

Interpretable Machine Learning for Load Prediction

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Outline

1. Background on the use of machine learning to model loads
2. Trade-off between prediction accuracy and interpretability
3. Methodology for model interpretation: Shapley values
4. Case study and implementation of proposed methodology
5. Opportunities for research and industry



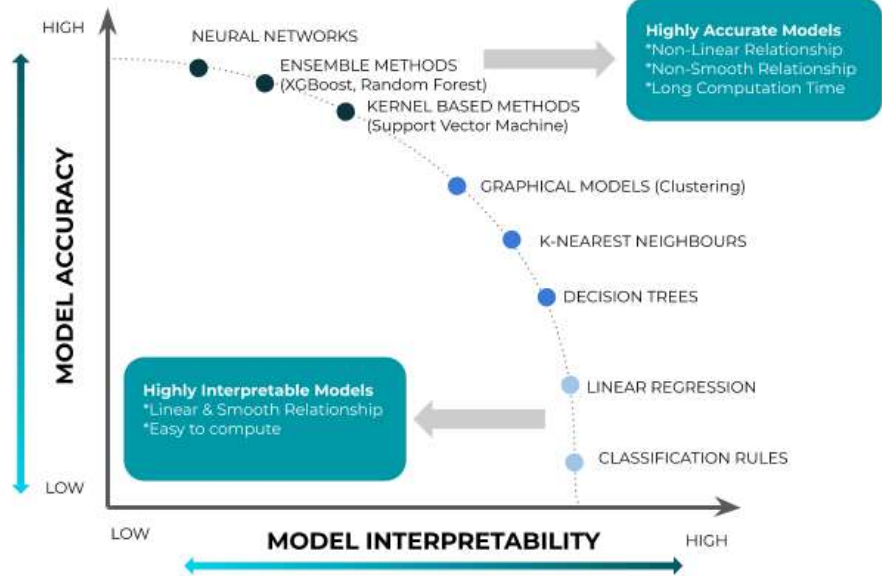
Background

- 38 publications found in SCOPUS with the search query:
 - "Monitoring" AND "Wind turbine" AND "Loads" AND "fatigue life"
- 7 publications include machine learning techniques for modelling
 - "Monitoring" AND "Wind turbine" AND "Loads" AND "fatigue life" AND ("Neural Networks" OR "deep learning" OR "Machine learning")
- Most papers using machine learning techniques were published in the last ten years
- Lack of interpretability

