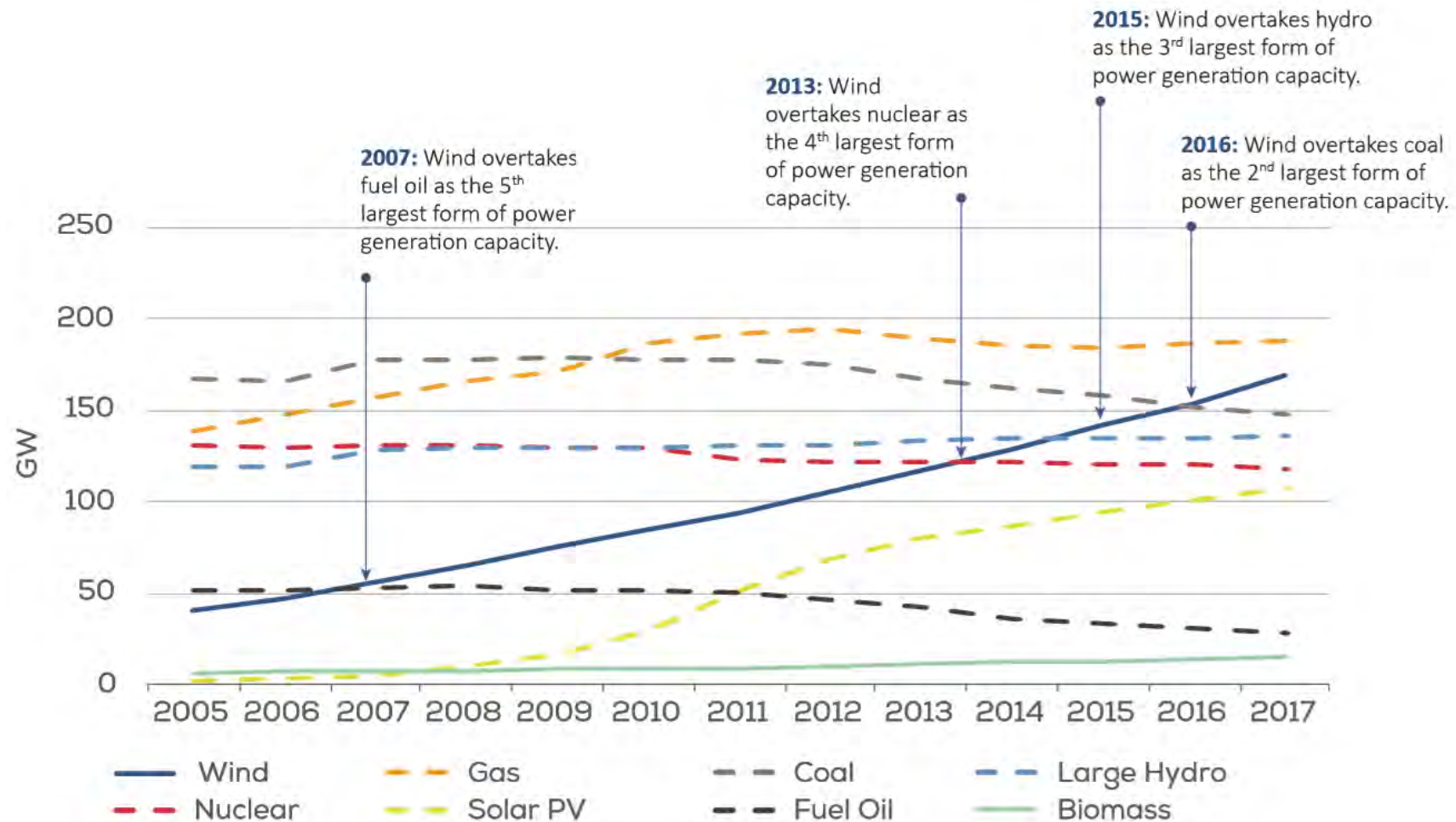
eurostat

La energía eólica supone el 12,4% del total de la energía producción primaria de energía procedente de fuentes renovables en la EU-28. La energía eólica y la solar están en rápida expansión. La energía eólica incrementó su contribución en un 6,3 % de la energía renovable producida en la EU-28 en 2016



## Potencia instalada en Europa 2005– 2017

Wind in power, Annual combined onshore and offshore wind energy statistics – 2017, Wind Europe

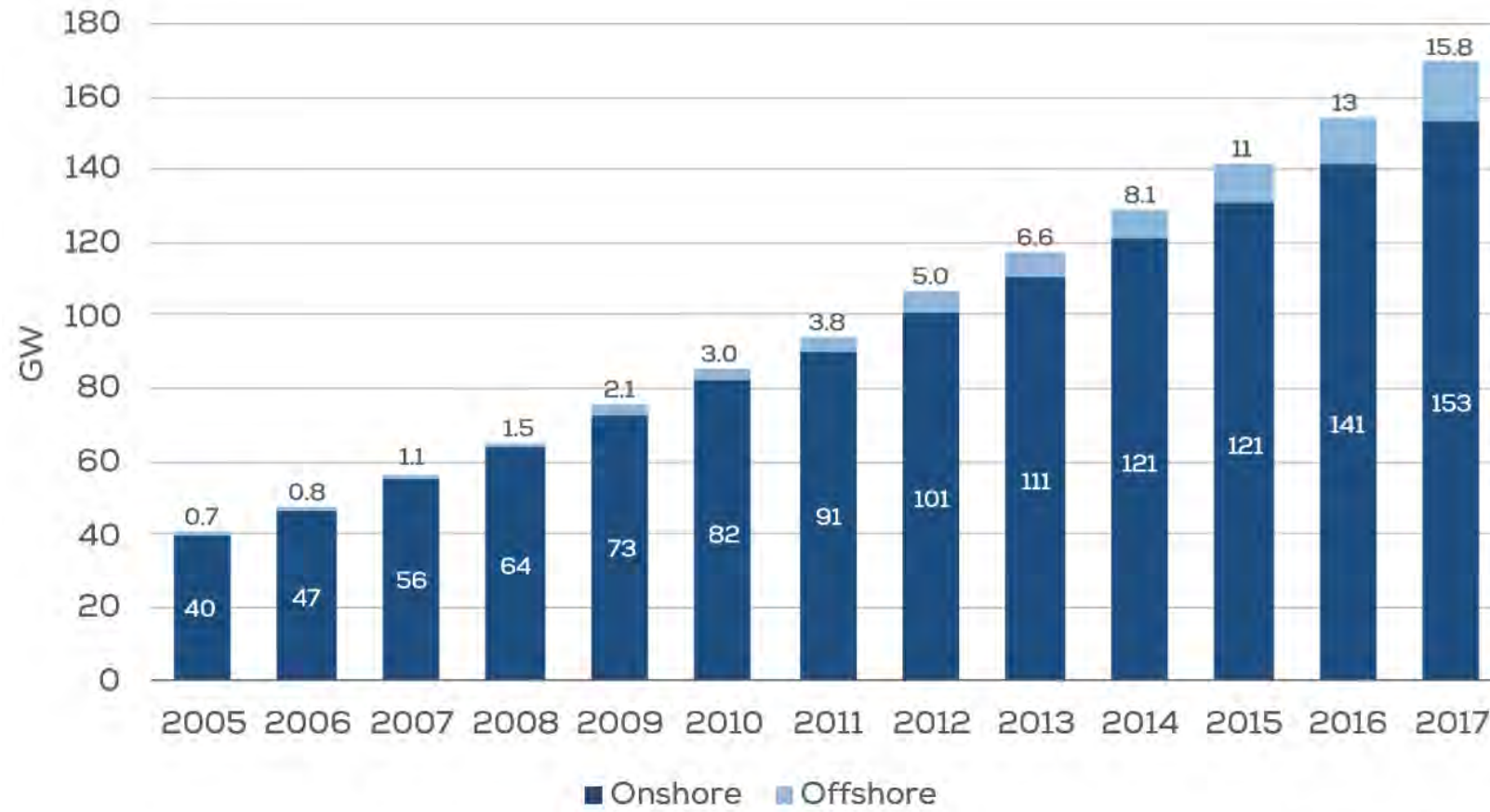


Source: WindEurope

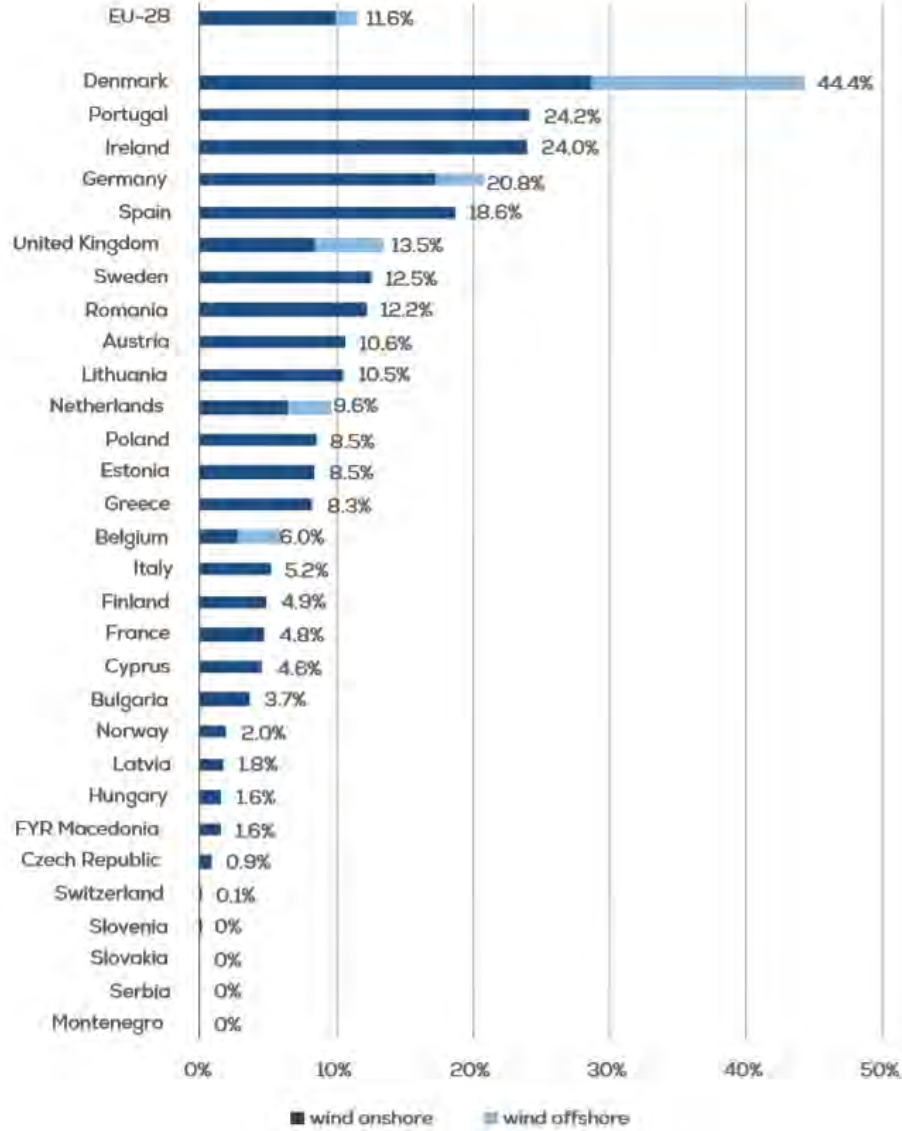


## Evolución de la potencia instalada eólica en Europa 2005– 2017

Wind in power, Annual combined onshore and offshore wind energy statistics – 2017, Wind Europe



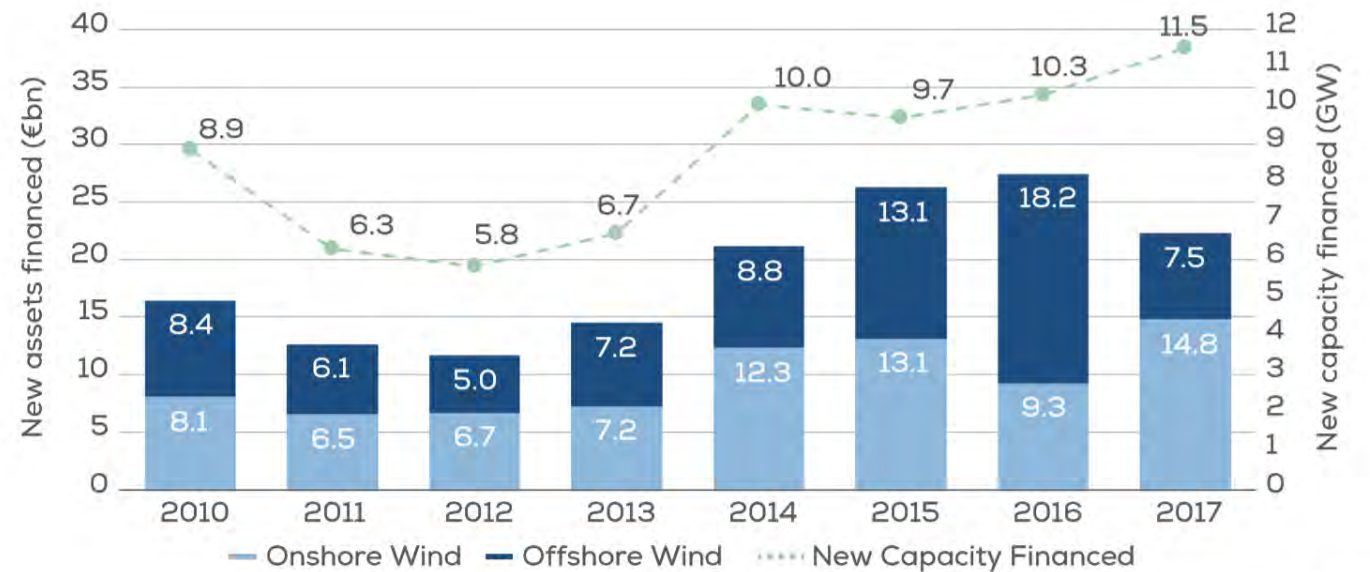
Source: WindEurope



## Distribución potencia instalada eólica en Europa 2005– 2017

Wind in power, Annual combined onshore and offshore wind energy statistics – 2017, Wind Europe

TOTAL EU ELECTRICITY CONSUMPTION (TWh)	ONSHORE WIND ENERGY PRODUCTION (TWh)	OFFSHORE WIND ENERGY PRODUCTION (TWh)	TOTAL WIND ENERGY PRODUCTION (TWh)	SHARE OF EU CONSUMPTION MET BY WIND ENERGY
2,906	292	43	336	11.6%



Source: WindEurope

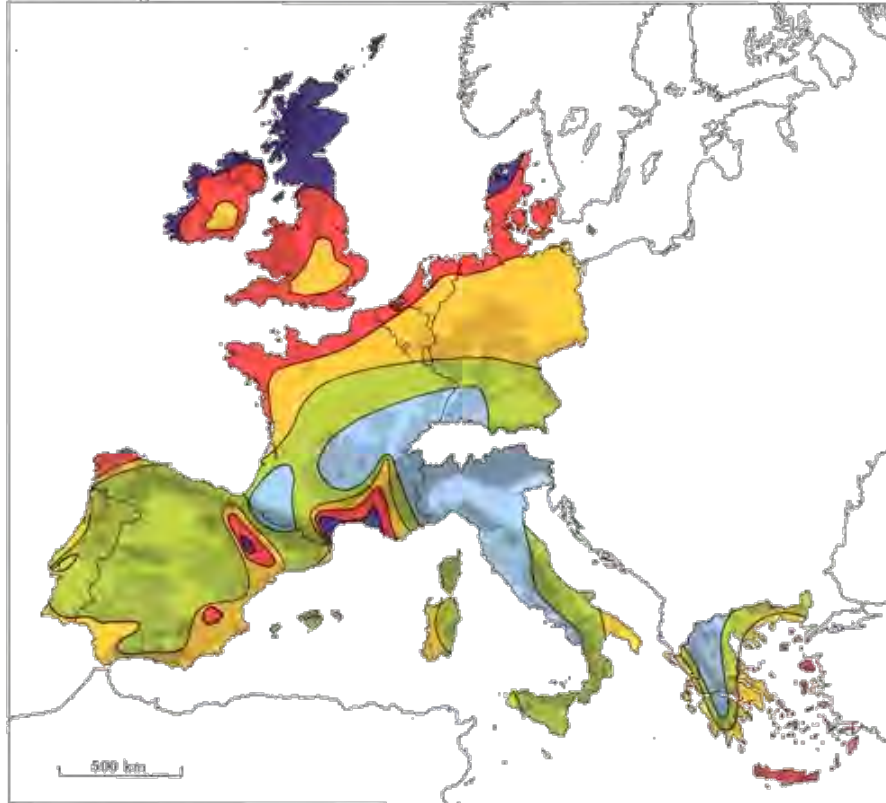


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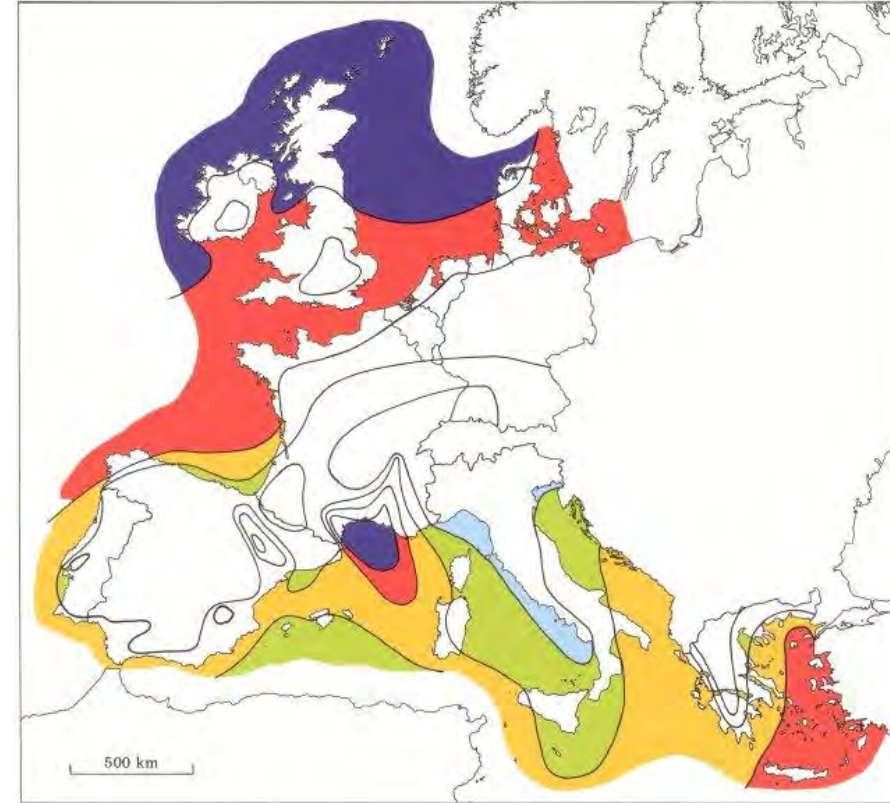
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-

✓ Disponibilidad de recurso estable y de gran intensidad



Wind resources<sup>1</sup> at 50 metres above ground level for five different topographic conditions

Sheltered terrain <sup>2</sup>		Open plain <sup>3</sup>		At a sea coast <sup>4</sup>		Open sea <sup>5</sup>		Hills and ridges <sup>6</sup>	
ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>
> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
< 2.5	< 50	< 4.5	< 100	< 5.0	< 150	< 6.5	< 200	< 7.0	< 400



Wind resources over open sea (more than 10 km offshore) for five standard heights

10 m		25 m		50 m		100 m		200 m	
ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>
> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300





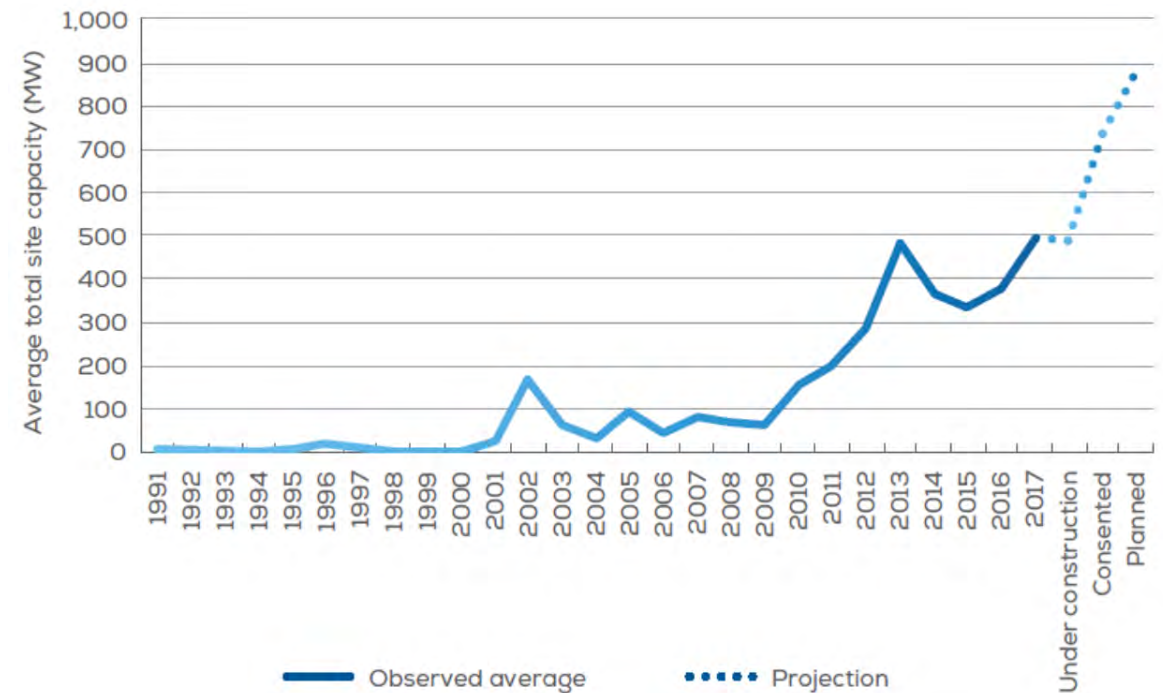
Economía de escala: Posibilidad de desarrollar grandes instalaciones

WIND FARM	CAPACITY CONNECTED IN 2017 (MW)	COUNTRY	STATUS
Walney 3 (Extension Phase 1 – West)	256	UK	Partially grid-connected
Burbo Bank Extension	200	UK	Fully grid-connected
Rampion	179	UK	Partially grid-connected
Galloper	72	UK	Partially grid-connected
Blyth	42	UK	Fully grid-connected
Hywind Scotland	30	UK	Fully grid-connected
Veja Mate	402	GERMANY	Fully grid-connected
Wikingen	350	GERMANY	Fully grid-connected
Nordsee One	332	GERMANY	Fully grid-connected
Nordergründe	111	GERMANY	Fully grid-connected
Sandbank	52	GERMANY	Fully grid-connected
Nobelwind (Belwind II)	165	BELGIUM	Fully grid-connected
Pori Tahkoluoto 2	36	FINLAND	Fully grid-connected
Kemi Ajos 1+2	24	FINLAND	Fully grid-connected
Floatgen	2	FRANCE	Fully grid-connected

Source: WindEurope

## Tamaño medio de los parques eólicos offshore instalados por año en Europa 1991– 2017

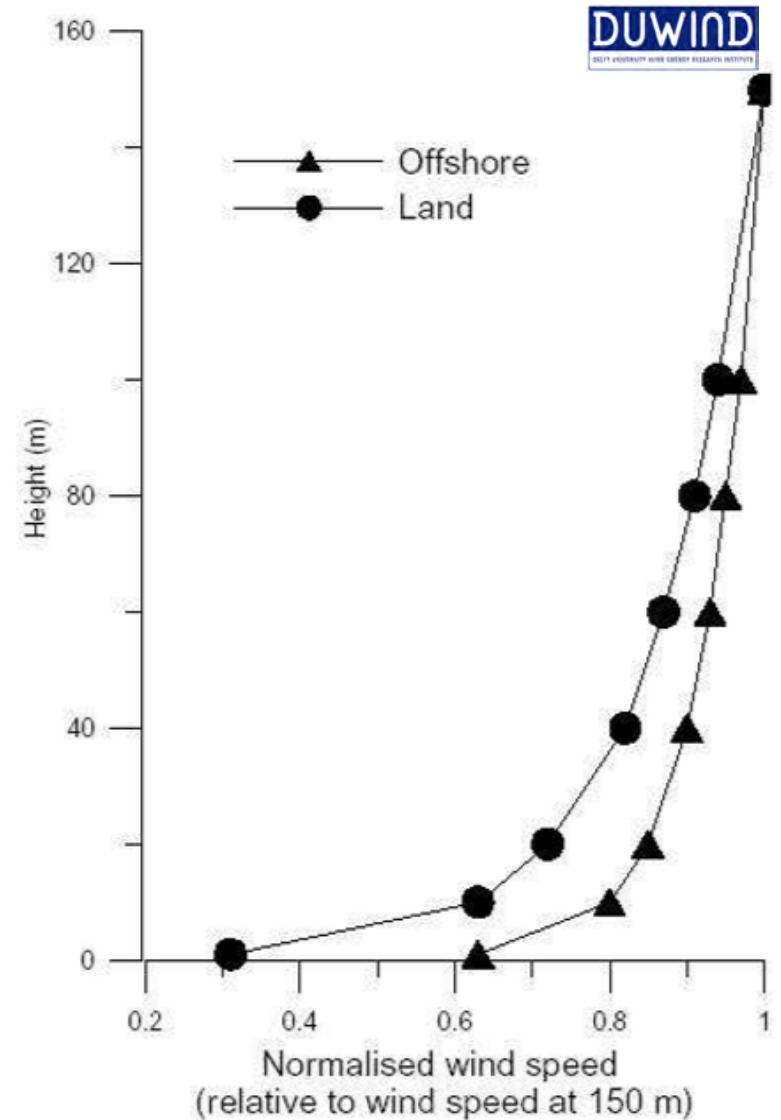
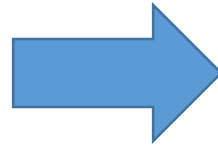
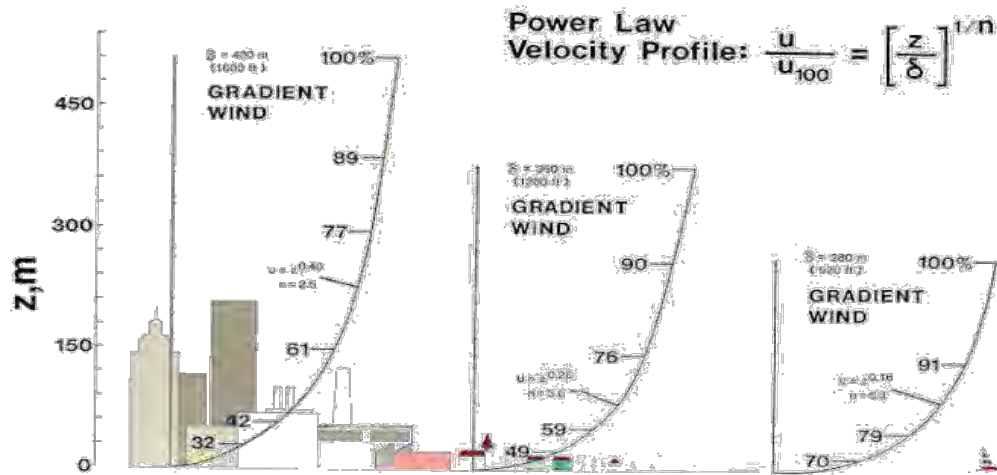
Offshore Wind  
in Europe, Key trends and statistics 2017, Wind Europe



