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Can offshore wind energy in the North Sea compete with fossil fuels?

The total costs of a unity of power produced with this technology is in constant reduction and will be very competitive even with the cheapest fossil fuels.

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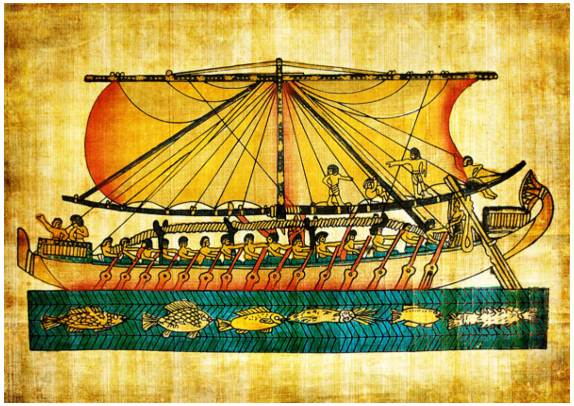
WIND POWER: THE STORY OF WIND ENERGY

Wind power has a very long history: used in the very ancient times to sail with ships,



Egyptian Ship

Ancient Greek Ship

Phoenician Ship

it was then used for mills, to pump water, or to grind and, even thanks to Lincoln, in the 19th century had a big impulse in the Great Plains of the US to irrigate or to generate electricity, making wind turbines becoming part of the landscapes, and even typical of some countries, in rural America as well as in Netherland, and in many other places.

US old wind turbine well in the plains

US old wind turbine well in the plains

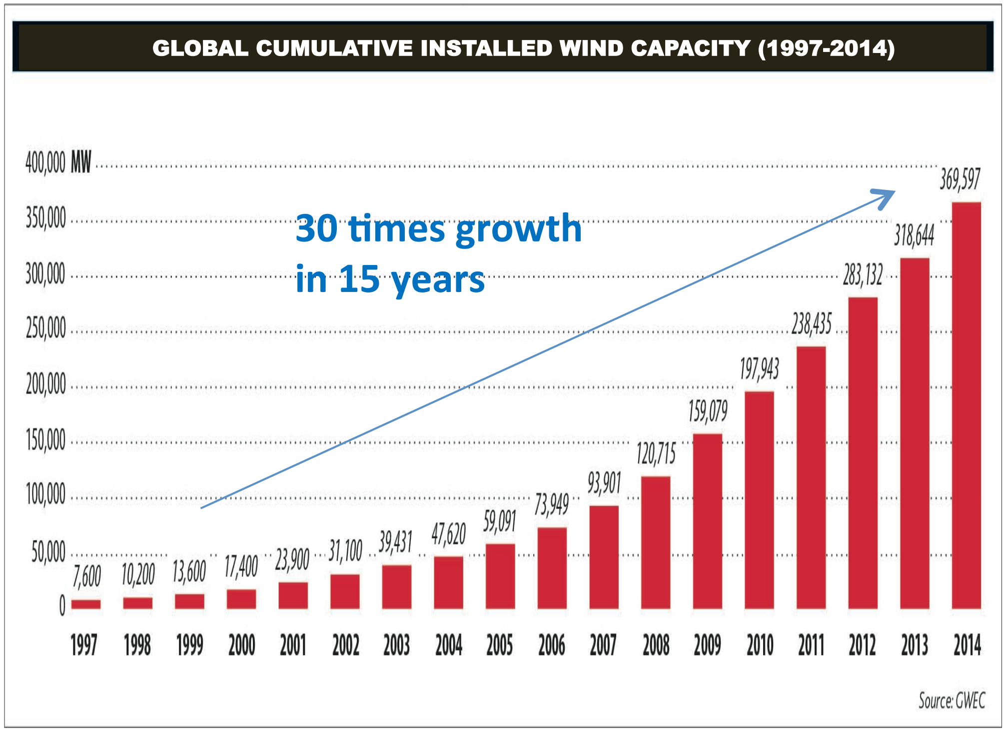
Old Wind turbine in Netherland

Old Wind turbine in Spain

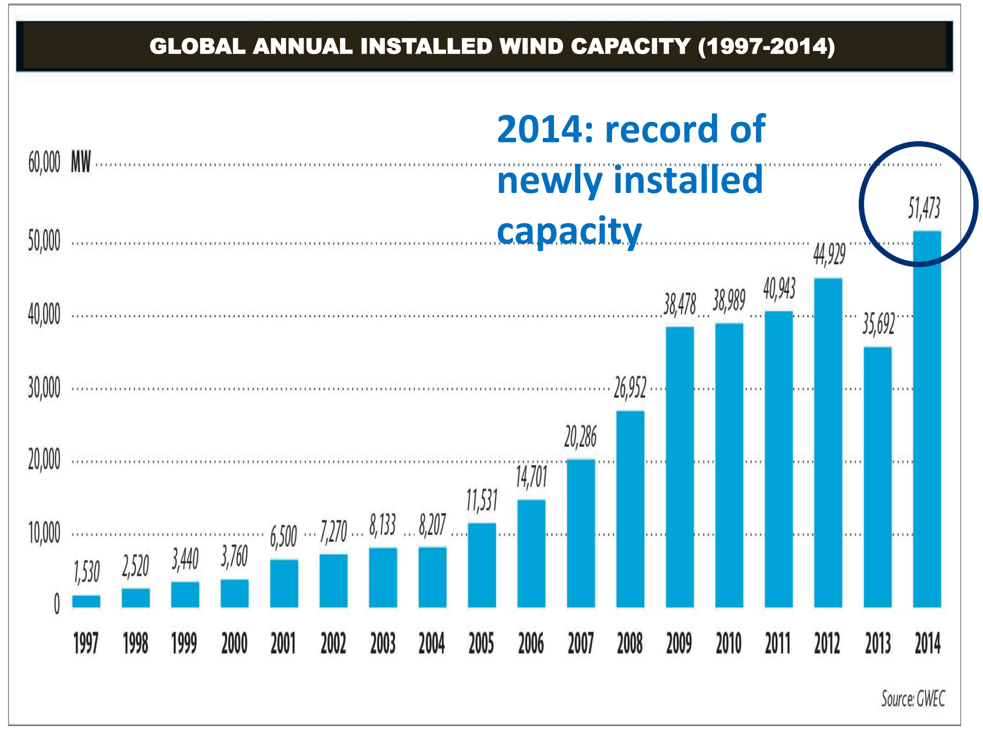
WIND POWER: THE DEVELOPMENT OF WIND ENERGY

After a period of abandon, due to the spread of the use of coal and then oil, in the seventies, with the increasing cost of fossil fuels, it became newly of great interest and many Countries put money in the research to develop this kind of power and in the last few years it has been experiencing an extraordinary development, that makes wind the first renewable in the world, and it is expected to grow even more in the next future.

In 2014 we had the record number of GW of wind power installed, 51.5 GW, bringing the total installed global capacity to more than 369.6 GW.



GWEC - Global Wind Energy Council – Global Wind Report – Annual Market Update 2014

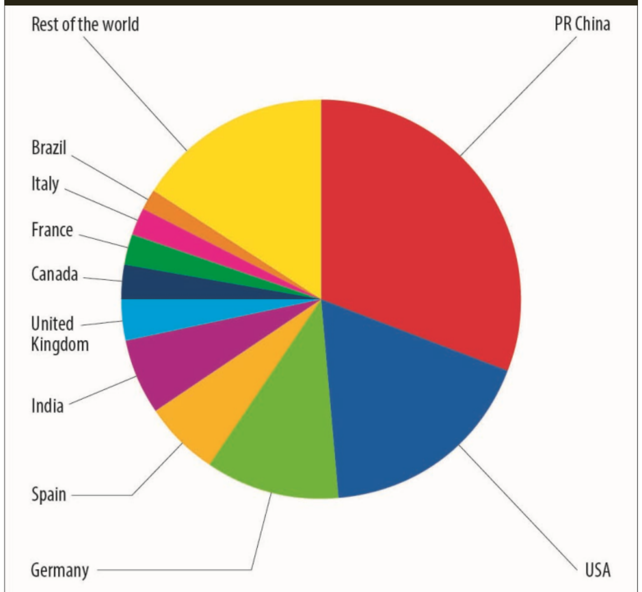


GWEC - Global Wind Energy Council – Global Wind Report – Annual Market Update 2014

By the end of 2020 it is expected almost to double and overtake 700 GW of capacity installed.

WIND POWER: THE DEVELOPMENT OF WIND ENERGY

TOP 10 CUMULATIVE CAPACITY DEC 2014



Country	MW	% SHARE
PR China	114,609	31.0
USA	65,879	17.8
Germany	39,165	10.6
Spain	22,987	6.2
India	22,465	6.1
United Kingdom	12,440	3.4
Canada	9,694	2.6
France	9,285	2.5
Italy	8,663	2.3
Brazil*	5,939	1.6
Rest of the world	58,473	15.8
Total TOP 10	**311,124**	**84.2**
World Total	**369,597**	**100**

** Projects fully commissioned, grid connection pending in some cases* *Source: GWEC*

GWEC - Global Wind Energy Council – Global Wind Report – Annual Market Update 2014

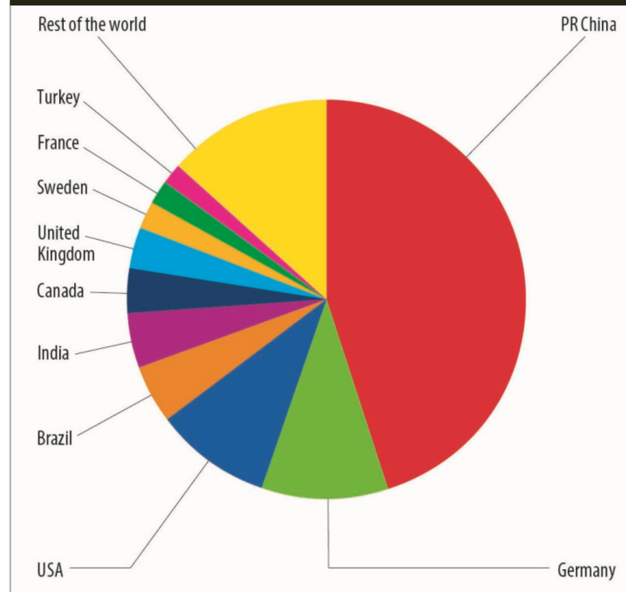
In 2014 China was the first in the world for total installed capacity (114.6 GW) followed by USA (65.9 GW) and Germany was the 3rd with 39.2 GW.

Sweden was the 11th with 5.4 GW, Denmark the 13th with 4.9 GW and The Netherlands the 18th with 2.8 GW.

In 2014 China was the first in the world also for new installed capacity (23.2 GW - +45%) followed by Germany (5.3 GW - +10%).

Sweden was the 8th with 1 GW, The Netherlands the 25th and Denmark the 29th

TOP 10 NEW INSTALLED CAPACITY JAN DEC 2014



Country	MW	% SHARE
PR China	23,196	45.1
Germany	5,279	10.2
USA	4,854	9.4
Brazil*	2,472	4.8
India	2,315	4.5
Canada	1,871	3.6
United Kingdom	1,736	3.4
Sweden	1,050	2.0
France	1,042	2.0
Turkey	804	1.6
Rest of the world	6,852	13.3
Total TOP 10	**44,620**	**87**
World Total	**51,473**	**100**

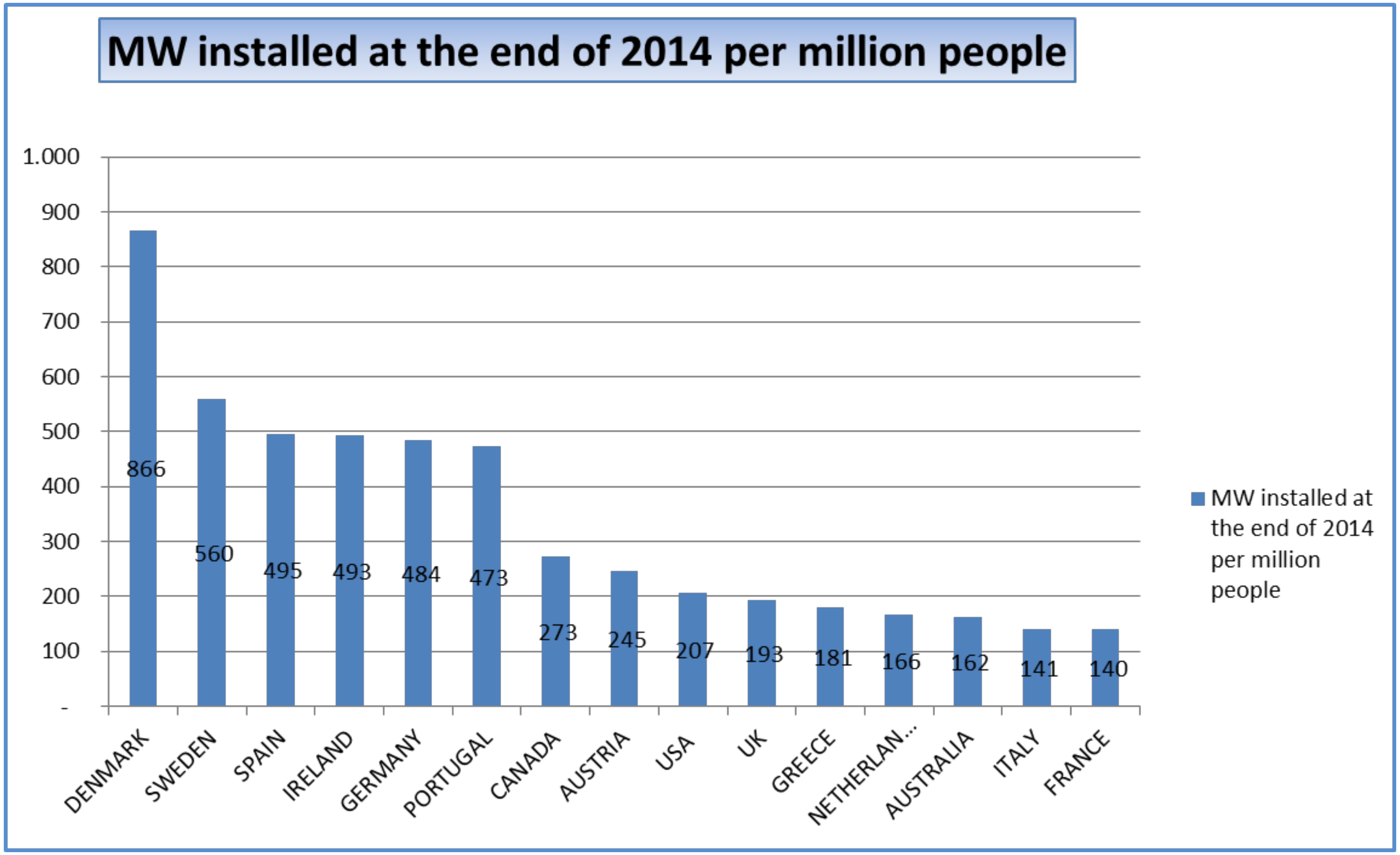
** Projects fully commissioned, grid connection pending in some cases* *Source: GWEC*

GWEC - Global Wind Energy Council – Global Wind Report – Annual Market Update 2014

WIND POWER: THE DEVELOPMENT OF WIND ENERGY

In term of capacity installed per capita, we see that Europe is absolutely leader with 12 countries in the first 15 ones:

Denmark is the 1st, with 866 MW installed per million capita in 2014;
Sweden is the 2nd, with 560,
Germany the 5th with 484 and
Netherlands the 12th with 166.



Outside Europe, only Canada and the United States are between the first 10 (7th the first and 9th the second) and Australia is 13th.

Graph made by the author -Sources used: CWEC (Global Wind Energy Council – Global Wind Report – Annual Market Update 2014) for istalled capacity and The Wolrd Bank for updated Population

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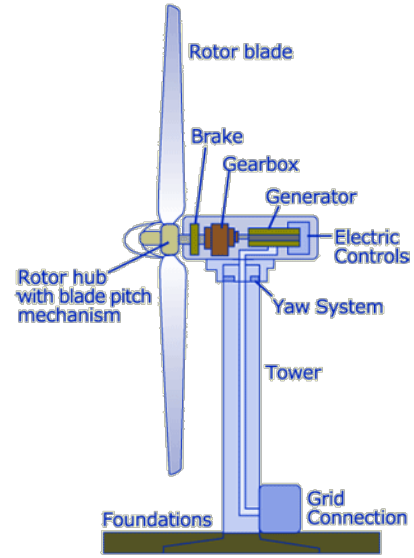
WIND OFFSHORE



WIND POWER:

the kinetic energy of the wind makes propellers rotate and the mechanical energy is turned into electrical power: it is a simple and cheap method.

WIND FARMS:

we can have Wind Farms:

- on-shore: generally distant at least 2 miles (3 kilometres) from the coast in open and windy areas or on hills or whatever heights; we can find most of the biggest in USA, but the biggest will be soon the Gansu Wind Farm in China (20 GW planned for 2020);

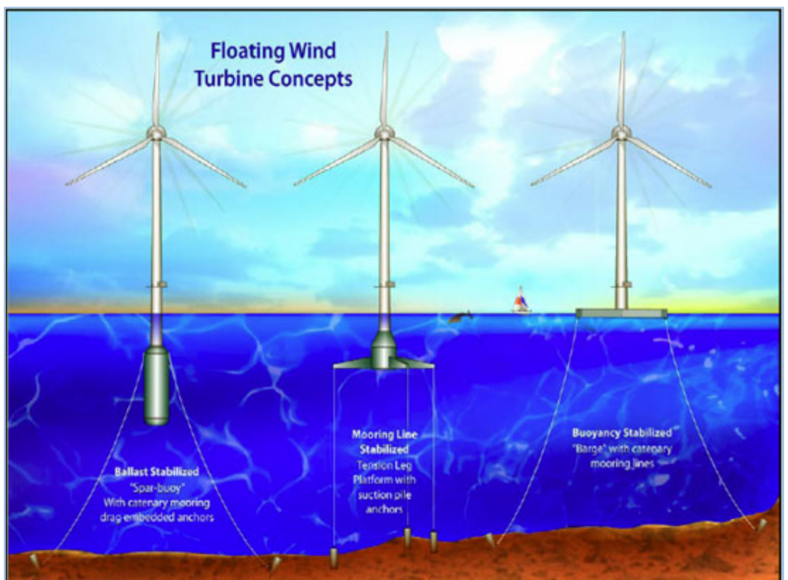
- near-shore: they can be on the land, far less than 2 miles from the shore, or in the sea, no more than 6 miles from the shore;

WIND OFFSHORE

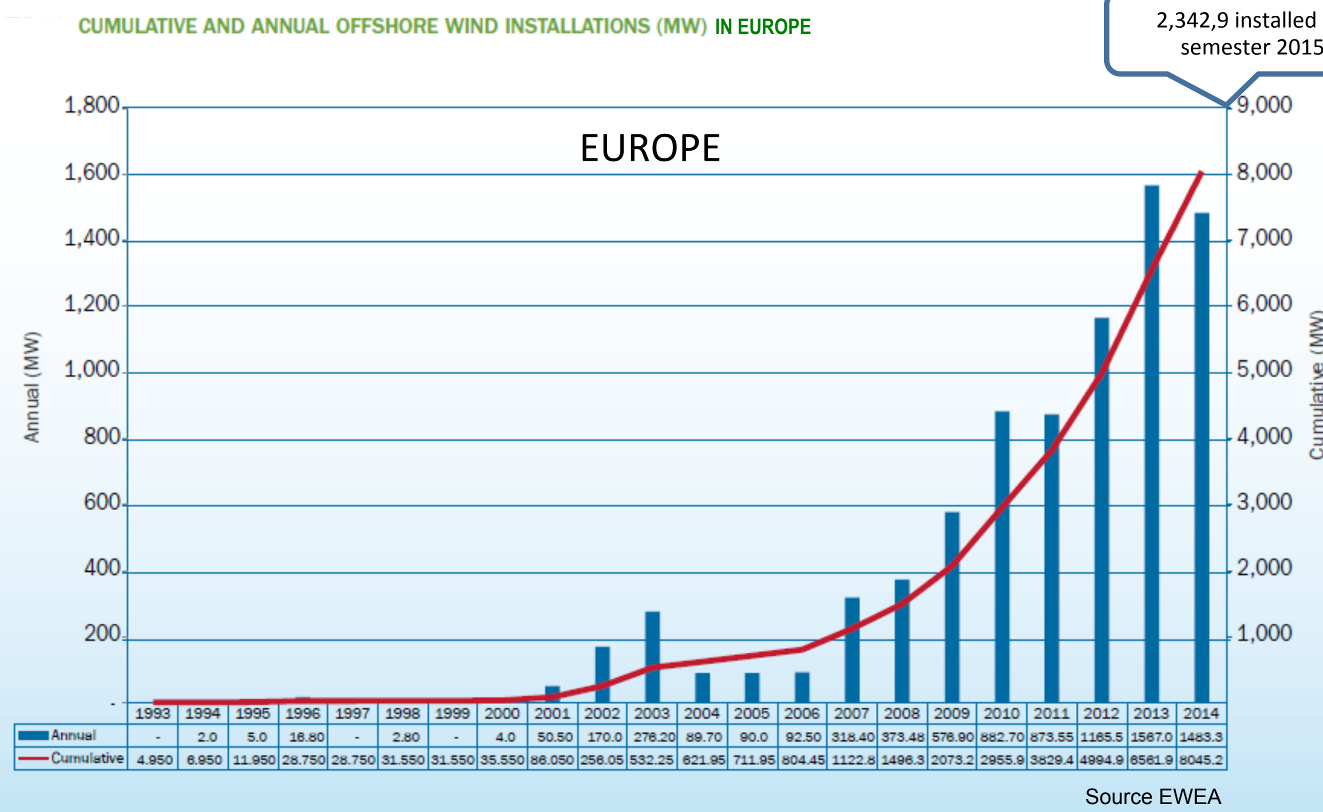
WIND FARMS:

- <u>off-shore</u>: they are far more than 6 miles from the shores of seas or lakes; in United Kingdom and Denmark we can find the biggest, but Norway will soon overtake (Havsul project);
- there are also the more recent <u>off-shore floating turbines</u>, which can be installed where the sea is deeper than 100 ft (30 meters).

In order, Italy, Portugal, Norway, Sweden have already built one, and Japan has in project to build 80 floating wind turbines by 2020, just off Fukushima coast, to solve the lack of energy caused by the earthquake and tsunami of 2011.



WIND OFFSHORE: THE DEVELOPMENT



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Annual	-	2.0	5.0	16.80	-	2.80	-	4.0	50.50	170.0	276.20
Cumulative	4.950	6.950	11.950	28.750	28.750	31.550	31.550	35.550	86.050	256.05	532.25

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Annual	89.70	90.0	92.50	318.40	373.48	576.90	882.70	873.55	1165.5	1567.0	1483.3
Cumulative	621.95	711.95	804.45	1122.8	1496.3	2073.2	2955.9	3829.4	4994.9	6561.9	8045.2

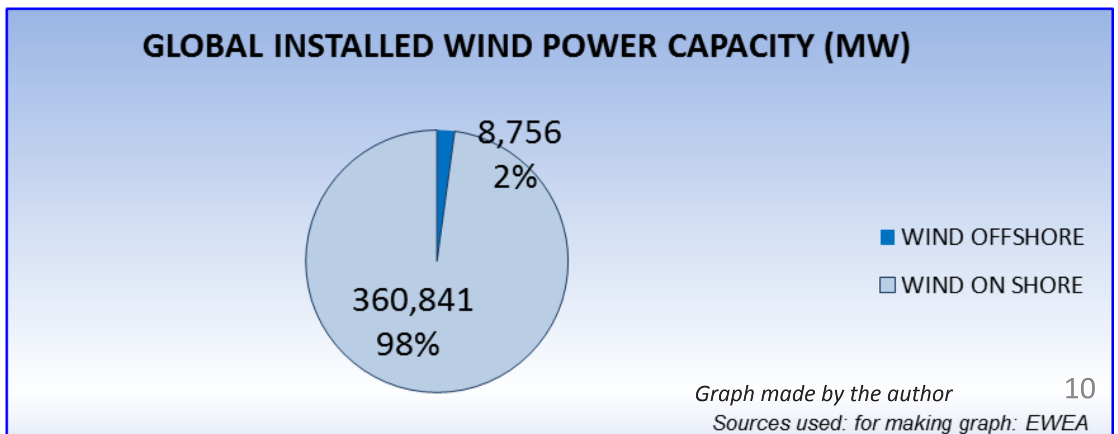
EWEA – European Wind Energy Association – The European offshore wind Industry – key trends and statistics 2014 – January 2015

Wind Offshore is relatively new, but it had a 10 time growth in the last 10 years **<u>in Europe</u>**: from 621 MW in 2004 to **8,045 MW in 2014**.