Accuracy vs. interpretability

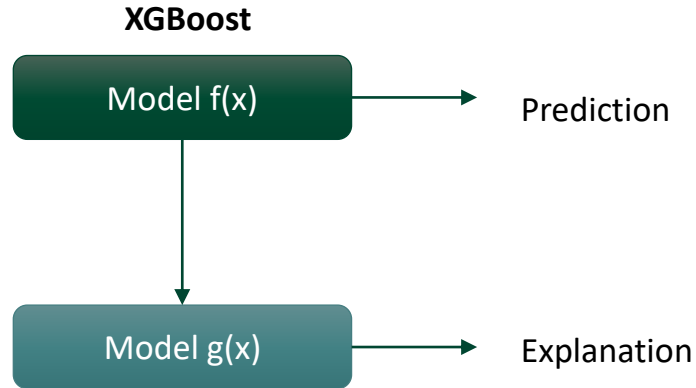
Why should I trust you? →

Your accuracy is too low! →



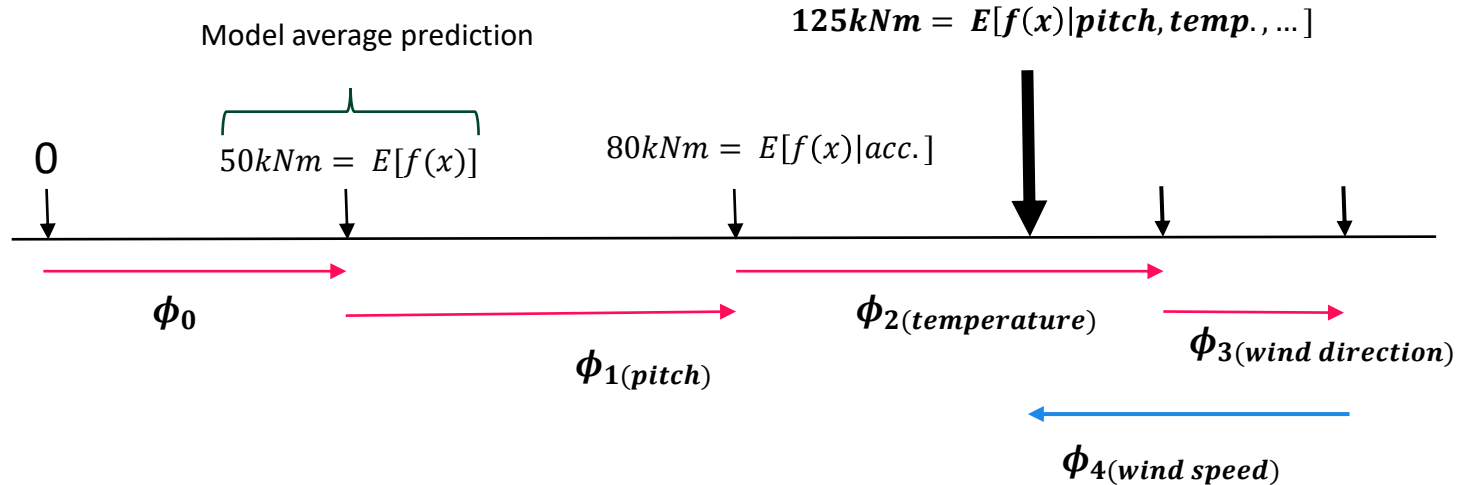
Source: <https://www.explainx.ai/resources/how-can-we-build-explainable-ai>

Interpretation of black-box models



Additive feature attribution

$$g(x) = \phi_0 + \sum_{i=1}^M \phi_i$$



Co-operative Game Theory

- Game Theory
 - Branch of micro-economics dealing with interactions between decision-making agents.
- Cooperative Game Theory
 - Sub-field of game theory where players are “working together” to achieve a common goal.
- Shapley values
 - Calculate the marginal contribution of every player (feature)



Shapley values

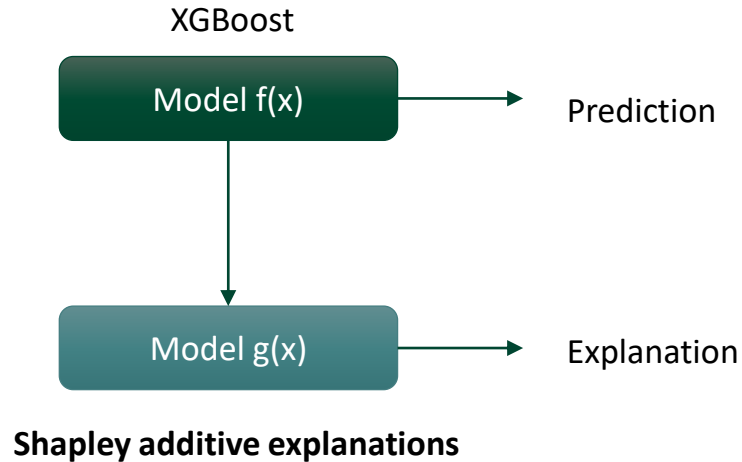
- Given a coalition game (X, f) , the Shapley Value divides the contribution among features according to:

$$\phi_i(X, f) = \frac{1}{X!} \sum_{S \subseteq X \setminus \{i\}} \underbrace{|S|! (|X| - |S| - 1)!}_{\text{Weighting by all possible combinations}} \underbrace{[f(S \cup \{i\}) - f(S)]}_{\text{Marginal calculations}}$$

- The Shapley values are the base of the “Shapley additive explanations” algorithm, which was proposed by Lundberg et al. (2017)

Lundberg, Scott M., and Su-In Lee. "A unified approach to interpreting model predictions." *Advances in neural information processing systems*. 2017.

Interpretation of black-box models



Project data - Research at Alpha Ventus (RAVE)