Source: WindEurope

✓ Calidad del recurso: Mayor intensidad, menor turbulencia,

**BOUNDARY-LAYER HEIGHTS  
AS A FUNCTION OF SURFACE ROUGHNESS**



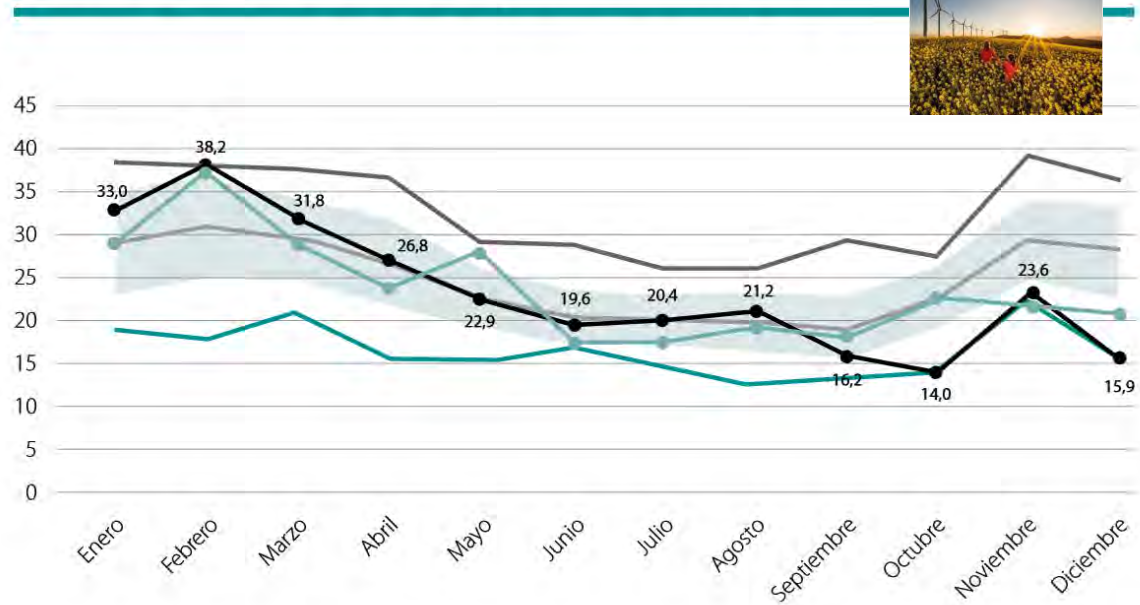




Calidad del recurso: Mayor intensidad, menor turbulencia

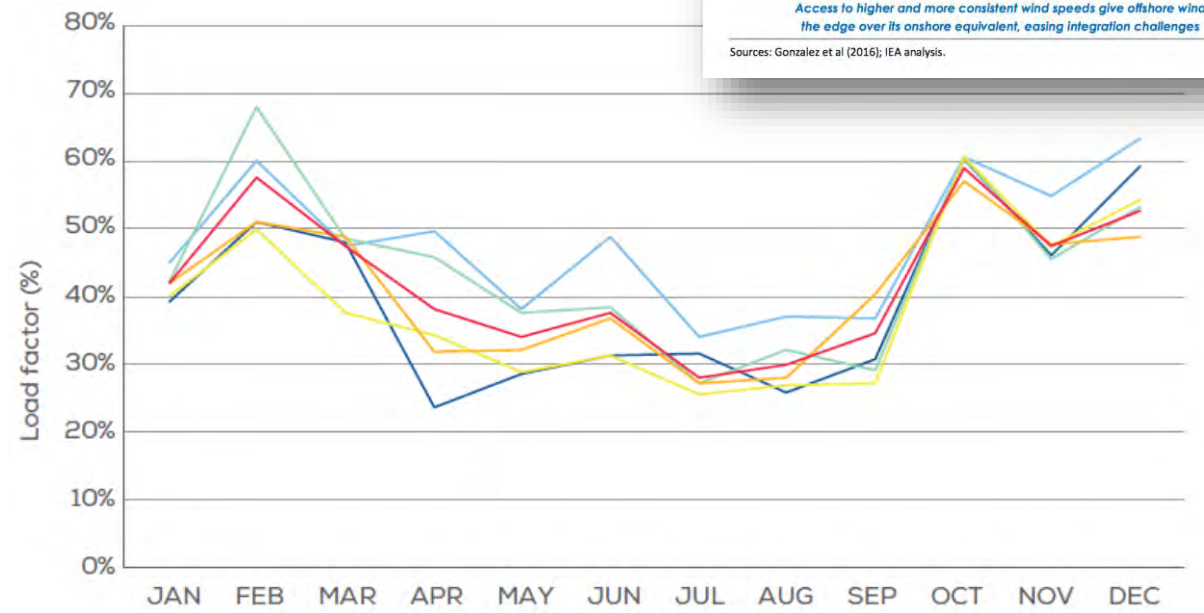
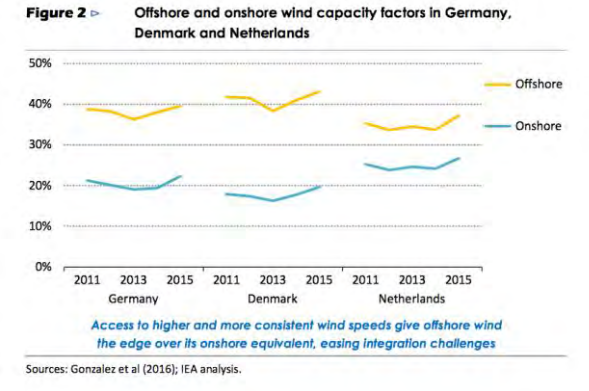
Onshore vs Offshore

**Gráfico I.05. Evolución del factor de capacidad de la eólica (en %)**



Banda Desv. Típica  
 Mínimo histórico  
 2015  
 Promedio histórico  
 Máximo histórico  
 2016

Fuente: AEE



— Belgium — Denmark — Germany — Netherlands — United Kingdom — Average  
 Source: WindEurope

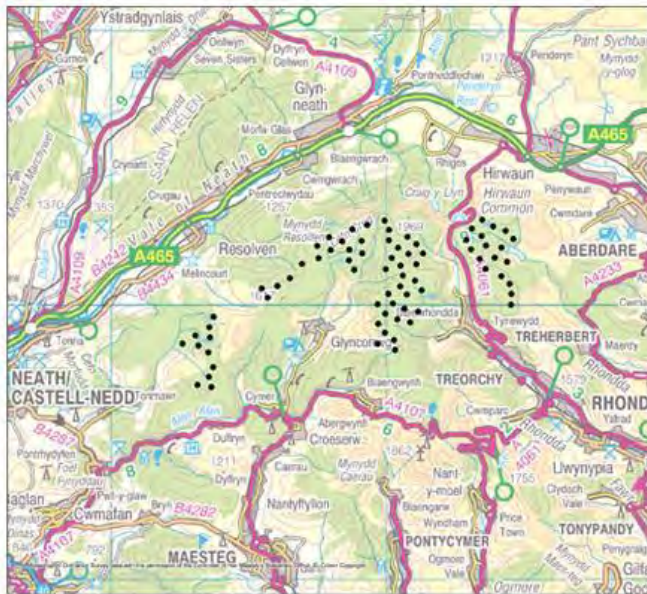
✓ Menor impacto visual y acústico...



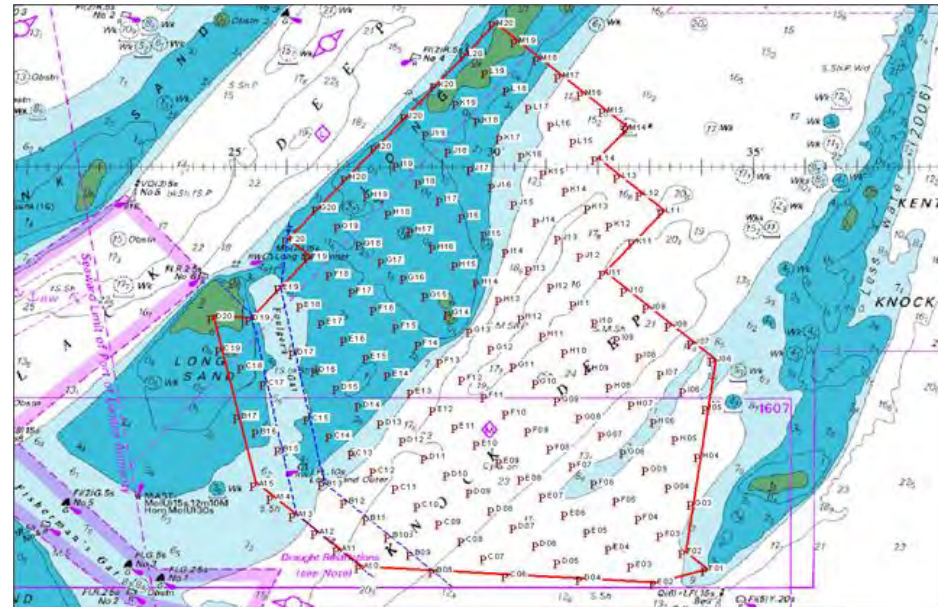


✘ Mayor complejidad en la gestión de parque: interacción entre turbinas

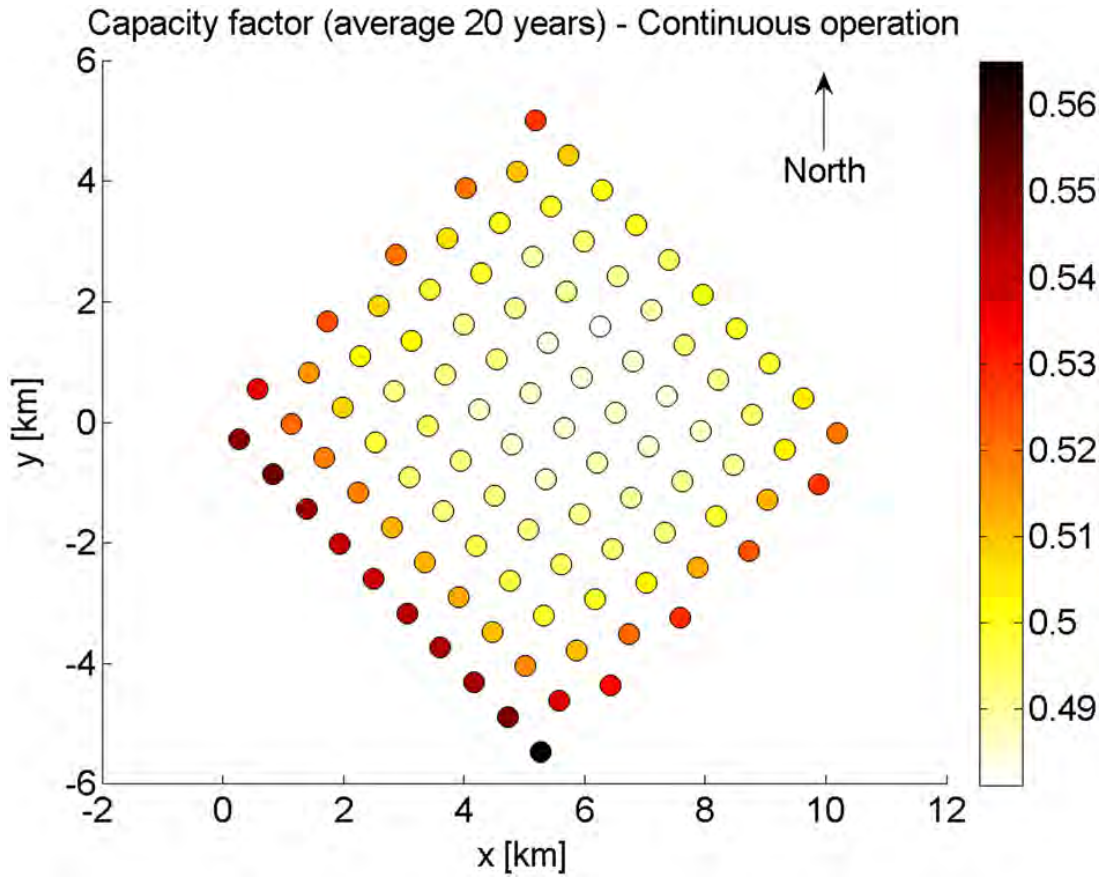
Onshore wind farm



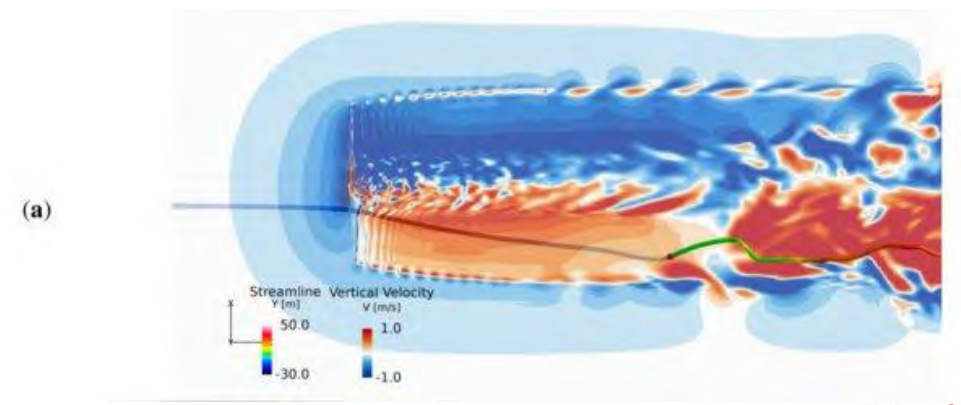
Offshore wind farm



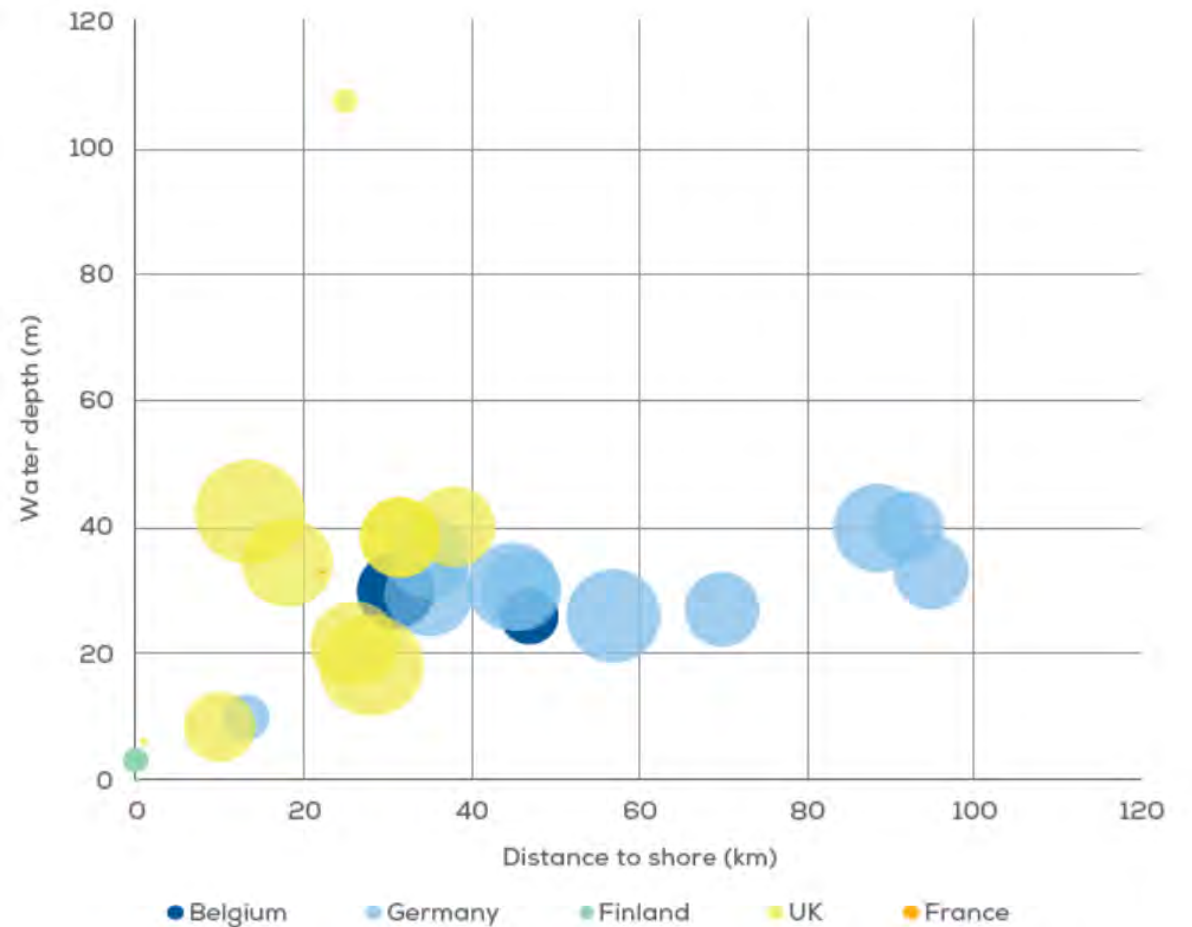
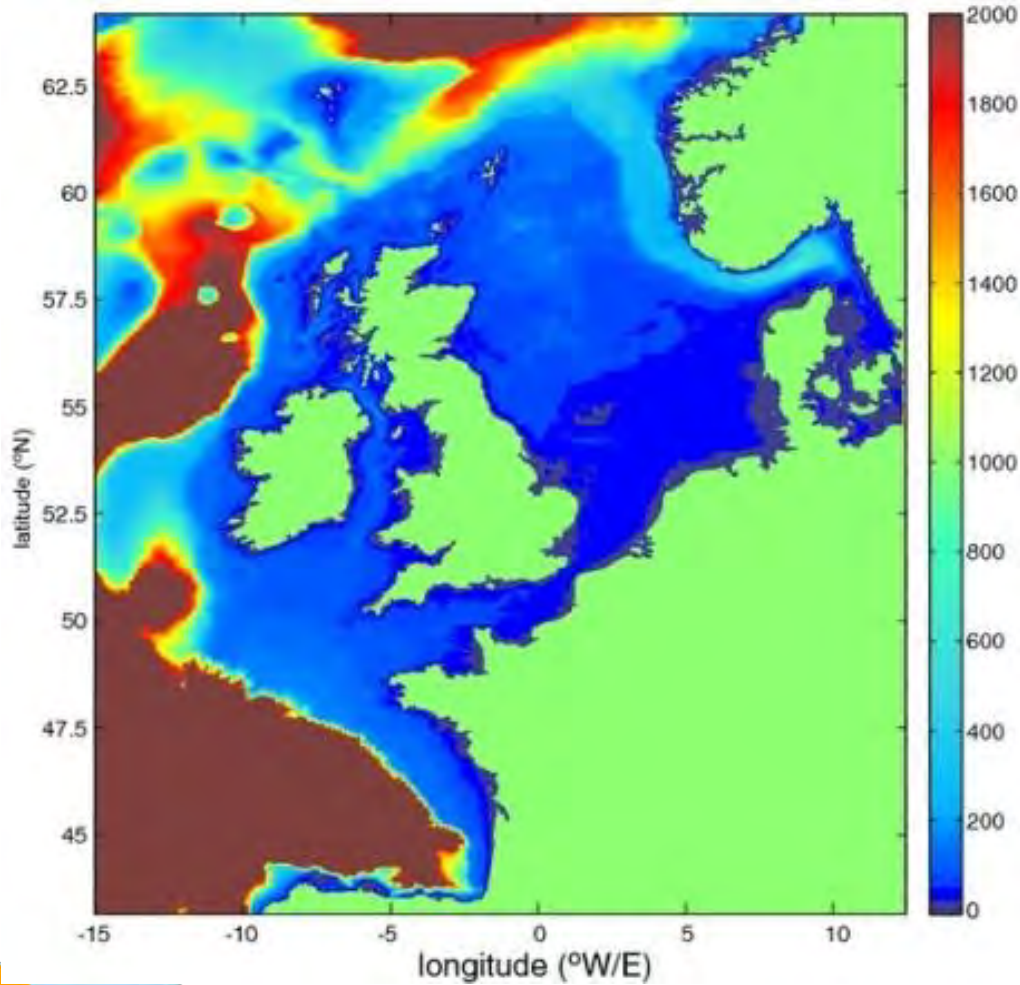




Martini, M., Guanche, R., Armesto, J. A., Losada, I. J., & Vidal, C. (2016). Met-ocean conditions influence on floating offshore wind farms power production. *Wind Energy*, 19(3), 399-420.



✘ Barreras físicas: profundidad, distancia a costa...



Source: WindEurope



**✗** Mayores costes y riesgos...

## Increase in offshore investment cost due to **distance to coast (in km)**

Cost split	5	10	15	20	25	30	35	40	45	60	75	93.8	112.5	131.3	150	>200
Turbine	772	772	772	772	772	772	772	772	772	772	772	772	772	772	772	772
Foundation	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352
Installation	465	471	476	482	488	494	500	506	511	559	607	659	712	764	816	964
<i>Inst.-turbine</i>	155	156	156	157	157	158	159	159	160	164	169	174	180	185	190	205
<i>Inst.-foundation</i>	155	156	156	157	157	158	159	159	160	164	169	174	180	185	190	205
<i>Inst.-grid</i>	155	159	164	169	173	178	183	187	192	230	269	310	352	394	436	554
Grid connection	133	146	159	172	185	198	211	224	236	275	314	362	411	459	507	702
Other	79	80	81	82	82	83	84	85	85	86	87	87	88	88	88	89
<b>Total cost</b>	<b>1801</b>	<b>1821</b>	<b>1840</b>	<b>1860</b>	<b>1879</b>	<b>1899</b>	<b>1919</b>	<b>1938</b>	<b>1956</b>	<b>2044</b>	<b>2132</b>	<b>2233</b>	<b>2334</b>	<b>2434</b>	<b>2535</b>	<b>2879</b>

In EUR/kW, Original data without shading, interpolated values shaded grey, assumed values in italics

## Increase in offshore investment cost due to **water depth (in m)**

Cost split	15	20	25	30	35	40	45
Turbine	772	772	772	772	772	772	772
Foundation	352	409	466	545.5	625	762.5	900
Installation	465	465	465	535	605	605	605
<i>Inst.-turbine</i>	155	155	155	162	169	169	169
<i>Inst.-foundation</i>	155	155	155	211	267	267	267
<i>Inst.-grid</i>	155	155	155	162	169	169	169
Grid connection	133	133	133	133	133	133	133
Other	79	82	85	88.5	92	98.5	105
<b>Total cost</b>	<b>1801</b>	<b>1861</b>	<b>1921</b>	<b>2074</b>	<b>2227</b>	<b>2371</b>	<b>2515</b>

In EUR/kW, Original data without shading, interpolated values shaded grey, assumed values in italics



## ✓ Ventajas

- Mayor intensidad del recurso
- Mejor calidad del recurso
- Economías de escala
- Menores restricciones socio-ambientales



## ✗ Desventajas

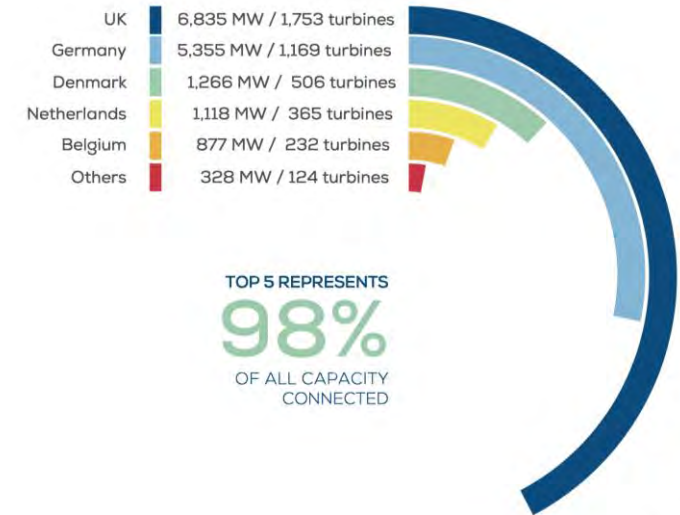
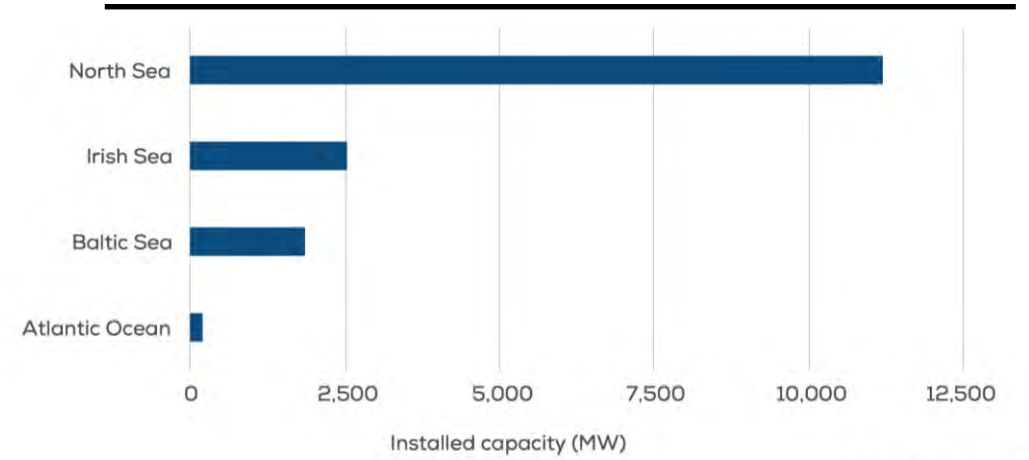
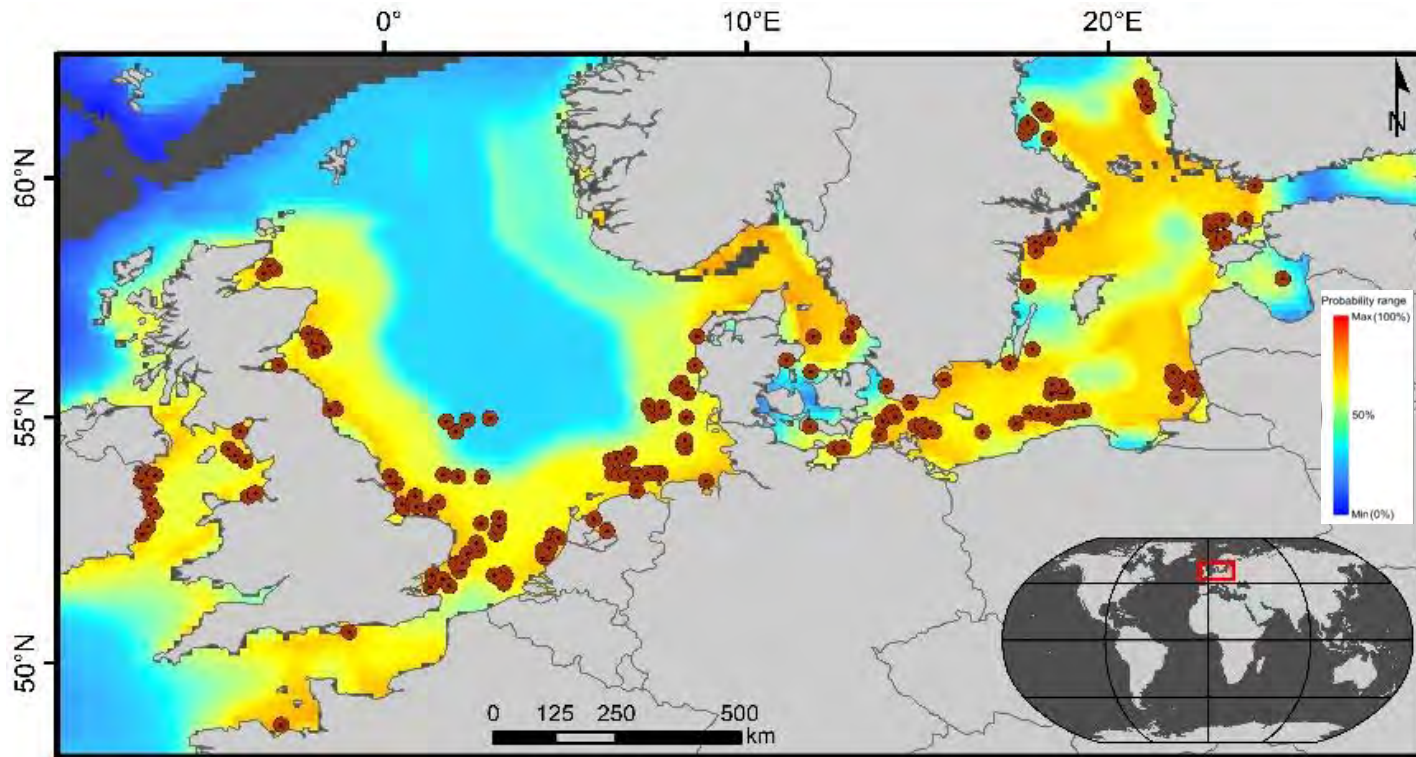
- Mayor complejidad de los parques
- Barreras físicas/tecnológicas
- Mayores costes y riesgos

*¡Reto y oportunidad!*

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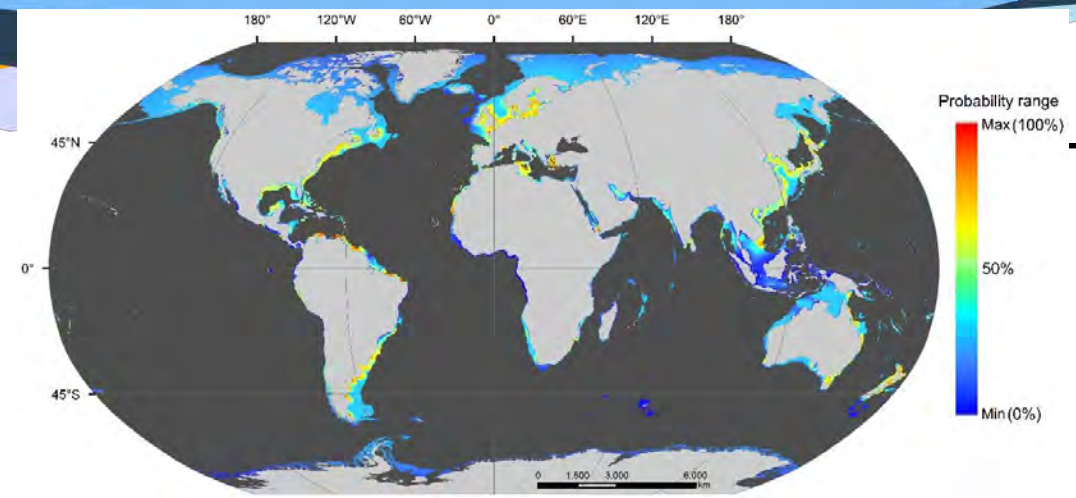
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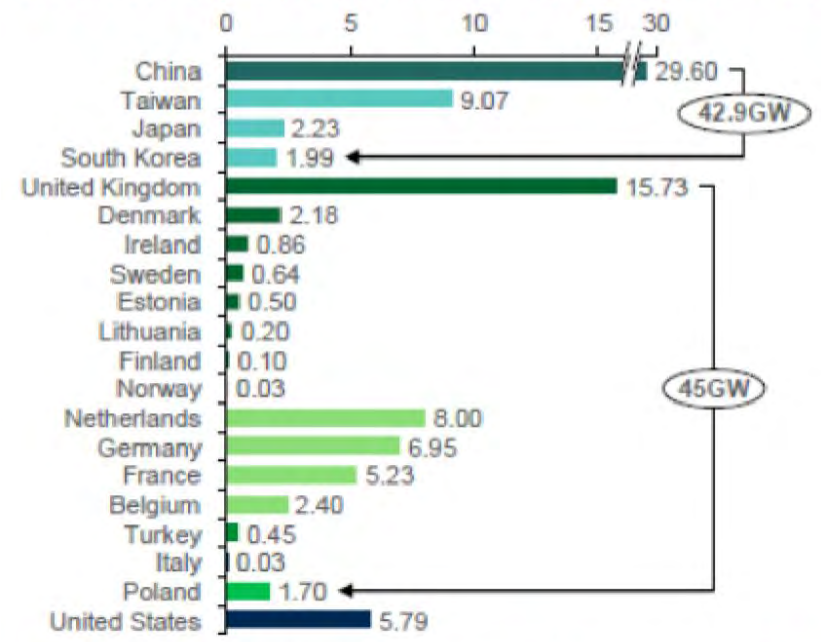
Carlos V.C. Weiss, Raúl Guanche, Bárbara Ondiviela, Omar F. Castellanos, José Juanes, Marine renewable energy potential: A global perspective for offshore wind and wave exploitation, Energy Conversion and Management, Volume 177, 2018, Pages 43-54, ISSN 0196-8904.



