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Deep offshore and new foundation concepts

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Abstract

As the offshore wind power sector moves to deeper waters, new foundation concepts are being developed. The European Wind Energy Association (EWEA) has created a task force under its Offshore Wind Industry Group, to look specifically at the issues revolving around the development of deep offshore and new foundation concepts. Within this paper a comprehensive presentation of state-of-the-art concepts and their maturity is provided. In addition the main technical, economic and political challenges are discussed and recommendations are provided to accommodate the sustainable development of the deep offshore wind sector in Europe.

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Keywords: Deep offshore foundations, floating, offshore wind

1. Introduction

Offshore wind is an important asset both in the European maritime and energy economy. In 2012 the offshore wind industry grew in terms of installations by 1.16 GW in Europe, bringing cumulative capacity to 4,995 MW. The wind farms are still located in relatively shallow waters: the average water depth of projects on which some work was carried out during 2012 was around 22 m. Nevertheless the European Wind Energy Association has identified a vast amount of projects planned in deep waters going even up to 215m depths.

There are numerous challenges and issues to be assessed for the offshore wind industry to be deployed in deeper waters and, thus, unlock the vast energy potential of the European seas. To address the economic and political challenges of moving to deeper waters, EWEA has created a task force[b] within the Offshore Wind Industry Group. Working together during a period of six months in 2012, the task force

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identified the most relevant challenges and provided concrete recommendations.

2. Offshore wind market

2.1. Current status

The offshore wind sector has been developing continuously over the past 20 years. During 2012, 1.16 GW of new capacity was installed. This translates to 293 new wind turbines installed and producing electricity in Europe, bringing cumulative capacity to 4,995 GW. Currently there are 61 offshore wind farms in ten European countries.

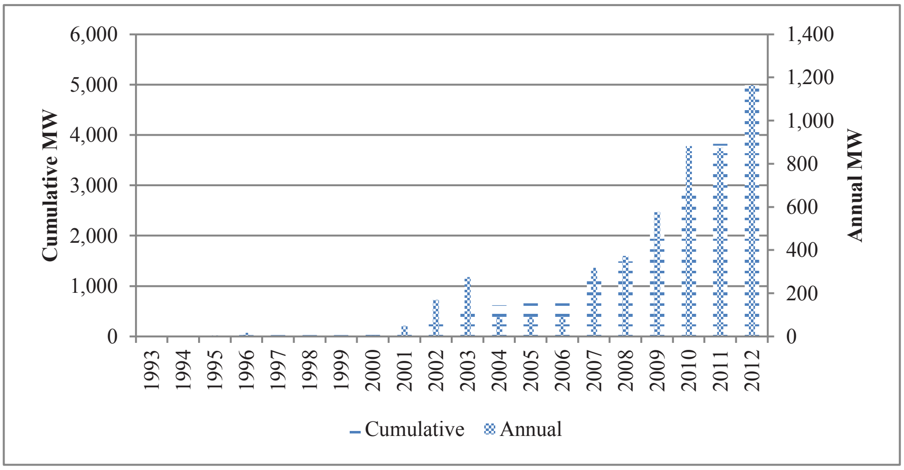

Figure 1: Annual and cumulative installation of offshore wind in Europe

Out of the total capacity, 65% is installed in the North Sea, 19% in the Atlantic and the rest 15% in the Baltic Sea. The majority of the installed wind turbines are supported by monopiles (74%), then by gravity based foundations (16%) followed by jackets (5%), tripiles (3%) and tripods (2%). There are 4 floating concepts online currently, two down-scaled (Poseidon 33kW and Sway 150kW) and two full-scale models:

- Hywind, operated by Statoil, with a 2.3MW Siemens turbine is located off the coast of Norway and was installed in 2009. It was the first large scale floating wind structure installed in Europe.
- Windfloat, the second full-scale floating system, was installed off the Portuguese coast in 2011 and started producing energy in 2012. Developed by Principle Power and EDP, it is equipped with a 2MW Vestas wind turbine.

[b] The Task Force 'Deep Offshore & new foundation concepts' included representatives from: Acciona, Alstom, Blue H, Catalonian Institute for Energy Research, CENER, DNV, EDF, EDP, HEXICON, IDEOL, Nass & Wind, National Technical University of Athens, Principle Power, Risø DTU, Statoil, The Glosten Associates.