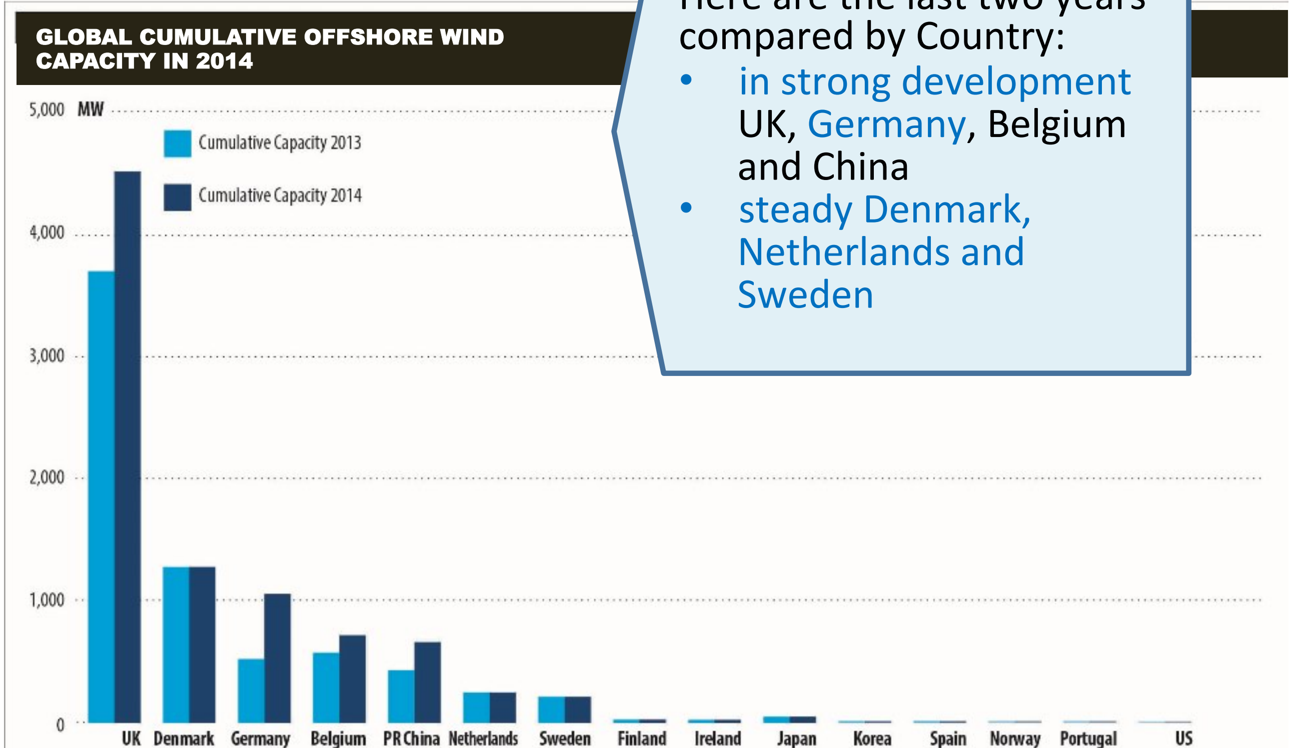
To have the **<u>whole world</u>** is sufficient to **add 711 MW in 2014** (658 China, 50 Japan and the remaining is Korea 3 and US 0,02**) and we reach 8,756 MW** installed that was 7,046 in 2013.

It still represents only the 2% of the total wind power installed capacity in the **<u>world</u>**, but its potential is much higher.

In the **first semester 2015** the newly installed capacity in Europe was 2,343 MW and it is expected to reach about 4,500 MW **at the end of 2015 (+55%)**



WIND OFFSHORE: THE DEVELOPMENT



	UK	Denmark	Germany	Belgium	PR China	Netherlands	Sweden	Finland	Ireland	Japan	Korea	Spain	Norway	Portugal	US	
Total 2013	3,680.9	1,271	520	572	429	247	212	26	25	50	5	5	2	2	0.02	7,046
New 2014	813.4	0	529	141	229	0	0	0	0	0	0	0	0	0	0	1,713
Total 2014	4,494.3	1,271	1,049	713	658	247	212	26	25	50	5	5	2	2	0.02	8,759

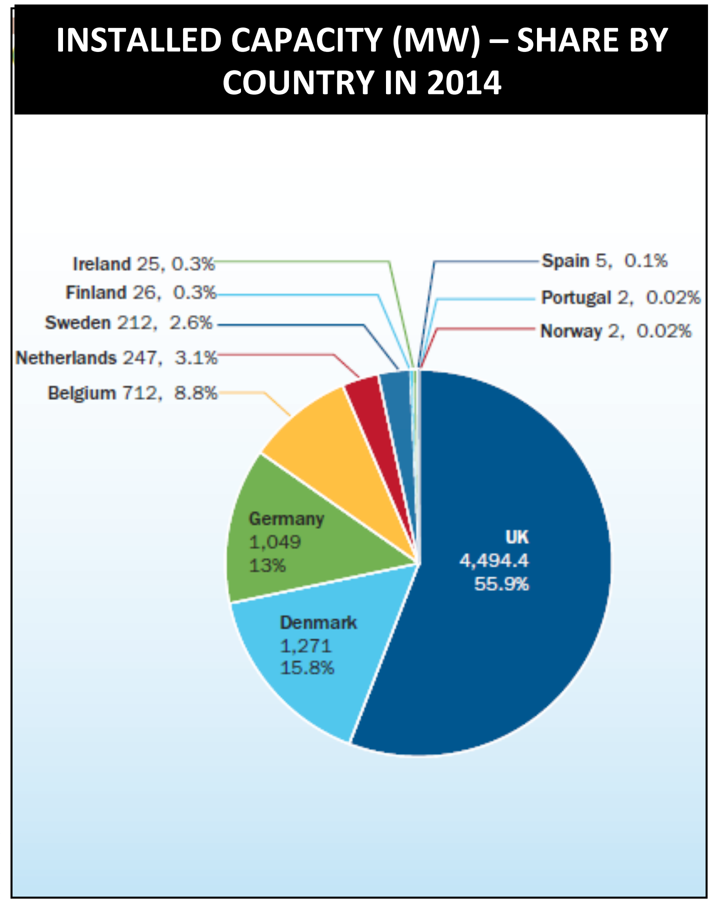
Source: GWEC

Here are the last two years compared by Country:

- in strong development UK, Germany, Belgium and China
- steady Denmark, Netherlands and Sweden

GWEC - Global Wind Energy Council – Global Wind Report – Annual Market Update 2014

That is the share by Country in Europe:
UK 55,9%,
Denmark 15,8%,
Germany 13% and
Netherlands 3,1%.



Source EWEA – European Wind Energy Association – The European offshore wind Industry – key trends and statistics 2014 – January 2015

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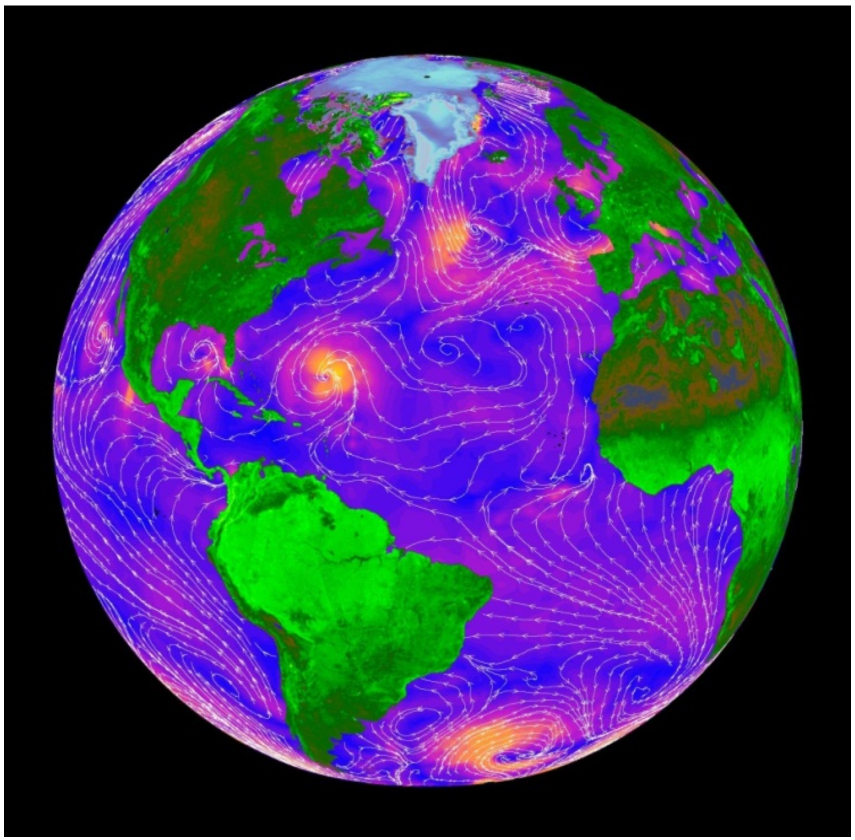
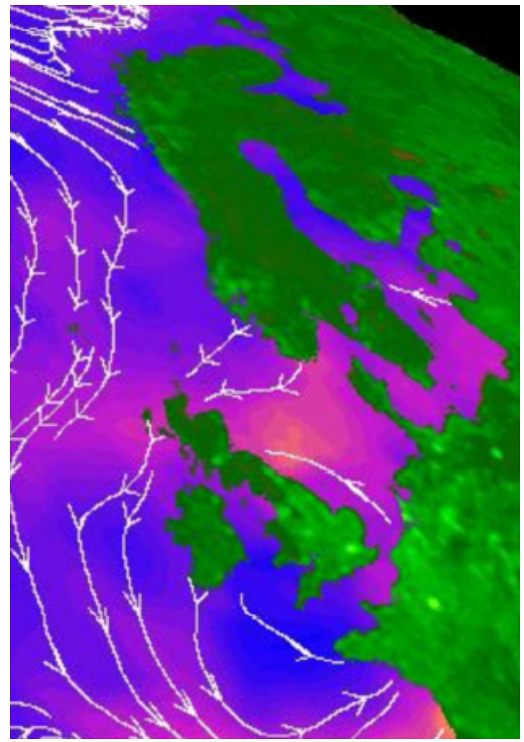
MAPS OF WIND SPEED: WIND SPEED OFFSHORE - The map of the world

Wind resources in the North Sea are some of the best in the world.

This is a false-color image of sea wind speed as measured by NASA's QuikScat satellite in 1999.
Orange represents the **fastest** wind speeds and **blue** the **slowest**.
White streamlines indicate the wind direction.



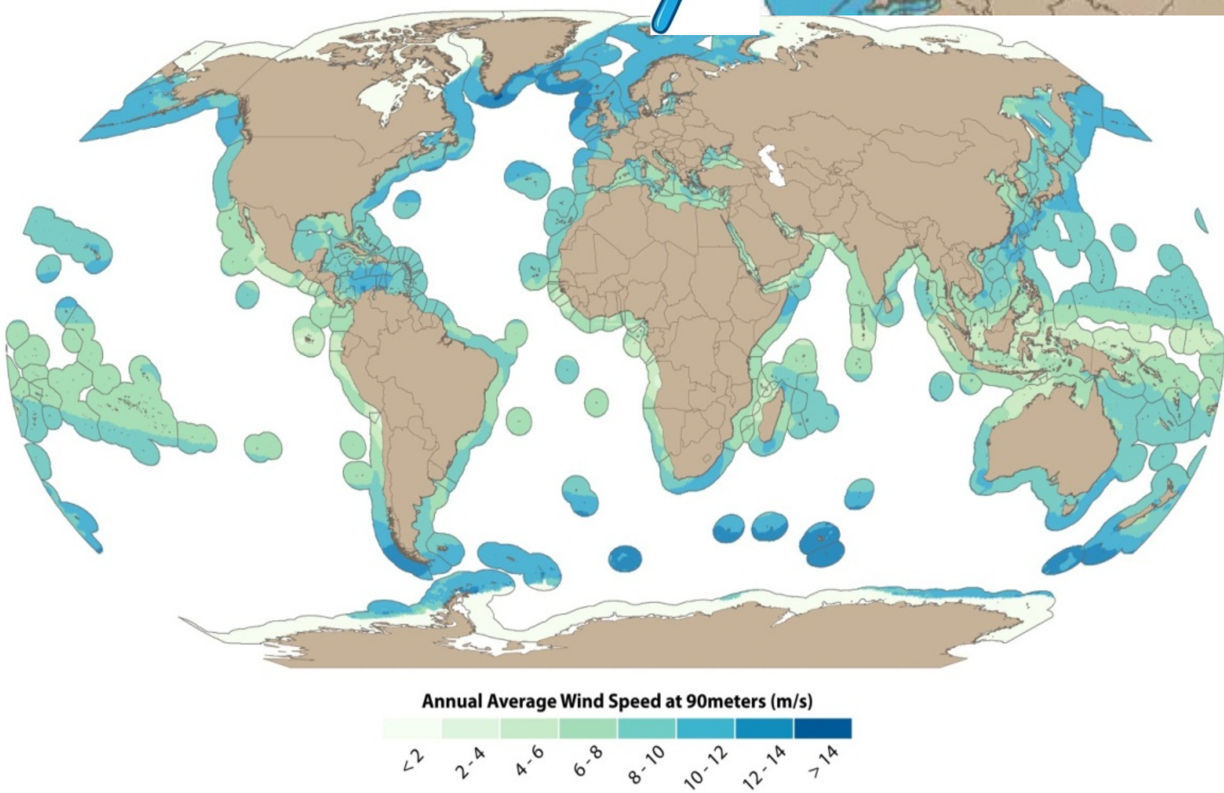


Focusing on our area of study, we can see that the color is particularly clear, i.e. the wind is strong, in all the area of the North Sea and the Baltic Sea, all around Denmark and UK, particularly Scotland, but also in the south coasts of Sweden and Norway, as well as in the whole coast from France, to Poland , passing through Belgium, Netherlands and Germany.

Credit: NASA/Jet Propulsion Laboratory. NASA's QuikScat satellite in 1999.

MAPS OF WIND SPEED: WIND SPEED OFFSHORE - The map of the world near the coasts

Excluding areas far in the Oceans, where the distance to any grid makes it almost impossible to exploit wind power, we can limit our analysis to the **waters not too distant from the coast.**



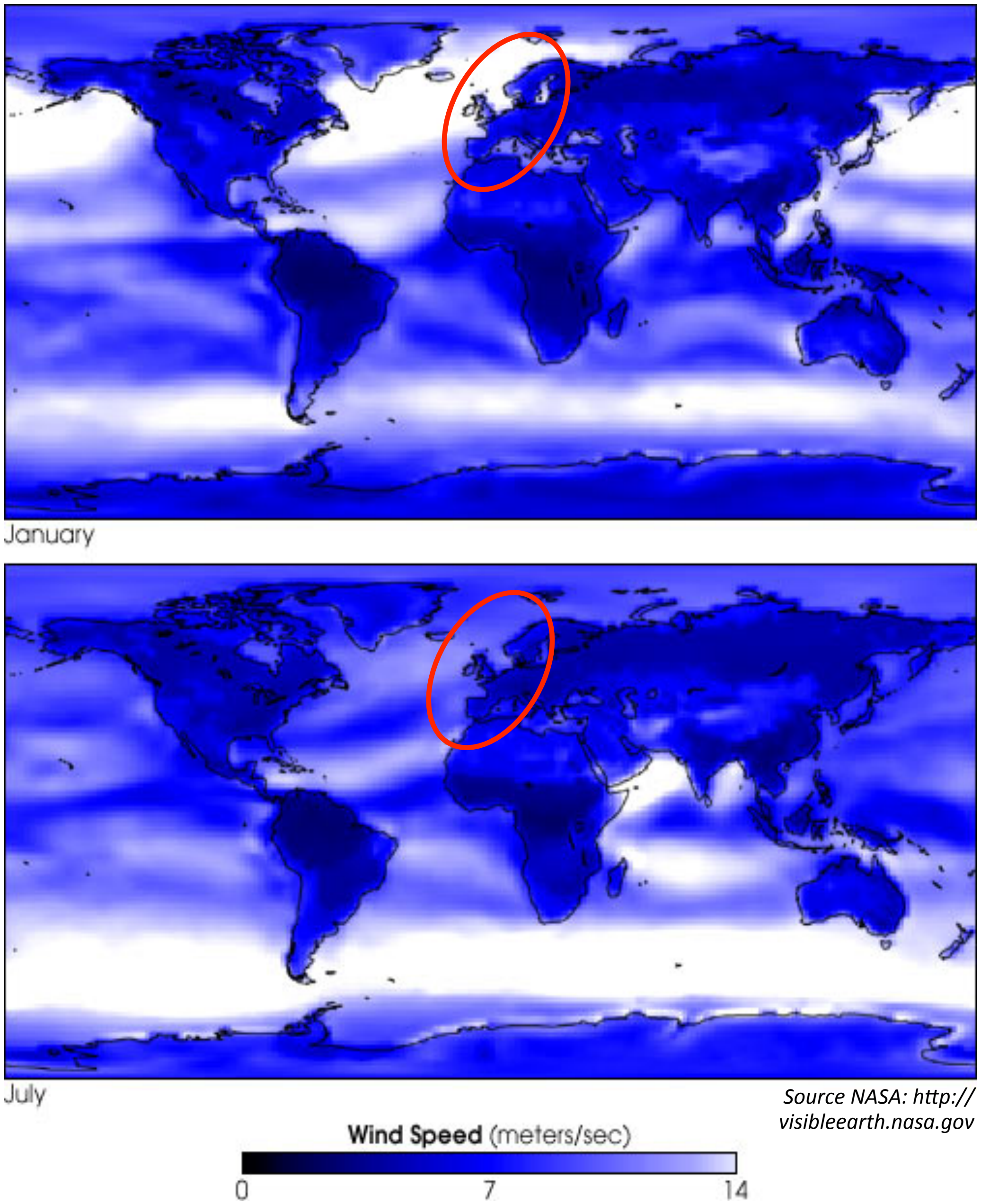
Blended Sea Winds annual average wind speed map; adjusted to 90m hub height.

NREL – National Renewable Energy Laboratory - Improved Offshore Wind Resource Assessment in Global Climate Stabilization Scenarios

The map of the blended annual average sea wind speed, shows, one more time, that in the North Sea there is a wide area where the wind speed is between 12 and 14 meter per second at a hub height of 90 meters.

Far out the **North West coasts of Scotland and Ireland and very near to the South coast of Iceland**, the annual average wind speed is **more than 14 m/s.**

Even if **Iceland** is not much interested in wind power, because its needs can rely on low-cost and abundant geothermal and hydropower options, if ever a submarine high voltage electricity **cable** between Iceland and Europe became realized, the **export** of wind power could become a business, if acceptable the cost of transport and transmission losses.



Source NASA: http://visibleearth.nasa.gov

There is a large variability in average wind speed in **<u>different years</u>**, and, obviously in **<u>different seasons</u>**.

This chart from NASA shows the difference in the average wind speed in two opposite seasons:

- January the one above and
- July the one below.

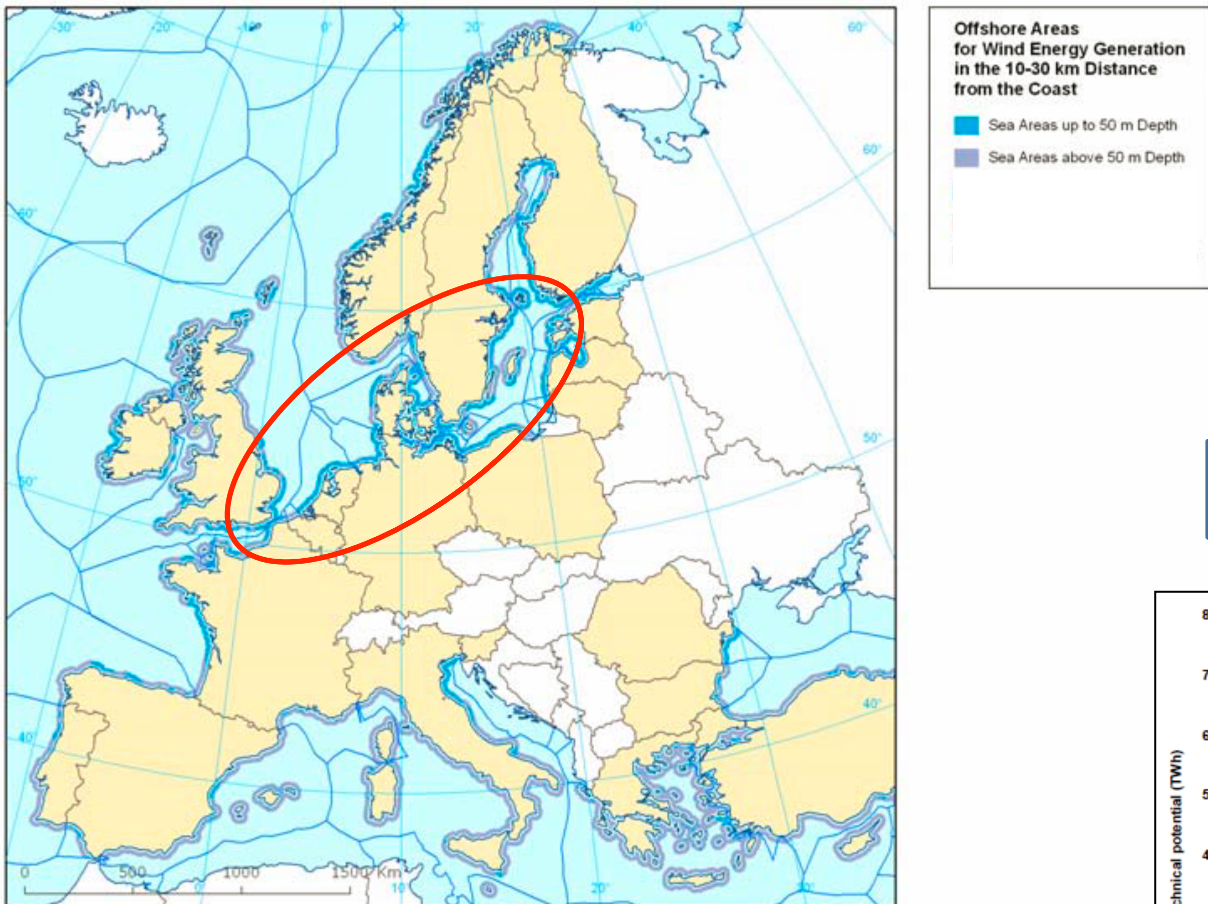
White means **strong wind**, where as **dark blu** means **slow speed**.

These global maps of average wind speed help determine where to develop wind energy, where is convenient to design, build, and market new technologies for harnessing this energy.

When planning a new plant, the first thing to do is to find a place where there is **sufficient wind** for the turbines to operate efficiently; the distance of wind turbines from the power plants, the lack of the electricity grid are second time problems, but no one can start a project without wind.

MAPS OF WIND SPEED: WIND SPEED OFFSHORE - The map of Europe near the coasts

Offshore areas for wind energy generation at a distance of 10–30 km from the coast

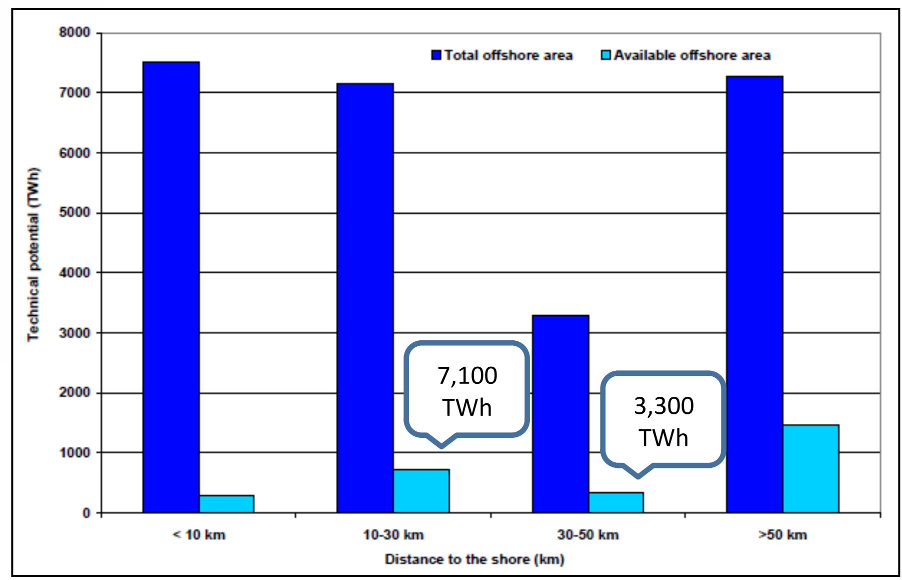


ETC/ACC – European Topic Centre on Air and Climate Change for EEA (European Environmental Agency) – Technical Paper -December 2008 - Wind Energy potential in Europe 2020-2030

The map illustrates that the offshore wind energy potential ■ , in the belt **between 10 and 30 kilometers**, is concentrated in the Baltic Sea and the North Sea, including the English Channel: more than 55% of the potential of **7,100 TWh** estimated in 2030.