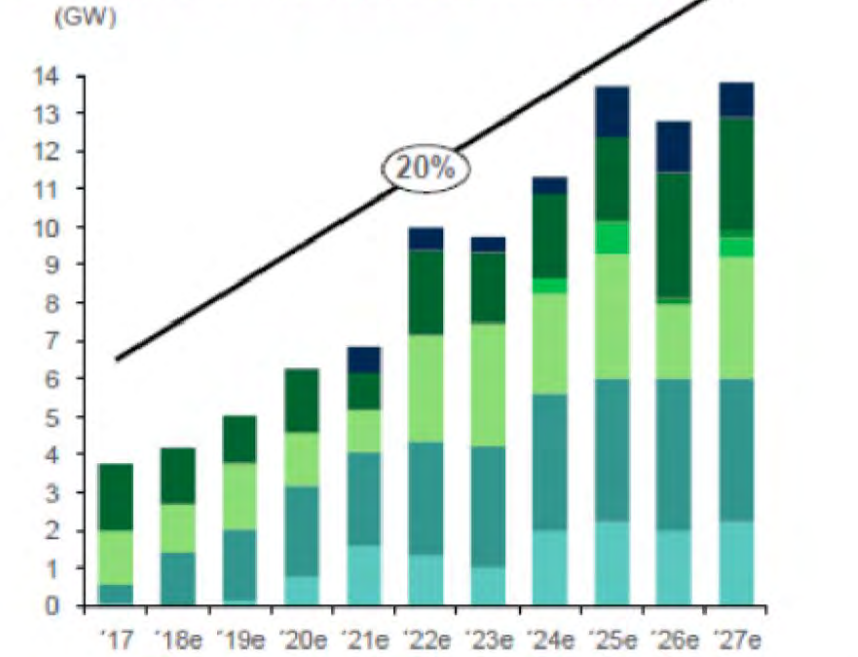


Carlos V.C. Weiss, Raúl Guanche, Bárbara Ondiviela, Omar F. Castellanos, José Juanes, Marine renewable energy potential: A global perspective for offshore wind and wave exploitation, Energy Conversion and Management, Volume 177, 2018, Pages 43-54, ISSN 0196-8904.

**Offshore top 20 markets: New capacity '18e-'27e**

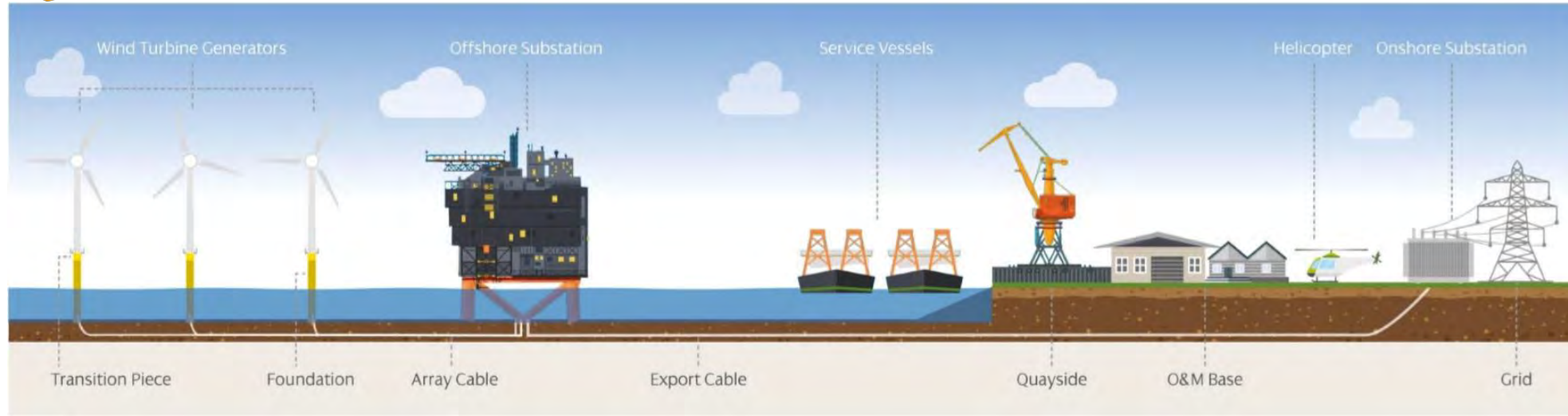


**Offshore market forecasts: 2017-2027e**

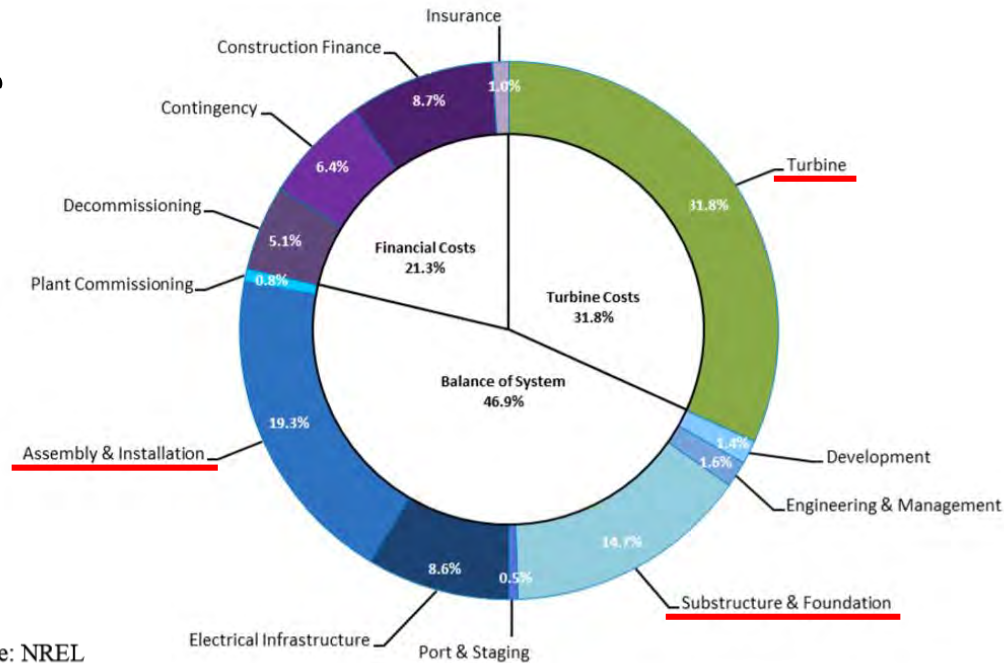


■ North America 
 ■ Northern Europe 
 ■ Southern Europe 
 ■ Eastern Europe 
 ■ Western Europe 
 ■ China 
 ■ Asia Pacific (Excl. China)

Source: MAKE

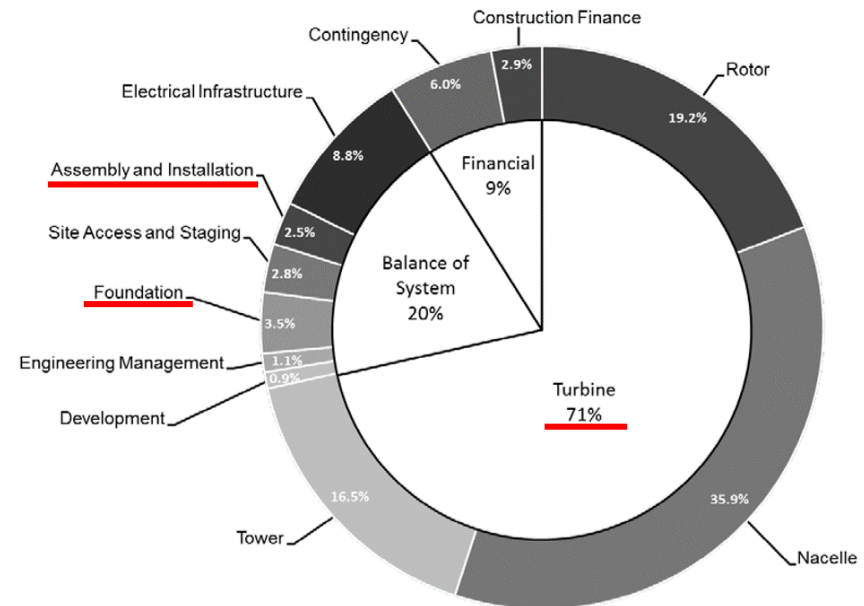


**CAPEX eólica marina fija**

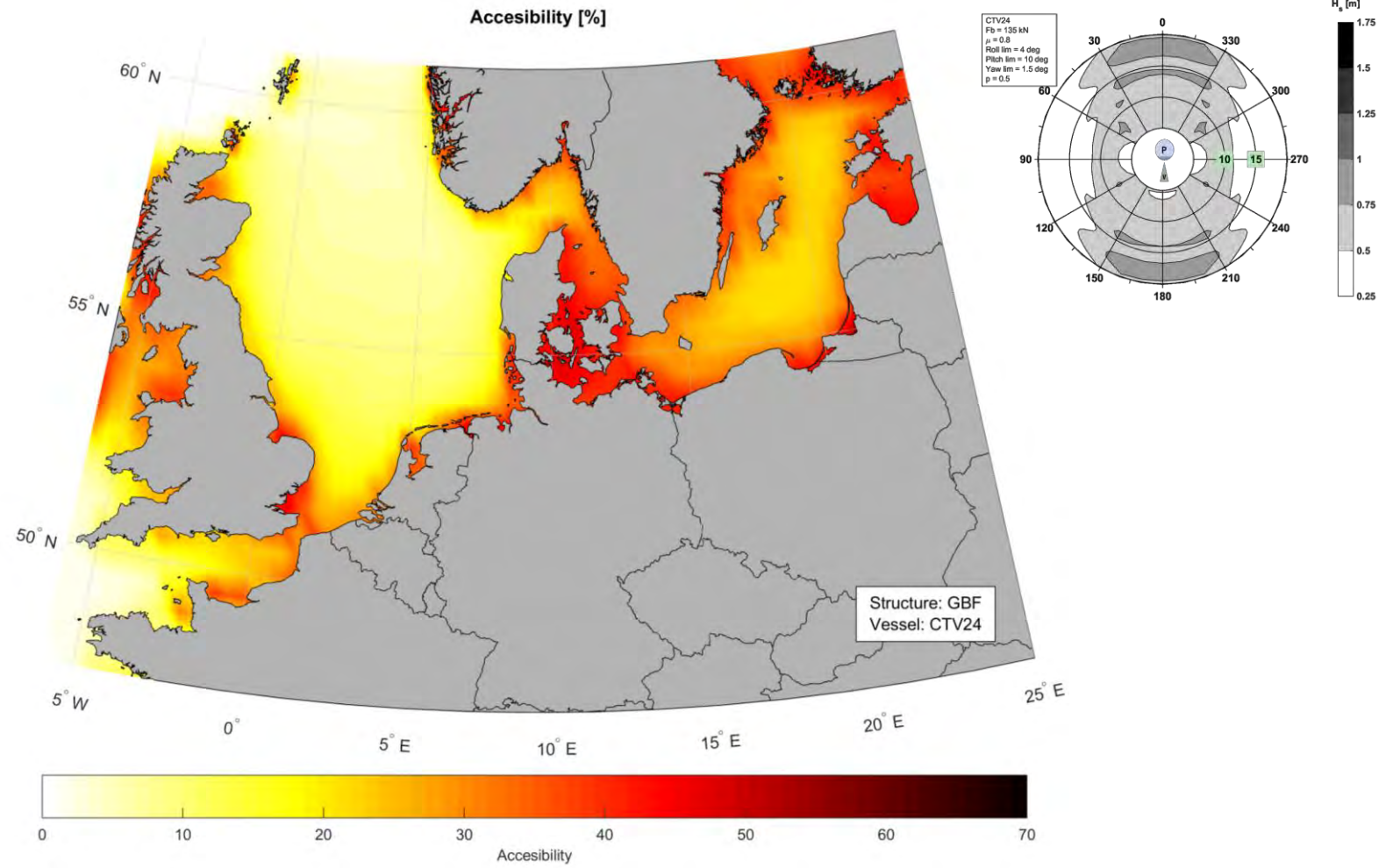


Source: NREL

**CAPEX eólica terrestre**



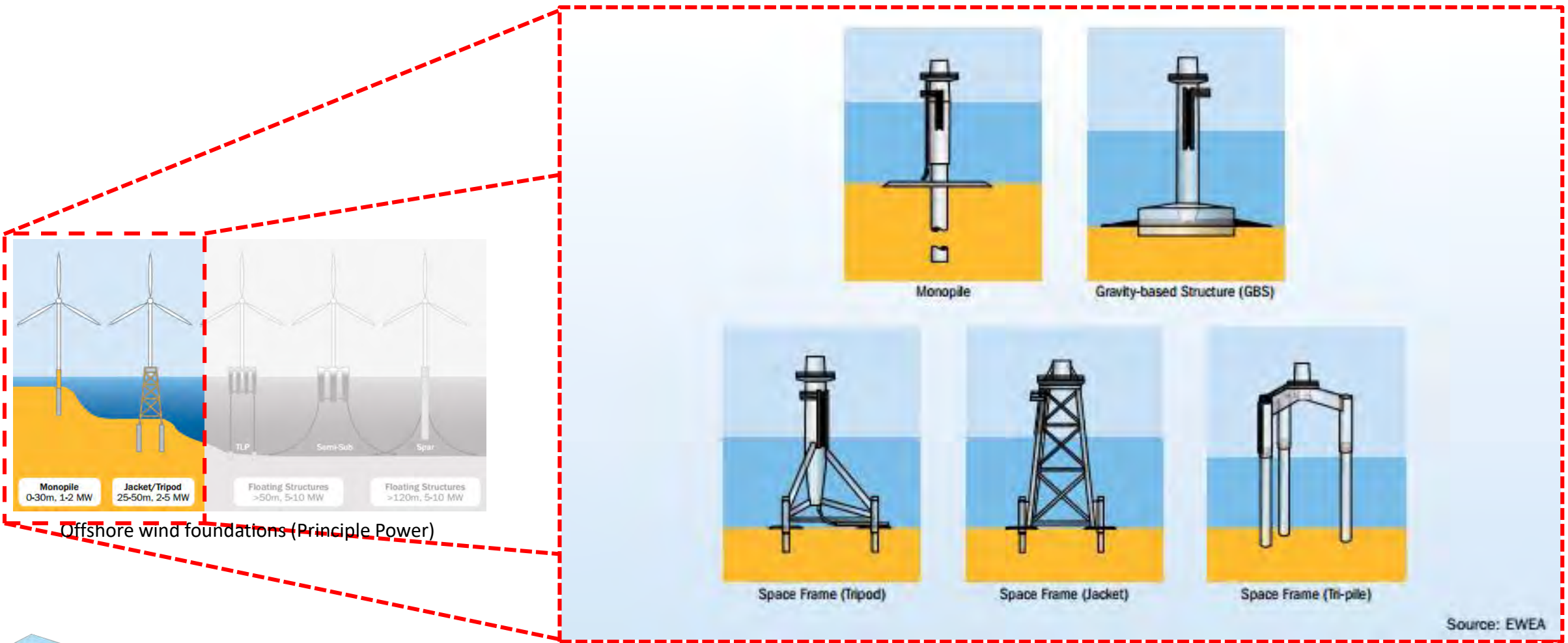




Martini, M., Guanche, R., Losada, I. J., & Vidal, C. (2017). Accessibility assessment for operation and maintenance of offshore wind farms in the North Sea. *Wind Energy*, 20(4), 637-656.

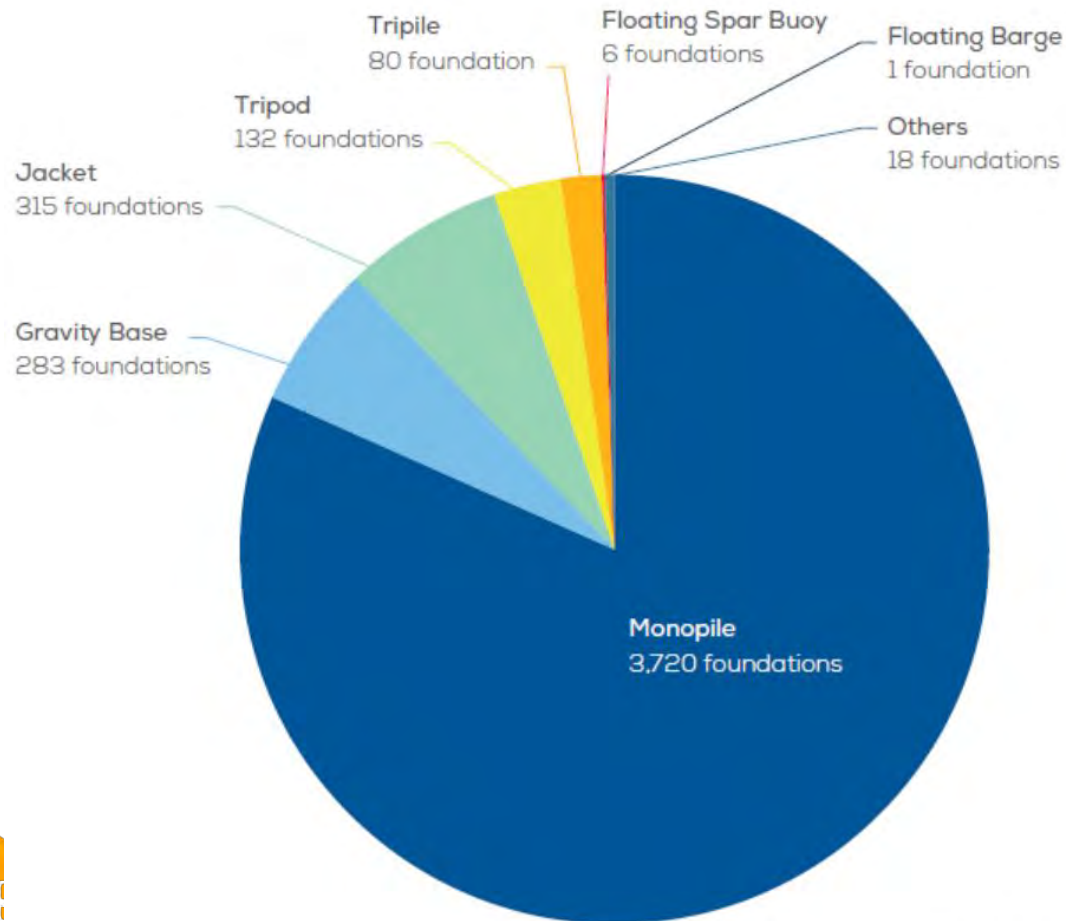


## Estructuras soporte o cimentaciones



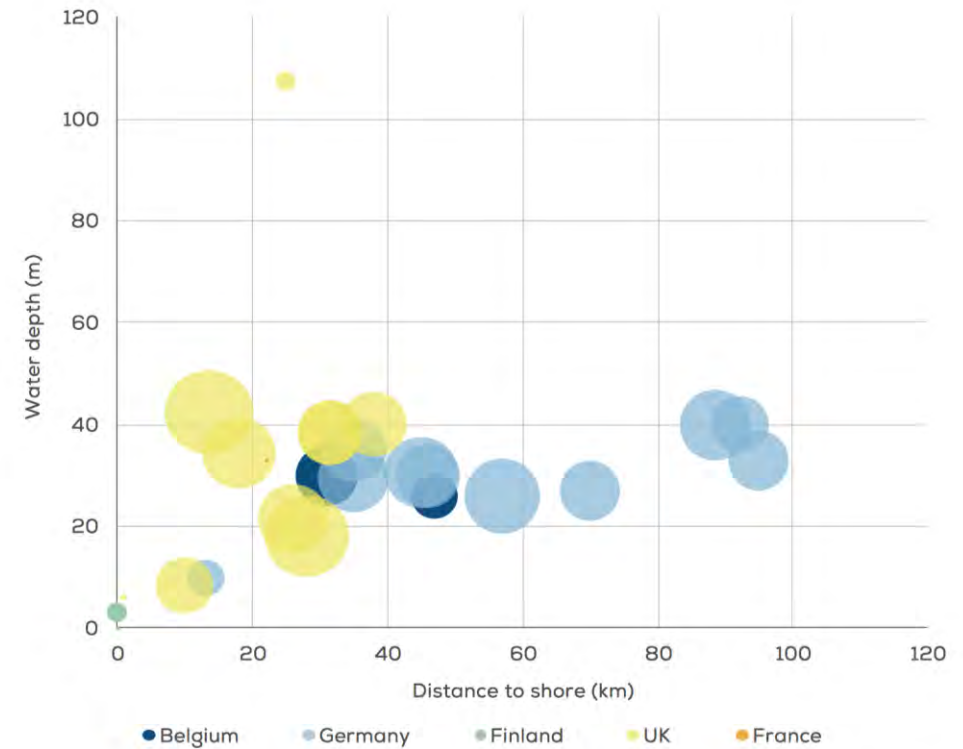
Estructuras soporte o cimentaciones

Distribución de las estructuras instaladas en Europa hasta 2017



Source: WindEurope

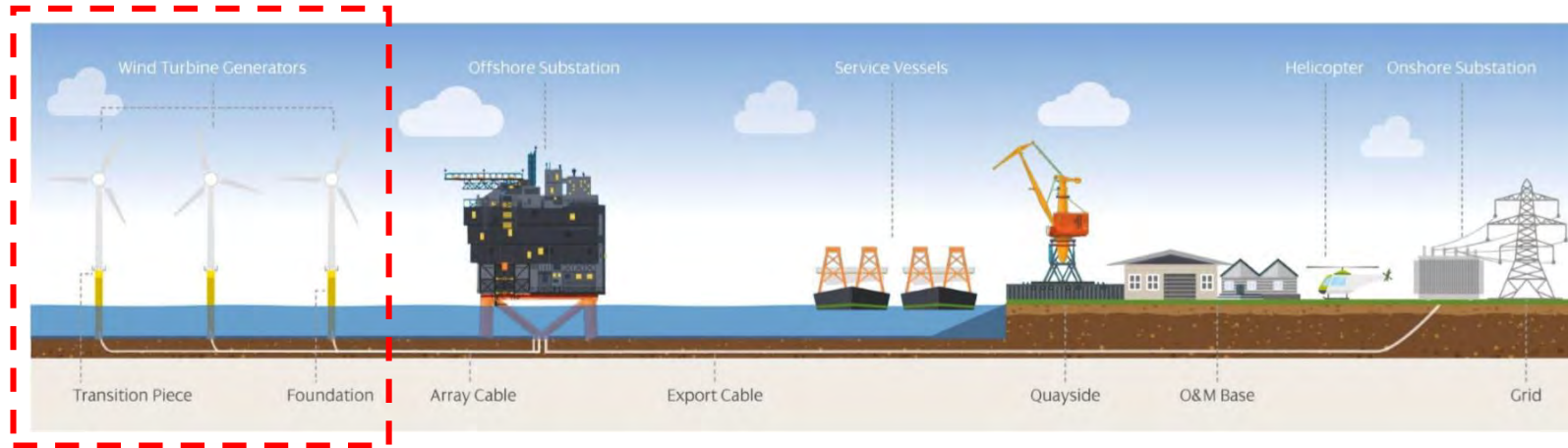
Localización de las estructuras instaladas en Europa en 2017



Source: WindEurope

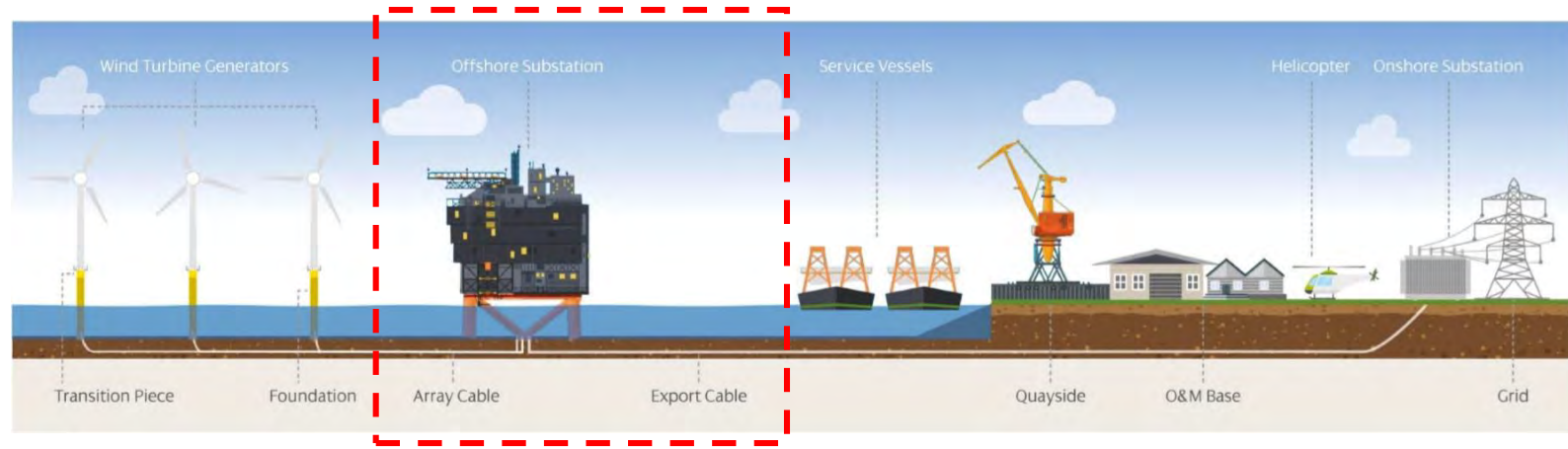


## Medios para la instalación





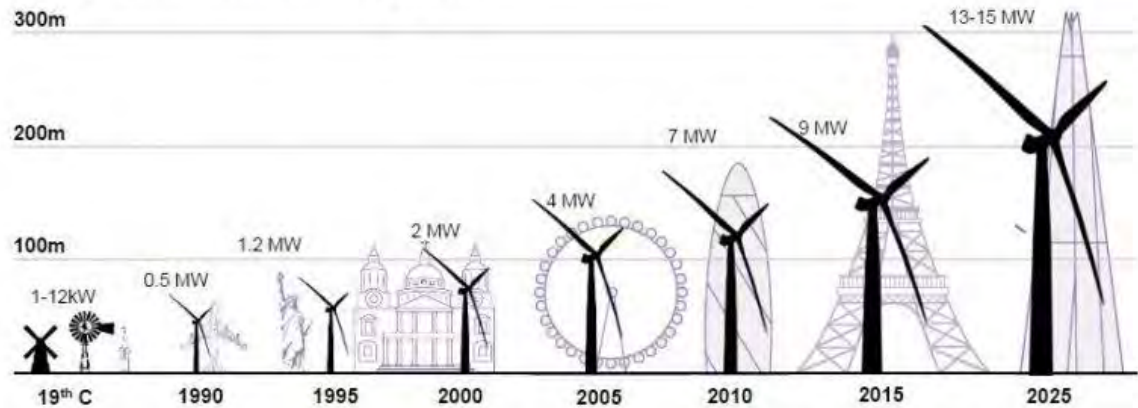
## Medios para la instalación



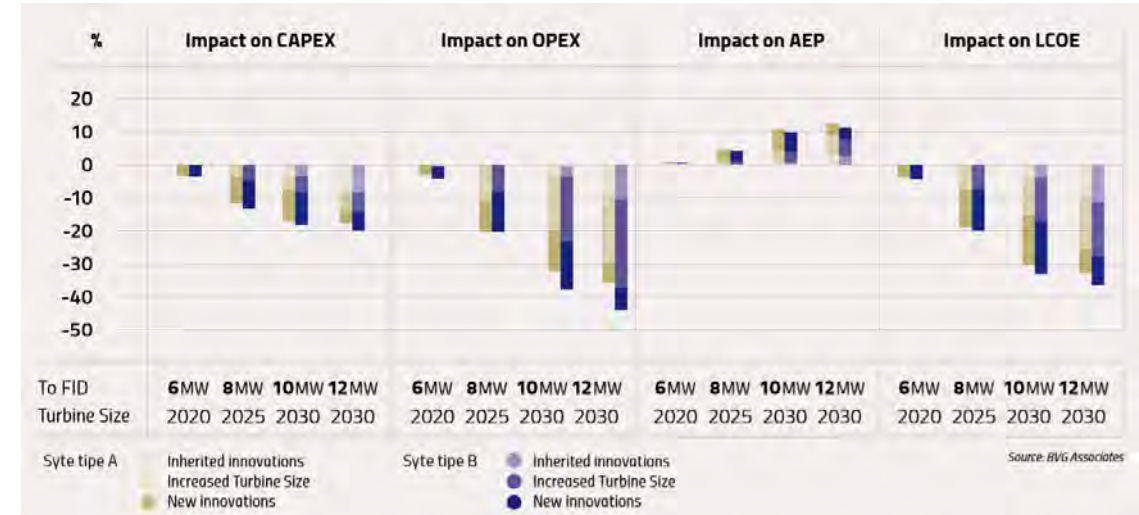


## La turbina: Economía de escala

### Evolution of wind turbine heights and output



Sources: Various; Bloomberg New Energy Finance



Turbine Size	2017 FID	2020 FID	2025 FID	2030 FID
6MW	○	○		
8MW	○	○	○	
10MW		○	○	○
12MW			○	○

