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Review

Emissions from corrosion protection systems of offshore wind farms: Evaluation of the potential impact on the marine environment

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ABSTRACT

Offshore wind energy is a fast growing sector of renewable energies worldwide. This will change the marine environment and thus, a wide range of environmental impacts of offshore wind farms are subject of current research. Here we present an overview about chemical emissions from corrosion protection systems, discuss their relevance and potential impact to the marine environment, and suggest strategies to reduce their emissions. Corrosion is a general problem for offshore infrastructures and corrosion protection systems are necessary to maintain the structural integrity. These systems are often in direct contact with seawater and have different potentials for emissions, e.g. galvanic anodes emitting substantial amounts of metals. Organic coatings may release organic substances due to weathering and/or leaching. Current assumptions suggesting a low environmental impact, but monitoring data is not sufficient to assess the environmental impact of this new source.

1. Introduction

1.1. Political background and current situation of offshore wind energy in Europe and Germany

The goal of the Paris Agreement to limit the temperature increase well below 2 °C was negotiated at the meeting of the United Nations Framework Convention on Climate Change (COP21, Paris 2015). In order to achieve this goal, the global greenhouse gas emissions have to be decreased significantly in the next decades. The reduction of greenhouse gas emissions by the increase of the use of renewable energy is one of the key strategies to mitigate global warming. The European Union renewable energy directive has the target to reach a contribution of at least 20% of renewable energy to the total energy consumption in 2020 and 27% in 2030 (European Commission, 2016a). This directive was transformed in national specific energy targets which range from 10% of renewable energy for Malta to 49% for Sweden. The climate action plan of the Federal Government of Germany aims to reduce the emissions of greenhouse gases by 40% until 2020 and by 80% to 95% in 2050, compared to emissions in 1990 (BMUB, 2016; 2014). The increase of renewable energy production and energy efficiency along with the reduction of energy consumption are the key elements used to reach this ambiguous goal. In 2017, the contribution of renewable energy to the gross electricity consumption in Germany was 36.2%. Offshore wind energy contributed only 8.2% to the total produced renewable energy, due to the fact that most of the offshore wind farms (OWF) were still under construction or not connected. Onshore wind energy is currently the leading renewable energy source in Germany with a contribution of 40.7% to total renewable energy production, followed by solar energy (18.3%) and biogas/biomethane (14.3%) (AGEE-Stat, 2018). For 2025, Germany aims to reach a contribution of renewable energy of around 40–45% to the total energy production and offshore wind energy is one important technology to reach this goal. Germany plans to achieve an offshore wind energy capacity of 15 GW by 2030 (Offshore Wind Energy Act, 2017).

On a European scale in total 15.8 GW capacity are installed offshore in 2017, which corresponds to 4149 grid-connected offshore wind turbines (OWT) (WindEurope, 2018) and an increase is expected for the next decades (Fig. 1). Based on the number of grid-connected wind turbines, United Kingdom (1753 turbines) is currently in the lead, followed by Germany, Denmark and the Netherlands. The major part of the OWF is located in the North Sea (72%). If compared to the current status of the offshore gas and oil industry (1350 facilities), a significantly higher number of offshore constructions in relation with wind

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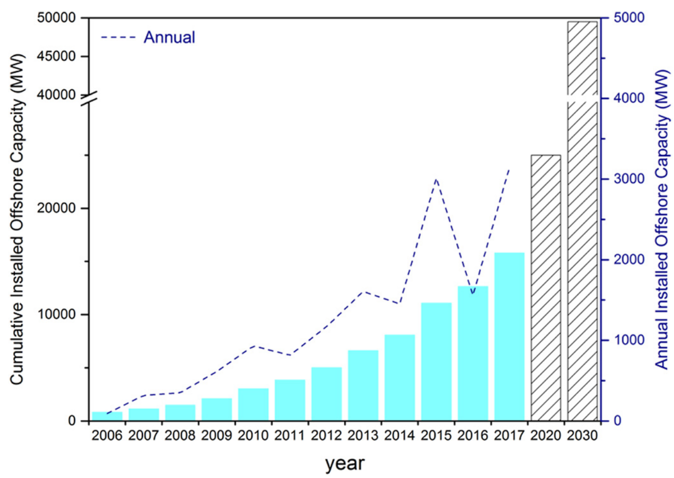

Fig. 1. European Offshore wind energy development 2006–2017. Dashed line: annual installed offshore capacity in Europe. Cyan blue bars: cumulative European offshore capacity. Striped bars: expected future capacity for 2020 and 2030. Based on the low scenario of the European Wind Energy Association (WindEurope, 2018). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

energy production can be expected in the future and will significantly increase the total number of offshore facilities in the OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) region and worldwide (OSPAR Commission, 2015). This demonstrates the dimension of offshore wind energy development, especially in the North Sea region (see Fig. 2). In 2017, 7.5 bn € (18.2 bn € in 2016) were invested for offshore projects in Europe (WindEurope, 2018). Also offshore wind energy is globally increasing. China reached already 2.8 GW in 2017 when the total global offshore wind energy capacity was 18.8 GW, demonstrating that Europe is currently leading in offshore wind energy (GWEC, 2018). This might change in the future, because several other countries are planning offshore wind projects (e.g. only the USA offshore wind project development pipeline includes 24.1 GW of potential installed capacity (Musial et al., 2016); and China wants to reach 30 GW by 2020 (Hong and Möller, 2012), which will increase the number of offshore wind farms rapidly (Poudineh et al., 2017).