Measurements

- Azimuth angle
- Generator speed
- Pitch angle
- Electrical power
- Wind speed
- Temperature

$$f(x) = y$$

Features

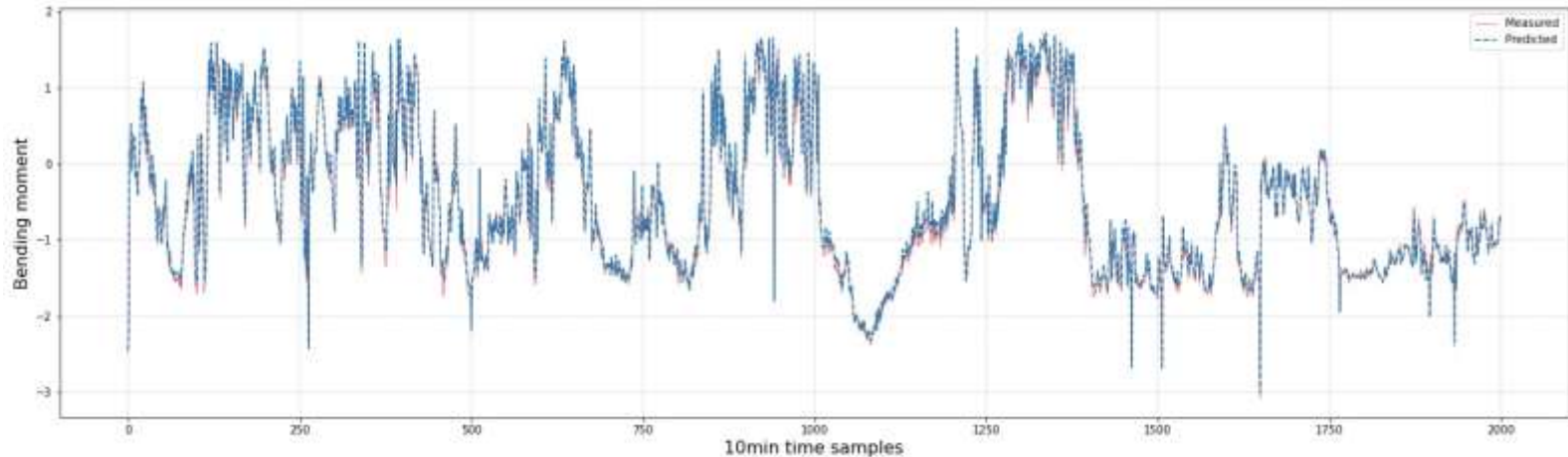
- Mean of a 10-min measurement
- Minimum
- Maximum
- Standard deviation

Target signal

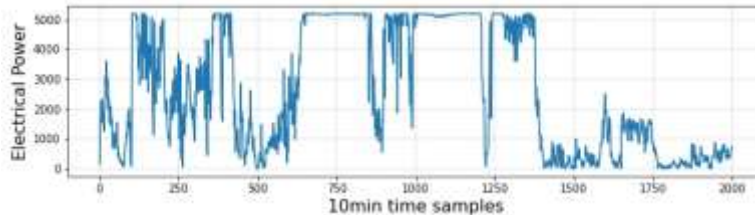
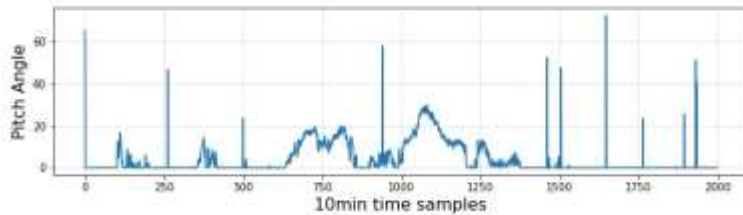
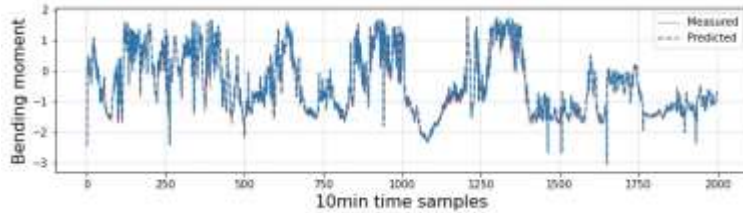
- Measured bending moment on the blade
- 10-min mean value