## Tendencias: Economía de escala

**WoDS**  
Rotor 120m



**WoDS**

Siemens SWT-3.6-120  
 108 WTG – 386 MW  
 Based on SWT-3.6-107

**Wikinger**  
Rotor 135m



**Wikinger**

Adwen M5000-135  
 70 WTG – 350 MW  
 Based on M5000-116

**EA One**  
Rotor 154m



**EA One**

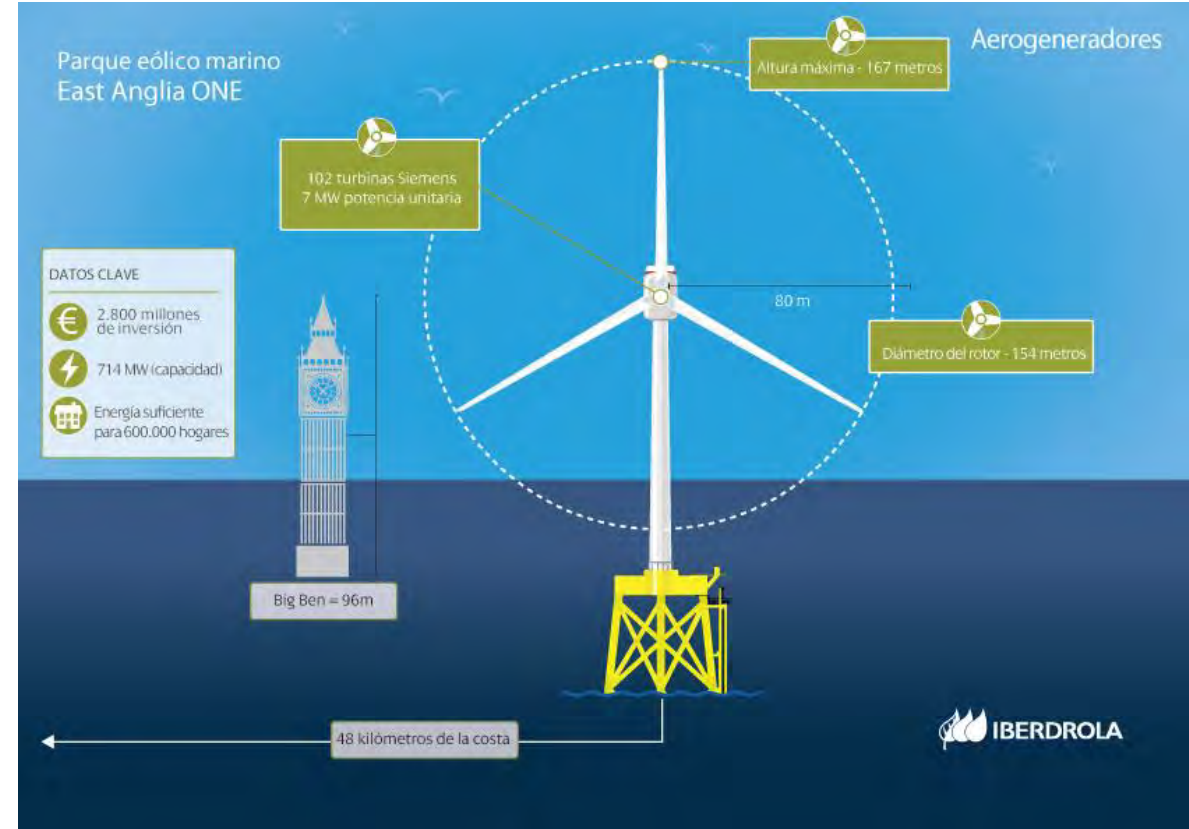
Siemens SWT-7.0-154  
 102 WTG – 714 MW  
 Based on SWT-6.0-154

**St Brieu**  
Rotor 167m

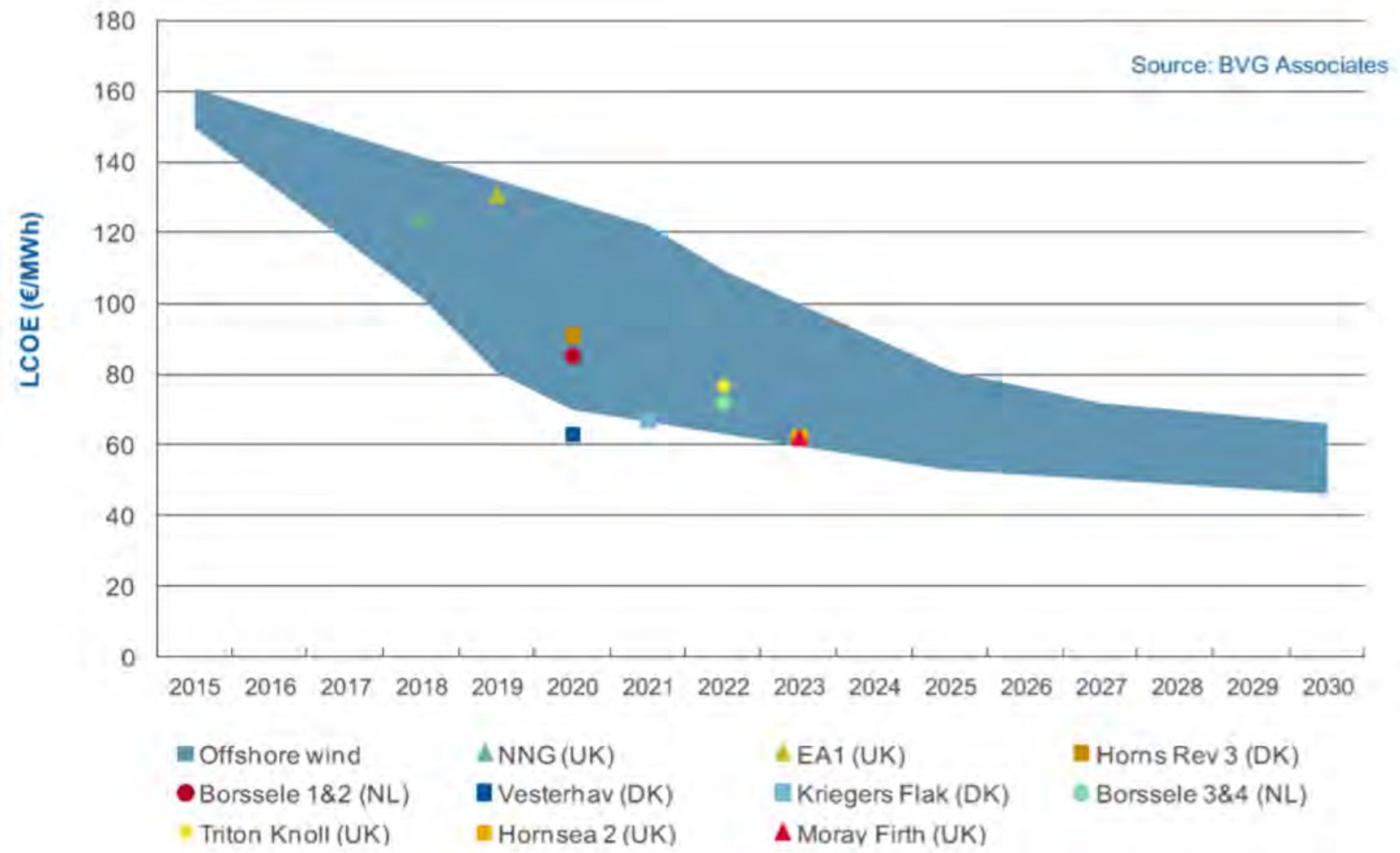


**St Brieu**

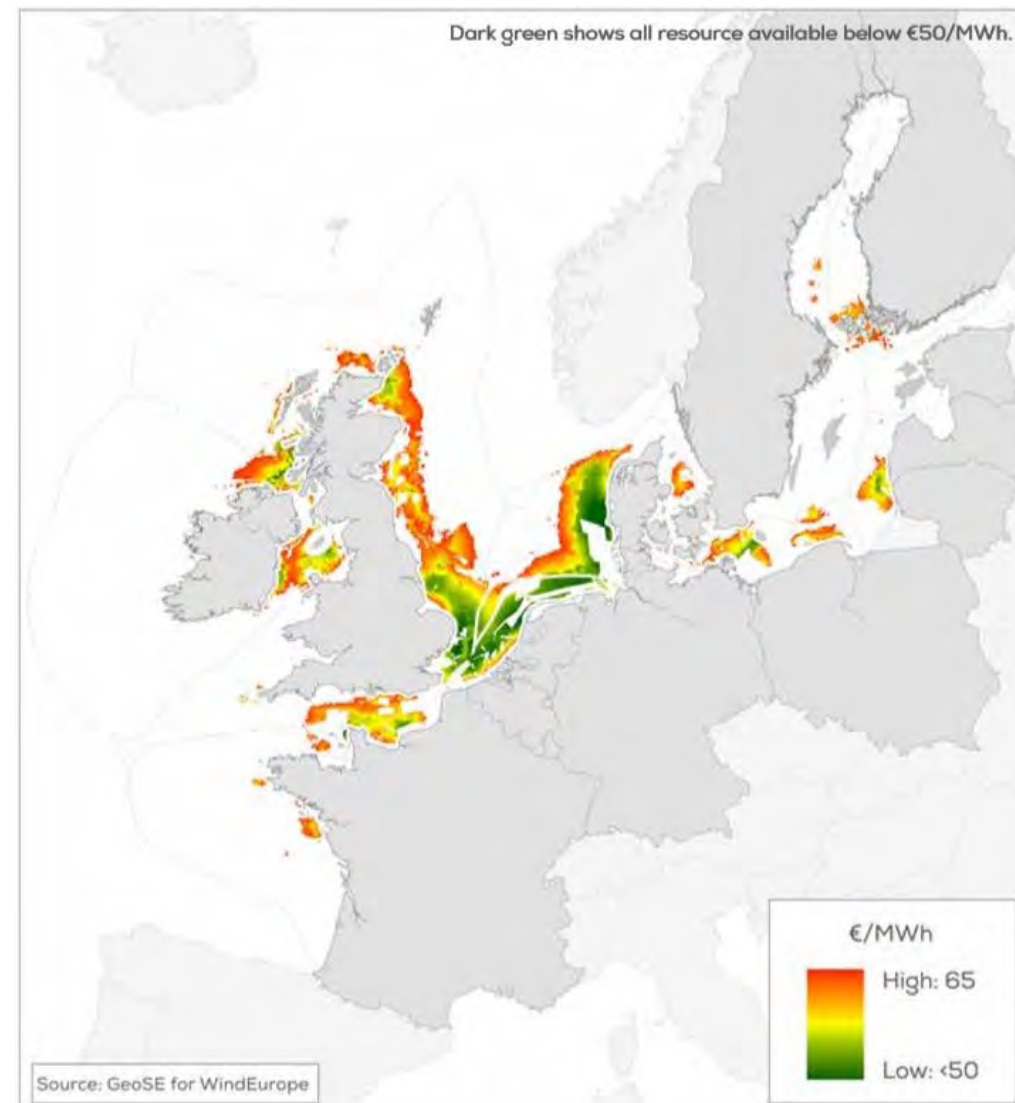
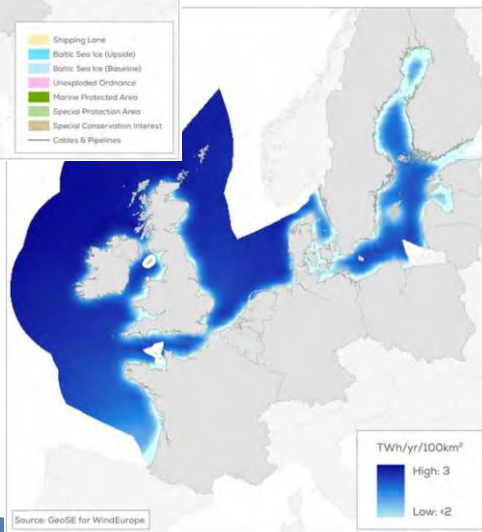
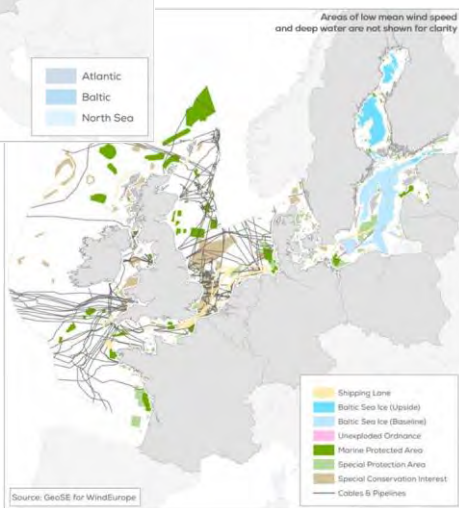
Siemens SWT-8.0-167  
 62 WTG – 496 MW  
 Not new generation







## Atractivo económico para explotaciones eólicas marinas: 2030



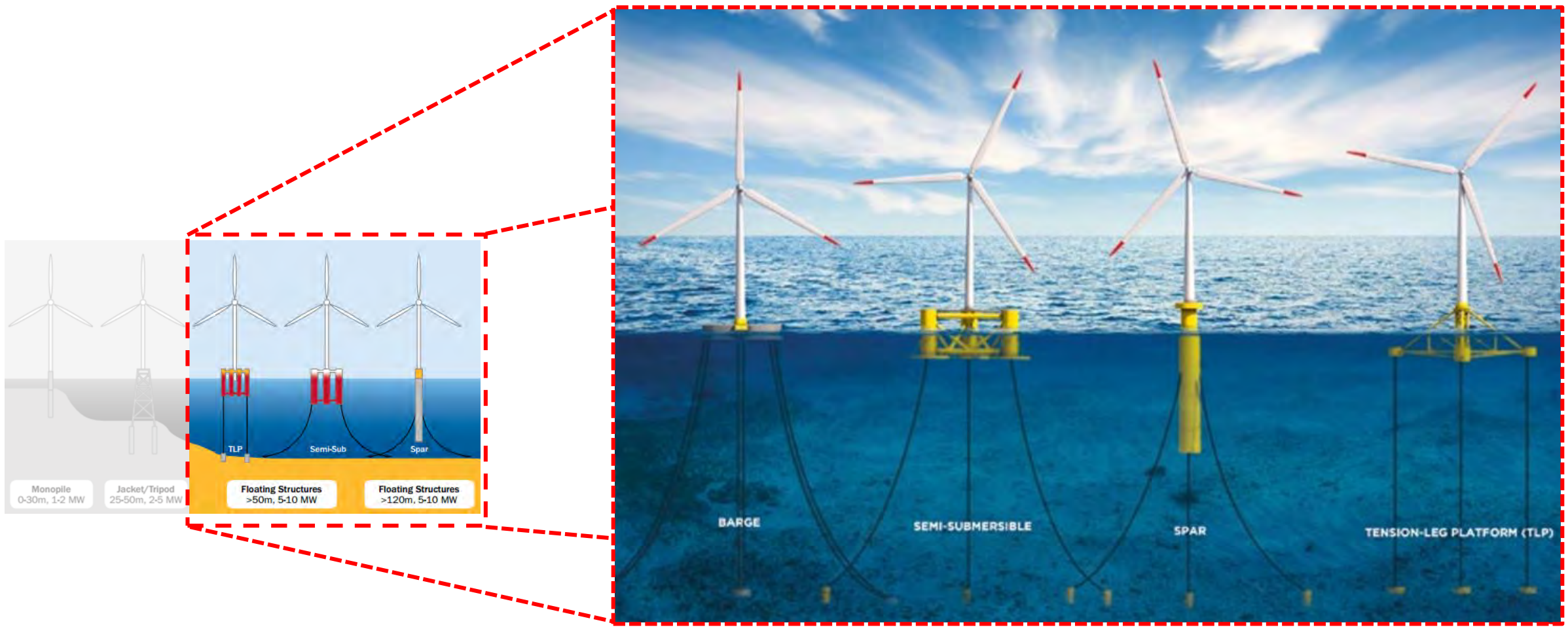


# Índice

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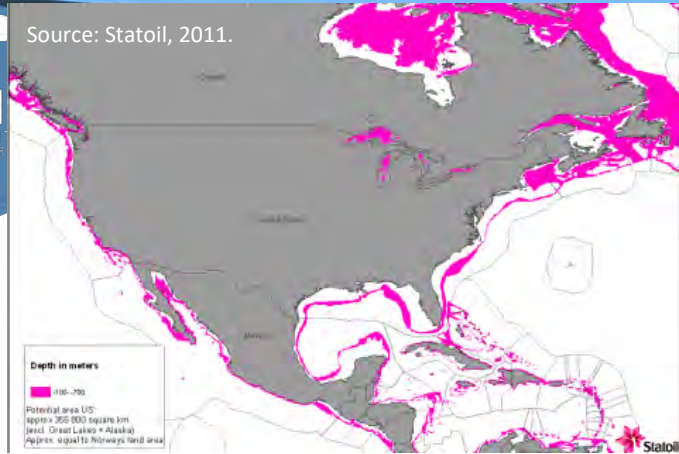
- Introducción
  - ¿Por qué eólica marina?
  - La energía eólica marina en la actualidad: eólica fija
  - **La energía eólica marina del futuro: eólica flotante**
  - Retos y oportunidades de la eólica marina
  - ¿Qué hace IHCantabria en eólica marina?
-

## Estructuras para eólica marina





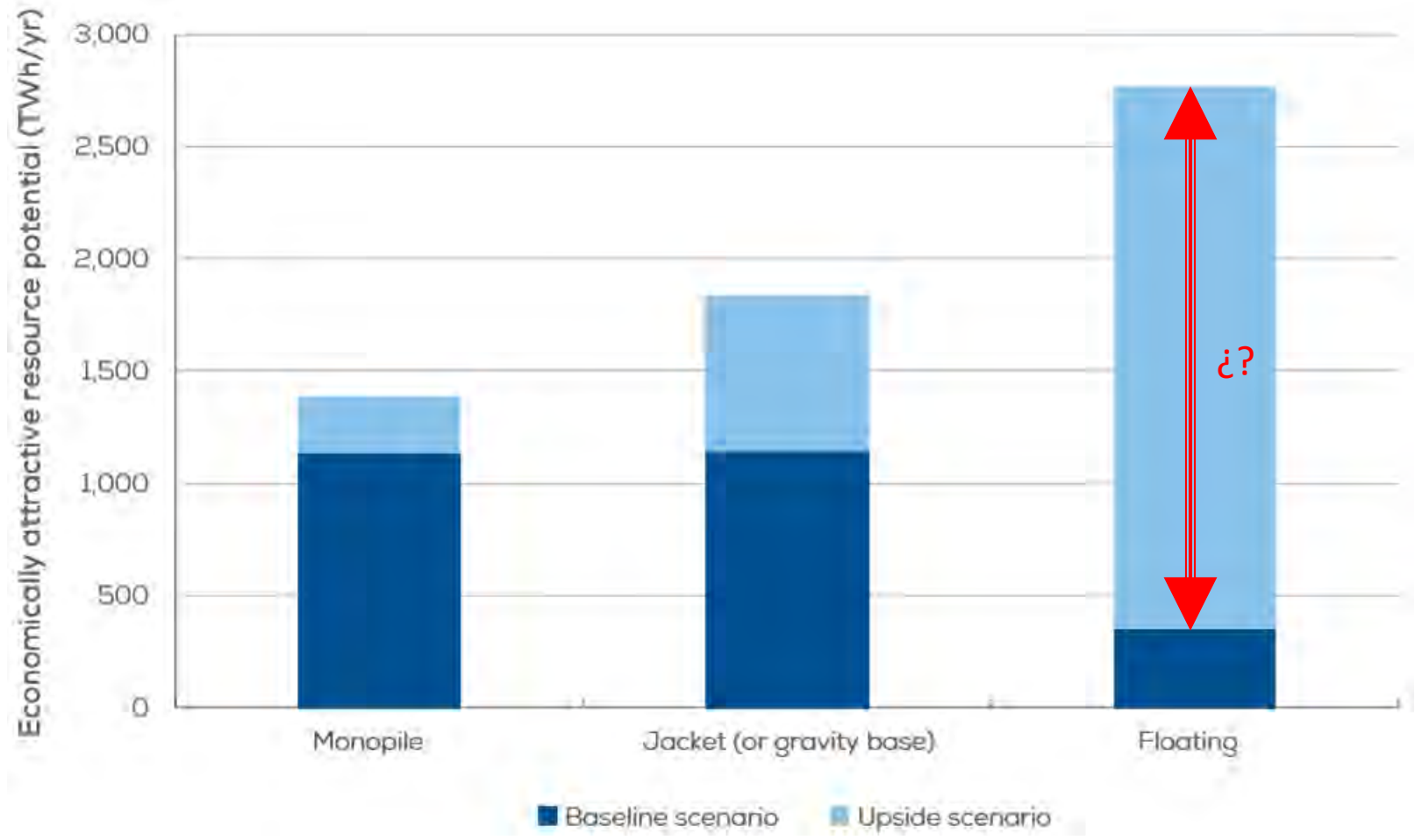
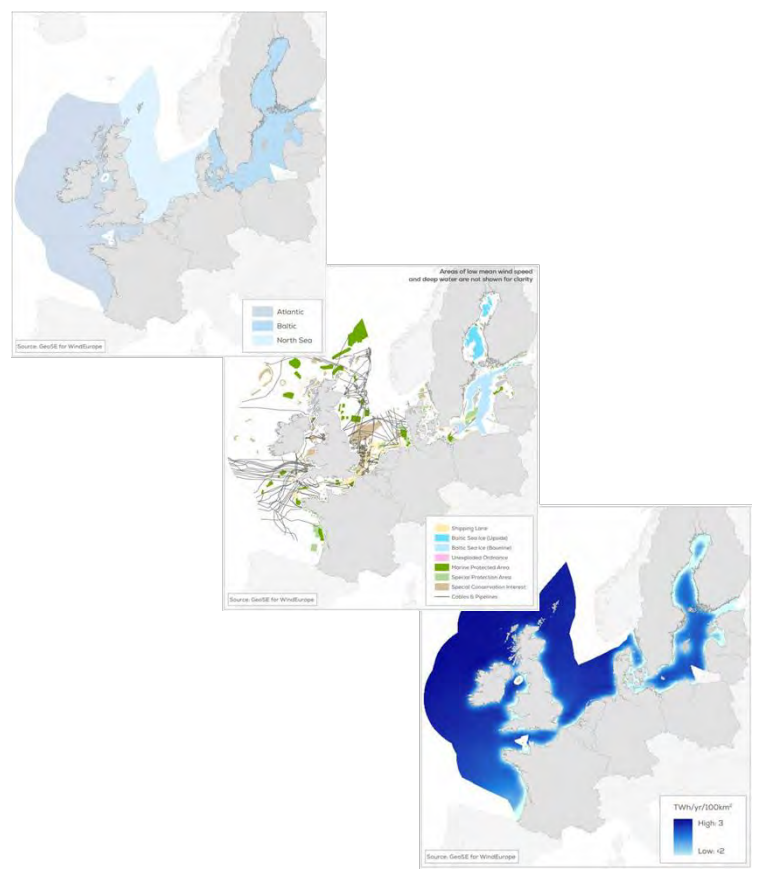
## El futuro eólico marino es flotante!



Country/Region	Share of offshore wind resource in +60m depth	Potential for floating wind capacity
Europe	80%	4,000 GW
USA	60%	2,450 GW
Japan	80%	500 GW
Taiwan	-	90 GW

Source: Carbon Trust, MOFA

## Atractivo económico para explotaciones eólicas marinas: 2030



Source: BVG Associates for WindEurope



Wind Farm Name	Country	Capacity (MW)	Commissioning date
Hywind Scotland	United Kingdom	30	2017 (in operation)
Windfloat Atlantic	Portugal	25	2019
Flocan 5 Canary	Spain	25	2020
Nautilus	Spain	5	2020
SeaTwirl S2	Sweden	1	2020
Kincardine	United Kingdom	49	2020
Forthwind Project	United Kingdom	12	2020
EFGL	France	24	2021
Groix-Belle-Ile	France	24	2021
PGL Wind Farm	France	24	2021
EolMed	France	25	2021
Katanes Floating Energy Park -Array	United Kingdom	32	2022
Hywind Tampen	Norway	88	2022

Source: WindEurope

## Oil&Gas... los precursores

### Resumen e hitos

Más de 60 años de experiencia en exploración y explotación de recursos en aguas profundas y muy profundas...  
 Actividad todavía en crecimiento

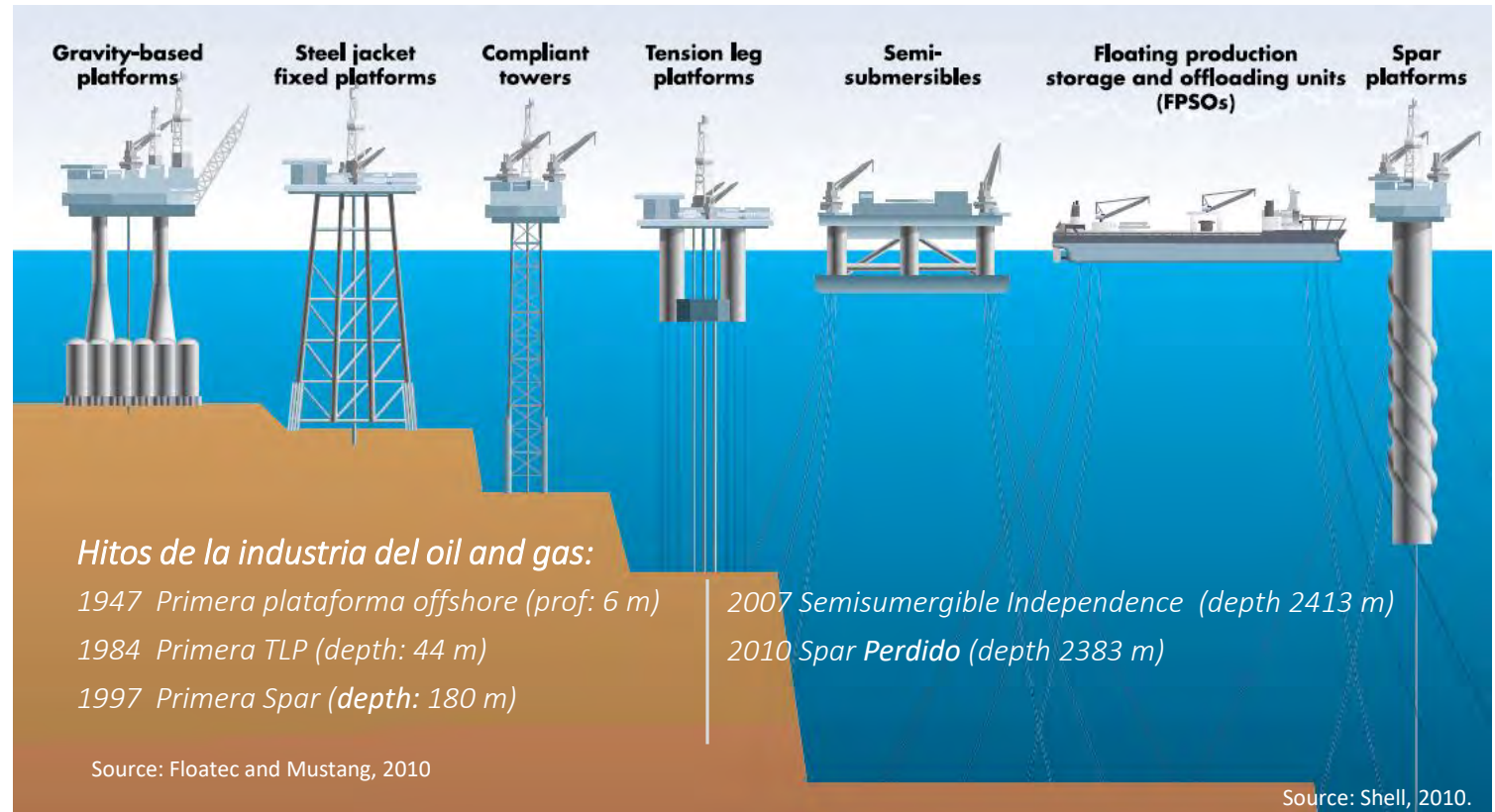
#### Parámetros para la toma de decisión

- Profundidad y condiciones meteoceánicas
- Tipología de instalación (Topside)
- Tipología del fondo
- Requerimientos de diseño y seguridad
- Riesgos e impactos
- Mercados: Capex / Opex

#### Estándares y reglas de buena práctica

- API RP - 2A
- OCS
- DNV
- Norsok
- BS6235
- DOE-OG
- EUROCODE 8
- ...

**Clima de diseño +100yr: Niveles de seguridad máximos**





## *Oil&Gas... los precursores*

### *Resumen e hitos*

Soluciones primarias aceptadas por la industria...

Probadas, Funcionales, Escalables, Adaptables a escala global.

