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An Overview of Wind Energy Production Prediction Bias, Losses, and Uncertainties

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Summary

The financing of a wind farm directly relates to the preconstruction energy yield assessments which estimate the annual energy production (AEP) for the farm. The accuracy and the precision of the preconstruction energy estimates can dictate the profitability of the wind project. Historically, the wind industry tended to overpredict the AEP of wind farms. Herein, we present a **literature review** of the energy yield assessment errors across the global wind energy industry, and we identify a weak, long-term trend of reduction in the overprediction bias. We also document the estimated and observed energy production loss and uncertainty values from the literature, according to the proposed framework in the International Electrotechnical Commission (IEC) 61400-15 wind resource assessment standard. In this study, the three main research questions of this review include:

- Is the P50 prediction bias changing over time, and what are the reasons for the changes?
- What are the ranges of different categories of energy production losses and uncertainties?
- Given our understanding on losses and uncertainties, what are the opportunities for improvements?

We conduct our literature review over a broad spectrum of global sources, such as the presentations from the American Wind Energy Association (AWEA) and the WindEurope conferences.

P50 prediction bias

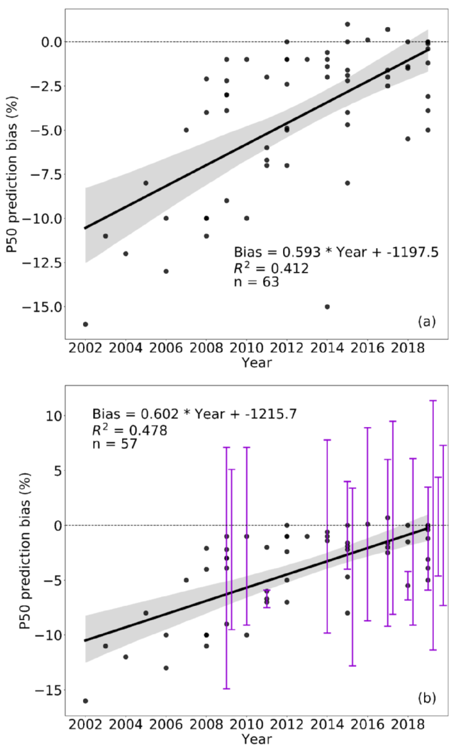

Fig. 1: The trend of P50 prediction bias: (a) scatterplot of 63 independent P50 prediction error values, where R^2 is the coefficient of determination and n is the sample size. Negative bias means the predicted AEP is higher than the measured AEP, and vice versa for positive bias. The black solid line represents the simple linear regression, the grey cone displays the 95% confidence interval, the horizontal black dashed line marks the zero P50 prediction error. (b) as in (a), but only for 57 studies that use more than 10 wind farms in the analyses. The vertical violet bars represent the estimated uncertainty bounds (typically presented as one standard deviation from the mean) of the mean P50 prediction errors in 16 of the 57 samples.