However the different colors of blue shows that some areas in the belt from 10 to 30 kilometers from shore have **sea depths of more than 50 meters ■ and so are not suitable for wind energy development.**

Total available areas at the different depths in term of technical potential in TWh

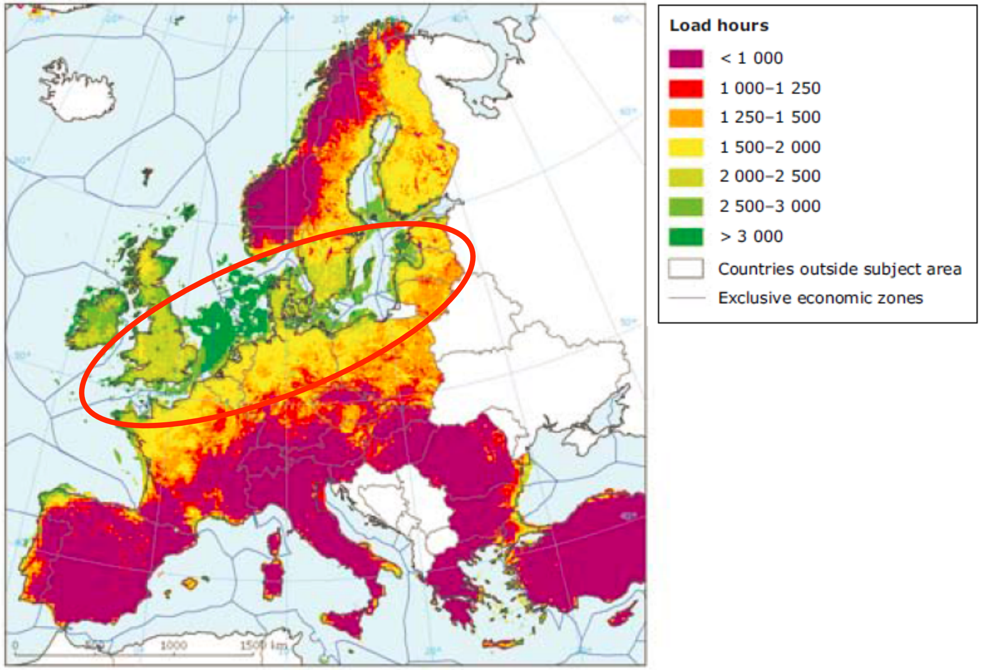


Source: ETC/ACC

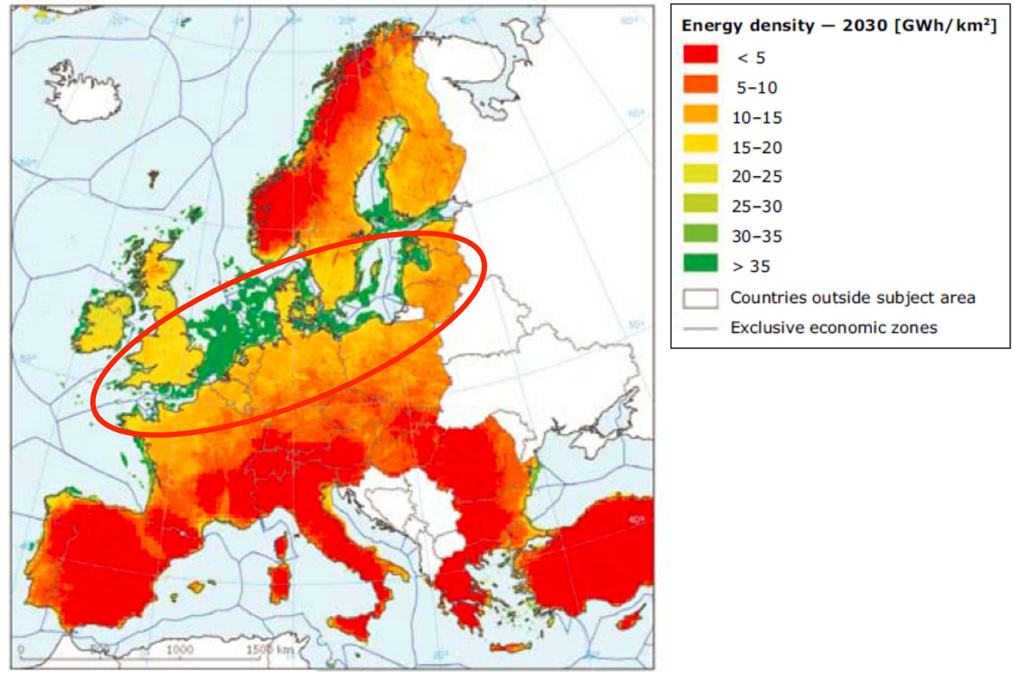
The deep offshore potential high too: in the **areas at 30 to 50 kilometers from the coast**, again, the Baltic Sea and the North Sea (including the English Channel) account more than 60% of the potential of **3,300 TWh** estimated in 2030 for this distance class.

MAPS OF WIND SPEED: WIND SPEED OFFSHORE - *The map of Europe near the coasts*

Distribution of full load hours in Europe (80 m hub height onshore, 120 m hub height offshore)



Distribution of wind energy density (GWh/km²) in Europe for 2030 (80 m hub height onshore, 120 m hub height offshore)



Source: EEA (European Environment Agency) - Technical report N.6/2009 – Europe's-onshore and offshore wind energy potential

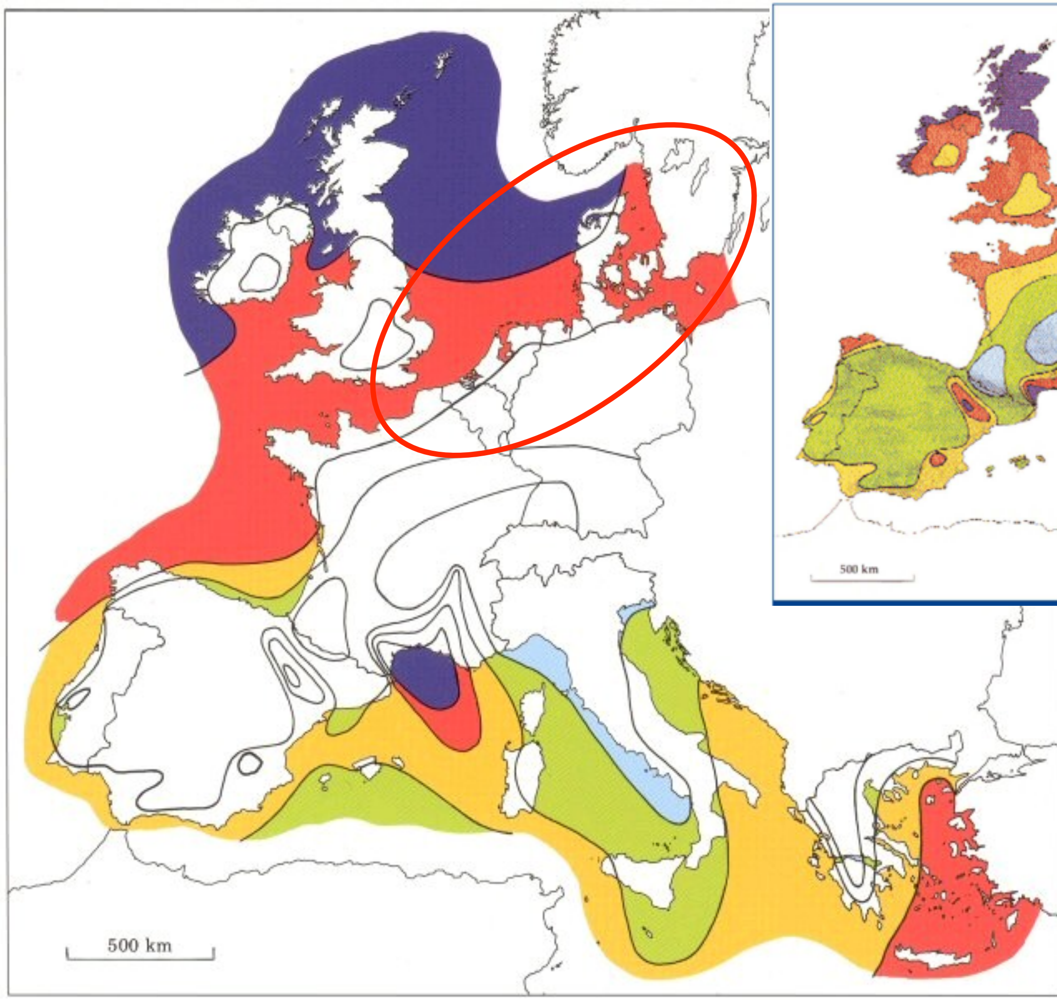
<u>Offshore resources tend to be better than onshore ones</u>, because on average they are characterized by higher load hours.

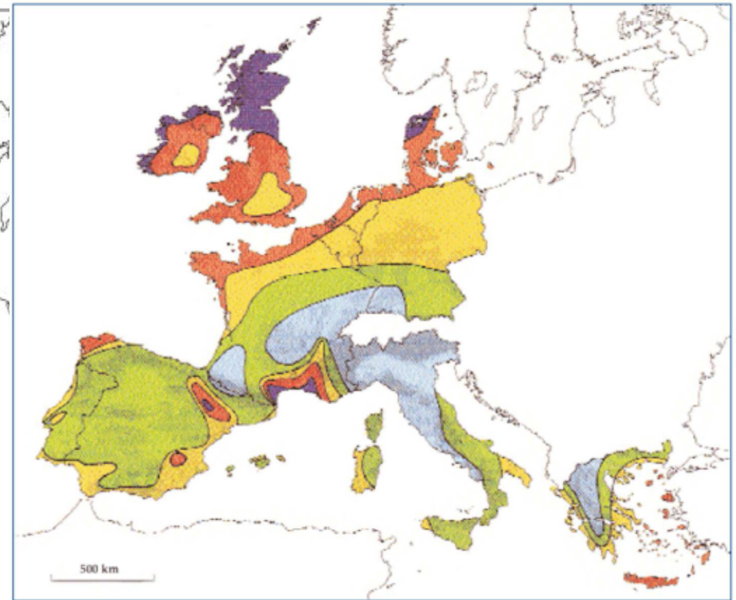
These charts clearly show that offshore wind speeds are considerably higher than onshore, due to the roughness of land surface compared to water, especially deeper waters. That means **higher annual load hours**.

Very windy onshore areas are located in United Kingdom, mostly Scotland, and Ireland, but no one of the areas on shore have potential exceeding 4,000 full load hours, and only 5% of land have a potential over 3,000.

Instead, 40% of the offshore areas are in the load class of more than 3,000: the **dark green areas** in the two maps.

MAPS OF WIND SPEED: WIND SPEED OFFSHORE - *The map of Europe > 10 km offshore*





<u>Windpower is proportional to the cube of wind speed: P = ½ ρAV³</u>.

A modest increase in mean wind speed, so, can transform into a large increase in annual electricity production. For example, at the height of 50 meters over Denmark, the annual mean wind velocities are 9 m/s over large regions of Danish North Sea.

On the land, at the same conditions, wind velocities are 6 m/s.

This means that off shore wind velocity are 50% higher than those on land: therefore, over these two different areas, the same wind turbine can produce 3.375 [= $(9/6)^3$] times the electricity at sea than on land.

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

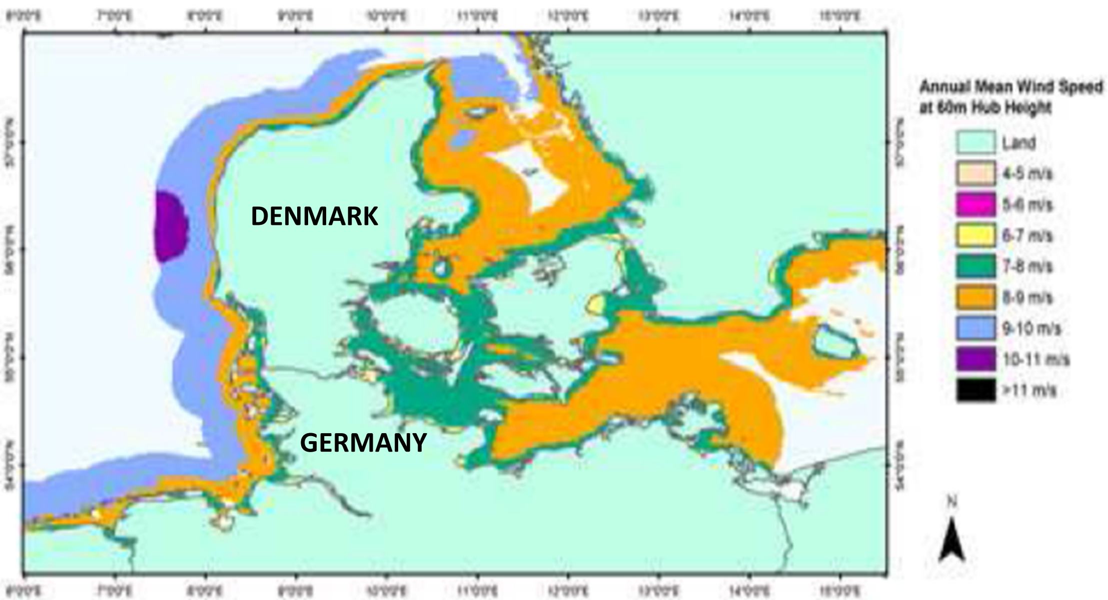
	10 m		25 m		50 m		100 m		200 m	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
(dark blue)	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
(red)	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
(orange)	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

Wind resources at 50 metres above ground level for five different topographic conditions

	Sheltered terrain		Open plain		At sea coast		Open sea		Hills and ridges	
	ms-1	Wm-2	ms-1	Wm-2	ms-1	Wm-2	ms-1	Wm-2	ms-1	Wm-2
(purple)	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
(orange)	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)	[illegible]	100 - 150	5.5 - 6.5	200 - 300	6.5 - 7.0	250 - 400	7.0 - 8.0	400 - 600	8.5 - 10.0	700 - 1200
(yellow-green)	3.5 - 4.5	50 - 100	4.5 - 5.5	100 - 200	5.5 - 6.5	150 - 250	5.5 - 7.0	200 - 400	7.0 - 8.5	400 - 700
(light blue)	< 3.5	< 50	< 4.5	< 100	< 5.5	< 150	< 5.5	< 200	< 7.0	< 400

Source: www.scotsrenewables.com /windresources.html - Scotland's Share of Europe's Wind Resource

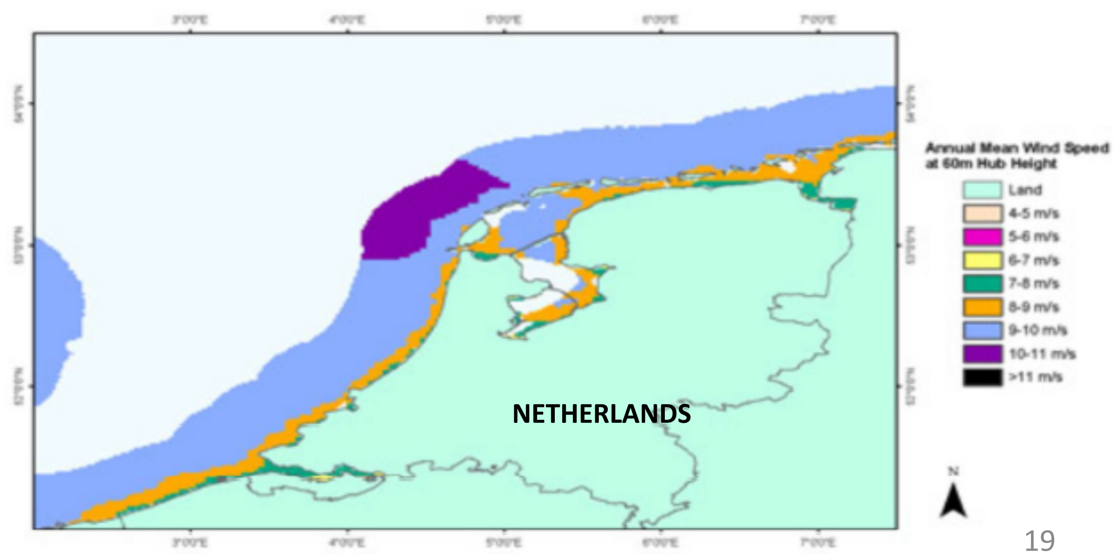
MAPS OF WIND SPEED: WIND SPEED OFFSHORE - The Countries



Source: http://www.wind-energy-the-facts.org/appendix-b.html

More specifically, here are the wind speeds maps, at 60 meter Hub Height, for the single countries: Denmark, Germany and the Netherlands.

- No Black areas (more than 11 m/s speed), but
- little Violet areas (10-11 m/s), out of Denmark (West coast) and Netherland (North West), and
- a large belt of Blue areas (9-10 m/s)
- and important areas of 8-9 m/s speed, near the coasts and in the inner waters.



Source: http://www.wind-energy-the-facts.org/appendix-b.html

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TECHNICAL CHARACTERISTICS OF WIND TURBINES

There are two types of wind turbines:

- vertical axis type (VAWT), independent from the wind direction, and

- horizontal axis type (HAWT), older and more common, with the electrical generator at the top of a tower, whose rotor must be oriented perpendicularly to the direction of the wind.

- Large arrays of big turbines are called "wind farms";

- smaller "stand alone" turbines may be installed on the roofs to contribute to the domestic power supply, or to little factories supplies, whilst selling unused power back to the utility supplier via the electrical grid;

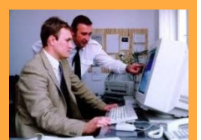
- the smallest turbines are generally used for battery charging for auxiliary power for caravans or boats or to power traffic warning signs.

TECHNICAL CHARACTERISTICS OF WIND TURBINES

WHY WIND OFFSHORE?

- **CONSTRUCTION**
  - **Higher costs of contruction**

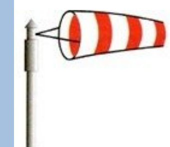
- **TECHIQUES:**
  - **Higher tecnical difficulties**



- **MAINTENANCE**
  - **Higher costs of maintenance**

- **POTENTIAL**
  - **Oceans are more extended than earth: two third of the planet**

- **WIND SPEED:**
  - **over the oceans wind speed is higher than on land: 15-20% near the shore and 30-40% in the open oceans**



- **YIELD**
  - **50-70% more power produced**

- **ACCEPTABILITY:**
  - **Wind offshore has no interference with human activities and the environment generally used by humans and so is very well accepted by public opinion**

TECHNICAL CHARACTERISTICS:

- **LARGE WIND FARMS**: due to some important «fixed» costs, like trasmission cables, larger wind farms reduce the costs per megawatt of capacity
- **LARGER TURBINES**: higher installation costs of each turbine in the water, makes it convenient to enlarge the size of turbines. Onshore farms use turbines with an average size of 1-2MW, while offshore average size is 3-4MW, but always more frequent are turbines of 6-7MW and Sea Twirl in Sweden reaches 10 MW

TECHNICAL CHARACTERISTICS OF WIND TURBINES: *Wind Farm Size*

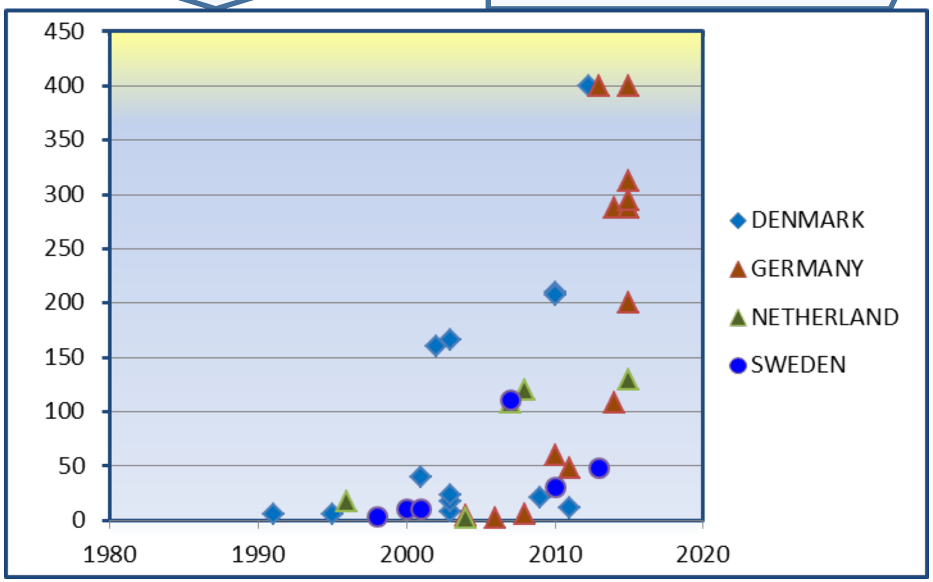
Offshore Wind Farm size (in MW installed) in the four Countries examined

There are already existent Farms with 400 MW installed, but the authorized ones almost reach 900 MW

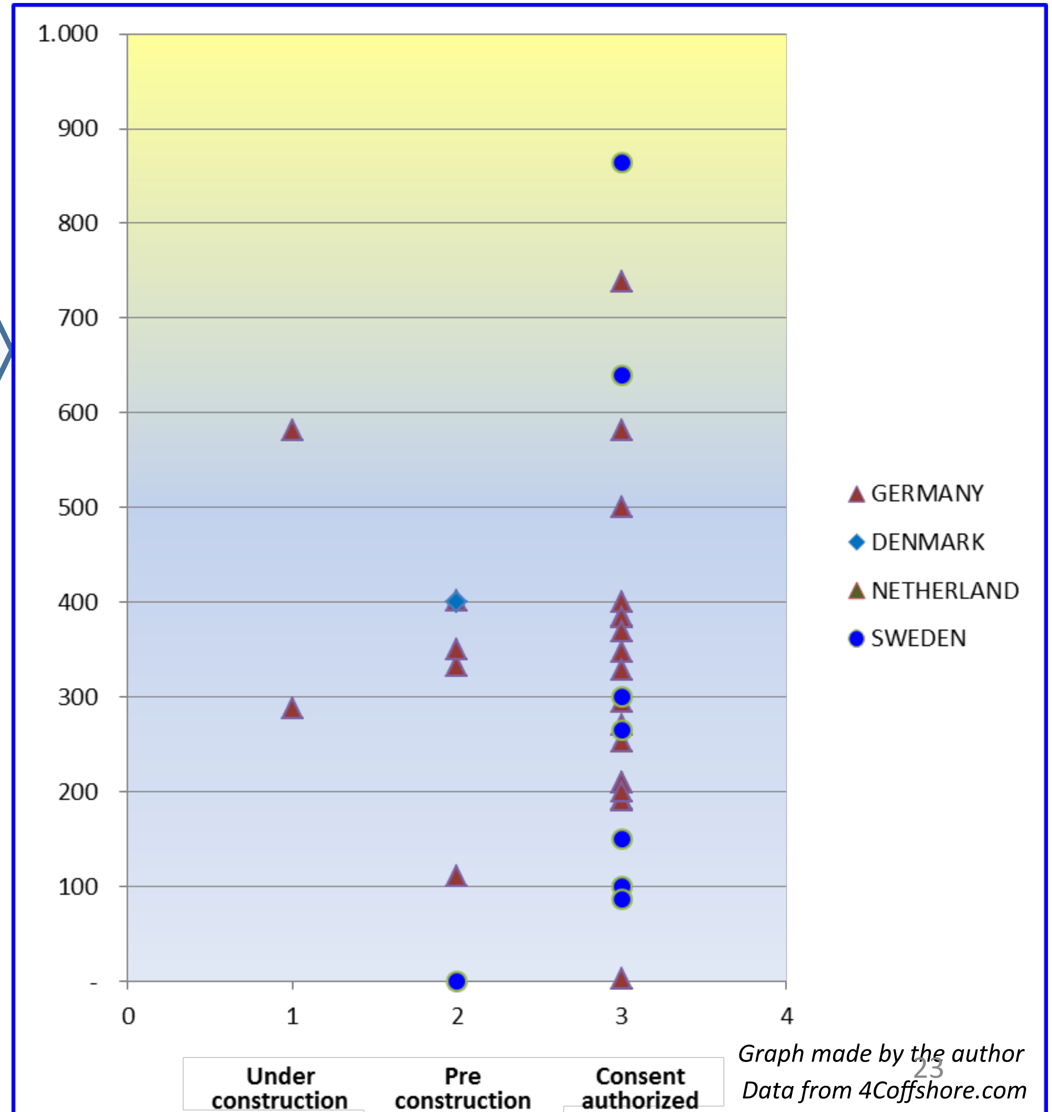
«Fully commissioned» plants

«Pre-contruction», «Under contruction», «Consent Authorized» plants

Offshore Wind Farm size in MW installed



Graph made by the author
Data from 4Coffshore.com

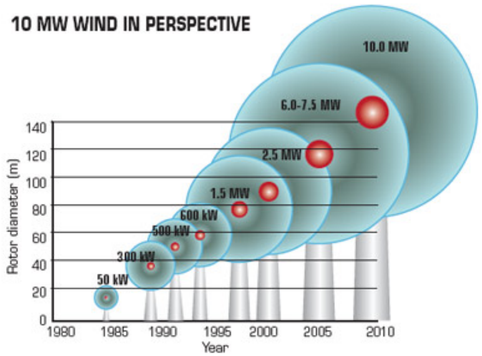


Graph made by the author
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Wind Turbine Size