#### **Spar**

(10.000 ft ~ 3000 m)

Cilindro hueco equipadas con un volume de lastre elevado en su parte más baja. Sistemas de fondeo en catenaria

Principios físico:

Configuración del casco.



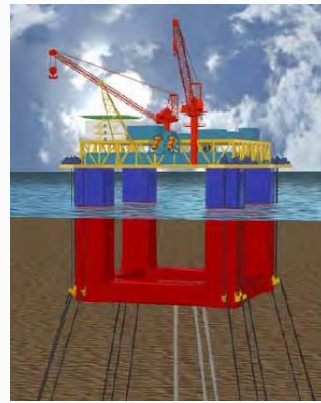
#### **Semi-Submeables**

(9.000 ft ~ 2700 m)

Cubierta soportada por columnas unidas ha pontonas sumergidas. Sistemas de fondeo en tension o catenarias.

Principio físico:

Configuración del casco.



#### **Tension Leg Platforms**

(6.000 ft ~ 1800 m)

Gran volumen de flotación sujeto en tensión por cables al anclados al fondo.

Principio físico:

Sistema de fondeo



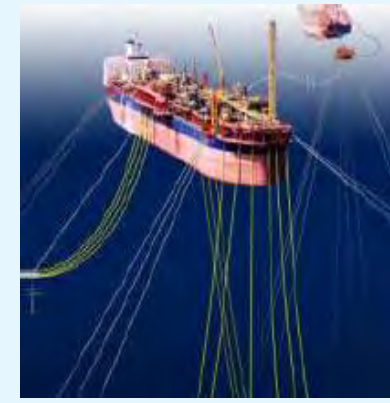
#### **Ship –Shape (FPSO)**

(10.000 ft ~ 3000 m)

Embarcación o buque conectado al fondo mediante “turret” (rotula de 3DOF-rotación libre)

Principio físico:

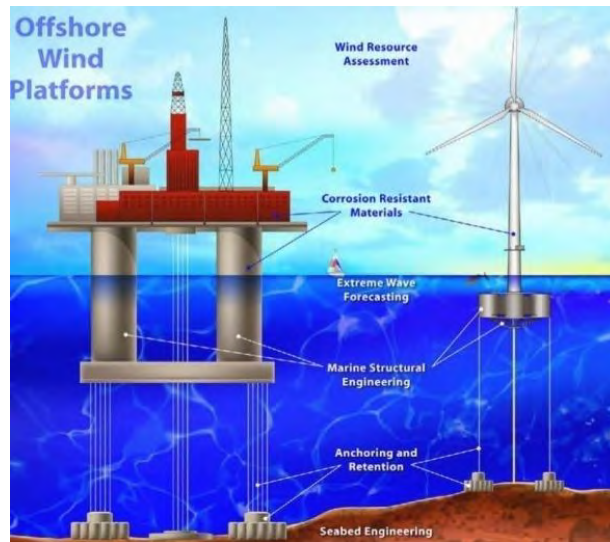
Forma del casco



Source: Floatec, 2016.

## Lecciones aprendidas de la industria offshore

### Sinergias



Source: NREL 2010

(!) API RP-2A O&G Design Standard does not address Offshore Wind specific loads and interactions. The best approach is using a joint application combining both IEC 61400 - 3

#### *Sinergias:*

*Seguridad, diseños, materiales...*

#### *Lecciones aprendidas:*

*Construcción y técnicas de instalación*

*Gestión de Proyectos, cadena de suministro*

#### *Similitud de requerimientos:*

*Equipos y personal especializado*

### Diferencias

#### *Economía de escala:*

*Valor añadido del Oil&Gas vs Coste de la Energía*

#### *Riesgos:*

*Vida útil de las estructuras, Medio-Ambiente, ...*

#### *Cargas medio ambientales de cálculo*

#### *Localización*

*Profundidad, Distancia a costa, cercanía a núcleos de población*

***No se puede aplicar de manera indiscriminada el "know-how" del oil&gas al sector offshore.***

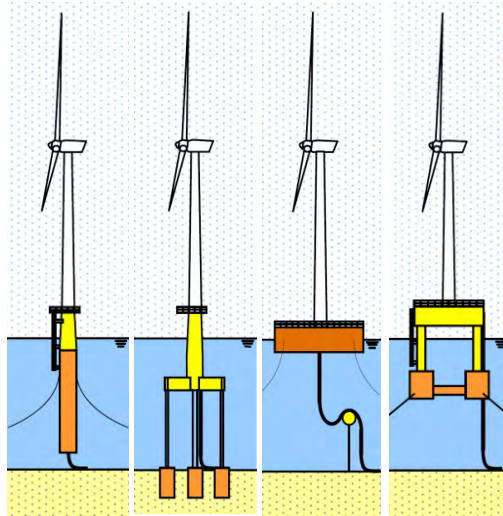
Source: "Overcoming challenges for the offshore wind industry and learning from O&G industry. Power cluster project, 2011



## Estructuras offshore para eólica marina flotante

Objetivos/requerimientos de un diseño para eólica marina flotante:

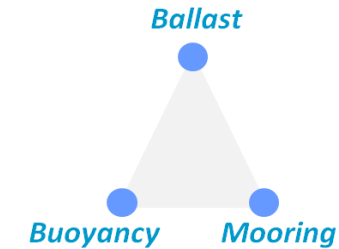
*Diseño optimizado que asegure integridad estructural, eficiencia, y coste.... Siempre cumpliendo objetivos financieros*



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.



*En la práctica todos los sistemas comparten los principios físicos de funcionamiento. No obstante, siempre existirá uno que sea más relevante que los demás.*

### SPAR

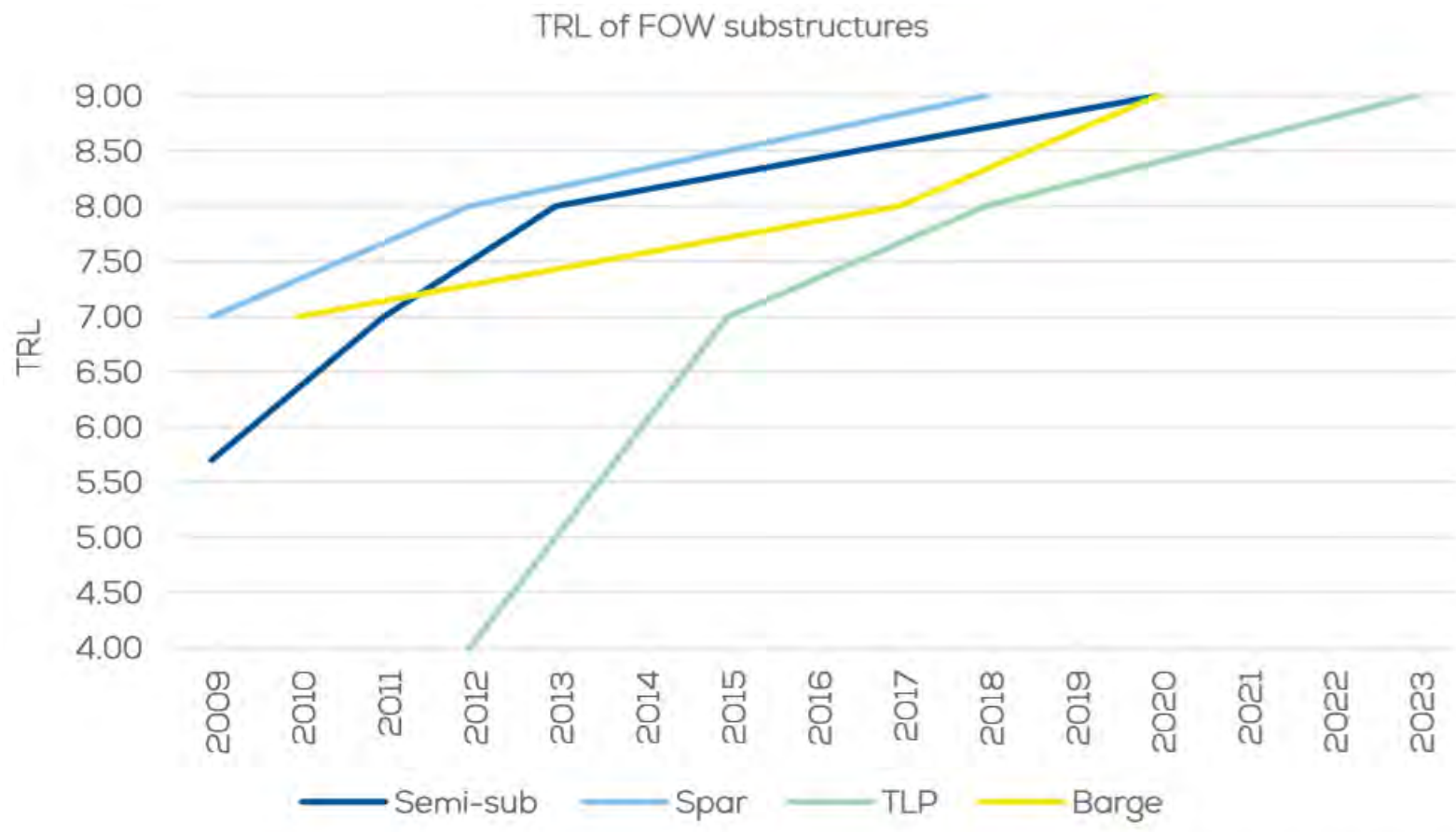
- Estabilidad, bajo riesgo
- Simple y económico
- Facil producción en masa
- Sistema de fondeo en catenaria o semi tensionado
- Grandes deformaciones y cabeceos
- Grandes profundidades

### TLP

- Gran estabilidad (bajo cabeceo y balance).
- Restriciones de emplazamiento: Tipo de fondo y profundidad.
- Sistemas de fondeo en tension: caros.
- Muy débiles a fatiga.
- Baja rigidez a guiñada.

### BARGUE / TRIFLOATER / SEMI-SUB

- Formas flexible y adaptables al topside.
- Facil producción en masa
- Sistemas de fondeo en tension o catenaria
- Sensibles al cabeceo y el balance
- Faciles de operar en tierra



Source: The Crown Estate<sup>1</sup> and WindEurope



**Hywind** **Statoil** 



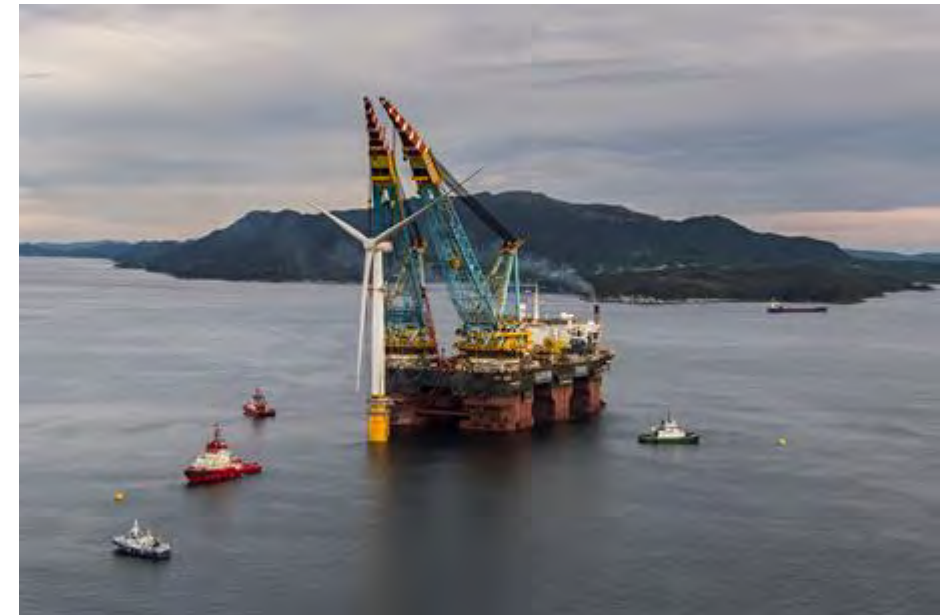
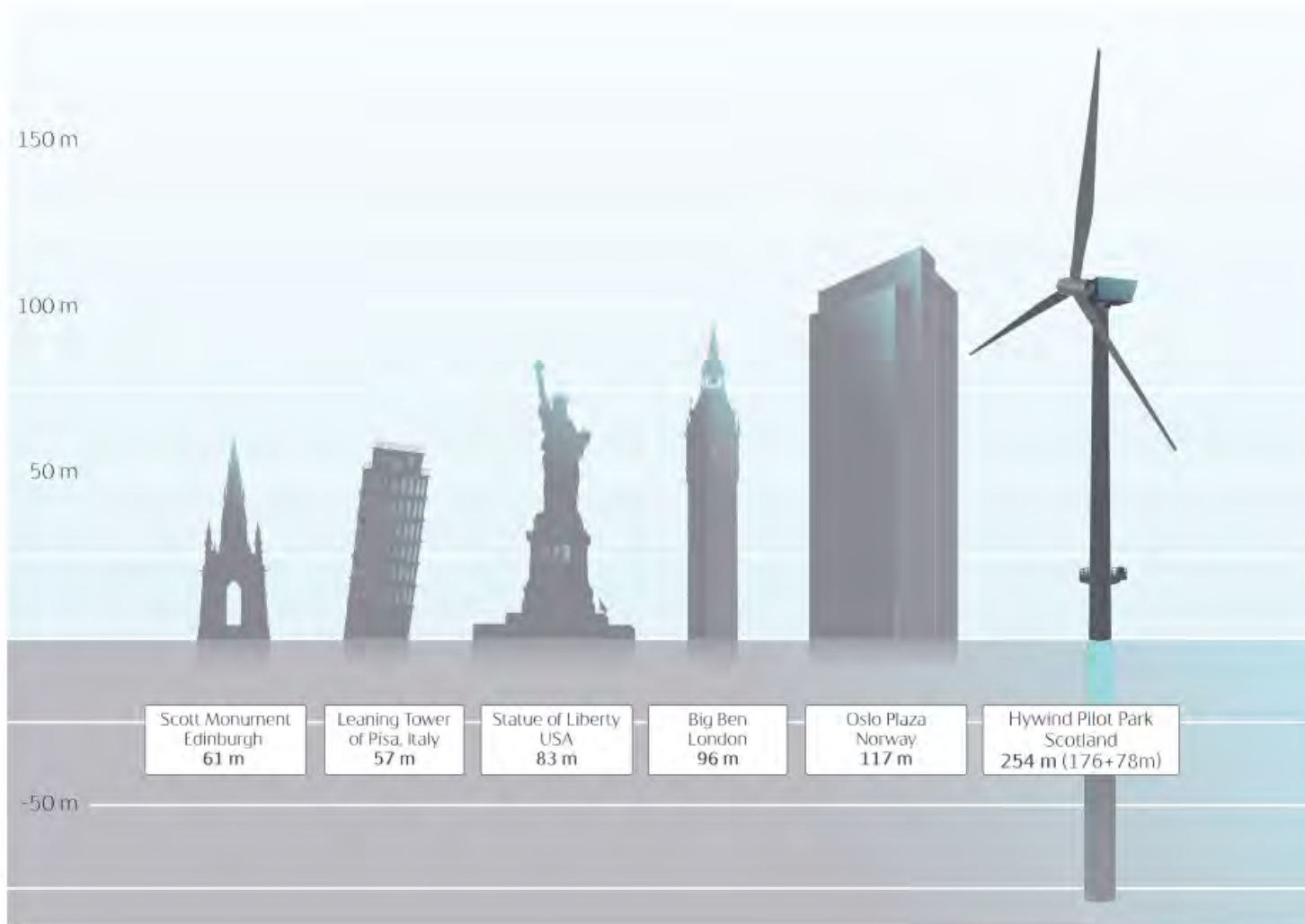
<b>Classification:</b>	Spar	<b>Primary material:</b>	Steel or concrete
<b>Depth range:</b>	100-500m	<b>Moorings:</b>	3 catenary
<b>Turbine axis:</b>	Horizontal	<b>No. blades:</b>	3
<b>Industrial partner(s):</b>	Statoil	<b>TRL:</b>	4
<b>Full-scale prototype:</b>	2009	<b>Pre-commercial array:</b>	2017

The Hywind spar-buoy is arguably one of the most mature floating concepts under development, having had a 2.3 MW prototype deployed off the coast of Norway since 2009. Hywind consists of a traditional spar buoy structure, with draft of 70-90m, and a catenary 3-line mooring system. There are plans to scale-up the device and install 5 x 6 MW turbines in a pre-commercial array off the coast of Scotland in 2017.

The design has been modified from the original prototype to allow for a shorter but thicker hull, which should result in a net reduction to material costs, as well as open up a wider market for its application. The ballast will also be adapted from a water ballast in the first Hywind to a stone ballast in the new design, in order to cope with the additional loads of the larger 6 MW turbines. In combination, Statoil expect these adaptations and optimisations to reduce LCOE by two-thirds from the 2.3 MW demonstration, with further cost reduction potential for commercial deployment. However, the exact dimensions and mass of the spar will be site-dependent.





<https://www.siemens.com/innovation/en/home/pictures-of-the-future/energy-and-efficiency/sustainable-power-generation-hywind.html>



<https://www.windpoweroffshore.com/article/1437693/hywind-turbines-complete-foundation-installation>



WindFloat	Principle Power 			
	Classification:	Semi-sub	Primary material:	Steel
	Depth range:	40m-1000m	Moorings:	3 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	EDPR; Repsol; Pilot Offshore; Atkins	TRL:	4
	Full-scale prototype:	2011	Pre-commercial array:	2018

WindFloat is one of the more mature concepts in the market, having had a 2 MW unit installed off the coast of Portugal since 2011. The design consists of a semi-submersible hull with three columns, one of which supports the turbine.

A static water ballast is used to achieve the desired operating draft while entrapment (heave) plates at the base of each column provide dynamic stability to dampen wave and turbine induced motion. This stability performance allows for the use of existing commercial wind turbine technology. The design is therefore considered to be 'turbine agnostic', with the ability to support most conventional three-blade upwind turbines with only minor design modifications.



The mooring system employs conventional components such as chain and polyester lines to minimise cost and complexity. Through the use of pre-laid drag embedded anchors, site preparation and impact is minimized.

The design is benefitting from its first-mover position in the market and there are ambitious plans to scale up development over the next 5-10 years, with projects planned in the US (Oregon, 30 MW; Hawaii, 2 x 408 MW), Scotland (Kincardine, 48-50 MW), and Portugal (Aguçadoura, 25 MW).



<https://www.windpowermonthly.com/article/1523934/portugals-offshore-wind-projections-ambitious>



Damping Pool		IDEOL		
	Classification:	Caisson/barge	Primary material:	Concrete or steel
	Depth range:	35m+	Moorings:	6-9 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	Hitachi Zosen; Adwen	TRL:	3
	Full-scale prototype:	2015	Pre-commercial array:	Undisclosed

The IDEOL platform is a square concrete hull with a central opening to create a patented 'damping pool' system that uses the entrapped water to minimise floater motions, resulting in strong hydrodynamic performance. The low floater motion means that the concept is compatible with conventional offshore turbines in the market, with only minor tower upgrades and adapted blade pitch control software required align with the floater's behaviour. The design can also be constructed using steel, but delivers greater cost reduction and higher local content when using concrete. The concept is classified as a caisson/barge concept, but for the purposes of this study it has been grouped as a semi-submersible design to avoid breach of confidential data in our analysis.

The modular structural design and use of concrete as the primary material means that the design is less prone to price volatility and is highly amenable to mass production with on-site construction, high local content, and versatile construction methods, depending on local infrastructure and capabilities. IDEOL has also developed its own patented 'mobility' solution which allows the floater to move along its mooring lines, allowing it to alter its position to reduce wake losses in an array.

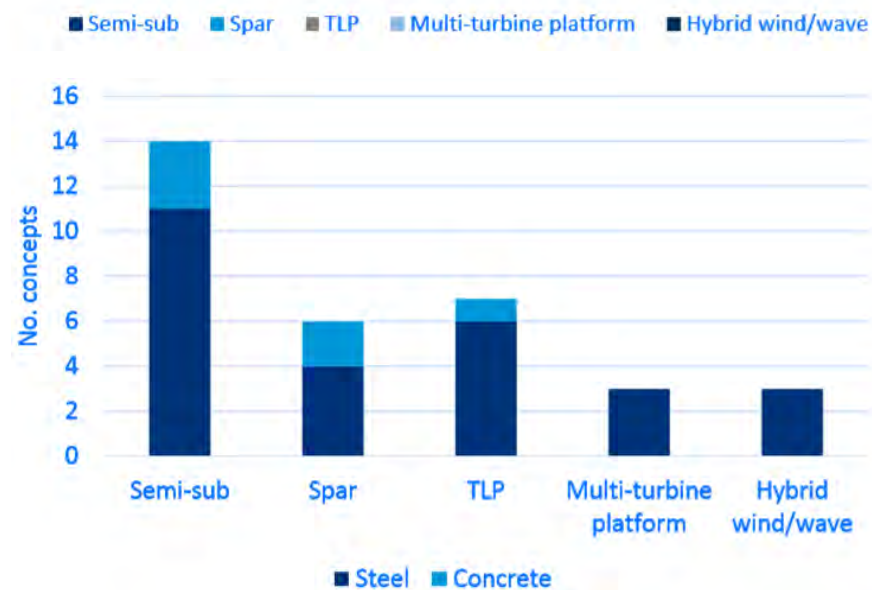
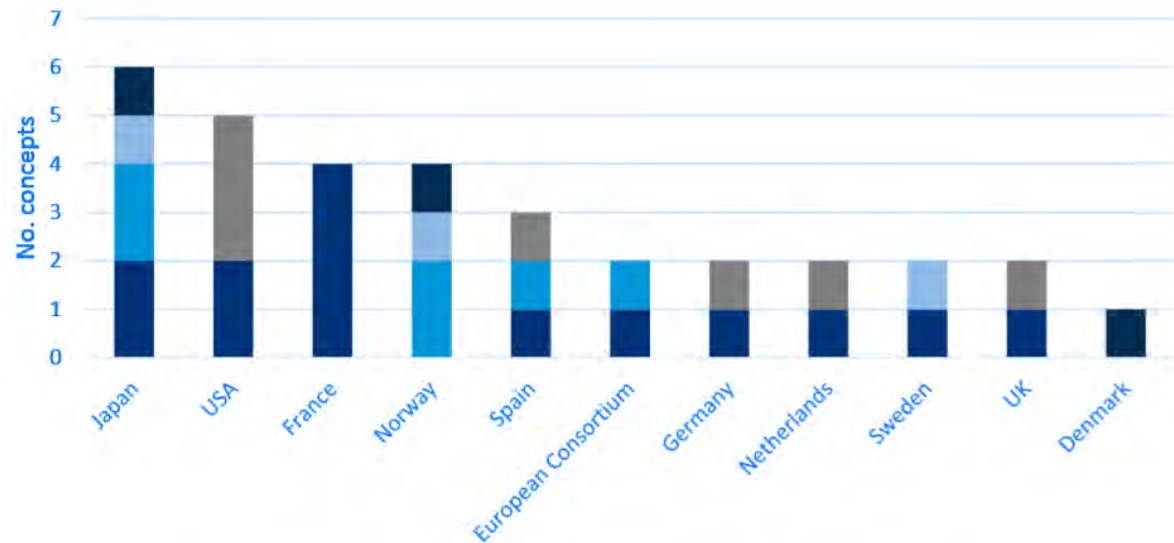
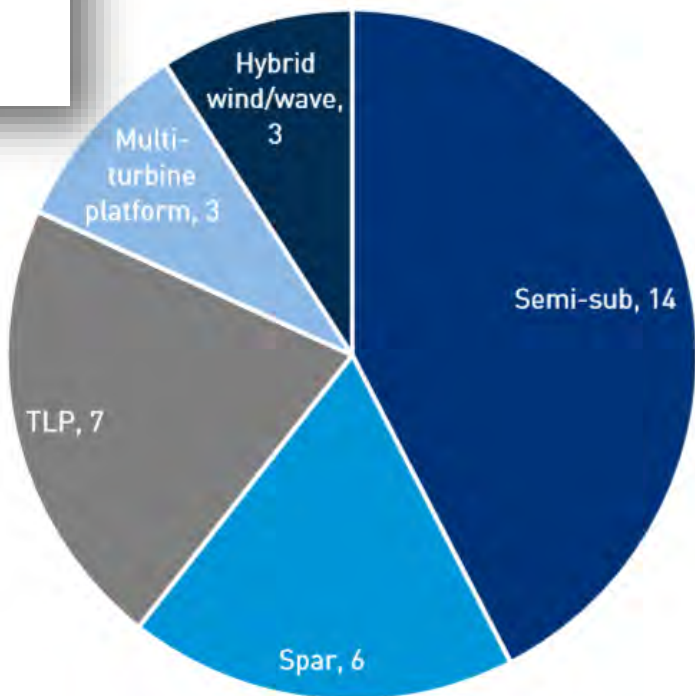
IDEOL have an initial 2 MW demonstration slated for installation at the SEM-REV test site in 2015, part funded by the European Commission's FLOATGEN and French Government (ADEME) OCEAGEN initiatives. IDEOL have also secured a partnership with Hitachi Zosen to deploy the IDEOL concept in Japan.



<https://www.ideol-offshore.com/en/actualites/floatgen-installed>



# La energía eólica marina en aguas profundas

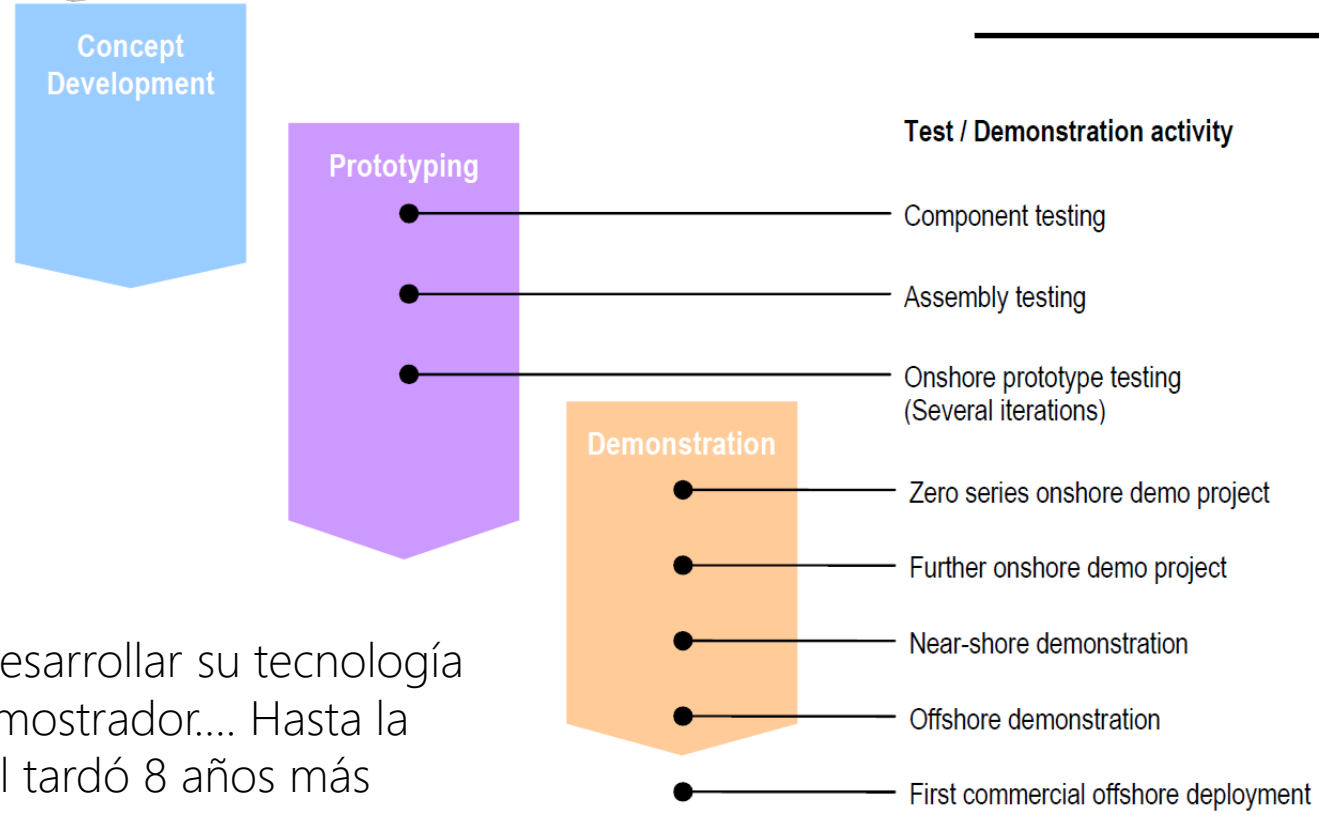


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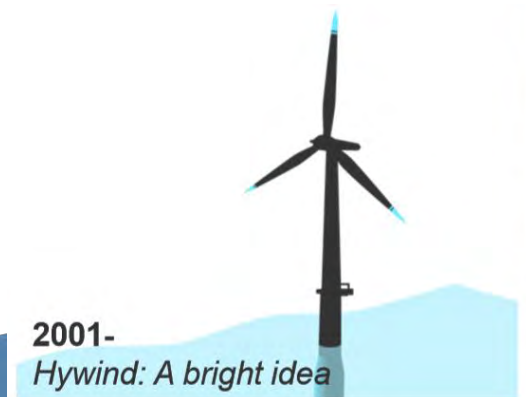
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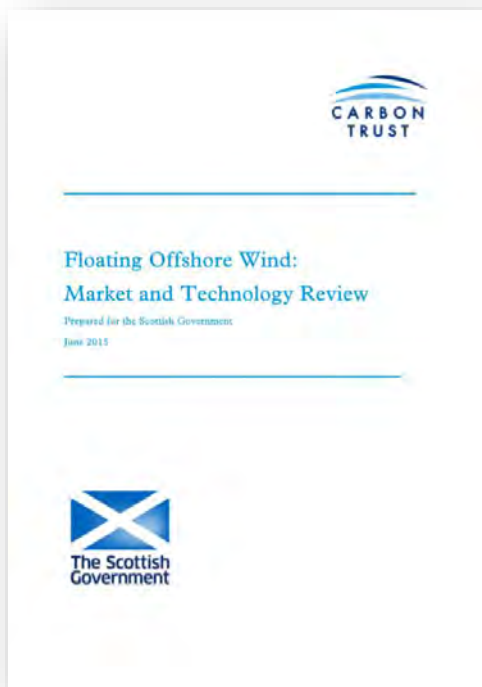
- Introducción
  - ¿Por qué eólica marina?
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  - **Retos y oportunidades de la eólica marina**
  - ¿Qué hace IHCantabria en eólica marina?
-





