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Wake Loss Modeling: A Benchmarking Analysis of Eight Models in Wind Farms with Multiple Rows in Brazil

ABSTRACT

Modeling wake losses in wind farms presents a challenging task due to the site-specific nature of the conditions, which include factors such as terrain complexity, roughness, strategic placement of meteorological masts, and measurement duration. The industry has developed several wake models, each with its own characteristics and suitability for particular scenarios involving terrain complexity, wind turbine quantities, and wind farm layouts, particularly those with multiple rows.

This study aims to perform a benchmarking analysis of eight wake models using operational data from four wind farms located in Brazil's northeast region, characterized by multiple rows. In addition to assessing variations in the performance of wake models across different rows, this study reveals that the absence of measurements within a row can result in inaccurate wake loss predictions, even if the nearest meteorological mast is positioned less than 3 kilometers away from the row.

OBJECTIVES

The objectives from this study are to:

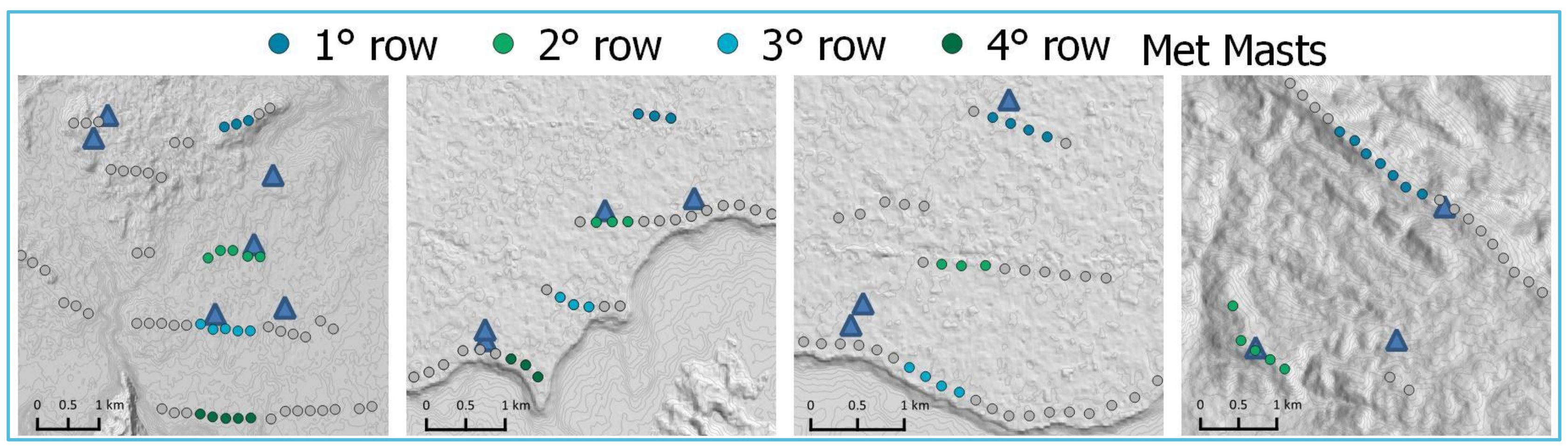
- Conduct a comprehensive benchmarking analysis of eight commonly used wake models in the wind energy industry.
- Assess the performance of these wake models using operational data collected from four wind farms located in Brazil's northeast region, characterized by multiple rows.
- Evaluate the variations in the performance of wake models across different rows within wind farms.
- Investigate the impact of the absence of measurements within a specific row on the accuracy of wake loss predictions, even when the nearest meteorological mast is located closer to the row.

METHODS

In line with a previous study (1), for the four evaluated sites, the respective wind models exclusively employed pre-operational data, which were processed and used to fine-tune the Wind Resource Grid (WRG). Once the WRG was calibrated, eight wake models were assessed: Bastankhah, DAWM Eddy Viscosity, DAWM Park Variant, Eddy Viscosity, Modified Park, N.O. Jensen, TurbOPark, and WakeBlaster.

Figure 1 illustrates the rows under analysis and the respective configurations of meteorological masts at the four evaluated sites.

For the comparison with operational data, we utilized one year of data for sites A and D, while sites B and C were based on two years of data. In order to have a fair analysis, the data was filtered to include only timestamps when all wind turbines were operating at full capacity.

