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Co-located wave-wind farms: Economic assessment as a function of layout

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ABSTRACT

Marine energies have a significant potential as an alternative to fossil fuels. However, the current high cost of the technology or the intermittency of the resources are often cited as a barrier to their large-scale development. The combined harnessing of different ocean resources in the same area can contribute to overcoming these issues. This work deals, in particular, with co-located wind and wave farms. With a currently operational wind farm as a reference, different co-located layouts are proposed and their impact on the Levelised Cost of Energy (*LCOE*) is analysed. A third-generation spectral wave model (SWAN) and real wave climate data are used. First, the combined use of the resource is characterised – energy yield per unit area, smoothing of power output, average power output and its seasonal variability. Second, a number of co-located layouts and the baseline (wind only) farm are compared in economic terms. Finally, conclusions are drawn on the potential cost reductions in co-located farms. We find that the energy cost is reduced by more than 50% relative to stand-alone wave farms. These results confirm the interest of combining wave and wind energy through co-located farms for the purpose of enhancing the economic viability of wave energy.

1. Introduction

In recent years with the depletion of fossil fuels and the environmental degradation, marine energy deployment has been accelerating due to its potential to supply energy, support energy security goals and contribute to less carbon-intensive energy production [1,2]. Notwithstanding these clear benefits, the initial stage of development of marine energy leads to high capital costs. Moreover, being installations located in the hard marine environment, the Operation and Maintenance (O&M) tasks required are greater than for installations on land [3]. This fact, together with other characteristics inherent to renewables, such as their intermittency [4,5], may hamper the large scale integration of marine energy into the grid.

At this point, the idea of taking advantage of different ocean renewable resources in the same offshore installation is gaining importance [6–9] as a way to achieve a better use of the marine resource [10,11] and make these renewables cost-competitive [12]. In this paper, the synergies between wind and wave energy [13–15] are analysed. On the one hand, offshore wind energy farms have been deployed within the last few years due to the fact that wind is more powerful and uniform in time and space on the sea than on land, and that the sea offers large open spaces for the installation of these plants [16–18]. On the other hand, wave energy technology [19–23] is less developed than offshore wind energy, but the enormous resource available makes it a promising renewable [24–29]. Wave production might compensate for the intermittency of offshore wind, while economies of scale developed from offshore wind could accelerate the cost reduction for the wave component. Moreover a reduced capital cost per MW installed may be achieved because of common elements like the electrical installation. In the same way, cost savings in maintenance tasks are expected due to sharing strategies and other factors such as the shielding effect of WECs [30–34] over the offshore wind farm [13,35–37], which increase the weather windows for O&M [38,39].

Therefore the aim of this paper is to analyse the above through a proposed co-located wind-wave farm at an operating wind farm – Alpha Ventus. This article is structured in four steps. First, the baseline scenario and the proposed co-located layouts are defined, and the numerical model is validated. Second, the use of the resource is characterised, with a focus on its availability and

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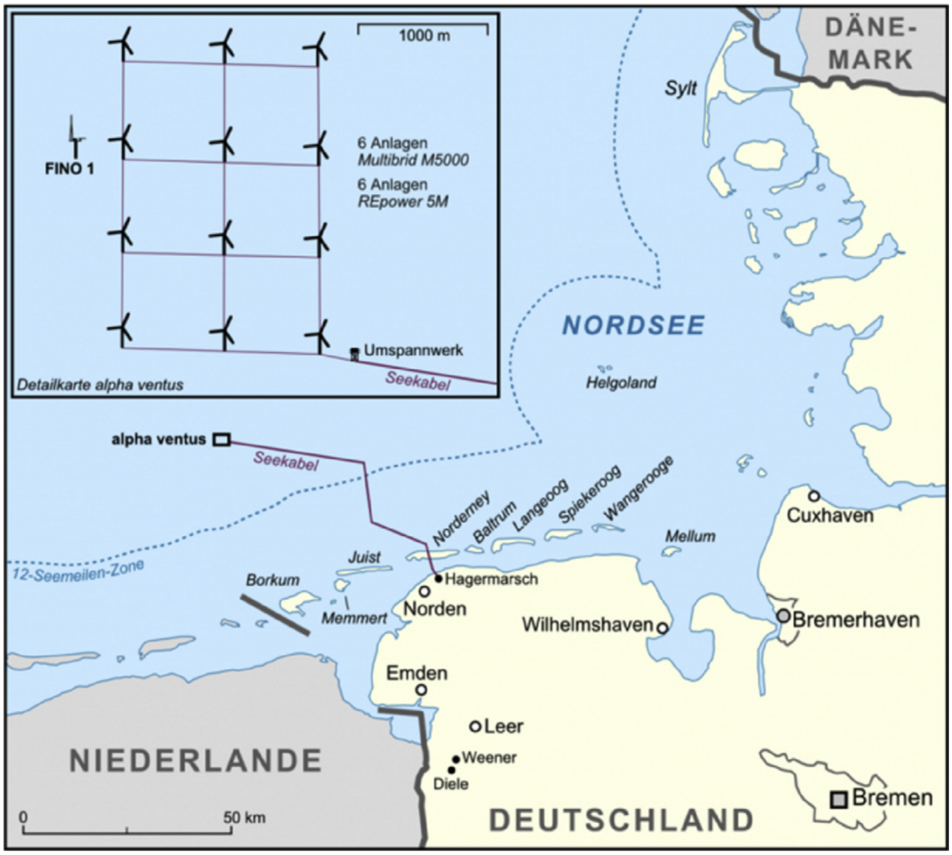