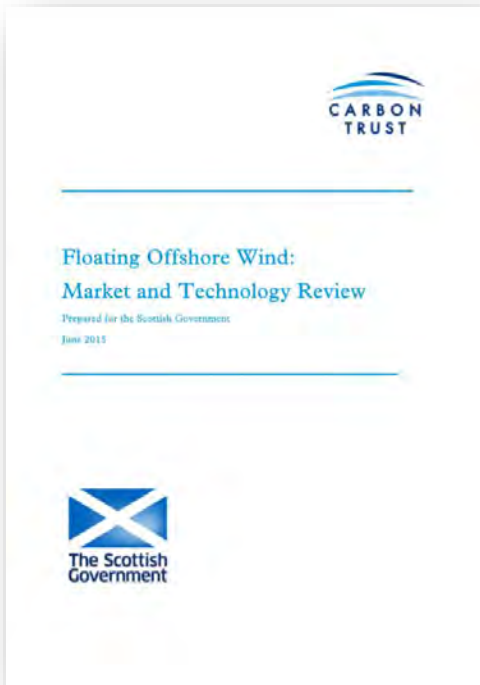
Hywind tardó 8 años en desarrollar su tecnología y realizar un primer demostrador... Hasta la planta precomercial tardó 8 años más





- Plataformas: materiales y tamaño
- Tecnologías y métodos de instalación
- Operación y Mantenimiento + Instalaciones portuarias
- Subestaciones flotantes + Cables submarinos dinámicos
- Modelos de simulación avanzados
- Sistemas avanzados de control
- Técnicas de ensayo en tanque avanzadas
- Operación de parque
- Estándares de diseño
- Impacto medioambiental



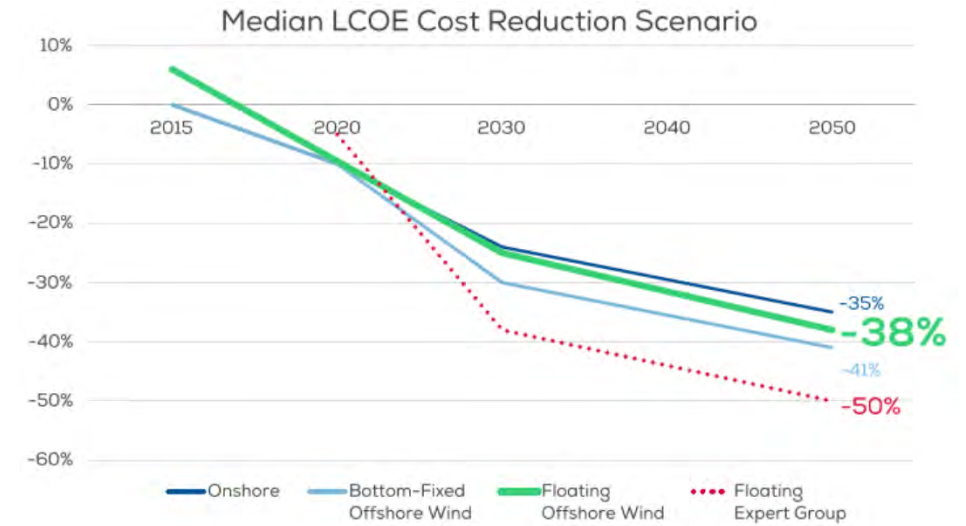
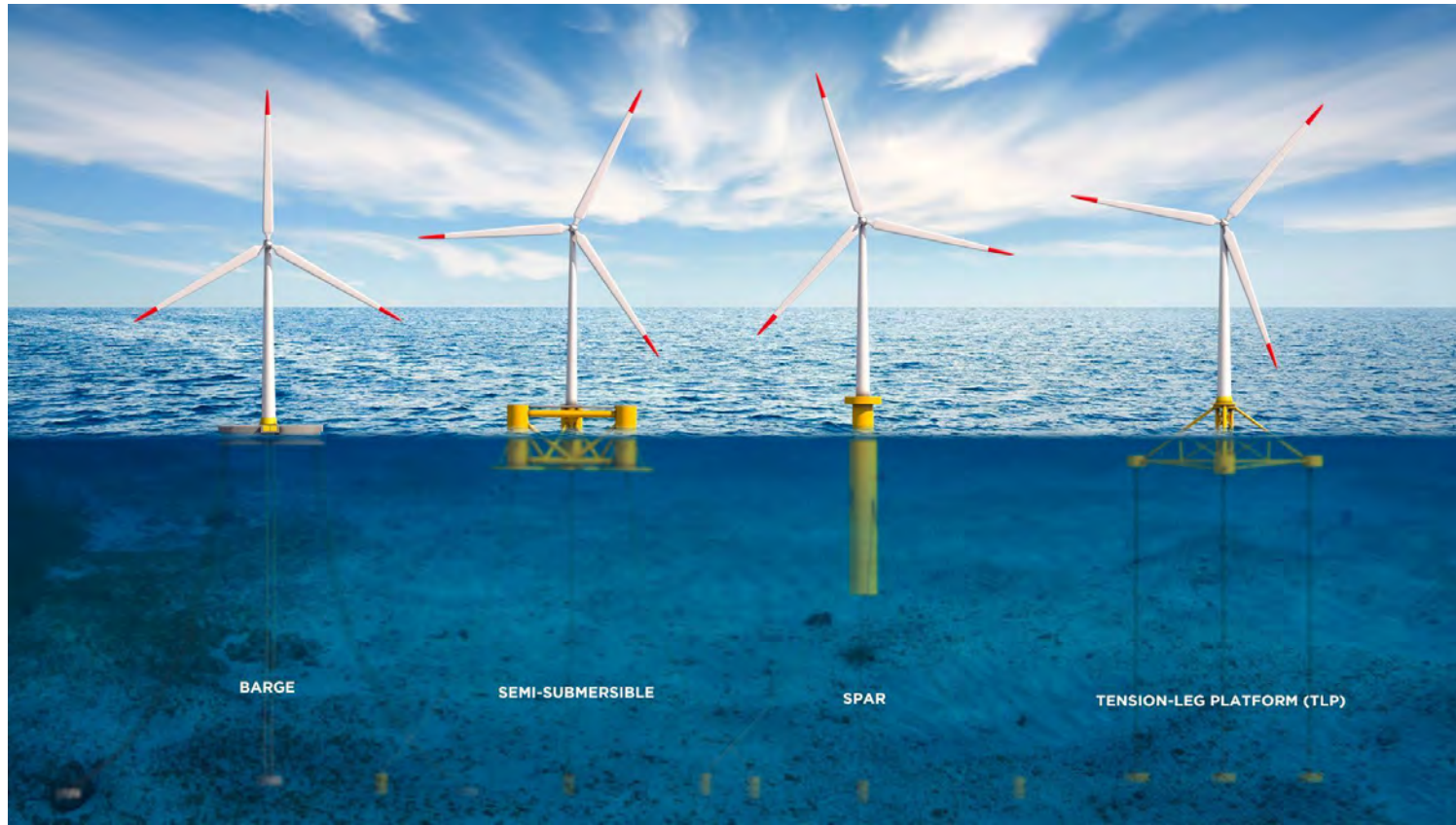


Technical challenge	Cost reduction potential	Urgency	IP sensitivity
Platform size & weight	2.7	2.4	2.8
Installation procedures	2.5	2.2	1.8
Port-side O&M (major repair procedures)	2.3	2.2	1.0
Floating substations/transformer modules	2.3	2.0	2.0
Advanced control systems for floating WTGs	2.2	2.2	2.6
Mooring 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

N.B. Scoring from 1-3; High = 3, Med = 2, Low = 1.

	Semi-submersible	Spar-buoy	TLP
1	> Platform size and weight	> Mooring design & installation	> Anchor design & installation
2	> Advanced control systems	> Platform size and weight (inc. reduced draft)	> Installation procedures (platform and moorings)
3	> Port-side major repair procedures	> Installation procedures (WTG assembly and mating)	> Platform size and weight

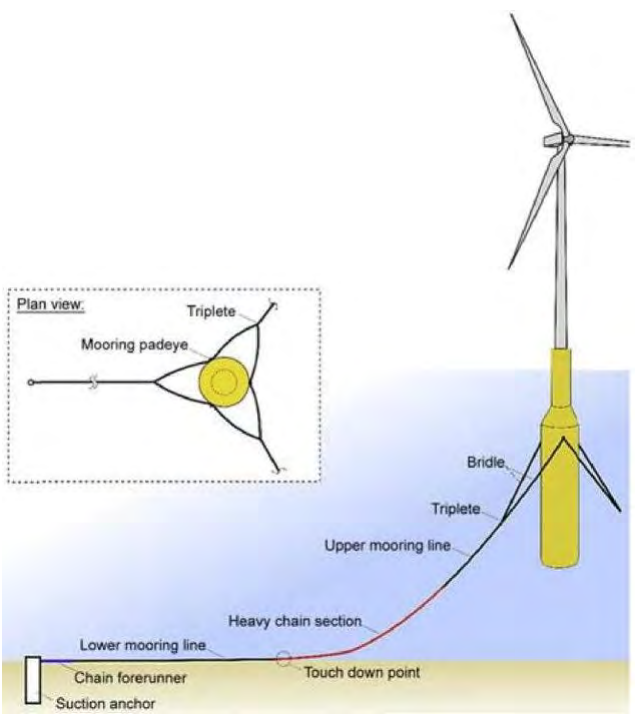
→ Diseño/Optimización plataforma



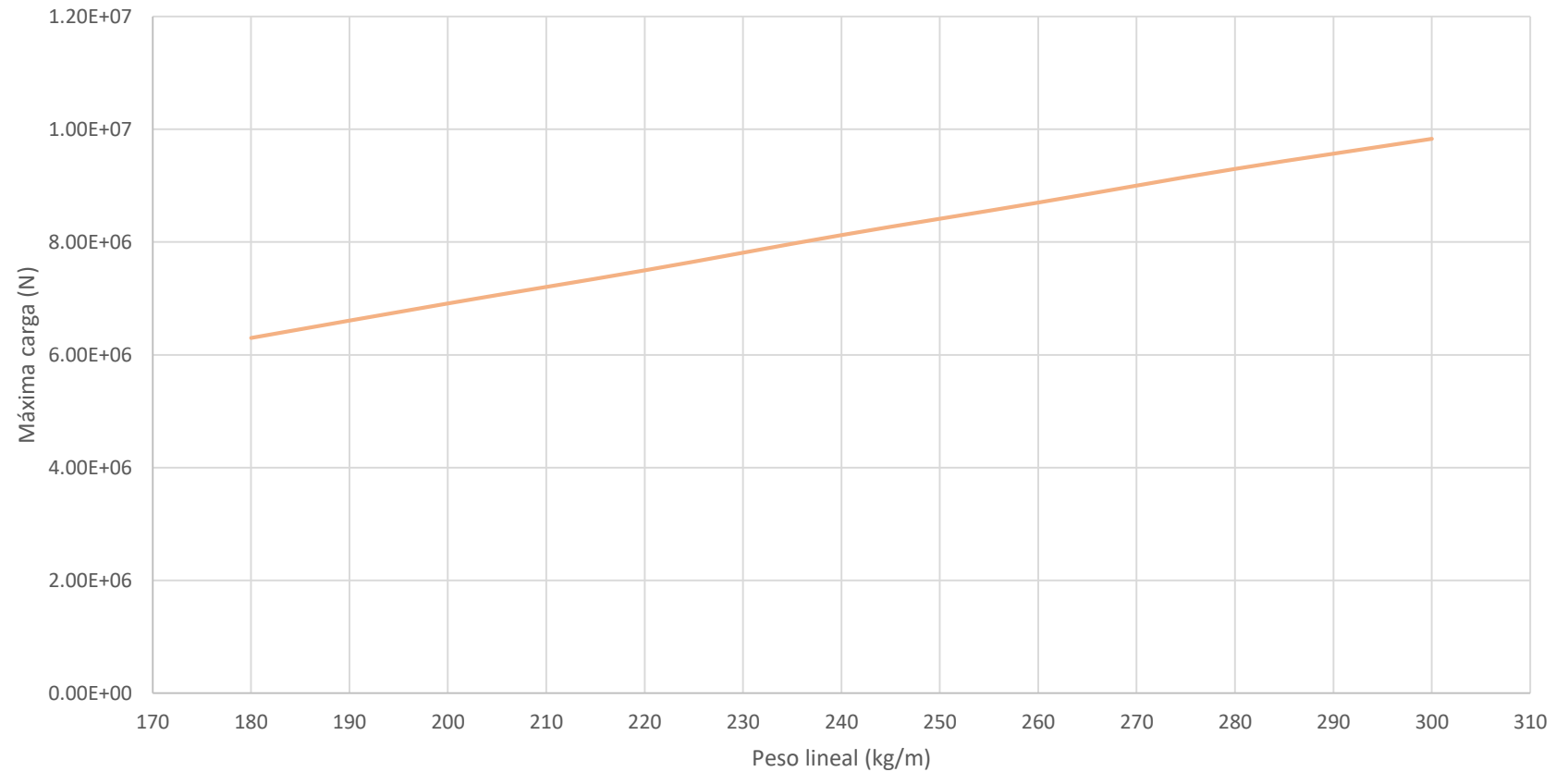


→ Optimización de los sistema de fondeo

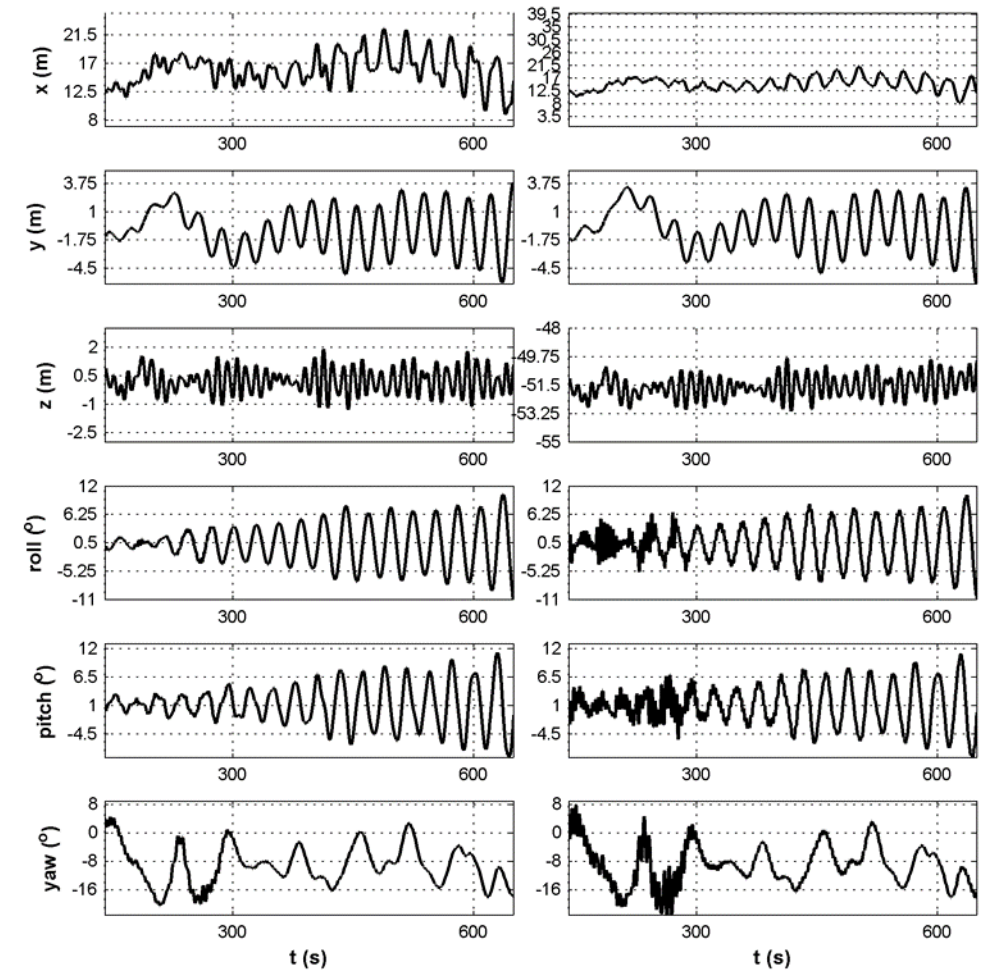
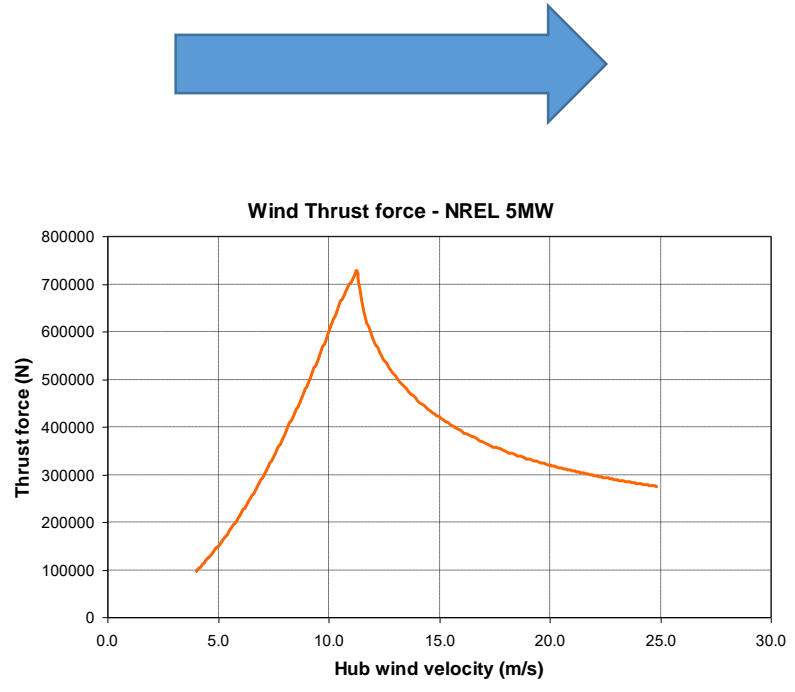
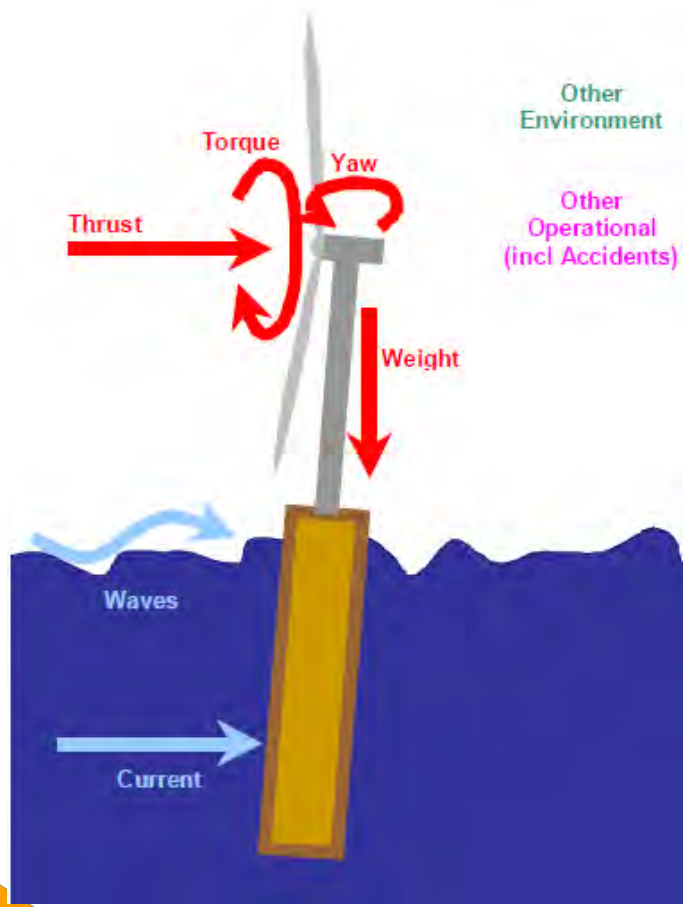
Ejemplo del sistema de fondeo de Hywind Scotland



Cargas máximas en una línea de fondeo en función del peso/metro de la línea de fondeo



→ Sistemas avanzados de control





→ Procedimientos de instalación

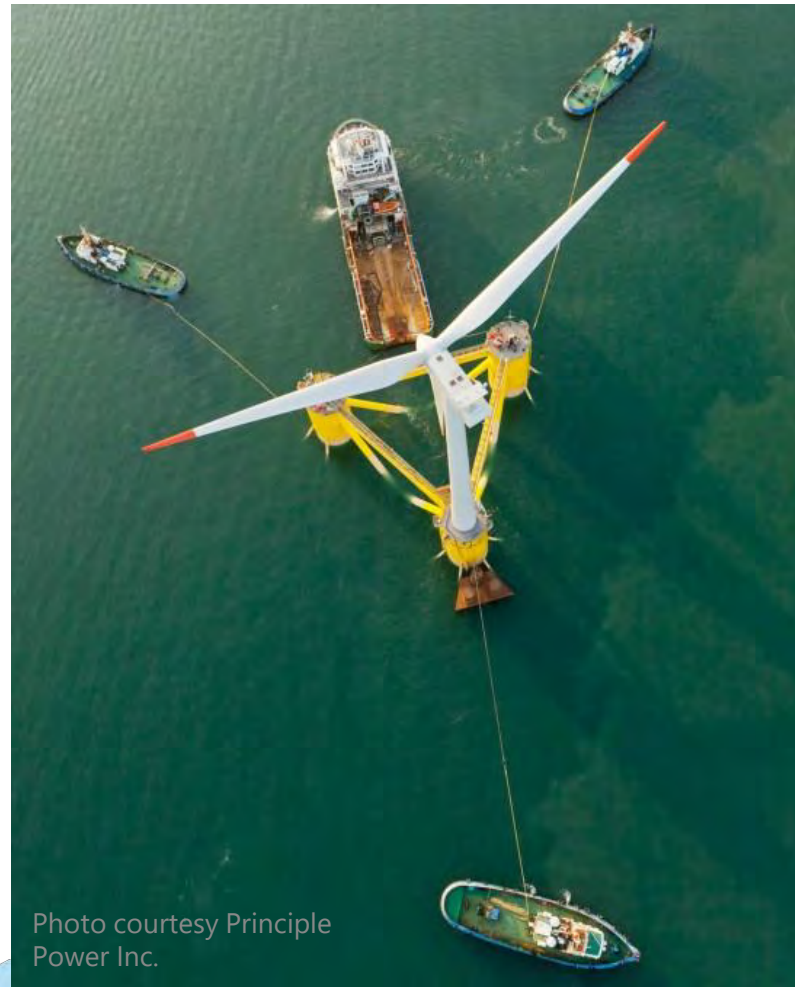


Photo courtesy Principle Power Inc.

Fixed-bottom installations		Floating wind installations	
Vessel	Day rate (€)	Vessel	Day rate (€)
Heavy lift vessel	150-500k	Standard tug	30-60k
Jack up vessel	150-200k	Anchor handling tug	20-50k
Mobilisation	Several M€	Mobilisation	<100k

Source: Carbon Trust

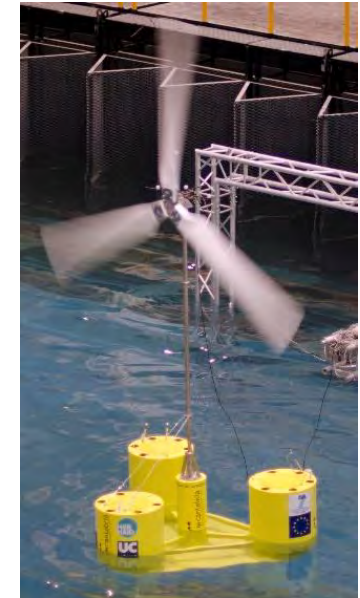
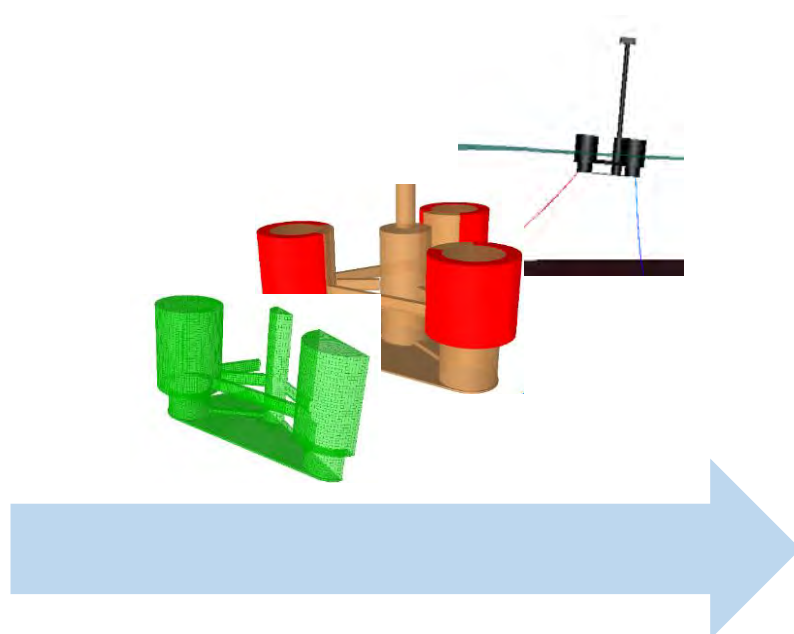
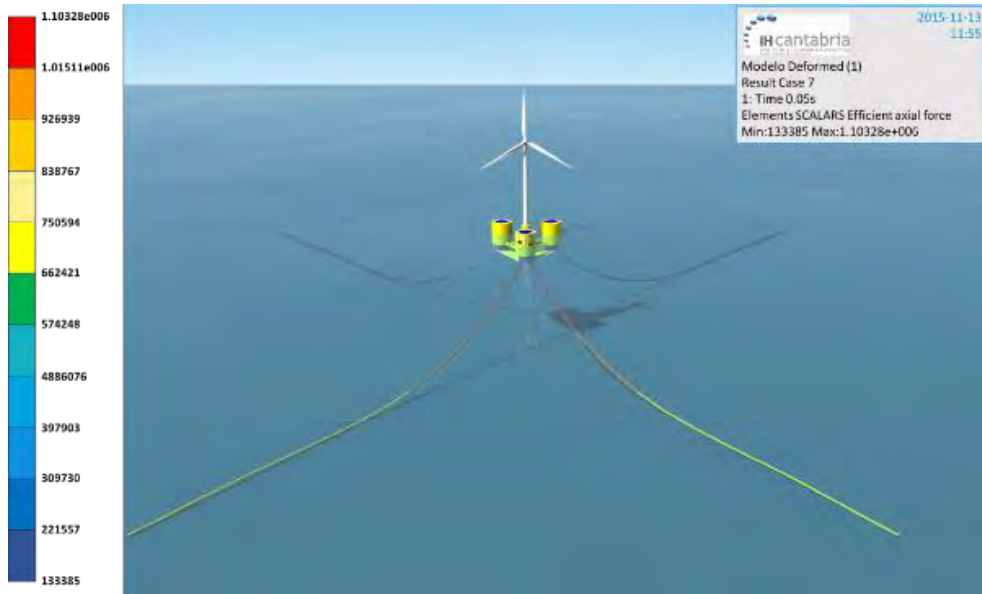
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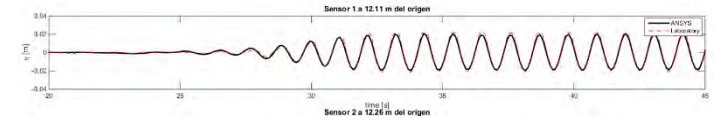
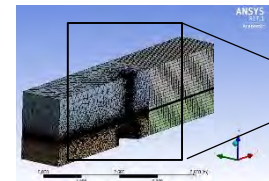
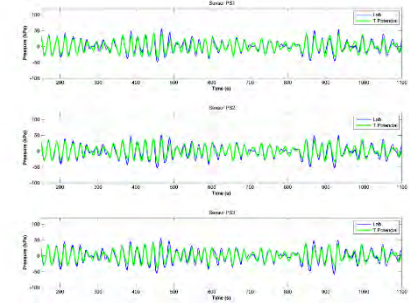
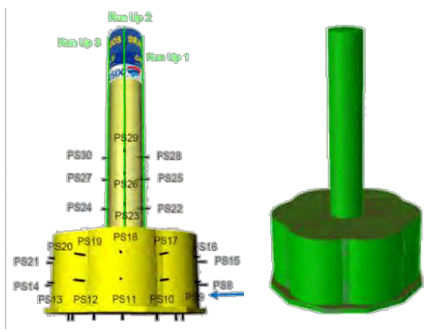
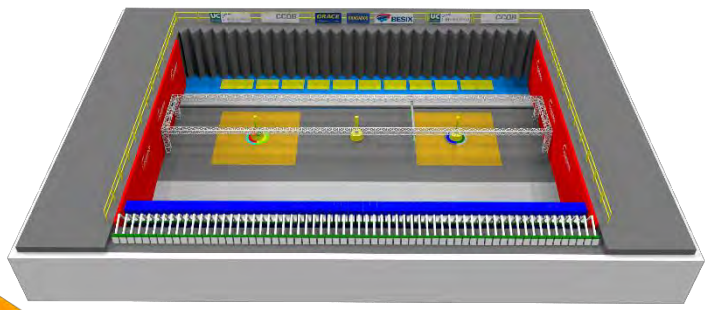
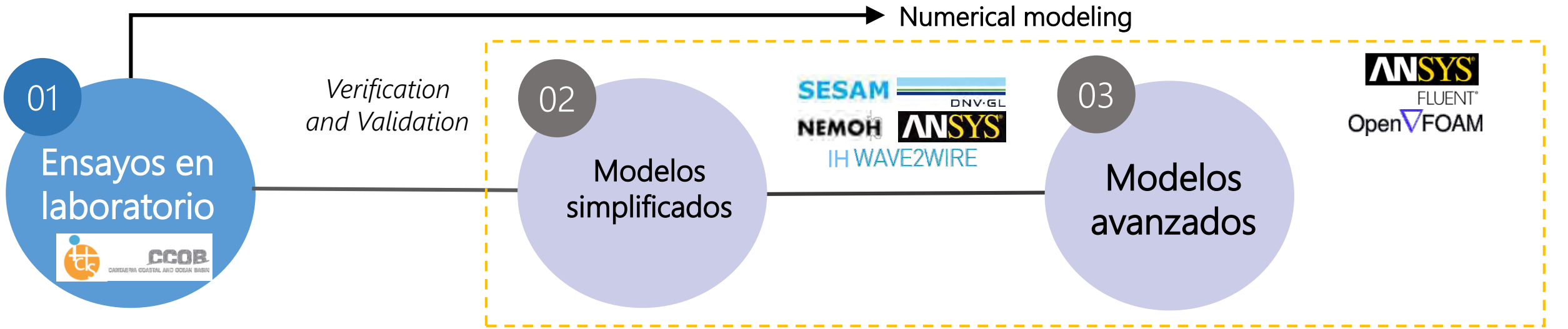
Afrontamos los retos científico-técnicos con una vision integral...