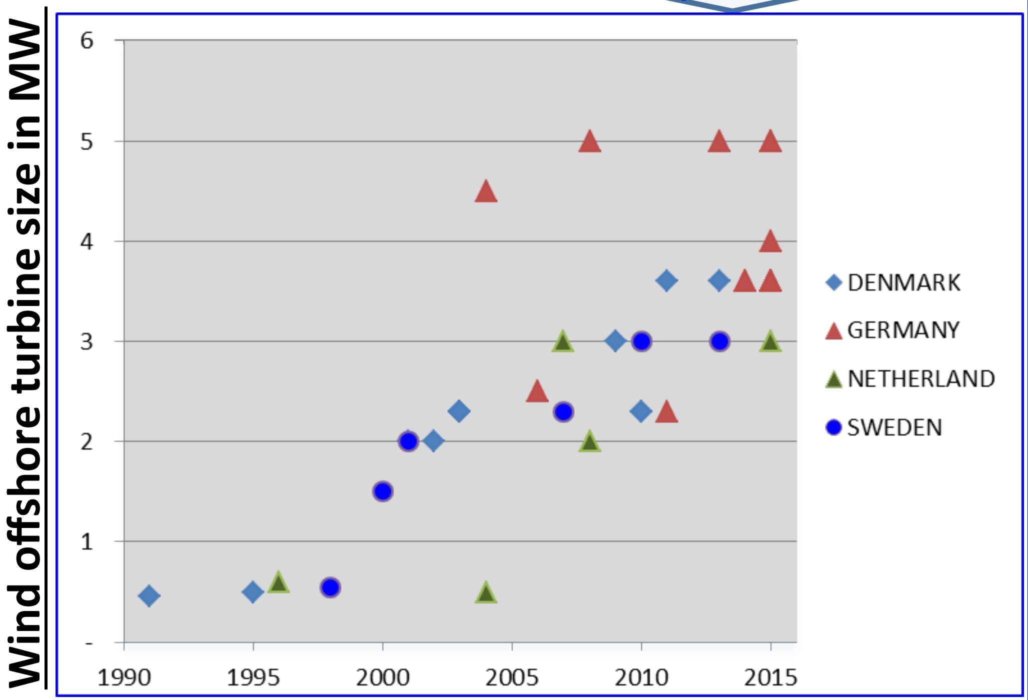
Wind offshore turbine size (in MW) in the four Countries examined

No turbines under 3 MW installed in recent years and the average size of the authorized ones is doubled to 6 MW

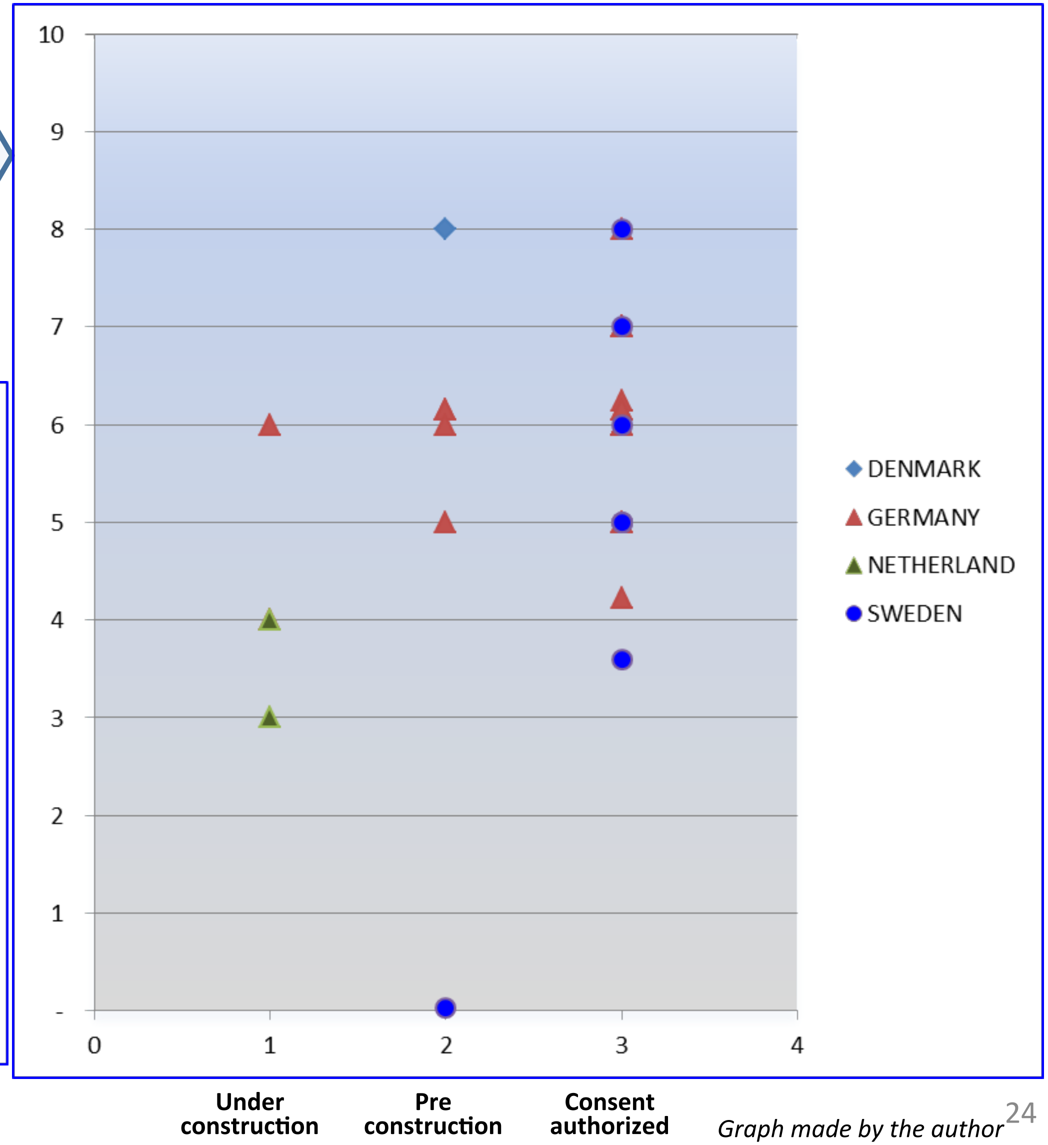


«Pre-contruction»,
«Under contruction»,
«Consent Authorized»
plants

«Fully commissioned»
plants

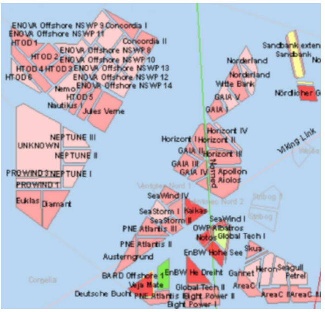


Graph made by the author
Data from 4Coffshore.com



Graph made by the author
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES: *Wind Farm Area*



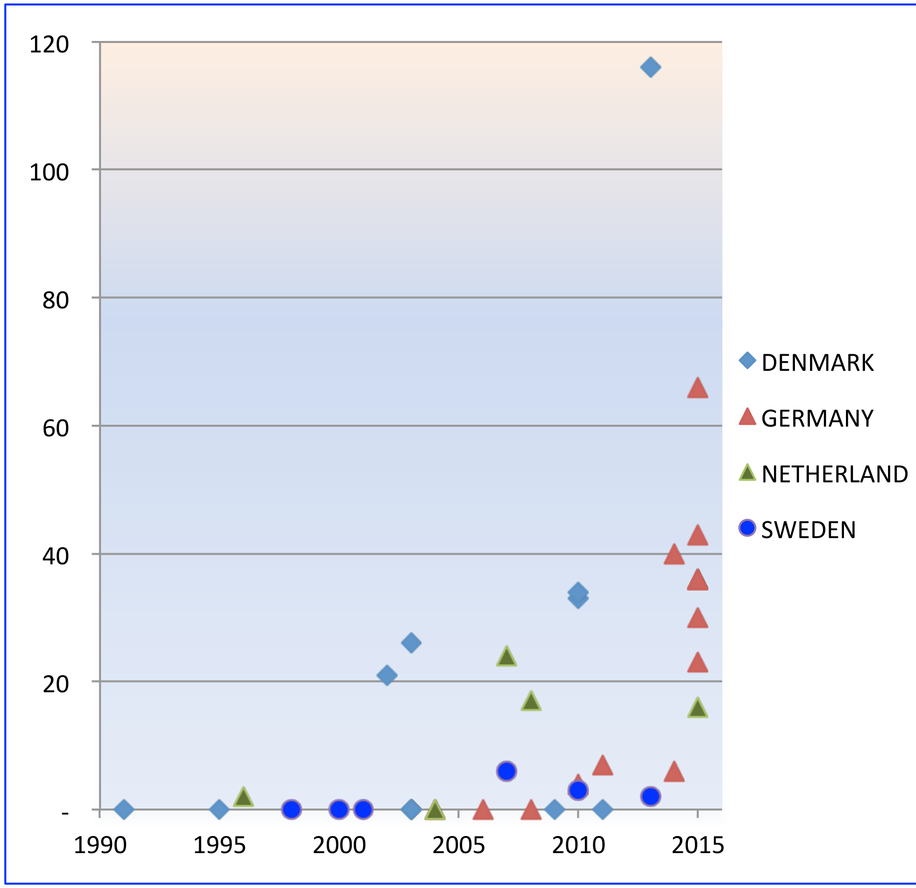
Wind Offshore farm area in km^2 in the four Countries examined

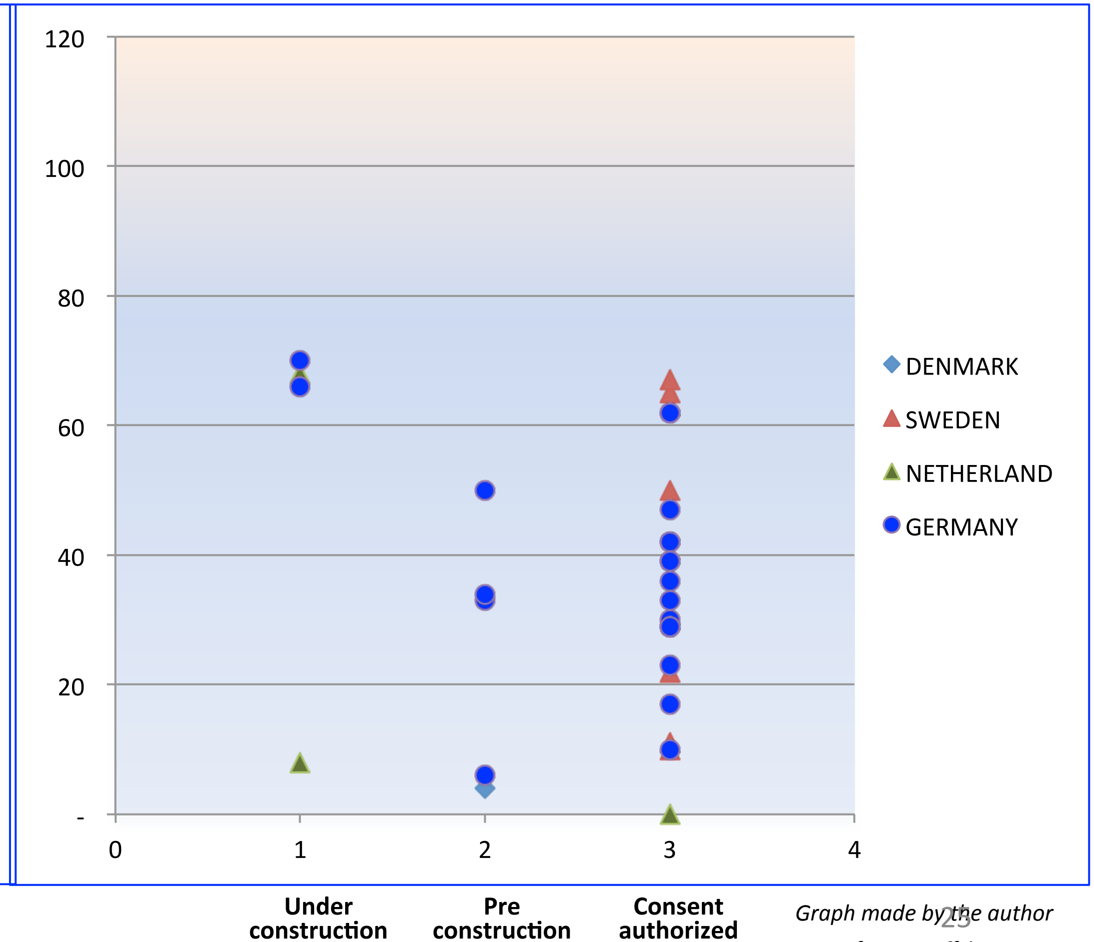
Wind Farm area is increasing too, but there are very few cases over 60 km^2

«Fully commissioned» plants

«Pre-contruction», «Under contruction», «Consent Authorized» plants

Wind farm area in km^2



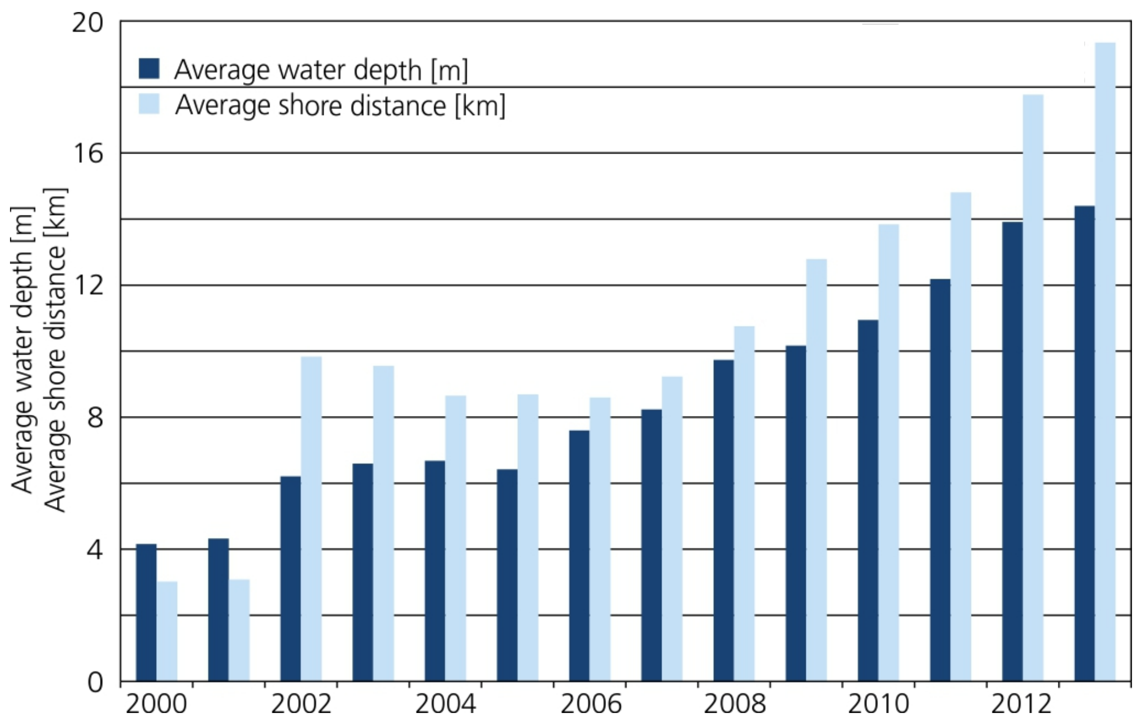


Graph made by the author
Data from 4Coffshore.com

Graph made by the author
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES - Evolution in water depth and distance to shore

Distance from the shore and water depth



Source: Fraunhofer IWES – Wind Monitor – Offshore – Technical Developments

The move away from the shore to far offshore is continuing.

The graph shows the changes over times of offshore wind turbines

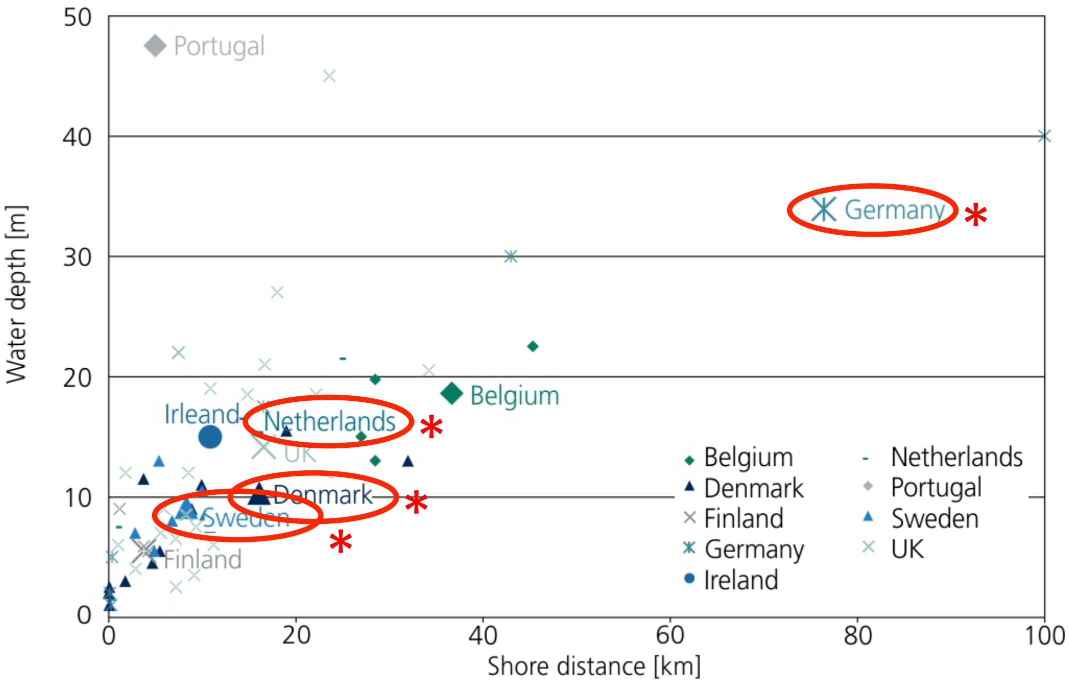
- in the average **distance from the shore** and
- in installation **depths**.

the first experimental offshore wind farms were constructed relatively close to the shore in rather calm waters

In 2002 the average offshore wind turbine was 9.8 km from the shore in 6.2 m of water.
In 2013 where offshore wind turbines are on average 19.3 km from the shore and at water depths of 14.4 m
Today, with an increasing experience, more projects have been realized further from the shore at greater water depth.

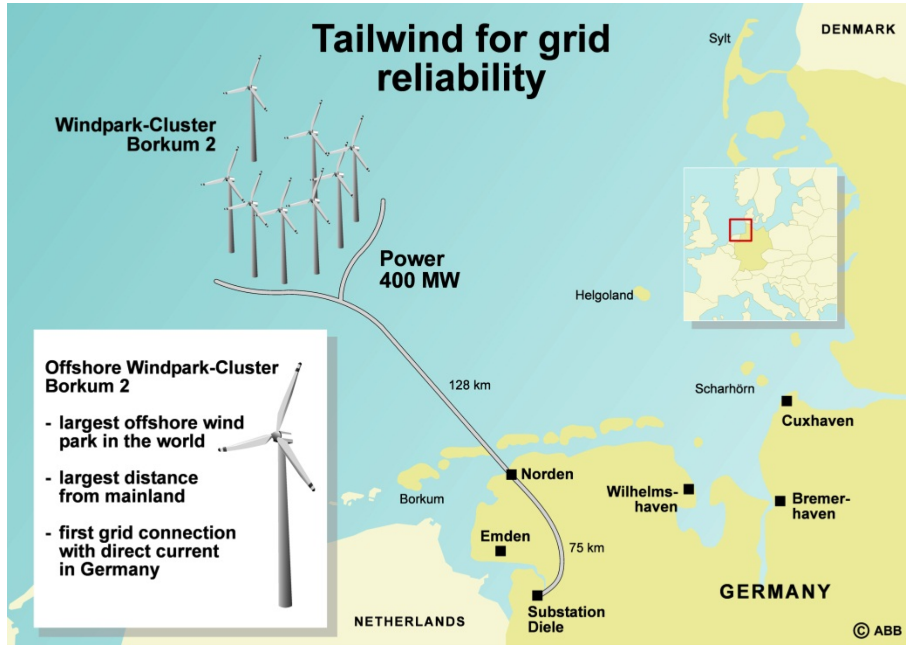
TECHNICAL CHARACTERISTICS OF WIND TURBINES - *Water depth and distance to shore*

Water depth and distance from the shore of offshore wind farms in different European countries



Source: Fraunhofer IWES – Wind Monitor – Offshore – Technical Developments

Borkum 2 (wind farm authorized) is more than 50 kilometers distant from shore



- **Portugal** has the greatest average **water depths** (48 m); **Germany** is the second (34 m), Belgium follows (19 m). The wind turbines in the shallowest waters are found in Finland (5.9 m) and Sweden (9 m). In greater water depths, we can found many projects and prototypes of floating wind turbine: Hywind in Norway is at a water depth of over 200 m.
- Excluding the Norwegian floating wind turbines, wind farms in **Germany** has the largest average **distance from the shore** (76 km); Belgium follows (37 km); the wind turbines in Finland have the smallest average distance from the shore (3.8 km). In **Germany, BORKUM 2** (in the figure above) is 57 km distant from shore, BARD Offshore 1 is more than 100 km out to sea and GLOBAL TECH 1 is almost 110.

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Water Depth

Wind offshore water depth (meters) in the four Countries examined

Wind Farm depth is increasing in recent years in every country, but most of all in Germany and the consent authorized plants have a higher average depth.

