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INSTITUTO DE HIDRÁULICA AMBIENTAL DE CANTABRIA
UNIVERSIDAD DE CANTABRIA

La energía eólica en alta mar (en aguas profundas, más de 50 m)
La experiencia internacional

Energía y medio ambiente en el mar

FUNDACIÓN NATURGY

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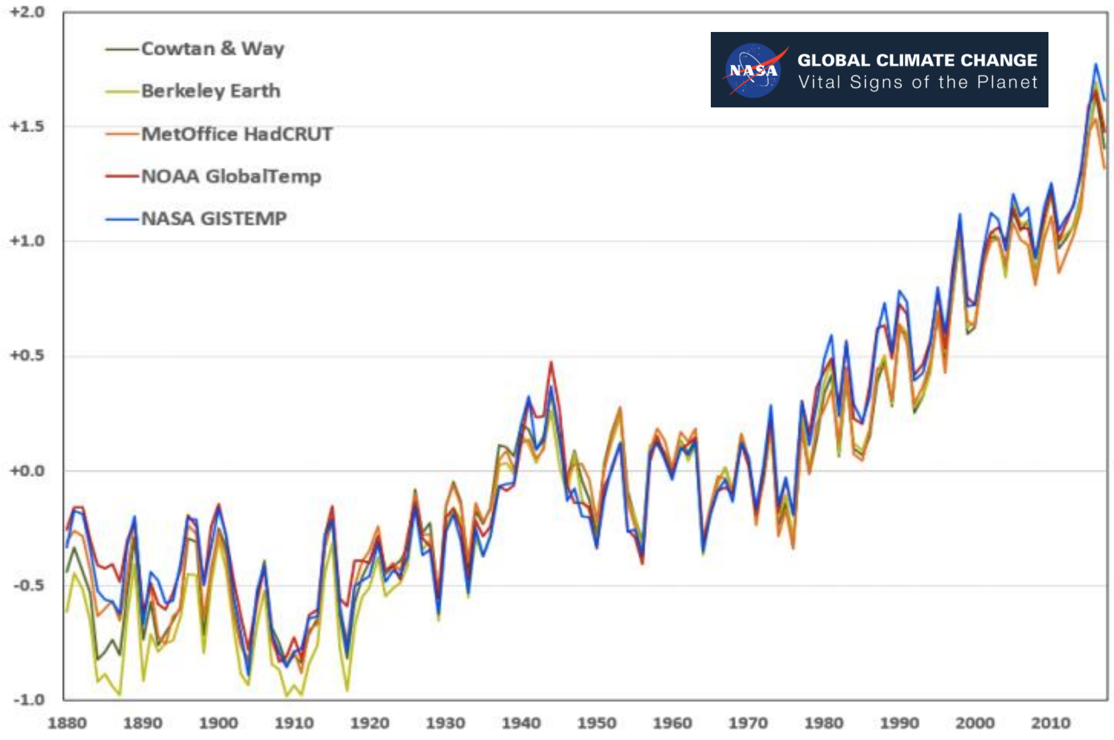
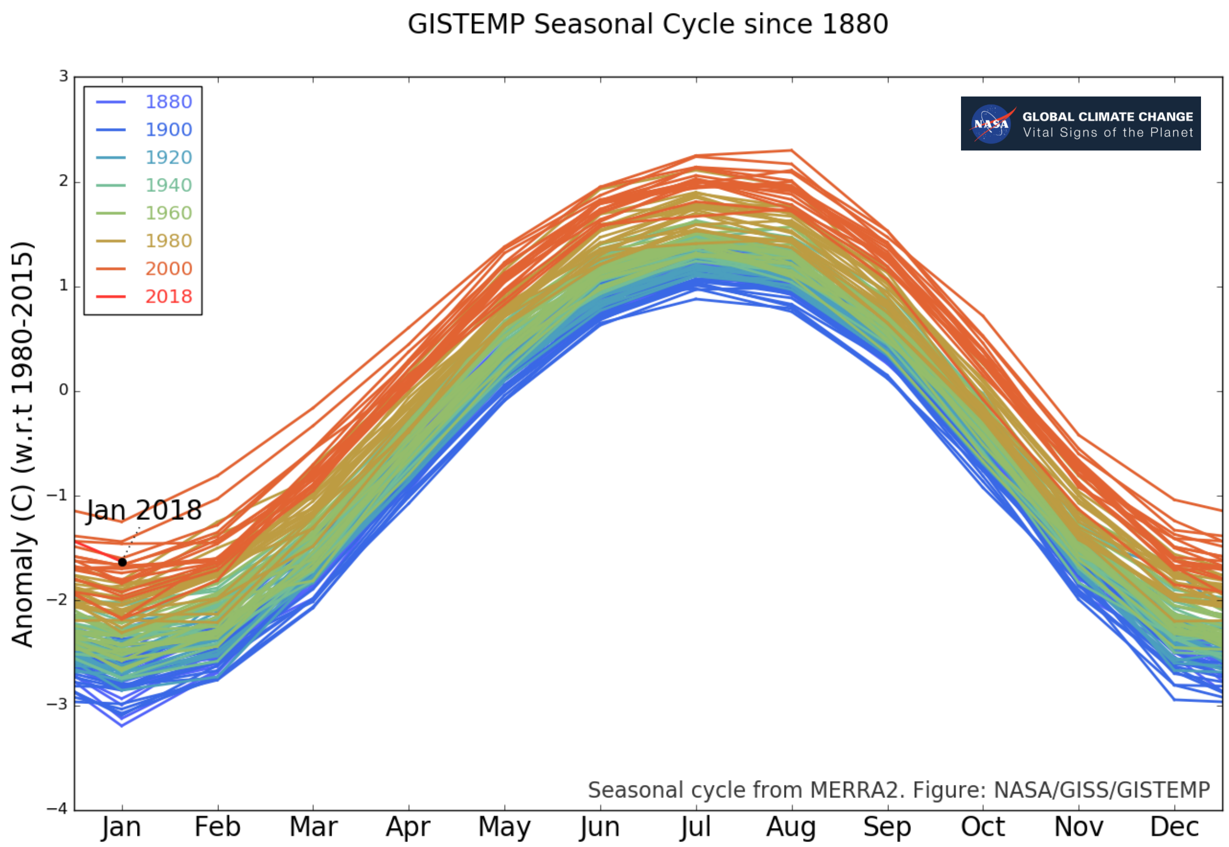
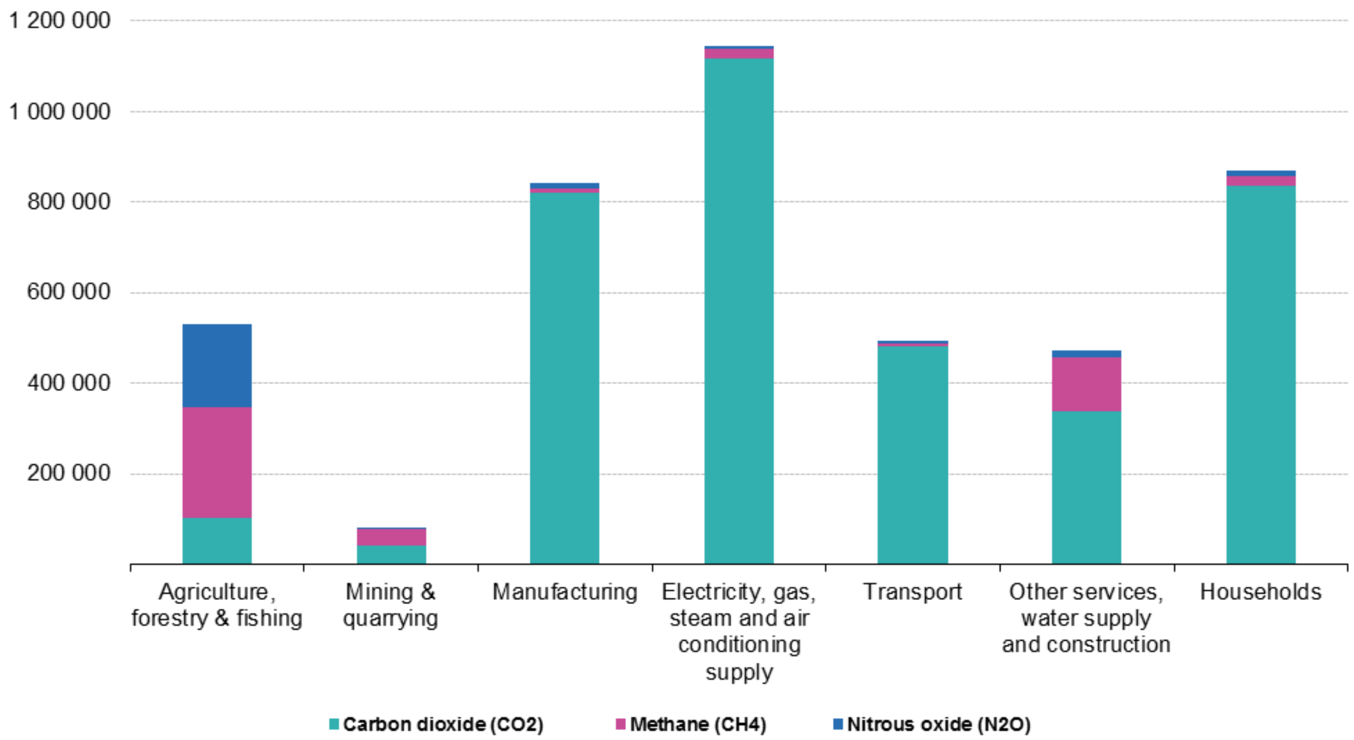




Calentamiento Global

Consenso internacional

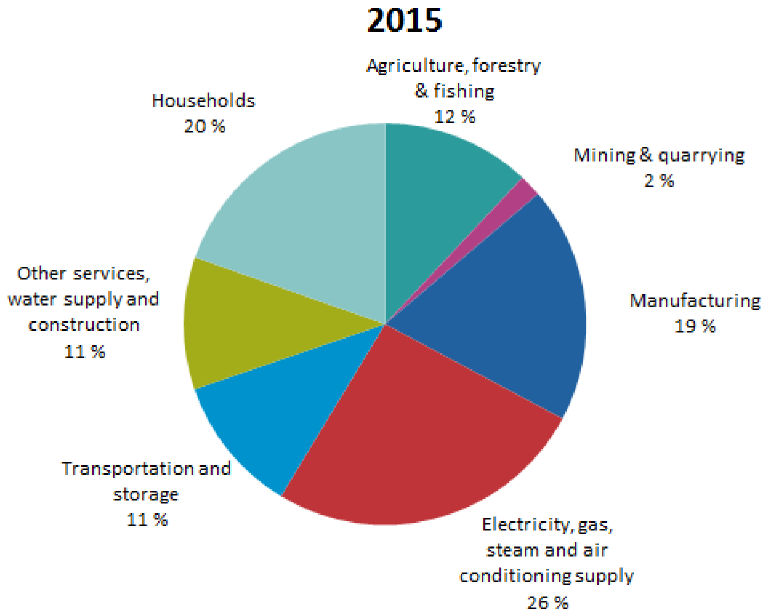
Greenhouse gas emissions by economic activity and by pollutant, EU-28, 2015
(thousand tonnes of CO_2 equivalents)



Source: Eurostat (online data code: env_ac_ainah_r2)

eurostat

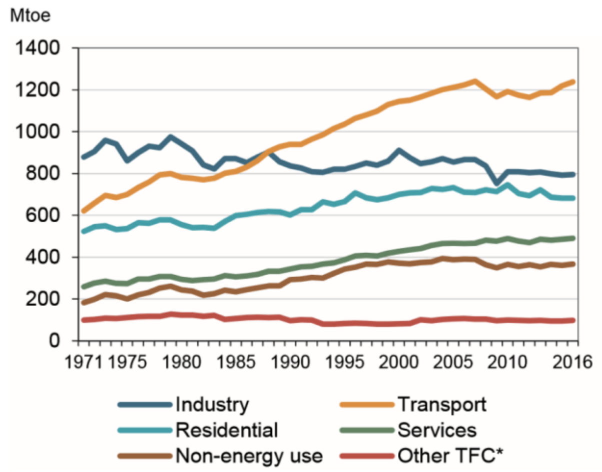
Greenhouse gas emissions by economic activity, EU-28, 2010 and 2015
(% of total emissions in CO_2 equivalents)



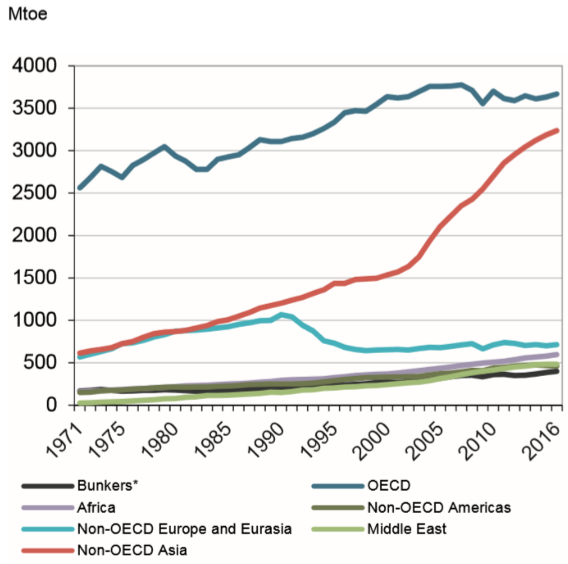
eurostat

Consumo energético en la OCDE – 2017

WORLD ENERGY BALANCES: OVERVIEW (2018 edition) - IEC



*Other TFC includes agriculture, forestry, fishing and non-specified (other).



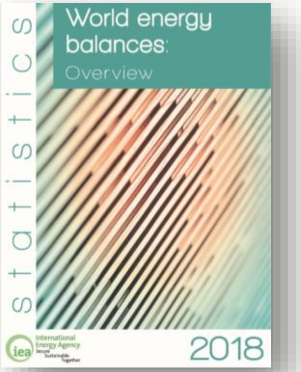
* Includes international marine and aviation bunkers.

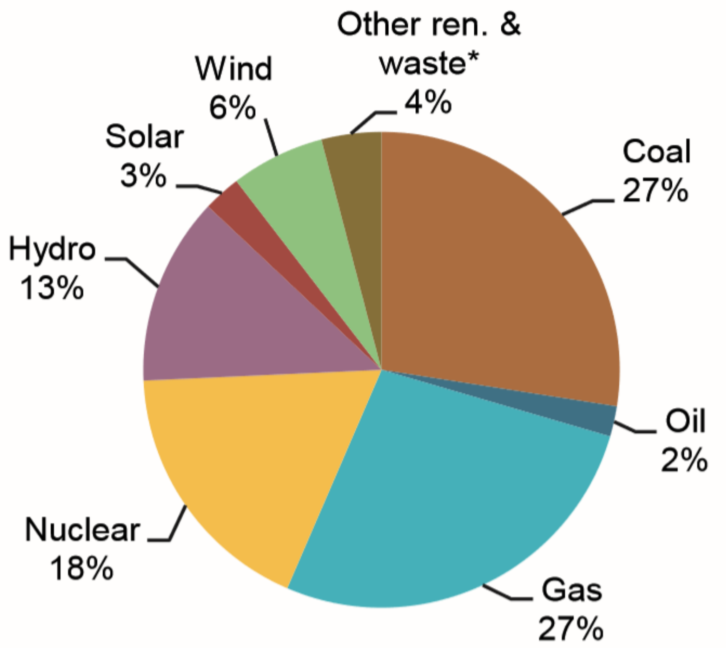
Entre 1971 y 2016, El consume total de energía se multiplicó por 2.25 veces

4 244 Mtoe »»»»»»»»»» 9 555 Mtoe

Mix eléctrico en la OCDE – 2017

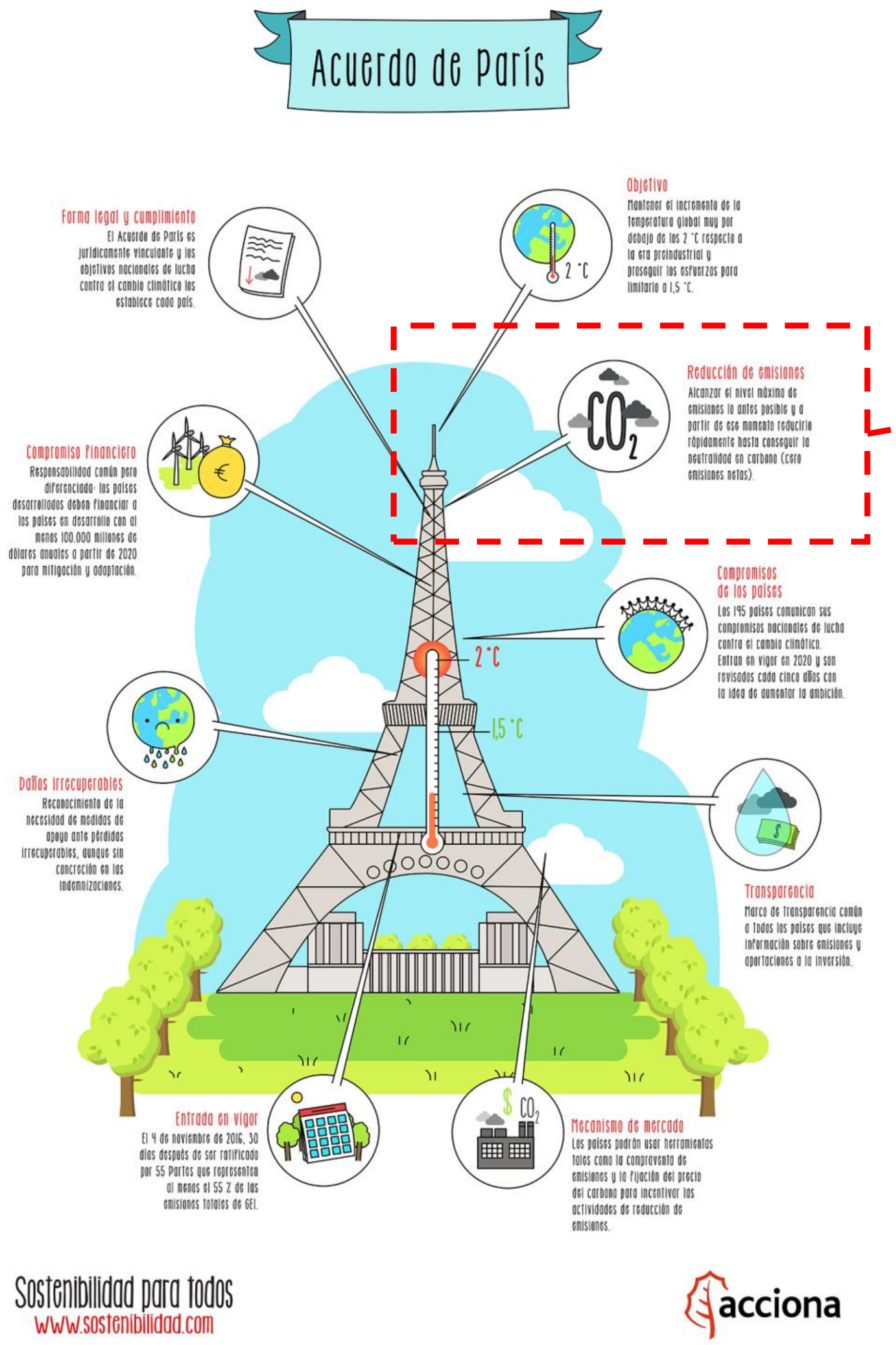
WORLD ENERGY BALANCES: OVERVIEW (2018 edition) - IEC

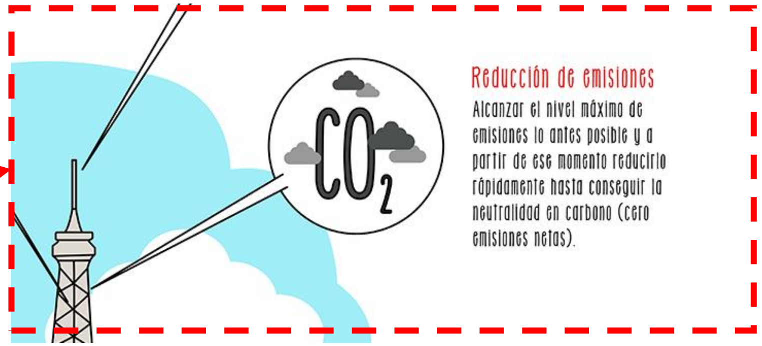




*Includes geothermal, tide, biofuels, all waste and heat.