# Metodología híbrida

-Interacción fluido estructura-

¿Qué hace IHCantabria en eólica marina?





+ de 16 tecnologías fijas analizadas

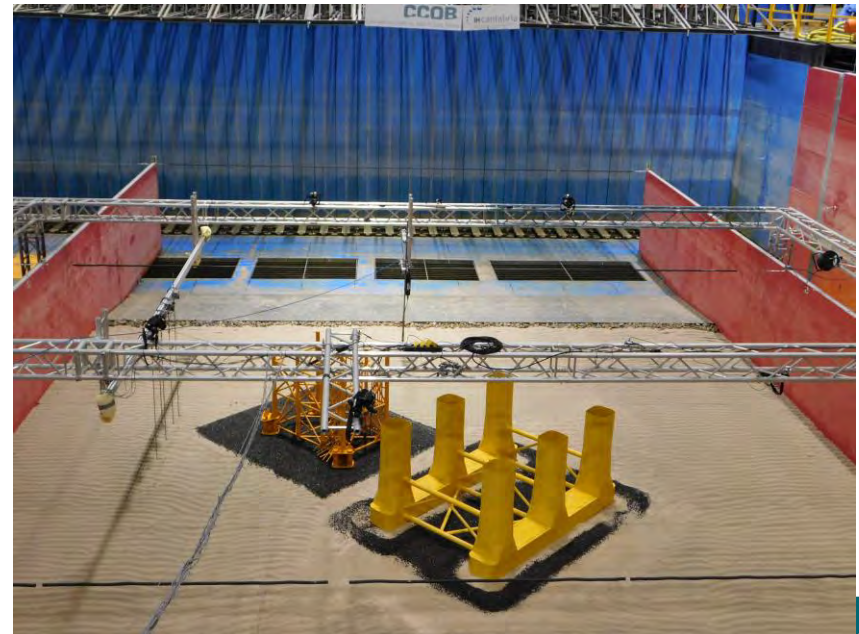
CCOB

CANTABRIA COASTAL AND OCEAN BASIN





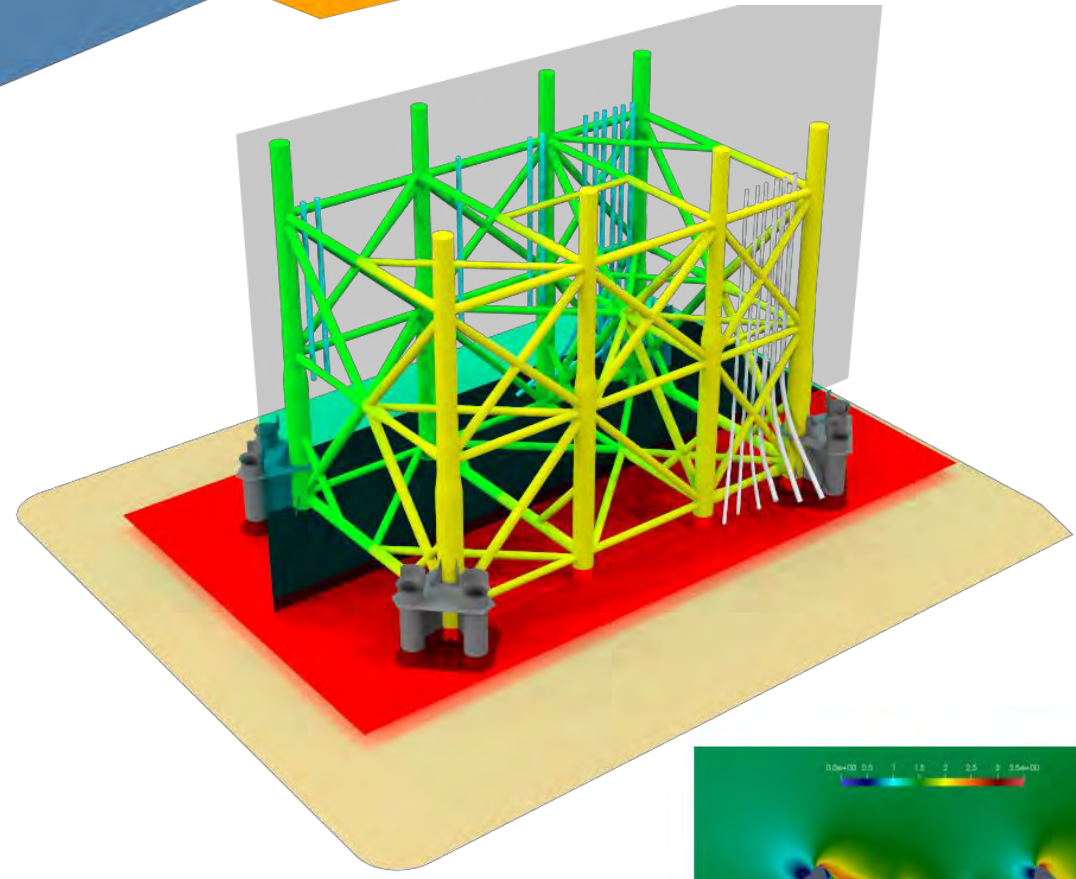
# ¿Qué hace IHCantabria en eólica marina?



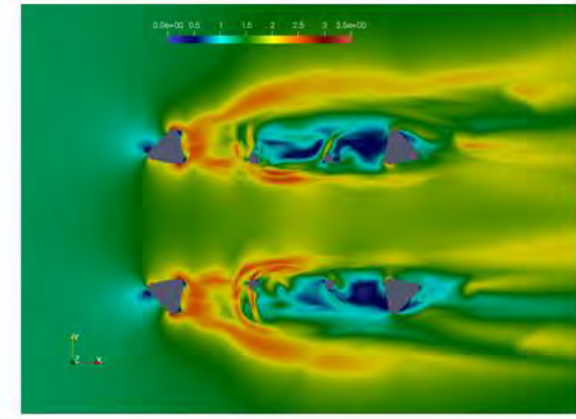
Dragados Offshore BUILDING EXCELLENCE WORLDWIDE



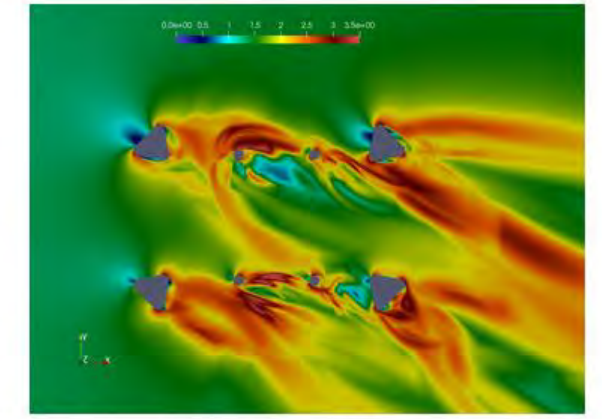
# ¿Qué hace IHCantabria en eólica marina?



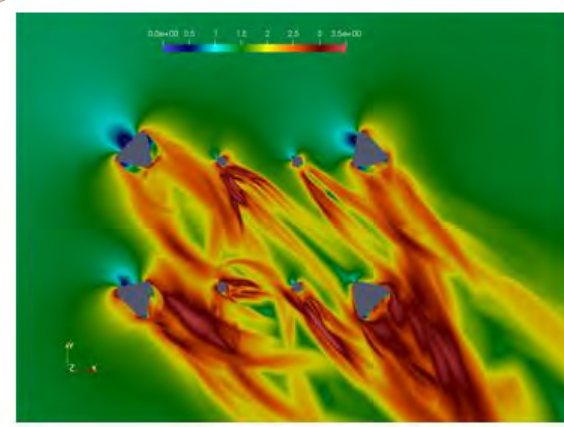
Dragados Offshore  
BUILDING EXCELLENCE WORLDWIDE



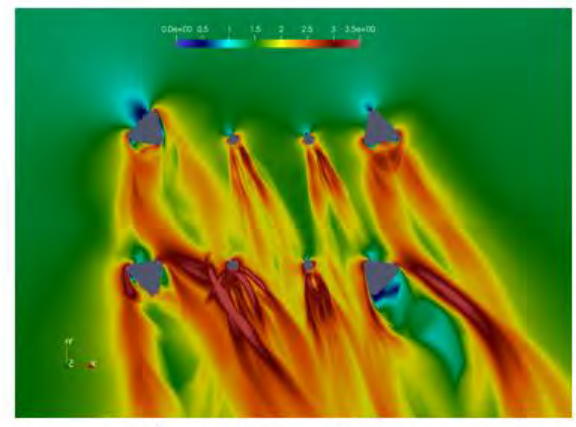
a) West



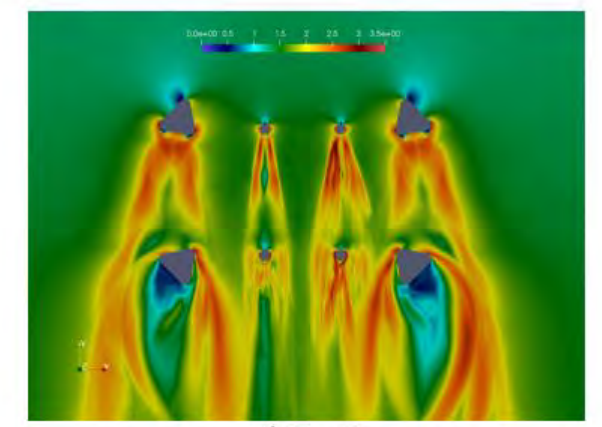
b) West North-West



c) North-West



d) North North-West



d) North



+ de 16 tecnologías flotantes analizadas

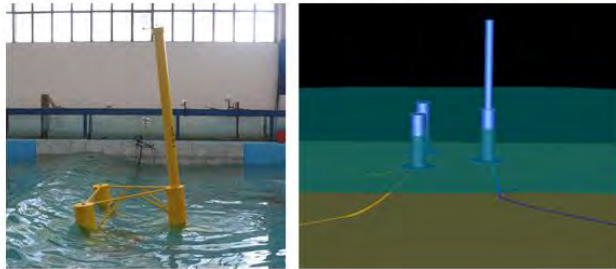
CCOB

CANTABRIA COASTAL AND OCEAN BASIN

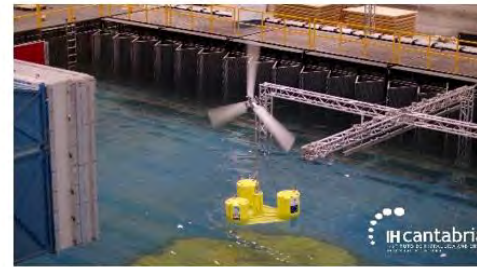
Idermar project



SAEMar: National research project



Mermaid Project: EC, FP 7



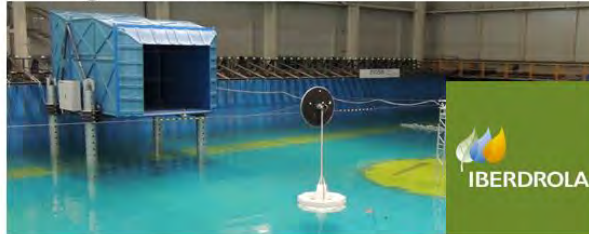
Nautilus Floating Solutions



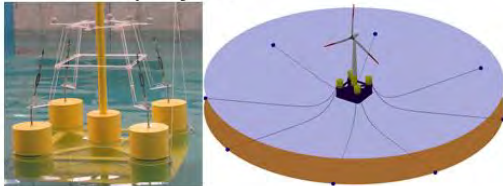
ELICAN project



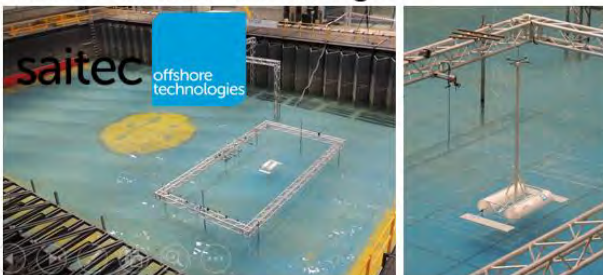
Emerge: IBERDROLA



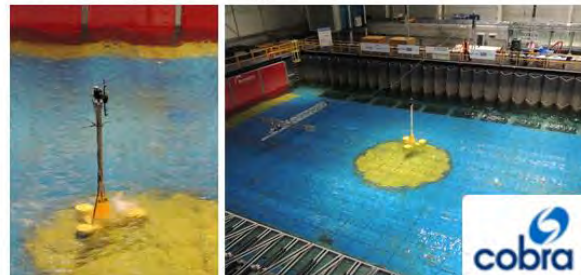
In house project



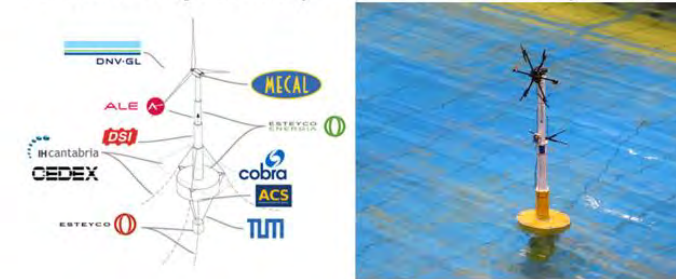
Saitec Offshore Technologies



Kinkardine: KOWL, COBRA

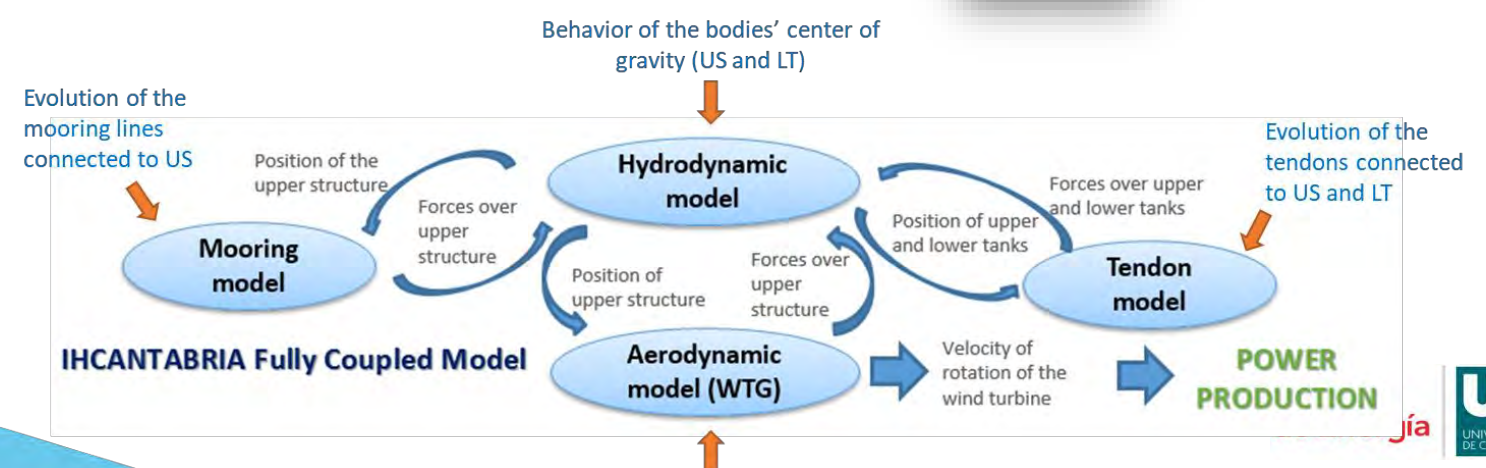
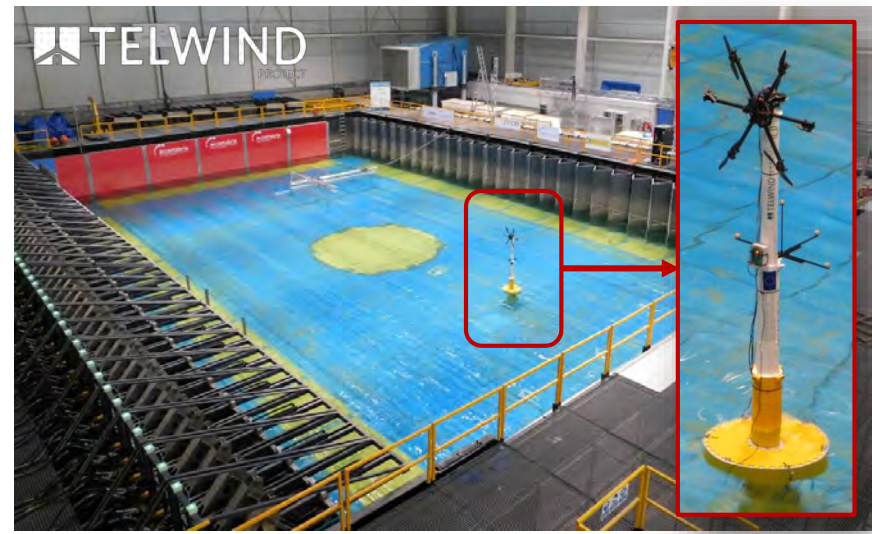
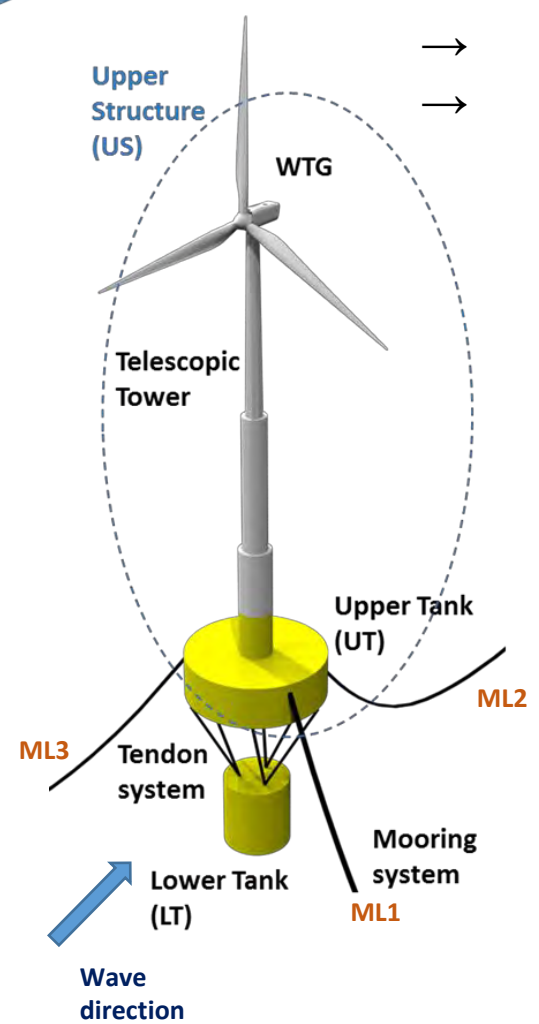


Telwind Project: EC (H2020-LCE-2015-1)





- Modelos de simulación avanzados
- Sistemas avanzados de control
- Técnicas de ensayo en tanque avanzadas

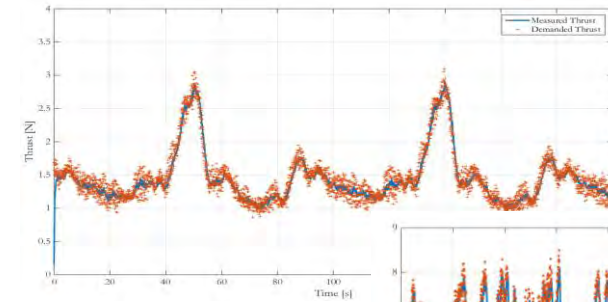
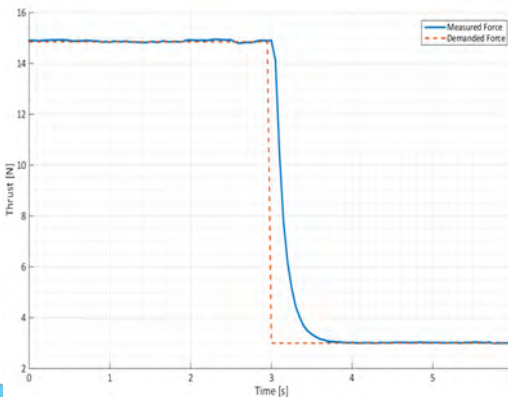
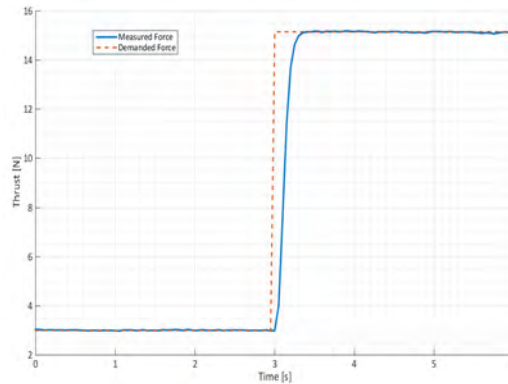
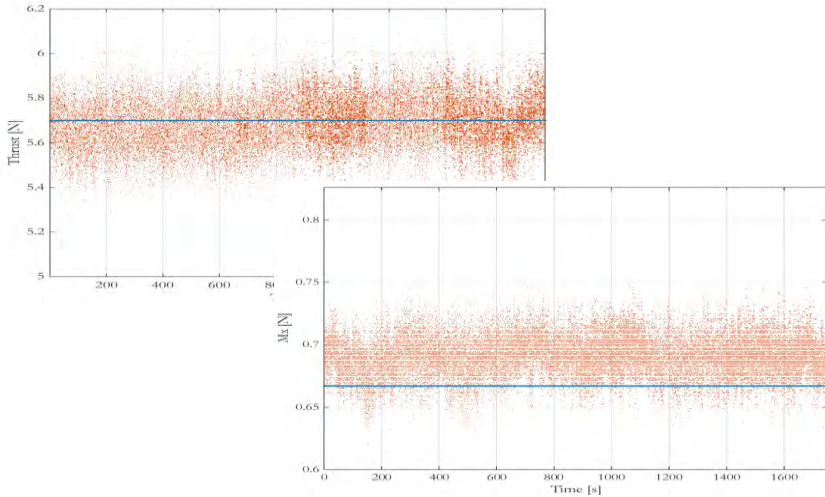


# Técnicas avanzadas de simulación aerodinámica en tanque

- NREL 5MW, 1:50 escala
- Empuje y momento aerodinámico constante

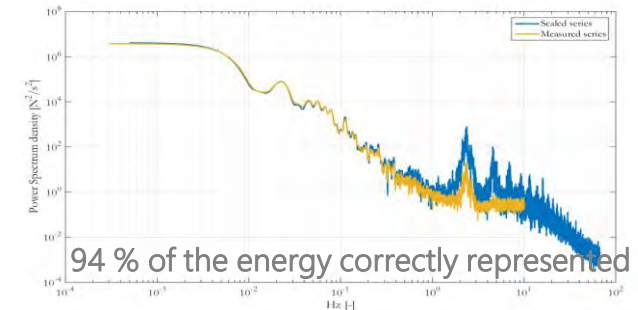
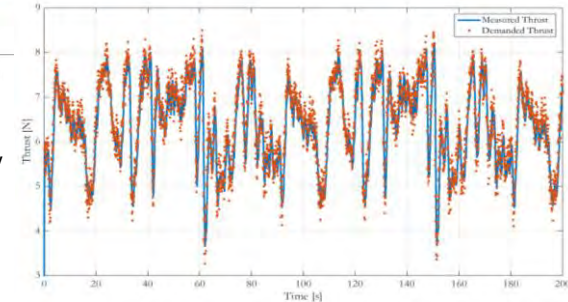
- Curvas de aceleración y deceleración
- Factor importante para los cambios rápidos de la intensidad (serie turbulenta, falta, parada de la emergencia)

- Serie de tiempo turbulenta proporcionada por el cliente
- Objetivo de comparación versus empuje medido



Algoritmo turbulento, media 4 m/s

Algoritmo turbulento, media 12 m/s



94 % of the energy correctly represented

	Mean Error	Std
<b>Thrust [N]</b>	0.25%	0.13
<b>Aerodynamic Moment [N·m]</b>	2.04 %	0.0017



Supporting MRE developers from concept to reality."