2.2. Market outlook – Future trends

The development of offshore wind is expected to continue, exploiting the vast potential of the European seas. At the end of 2012, EWEA has identified a further 4.5 GW of projects under construction, around 18.4 GW of consented capacity and more than 140 GW of planned offshore projects.

Moreover, the project site characteristics are expected to evolve in the future, moving into deeper waters and further from shore. Figures 2 and 3 present the average water depth and distance to shore of online, under construction and consented projects.

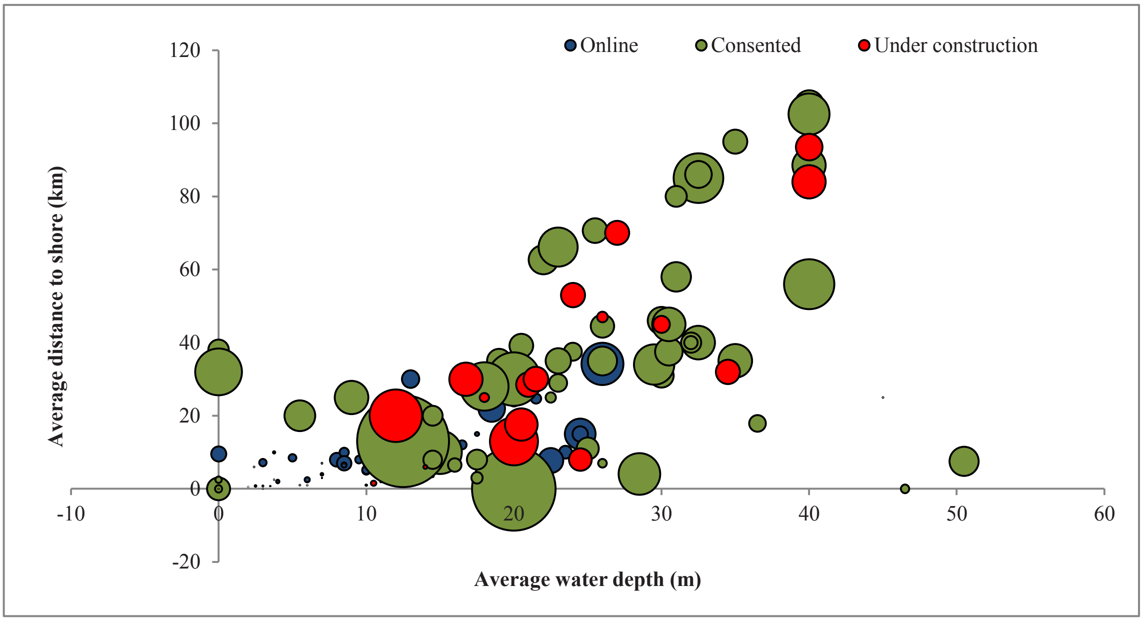

Figure 2: Average water depth and distance to shore for online, under construction and consented projects.

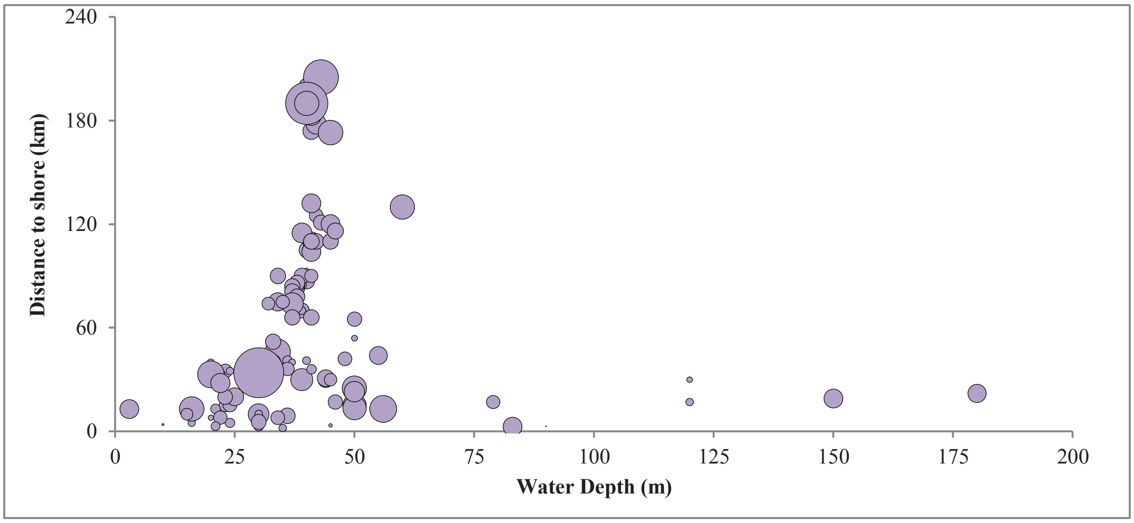

Figure 3: Average water depth and distance to shore of planned offshore wind projects

3. The coming of the deep offshore concepts

The European offshore wind industry is increasingly demonstrating its interest in developing deep offshore concepts. As a first step to collecting and assessing required information on deep offshore wind energy, the Task Force defined the *deep offshore environment* and the *maturity of concepts*.