Introducción



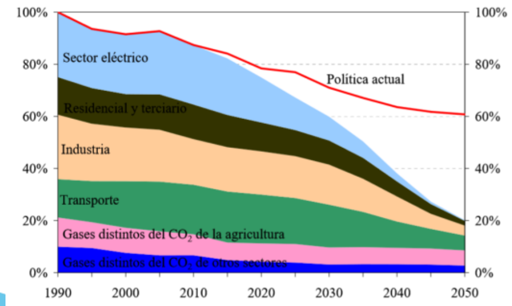


Comisión Europea

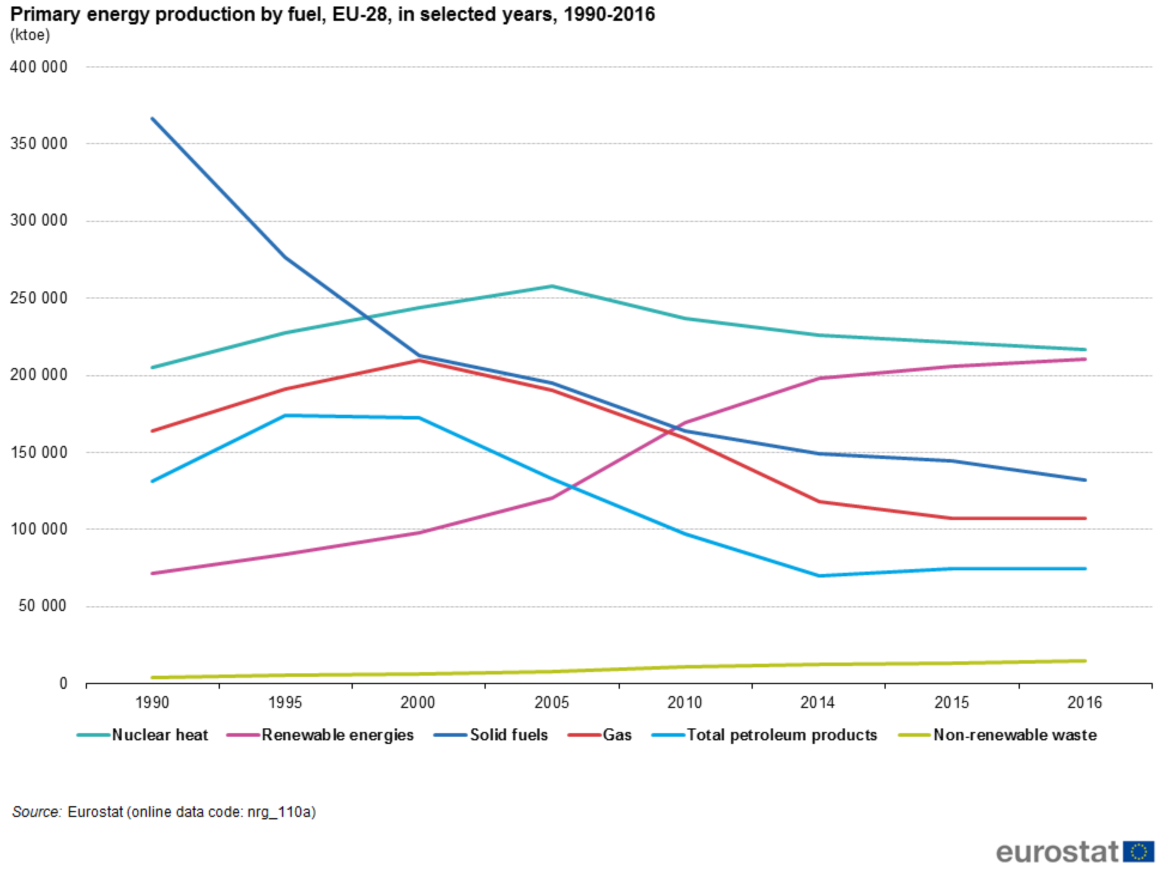
Marco sobre clima y energía para 2030

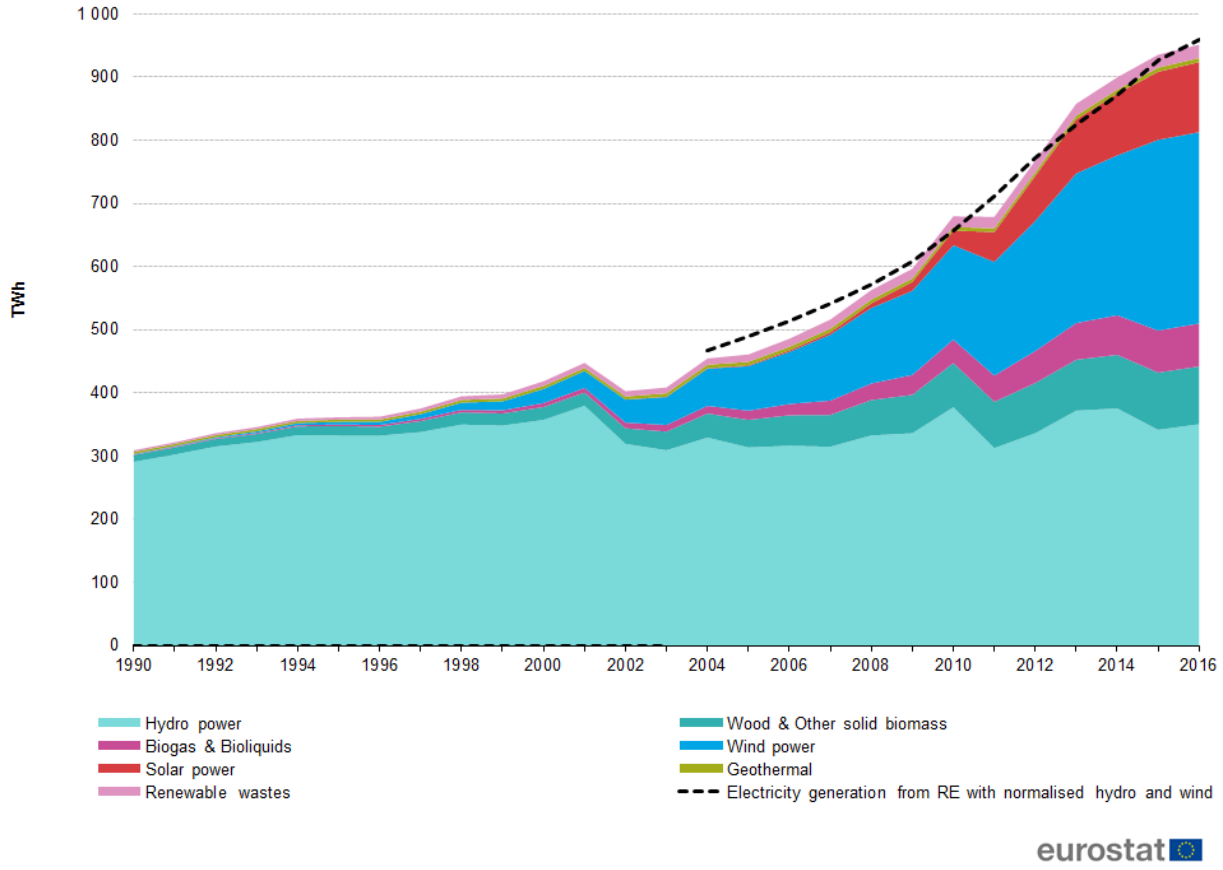
https://ec.europa.eu/clima/policies/strategies/2030_es

- 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

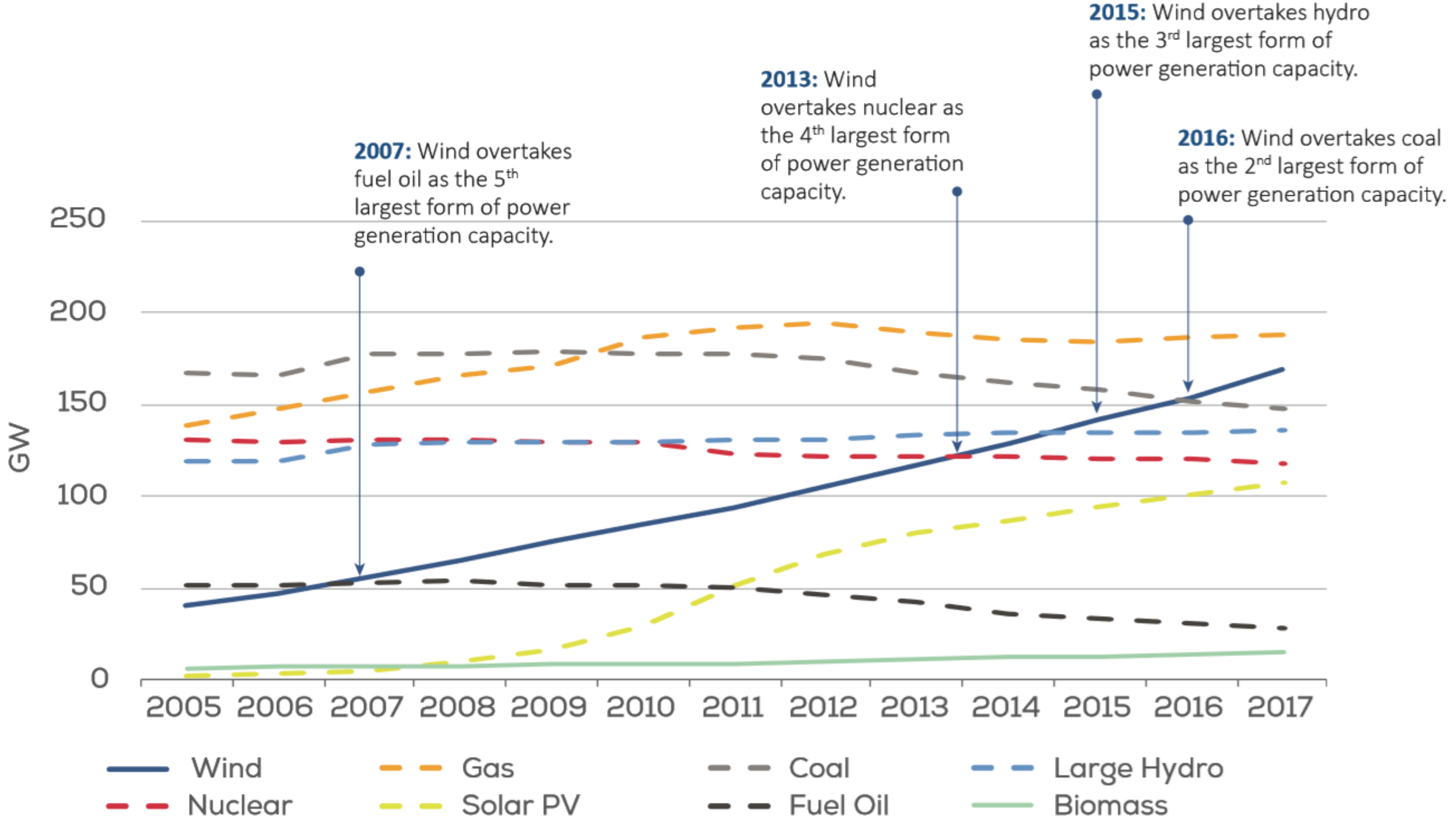




La energía eólica supone el 12,4% del total de la energía producción primaria de energía procedente de fuentes renovables en la EU-28. La energía eólica y la solar están en rápida expansión. La energía eólica incrementó su contribución en un 6,3 % de la energía renovable producida en la EU-28 en 2016

Potencia instalada en Europa 2005– 2017

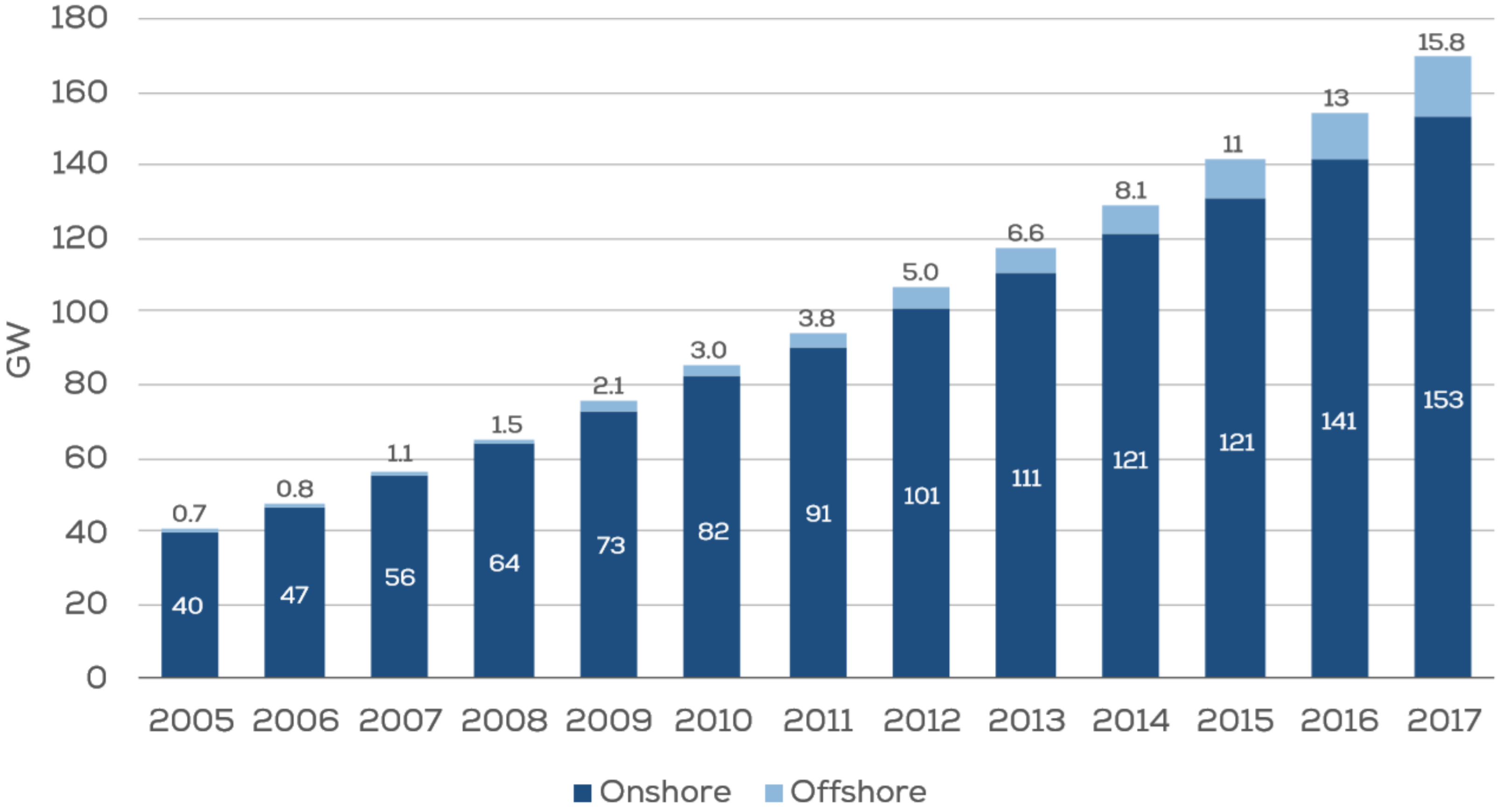
Wind in power, Annual combined onshore and offshore wind energy statistics – 2017, Wind Europe



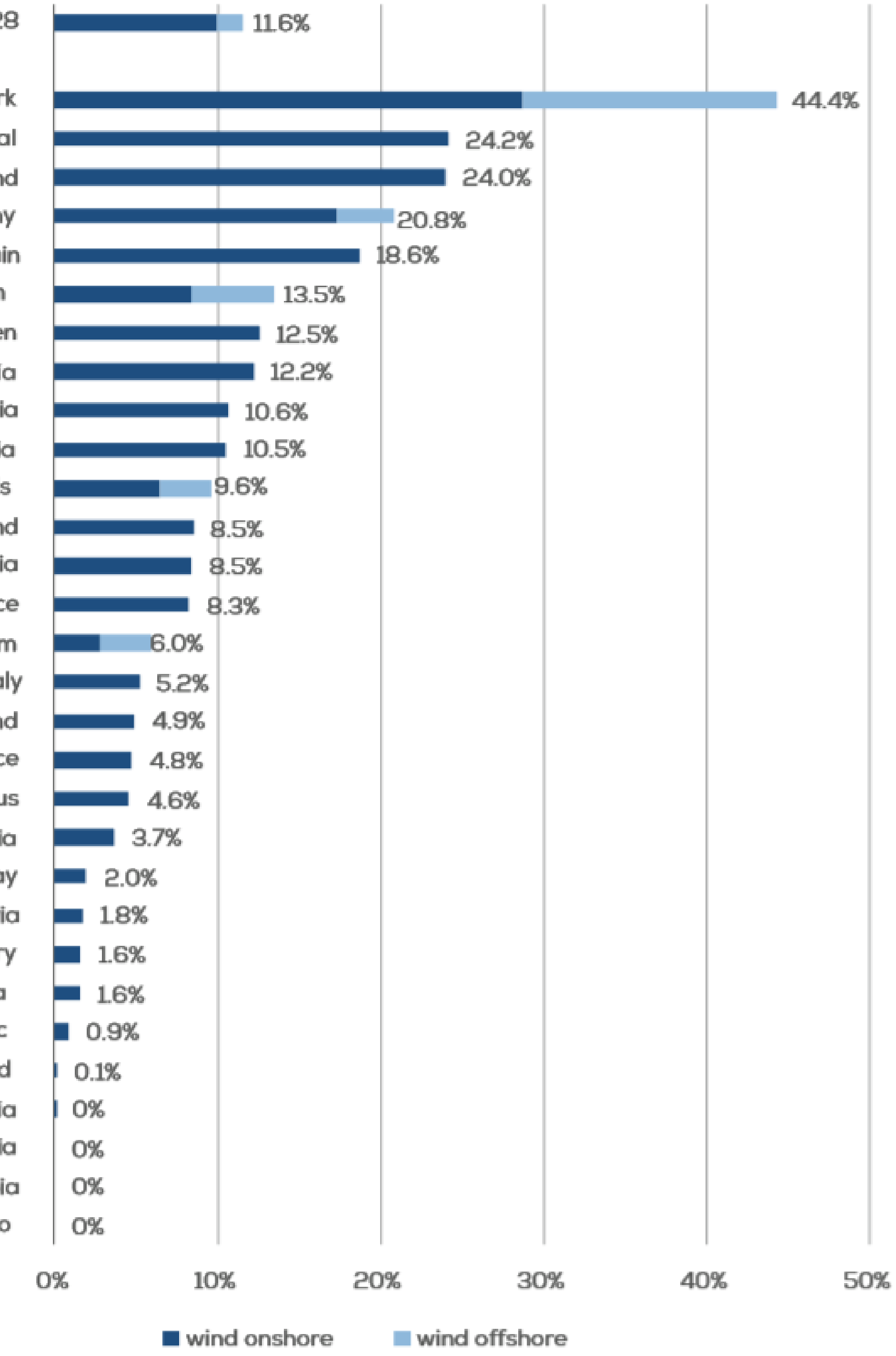
Source: WindEurope

Evolución de la potencia instalada eólica en Europa 2005– 2017

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



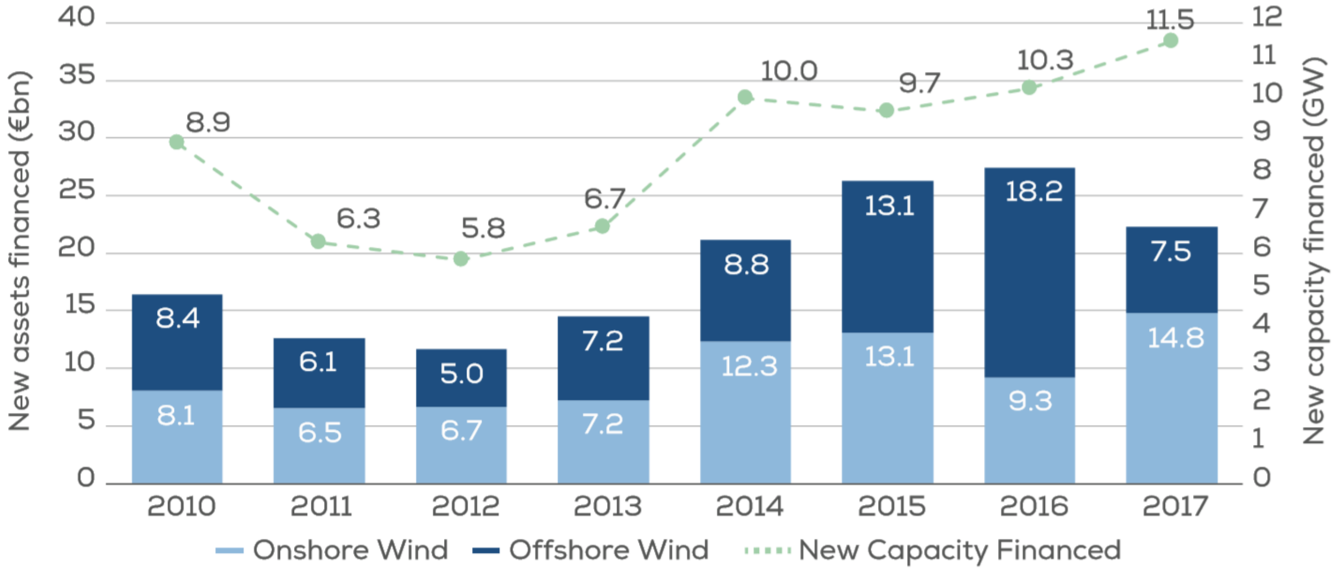
Source: WindEurope



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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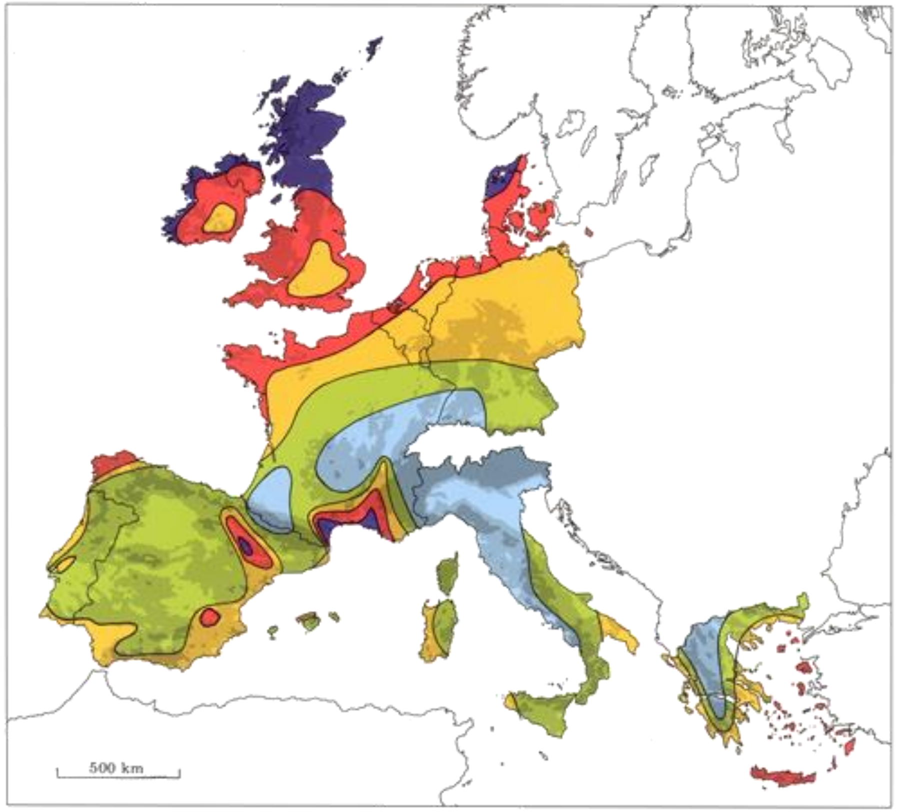
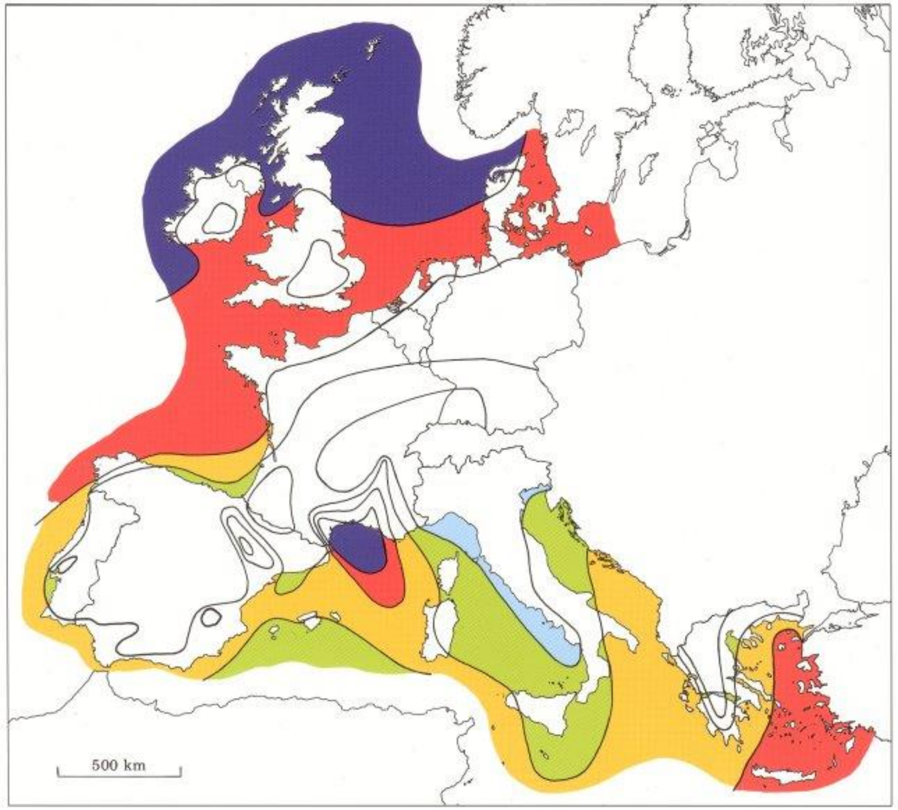
✓ Diponibilidad de recurso estable y de gran intensidad