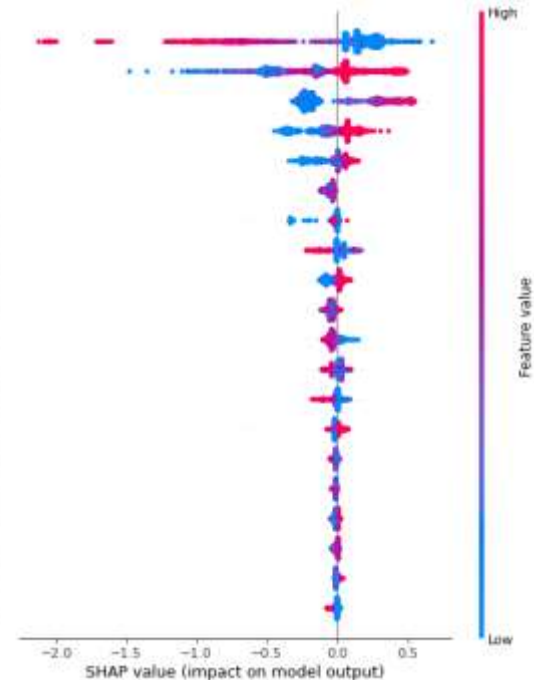
Predicting blade loads



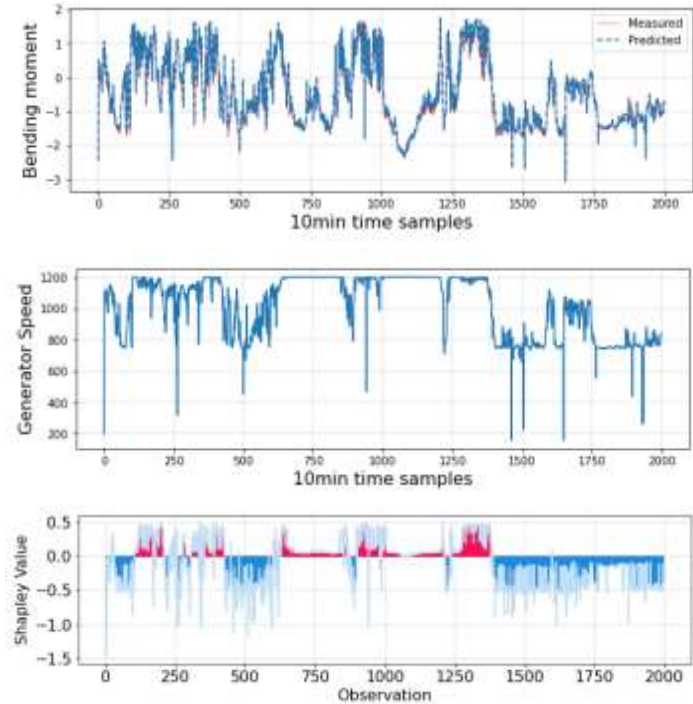
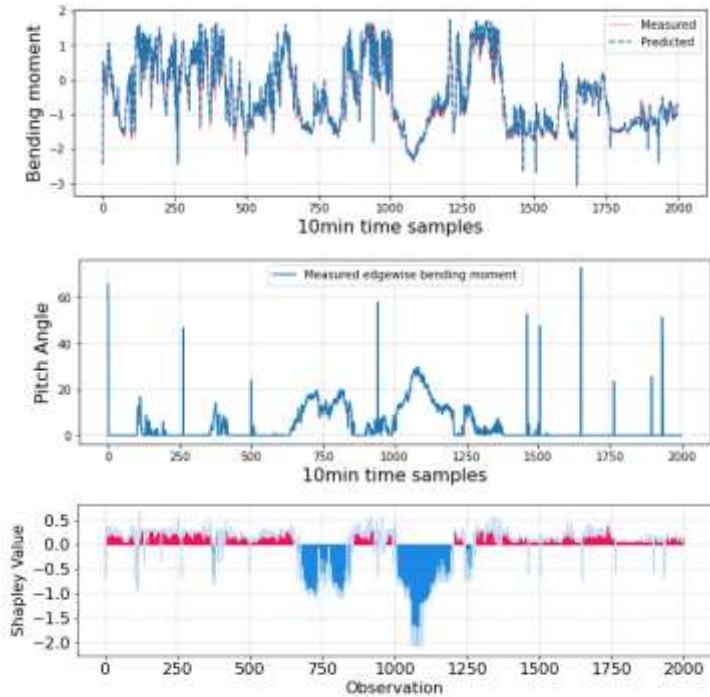
Global marginal contribution