3.1. Definitions

- Deep offshore

The main variable defining deep offshore is considered to be the water depth, as it dictates the type of substructure used in an offshore wind farm. Current substructures are economically viable up to water depths of 40-50 m. Therefore the *deep offshore environment* starts at water depths greater than 50 m.

- Concept maturity

As deep water substructures are quite new to the wind industry and need to go through different development stages before they become commercial, the different stages were determined.

- R&D stage: research and development on various designs using modelling tools.
- Demonstration stage: numerical demonstration of concept feasibility including dedicated experiments of the concept.
- Pilot stage: testing a down-scaled model in a controlled environment to provide realistic indicators for feasibility and cost effectiveness.
- Prototype stage: testing a full scale model to assess its concept maturity before commercialisation.
- Pre-production: deploying a limited number of full scale devices in one location to validate overall system principles, fabrication and installation methodologies.
- Serial (commercial) production stage: commercial deployment following pre-commercial deployment, within a wind farm layout.

3.2. State of the art

The concept of floating wind turbine systems was for the first time introduced in 1972 by professor Heronemus. However, it is only in the mid 1990's that the wind power industry started allocating research resources to deep offshore concepts.

In 2007, Blue H technologies installed the first test floating wind turbine in Italy. It generated 80 kW and after a year of testing and data collection it was decommissioned.

Two years later, in 2009, Statoil installed the first grid connected floating wind turbine, Hywind, in Norway. With a 2.3MW Siemens turbine, it is the first large scale floating wind structure installed in Europe.

Finally in 2011, the second large scale floating system, WindFloat developed by Principle Power in partnership with EDP and Repsol, was installed off the Portuguese coast. Equipped with a 2MW Vestas wind turbine the WindFloat installation started producing energy in 2012.

Three main types of deep offshore foundations have been developed so far:

- Spar Buoy: a very large cylindrical buoy stabilises the wind turbine using ballast. The centre of gravity is much lower in the water than the centre of buoyancy. Whereas the lower parts of the structure are heavy, the upper parts are usually empty elements near the surface, raising the centre of buoyancy. The Hywind concept consists of this slender, ballast-stabilised cylinder structure.

- Tension Leg Platform: a very buoyant structure is semi submerged. Tensioned mooring lines are attached to it and anchored on the seabed to add buoyancy and stability.

- Semi-submersible: combining the two previous designs' main principles, a semi submerged structure is added to reach the necessary stability. WindFloat uses a semi-submersible floater.

A comprehensive list of deep offshore wind concepts developed in Europe and the USA is provided in Annex A.

4. Deploying deep offshore technologies – key challenges.

The continuous trend to deeper waters provides an incentive for deep offshore concepts to be developed. However, since this segment of the offshore wind industry is new, there are numerous challenges to tackle. An overview of the most prominent challenges is presented in the following chapters.