«Fully commissioned» plants

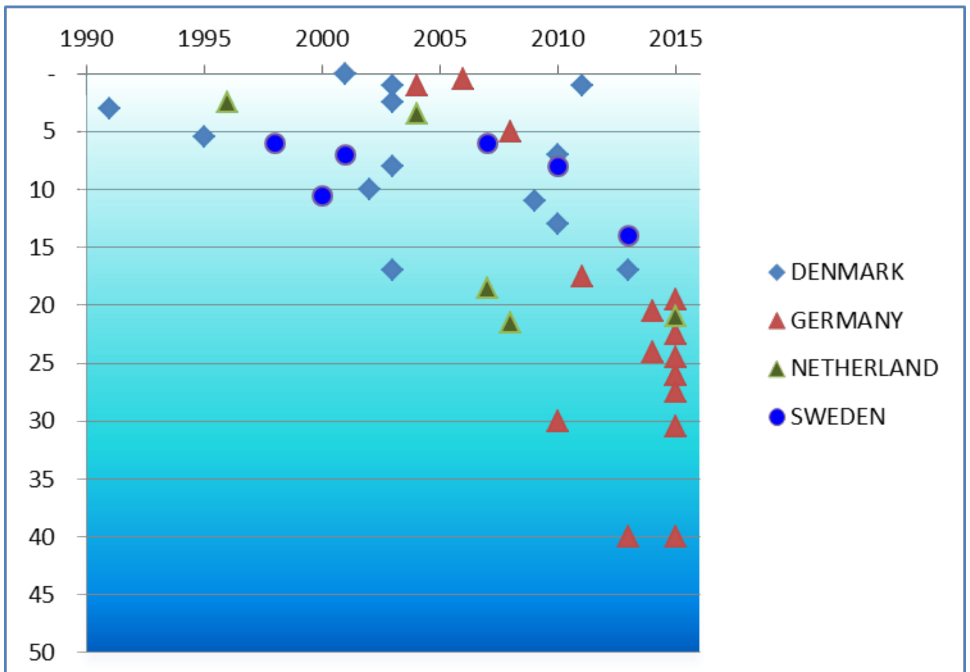
«Pre-contruction», «Under contruction», «Consent Authorized» plants

Water depth (m)

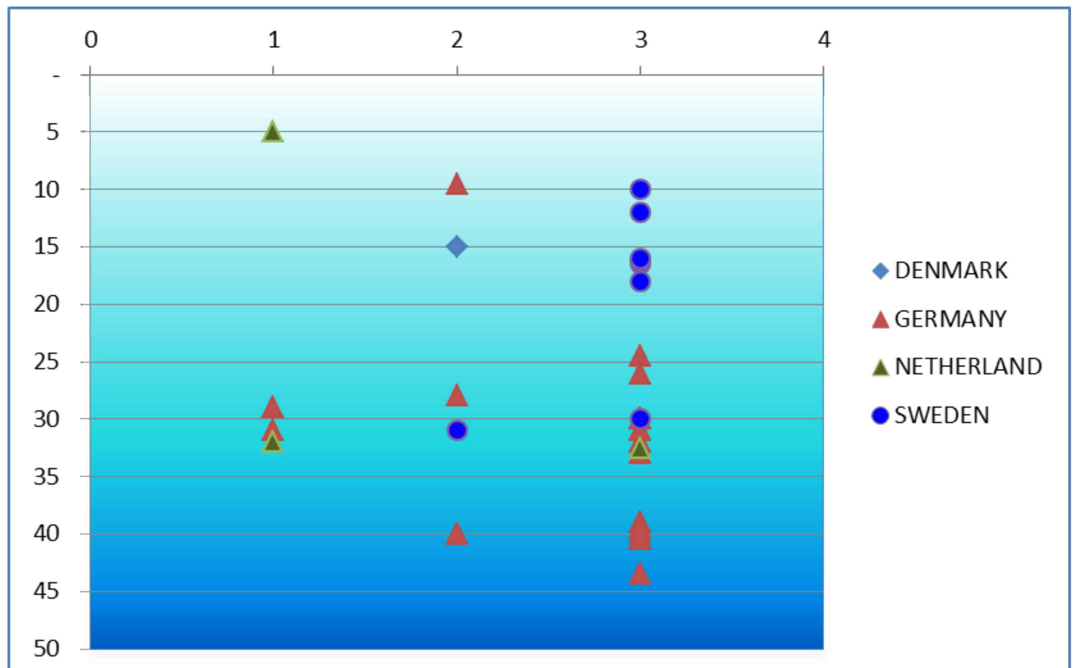
Under construction

Pre construction

Consent authorized



Graph made by the author
Data from 4Coffshore.com



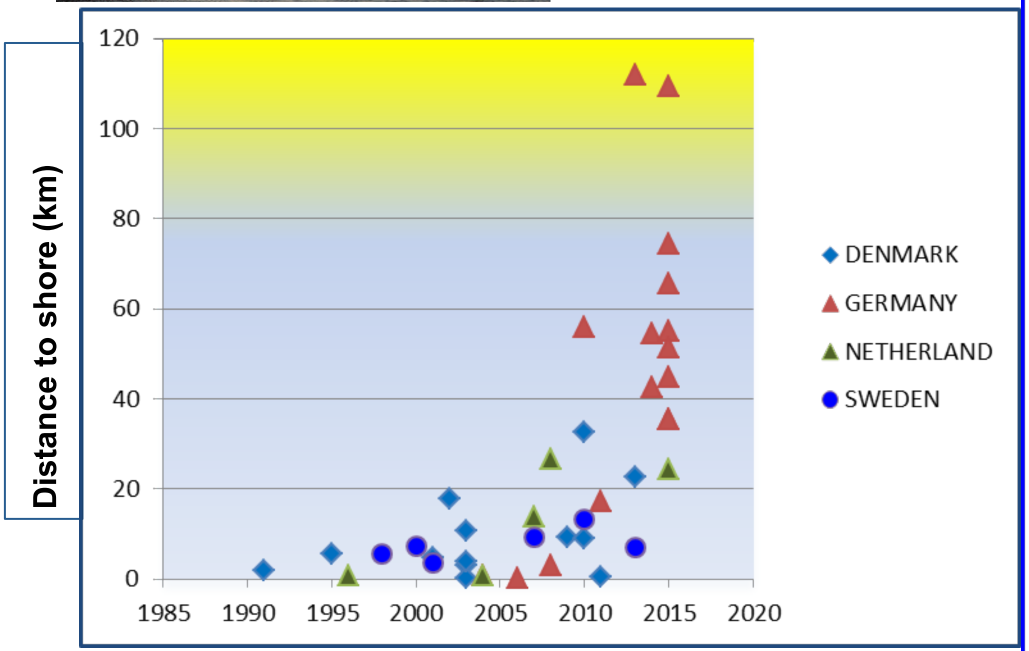
Graph made by the author
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Distance to Shore

Evolution in the distance to shore in the four Countries examined

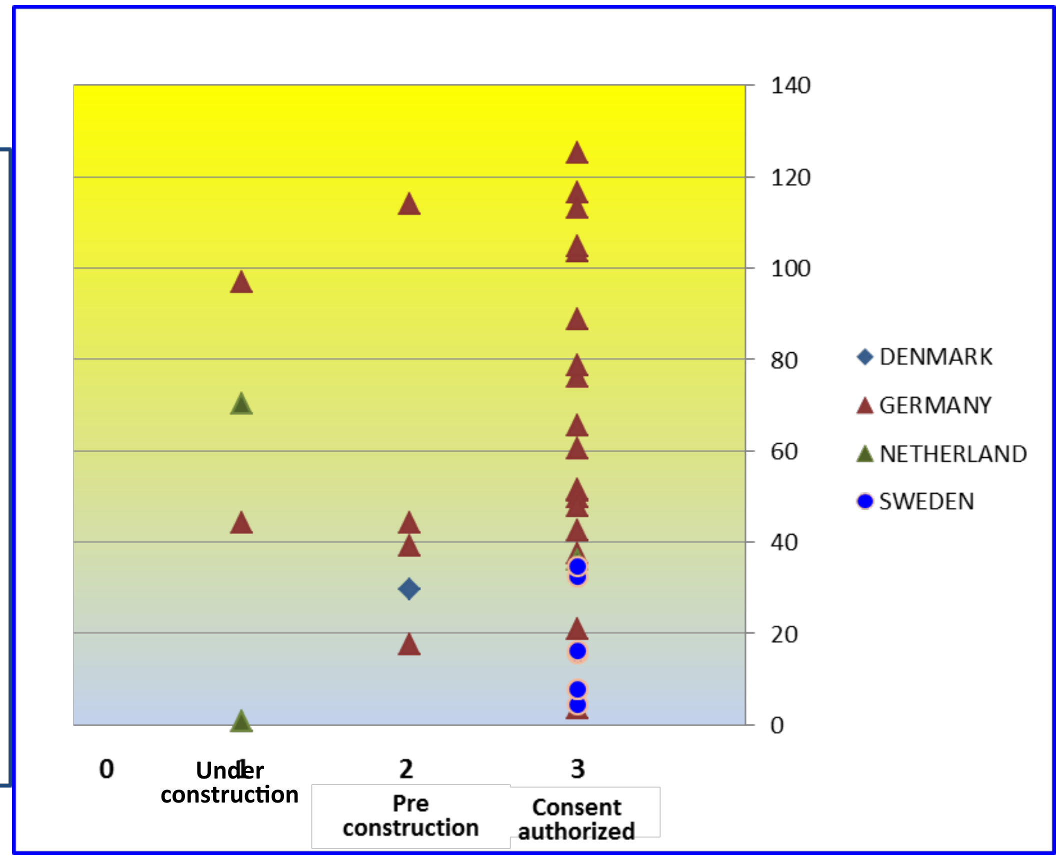
The distance to shore was always under 30 km till only five years ago, while almost all the plants completed in 2015 are over 30 km and so are the consent authorized ones, reaching even 130 km to shore

«Fully commissioned» plants



Graph made by the author
Data from 4Coffshore.com

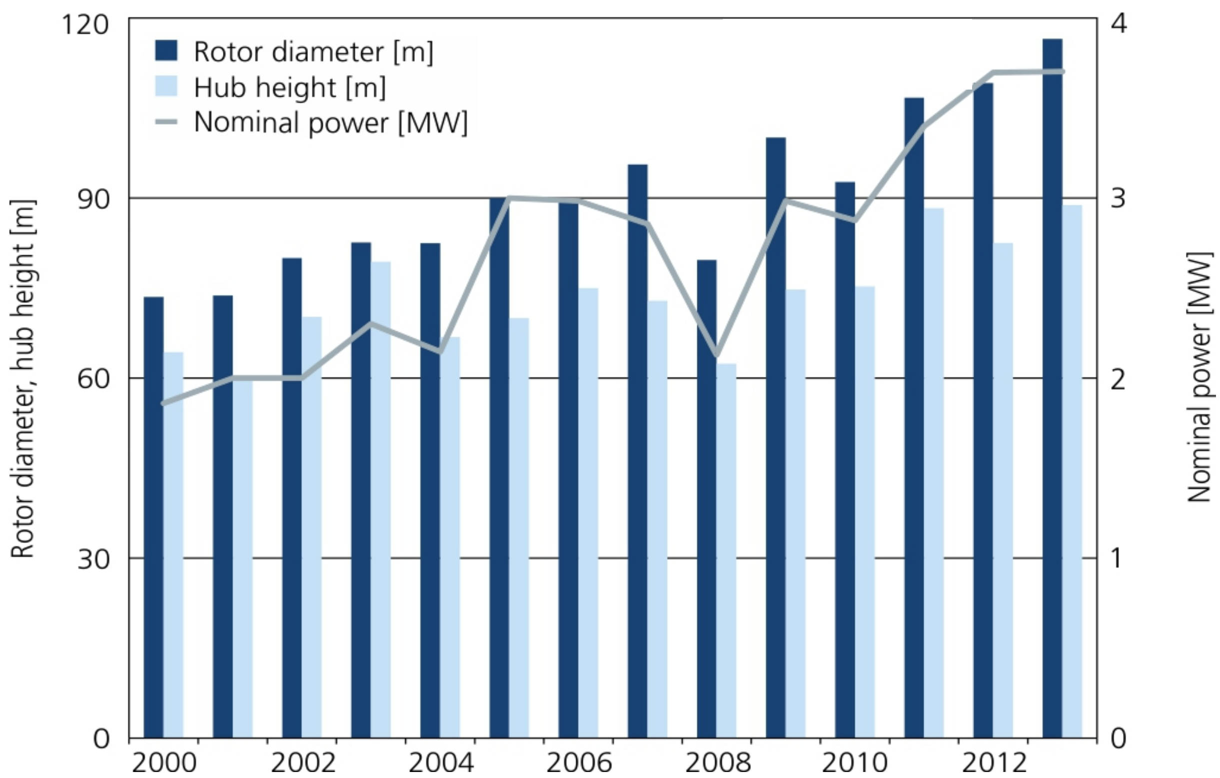
«Pre-contruction», «Under contruction», «Consent Authorized» plants



Graph made by the author
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES - *Evolution in rotor diameter and hub height*

<u>The changing physical size of newly installed offshore wind turbines (world)</u>



Source: Fraunhofer IWES – Wind Monitori– Offshore – Technical Developments

Offshore locations allow the installation of wind turbine having a high nominal power and **relatively low hub height,** considerably lower than onshore, due to the smoothness of the sea surface.

The **<u>average hub height offshore</u>** is just under 89 m and it was just over 60 m in 2000 (**30-40% increase**).

<u>Rotor blade diameters</u> have markedly increased.
The average rotor diameter in 2013 was 117 m while it was under 75 in 2000 (**+50-60% increase**). The new 6 MW wind turbines have rotor diameters of 150 m and above (**+100% increase**).

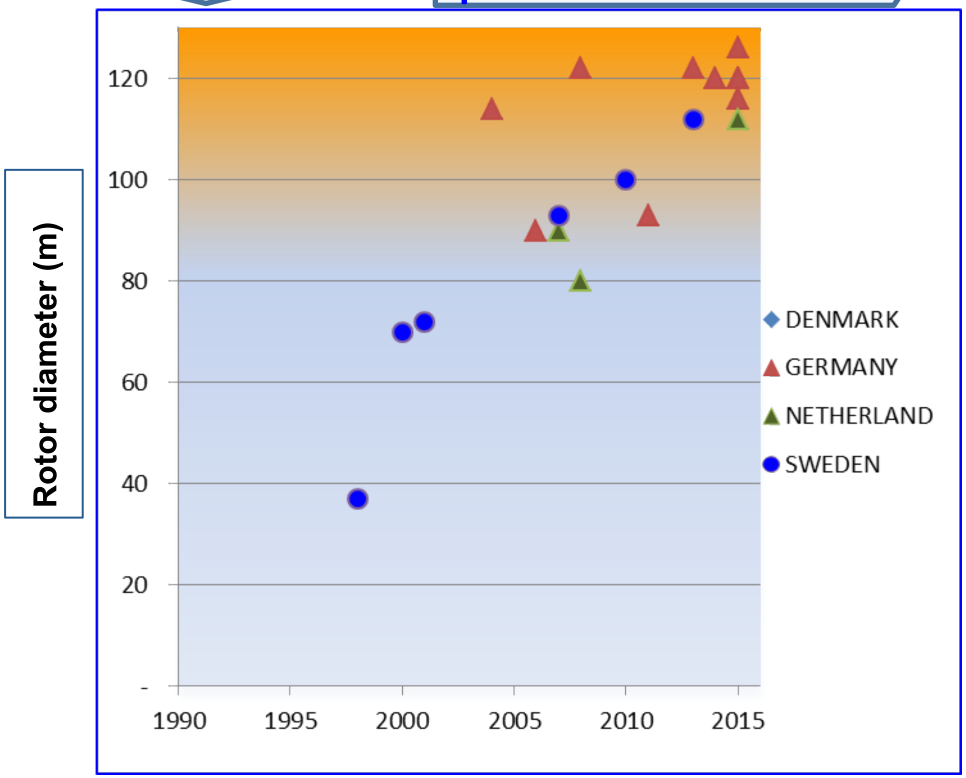
TECHNICAL CHARACTERISTICS OF WIND TURBINES: Rotor diameter

Wind offshore rotor diameter (meter) in the four Countries examined

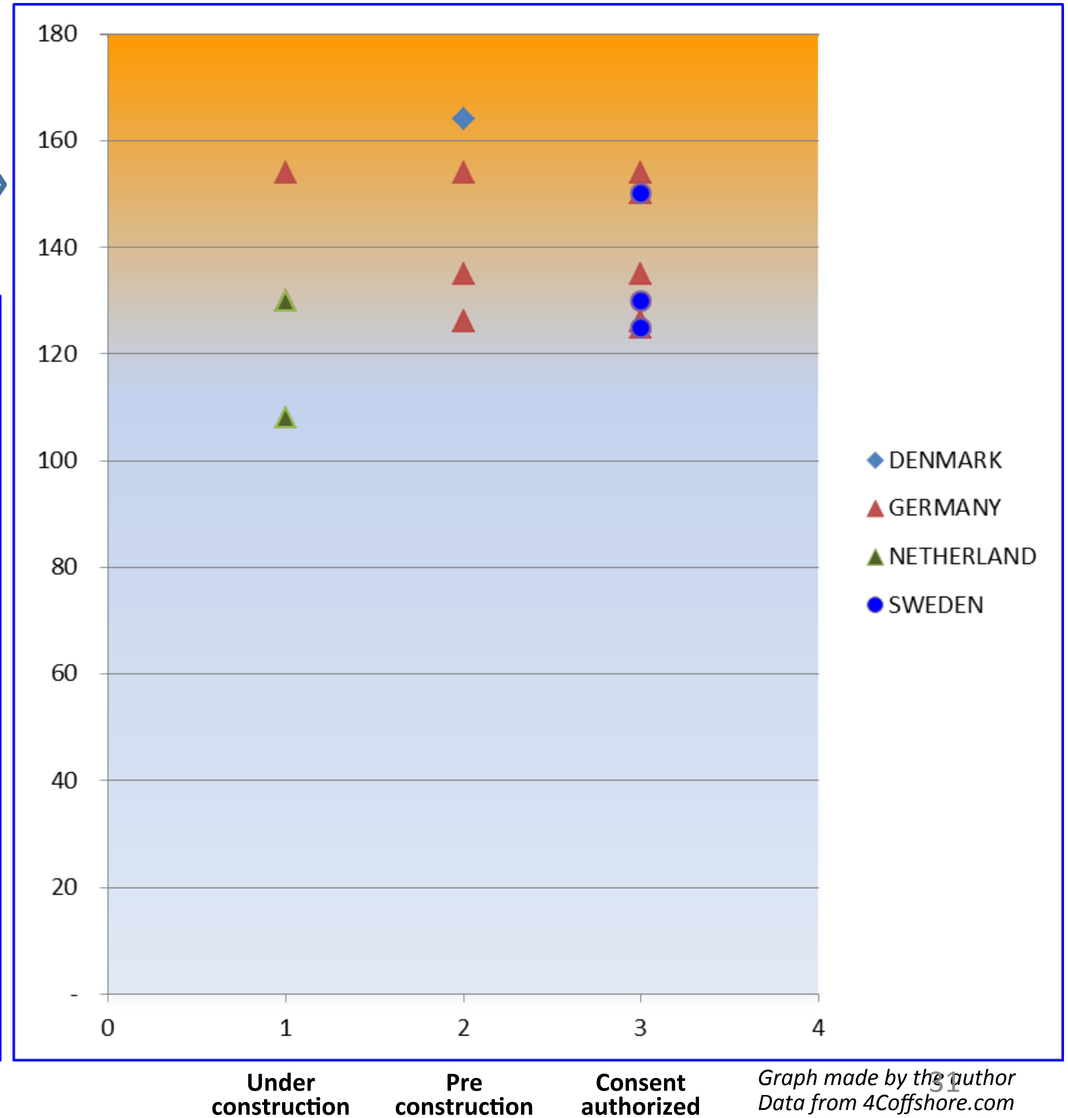
Rotor diameter is in constant growth: all the plants completed in 2015 are over 100 m and the consent authorized ones are all over 120 m, even over 160 m

«Fully commissioned» plants

«Pre-contruction», «Under contruction», «Consent Authorized» plants



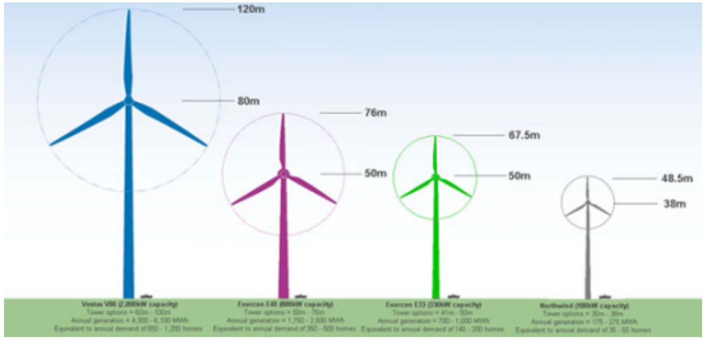
Graph made by the author
Data from 4Coffshore.com



Graph made by the author
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Hub Height

Wind offshore hub height (meters) in the four Countries examined

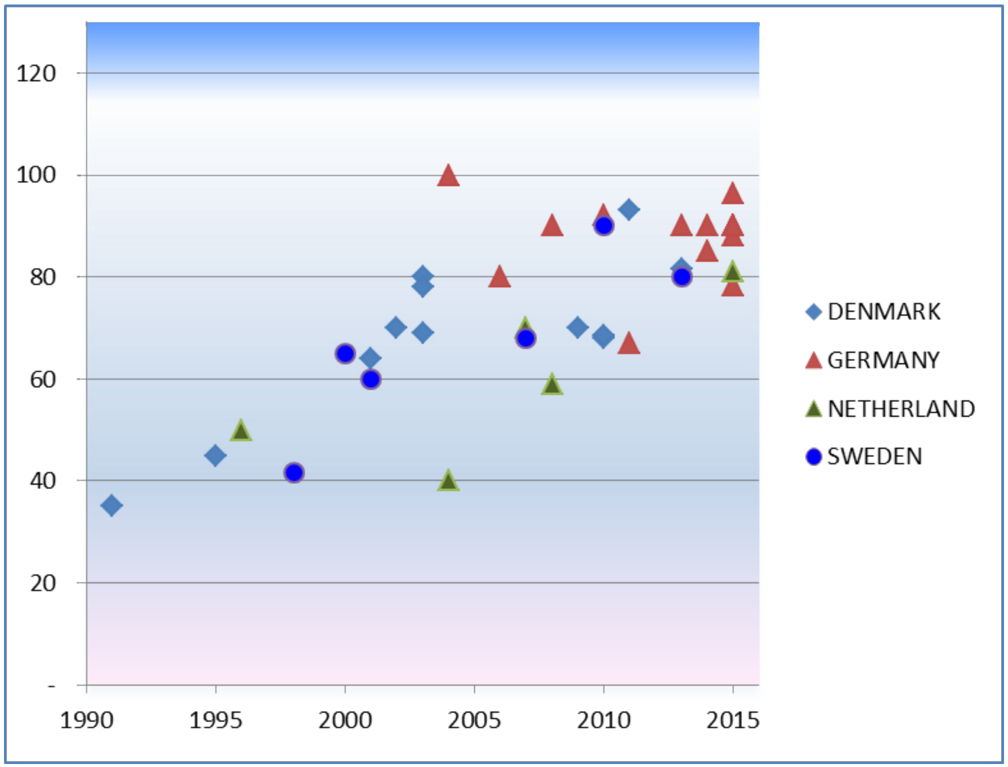


Also hub height is in constant growth: all over 80 m the plants completed in 2015 and till 120 m the consent authorized ones

«Fully commissioned» plants

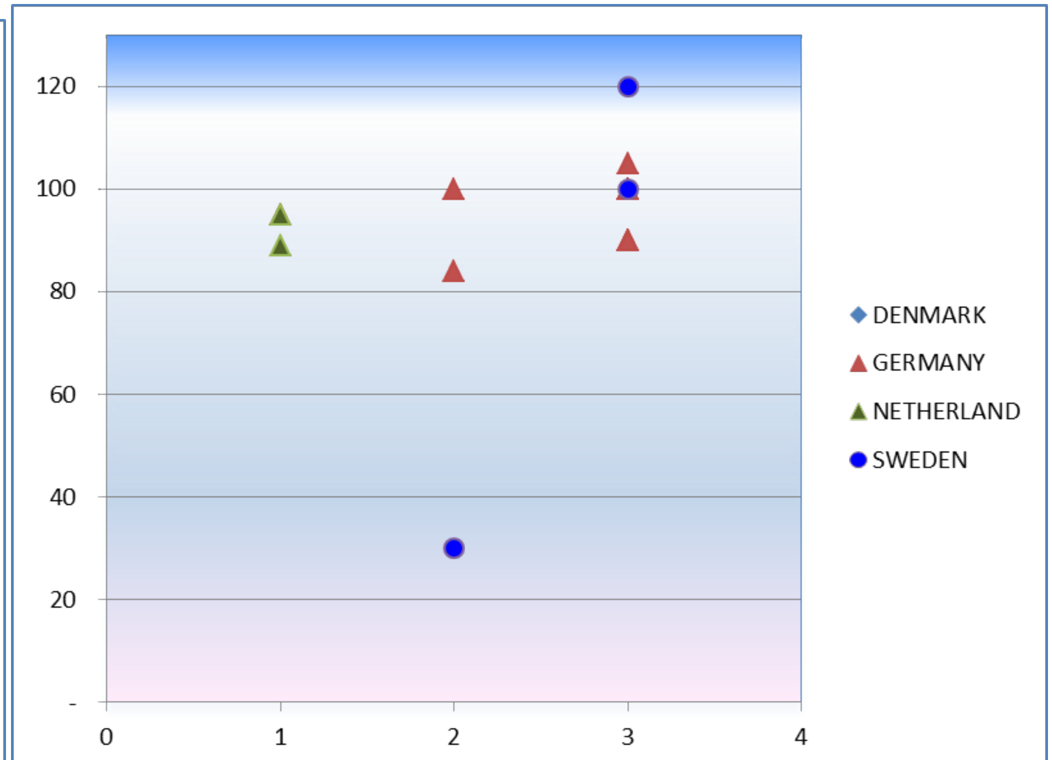
Hub height (m)