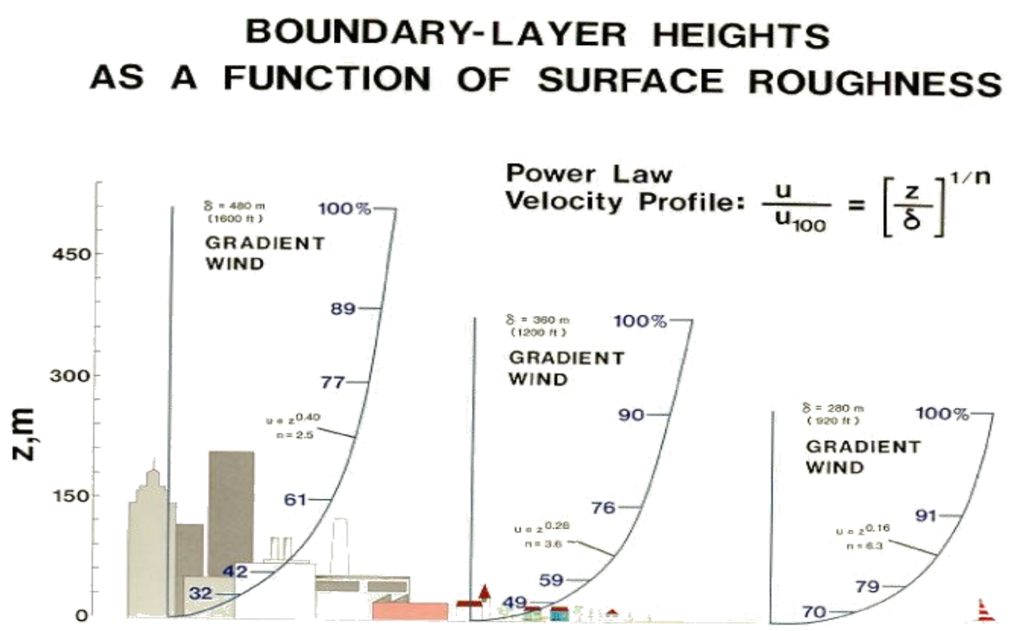


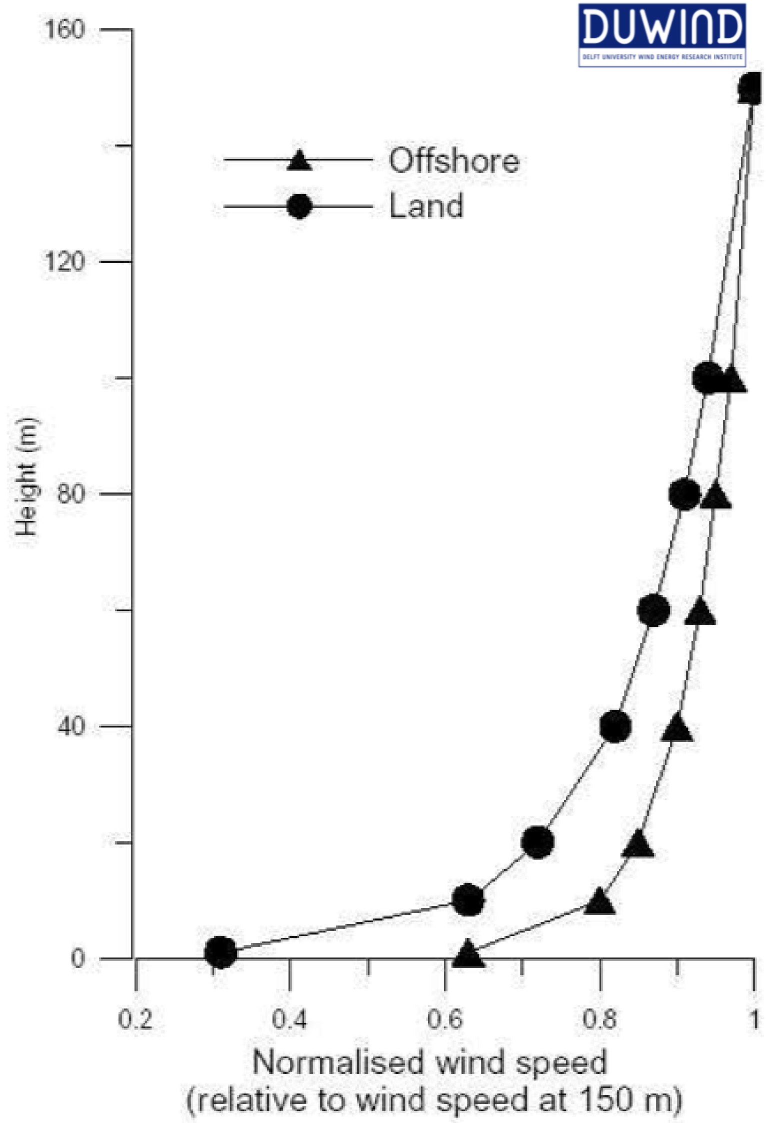
Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
(purple)	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
(red)	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
(yellow)	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
(green)	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
(light blue)	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 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	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
(purple)	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
(red)	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
(yellow)	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
(green)	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
(light blue)	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

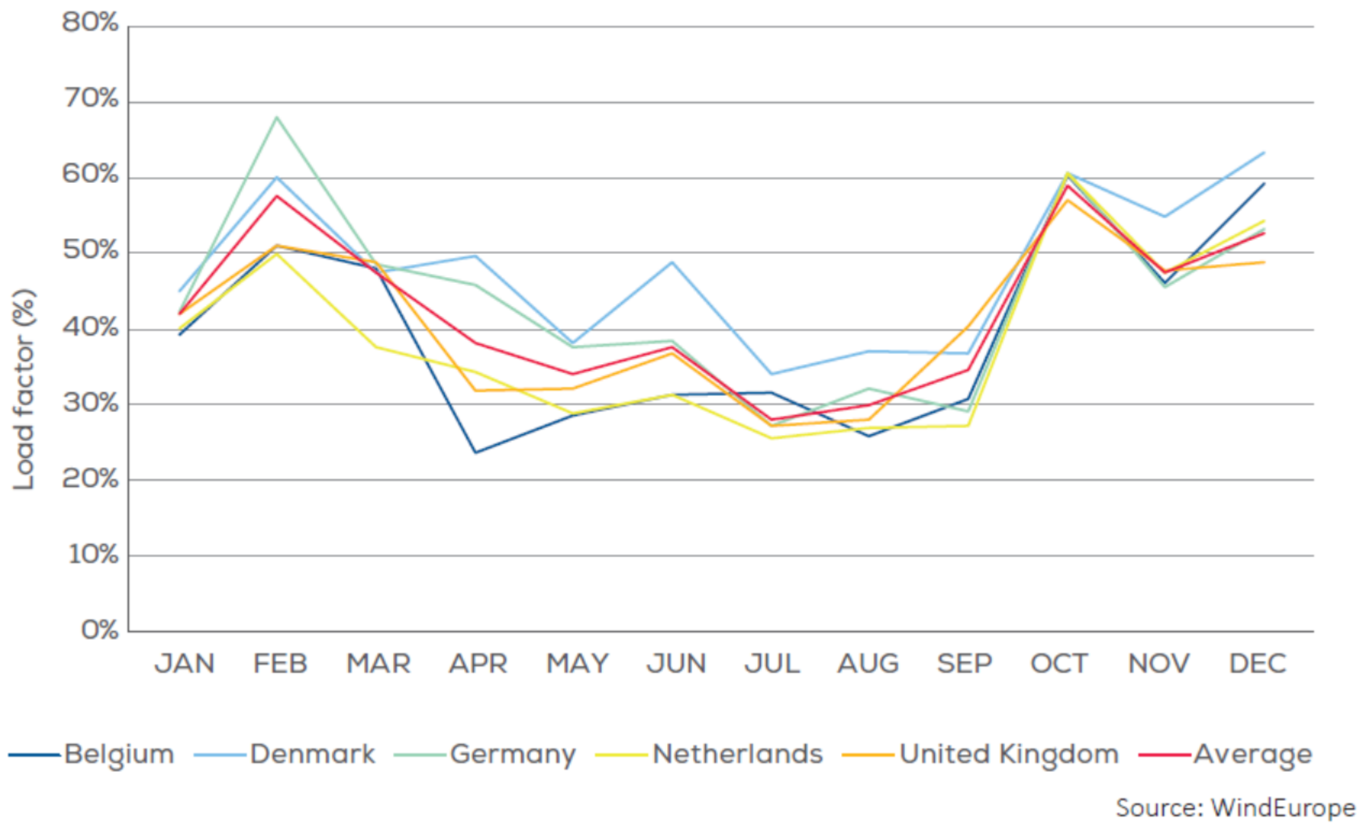
Calidad del recurso: Mayor intensidad, menor turbulencia,





¿Por qué eólica marina?

✓ Calidad del recurso: Mayor intensidad, menor turbulencia,



Factor de capacidad en los parques eólicos daneses

http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms

Data is to the end of Feb 2018. Analysis by EnergyNumbers.info. Raw data from ens.dk	Latest rolling 12-month capacity factor	Life capacity factor	Age (y)	Installed capacity (MW_p)	Total elec. gen. (GWh)
Anholt 1	**52.8%**	49.4%	4.9	399.6	8 487
Avedøre Holme	**40.4%**	38.4%	7.7	10.8	279
Frederikshavn	**29.8%**	30.6%	14.8	7.6	301
Horns Rev I	**41.6%**	42.0%	15.3	160	9 031
Horns Rev II	**49.2%**	48.1%	8.5	209.3	7 495
Middelgrunden	**24.9%**	25.5%	17.2	40	1 533
Nissum Bredning			0.2	28	2
Nysted (Rødsand) I	**39.9%**	37.3%	14.7	165.6	7 963
Nysted (Rødsand) II	**45.5%**	44.0%	7.7	207	6 147
Rønland I	**45.0%**	44.5%	15.1	17.2	1 015
Samsø	**40.1%**	39.3%	13.7	23	1 192
Sprogø	**28.5%**	33.9%	8.3	21	520
Tunø Knob	**33.1%**	30.4%	22.8	5	303
Vindeby (closed)		22.0%	25.5	4.95	244
Total	***45.8%***	***41.9%***		***1271***	***44 512***

¿Por qué eólica marina?

✔ Calidad del recurso: Mayor intensidad, menor turbulencia,

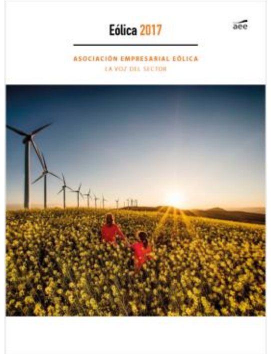
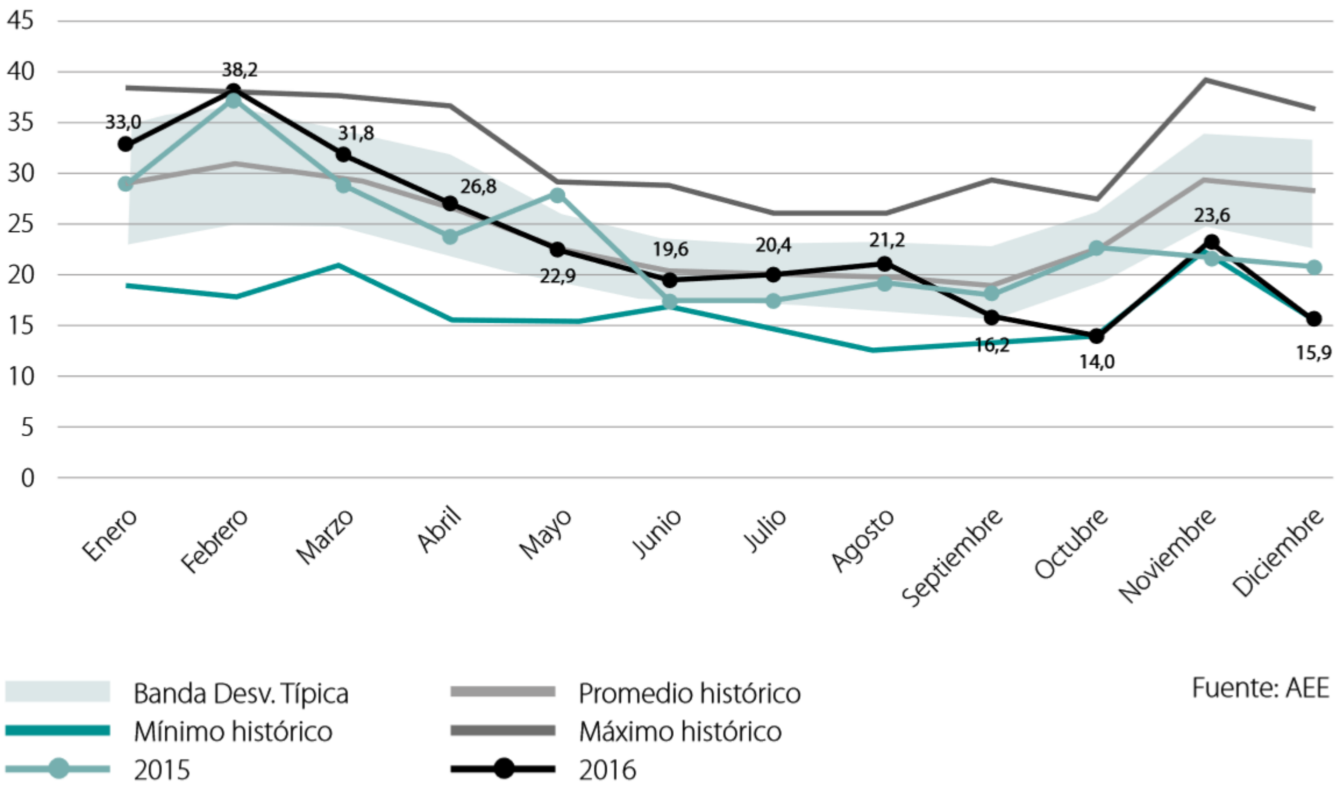
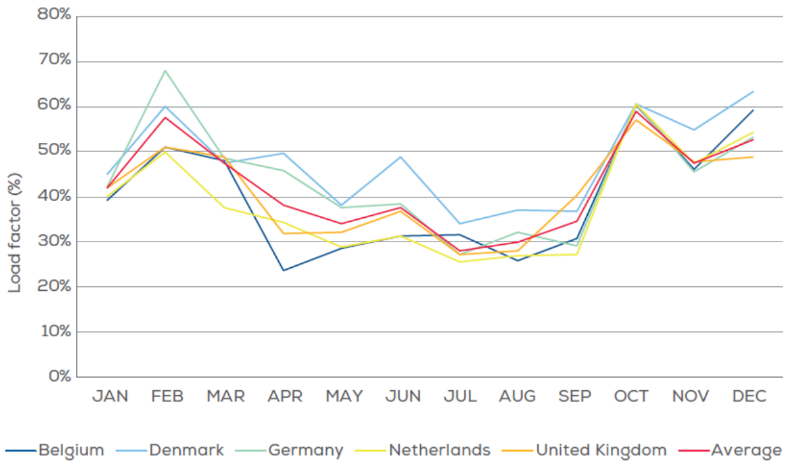


Gráfico I.05. Evolución del factor de capacidad de la eólica (en %)



Fuente: AEE



Source: WindEurope

✓ Menor impacto virual y acústico...

¿Por qué eólica marina?

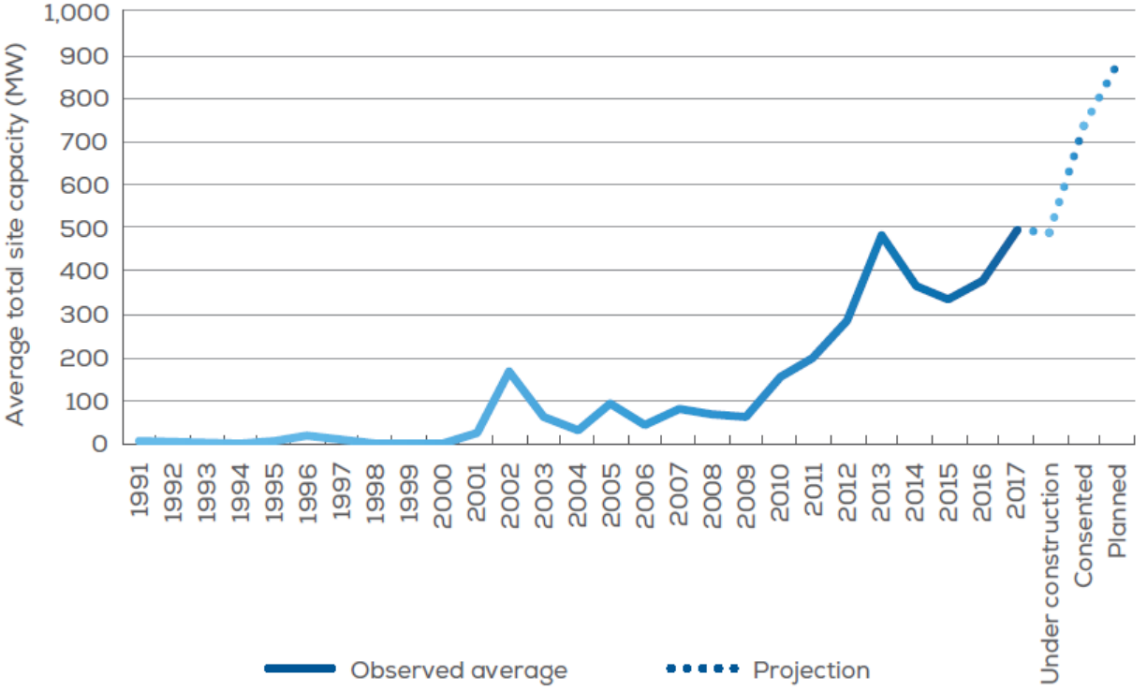
✓ Economía de escala: Posibilidad de desarrolar grandes instalaciones

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
Wikinger	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

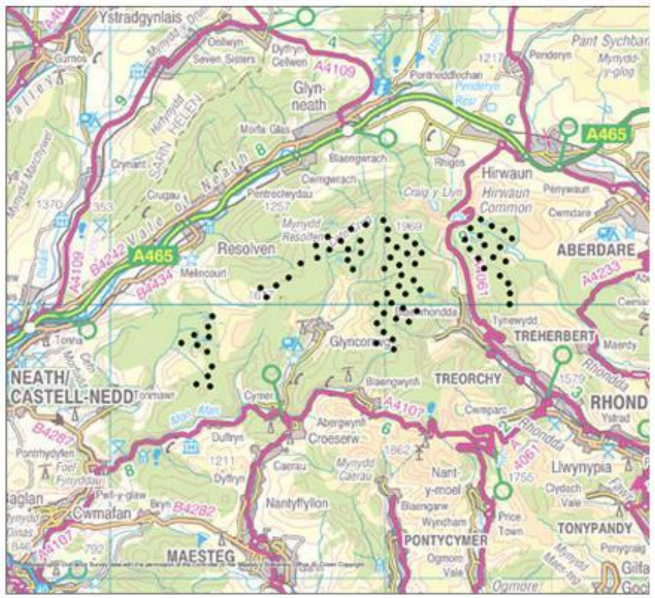


Source: WindEurope

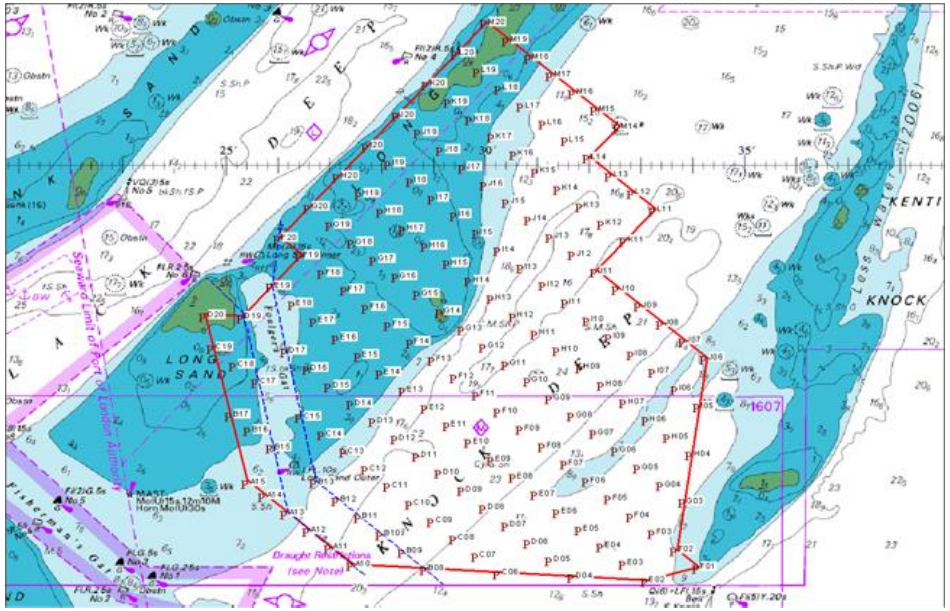
¿Por qué eólica marina?

❌ Mayor complejidad en la gestión de parquet: interacción entre turbinas

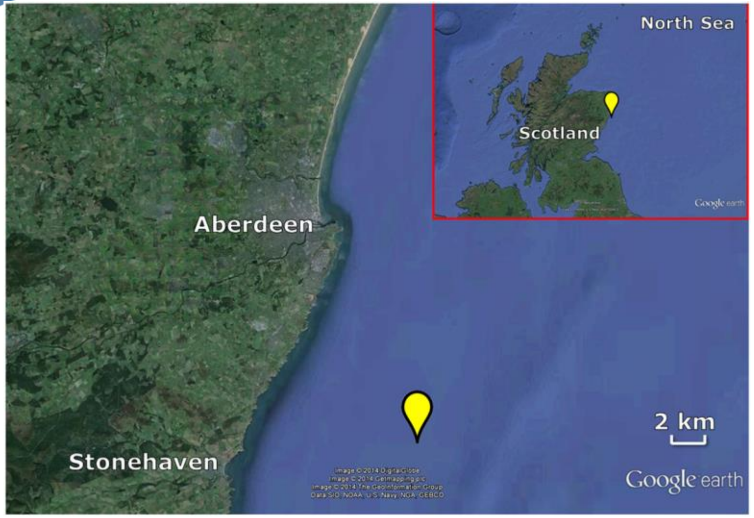
Onshore wind farm

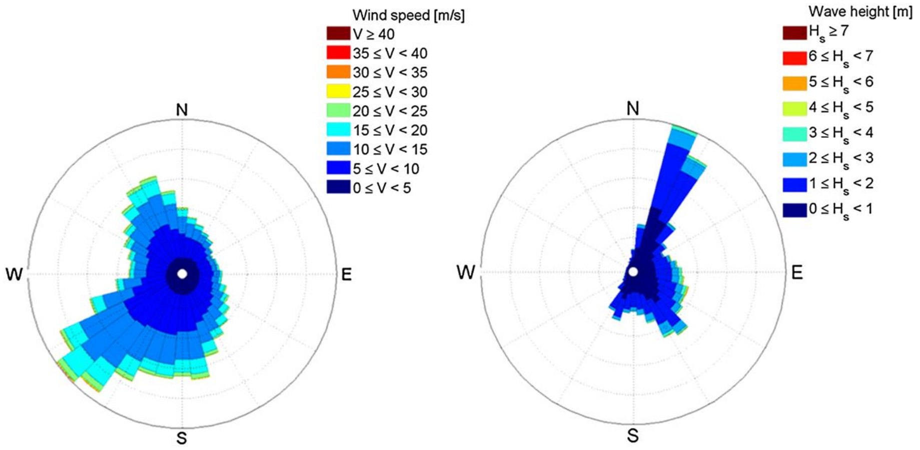


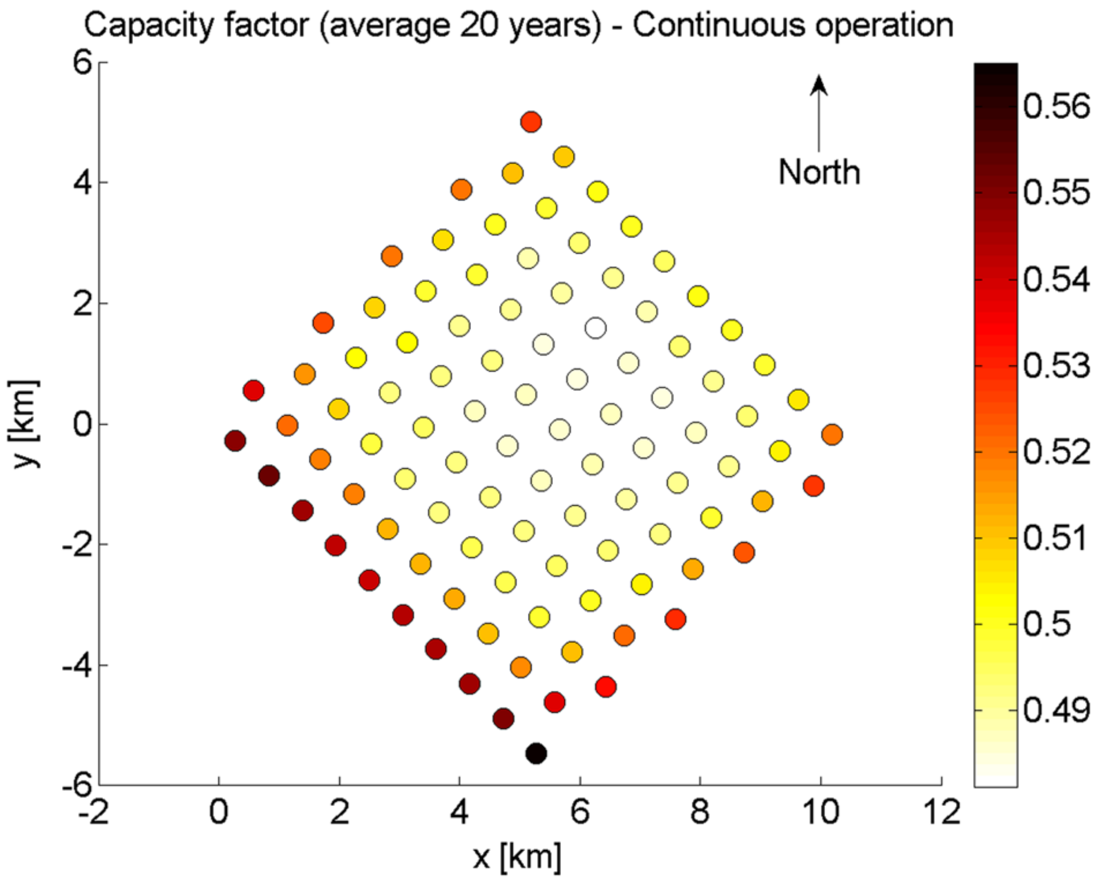
Offshore wind farm



¿Por qué eólica marina?