4.1. Technical challenges

- Modelling and numerical tools: Modelling tools combining the behaviour of the turbine together with the substructure are not currently validated for the deep offshore concepts. More experimental set ups and prototypes are necessary in order to validate new numerical tools.
- Optimised wind turbines for deep offshore support structures: Integration of the wind turbine with the deep offshore platform or the 'superstructure' design is another important technical aspect to lower overall project cost of energy. Additionally, typology, the combination of site and technology specific variables, is the basic parameter for every different concept and site. The choice between different kinds of substructures is closely linked to wind turbine operation.
- Control of the whole system: different strategies for controlling the combination of substructure and turbine will potentially optimise the feasibility of deep offshore concepts. Control systems should work on stabilising the structure and therefore enhance energy production, minimising loads and losses.
- Connection to the grid: for floating offshore wind farms' grid connection, the challenges do not significantly differ from those of fixed foundation wind farms. The distance from shore and the availability of networks at the point of connection remain a potential bottleneck. However, as far as cable technology is concerned, the potential challenge for floating offshore wind concepts relates to the dynamic section of the cables. The motion induced by the turbine and the non-fixed foundation can, indeed, increase loads on the cables.
- Installation: most of the deep offshore concepts can be assembled onshore and then towed to sea. This will eventually reduce installation time and cost as most floating concept construction and installation are less dependent on weather and sea conditions. However, the main challenge for deep offshore concepts installation relates to mooring lines and anchors. Handling and installing mooring lines and anchors is, potentially, the main installation challenge and needs special attention as to what equipment is used. The moorings and anchors must be carefully designed to ensure the concept's stability throughout its lifetime.
- Economics of deep offshore concepts: to evaluate the economics of floating concepts, EWEA performed a comparison with jacket foundations as their technical characteristics allow for installation in water depths up to 45-50m. The task force came to the conclusion that for a 100MW wind farm, equipped with 5MW turbines and installed in 100m water depth, the

CAPEX for floating concepts is very similar to the CAPEX of farms using jacket or tripod foundations at 50m water depths. Similarly the cost of energy produced by the floating concepts would be competitive with the fixed-bottom foundations solution.

4.2. Non-technical challenges

- Stable and clear legislative framework: regulatory uncertainty is the main non-technological barrier threatening deep offshore wind market potential. Deep offshore wind development depends on numerous factors and crucially on stable and clear regulatory framework post 2020. Although Europe's seas and oceans offer enormous opportunities for innovation, sustainable growth and employment, their market promise will not be kept without a dynamic agenda in place at national and European level. Member States must not only take the means to reach their 2020 ambitions, but also commit to a 2030 renewable energy target. This target, combined with tailored and stable support schemes will create the necessary confidence for both industry and financial players to invest in innovative deep offshore wind farms.
- Spatial planning is a key element of the regulatory framework. The decision to perform maritime spatial planning (MSP) and dedicate zones for offshore wind development and electricity interconnectors, would send positive signals to the industry. Spatial planning not only provides stability and clarity for investors, it also helps bring down project costs through an optimum integration in the marine environment.
- High technology risks perception: deep offshore wind is at an early stage of development. There is a growing risk perception in line with the increasing scale and complexity of the projects and there is, therefore, a need for the deep offshore industry to focus its efforts on increasing technology reliability and minimise costs to move to commercialisation. This will contribute to reduce the risk perception of the finance community. Continuous R&D support is key to deep offshore development. This R&D support must not only facilitate technology development but also favour its demonstration, allowing developers and associated companies to test new technologies before commercial deployment. This will reduce development risks and capital costs and provide an opportunity to test reliability and capacity in real time and in a real environment.
- Lack of standardisation and cooperation: as a new sector, there are no specific standards adapted to the deep offshore concepts. Certification bodies have addressed the issue by blending offshore wind energy fixed-bottom and offshore oil and gas rig standards. However, this has resulted in unnecessary structure over-dimensioning and, thus, cost increases. New standards must be developed specific to floating systems. These are essential for the technology to reach commercial maturity. Currently such standards are being looked at by several certification bodies. Furthermore, cooperation between the different supply chain players is important. It is, therefore, necessary to adopt an integrated approach to the links between R&D community and the industry. This will help develop reliable, innovative and marketable concepts.

5. Recommendations

After assessing the challenges related to the development of the deep offshore wind sector, the Task Force members produced a non-exhaustive list of recommendations.

5.1. Technical Recommendations

- Modelling tools and numerical codes that simulate the whole structure's behaviour should be developed and validated to allow for an improved design.
- Wind turbine design and size must be optimised for use on floating support structures.
- There is a need to develop sufficient and appropriate control systems.
- More research must be carried out on mooring and anchoring systems with the industry benefiting from the experience gained in the offshore oil and gas sector.
- New measuring techniques and tools should be developed to assess wind and wave conditions at wind farm locations.
- More research is required in the field of wake and turbulence effects and how they impact the load and motions of the floating platforms. This can be achieved by deploying floating demonstration farms of around 4 or 5 units, rather than single unit prototypes.
- Ports must allow for increased throughput as well as provide enough space to accommodate installation and component storage.
- Self- transporting systems must be developed to minimise installation costs.
- Suitable training courses should be developed to remedy the shortage of skilled professionals.

