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Review

Environmental and social footprint of offshore wind energy. Comparison with onshore counterpart

J.K. Kaldellis [a,*], D. Apostolou [a], M. Kapsali [a], E. Kondili [b]

[a] Lab of Soft Energy Applications & Environmental Protection, Piraeus University of Applied Science (PUAS), Greece
[b] Optimisation of Production Systems Laboratory (PUAS), P.O. Box 41046, Athens 12201, Greece

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A B S T R A C T

Offshore wind power comprises a relatively new challenge for the international wind industry with a demonstration history of around twenty years and a ten-year commercial history for large, utility-scale projects. By comparison to other forms of electric power generation, offshore wind energy is generally considered to have relatively benign effects on the marine environment. However, offshore projects include platforms, turbines, cables, substations, grids, interconnection and shipping, dredging and associated construction activity. The Operation & Maintenance (O&M) activities include the transport of employees by vessel or helicopter and occasional hardware retrofits. Therefore, various impacts are incurred in the construction, operation and decommissioning phases; mainly the underwater noise and the impacts on the fauna. Based on the fact that in many of the aforementioned issues there are still serious environmental uncertainties, contradictive views and emerging research, the present work intents to provide a thorough literature review on the environmental and social impacts of offshore wind energy projects in comparison with the onshore counterparts.

Contents

1. Introduction

During the last twenty years, many countries all over the globe have invested in wind power technology in view of achieving future carbon emissions reduction and renewable energy targets. In the 90s', there were no more than 15 GW of wind power installed

* Corresponding author.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).

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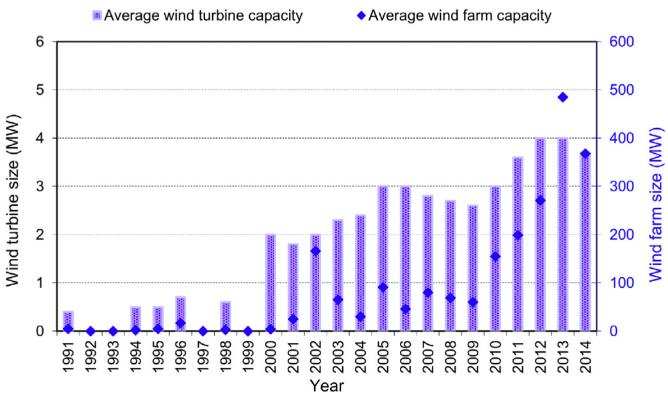

Fig. 1. Average size evolution of existing offshore wind farms and wind turbines in Europe. Based on data from Ref. [3].

across the world. By the end of 2014, cumulative installations increased more than 24 times, reaching 370 GW. Apparently, wind energy has established its role as a mainstream power generation technology able to meet a substantial share (i.e. approx. 3%) of the world's electricity demand. However, onshore wind turbines are associated with some minor but commonly accepted negative environmental implications (such as visual and noise impacts, impacts on birdlife and other types of impacts on the ecological environment) [1]. This condition decelerates future development of new installations and makes difficult for energy planners to localize suitable sites.

Thus, during the last decade, the point of interest in wind energy -mainly in Europe-has moved from onshore to offshore locations, taking also advantage of the higher and steadier wind speeds met in the open sea, even exceeding 10 m/s at heights of 50 m. In fact, compared to the onshore counterpart, offshore wind energy has greater resource potential, which generally increases with distance from the shore and thus resulting in considerably higher energy yield [2]. On the other hand, operation of wind turbines at sea poses a different design than that of onshore machines with quite different requirements to take into account. In 2013, the average turbine size remained similar to 2012 at 4 MW, while the average wind farm capacity reached 485 MW (78% increase from previous year) [3]. However, it is appropriate to mention that in 2014 the average turbine capacity was decreased to 3.7 MW (7.5% less than 2013) due to the increased share of installations of the Siemens 3.6 MW wind turbine. Additionally, the wind farm capacity was also reduced to 368 MW (24.1% lower than the previous year) because of the 2013 completion of the record breaking London Array [3] (Fig. 1). Despite this trend, it is a fact that offshore projects include many kilometers of underground cables and on-site substations, while wind turbines are placed on substructures that extend to the bottom of the sea or further out through the use of floating platforms. Hence, compared with land-based wind power projects, the construction of offshore wind farms requires higher accuracy and use of materials that resist the corrosive marine environment. Moreover, installation of an offshore project comprises a more difficult and more expensive task than onshore, concerning also the accessibility for maintenance purposes, by using special vessels or helicopters.