Energy production loss

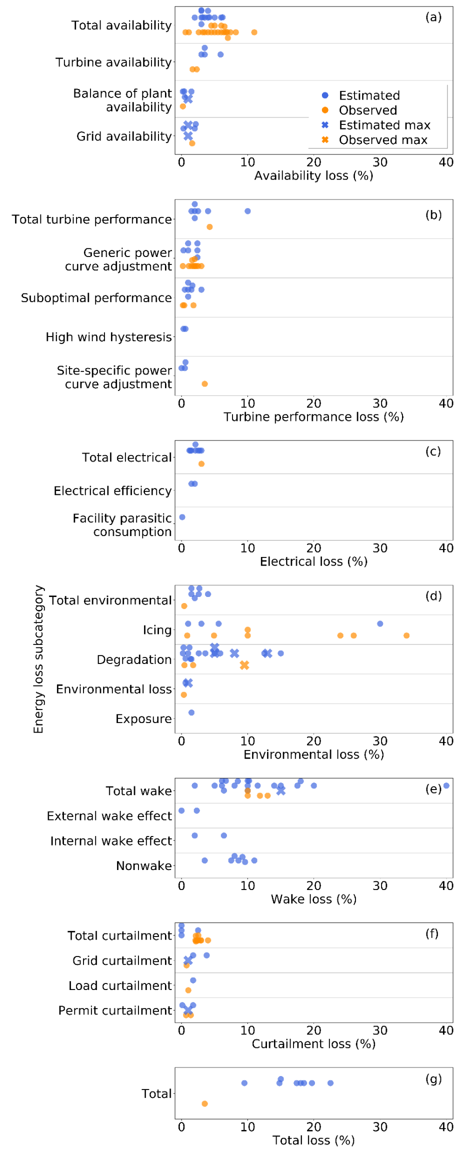

Fig. 2: Ranges of energy production losses in different categories and subcategories, according to the proposed framework of the IEC 61400-15 standard, except for nonwake in (e), which is an extra subcategory summarizing other nonwake categories. Each blue and orange dot, respectively, represent the mean estimated loss and mean observed loss documented in each independent study. The blue and orange crosses, respectively, indicate the maximum of estimated loss and the maximum of observed loss reported, where the minima are not reported, and thus the averages cannot be calculated. The units are in AEP percent. For clarity, the grey horizontal lines separate data from each subcategory.

Energy production uncertainty

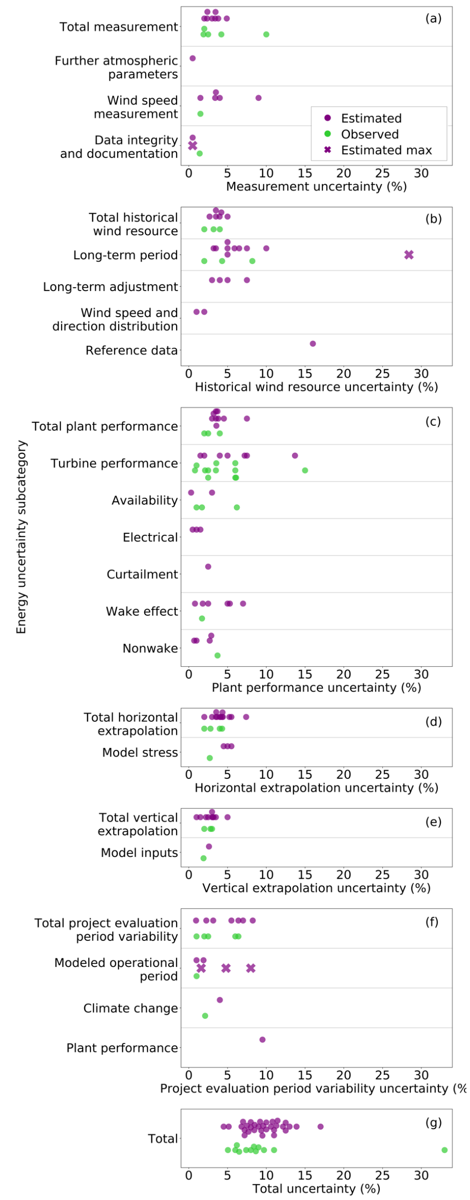

Fig. 3: Ranges of energy production uncertainties in different categories and subcategories, according to the proposed framework of the IEC 61400-15 standard. The annotations correspond to those in Fig. 2, where each purple dot, green dot, and purple cross represent the mean estimated uncertainty, the mean observed uncertainty, and the maximum of estimated uncertainty from each independent reference, respectively. The units are in AEP percent. For clarity, the grey horizontal lines separate data from each subcategory.

Opportunities for industry improvements

- The uncertainties in the wind resource assessment process, rather than the magnitude of the prediction errors, develops as an obstacle to the industry. Even though the average P50 prediction bias approaches zero, the associated mean P50 uncertainty remains at over 6%, even for the studies reported after 2016 (Fig. 1b).
- To reduce the overall AEP uncertainty, the industry should continue to validate the energy impacts of plant performance losses. The industry predicts and records the substantial energy depletion caused by extreme environmental events (Fig. 2d) and wake effect (Fig. 2e), and their site-specific impacts on AEP for the whole wind farm and its time-varying production impact on downwind turbines can be highly uncertain.
- Overall, more observations are necessary to validate the loss and uncertainty estimates listed in this study.
- An article for the *Wind Energy Science* journal is in preparation.

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