Fig. 1. Alpha Ventus location [42].

intermittency. Third, an economic assessment is carried out considering common elements and strategies. Finally, conclusions are drawn, in particular regarding the energy cost.

2. Materials and methods

2.1. Case study

In this paper, a co-located wind-wave farm [40] is proposed for the Alpha Ventus wind farm (Fig. 1), which is located about 45 km north of the island of Borkum (Germany), at an approx. water depth of 30 m [41]. This wind farm is composed by 12 wind turbines: 6 AREVA turbines with a tripod substructure and 6 Repower 5 M turbines with a jacket-frame substructure – with a spacing between turbines of around 800 m [41,42], covering an area of 4 km^2. In this study annual sea conditions (Table 1), from January to December 2013, were simulated considering the full scatter diagram. The data series was provided by FINO1 research platform (Fig. 1), located 400 m away from the farm [42]. The mean values of the significant wave height (H_s), mean wave period (T_{m01}) and predominant wave direction were 1.5 m, 5.4 s and 330° respectively. As for the wind, the most frequent wind speed at 10 m was 10 m/s, with a frequency of occurrence of 25% according to the Weibull distribution and 210–240° as the most frequent direction.

As for the co-located farm, four layouts (Table 2, Fig. 2) were proposed in this paper on the basis of previous studies [43–45]. In all cases, the Wave Energy Converter (WEC) considered was WaveCat [46,47], a floating offshore WEC whose principle of operation is wave overtopping. The wave transmission coefficient was based on the tests carried out with a model at 1:30 scale to determine the wave field-WEC interaction [47]. The nominal power at 1:1 scale is expected to be 1.2 MW [48]. The spacing between devices was 198 m, which corresponds with the minimum spacing allowed −2.2D, where $D = 90$ m is the distance between the twin bows of a single WaveCat [46].

2.2. Wave propagation model

The co-located wind-wave farms proposed were simulated using a third-generation numerical wave model: SWAN (Simulating WAves Nearshore), which was successfully used in previous works [38,39,45]. The model was implemented in using two levels of computational grids: (i) a coarse grid from offshore to the coast, encompassing an area of approx. 40 km × 30 km with a resolution of 100 m × 100 m; and (ii) a fine (nested) grid focused on the Alpha Ventus site, covering an area of 8.5 km × 8.5 km with a resolution of 17 m × 17 m (Fig. 3). The bathymetric data from Germany's Bundesamt fuer Seeschifffahrt und Hydrographie (BSH) were interpolated onto this grid.

Both the wind turbines and WECs were implemented in SWAN as individual obstacles characterised by a transmission coefficient with values ranging from 0% (i.e., 100% of incident wave energy absorbed) to 100% [49–52]. Diffraction and reflection are significant processes when the ratio between the pile diameter (D) and the wavelength (L) is higher than 0.2 [53]. In this case, D/L is less than 0.1, so reflection and diffraction are negligible. In the case of the wind turbines, the transmission coefficient can be calculated by Eqs. (1) and (2) [54]. As for the WECs, the wave transmission coefficient was based on the results of laboratory tests carried out to determine the wave field-WEC interaction [47].