All the above issues are extensively analyzed in this work. More precisely, the present study aims at delivering a detailed review of the offshore wind development impacts through the presentation of the key findings and current state-of-knowledge of existing peer-reviewed literature on basic documented environmental and social parameters. Additionally, a comparison with onshore counterparts in common areas is also attempted in order to provide a more comprehensive view of the subject. In this context, the second section gives a brief analysis of the current state of the art of offshore wind power projects. This is followed by a detailed study of the offshore installations' impacts along with a research on the main mitigation measures based on the international literature data.

2. State of the art of the offshore wind power technology and implementation

Offshore wind power comprises a relatively new challenge for the international wind industry with global offshore wind power installations currently reaching 8.76 GW (see Fig. 2). This capacity comprises at the moment only 2.4% of the global wind power installations. Europe is by far the world leader in the offshore wind power market, with installed capacity of almost 8.1 GW (92.5% of total) which corresponds in 29.6 TWh annual electricity in a normal wind speed year [3,4]. Fourteen countries across the world have offshore wind power capacity. With almost 0.66 GW, China is the fifth biggest market behind the UK (4.49 GW), Denmark (1.27 GW), Germany (1.05 GW) and Belgium (0.71 GW). Japan (50 MW) is still only beginning to exploit its offshore potential and is the eighth biggest market, still significantly behind the top seven [5].

As far as the technology employed, the design of offshore wind power projects has been based considerably on the long-term experience gained from onshore wind farms and from the oil and gas industry. Commercial wind turbines used in offshore installations comprise adaptations from land-based counterparts and currently have capacity ratings up to 6 MW [3]. However, the harsh marine conditions (weather, winds, waves, water currents) have posed considerable challenges to project developments which require different approach in terms of wind turbine technology, support structures, electrical infrastructure and logistics for installation and maintenance.

Offshore installations have been predominantly limited to fixed-bottom support structures such as monopiles and gravity-based foundations (Fig. 3) installed in shallow water depths (Fig. 4). In fact, 2920 substructures in total have been installed in Europe by the end of 2014. The most common ones are the monopiles, comprising 78.8% of all installed foundations. Gravity-based foundations are the second most common with 303 units installed (10.4%), followed by jackets (4.7%), tripods (4.1%), tripiles (1.9%) and floating substructures (0.1%) [3] (Fig. 3).

Although most projects are at the moment located in distances less than 35 km from shores, the idea of going deeper in order to exploit the higher and steadier wind speeds found in open sea is gradually moving closer towards implementation. At the end of 2014, the average water depth of wind farms was 22.4 m and the average distance to shore 33 km (see Fig. 4). Looking at projects under construction, consented or planned (only in Europe this amount corresponds to a further 2.9 GW of capacity installed up to the year of 2016), it is clear that average water depths and distances to shore are likely to increase, with projects announced up to 200 km from shore and in water depths of up to 215 m [3].

One of the main advantages of offshore wind power installations is that wind turbines may have the ability to demonstrate quite higher capacity factors than onshore counterparts, typically ranging between 20 and 40% [2]. Offshore wind power follows the following simple principle: The further the distance from the shore is, the greater the wind speed values, resulting in higher energy production. In contrast, further distance from shore suggests greater water depths, which in turn increase the development and operation costs of such projects. Thus, the net gains due to the higher offshore energy production are counterbalanced by the

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