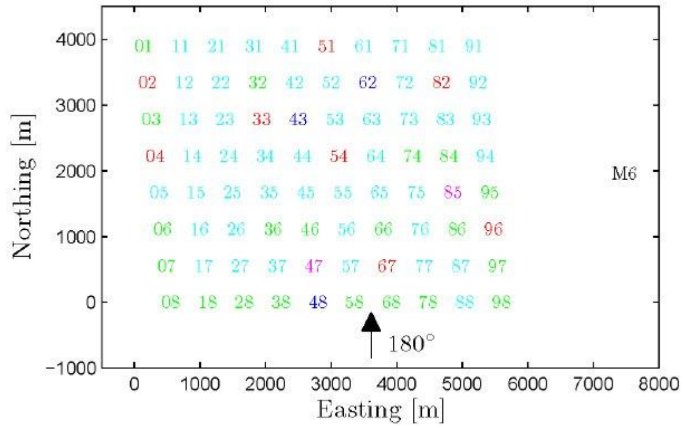


Martini, M., Guanche, R., Armesto, J. A., Losada, I. J., & Vidal, C. (2016). Met-ocean conditions influence on floating offshore wind farms power production. *Wind Energy*, *19*(3), 399-420.

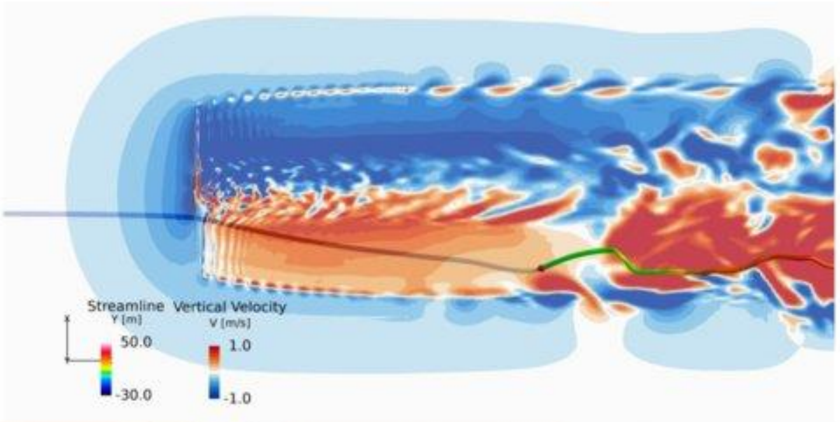
❌ Mayor complejidad en la gestión de parquet: interacción entre turbinas

Hasager, C & Rasmussen, Leif & Peña, Alfredo & Jensen, Leo & Réthoré, Pierre-Elouan. (2013). Wind farm wake: The Horns Rev photo case. Energies. 6. 696-716. 10.3390/en6020696.

Horns Rev

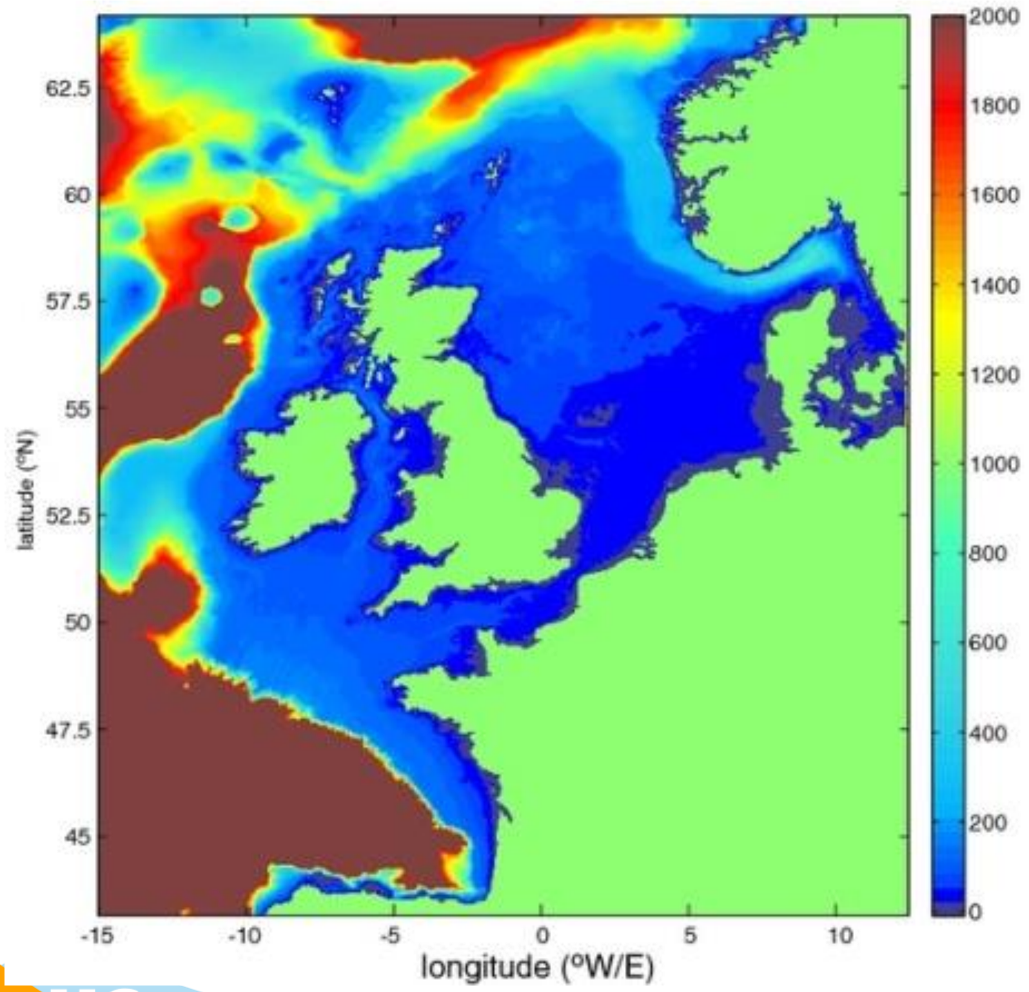


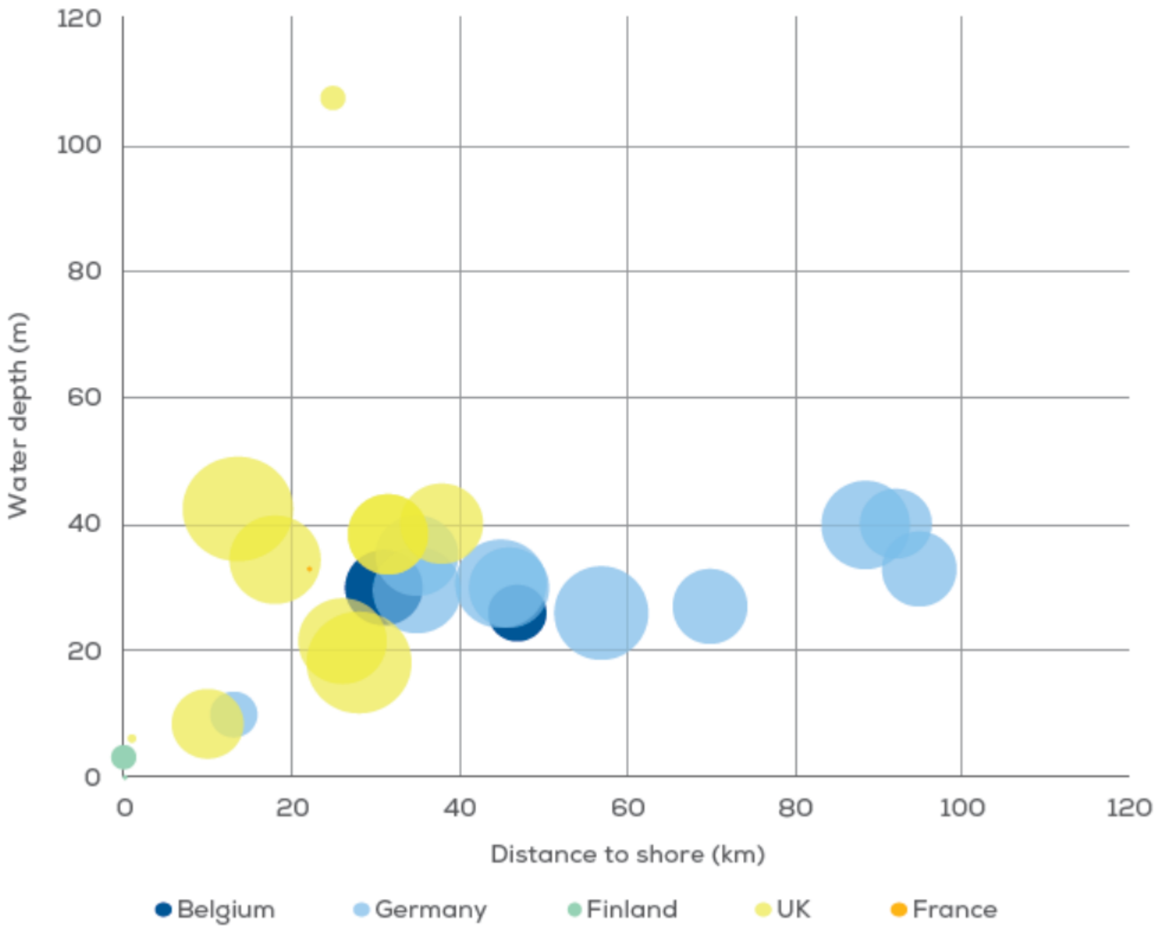
(a)



¿Por qué eólica marina?

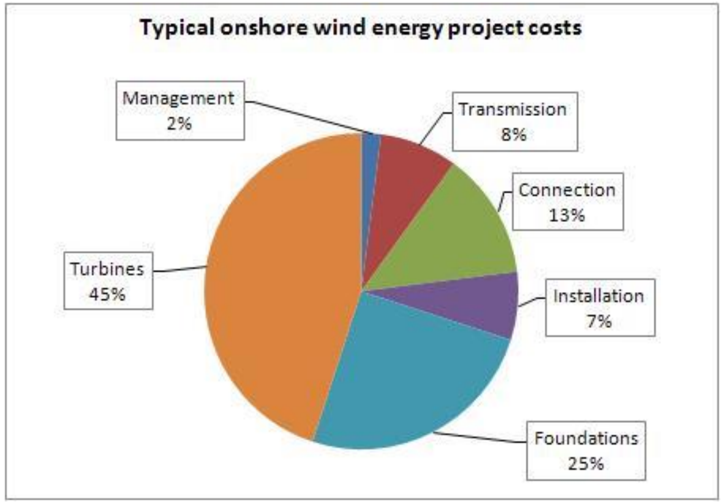
Barreras físicas: profundidad, distancia a costa…

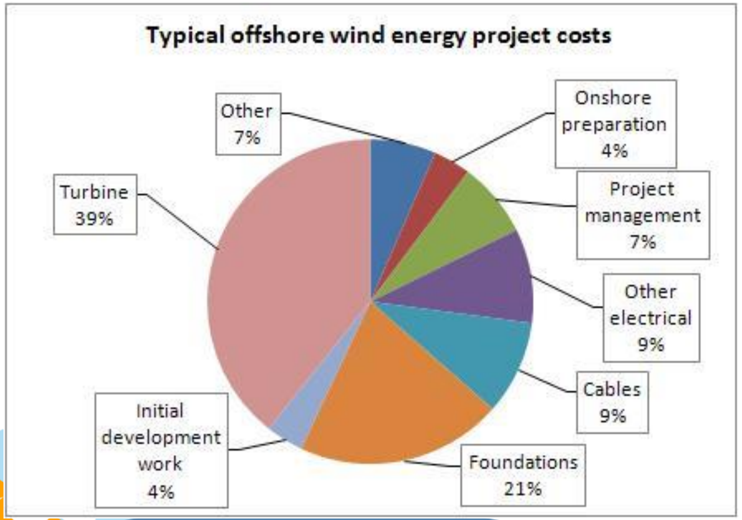




Source: WindEurope

✗ 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
Inst.-turbine	*155*	*156*	*156*	*157*	*157*	*158*	*159*	*159*	*160*	*164*	*169*	*174*	*180*	*185*	*190*	*205*
Inst.-foundation	*155*	*156*	*156*	*157*	*157*	*158*	*159*	*159*	*160*	*164*	*169*	*174*	*180*	*185*	*190*	*205*
Inst.-grid	*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
Total cost	1801	1821	1840	1860	1879	1899	1919	1938	1956	2044	2132	2233	2334	2434	2535	2879

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
Inst.-turbine	*155*	*155*	*155*	*162*	*169*	*169*	*169*
Inst.-foundation	*155*	*155*	*155*	*211*	*267*	*267*	*267*
Inst.-grid	*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
Total cost	1801	1861	1921	2074	2227	2371	2515

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

¿Por qué eólica marina?

Ventajas

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

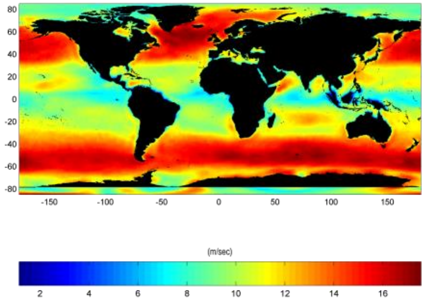
Desventajas

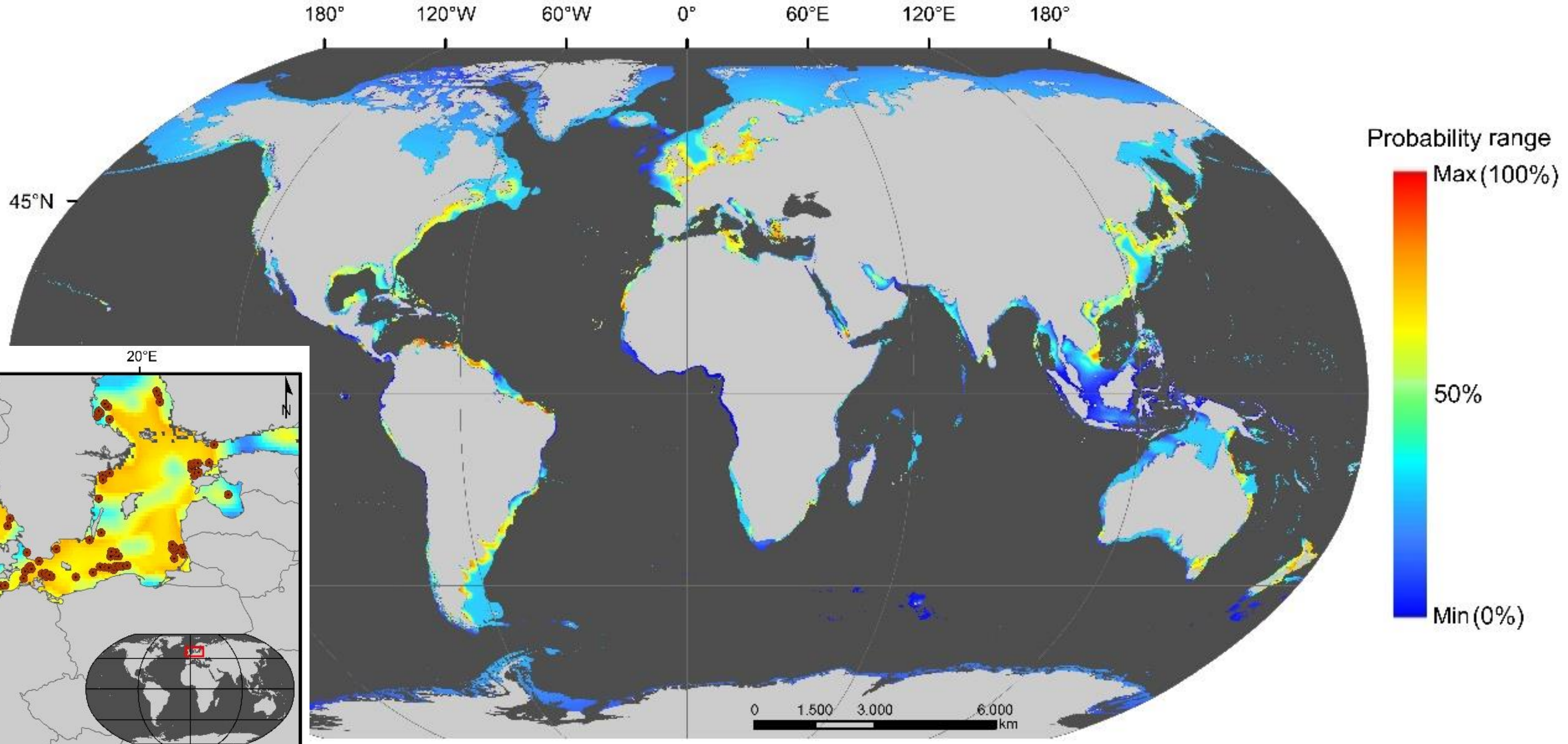
- Mayor complejidad de los parques
- Barreras físicas
- Mayores costes y riesgos

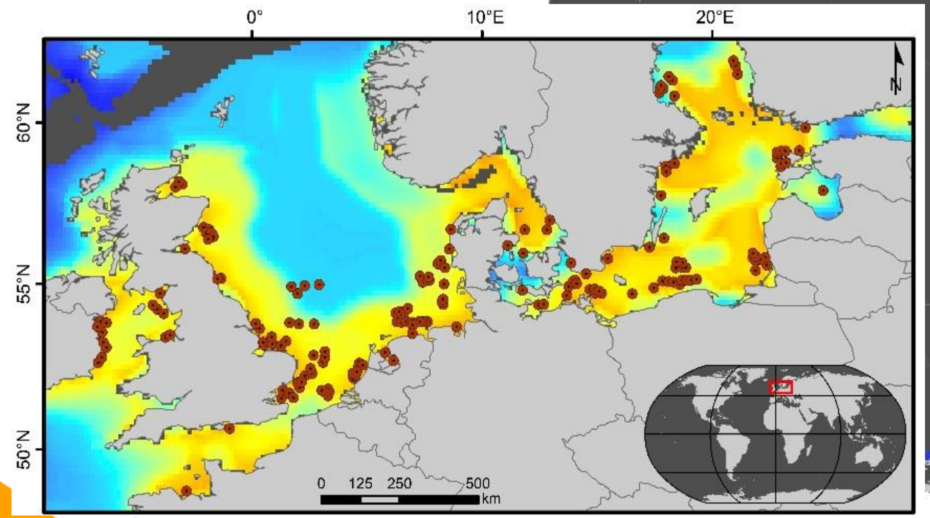
¡Reto y oportunidad!

Índice

Potencial de la energía eólica flotante atendiendo a profundidad, recurso, severidad del clima, centros de consumo y distancia a costa (<200km)

