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# Offshore Wind Energy Analysis of Cyclone Xaver over North Europe

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**Abstract**

Cyclone Xaver (5 December 2013; North Sea) was an extreme weather event which affected northern Europe, yielding a record of wind power generation. The most striking aspects of this atmospheric phenomenon were the gale-force winds and the upcoming abrupt increase of the wind power over the North Sea. The main objective of the study is the analysis of the impact of Xaver on offshore wind power production. In this way, the WRF numerical model was used to simulate the cyclone in a fine horizontal resolution (5km x 5km). The focus of the simulation is on the extended region of the North Sea and the Baltic Sea. The evaluation of the model outputs against observational data from 3 offshore locations denotes a sufficient agreement (SI$\approx$0.12) and supports a realistic analysis of the wind field. The simulation exposed much higher values for wind speed over the North Sea compared to the neighboring regions during the passage of the cyclone. The wind speed at the 100 m level ranged within 11-25 m/s (rated output wind speed) for 40 hours over the North Sea and 70 hours over the Baltic Sea. On the other hand, the wind speed at 100 m exceeded 25 m/s (cut out wind speed) for ca 30 hours over the North Sea. In addition, comparison of wind power density between two different height levels (100 m and 200 m) is presented. The model results indicate 15% to 20% higher wind power density at 200 m than for 100 m for the largest part of the North Sea. For some regions the difference exceeds 25%.
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## 1. Introduction

On 4 December, 2013 a cyclonic system was generated southeasterly of Greenland. During its formation, the upper air conditions intensified the cyclonic circulation and the system progressed southeasterly. The cyclone known as Xaver by Free University of Berlin [1] (also known as Bodil [2], [3] by Danish Meteorological Institute and Sven [4] by Swedish Meteorological and Hydrological Institute) was continuously deepening during its movement towards Scandinavian Peninsula. In total, Xaver influenced an extensive region of North Europe, moving gradually from southeastern Greenland to the Baltic Sea, passing over the north shore of United Kingdom, the North Sea and Scandinavia. It was a remarkable phenomenon as it was accompanied by gale-force winds over North Sea and low values of mean sea level pressure in the center.

The impact of the strong winds was substantial mainly for the coastal areas of North Europe. The intensity of the wind field had a major impact in the energy industry. The wind resources affected the safety and performance of the grid [5]. Thousands of households encountered electricity problems [6], whereas in Germany onshore and offshore wind turbines set wind energy production records higher than 26000 MW [7] causing decrease of power spot prices lower than 25 €/MWh [8]. Moreover, in Denmark the shutdown of the wind turbines due to extreme wind speeds together with high electricity consumption led to a significant increase in the power spot prices up to 580 DKK/MWh [5].

This study aims to investigate the impact of offshore wind energy of Cyclone Xaver over the North Sea and the Baltic Sea. Additionally, the ability of a numerical model to simulate the event with respect to this aspect is tested. Weather Research & Forecasting (WRF) model has been used in the past for offshore wind energy applications with satisfying results for wind climatology [9] [10] [11] [12]. These evaluation studies have been focused mainly on average wind speed. Here we will extend the model evaluation to extreme wind conditions. Thus, the WRF numerical model was utilized for the simulation of Xaver and for a better representation of the physical and dynamical conditions which supported the development and determined the track of the system. The time period under study expands from 4 December, 2013 00:00 UTC to 7 December, 2013 12:00 UTC. The focus is on the extended region of the Baltic Sea and the North Sea, home of the largest operational offshore wind farms in the world [13].

## 2. Theoretical Background

### *2.1. Wind Power Density*

The wind power density (WPD), measured in W/m$^2$, is estimated for the investigation of the event [14]. It is used as an indication of the wind energy available for conversion by wind turbines during the cyclone's passage. It is a function of the air density (ρ) and the third power of the wind speed (U).

$$WPD = \frac{1}{2}\rho U^3 \tag{1}$$

Offshore areas of North Europe such as the North Sea and the Baltic Sea show high WPD values. The annual mean value for WPD at these areas is higher than 650 W/m$^2$ at 100 m and 900 W/m$^2$ at 200 m [15].

### *2.2. Wind Turbines and Wind Speed*

A wind turbine starts to rotate its blades and generate power for wind speed usually greater than 3 m/s, known as cut-in wind speed. As the wind speed increases, the level of generated power raises until reaches the turbine generation limit. The wind speed at which this limit is reached, called the rated output wind speed and it is typically at 11-12 m/s [16] [17]. Wind turbines tend to perform to their utmost capacity regarding wind power generation at the 11-25 m/s range. The 25 m/s threshold is typically the cut out wind speed and it is defined as the speed at which the wind turbines stop rotating to avoid damage [18].

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