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Trends of offshore wind projects

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A B S T R A C T

The aim of this paper is to present the current status of the offshore wind industry and to identify trends in Offshore Wind Projects (OWPs). This was accomplished via a thorough analysis of the key characteristics – commissioning country, installed capacity, number of turbines, water depth, project area, distance to shore, transmission technology and investment cost – of the commissioned and under construction European OWPs. Furthermore, the current status of the several countries outside of Europe was also investigated. The analysis revealed that the European offshore wind power grew on average 36.1% yearly since 2001. Currently, there are 7748 MW installed and 3198 MW under construction distributed among 76 OWPs situated in European waters. These projects are spread among ten countries, with the highest share of offshore projects belonging to the northern European countries. The UK has 46% of the total installed European offshore wind capacity with 26 projects, Germany ranks second with 16, while Denmark is third with 13 projects. These countries constitute 88% of the European offshore capacity. The analysis also showed that, although the installed capacity of the OWPs is growing, the projects' area is not increasing at the same pace due to the release of turbines with higher rated capacities which allow projects to increase their power nameplate without proportionally increasing the number of turbines. The average distance to shore and the water depth are both increasing throughout the years. Although the average investment cost per project is rising with the higher distances to shore and water depths, the multi-GW plans of the northern European and Asian countries indicate that the industry will continue to grow. The European Union targets of having 40 GW of offshore wind capacity deployed by 2020 in Europe and 150 GW by 2030 may represent plausible scenarios since the required growth is below the European.

Contents

Abbreviation: ASG, Asian supergrid; CAPEX, capital expenditure; CTL, cascaded two-level; EEZ, exclusive economic zone; EIA, environmental impact assessment; EU, European Union; EWEA, European wind energy association; FIT, feed-in tariff; HVac, high-voltage alternate current; HVdc, high-voltage direct current; MMC, modular multi-level converter; MTdc, multi-terminal direct current; MVac, medium-voltage alternate current; OWP, offshore wind project; O&M, operation & maintenance; OMA, office for metropolitan architecture; R&D, research & development; UXO, unexploded ordnance; UC, under construction

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1. Introduction

The global energy consumption is growing and it is expected to increase by 36% until 2035 [1]. In 2010, 81.1% of all the world primary energy use was obtained through fossil fuels: oil, coal and natural gas [2]. The use of fossil fuels has energy source that has several disadvantages: they are non-renewable at human time-scale, they increase the greenhouse effect through the release of CO_2 and they are not evenly spread throughout the world. Hence, countries with either small or no fossil resources should minimize their dependency. The solution is to either decrease the energy consumption or to alter the energy source to more sustainable, cleaner and renewable energy sources.

In 2007 the European Union (EU) targeted to generate 20% of its energy consumption through renewable sources and to improve 20% of its energy efficiency by 2020 compared to 1990 levels. Hence, it is predicted that 34% of electricity will need to be generated from renewable sources [3,4]. In the longer term, the EU has committed to reduce emissions by 80–95% when compared to 1990 levels by 2050 [5].

Renewable energy sources are anticipated to help Europe to meet these challenging targets. Specifically, the EU and the European Wind Energy Association (EWEA) expect that 40 GW of offshore wind will be installed in Europe by 2020 and 150 GW by 2030 [6]. In fact, the northern European countries have been investing in Offshore Wind Projects (OWPs) for more than two decades due to higher and steadier mean wind speeds and lower visual impact [7,8]. Fig. 1 shows that higher mean wind speeds are found offshore. The Irish and North seas have the most promising offshore wind resource of northern Europe, whereas the Aegean Sea and two areas located south of France and Spain are the most suitable areas for offshore wind deployment in southern Europe.

Although the general opinion is that there is plenty of free offshore space to install wind farms, there is more to the problem than meets the eye. Fig. 2 shows the Belgian Exclusive Economic Zone (EEZ), in the North Sea, which with an area of 3453 km^2 (nine times smaller than the Belgian land area) is the 9th smallest and one of the most exploited EEZs in the world [10,11]. The EEZ is the sea zone which stretches from the baselines from which the breadth of the territorial sea is measured to 200 nautical miles (approximately 370 km) towards the sea. Within the EEZ the state has sovereign rights for exploring, conserving and managing the natural resources of the waters and seabed. Furthermore, it has also exclusive right to construct, authorize and regulate the construction, operation and use of artificial islands and structures for economic exploitation and exploration of the zone, such as the production of energy from the water, currents and wind [12]. In 2005, the legal allocated offshore area represented 264% of the Belgian EEZ with a small fraction of 0.6% being appointed to offshore wind development [13]. The area of an OWP has to comply with several constraints which are both nature and human-based. The following criteria are important for the choice of a location (not in order of importance) [11]:

- Military operation or exercise zones.
- Piloting zones.
- Environmental protected areas.
- Lanes and harbor entrances.
- Oil & gas lease or concession areas.
- Minimum suitable available space.
- Minimum distance to the high voltage grid.
- Suitable wind resource.
- Distance to nearest port with sufficient capacity.
- Environmental impact.
- Seabed characteristics.
- Vessel traffic routes, separation and precautionary zones.
- Fishing areas.
- Extraction, dredging and dumping sites.
- Water depth.
- Pipelines (oil & gas) and cables (power & telecom) rights of way.
- Existing OWPs and wave park areas.
- Shipwrecks, UneXploded Ordnance (UXO) and other obstructions.
- No anchoring areas.
- Suitable export corridor area.

The northern European seas have good wind resource, as previously noted, and a seabed with relatively low water depths. These characteristics have allowed the northern European countries to make the initial offshore steps and to be leaders of the offshore wind industry nowadays. The initial offshore steps, as with any technology, were simple in order to minimize risk and to serve mostly as proof of concept [15–17]. Hence, the projects had few turbines (twelve on average) and were placed in shallow waters located up to 10 km from shore. The Capital Expenditure (CAPEX) was low (15M€ on average) and highly dependent on the number of turbines [15–17].

Since 1991, when Denmark erected Vindeby, the world's first OWP, the installed capacity of the offshore wind industry has grown on average 52% each year and, therefore, much has changed [15–17]. Since 2002, commercial projects are larger, with an average installed capacity of 154 MW. They are also more capital intensive (costing on average 487M€) due mainly to the larger seabed areas, distance to shore, water depth and number of