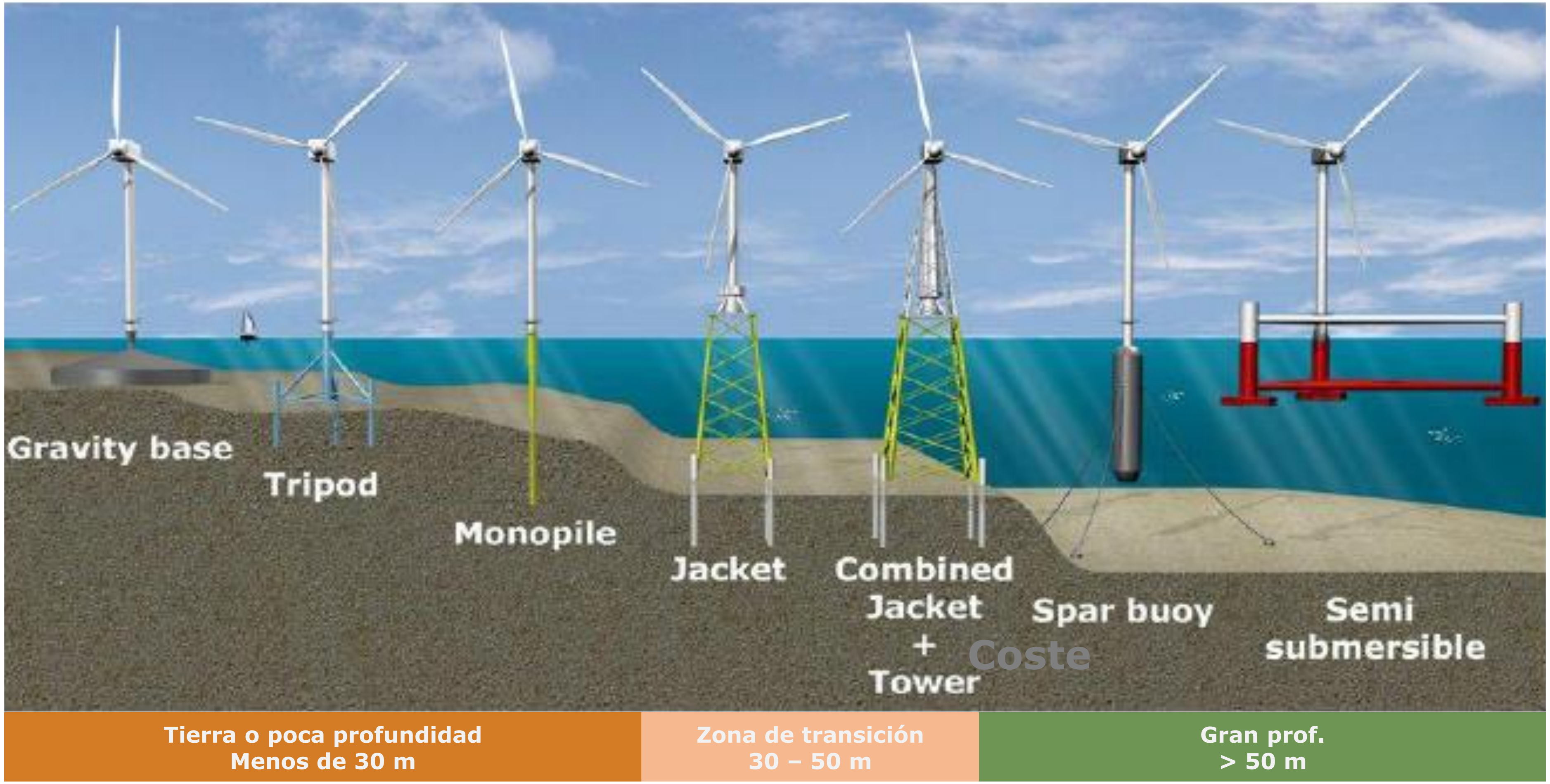




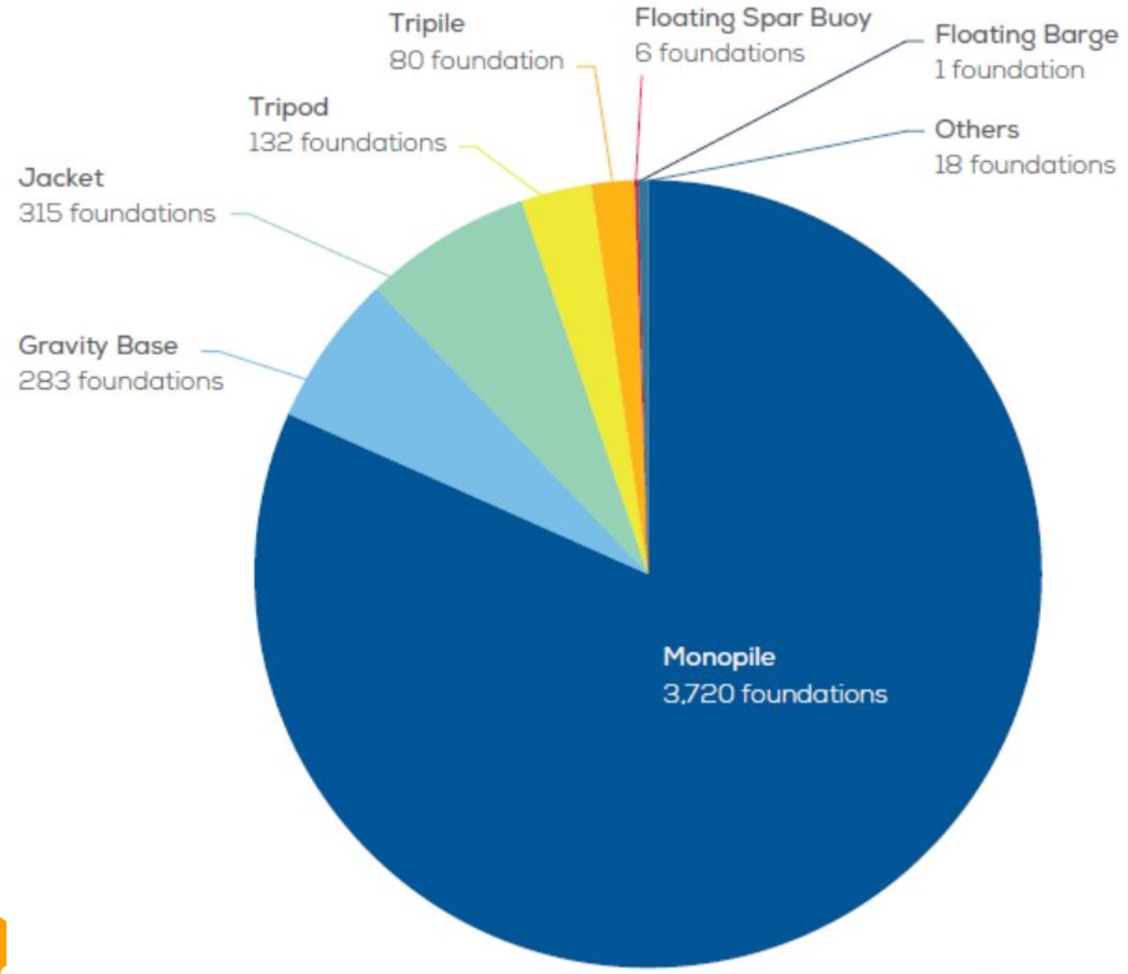


Carlos V.C. Weiss, Raúl Guanche, Bárbara Ondiviela, Omar F. Castellanos, José Juanes, Marine renewable energy potential: A global perspective for offshore wind and wave exploitation, Energy Conversion and Management, Volume 177, 2018, Pages 43-54, ISSN 0196-8904.

La energía eólica marina en aguas profundas



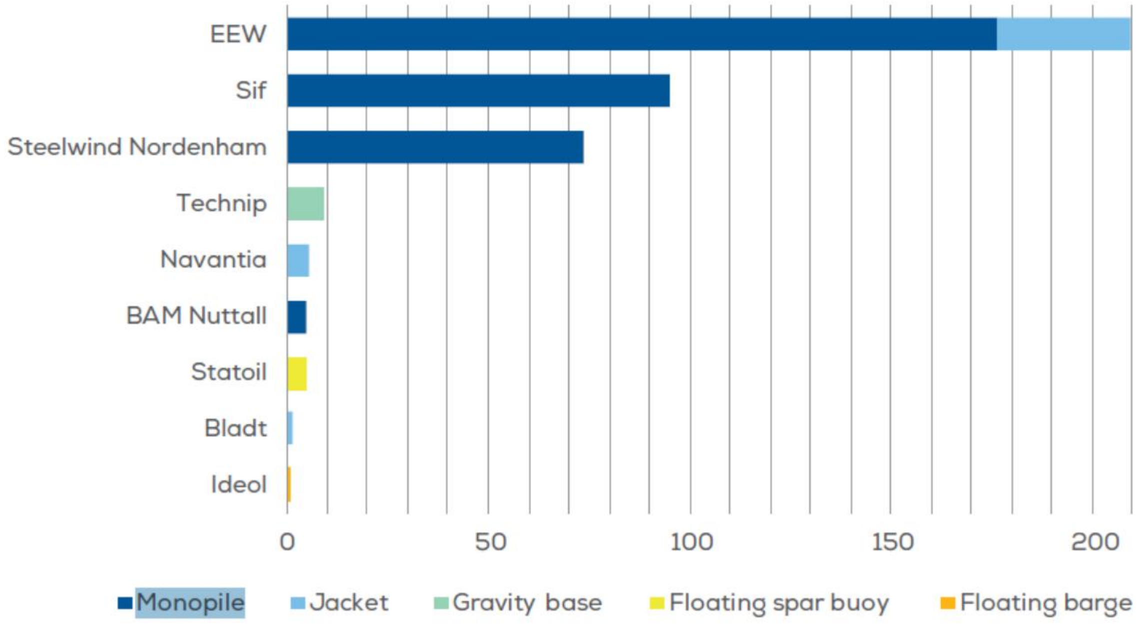
Distribución de las estructuras instaladas en Europa hasta 2017



Source: WindEurope

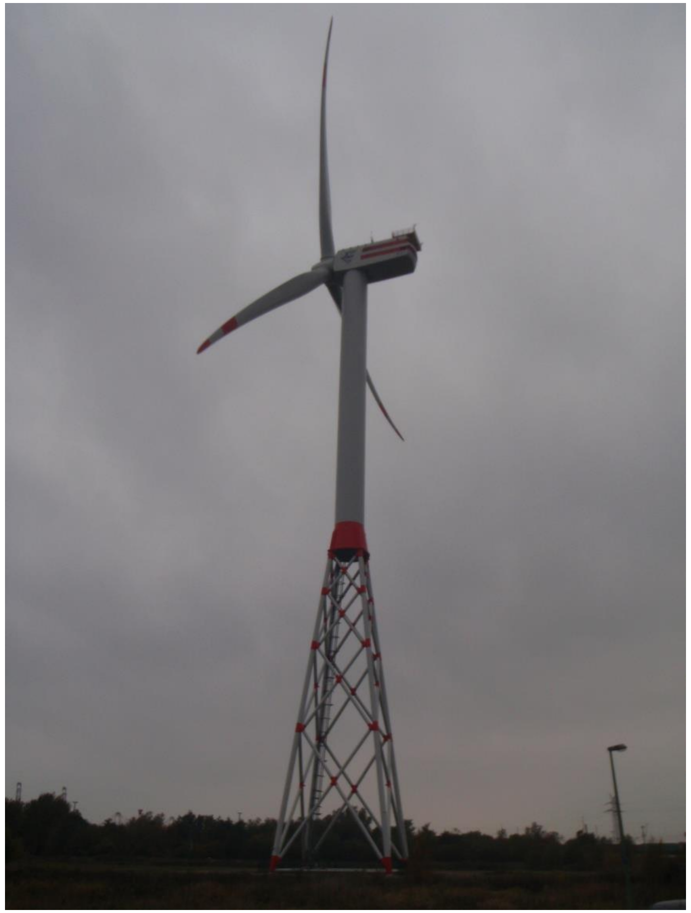
Distribución por fabricante de las subestructuras instaladas en 2017

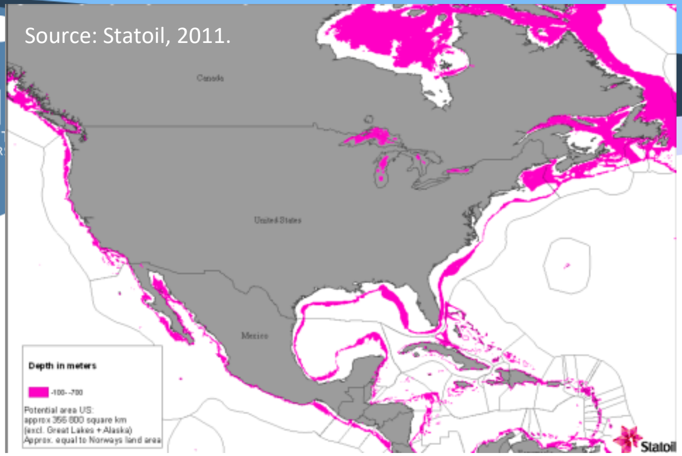
Offshore Wind
in Europe, Key trends and statistics 2017, Wind Europe

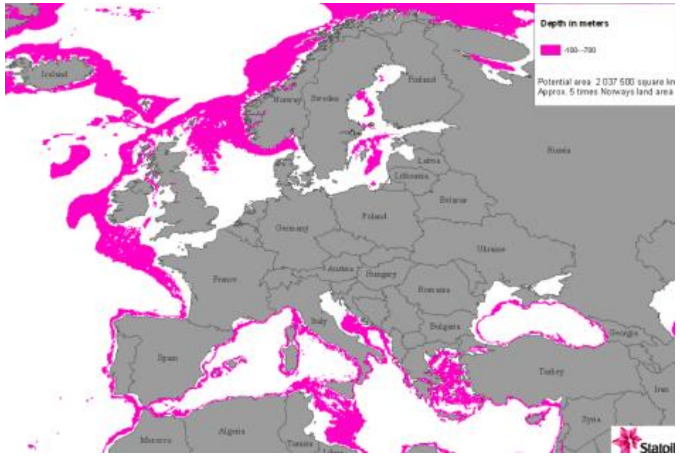


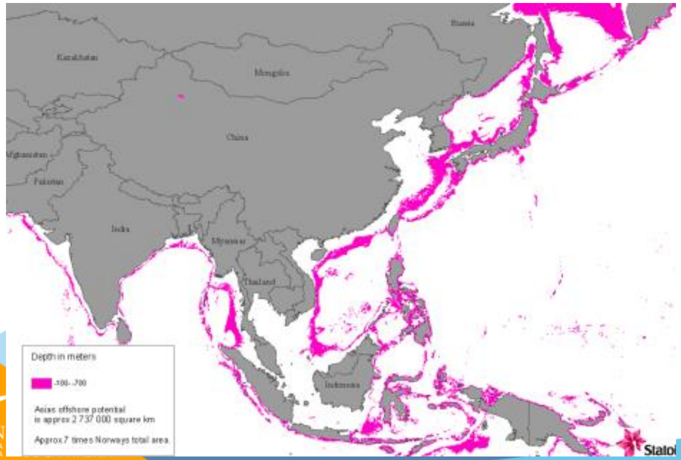
Source: WindEurope

Ejemplos de jacket y monpile: Bremehaven, 2011









La energía eólica marina en aguas profundas

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

equinor


Current project
Potential future markets
Long-term potential prospects

La energía eólica marina en aguas profundas

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 profungas…
Actividad todavía en crecimiento

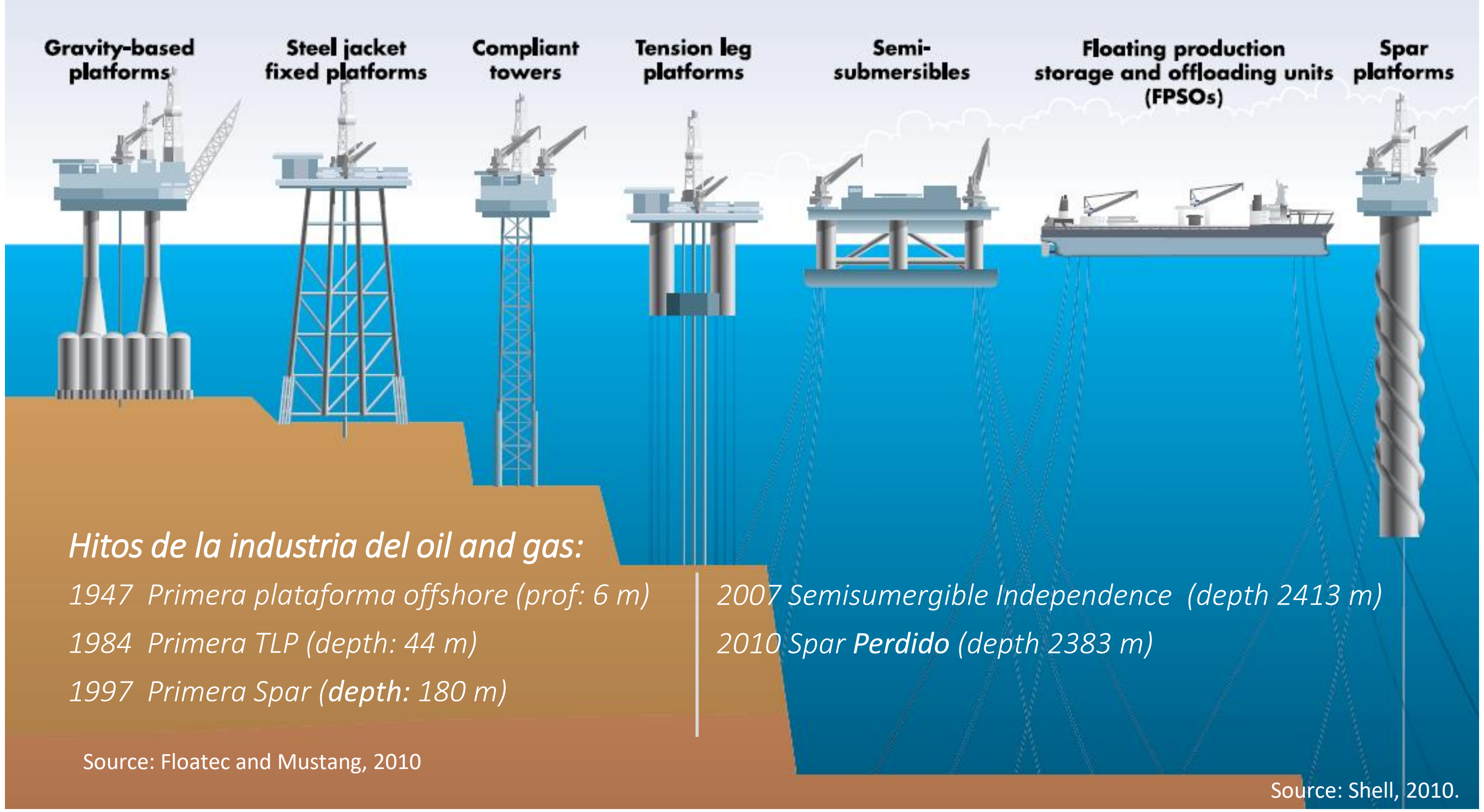
Parámetros para la toma de decisión

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

Éstandares y reglas de buena práctica

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

Clima de diseño +100yr: Niveles de seguridad máximos



Hitos de la industria del oil and gas:

1947 Primera plataforma offshore (prof: 6 m)
1984 Primera TLP (depth: 44 m)
*1997 Primera Spar (**depth:** 180 m)*

2007 Semisumergible Independence (depth 2413 m)
*2010 Spar **Perdido** (depth 2383 m)*

Source: Floatec and Mustang, 2010

Source: Shell, 2010.

Oil&Gas… los precursores

Resumen e hitos

Soluciones primarias aceptadas por la industria…

Probadas, Funcionales, Escalables, Adaptables a escala global.

Spar

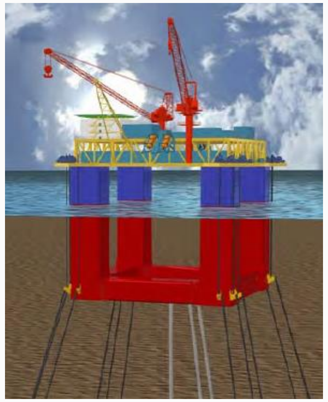
(10.000 ft ~3000 m)
Cilindro hueco equipadas con un volume de lastre elevado en su parte más baja. Sistemas de fondeo en catenaria

Principios físico:
Configuración del casco.

Semi-Submegibles

(9.000 ft ~ 2700 m)
Cubierta soportada por columnas unidas ha pontonas sumergidas. Sistemas de fondeo en tension o catenaries.

Principio físico:
Configuración del casco.



Tension Leg Platforms

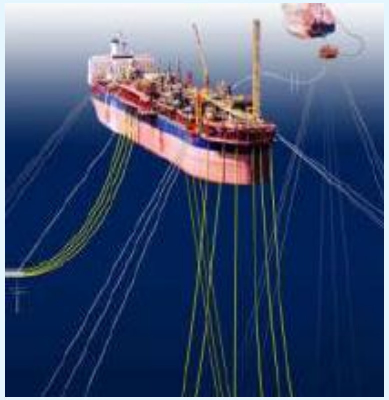
(6.000 ft ~1800 m)
Gran volumen de flotación sujeto en tensión por cables al anclados al fondo.

Principio físico:
Sistema de fondeo

Ship –Shape (FPSO)

(10.000 ft ~3000 m)
Embarcación o buqye contectado al fondo mediante "turret" (rotula de 3DOF-rotación libre)

Principio físico:
Forma del casco



Source: Floatec, 2010.

Lecciones aprendidas de la industria offshore

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

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 nucleos de población

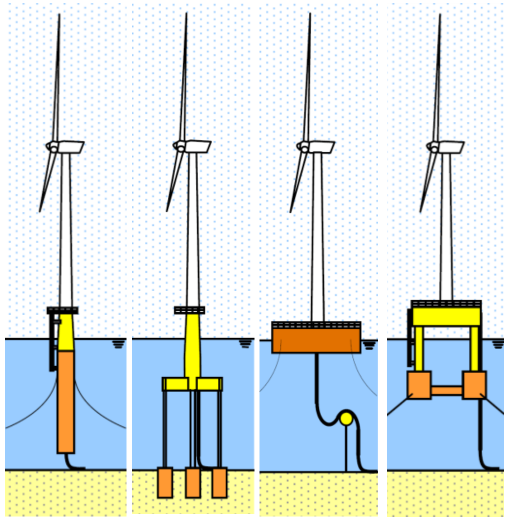
No se puede aplicar de manera indiscriminada el "know-how" del oil&gas al sector offshore.

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/requerimeintos de un diseño para eóliac marina flotante:

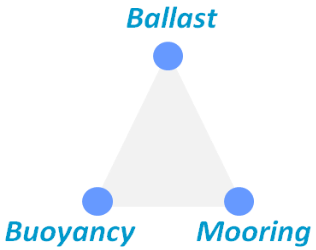
Diseño optimizado que asegure integridad structural, eficiencia, y coste…. Siempre cumpliendo objetivos financieros



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 funcionamlento. 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

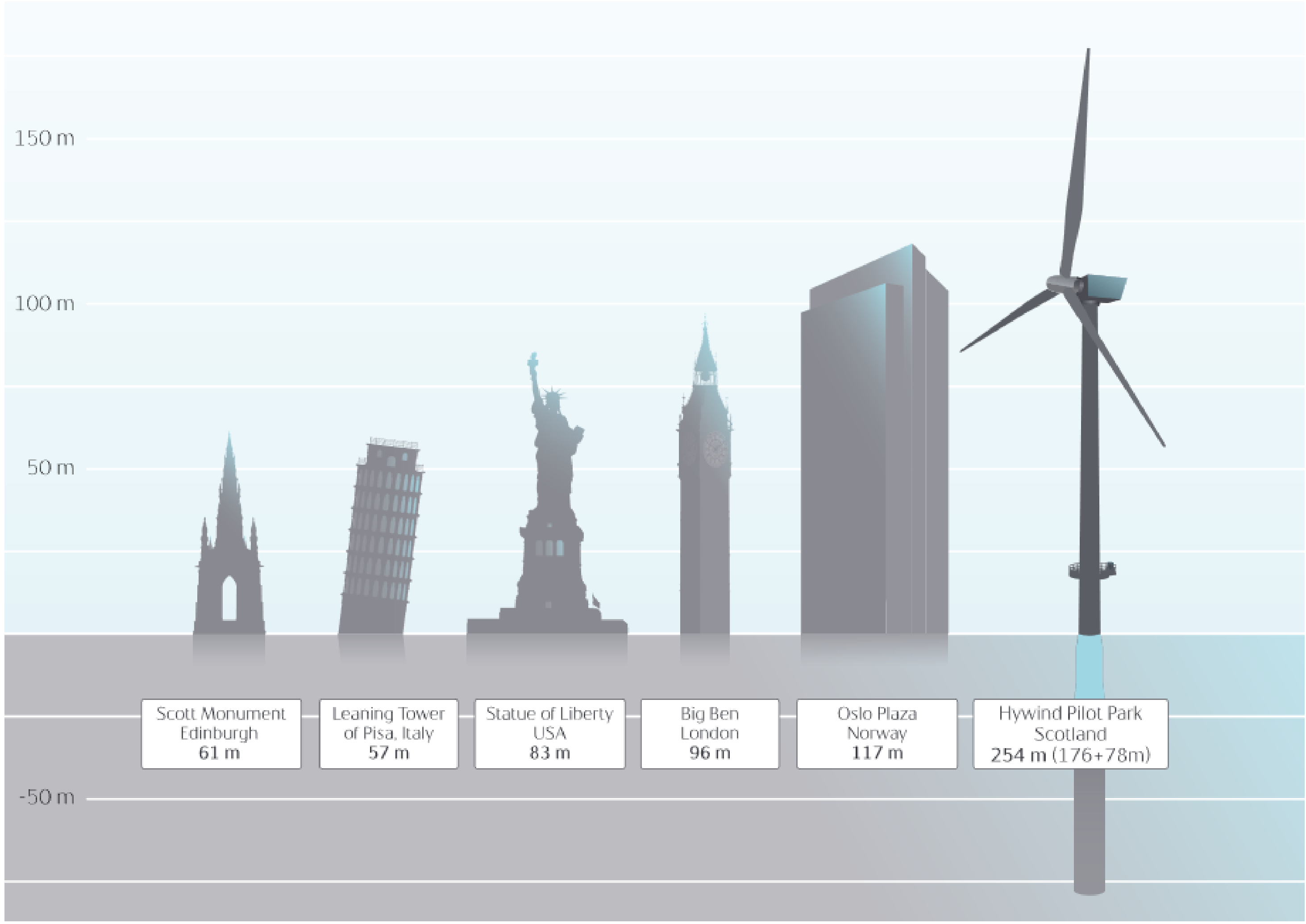
- Formas flexible y adaptables al topside.
- Facil producción en masa
- Sistemas de fondeo en tension o catenaria
- Sensisbles al cabeceo y el balance
- Faciles de operar en tierra

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

La energía eólica marina en aguas profundas



La energía eólica marina en aguas profundas

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).

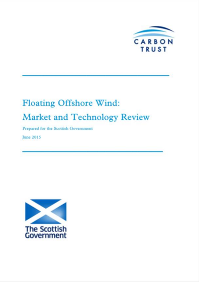
Damping Pool	IDEOL		
Classification:	Caisson/barge	Primary material:	Concrete or steel
Depth range:	35m+	Moorings:	6-9 catenary
Turbine axis:	Horizontal	No. blades:	3
Industrial partner(s):	Hitachi Zosen; Adwen	TRL:	3
Full-scale prototype:	2015	Pre-commercial array:	Undisclosed

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.