«Pre-contruction», «Under contruction», «Consent Authorized» plants



Graph made by the author

Data from 4Coffshore.com

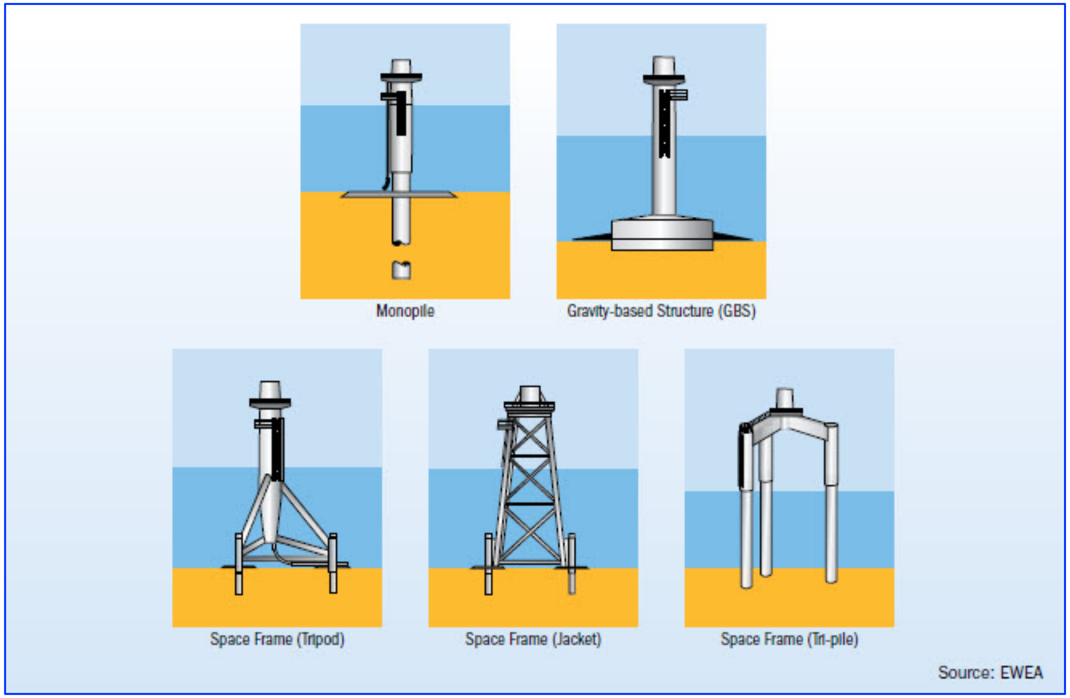


Under construction **Pre construction** **Consent authorized**

Graph made by the author

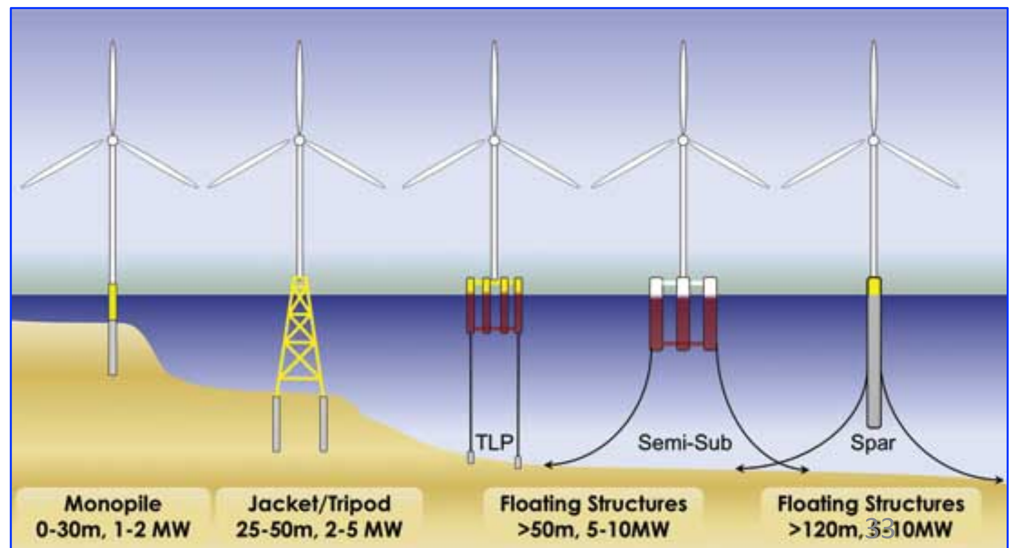
Data from 4Coffshore.com

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Foundations



Here are the most frequently used type of foundations for wind turbines

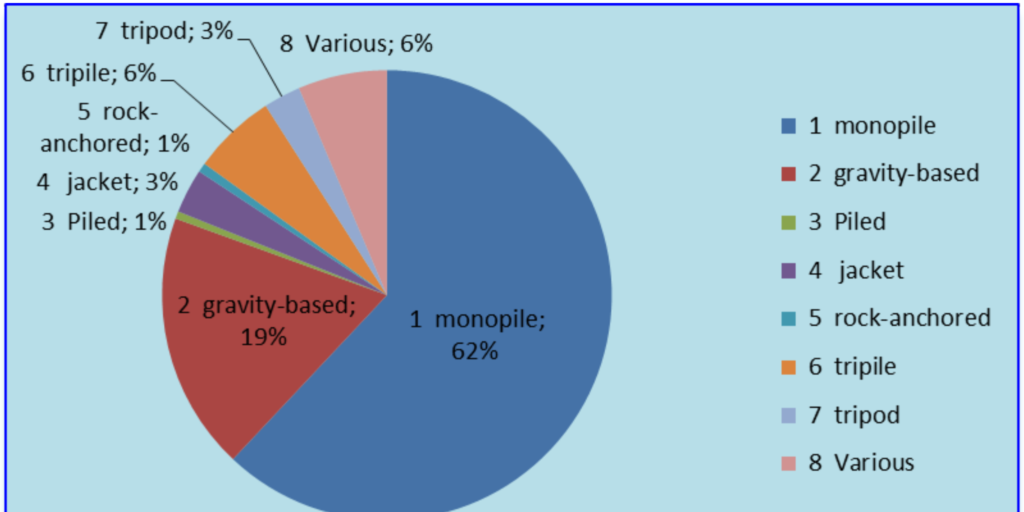
Conditions of use of the different kinds of wind turbines: monopile is no more used when waters deepen and the dimension of turbines increases



Source: http://*freeliff.com/offshore-wind-turbine-foundations/*

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Foundations

Wind offshore foundations in the four Countries examined



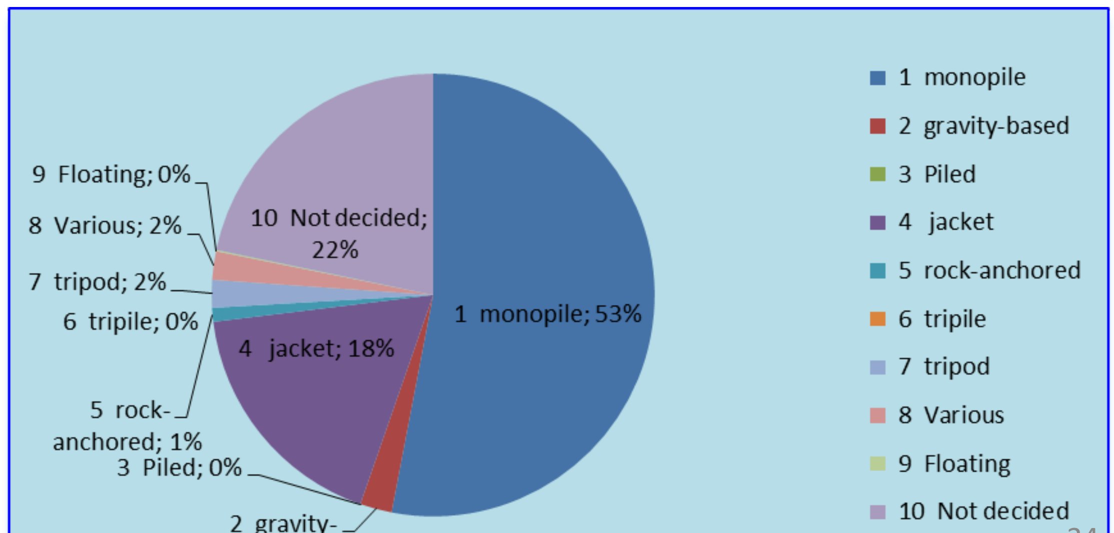
Graph made by the author

Data from 4Coffshore.com

«Fully commissioned» plants

As depth and distance to shore grow, monopile base looses share (**53% of share versus 62%**), but still remains the more frequent type of foundation

«Pre-contruction», «Under contruction», «Consent Authorized» plants

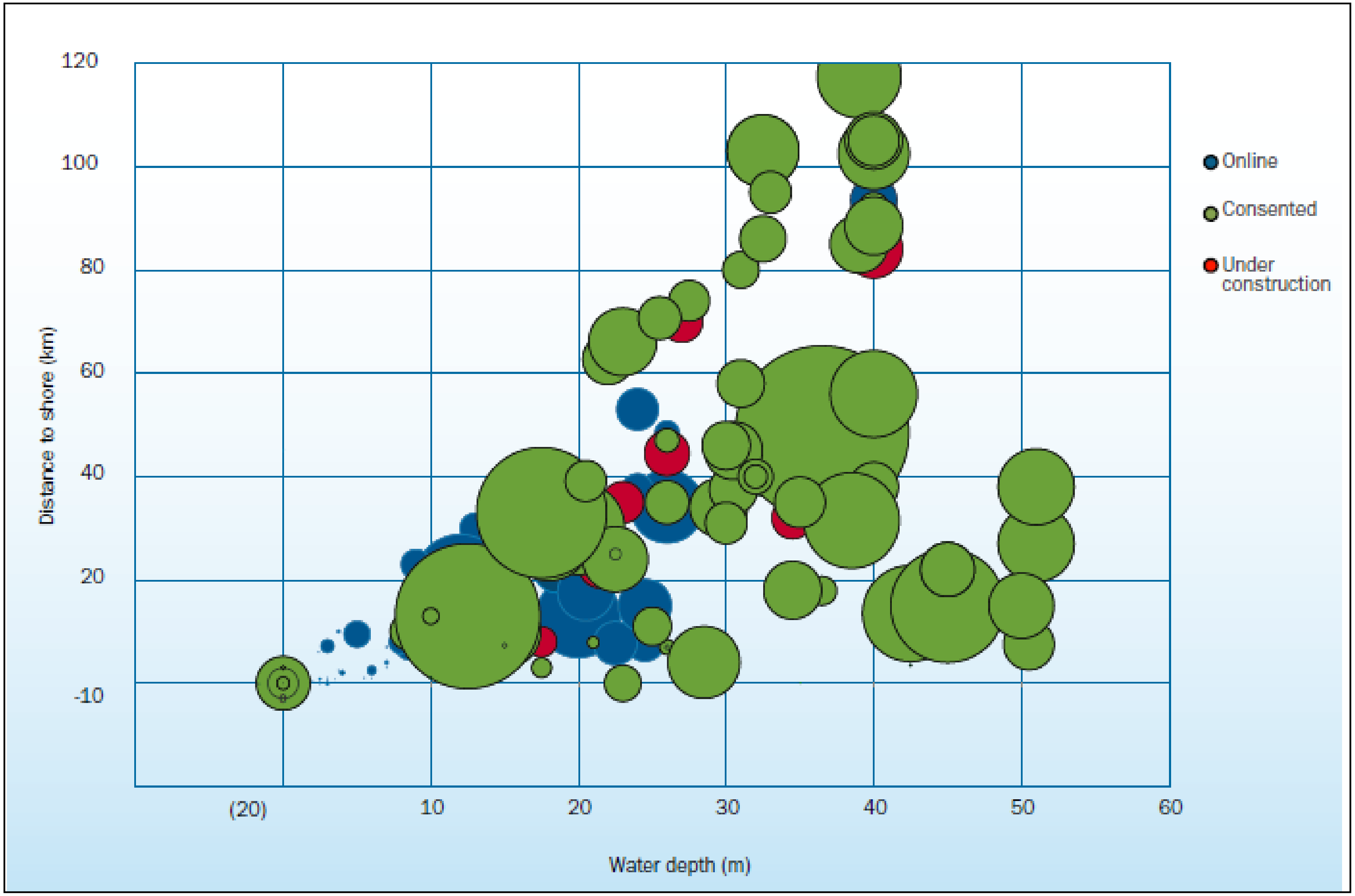


Graph made by the author *Data from 4Coffshore.com*

TECHNICAL CHARACTERISTICS OF WIND TURBINES: Evolution expected

The evolution espected: BIGGER, DEEPER and FURTHER

AVERAGE WATER DEPHT AND DISTANCE TO SHORE OF OPERATIONAL (ONLINE), UNDER CONTRUSCTIN AND CONSENTED WINDFARMS



At the end of 2014, the **average water depth of online wind farms was 22.4 m** and the **average distance to shore 32.9 km**.

<u>Projects under construction, consented and planned</u> confirm that average water depths and distances to shore are likely to increase.

Source: EWEA-European-Offshore-Statistics-2014

Northern Europe Energy Research

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WIND OFFSHORE

MAPS OF WIND SPEED

TECHNICAL CHARACTERISTIC OF WIND TURBINES: FOCUS ON THE FOUR COUNTRIES ANALIZED

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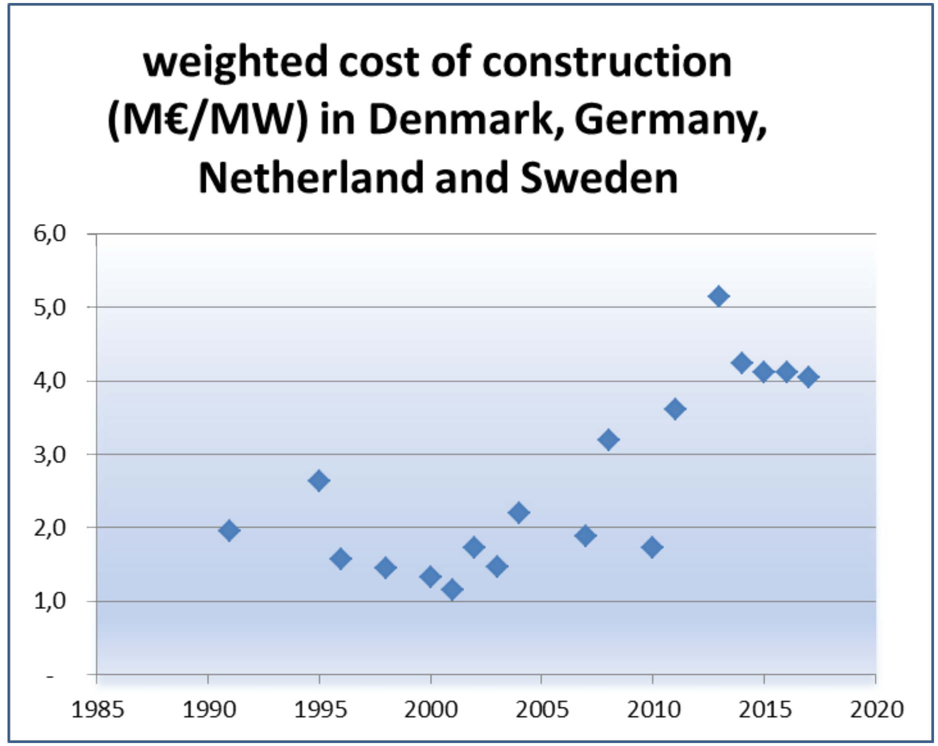
COSTS OF WIND POWER OFFSHORE - *the cost of a MW installed*

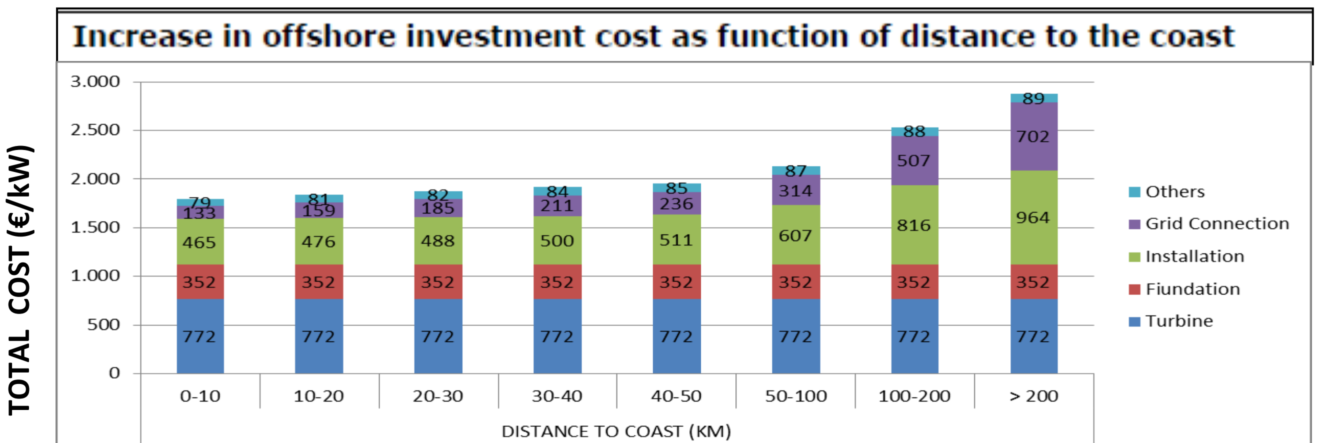
Evolution in the cost of construction of a MW in the four countries (Denmark, Germany, Netherland and Sweden)

The **increase in the cost of a unit of power installed** is due to the different daring conditions: **higher depths, bigger distance to shore, in search of a higher load factor of the plants**.

But **the cost of a unit of power produced is in costant reduction**, due to the bigger energy yield obtained in the new challanging conditions.



Graph made by the author Data from 4Coffshore.com



Total	1800	1839	1878	1918	1956	2131	2534	2878
Scale factor	1	1.022	1.043	1.065	1.086	1.183	1.408	1.598

Source: Graph made by the author with data from EEA (European Environment Agency) - Technical report N.6/2009 – Europe's-onshore and offshore wind energy potential

In the graph, even if not updated, we see that there are **components of the total cost,** like the installation and the connection to the grid, that **multiply when the distance to the coast increases.**

COSTS OF WIND POWER OFFSHORE - *the cost of a MW installed*

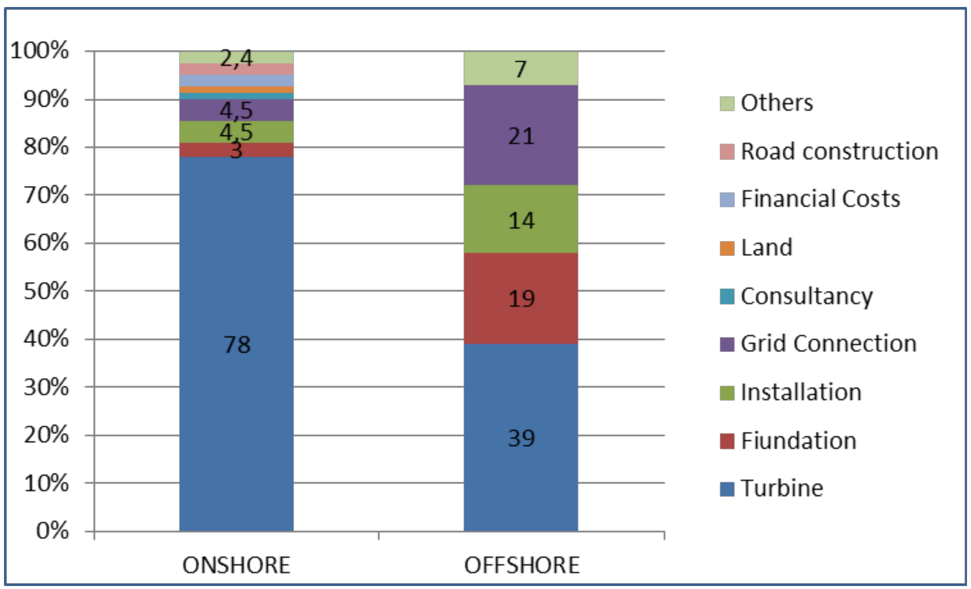
Scale factors costs increase as function of water depth and distance to coast

	0 -10 km	10 – 20 km	20 – 30 km	30 -40 km	40-50 km	50-100 km	100-200 km	>200 km
10 - 20 m	1	1.022	1.043	1.065	1.086	1.183	1.408	1.598
20 - 30 m	1.067	1.090	1.113	1.136	1.159	1.262	1.501	1.705
30 - 40 m	1.237	1.264	1.290	1.317	1.344	1.464	1.741	1.977
40 - 50 m	1.396	1.427	1.457	1.487	1.517	1.653	1.966	2.232

Source: EEA (European Environment Agency) - Technical report N.6/2009 – Europe's-onshore and offshore wind energy potential

Investment costs seen as a function of water depth and distance to coast: **a wind turbine distant to the coast more than 200 kilometers in water from 40 to 50 meters deep costs more than double than a turbine witin 10 kilometers and 20 m depth**

Estimated share of total investment costs for onshore and offshore wind farms



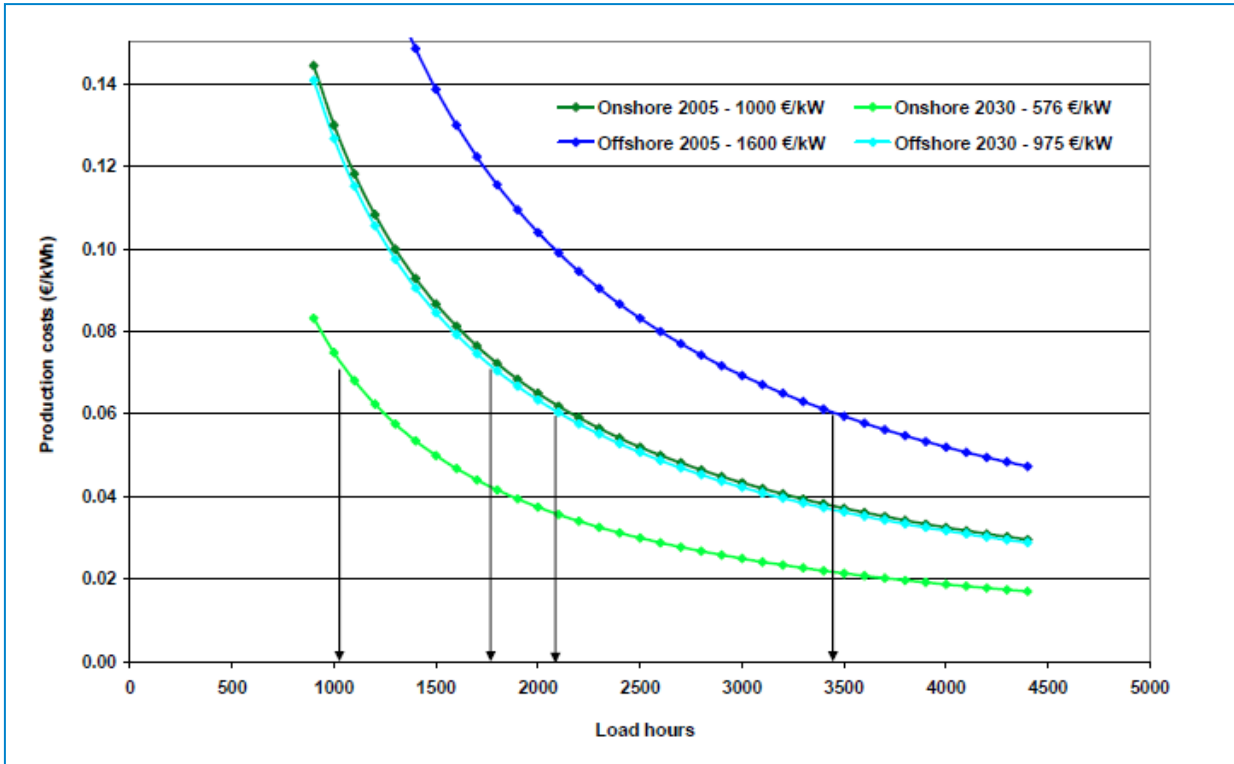
Graph made by the author- Source EEA European Environment Agency

The cost for turbines represents almost the 80% of the total investment cost in the **Onshore** Wind, while in the **Offshore** is no more than 40%: foundations, installation and grid connection totalize a 55%.

COSTS OF WIND POWER OFFSHORE - *the cost of a kWh produced*

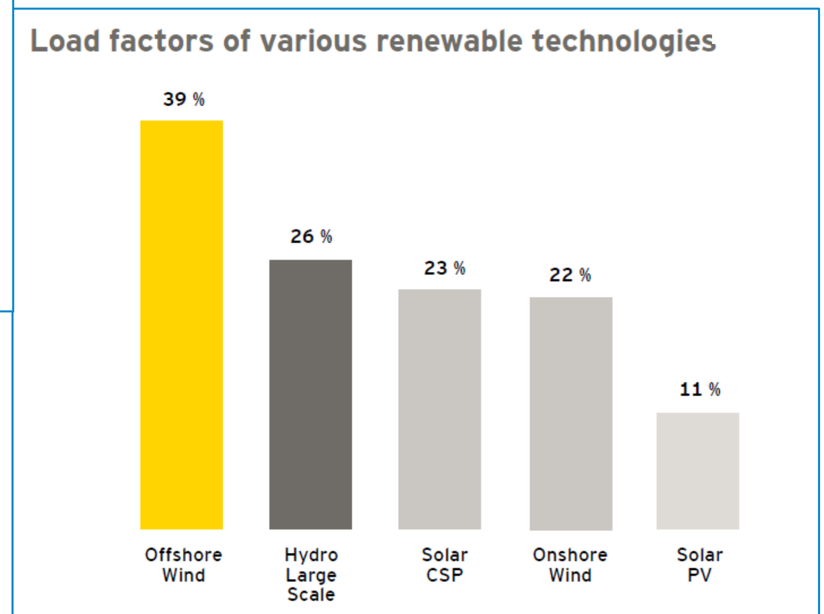
The variability of the cost of a unit of power produced

Electricity generation costs for onshore and offshore wind in 2005 and 2030



ETC/ACC – European Topic Centre on Air and Climate Change for EEA (European Environmental Agency) – Technical Paper -December 2008 - Wind Energy potential in Europe 2020-2030

Different curves represent the different initial investment for a KW installed:
it changes in the **time** and it is different from **Onshore to Offshore.**
This cost defined, **the cost for a unit of power produced is function of load hours**



Offshore wind has the highest "Load factor" within all the renewable energies: 39% by now.
In electrical engineering the ***load factor*** *is defined as the average load divided by the peak load in a specified time period.*
F_{load} = Average load/Maximun load in given time period

Source. Ernst & Young – Offshore Wind iN Europe – March 2015

COSTS OF WIND POWER OFFSHORE - non monetary costs

There are some issues on wind, regarding its **non-monetary costs**.
The main ones are listed below.