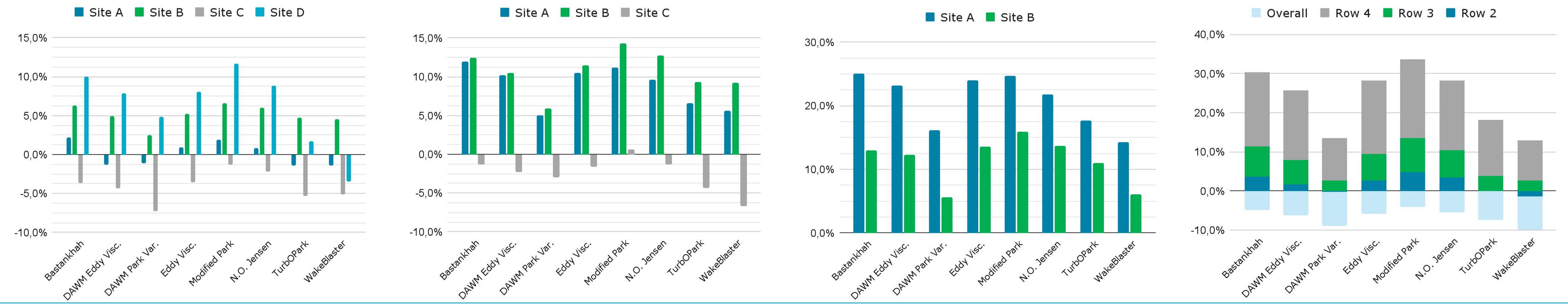


(a) Site A (b) Site B (c) Site C (d) Site D

Figure 1: Highlighted Wind Farm Layouts with Wind Turbine Selection Per Row. Note: Real north is anonymized.

RESULTS

Considering the variability in the number of wind turbines within rows on the same site, we conducted a row-by-row assessment by calculating the average power generation per wind turbine within each row. Subsequently, we employed both operational and simulated data from the initial row to standardize the simulated energy for all rows. This procedure enabled us to compute the percentage difference between the operational data and the standardized simulated energy, focusing specifically on the impact of wake effects on subsequent rows, as depicted in Figure 2. To compare the average wake evaluation across all rows, we applied the same analytical approach used for individual rows, with the exception of normalization. In this context, the simulated generation for all rows was considered without accounting for wake loss. As a result, we anticipate the outcomes of this analysis to reveal a negative difference, given that production estimates by all models incorporate wake losses. To summarize the assessment, Figure 2 (d) shows the mean wake models performance by row and for the all rows.



(a) 2° row analysis *(b) 3° row analysis* *(c) 4° row analysis* *(d) Overall analysis and performance by row*

Figure 2: Comparison of percent error for 2º row (a), for 3º row (b), for 4º row (c). The overall and per row performance comparison (d).

CONCLUSIONS

The analysis in Row 2, Figure 2(a), indicates that Site A delivered the best performance across all wake models, while Site D exhibited the most divergent results for nearly all models, followed by Site C. On average, **TurbOPark and WakeBlaster** demonstrated consistent results for the **second row** across the evaluated sites. It's important to note a few factors explaining the disparities in results: Site C lacked measurements in the second row, and Site B had the shortest distance to Row 1 (approximately 1.3 km), intensifying wake impact on Row 2. In contrast, Site D had the greatest distance between rows but a large number of turbines in the first row, which heightened the wake effect on the turbines behind.

Figure 2(b) shows that Site B, the only site without measurements in the **third row**, had the largest errors. Site A, although displaying a slight improvement compared to Site B, faces more complex terrain, potentially accounting for variations in wake model performance. Site C performed better with the Modified Park, N.O. Jensen, and Bastankhah models, while the other sites **performed better** with the **DAWM Park Variant** model. The behavior observed in Sites A and B is reversed when we examine Figure 2(c), owing to the absence of measurements in the **fourth row** of Site A. In this row, the **WakeBlaster and DAWM Park Variant** models also demonstrated superior performance, in line with the patterns observed in the other rows.

Figure 2(d) shows that the **Modified Park, Bastankhah, and N.O. Jensen** models are **more accurate** in predicting the **overall wake** within the wind park. In contrast, the **DAWM Park Variant, WakeBlaster, and TurbOpark** models tend to overestimate mean wake losses, but they are **better** at predicting wakes **within individual rows.** This enhancement in the results can be attributed to the fact that the DAWM Park Variant and TurbOpark models offer significant improvements over simpler models (2; 3), and for WakeBlaster, enhancements include interactions between wakes, as well as interactions with the atmospheric boundary layer (4).

This study expands on previous work, and it would be beneficial for future studies to use a larger operational dataset and a model that seamlessly integrates operational and pre-operational data. This approach would enable a comprehensive comparison between operational data and a model that accurately reflects the resource variability observed in each year of operational data.

REFERENCES

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