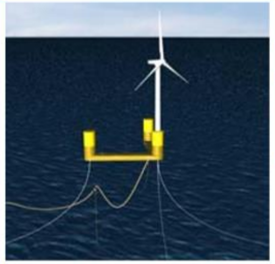
La energía eólica marina en aguas profundas



Advanced Spar — Japan Marine United

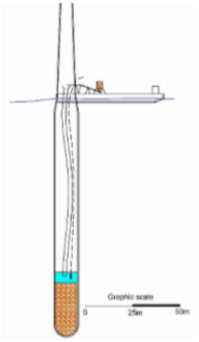
Classification:	Spar	Primary material:	Steel
Depth range:	80m+	Moorings:	3 catenary
Turbine axis:	Horizontal	No. blades:	3
Industrial partner(s):	Marubeni Corporation	TRL:	4
Full-scale prototype:	2013 (sub-station)	Pre-commercial array:	TBC

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

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

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

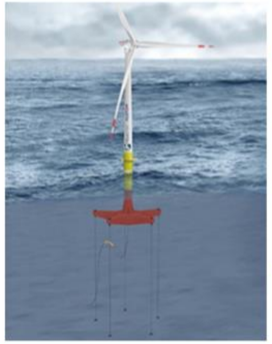
VolturnUS — DeepCWind Consortium

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

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

PelaStar — Glosten Associates

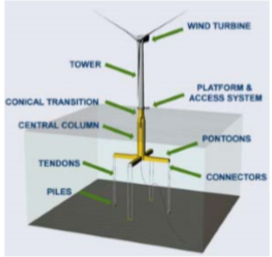


Classification:	TLP	Primary material:	Steel
Depth range:	70-200m	Moorings:	5 taut-leg
Turbine axis:	Horizontal	No. blades:	3
Industrial partner(s):	Alstom	TRL:	3
Full-scale prototype:	TBC	Pre-commercial array:	TBC

GICON-SOF — GICON

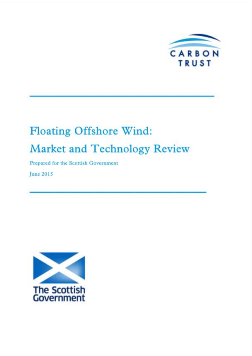
Classification:	TLP	Primary material:	Steel
Depth range:	40-250m	Moorings:	8 taut-leg
Turbine axis:	Horizontal	No. blades:	3
Industrial partner(s):	-	TRL:	3
Full-scale prototype:	2015	Pre-commercial array:	2017

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

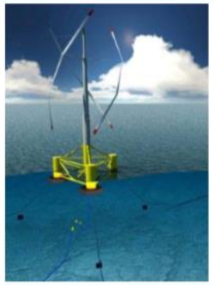

CARBON TRUST

Floating Offshore Wind:
Market and Technology Review

The Scottish Government

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

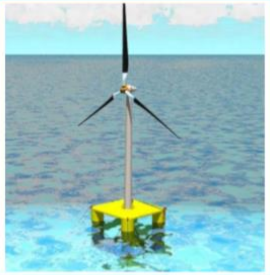


SeaReed	DCNS		
Classification:	Semi-sub	Primary material:	Steel
Depth range:	50-200m	Moorings:	Undisclosed
Turbine axis:	Horizontal	No. blades:	3
Industrial partner(s):	Alstom	TRL:	3
Full-scale prototype:	2018	Pre-commercial array:	2020

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

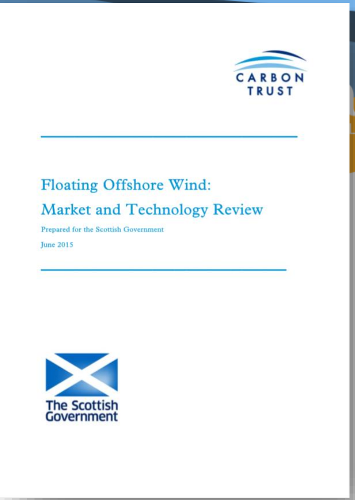


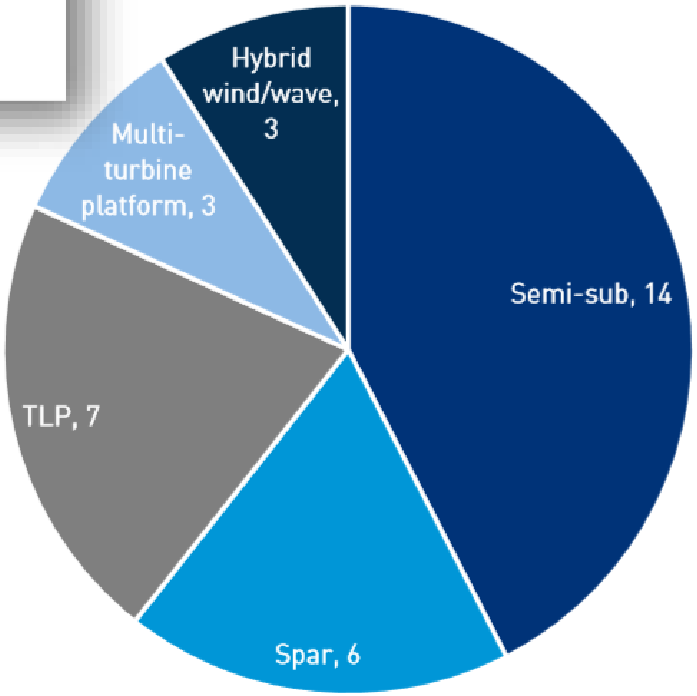
Hexicon	Hexicon		
Classification:	Multi-turbine platform	Primary material:	Steel
Depth range:	50-500m	Moorings:	8 catenary
Turbine axis:	3 x Horizontal	No. blades:	3
Industrial partner(s):	-	TRL:	2
Full-scale prototype:	TBC	Pre-commercial array:	TBC

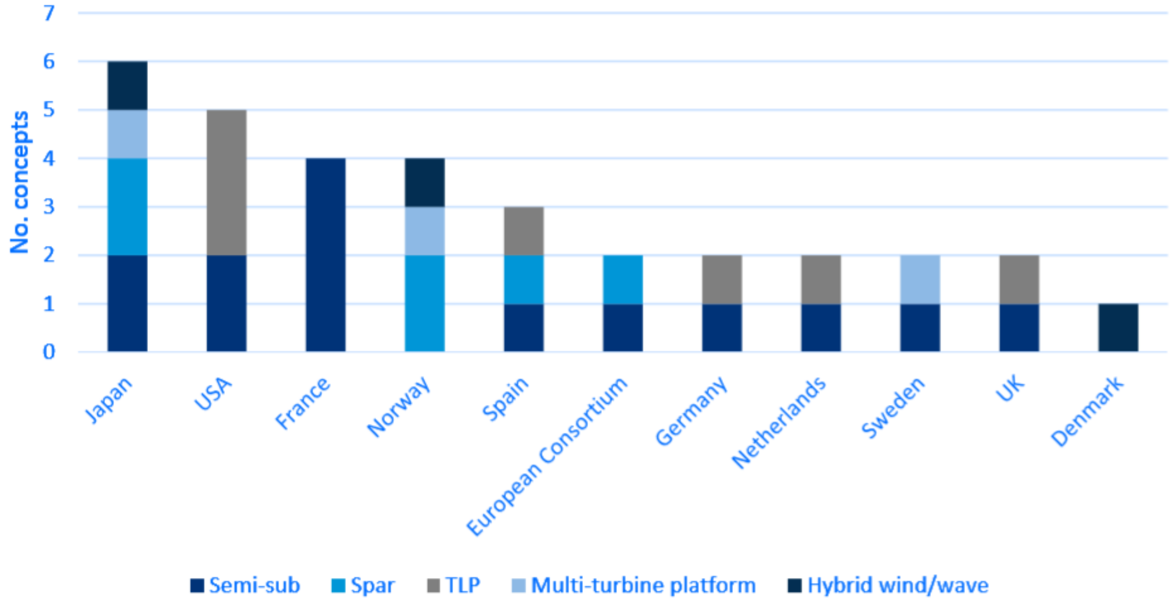
Tri-Floater	GustoMSC		
Classification:	Semi-sub	Primary material:	Steel
Depth range:	50-300m	Moorings:	3 catenary
Turbine axis:	Horizontal	No. blades:	3
Industrial partner(s):	-	TRL:	3
Full-scale prototype:	TBC	Pre-commercial array:	TBC

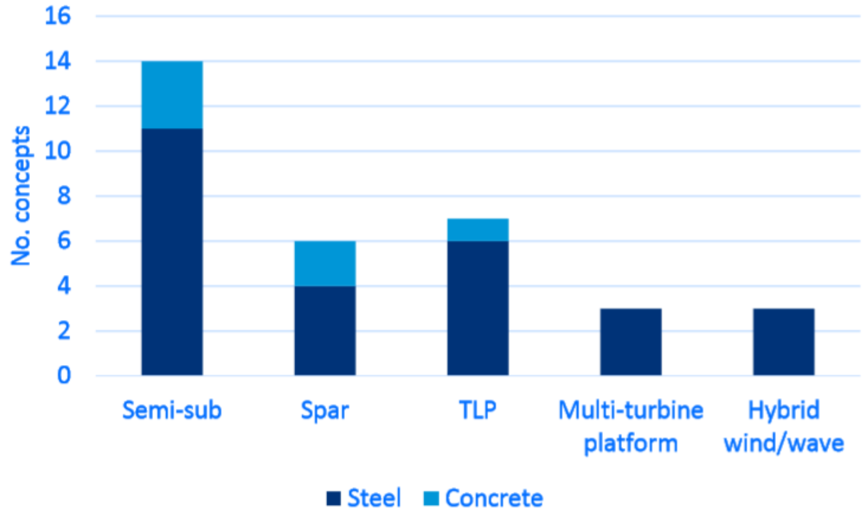
Nezzy SCD	Aerodyn Engineering		
Classification:	Semi-sub	Primary material:	Concrete
Depth range:	35-200m	Moorings:	5 semi-taut (turret system)
Turbine axis:	Horizontal	No. blades:	2
Industrial partner(s):	-	TRL:	2
Full-scale prototype:	TBC	Pre-commercial array:	TBC

La energía eólica marina en aguas profundas





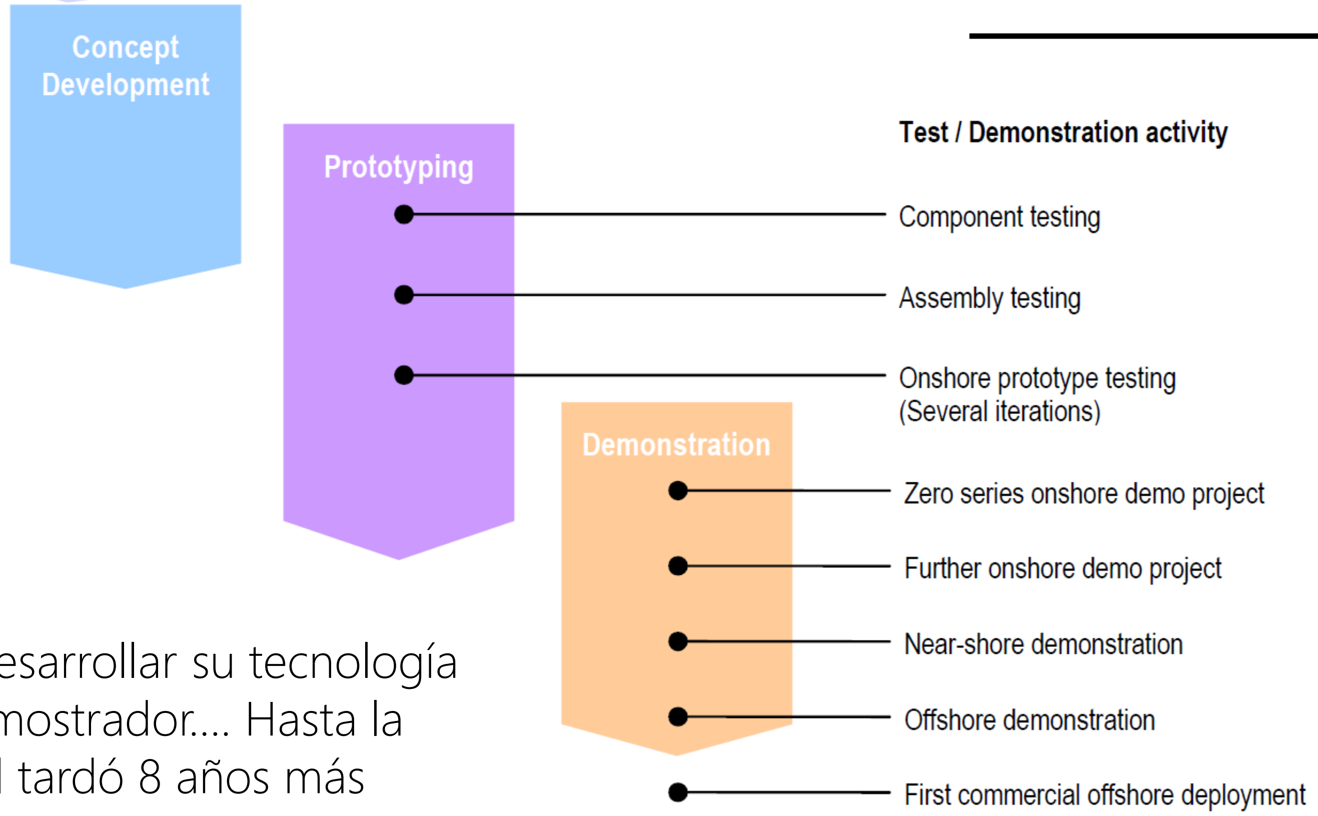




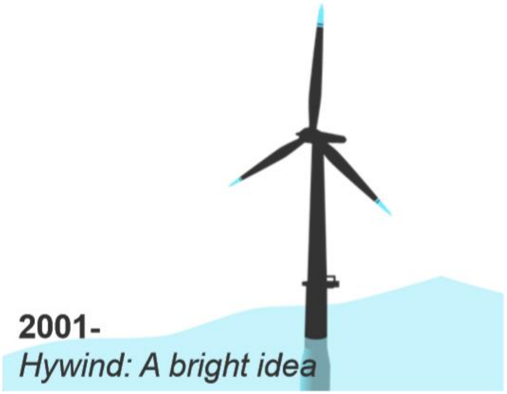
Índice

→ Introducción
→ ¿Por qué eólica marina?
→ La energía eólica marina en aguas profundas
→ **Retos y oportunidades de la eólica marina**
→ ¿Qué hace IHCantabria en eólica marina?

Retos y oportunidades de la eólica marina



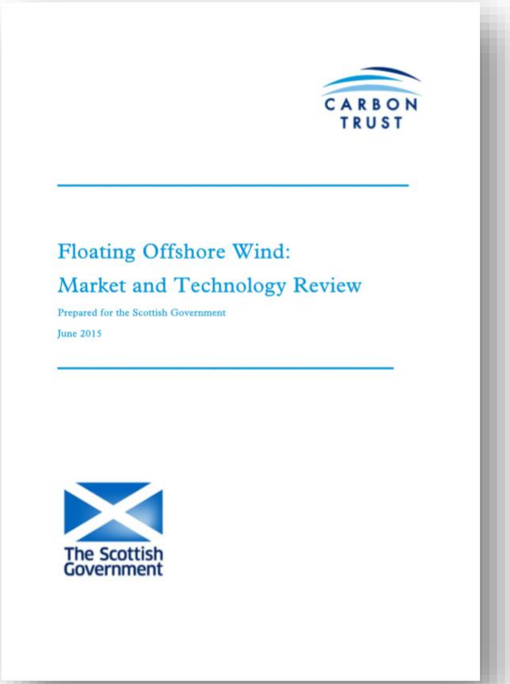
Hywind tardó 8 años en desarrollar su tecnología y realizer un priemr demostrador…. Hasta la planta precommercial tardó 8 años más


2001-
Hywind: A bright idea


2009-
Demo: Proven in the North Sea


2017-
Pilot park: A world's first

La energía eólica marina en aguas profundas


CARBON TRUST

Floating Offshore Wind:
Market and Technology Review

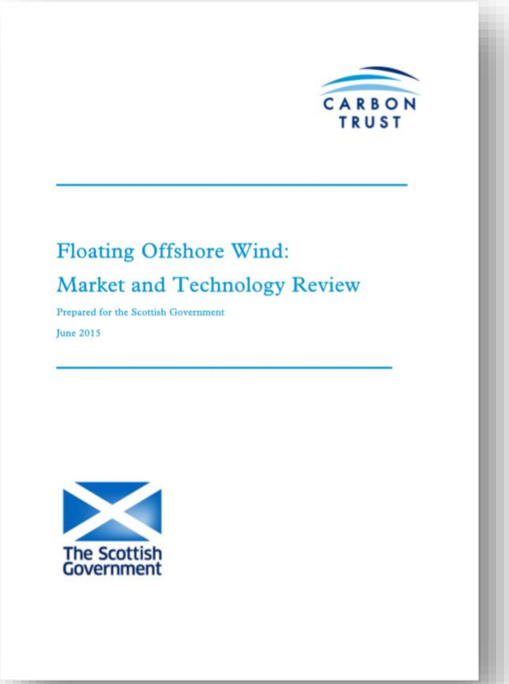
Prepared for the Scottish Government

June 2015

The Scottish Government

- → Plataformas: materiales y tamaño
- → Tecnologías y métodos de instalación
- → Operación y Mantenimeinto + 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

Retos y oportunidades de la eólica marina


CARBON TRUST

Floating Offshore Wind:
Market and Technology Review

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June 2015

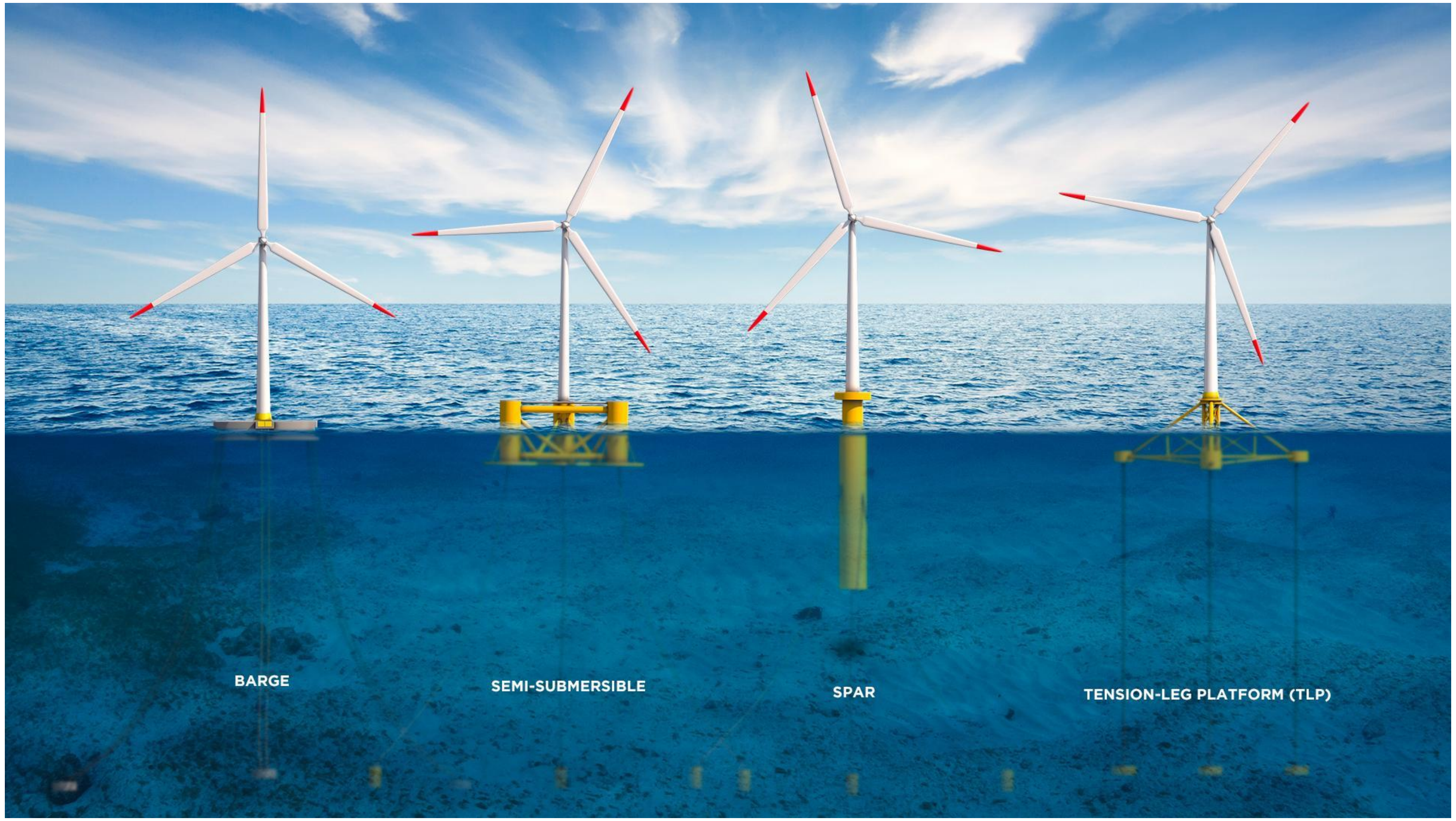
The Scottish Government

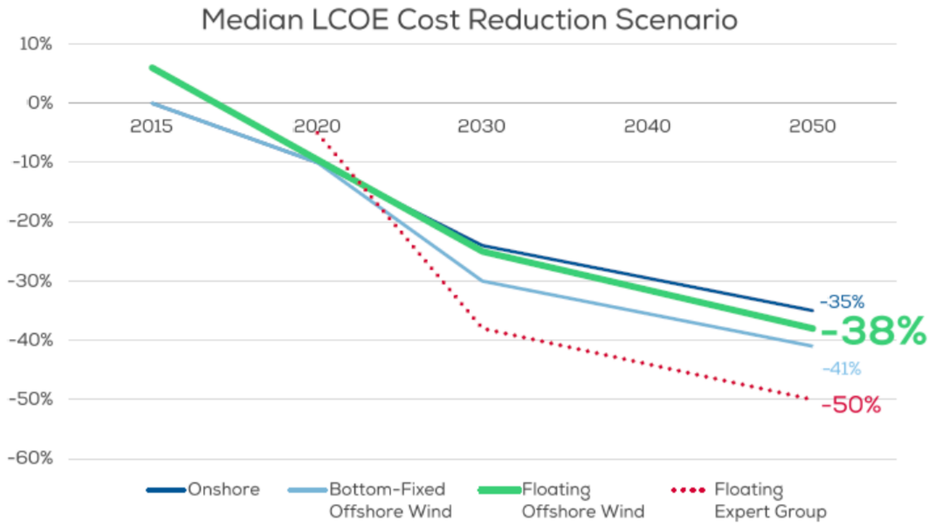
Technical challenge	Cost reduction potential	Urgency	IP sensitivity
Platform size & weight	2.7	2.4	2.8
Installation procedures	2.5	2.2	1.8
Port-side O&M (major repair procedures)	2.3	2.2	1.0
Floating substations/transformer modules	2.3	2.0	2.0
Advanced control systems for floating WTGs	2.2	2.2	2.6
Mooring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