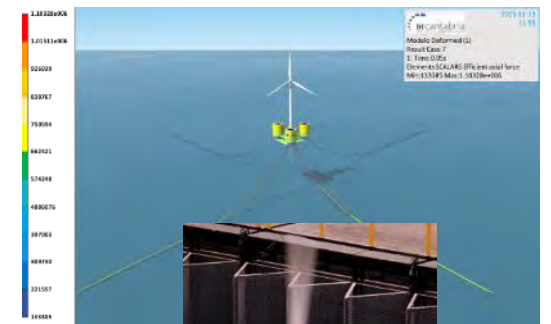
**TRL<sup>+</sup>** = **bimep** + **IH cantabria**  
INSTITUTO DE HIDRÁULICA AMBIENTAL  
UNIVERSIDAD DE CANTABRIA

**Test site**

**Research institute**



+



TRL 9

TRL 6 - 8

TRL 4 - 5

TRL 1 - 3

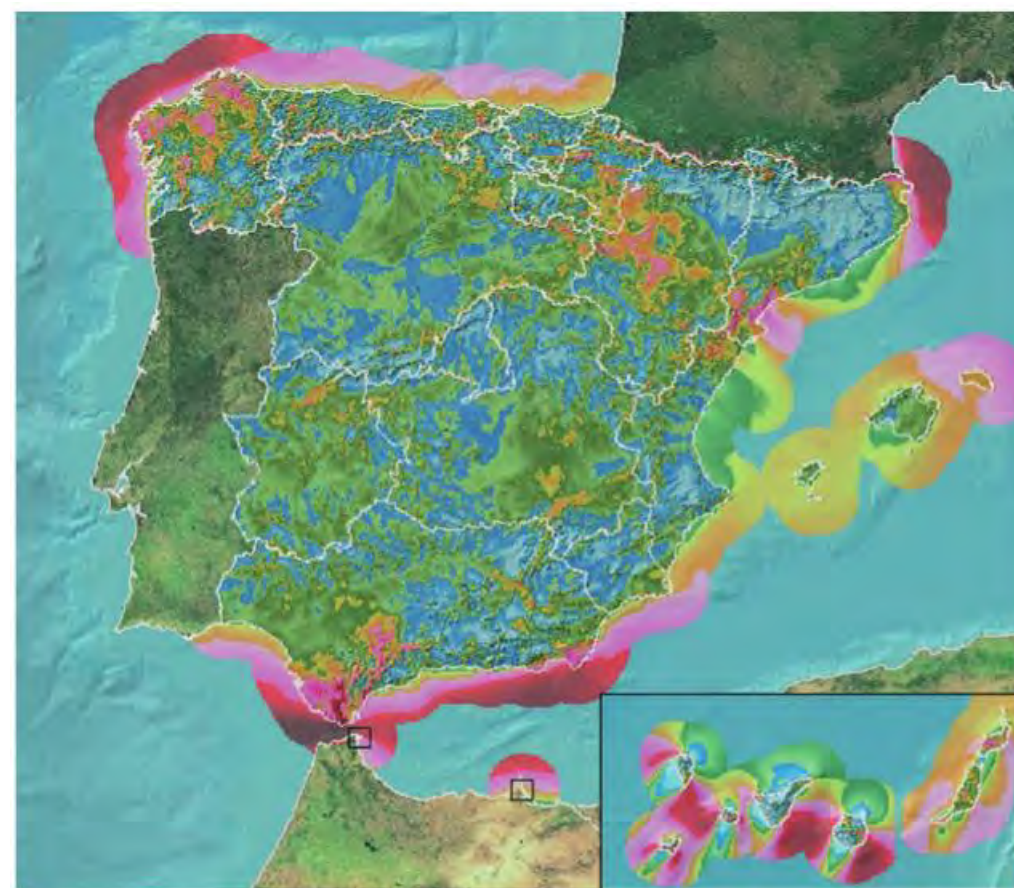
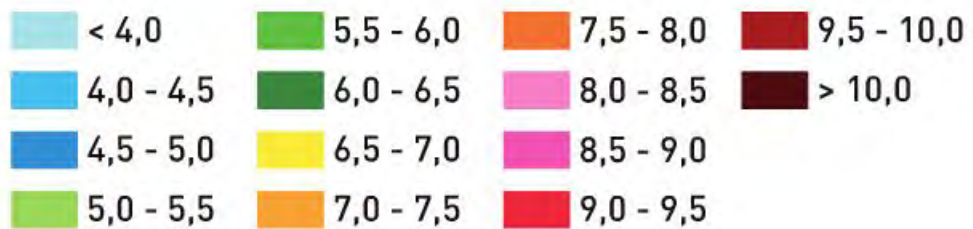


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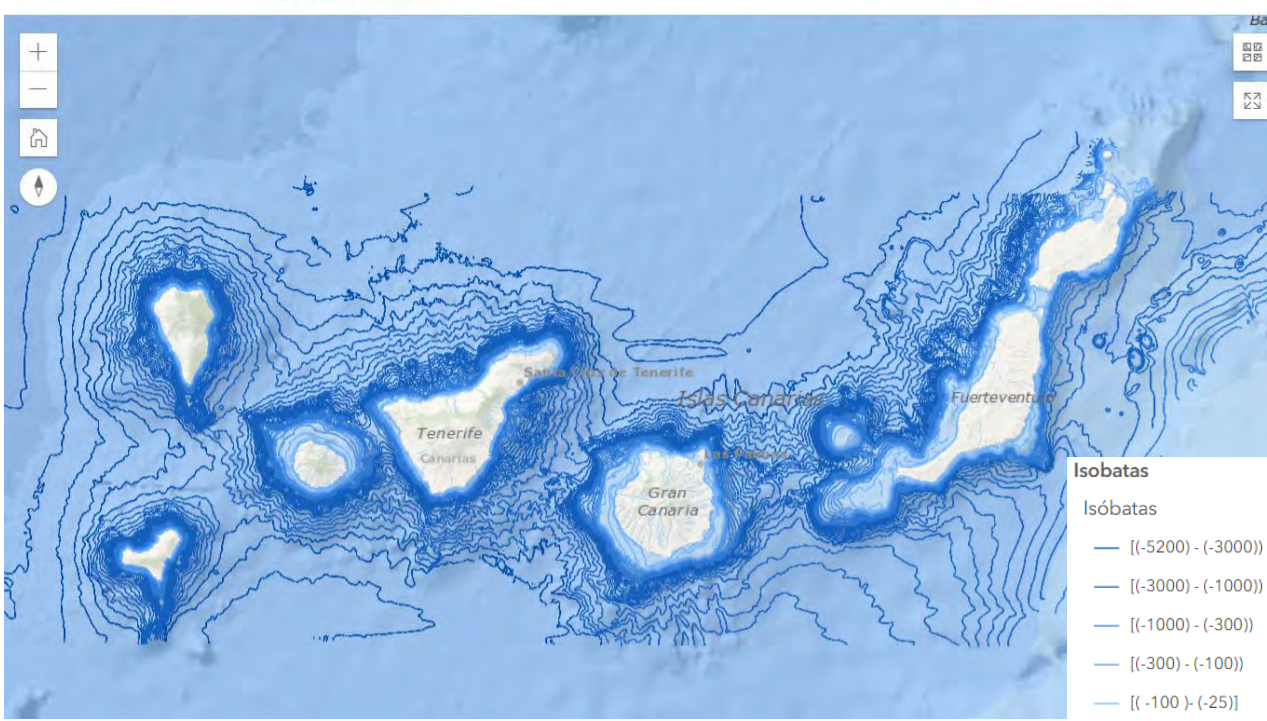
Viento medio a 100 m (m/s)



Horas eqv. a 80 m

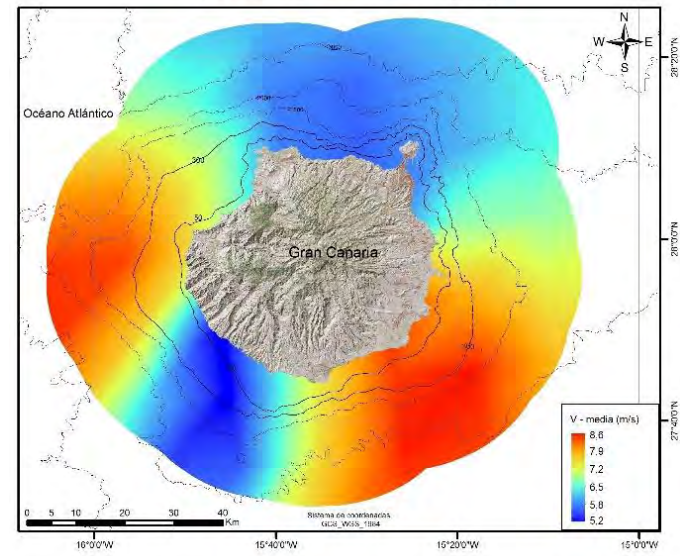




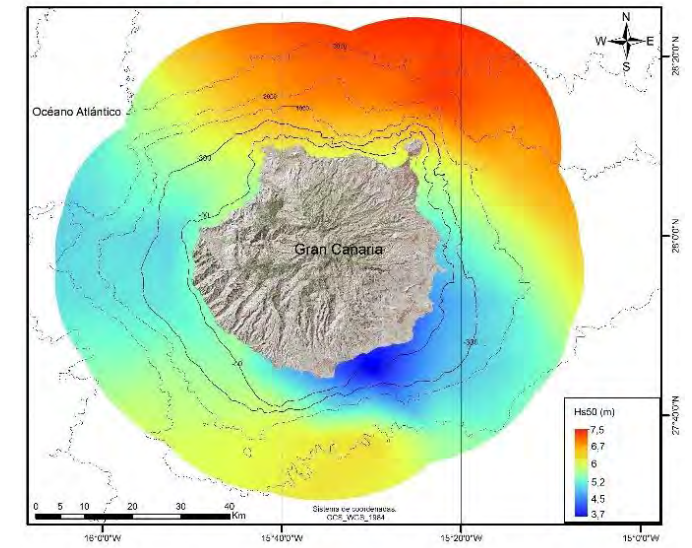




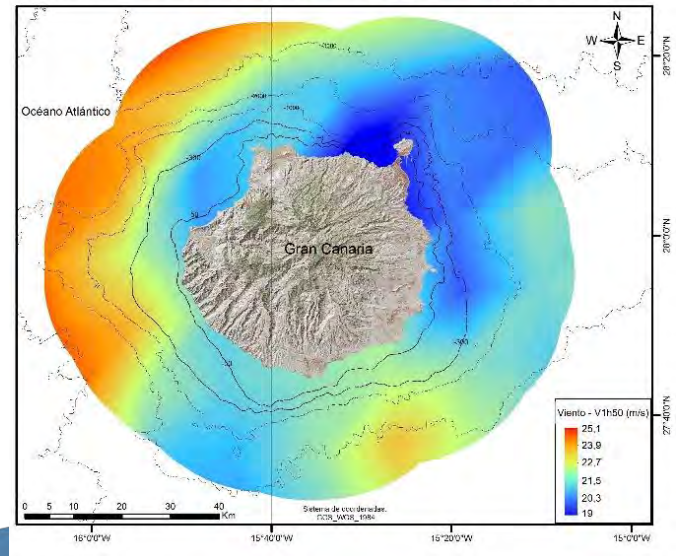
Velocidad del viento media (m/s)



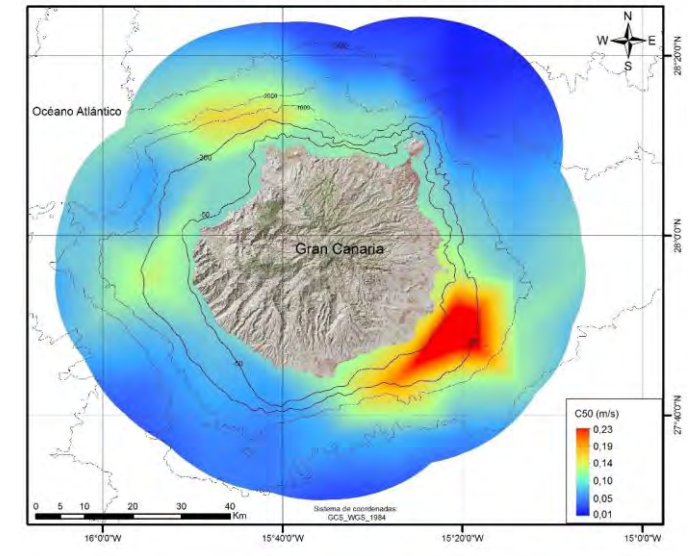
Altura de ola significativa de 50 años de periodo de retorno (m)



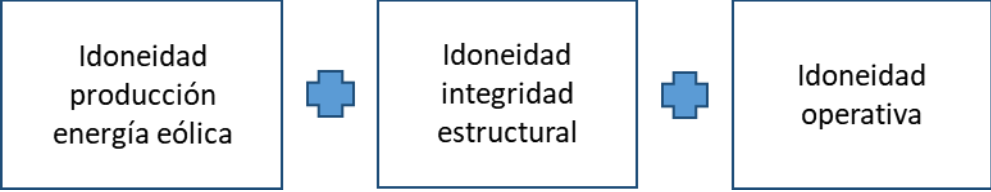
Velocidad de viento de 50 años de periodo de retorno (m/s)



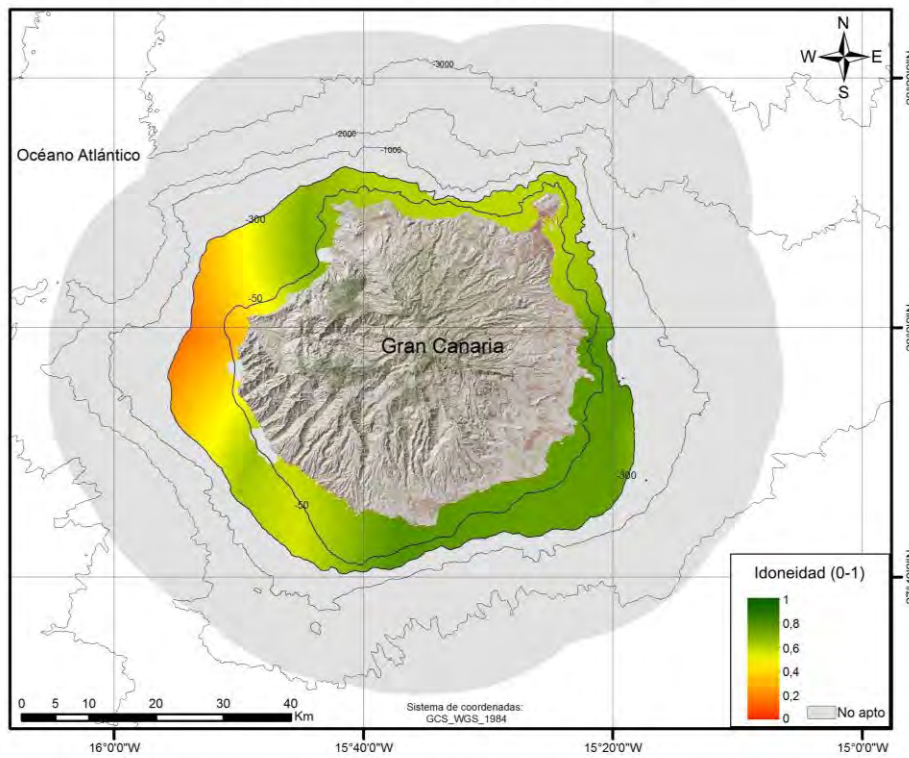
Velocidad de la corriente de 50 años de periodo de retorno (m/s)



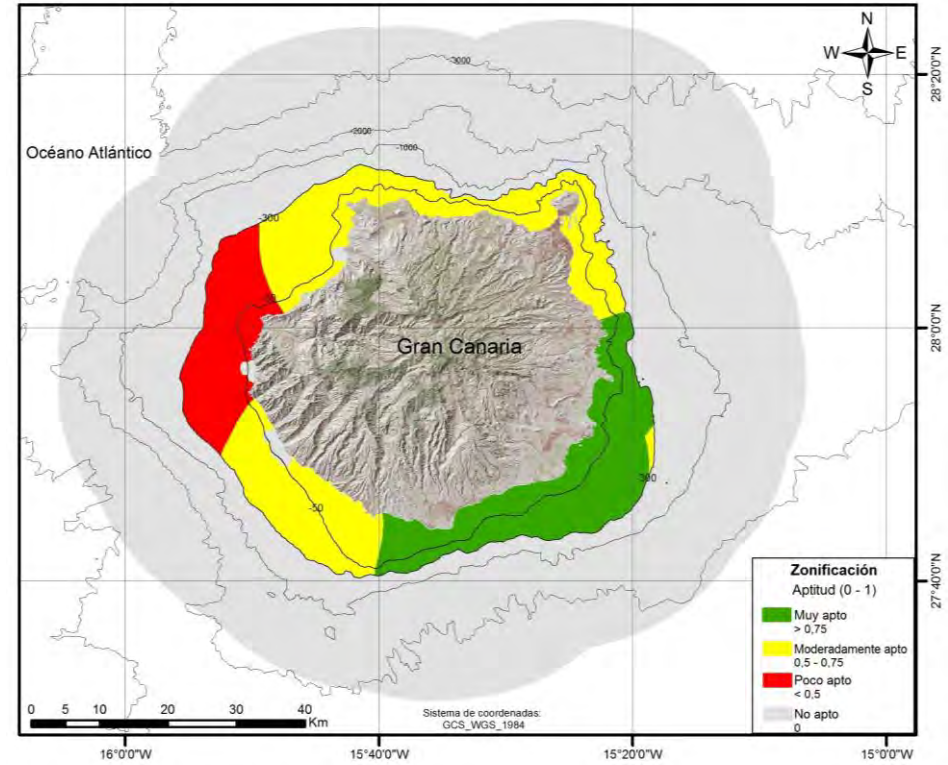




Mapa de idoneidad: Energía eólica



Mapa de zonificación: Energía eólica



Producción energética	Eólica
Viento (V, m/s)	4<V<25
Oleaje (Hs, m)	<5

Integridad estructural	
Viento (V, m/s)	<40
Oleaje (Hs, m)	<15
Corriente (C, m/s)	<0,5

Idoneidad Operativa	
Distancia a Puerto (km)	<40
Oleaje (Hs,m)	< 5
Viento (V,m/s)	< 15



# IHCANTABRIA

## INSTITUTO DE HIDRÁULICA AMBIENTAL DE CANTABRIA

### UNIVERSIDAD DE CANTABRIA

## Situación actual y futuro de la eólica marina

Cátedra  
de Energía



Raúl Guanche [guancher@unican.es](mailto:guancher@unican.es)

Santander, 13 de Marzo de 2019

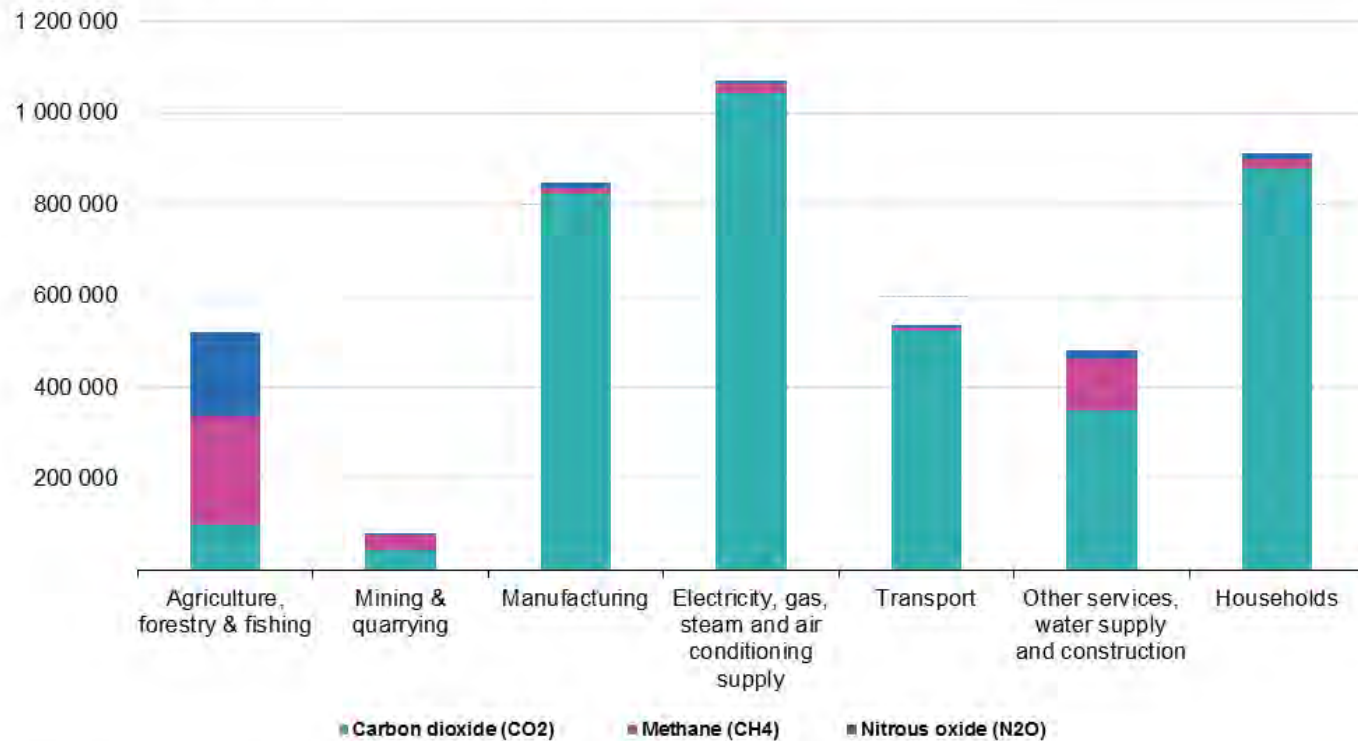




# Calentamiento Global

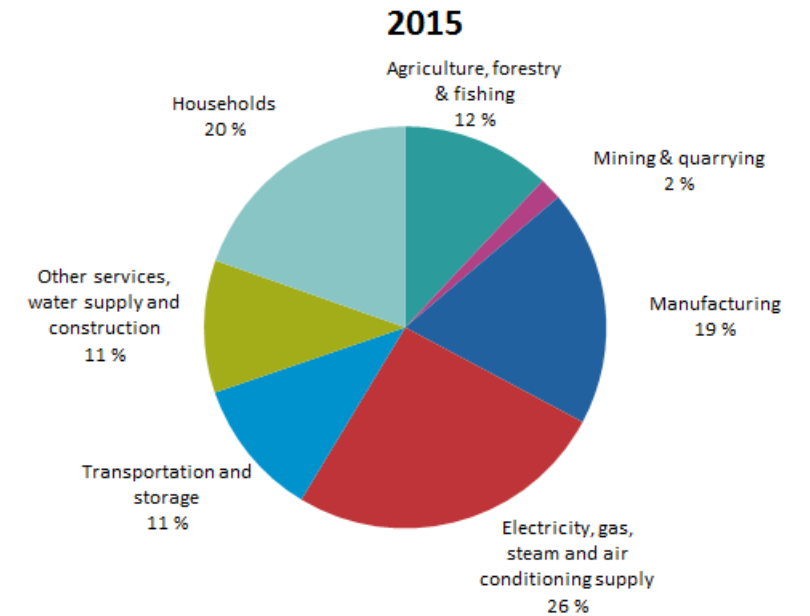
## Consenso internacional

**Greenhouse gas emissions by economic activity and by pollutant, EU-28, 2017**  
(thousand tonnes of CO2 equivalents)

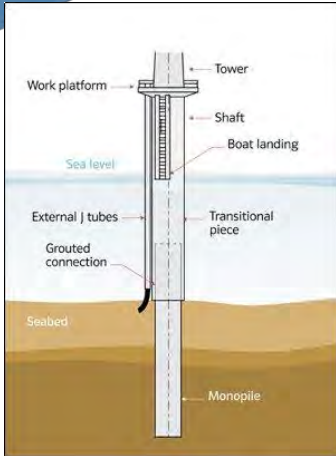


Source: Eurostat (online data code: env\_ac\_ainah\_r2)

**Greenhouse gas emissions by economic activity, EU-28, 2010 and 2015**  
(% of total emissions in CO2 equivalents)



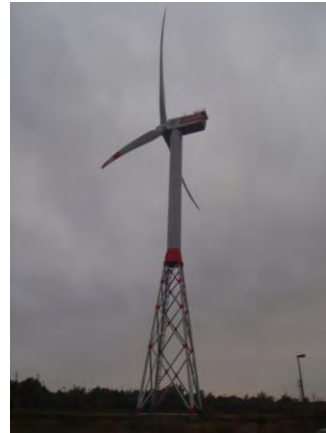
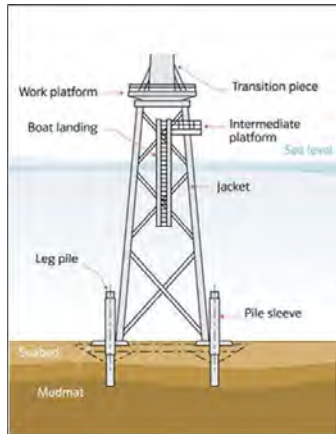
- agriculture, forestry and fishing — NACE Rev. 2 Section A;
- mining and quarrying — NACE Rev. 2 Section B;
- manufacturing — NACE Rev. 2 Section C;
- electricity, gas, steam and air conditioning supply — NACE Rev. 2 Section D;
- transportation and storage — NACE Rev. 2 Section H;
- other services, water supply and construction — NACE Rev. 2 Sections E to G and I; in other words all remaining economic activities as defined in NACE;
- households — households as consumers.



## Monopilotes

- Diseño muy simple y eficiente, estructura tubular de acero hincada en el terreno sobre la que se instala una pieza de transición sobre la que se instala la torre eólica.
- Es la estructura más empleada debido a su simplicidad en el modo de instalación y costs reducidos.
- Es la estructura óptima para profundidades entre 0-30 m.

## Jackets



(4COffshore)


- Estructura en celosía de planta rectangular o triangular construida mediante tubos de acero de sección circular.
- Instalada y fijada al terreno mediante pilotes (solución principal), “suction buckets” o por gravedad.
- De acuerdo con los estándares habituales, es la solución adecuada para profundidades entre 30 y 50m (DNV).




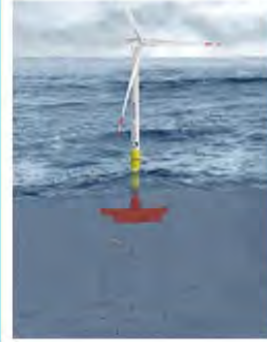
# La energía eólica marina en aguas profundas

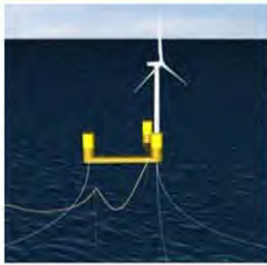



abria  
SOLUCIONES AMBIENTALES


Advanced Spar		Japan Marine United		
	Classification:	Spar	Primary material:	Steel
	Depth range:	80m+	Moorings:	3 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	Marubeni Corporation	TRL:	4
	Full-scale prototype:	2013 (sub-station)	Pre-commercial array:	TBC


Hybrid concrete-steel spar		Toda Construction		
	Classification:	Spar	Primary material:	Concrete/steel hybrid
	Depth range:	100m+	Moorings:	3 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	-	TRL:	4
	Full-scale prototype:	2013	Pre-commercial array:	TBC

PelaStar		Glosten Associates		
	Classification:	TLP	Primary material:	Steel
	Depth range:	70-200m	Moorings:	5 taut-leg
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	Alstom	TRL:	3
	Full-scale prototype:	TBC	Pre-commercial array:	TBC

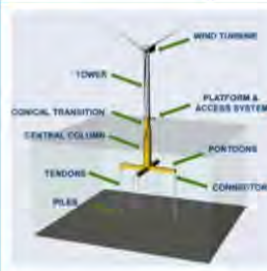
V-Shape Semi-Sub		Mitsubishi Heavy Industries		
	Classification:	Semi-sub	Primary material:	Steel
	Depth range:	Undisclosed	Moorings:	8 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	Marubeni Corporation	TRL:	3
	Full-scale prototype:	2015	Pre-commercial array:	TBC

VolturnUS		DeepCWind Consortium		
	Classification:	Semi-sub	Primary material:	Concrete
	Depth range:	Undisclosed	Moorings:	Undisclosed
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	-	TRL:	3
	Full-scale prototype:	2018	Pre-commercial array:	TBC

GICON-SOF		GICON		
	Classification:	TLP	Primary material:	Steel
	Depth range:	40-250m	Moorings:	8 taut-leg
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	-	TRL:	3
	Full-scale prototype:	2015	Pre-commercial array:	2017

WindCrete		Universitat Politècnica de Catalunya		
	Classification:	Spar	Primary material:	Concrete
	Depth range:	150-1000m	Moorings:	3 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	-	TRL:	3
	Full-scale prototype:	TBC	Pre-commercial array:	TBC

Compact Semi-Sub		Mitsui Engineering & Shipbuilding		
	Classification:	Semi-sub	Primary material:	Steel
	Depth range:	Undisclosed	Moorings:	6 catenary
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	Marubeni Corporation	TRL:	4
	Full-scale prototype:	2013	Pre-commercial array:	TBC

TLPWind		Iberdrola		
	Classification:	TLP	Primary material:	Steel
	Depth range:	Undisclosed	Moorings:	4 taut (8 tendons)
	Turbine axis:	Horizontal	No. blades:	3
	Industrial partner(s):	-	TRL:	3
	Full-scale prototype:	TBC	Pre-commercial array:	TBC



# La energía eólica marina en aguas profundas

TetraFloat		TetraFloat Ltd.			
	Classification:	Semi-sub	Primary material:	Steel	
	Depth range:	30-200m	Moorings:	1 catenary chain	
	Turbine axis:	Horizontal	No. blades:	3	
	Industrial partner(s):	-	TRL:	3	
	Full-scale prototype:	TBC	Pre-commercial array:	TBC	

VERTIWIND		Technip/Nenuphar			
	Classification:	Semi-sub	Primary material:	Steel	
	Depth range:	50m+	Moorings:	3 catenary	
	Turbine axis:	Vertical	No. blades:	3	
	Industrial partner(s):	EDF Energy; Areva	TRL:	3	
	Full-scale prototype:	2016	Pre-commercial array:	2018	

SeaReed		DCNS			
	Classification:	Semi-sub	Primary material:	Steel	
	Depth range:	50-200m	Moorings:	Undisclosed	
	Turbine axis:	Horizontal	No. blades:	3	
	Industrial partner(s):	Alstom	TRL:	3	
	Full-scale prototype:	2018	Pre-commercial array:	2020	

Eco TLP		DBD Systems			
	Classification:	TLP	Primary material:	Concrete	
	Depth range:	100m+	Moorings:	Undisclosed	
	Turbine axis:	Horizontal	No. blades:	3	
	Industrial partner(s):	-	TRL:	3	
	Full-scale prototype:	2018	Pre-commercial array:	TBC	

SPINFLOAT		EOLFI/GustoMSC			
	Classification:	Semi-sub	Primary material:	Steel	
	Depth range:	50-300m	Moorings:	3 catenary	
	Turbine axis:	Vertical	No. blades:	3	
	Industrial partner(s):	-	TRL:	Undisclosed	
	Full-scale prototype:	TBC	Pre-commercial array:	TBC	

Nautilus Semi-Sub		Nautilus Floating Solutions			
	Classification:	Semi-sub	Primary material:	Steel	
	Depth range:	60-150m	Moorings:	4	
	Turbine axis:	Horizontal	No. blades:	3	
	Industrial partner(s):	-	TRL:	3	
	Full-scale prototype:	TBC	Pre-commercial array:	TBC	

Hexicon		Hexicon			
	Classification:	Multi-turbine platform	Primary material:	Steel	
	Depth range:	50-500m	Moorings:	8 catenary	
	Turbine axis:	3 x Horizontal	No. blades:	3	
	Industrial partner(s):	-	TRL:	2	
	Full-scale prototype:	TBC	Pre-commercial array:	TBC	

Tri-Floater		GustoMSC			
	Classification:	Semi-sub	Primary material:	Steel	
	Depth range:	50-300m	Moorings:	3 catenary	
	Turbine axis:	Horizontal	No. blades:	3	
	Industrial partner(s):	-	TRL:	3	
	Full-scale prototype:	TBC	Pre-commercial array:	TBC	

Nezzy SCD		Aerodyn Engineering			
	Classification:	Semi-sub	Primary material:	Concrete	
	Depth range:	35-200m	Moorings:	5 semi-taut (turret system)	
	Turbine axis:	Horizontal	No. blades:	2	
	Industrial partner(s):	-	TRL:	2	
	Full-scale prototype:	TBC	Pre-commercial array:	TBC	



