Wind Energy Institute
Prof. Dr. **Carlo L. Bottasso**

Technische Universität München

Semester thesis / Research internship proposal

Forecasting extreme weather events for wind energy applications using data-driven approaches

Supervision:
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Background and motivation

Accurate wind power forecasting is becoming increasingly important as power systems integrate larger shares of renewable energy. While substantial progress has been made in forecasting normal operating conditions [1-3], extreme weather events remain a major challenge. Events such as severe storms, extreme wind gusts, icing conditions, hail, and heavy precipitation can have significant impact on wind turbine operation and power production. In some cases, turbines may be curtailed or shut down entirely, leading to substantial forecast errors and potentially affecting grid stability.

Scope

The objective of this thesis is to investigate the prediction of extreme weather events relevant to wind farm operation and assess how such predictions can be integrated into wind power forecasting applications. Emphasis will be placed on forecasting horizons that are relevant for electricity market participation, including day-ahead (12-48 hours) and intraday (1-12 hours) decision-making. Specifically, the thesis will address the following research question:

How can extreme weather events that affect wind farm power production be predicted at day-ahead and intraday horizons, and how can such predictions be incorporated into operational forecasting workflows?

Addressing this question requires identifying the weather phenomena with the largest impact on wind power production, assessing the capabilities of existing forecasting approaches, and evaluating the potential of modern weather prediction models for site-specific forecasting of such events. The ultimate goal is to determine how these forecasts can improve wind power predictions and support informed bidding decisions in day-ahead and intraday electricity markets.

The project will involve a combination of literature review, data analysis, and practical model assessment and implementation.

The student is expected to perform the following tasks:

- Identify extreme weather events relevant to wind farm operation through a review of the scientific literature. Potential events include storms, extreme wind speeds, wind gusts,

heavy precipitation, hail, icing, and other weather phenomena that may lead to turbine shutdowns or abnormal operation.

- Review state-of-the-art forecasting approaches, including Numerical Weather Prediction (NWP), Machine Learning Weather Prediction (MLWP), and methods for forecasting severe weather events. Particular attention will be given to recent MLWP models such as GraphCast [4], FourCastNet [5], and related approaches.
- Investigate whether existing forecasting systems can provide useful information on extreme weather events at wind farm locations and assess their potential impact on wind power forecasting accuracy.
- Depending on the scope of the thesis or research internship, either evaluate existing forecasting models for a selected application or develop a dedicated model for predicting weather events relevant to wind energy applications.

Profile

We are looking for a motivated student with an interest in wind energy, weather forecasting, machine learning, and data analysis.

Required

- Background in engineering, physics, mathematics, computer science, or a related field
- Basic understanding of wind energy technology
- Knowledge of machine learning concepts
- Interest in data analysis
- Basic programming skills in Python
- Ability to work independently and communicate well

Beneficial

- Experience with Python scientific libraries (NumPy, Pandas, Scikit-learn, TensorFlow/Keras or PyTorch)
- Familiarity with weather or climate data
- Background in renewable energy systems or wind energy

Start date

Flexible. The project can start immediately, with January 2027 being the preferred starting date.

If you are interested in this topic and meet the required profile, please send an email to antonina.vukobrat@tum.de including a brief statement of motivation, your CV, and a current grade transcript. We will then arrange a meeting to discuss the project and answer any questions.

References

[1] Ally, S., Verstraeten, T., Daems, P.-J., Nowé, A., and Helsen, J.: Modular deep learning approach for wind farm power forecasting and wake loss prediction, *Wind Energ. Sci.*, 10, 779–812, https://doi.org/10.5194/wes-10-779-2025, 2025.
[2] Braunbehrens, R., Strecker, K., Anand, A., Felder, M., Petzschmann, J., and Bottasso, C. L.: Site-specific production forecast through data-driven and engineering models, *Journal of Physics: Conference Series,* **2767,** 092054, 2024.
[3] Mian, H. H., Rognskog Nordbak, B. E., Skoglund, E., Asim, T., Yang, L., and Siddiqui, M. S.: Extracting Data-Driven Insights from LiDAR and SCADA Data for Improved Analysis of Offshore Wind Farms, *Journal of Physics: Conference Series,* **3131,** 012031, 2025.
[4] Lam *et al.* Learning skillful medium-range global weather forecasting, *Science*, **382**(6677), 1416-1421, https://doi.org/10.1126/science.adi2336, 2023.
[5] Pathak *et al.* FourCastNet: A Global Data-driven High-resolution Weather Model using Adaptive Fourier Neural Operators, https://arxiv.org/abs/2202.11214v1