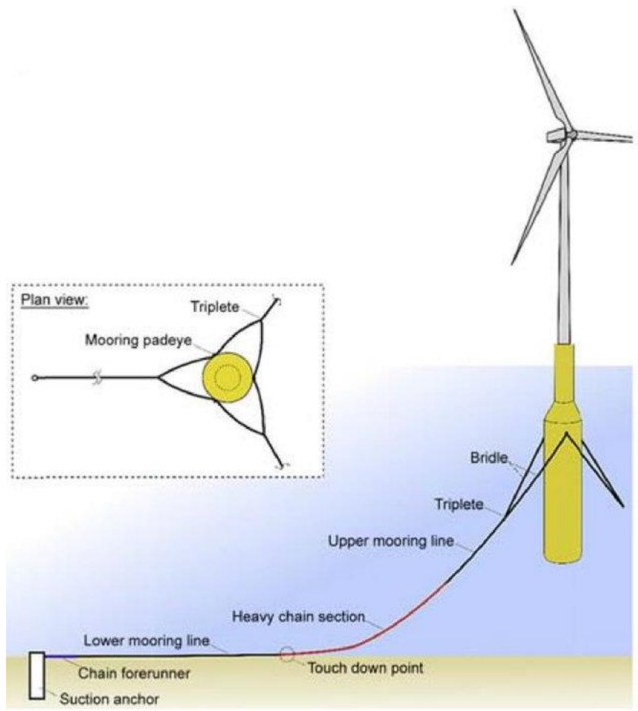
→ Diseño/Optimización plataforma



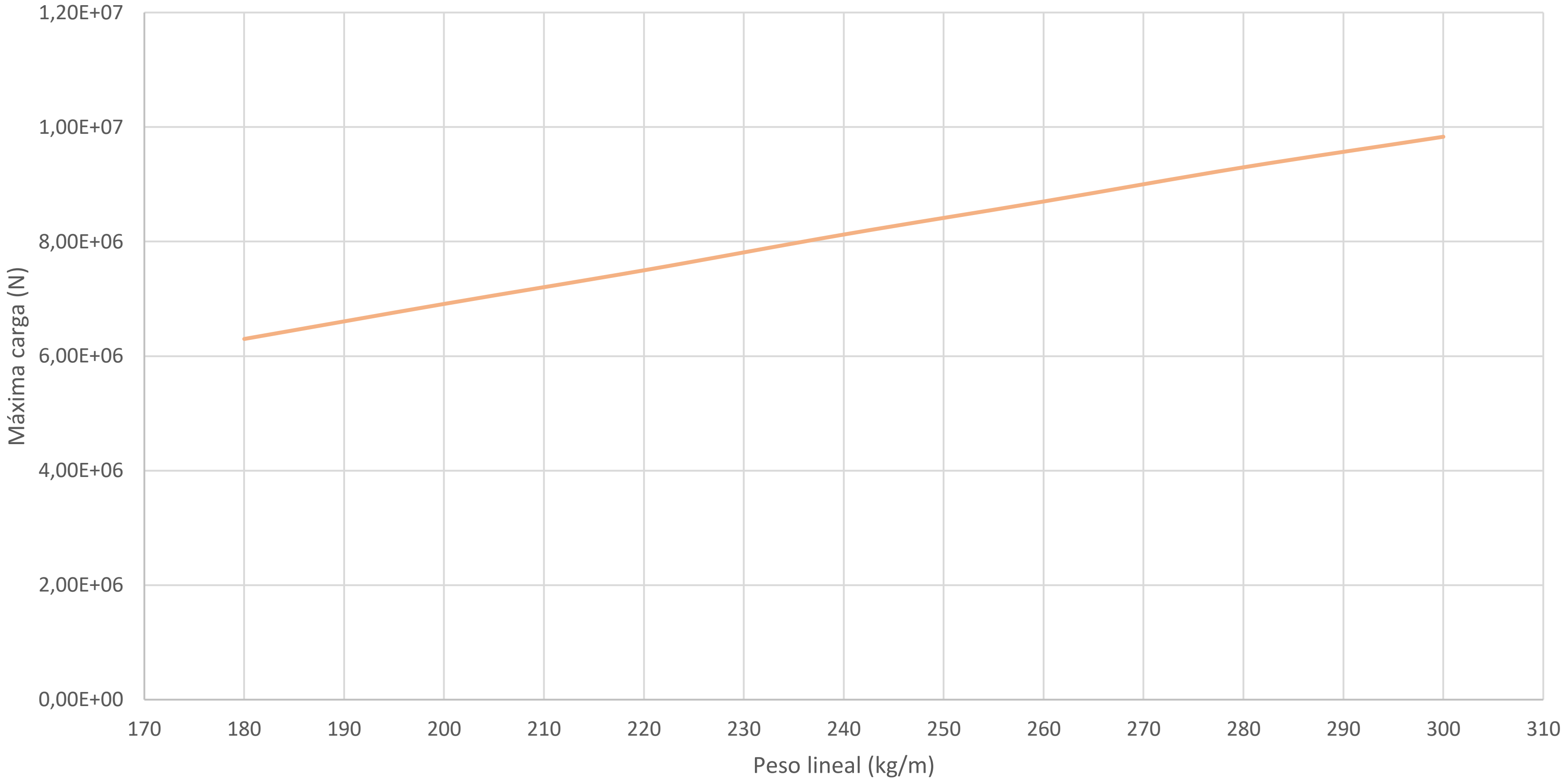


→ Optimización de los sistema de fondeo

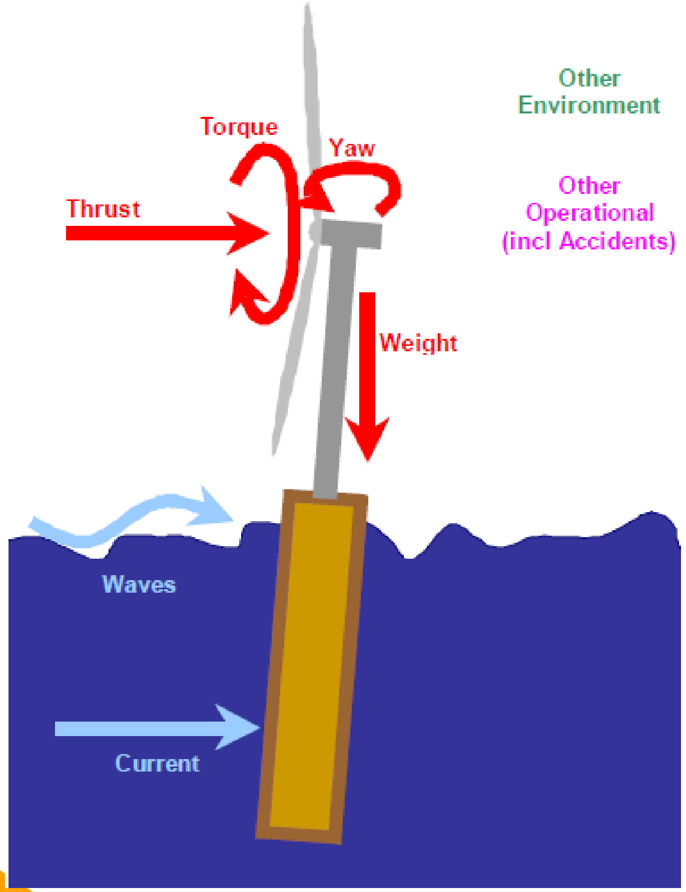
Ejemplo del sistema de fondeo de Hywind Scotland

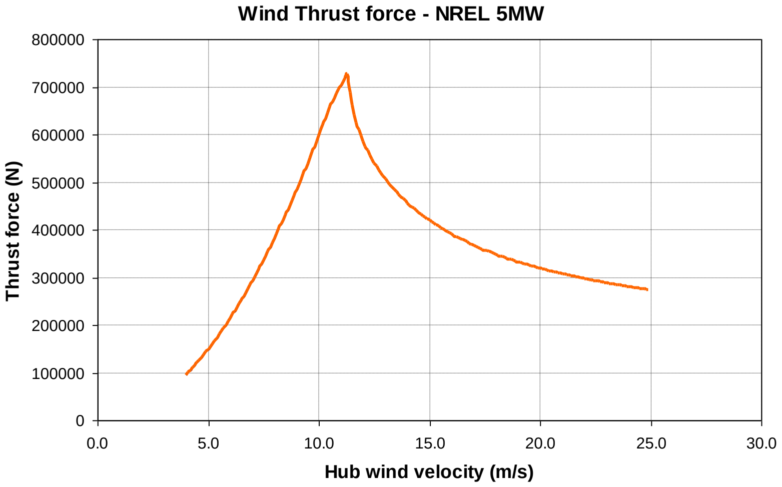


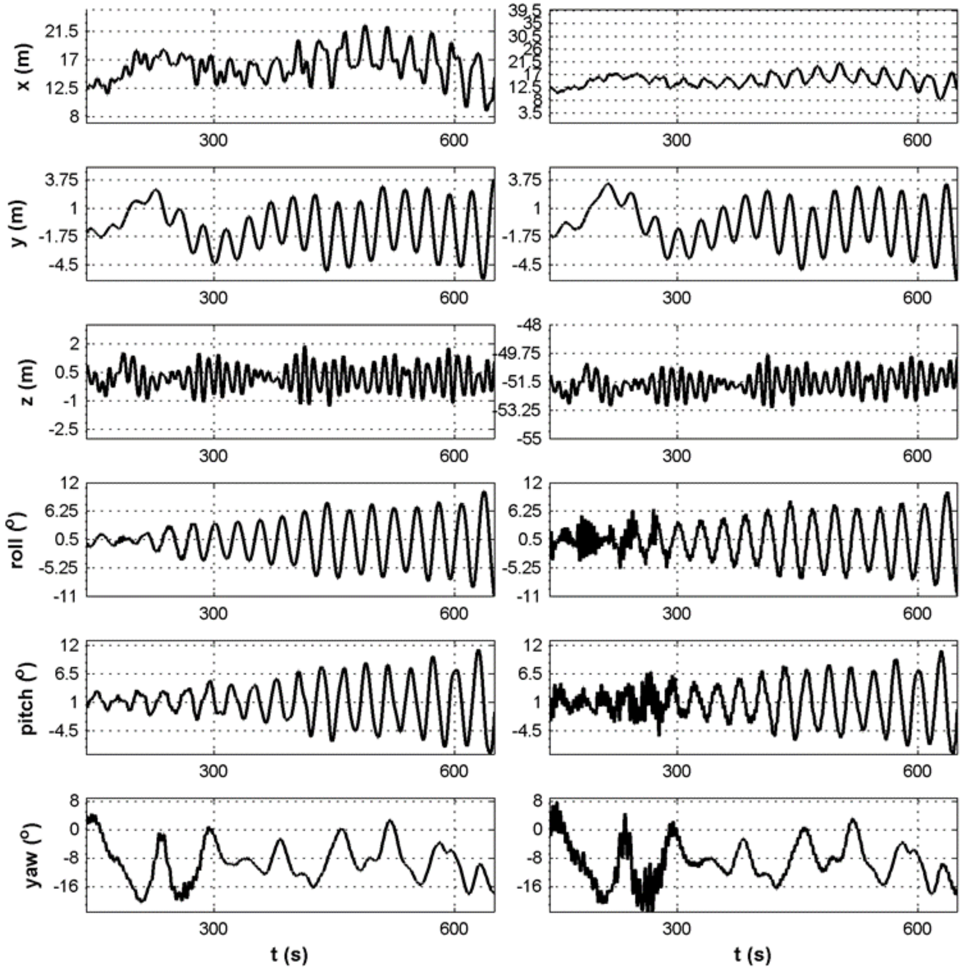
Cargas máximas en una línea de fondeo en función del peso/metro de la línea de fondeo



→ Sistemas avanzados de control





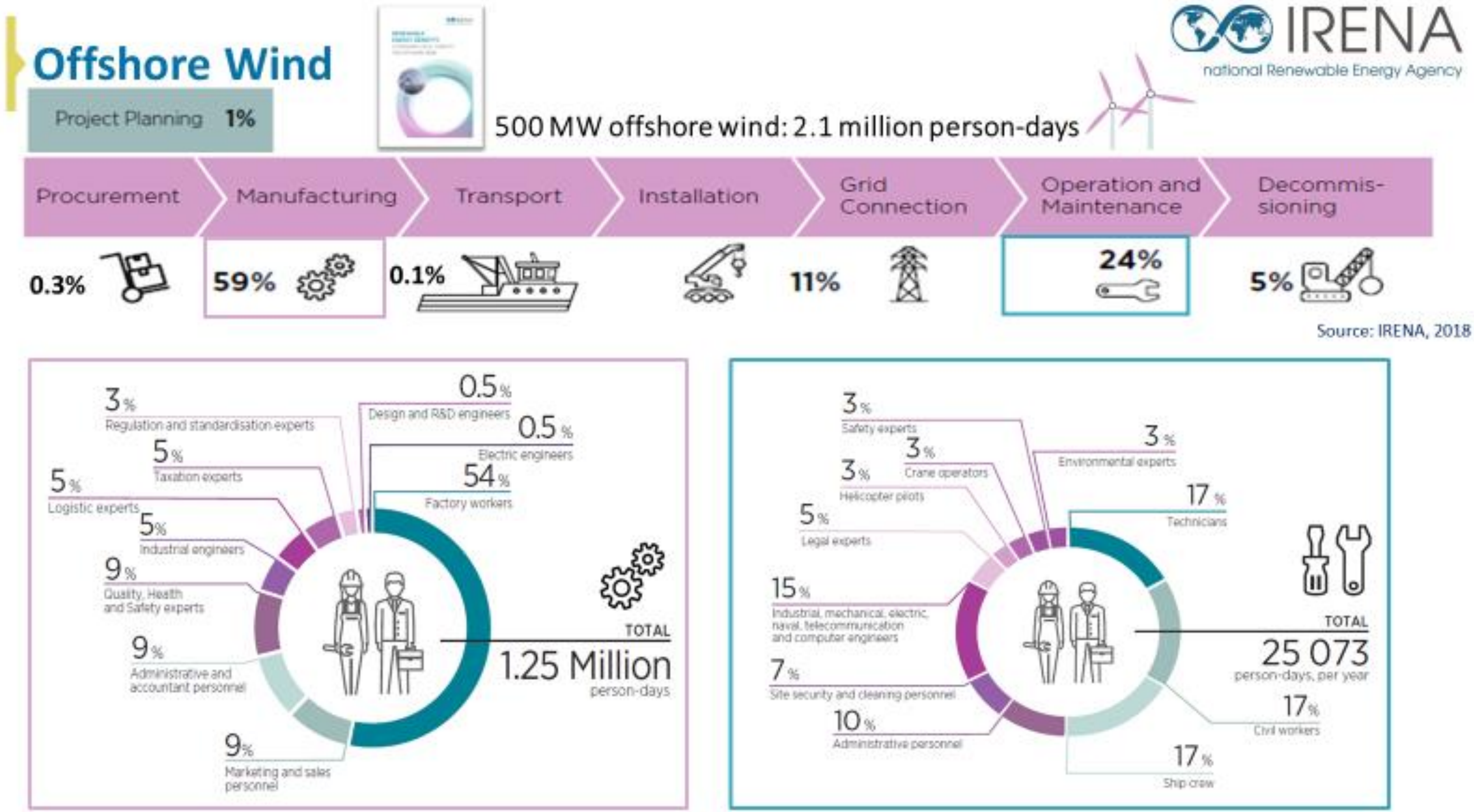


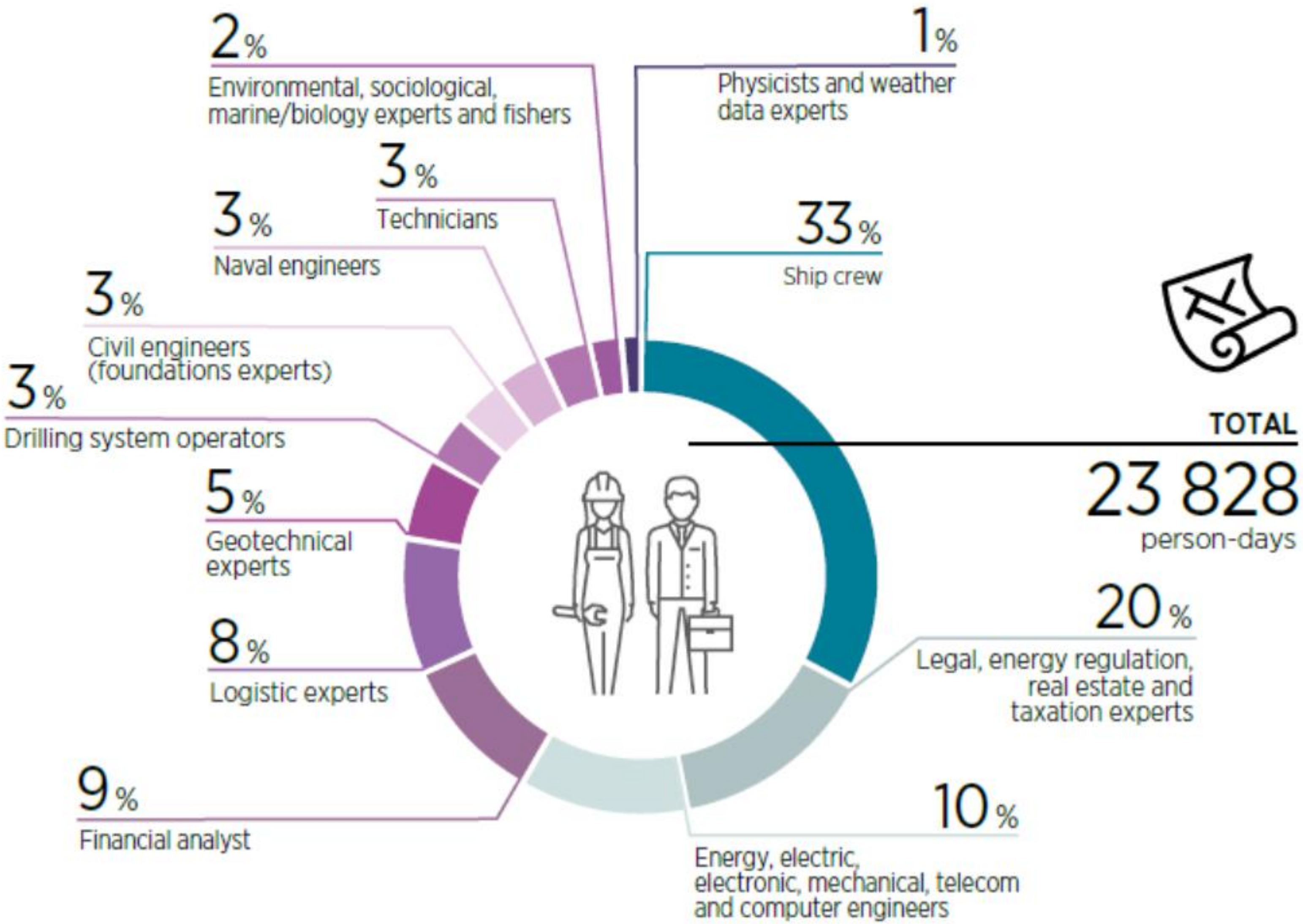
→ Procedimientos de instalación


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

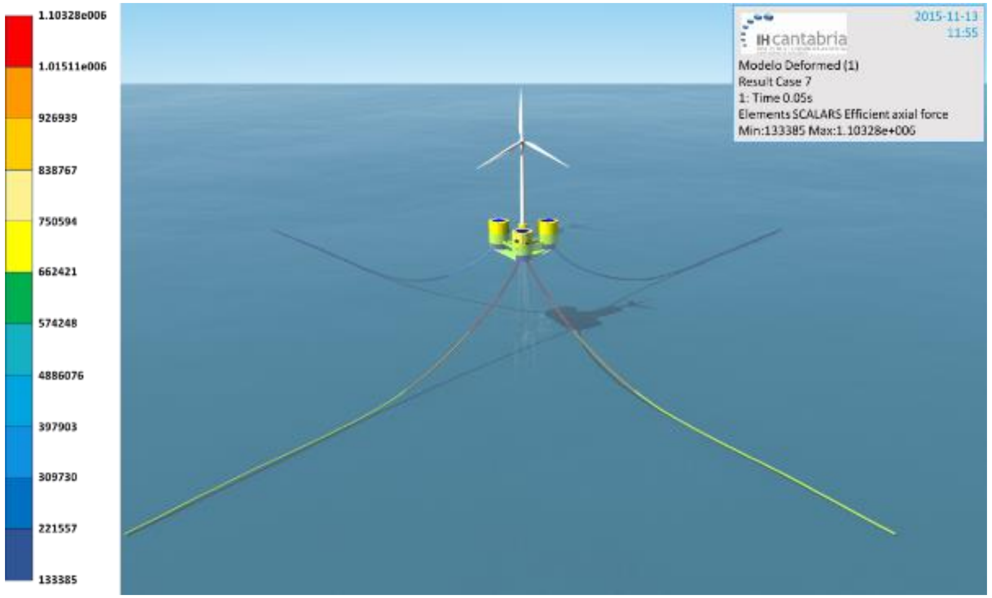

Offshore Wind
Project Planning 1%
500 MW offshore wind: 2.1 million person-days
IRENA
national Renewable Energy Agency
Procurement
Manufacturing
Transport
Installation
Grid Connection
Operation and Maintenance
Decommis-sioning
0.3%
59%
0.1%
11%
24%
5%
Source: IRENA, 2018
3% Regulation and standardisation experts
0.5% Design and R&D engineers
0.5% Electric engineers
5% Taxation experts
54% Factory workers
5% Logistic experts
5% Industrial engineers
9% Quality, Health and Safety experts
9% Administrative and accountant personnel
9% Marketing and sales personnel
TOTAL
1.25 Million person-days
3% Safety experts
3% Crane operators
3% Environmental experts
3% Helicopter pilots
5% Legal experts
17% Technicians
15% Industrial, mechanical, electric, naval, telecommunication and computer engineers
7% Site security and cleaning personnel
10% Administrative personnel
TOTAL
25 073 person-days, per year
17% Civil workers
17% Ship crew

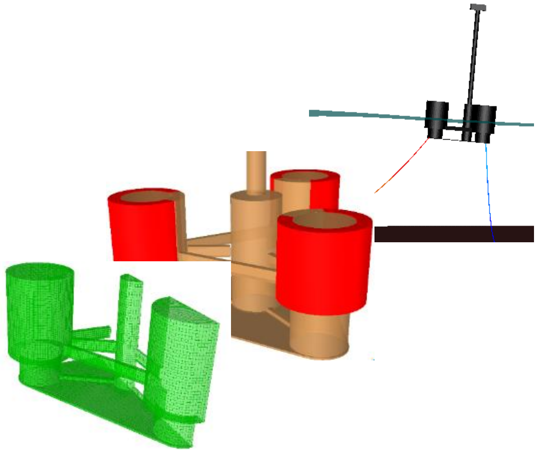

2%
Environmental, sociological, marine/biology experts and fishers
1%
Physicists and weather data experts
3%
Technicians
3%
Naval engineers
33%
Ship crew
3%
Civil engineers (foundations experts)
3%
Drilling system operators
TOTAL
23 828
person-days
5%
Geotechnical experts
8%
Logistic experts
20%
Legal, energy regulation, real estate and taxation experts
9%
Financial analyst
10%
Energy, electric, electronic, mechanical, telecom and computer engineers

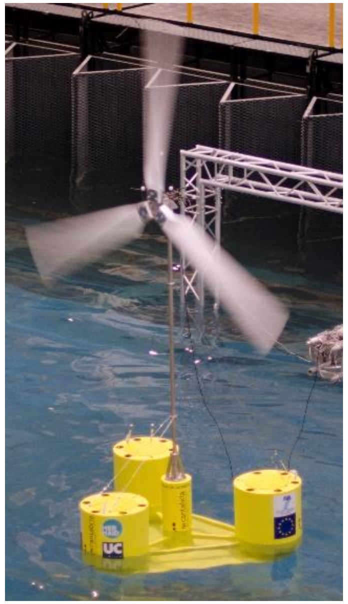
Índice

¿Qué hace IHCantabria en eólica marina?

