Mitigation of large-scale wind farm wake effects

C2-Wakes: Investigation of approaches for controlling and mitigating large-scale wind farm effects by the means of numerical simulations

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In Short

- The capacity of offshore wind turbines installed in German offshore waters shall increase from 8.1 GW in 2022 to 70 GW in 2045.
- The predecessor project X-Wakes investigated the large-scale effects of wind farm clusters in the German Bight.
- This project aims at developing methods for the control and mitigation of these large-scale effects.
- The impact of the wind farm layout, wind turbine technology, wind turbine hub height as well as of wind farm control and novel wind farm operation strategies on the large-scale effects will be tested.
- Thus, the project aims at contributing to an optimized utilization of wind energy resources in the German offshore waters with its limited size.

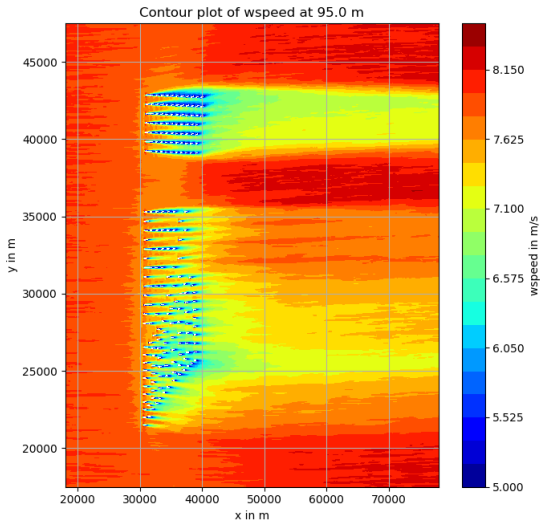

Figure 1: *Exemplary result for the field of the wind speed in the region of the wind farm cluster N4 in the German Bight from large-eddy simulations for a situation with strong wake effects. Downstream of the wind farm the wind speed is reduced over several tens of kilometers.*

As of December 31, 2022, 1,539 offshore wind turbines with a total capacity of 8.1 GW were in operation in Germany 1. By adding an amendment to the Act on the Development and Promotion of Wind Energy at Sea, the German government has significantly increased the expansion targets for offshore wind energy in German waters. With 30 GW of installed capacity in 2030 and 70 GW by 2045, significantly increased expansion targets must be achieved 2. The areas available for the expansion of wind energy utilization in German waters are however limited. Improved modelling of the interaction between adjacent wind farms is necessary to determine the wind conditions in German offshore waters with a high accuracy. Optimization of wind farm topology, control and operation is required to reduce wake effects of adjacent wind farms and guarantee a highly efficient extraction of energy from the wind.

The modelling of large-scale wind farm effects has been identified as one of the Grand Challenges of wind energy research 3. National German research projects related to this topic include, in particular, the previous projects GW-Wakes, WIPAFF and X-Wakes that have been funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). These projects primarily focused on improving our understanding of large-scale wind farm effects such as wind farm wakes and the global blockage effect. The wind farm wake is a region downstream of a wind farm that is characterized by a reduced wind speed and an increased turbulence intensity compared with conditions upstream of the cluster. Figure 1 and figure 2 show examples of the wake effect for the wind farm cluster N4 situated north-west of the island of Heligoland in results of large-eddy simulations done by members of the team of this NHR project in the predecessor project X-Wakes by simulations on the HPC clusters of the HLRN. Depending on the atmospheric conditions wind farms situated downstream of other wind farms can be affected by these wake effects and produce less power than they would produce if they were in the undisturbed flow. The global blockage effect is a deceleration of the flow when it approaches a wind farm. The global blockage effect is roughly an order of magnitude smaller than the wake effect.
An investigation of how these large-scale wind farm effects can be reduced by optimizing the design and the control of wind farms in German offshore waters is now the next step of research. In the joint

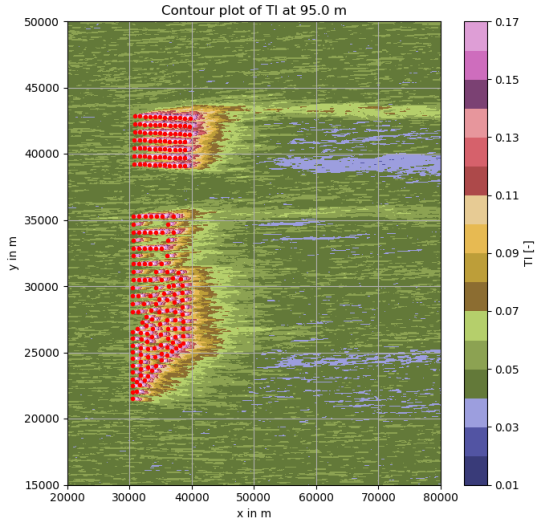

Figure 2: *Exemplary result for the field of the turbulence intensity in the region of the wind farm cluster N4 in the German Bight from large-eddy simulations for a situation with strong wake effects. In the wake region the turbulence intensity field shows a clear asymmetry.*

BMWK-funded project C2-Wakes various technical and methodological issues that will help to understand how large-scale wind farm effects can be influenced will be addressed by the means of atmospheric measurements and numerical simulations. One of the work packages of the project C2-Wakes will deal with the investigation of how the wind farm layout influences the large-scale wake effects of wind farms. The focus of another work package will be on the impact of the turbine technology and distribution of hub heights used in a wind farm on the large-scale wind farm effects. How the application of wind farm control and novel approaches for the operation of a wind farm changes these large-scale effects is part of a separate work package.
In this NHR project the different mitigation strategies will at first be investigated by the means of large-eddy simulations for single wind farm clusters and pair of wind farm clusters for single situations. Data from atmospheric measurements in C2-Wakes will be used to validate the large-eddy simulations. The impact of an application of the mitigation strategies developed in the framework of the project on the spatial scale of the whole German Bight and for a longer time period as required for site assessment will be done with the means of mesoscale simulations.
The data from the numerical studies will be used to improve the computationally much faster wind farm flow models that are used by the wind energy industry and authorities for planning wind farms, e.g. by implementing the mitigation strategies developed into them. A separate work package will focus especially on a better representation of the global blockage effect in this type of model. Overall, the project aims at contributing to an optimized planning and highest efficiency of large-scale wind farms and wind farm clusters to be built until 2045 in the German Bight.

WWW

https://uol.de/we-sys

More Information

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[3] P. Veers et al., Grand challenges in the science of wind energy, *Science*, **6464** (2019)

Project Partners

Fraunhofer IWES

Funding

BMWK

DFG Subject Area

313-01