MAIN ISSUES ON WIND

	Offshore		Near shore (<12 miles)
1.	Visual impact at the shore and tourism	1.	Visual impact at the shore and tourism
2.	Spatial impact on fisheries	2.	Spatial impact on fisheries
3.	Flora and fauna	3.	Flora and fauna
4.	Spatial impact on shipping and oil and gas platforms	4.	Subsidy (potential to rise to 2nd most important)
5.	Subsidy (potential to rise to 1st most important)	5.	Spatial impact on shipping and recreation
6.	Onshore cables	6.	Onshore cables
7.	Visual impact on neighbouring countries		

Universiteit Utrecht - Siemens (Offshore Wind Power together towards Social Support)

Others are the noise caused by turbines and the light reflection of blades.

2005 *Comparative noise levels from different sources (Sustainable Development Commission,*

Source/activity	Indicative noise level (dBA)
Threshold of pain	140
Jet aircraft at 250m	105
Pneumatic drill at 7m	95
Truck at 48 kph at 100m	65
Busy general office	60
Car at 64 kph at 100m	55
Wind farm at 350m	35–45
Quiet bedroom	35
Rural night-time background	30–40

ETC/ACC – European Topic Centre on Air and Climate Change for EEA (European Environmental Agency) – Technical Paper -December 2008 - Wind Energy potential in Europe 2020-2030

This study shows that if turbines are at a distance of more than 300 metres, noise is absolutely sustainable (not much more than a quiet bedroom)

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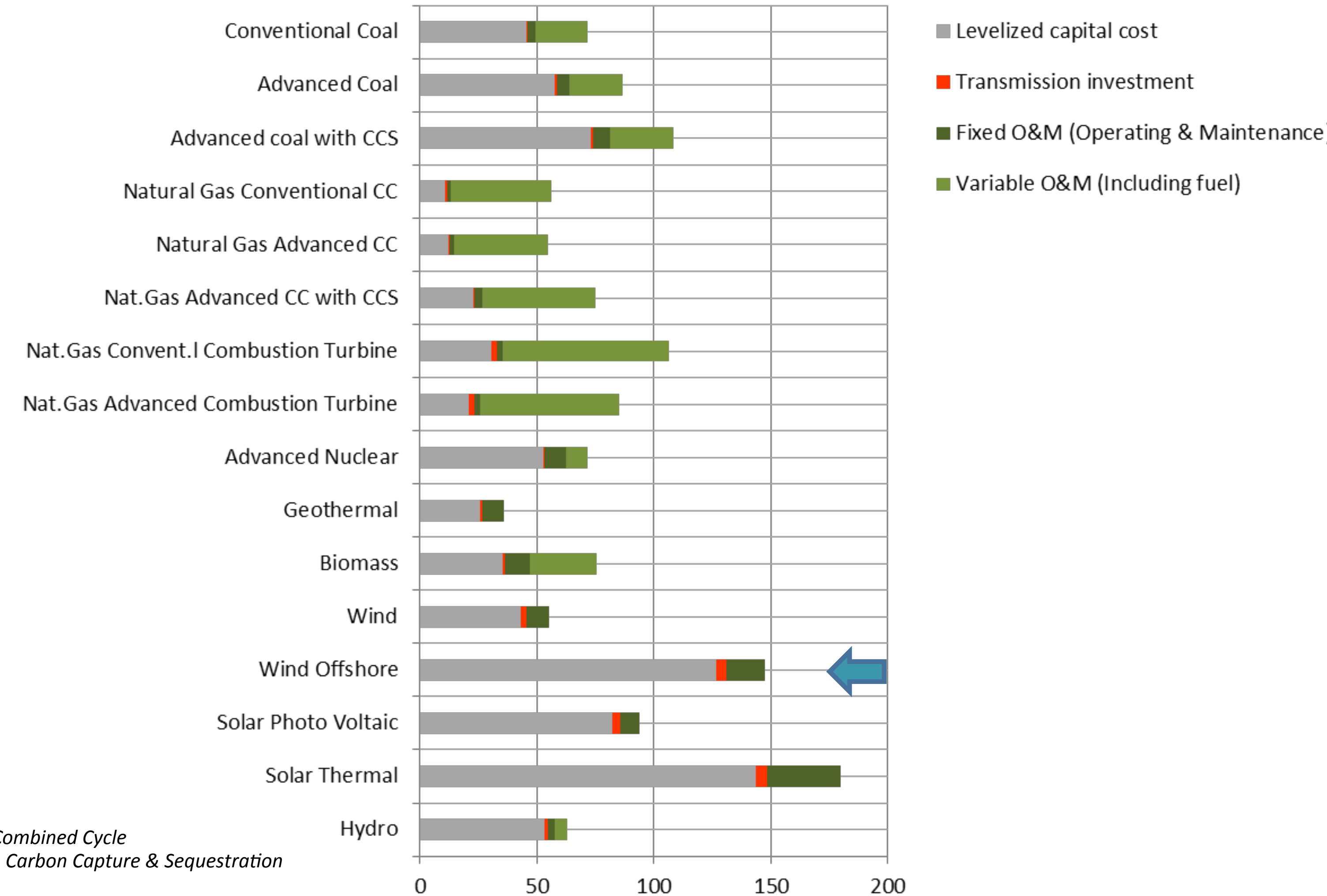
COMPARISON WITH THE OTHER ENERGIES - *Levelized Cost of Electricity (LCoE)*

Estimated Levelized Cost of Electric Generating Technologies in 2020 (2013 €/MWh)

Levelized costs represent the present value of the total cost of building and operating a generating plant over its financial life, converted to equal annual payments and amortized over expected annual generation from an assumed duty cycle.



CC Combined Cycle
CCS Carbon Capture & Sequestration

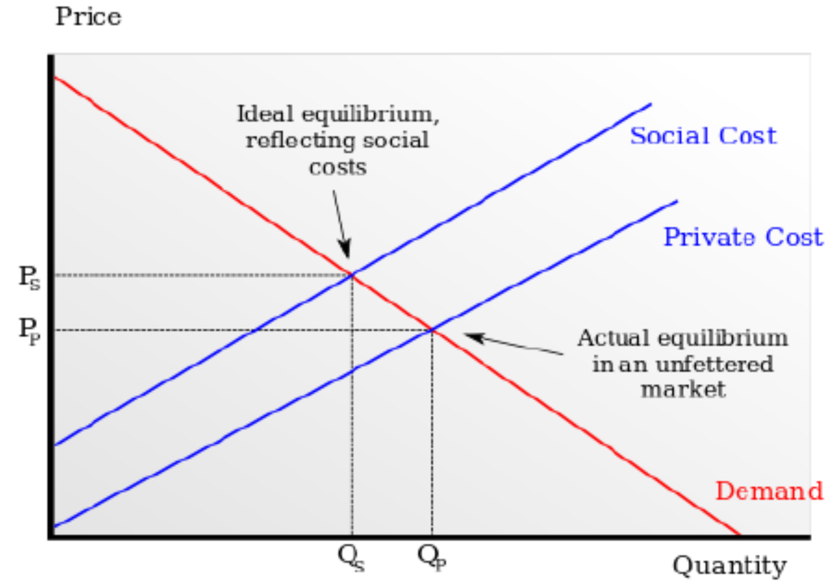
Graph made by the author with data from EIA Energy Infromation Administration – Levelized Cost and levelized avoided cost of new generation resources in the Annual Energy Outlook 2015

In terms of pure costs of construction, maintenance and operating, wind offshore is still expensive for a unit of energy produced, due to the **important capital cost** required.

COMPARISON WITH THE OTHER ENERGIES - *external costs*

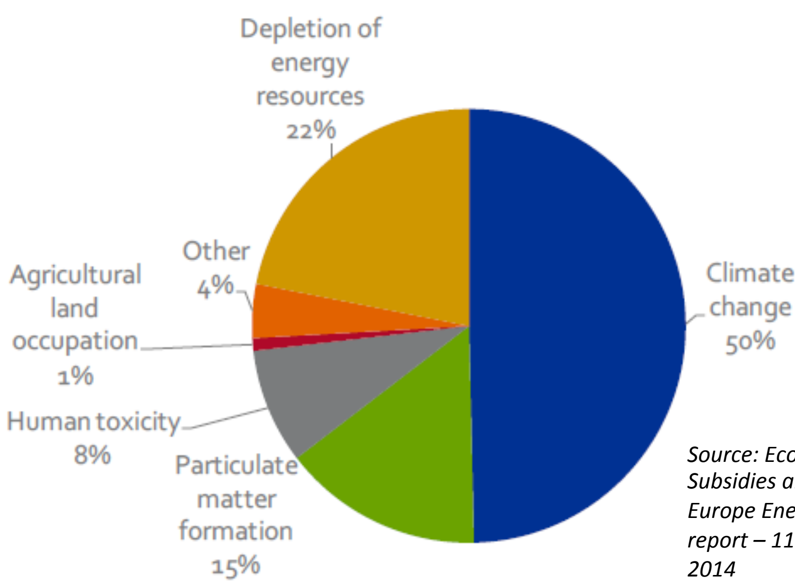
However, if we consider all the external costs, the situation is completely different.

Externalities are the result from the difference in private and social costs



Here is the estimate of the aggregate **external costs** of energy in the Europe of 28 Countries:

- **Climate change** represents the 50% of all the external costs;
- **Depletion of energy resources** is the 22%
- **Particulate matter formation** is the 15% and
- **Human toxicity** represents the 8%



Source: Ecofys for EU– Subsidies and costs of Europe Energy – Final report – 11 November 2014

Breakdown of total aggregate external costs energy of €2012 199 billion in 2012.

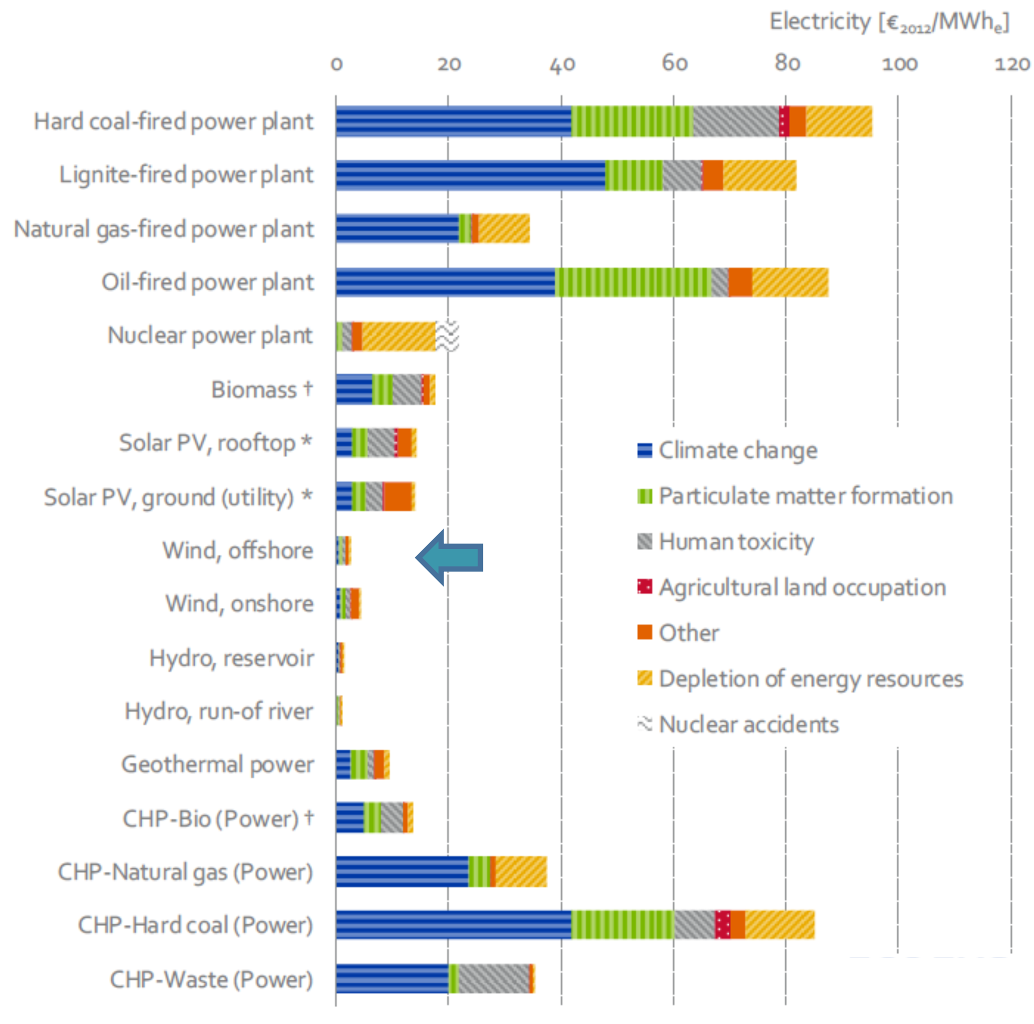
Summery of impact categories and **monetisation** values

Impact categories	Unit	External costs ($€_{2012}$/ unit)
Climate change[1)]	kg CO_2 eq	0.043
Ozone depletion	kg CFC-11 eq	107
Terrestrial acidification	kg SO_2 eq	0.2
Freshwater eutrophication	kg P eq	0.2
Marine eutrophication	kg N eq	1.8
Human toxicity	kg 1.4-DB eq	0.04
Photochemical oxidant formation	kg NMVOC	0.0023
Particulate matter formation	kg PM_{10} eq	15
Terrestrial ecotoxicity[2)]	species.yr.m^2	1.04E-09
Freshwater ecotoxicity[2)]	species.yr.m^3	2.95E-12
Marine ecotoxicity[2)]	species.yr.m^3	5.68E-17
Ionising radiation	kg U235 eq kBq	0.001
Agricultural land occupation[3]	m^2a	0.09
Urban land occupation	m^2a	0.1
Natural land transformation	m^2	3.6
Water depletion	m^3	0.2
Metal depletion	kg Fe eq	0.07
Depletion of energy resources[4)]	kg oil eq	0.05

Source of the 3 graphs: Ecofys for EU – Subsidies and costs of Europe Energy – Final report – 11 November 2014

COMPARISON WITH THE OTHER ENERGIES - external costs

Estimated External Cost of Electric Generating Technologies (€ 2012/MWh)



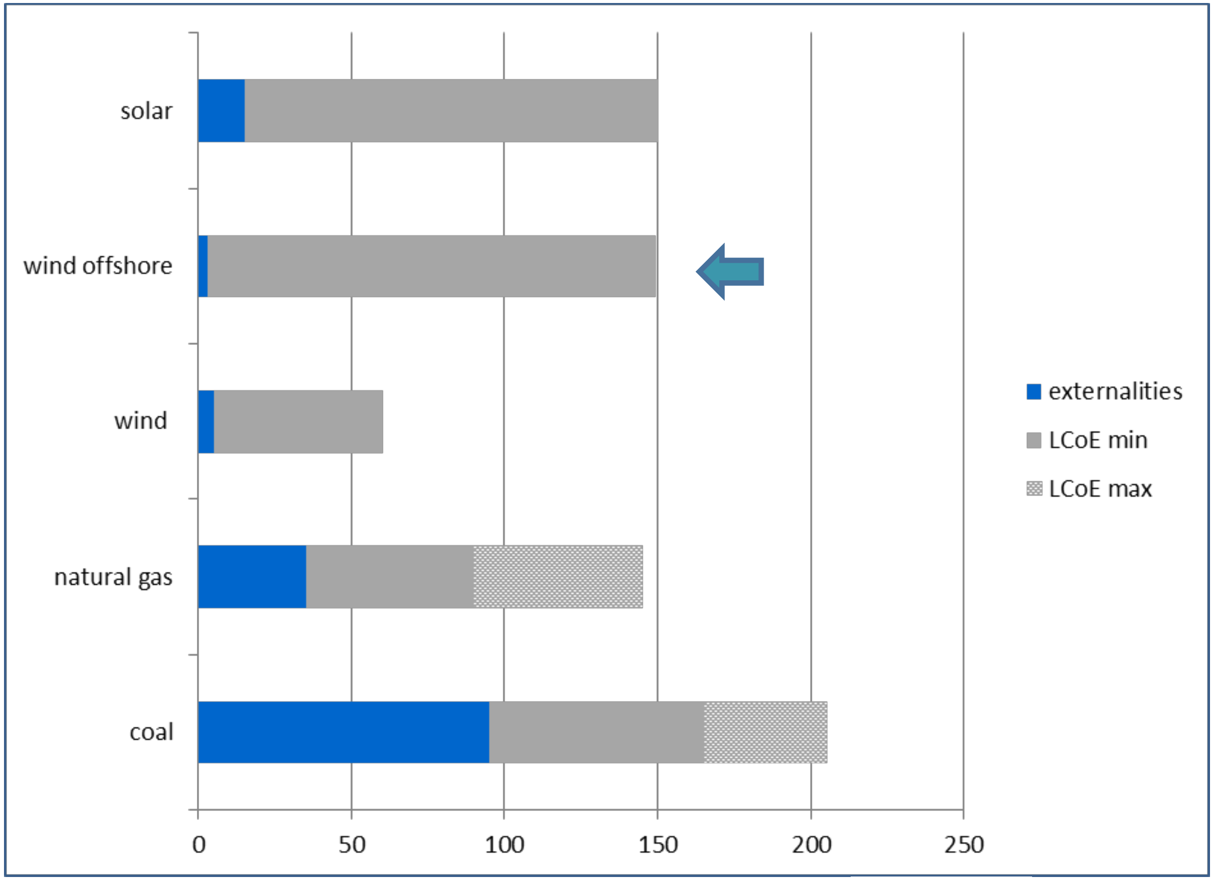
External costs per technology for electricity technologies, EU28 weighted averages (in €2012/MWhe).

If we consider all the external costs, the situation is overturned: we can see that **wind offshore has almost no costs, while fossil fuels have huge external costs**, mainly related to Climate Changes and particulate production.

Source: Ecofys in order of European Commission – Subsidies and costs of Europe Energy – Final report – 11 November 2014

COMPARISON WITH THE OTHER ENERGIES - the total estimated cost of electricity

The total Estimated Cost of Electric Generating Technologies (€ MWh)



Graph made by the author using EIA and Ecofys data seen above

Everything considered, **the total cost of wind offshore is about 150€/MWh, while gas, the cheapest fossil fuel, is between 90 and 140 €/MWh**, depending on technologies used.

That's not all, because **the cost of wind offshore is in constant reduction**

COMPARISON WITH THE OTHER ENERGIES - the "Society Cost of Electricity"

The true cost of offshore wind energy: the «Society Cost of Electricity»
The case of Germany

If we add to **Levelized Costs of Electricity (LCoE)**

\+

more **costs and benefits of macroeconomic factors** (like, Employment effects, Geopolitical Impact, etc.)

=

we have the **«Society Cost of Electricity» (SCoE)**

€ct/kWh	Nuclear	Coal	Gas	Solar PV	Wind Onshore	Wind Offshore
LCoE + Subsidies + Transmission + Variability	7.9	8.0	6.7	10.0	5.5	9.5
LCoE + system costs + Social impact + Employment effects + Geopolitical impact	12.8	8.1	6.8	12.6	7.3	11.1
SCoE	9.4	7.7	7.4	7.7	5.8	6.2

Germany SCoE in 2025 shows offshore wind to be more competitive than conventional generation (Nuclear, Coal and Gas) or solar PV.

Source. Ernst & Young – Offshore Wind iN Europe – March 2015

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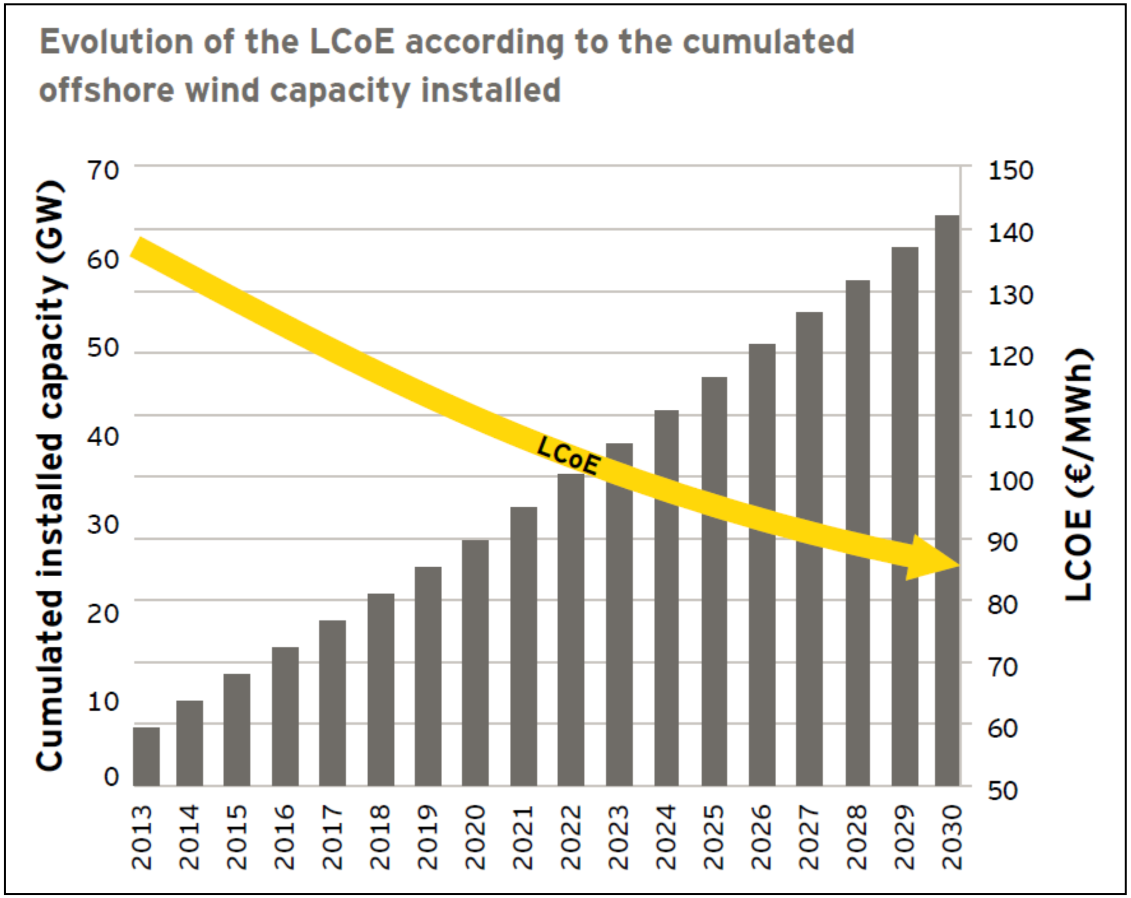
CONCLUSION: FUTURE TREND OF COSTS



Source. Ernst & Young – Offshore Wind iN Europe – March 2015

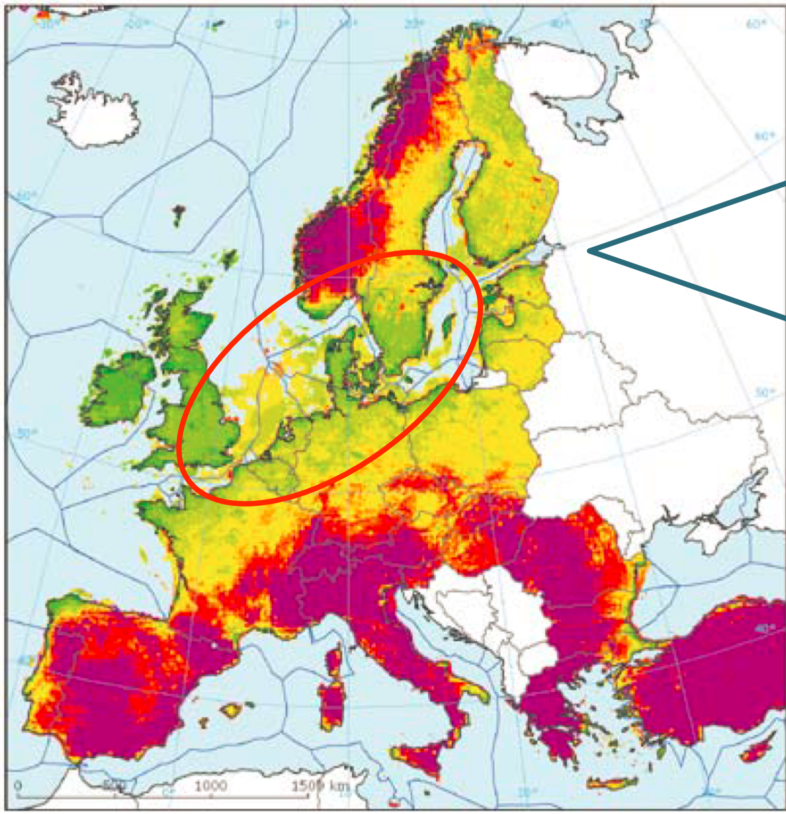
- **The best trade off between**
  - **distance to shore,**
  - **water depth,**
  - **turbine power,**
  - **farm dimension,**
  - **rotor diameter,**
  - **hub height,**
- **the new techologies and researches**
- **the increasing competition in a sector fastly developing**

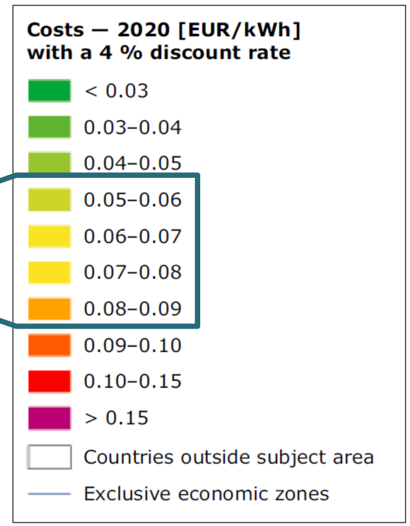
will result in a huge reduction of the average cost per MWh, from the actual 140€/MWh to the expected 80-90 €/MWh in 2030: -40%

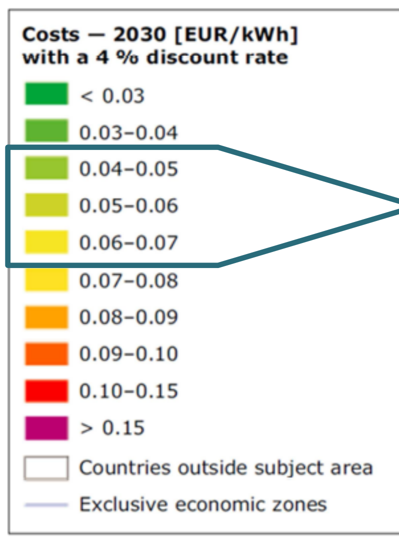
A reduction of the 40% of the average future cost of a developing technology will completely change the rate of wind offshore in the compared levelized costs of energy (LCoE).