In 2010, the first German offshore wind farm "Alpha Ventus" (54° 0′ 30″ N, 6° 35′ 54″ E) started its operation. Currently (as of 6/2018) already 17 wind farms are installed in the German North and Baltic Seas; six are currently under construction. The majority of these windfarms are situated beyond the German territorial waters in Germany's exclusive economic zone (EEZ) in the North Sea. In total, 1138 OWT are already installed or under construction in the North Sea and 232 OWT in the Baltic Sea representing a total power of 4695 MW and 692 MW of the installed OWT, respectively. To achieve an effective energy conversion and transmission to the mainland via subsea-cables, further offshore facilities are consequently constructed. Thus, 23 offshore substations (OSS) and 8 converter platforms (HVDC stations) are installed or under construction in German marine waters.

1.2. Offshore wind energy

The major advantage of offshore wind energy compared to onshore wind energy is the increased availability of the resource "wind". Although offshore wind is cost intensive in planning, design, construction, operation and maintenance, compared to onshore, it is economically very attractive. Higher speed and continuous wind allows a high percentage of full-load hours. Furthermore less wind turbulences in the offshore areas may increase the lifetime of wind turbines (Bilgili et al., 2011; Esteban et al., 2011). The offshore and onshore wind turbine capacity is still comparable, but future developments will allow

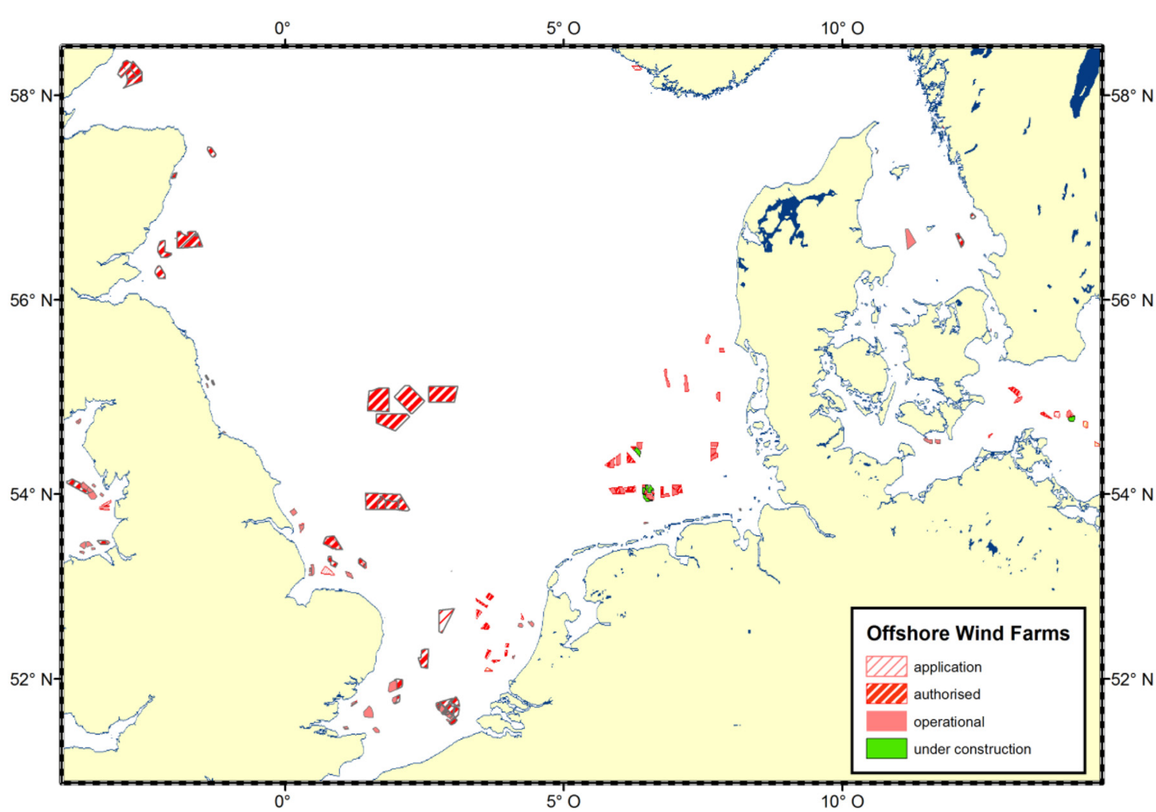

Fig. 2. Overview of Offshore Wind Farms in the North and Western Baltic Sea. Modified map based on data from OSPAR (https://odims.ospar.org, latest Data 2016) and BSH (https://www.geoseaportal.de, latest data 2018).