5.2. Non-technical recommendations

- A clear and stable legislative framework post 2020 is necessary to drive deep offshore wind development and deployment.
- Licensing and permitting procedures should be simplified to minimise lead times and capacity of permitting bodies enhanced to handle the expected growth in deep offshore concepts.
- R&D support should be continued and increased to maintain European technology and market leadership in deep offshore concepts.
- Strong collaboration between the different players (and sometimes competitors) should be incentivised through new project partnerships. Exchange of experience, lessons learned and data is crucial and will prove beneficial to all stakeholders.
- The European Wind Initiative (EWI), with the network and R&D forum TP Wind, has proven a good platform to take the wind industry and mainly the deep offshore industry to the next stage. It should be continued and sufficient funding allocated to ensure its implementation.
- New standards specific to floating systems must be developed to help reach commercial maturity
- Access to financing should be ensured for deep offshore concepts with a right risk perception applied.

6. Conclusions

The deployment of the deep water offshore wind energy is on the starting blocks. The offshore wind industry is identifying and addressing the new challenges this poses. Different concepts are being developed and, in the coming years, significant steps towards their deployment will be taken, in order to tap the vast resource of the European seas.

Acknowledgements

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Appendix A. Overview of deep offshore concepts

Nr	Project name	Company	Type of floater	Prototype		Pre-Production / Serial		
				Turbine size (MW)	Year	Turbine size (MW)	Year	Origin
Grid connected systems								
1	Hywind	Statoil	Spar buoy	2.3 MW	2009-2012	3-7MW	2016	Norway
2	WindFloat	Principle Power	Semi - submersible	2MW	2011	5-7MW	2017	Portugal
Concepts under development								
1	Advanced Floating Turbine	Nautica Windpower	Buoyant tower and downwind turbine		2012	5MW	2014	US
2	Aero-generator X	Wind Power Ltd, Arup		10MW	2013			UK
3	Azimut	Consortium of Spanish Wind Energy Industry leaded by Gamesa	Generating the know-how required to develop a large-scale marine wind turbine	15MW			2020	Spain
4	Blue H TLP	Blue H	Submerged deepwater platform	2MW	2013	5MW	2015	Netherlands

5	DeepCWind Floating wind	Consortium: University of Maine, AEWC, Seawall, Maine Maritime Academy, Technip, NREL,MARIN, etc.	Design of one or more scale floating wind turbine platforms	Scale model in near shore waters	2013	5MW	2017	USA
6	Deepwind	EU project	Floating and rotating foundation plus vertical wind turbine	1kW	2012	5MW		Europe
7	DIWET Semisub	Pole Mer	Semi - submersible floater					France
8	EOLIA	Acciona Energy	SPAR, TLP and semisubmersible			5 MW		Spain
9	IDEOL	IDEOL	Concrete floater	5-6MW	2013	50 MW pre - series wind farm	2015	France
10	GICON TLP	GICON et.al.	Modular tension leg Platform	2MW	2013			Germany
11	Hexicon platform	Hexicon	floater			54MW wind and 15MW wave	2014-2015	Sweden
12	HiPRwind	EU project			2013		2016	Europe
13	Karmoy	Sway	Spar buoy	2.3MW	2013	2.5-5MW		Norway
14	Ocean Breeze	Xanthus Energy	Taught tethered buoyant					UK

15	Pelagic Power	W2power	Hybrid wind & wave energy conversion plant			2X3.6MW	2015	Norway
16	Pelastar	Glosten Associates	Tension leg turbine platform		2012			USA
17	Poseidon Floating power	Floating Power	Semi - submersible	6MW	2014			Denmark
18	Sea Twirl	Sea Twirl	Floating spar and vertical wind turbine					Sweden
19	Trifloater Semisub	Gusto	Semi - submersible			5MW		Netherlands
20	Vertiwind	Technip/Nenuphar	Semi - submersible	2MW	2013	2MW	2016	France
21	WindSea floater	Force technology NLI	semi-submersible vessel with 3 corner columns	3x1MW		3x3.6MW		Norway
22	Winflo	Nass and Wind/DCNS	Semi - submersible	1MW	2013	2.5MW	2016	France
23	ZÈFIR Test Station	Catalonia institute for Energy Research	The development of a new, highly complex technology for deep-water offshore wind turbines	20MW bottom fixed and 50MW (e.g 6-8) floating wind turbines	2013 bottom fixed, 2015-2016 floating	Test wind farm, not commercial	Test wind farm, not commercial	Spain

24	Haliade	Alstom	Floating substructure	6MW	n/a	6MW		France