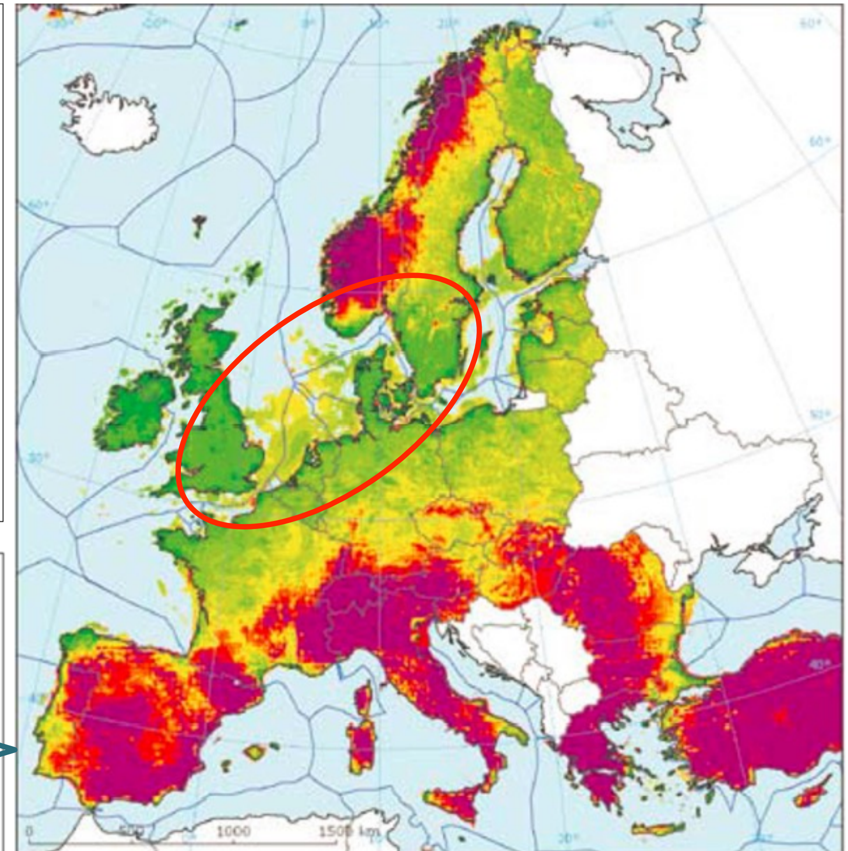
CONCLUSION: FUTURE TREND OF COSTS IN THE FOUR COUNTRIES

Generation costs for wind energy in Europe in 2020 (left) and 2030 (right)









The cost of a kWh of energy in the area offshore of the four contries examined, in 2020 will low to a range of 0,05 to 0,09 €cent (50 to 90 €/MWh).

In 2030 this cost will be even lower: from 0,04 to 0,07 €cent/kWh (40 to 70 €/MWh).

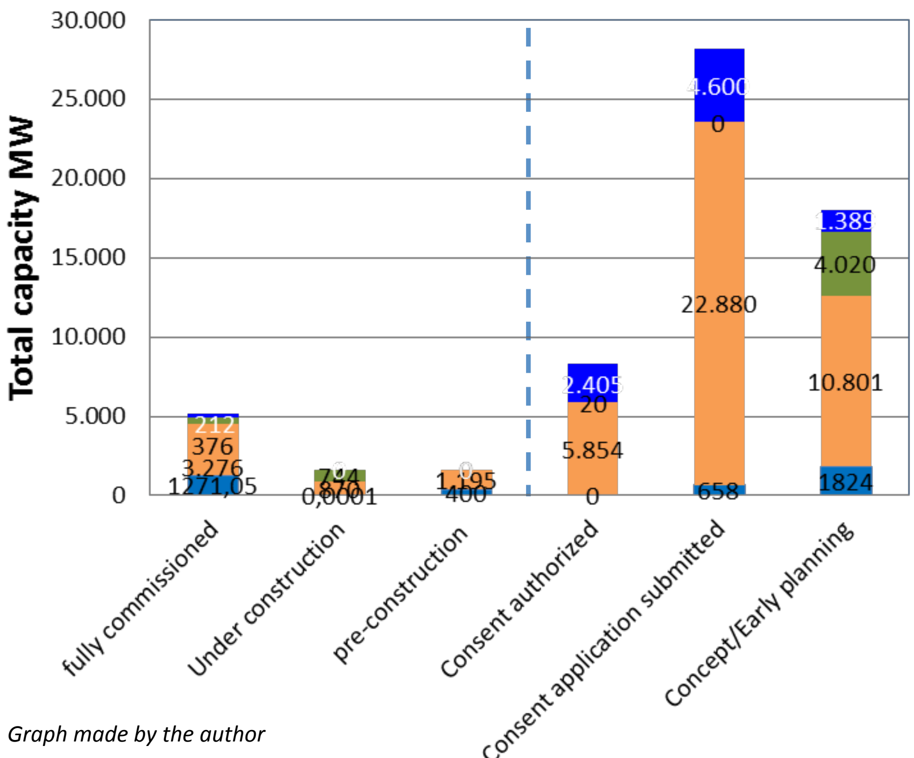
Source: EEA (European Environment Agency) - Technical report N.6/2009 – Europe's-onshore and offshore wind energy potential

CONCLUSION: EXPECTATIONS IN THE FOUR COUNTRIES

Expectations are high:

- besides **5,1 GW «fully commissioned»,** and a total of
- **3,2 GW «under or in pre construction**», the
- **plants in «consent authorized» status reach 8,3 GW,**
- those **in «consent application submitted» 28,1 GW**
- and **18 GW are in the «concept/early planning» status**.

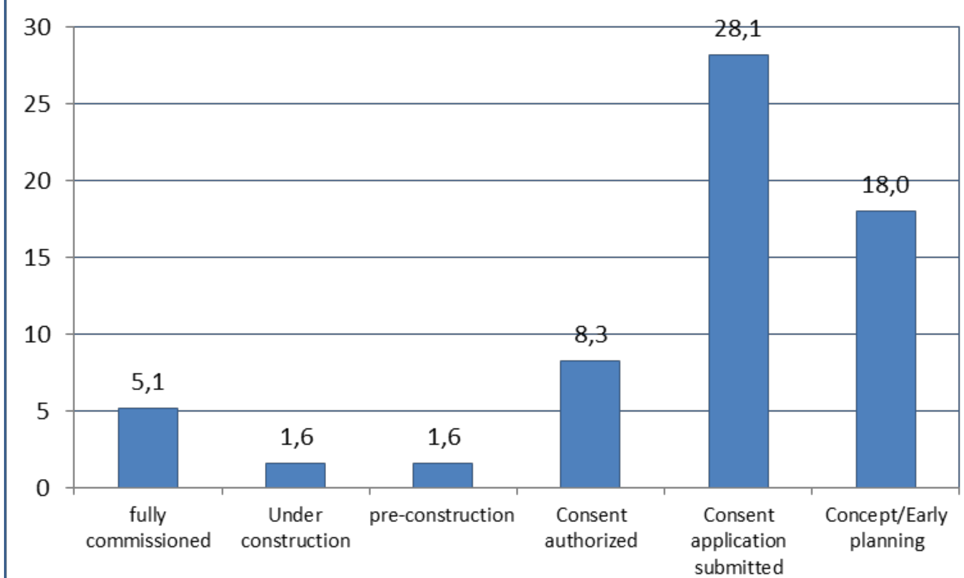
total installed/to install capacity (MW) per Country



Graph made by the author

Data from 4Coffshore.com

total installed/to install capacity (GW)



Graph made by the author   Data from 4Coffshore.com

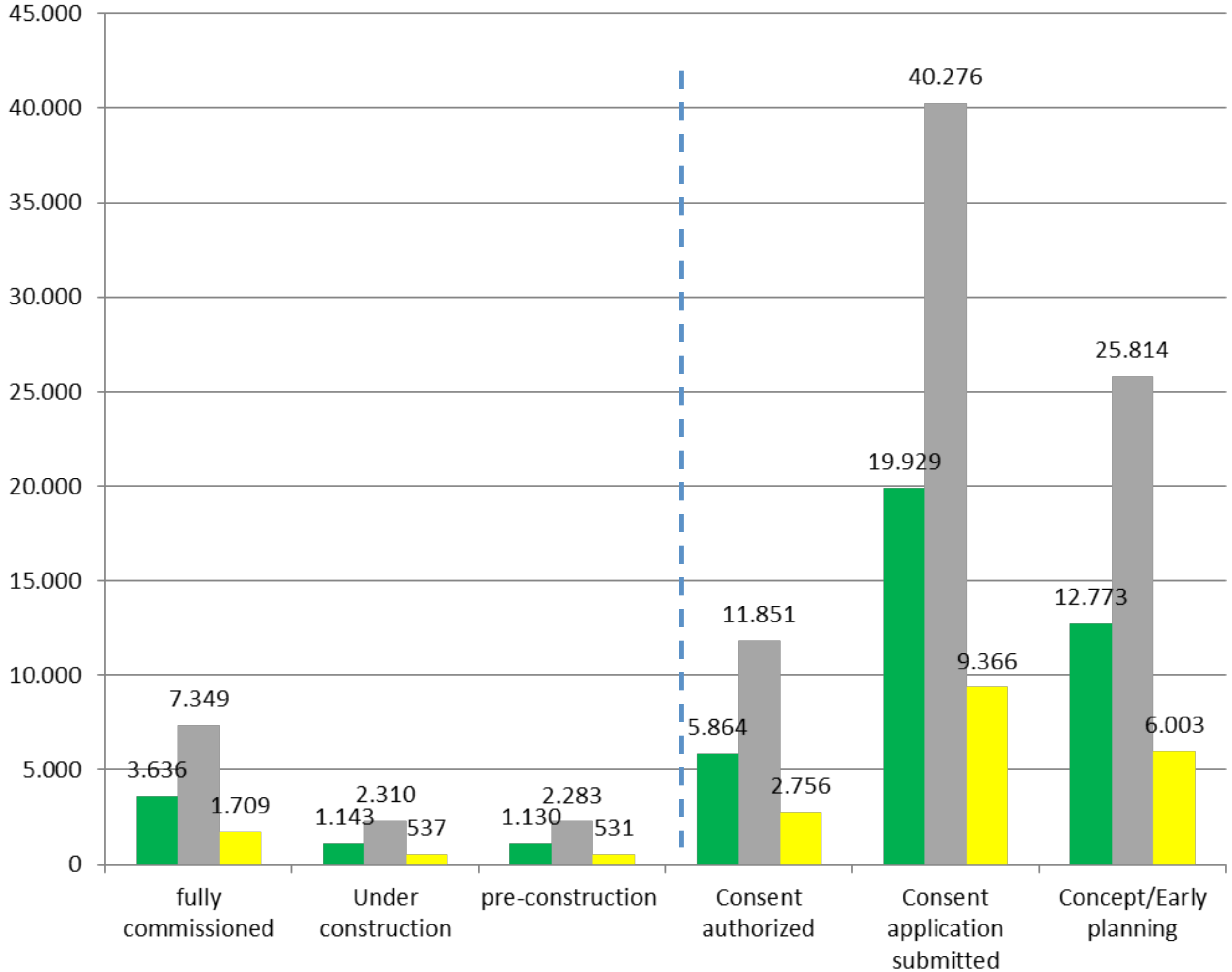
Germany has the major part of the projects to develop.

From the bottom:

- **Denmark (light blue) 4,2 GW: 1,7 in function or under/pre construction, and 2,5 to start/ authorize or plan;**
- **Germany (orange) 44,9 GW: respectively 5,3 GW and 39,5 GW;**
- **Netherland (green) 5,2 GW: 1,1 and 4,1;**
- **Sweden (blue) 8,6 GW: 0,2 and 8,4.**

CONCLUSION: EXPECTATIONS IN THE FOUR COUNTRIES

Present and expected environmental benefits of wind offshore in the four Countries examined



This graph shows the **expected good effects on the environment of all the capacity realised and planned,** in terms of:

- **Homes powered annually**
- **CO_2 emission avoided per year**
- **SO_2 emission avoided per year**

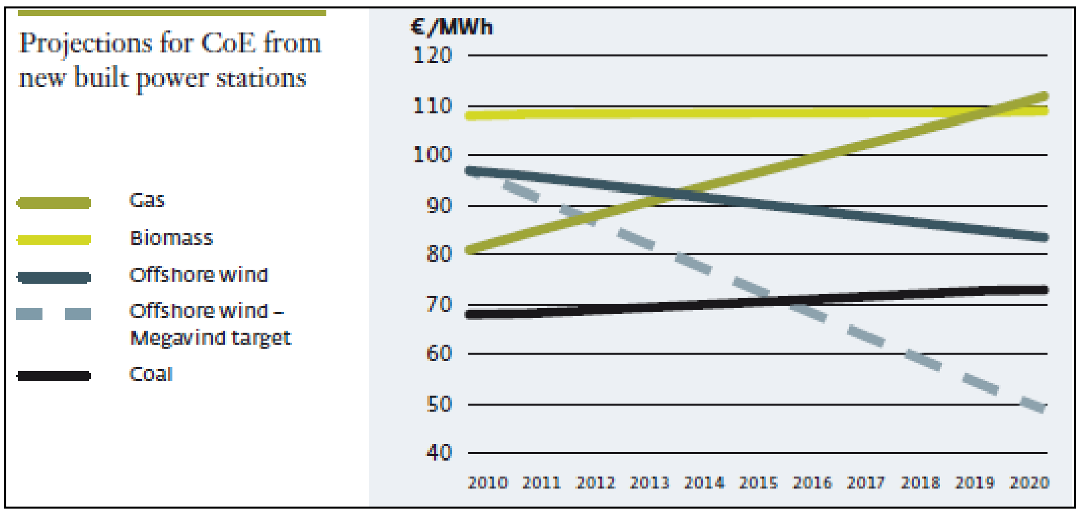
Graph made by the author Data from 4Coffshore.com

CONCLUSION: EXPECTATIONS IN THE FOUR COUNTRIES

Research and Development in Denmark

The Danish Government has estabished a public-private partnership with State, Universities and important industries to accelerate innovation for green technologies: the partnership for wind energy is called **Megawind** (private partners are big companies like Vestas, Siemens, Dong, etc.).

The challenge of Megawind is just to enable **offshore wind power to become competitive with other energy technologies in terms of pure cost of energy CoE**, as described below.



CoE equals costs divided by production

$$CoE = \frac{\text{Annualised CAPEX} + \text{Annualised OPEX}}{\text{Annual Energy Production}}$$

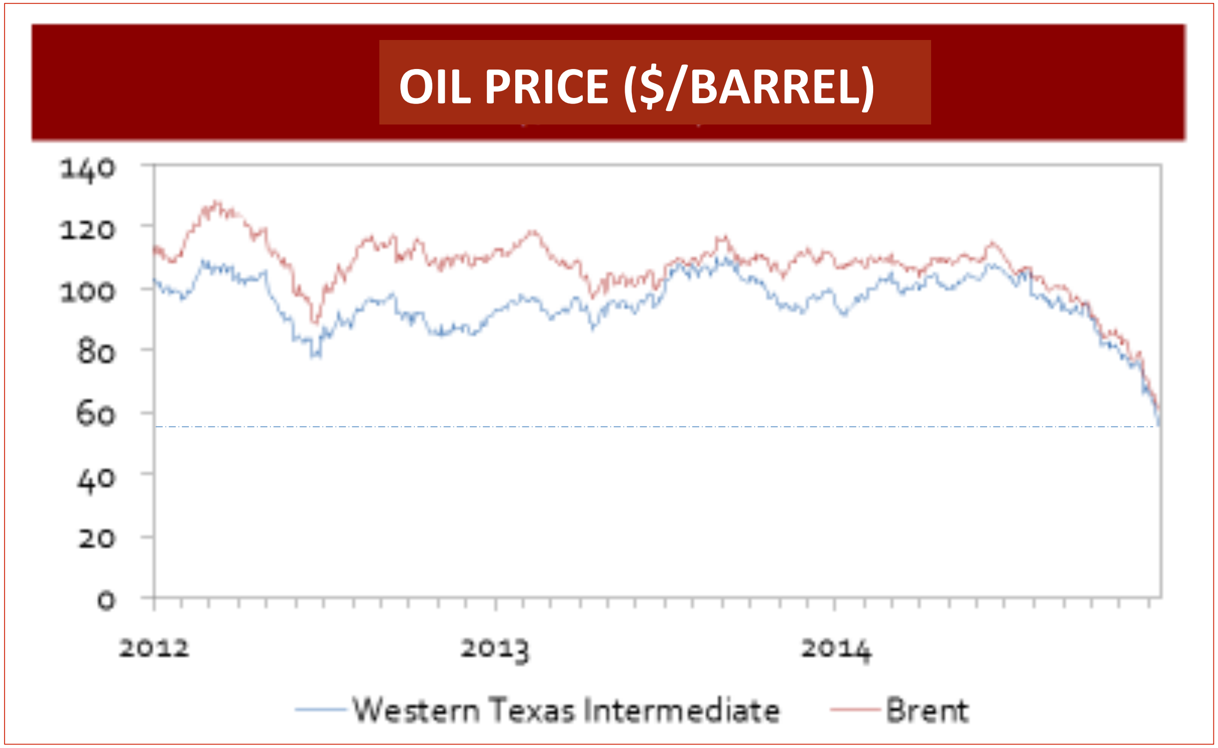
The Danish Wind Industry Association, secretariat for Megavind

This graph shows the

- **expected trend of wind offshore,** as seen before, and
- the **Megawind target, that is to reduce of another 50% the expected cost of the newly built wind farms** by:
  - ✓ **a 25% increase of energy produced per installed MW**
  - ✓ **a 40% reduction in the capital expenditure**

CONCLUSION: VOLATILITY OF MARKET

What will be the impact the recent fall of oil price (graph below) on all the decisions to take in term of energy policy?



Source: EIA - US Energy Information Administration

The answer … maybe from Paris Climate Conference…!

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WIND POWER

WIND OFFSHORE

MAPS OF WIND SPEED

TECHNICAL CHARACTERISTIC OF WIND TURBINES: FOCUS ON THE FOUR COUNTRIES ANALIZED

COSTS OF WIND POWER OFFSHORE

COMPARISON WITH THE OTHER ENERGIES

CONCLUSION

DATABASE AND SOURCES

DATABASE

The **database built to realize all the graphs** with the technical characteristics of the four countries analized, has been created with a selection of the data of "***4C Global Offshore Wind Farms Database***".

The data collecting has regarded 215 plants in different status:

- 40 Online,
- 10 Under/Pre Construction;
- 27 Consent Authorized;
- 61 Consent application submitted
- 77 Concept to plan

Tha **allocation** of these 215 plants/projects is as follows:

- Germany: 136;
- Denmark: 30,
- Netherland: 20 and
- Sweden: 29

All the plants/projects have been analyzed for all the dimensions present in the table

COUNTRY
N.
PLANT
STATUS
Owner
Operator
year of construction
costs of construction (M€)
total installed capacity (MW)
depth (m)
depth (m) medium value of the farm
distance to shore - computed from center (km)
number of turbines
turbines capacity (MW)
type of turbines
rotor diameter (m)
hub height (m)
area (km2)
foundation
expected life (Y)
homes powered annually (n.)
CO2 emissions avoided/y (tonnes)
SO2 emissions avoided/y (tonnes)

An example

COUNTRY	N.	PLANT	STATUS	Owner	Operator	Notes	year of construction	costs of construction (M€)	total installed capacity (MW)	depth (m)	distance to shore - computed from center (km)	number of turbines	turbines capacity (MW)	type of turbines	rotor diameter (m)	hub height (m)	area (km2)	foundation	expected life (Y)	homes powered annually (n.)	CO2 emissions avoided/y (tonnes)	SO2 emissions avoided/y (tonnes)
DENMARK	1	Anholt	fully commissioned	Dong Energy	Dong Energy		2013	1.340	399,6	15-19	22,6	111	3,6	SWT-3.6-120 (Siemens)	120	81,6	116	grounded: monopile		283.019	571.981	13.302
DENMARK	2	Avedøre Holm	fully commissioned	Dong Energy AS	Dong Energy AS		2011	13	10,8	0-2	0,4	3	3,6	SWT-3.6-120 (Siemens)	120	93	0	grounded: gravity-based		7.649	15.459	360

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BACK UP

Northern Europe Energy Research

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1. **RESEARCH OBJECTIVES/HYPOTHESIS**
2. **APPROACH**
3. **ESPECTED RESULTS/OUTCOMES**

Objectives

Can offshore wind energy in the North Sea compete with fossil fuels?

1. The wind resources in the North Sea are some of the best in the world.
2. This research will look for the newest and future offshore wind turbines in North Europe to investigate problems and opportunities for the near future.
3. Objective of this research is to evaluate and forecast the trend of costs to produce a single unit of power (MWh)
4. My hypothesis is that the production of wind energy with big offshore wind turbines will become the cheapest way within wind energy production and very competitive with the other traditional ways of production, thanks to a very high yield, the easiness to design and acceptable building costs.
5. Other than convenient it will remain a very worthy way to produce sustainable energy, thanks to wind renewability and cleanness, its characteristic of being not earth consuming, not impacting on landscapes, if well managed.

Approach

1. For each nation I will look for a feasibility study with the locations where the wind is more powerful and constant.
2. I will identify all the plants existent in the four countries we are visited Netherlands, Germany, Denmark, Sweden.
3. I will identify the plants in construction or in project.
4. I will classify them with a range of characteristics: year of construction, installed capacity (MW), depth (m), distance to shore, number of turbines, type of turbines, build costs (US$), working costs (US$), CO_2 emissions avoided/y …
5. I will investigate all the analysis made by the building companies: feasibility, place, problems of construction, distance to the grid, costs and yield.
6. I will use those data to compare the cost of energy production.

Outcomes

The total costs of a unity of power produced with this technology is in constant reduction and will be very competitive even with the cheapest fossil fuels.