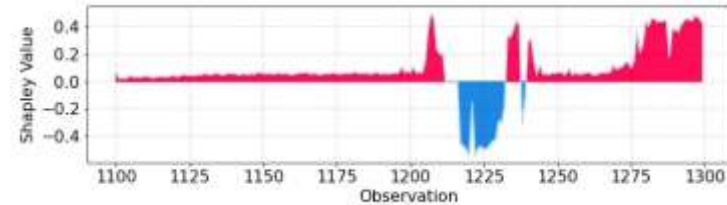
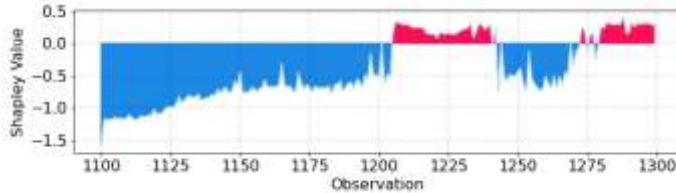
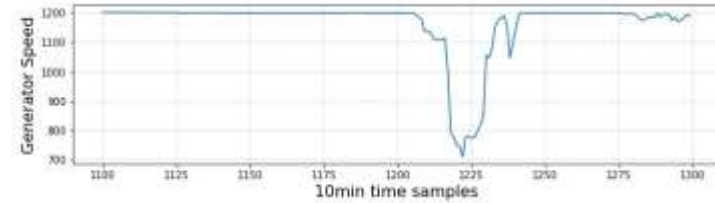
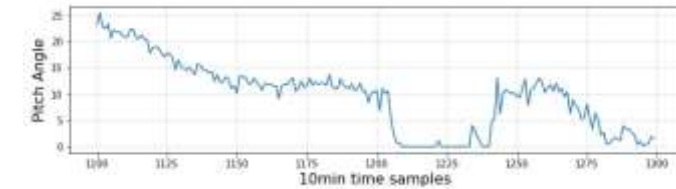
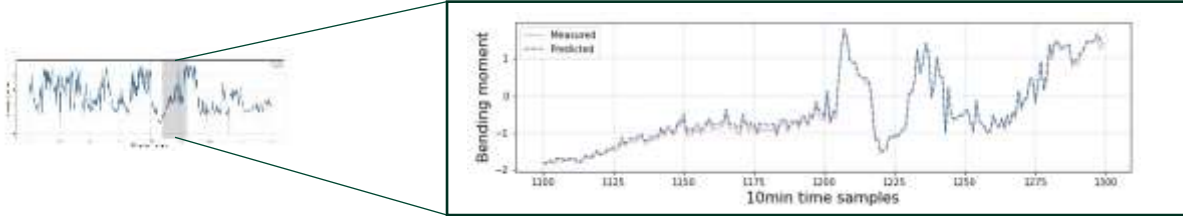
R4_Pitchwinkel_1st_B4_50Hz_mean
 R4_Generatordrehzahl_B4_50Hz_mean
 R4_elektrische_Leistung_B4_50Hz_std
 R4_elektrische_Leistung_B4_50Hz_mean
 R4_elektrische_Leistung_B4_50Hz_min
 R4_D-B5b1_Temp_90_mean
 R4_Generatordrehzahl_B4_50Hz_std
 R4_Pitchwinkel_1st_B4_50Hz_max
 R4_Generatordrehzahl_B4_50Hz_min
 R4_D-B5b1_Temp_0_mean
 R4_B-A12o(y)_mean
 R4_Windgeschwindigkeit_B4_1Hz_mean
 R4_Pitchwinkel_1st_B4_50Hz_std
 R4_Generatordrehzahl_B4_50Hz_max
 R4_B-A12o(x)_mean
 R4_D-B5b1_Temp_0_min
 R4_elektrische_Leistung_B4_50Hz_max
 R4_Azimuthwinkel_B4_50Hz_min
 R4_B-A12o(y)_std
 R4_Pitchwinkel_1st_B4_50Hz_min



Global marginal contribution



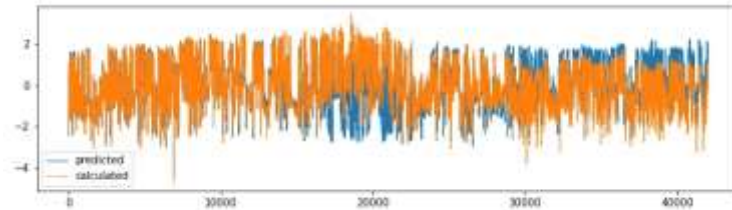
Global marginal contribution



Opportunities for research and industry

Further Research

- Improving model accuracy through interpretability
- Building reliability in model predictions
- Further analysis on aeroelastic models



Industrial Application

- Automated decision making
- Knowing why
- Uncertainty analysis
- Troubleshooting with limited domain expertise



Thank you

Questions and comments are welcome