Afrontamos los retos científico-técnicos con una vision integral…







Metodología híbrida

-Interacción fluido estructura-

Numerical modeling

01 Ensayos en laboratorio

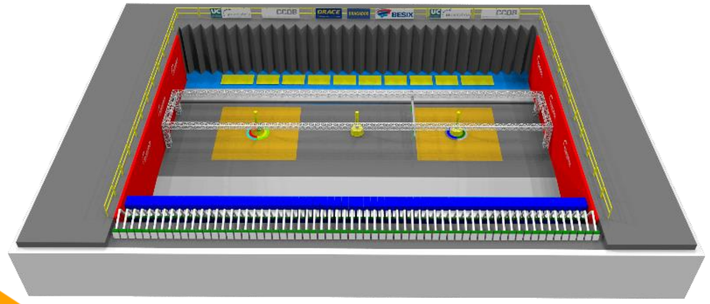
Verification and Validation

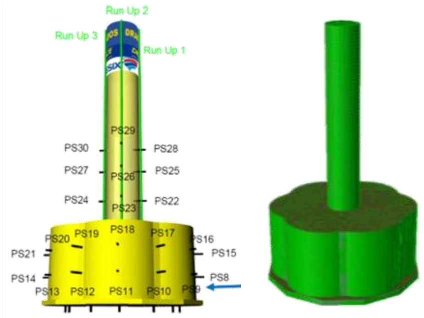
02 Modelos simplificados

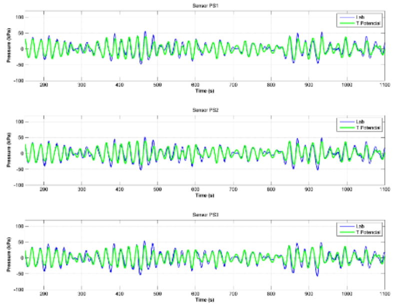
SESAM DNV·GL NEMOH ANSYS IH WAVE2WIRE

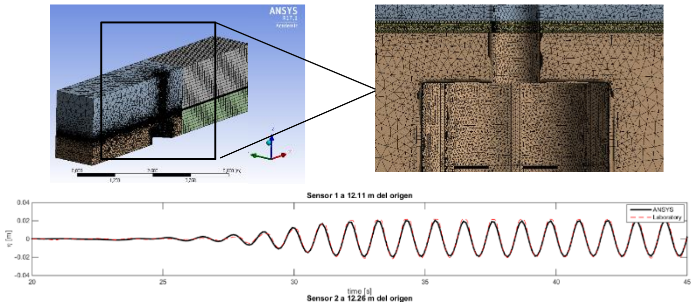
03 Modelos avanzados

ANSYS FLUENT OpenFOAM









¿Qué hace IHCantabria en eólica marina?

+ de 16 tecnologías fijas analizadas

CCOB
CANTABRIA COASTAL AND OCEAN BASIN

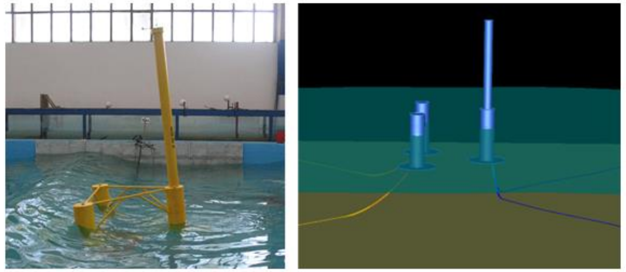
¿Qué hace IHCantabria en eólica marina?

+ de 16 tecnologías flotantes analizadas

CCOB
CANTABRIA COASTAL AND OCEAN BASIN

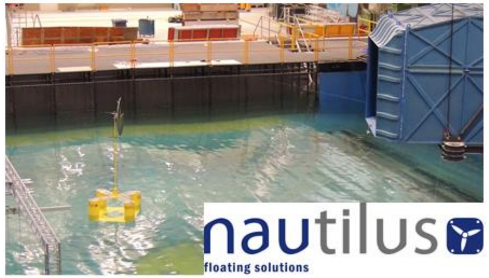
Idermar project

SAEMar: National research project



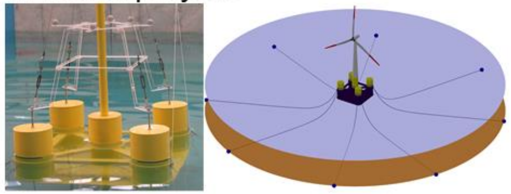
Mermaid Project: EC, FP 7

Nautilus Floating Solutions

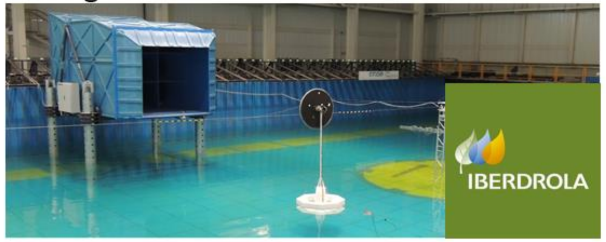


ELICAN project

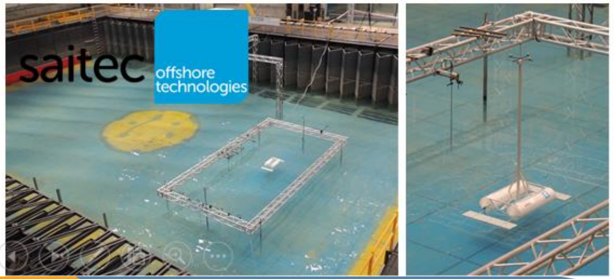
In house project



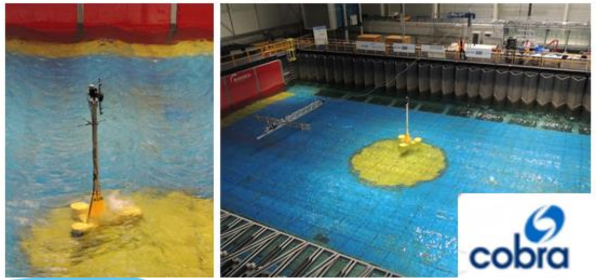
Emerge: IBERDROLA



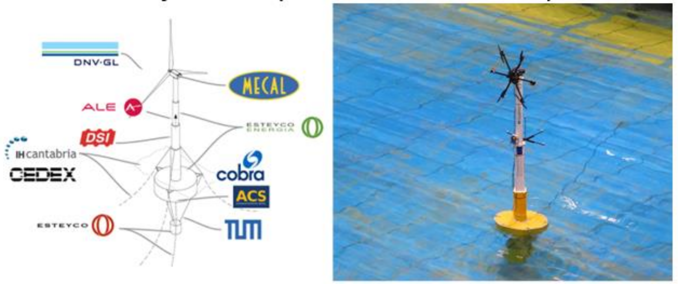
Saitec Offshore Technologies



Kinkardine: KOWL, COBRA

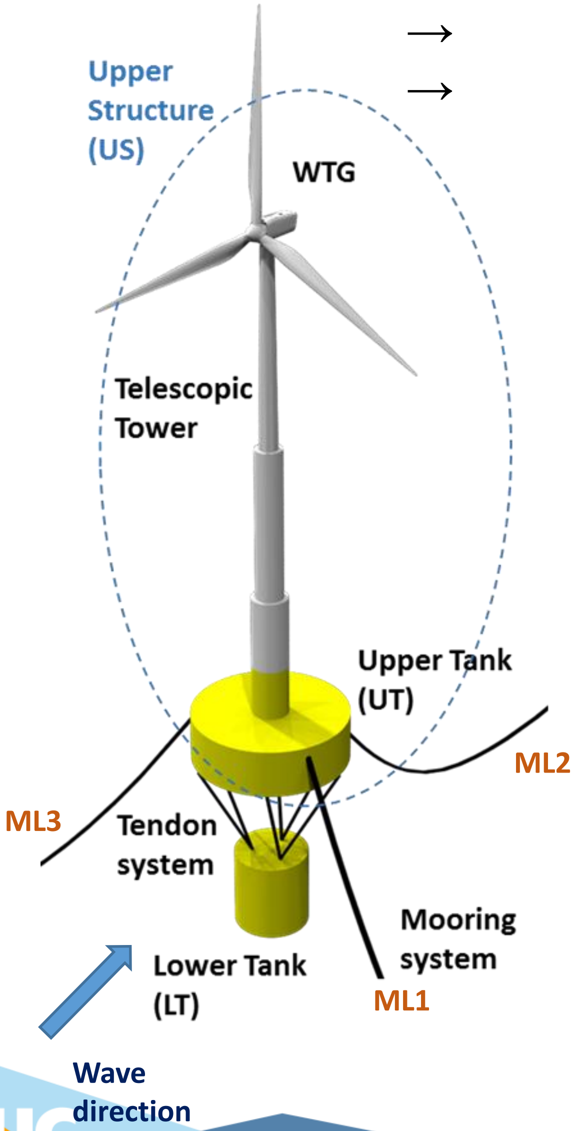


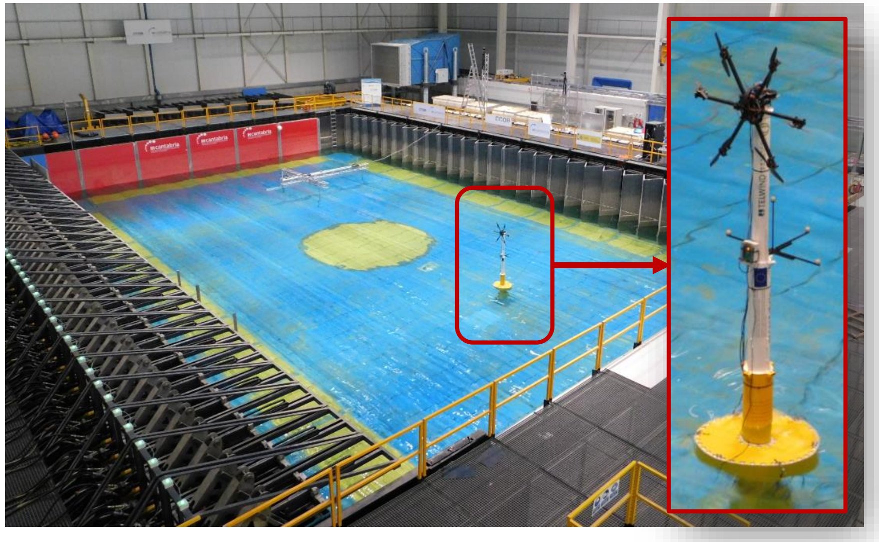
Telwind Project: EC (H2020-LCE-2015-1)

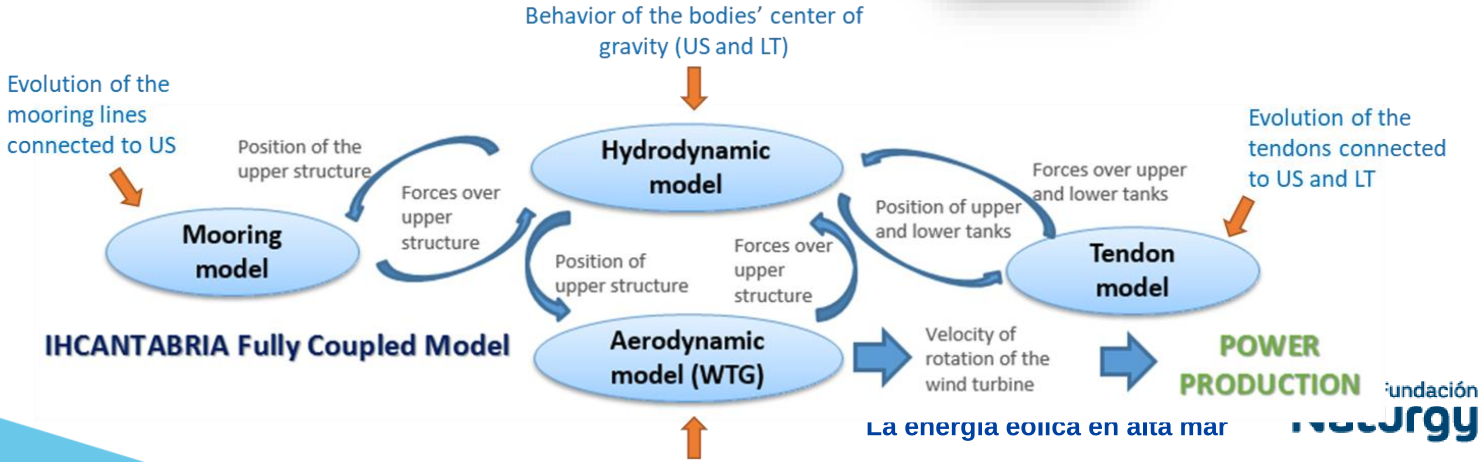


¿Qué hace IHCantabria en eólica marina?

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



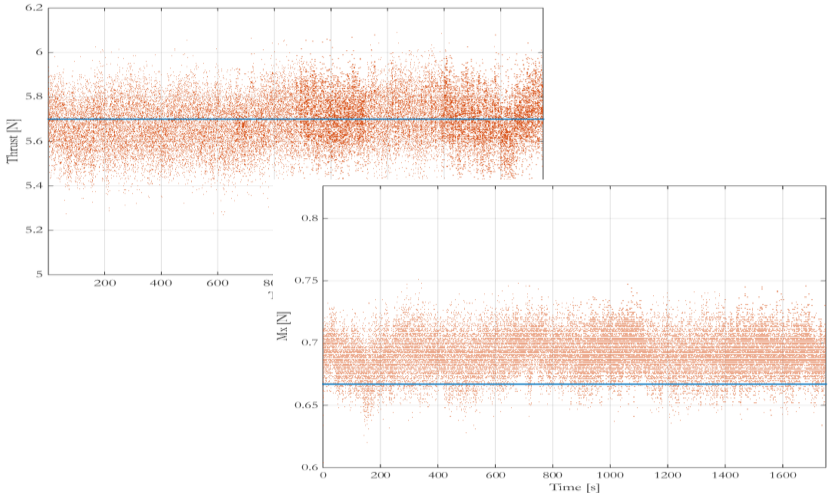




Basin Characteristics

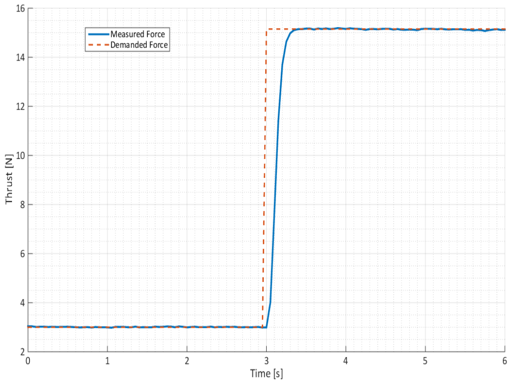
Tecnicas avanzadas de simulación aerodinámica en tanque

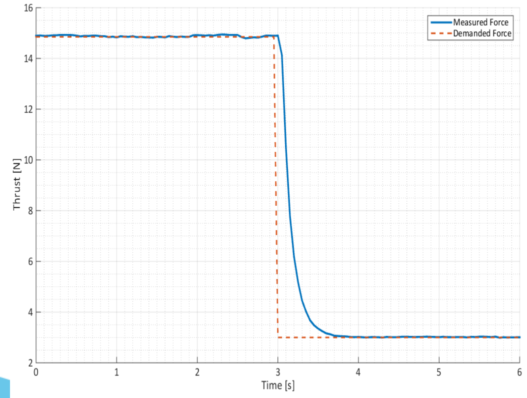
-NREL 5MW, 1:50 escala
-Empuje y momento aerodinámico constante



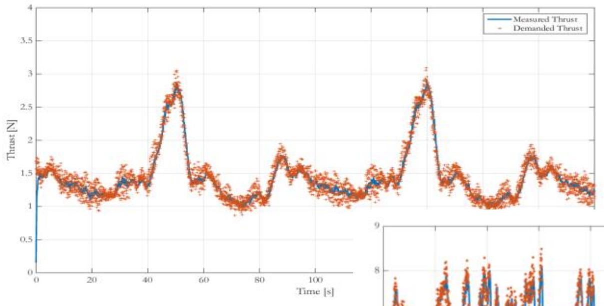
	Mean Error	Std
Thrust [N]	0.25%	0.13
Aerodynamic Moment [N·m]	2.04 %	0.0017

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

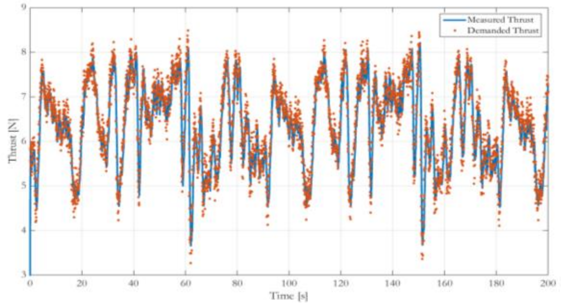




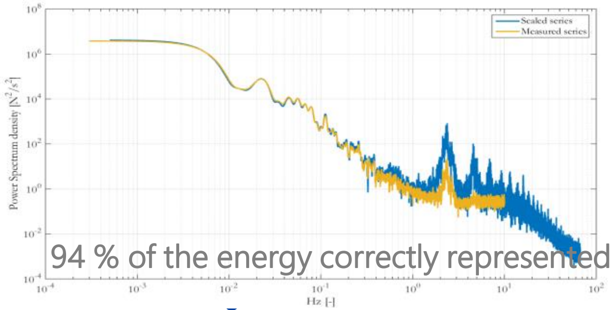
-Serie de tiempo turbulenta proporcionada por el cliente
-Objetivo de comparación versus empuje medido



Algoritmo turbulento, media 4 m/s



Algoritmo turbulento, media 12 m/s



94 % of the energy correctly represented

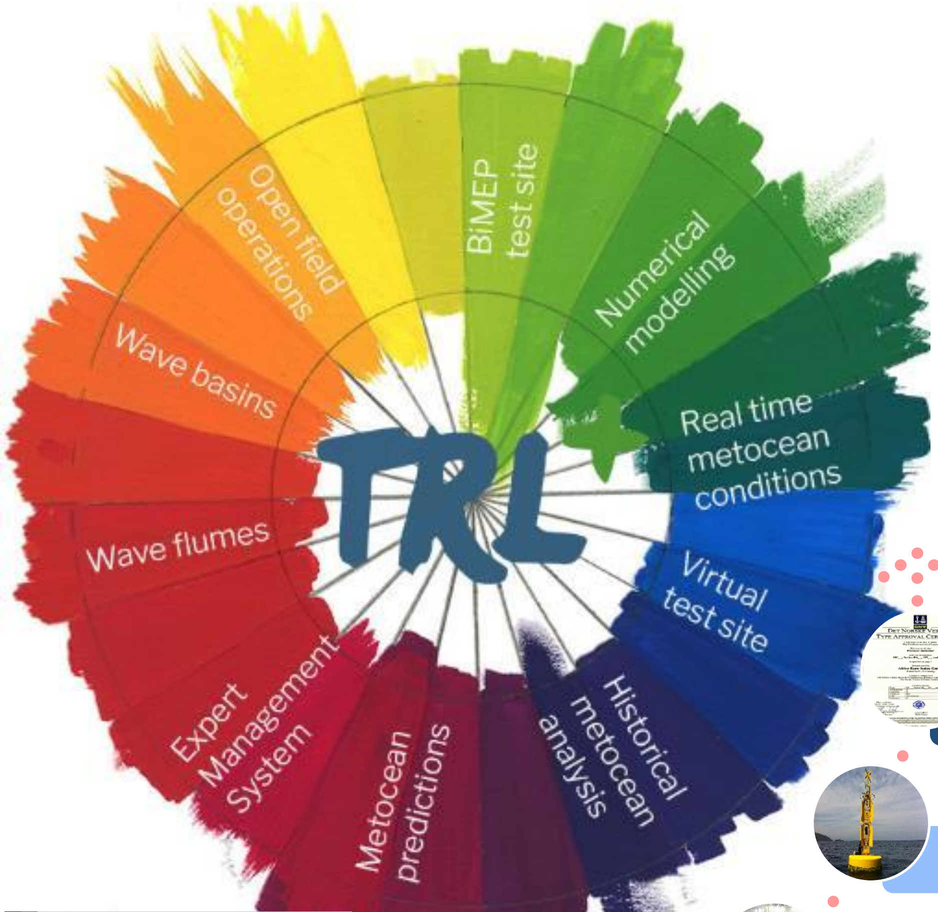
f Jacket F
09/02/2

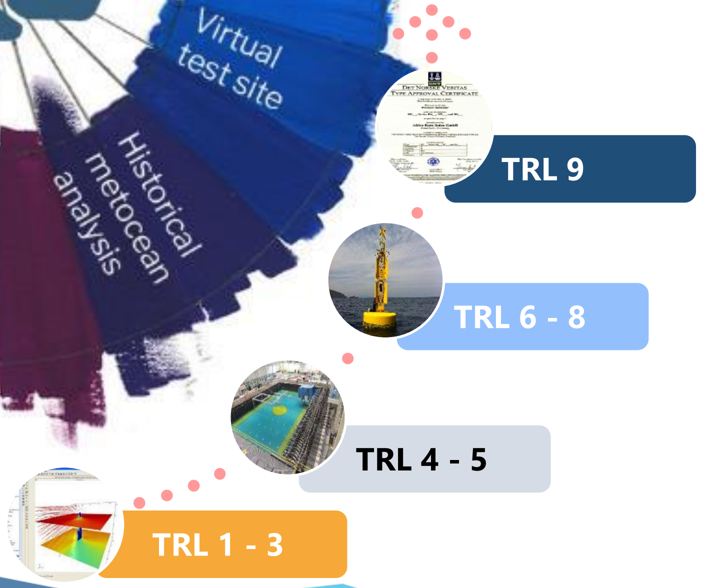
IH Cantabria R&D Strategy: Collaboration

Key collaborations: TRL+

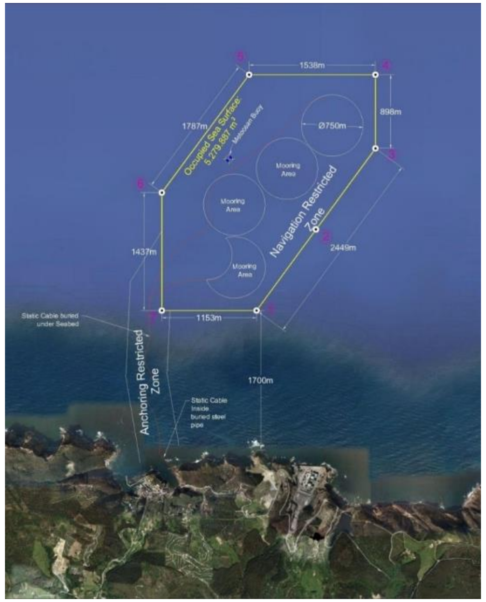
"Supporting MRE developers from concept to reality."

TRL+ = bimep + IH cantabria



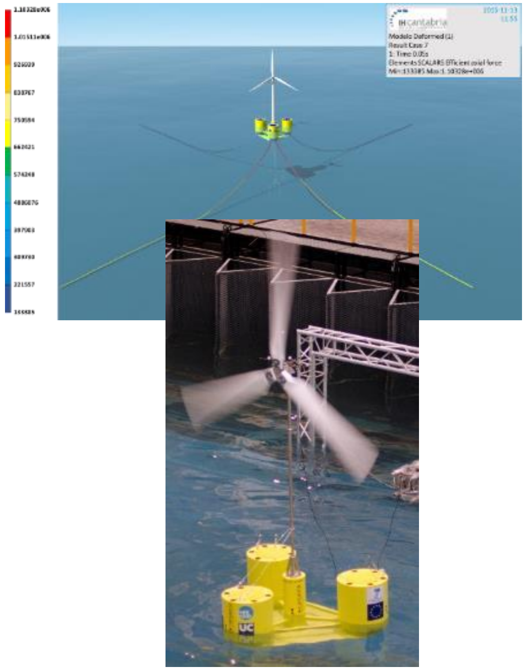


Test site



+

Research institute



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IHCANTABRIA

INSTITUTO DE HIDRÁULICA AMBIENTAL DE CANTABRIA

UNIVERSIDAD DE CANTABRIA

La energía eólica en alta mar (en aguas profundas, más de 50 m)
La experiencia internacional

Energía y medio ambiente en el mar

FUNDACIÓN NATURGY

Fundación Naturgy

Raúl Guanche guancher@unican.es

Santander, 16 de Octubre de 2018