

Responses to Reviewer #1

Dear Authors,

Thank you for a well-written paper. You have collected a comprehensive dataset of wind measurements (62 sites) and production data (55 small wind turbines) and used it to evaluate three wind resource models (WIND Toolkit, ERA5, and MERRA-2) and three simulation tools (SAM, Wind Report, and MyWindTurbine.com). It is an ambitious analysis. The comprehensive evaluation is the strength but also the weakness of the paper. There are many uncertainties associated with energy yield assessment, wind measurements and small wind turbine performance (e.g. SAM and MyWT assumes 18% & 7% loss), but the manuscript can not detail all aspects. I would like to see a general discussion about the prediction error and whether it is within the expected uncertainty - does the simulation tools provide added value, or are wind measurements needed for proper energy yield assessments?

Thank you, Dr. Bechmann, for your time, thoughtful review, and suggestions for improvement of our article. We are very appreciative and have addressed your comments in the revised draft as outlined below. Many thanks again!

We completely agree that many challenges and uncertainties exist with measurements and simulations for both wind speed and energy production. We are attempting to bring together observations and simulation in a validation dedicated to helping the small wind community account for model and tool uncertainty and to help identify challenges for model and tool developers. We are thankful for your help in this endeavor by providing us valuable feedback.

Given the rarity of tool validations using actual small wind turbine observations and our inability to locate expected uncertainty information in the tool documentation, we hope that this work provides some of the foundational information for setting such expectations. Per your helpful suggestion, we have added the following general discussion on the value of simulation tools to our conclusions on lines 529-538:

“Given the significant time and costs associated with collecting pre-installation onsite wind resource measurements for small wind turbine deployment, the tools evaluated in this manuscript provide essential value to the small wind community by providing quick, low-cost energy production estimates that can be adjusted using the validation results of this study. In addition to the energy production estimates, each tool offers unique features that are beneficial to the small wind community. SAM and Wind Report provide customizable wind shear exponents in their calculations, allowing for energy production simulation during under different atmospheric stability regimes. MyWindTurbine.com enables users to input actual building and vegetation dimensions into their flow model in order to account for obstacle losses. GWA3 provides especially high spatial resolution for wind resource and energy production mapping. Of significant importance given the findings of this work, SAM incorporates multiple individual years of wind resource modelling that provide guidance on setting interannual energy production expectations.”

Wind Report and SAM make estimates by interpolating within coarsely resolved wind resource grids (2 and 5km). MyWT is fundamentally different in that it uses high-resolution micro-scale and obstacle flow models (<1m) to downscale the large-scale forcing found from the wind resource model (50km in GWA1). The paper hints that the poor performance of MyWT is due to the coarse resolution of the wind resource model. However, as the sheltering effect of nearby trees and buildings can be significant for small turbines (like the 8.9 kW turbine), they should be included in the analysis. MyWT requires the user to input the exact location and type of obstacles; these are not defaults. The paper does not mention if obstacles were included, but if not, it should be noted as the probable cause for the high wind speeds predictions.

Thank you for pointing out the necessity of including whether obstacles were incorporated in the assessment of MyWindTurbine.com, and we apologize for neglecting this information in the first draft. We have made clarifications on lines 188-191 of the revised draft as follows:

“In addition to the static loss assumptions, MyWindTurbine.com provides high resolution obstacle flow modelling to simulate wake loss. As this feature requires the knowledge of the precise dimensions of obstacles, it is not

considered in this performance analysis, but should be utilized in practice in order to take full advantage of the MyWindTurbine.com modelling capabilities.”

The Global Wind Atlas 3 (GWA3) is another easy-to-use tool to estimate wind speed and the energy yield of wind turbines. The GWA3 is based on large-scale forcing from WRF simulations (3km) with global coverage down-scaled to 250m resolution. It would be interesting to compare GWA3 (3km) and GWA1 (50km) as this could indicate if the prediction error is caused by the resolution of the wind resource model or the lack of an obstacle model.

Thank you for this excellent suggestion! We have added GWA3 to the energy production validation alongside MyWindTurbine.com, SAM, and Wind Report throughout the revised draft. Lines 7-10 in the abstract now read: “Observations from small wind turbines across the United States provide references for validating energy production estimates from the System Advisor Model (SAM), Wind Report, MyWindTurbine.com, and Global Wind Atlas 3 (GWA3), which are seen to overestimate actual annual capacity factors by 2.5, 4.2, 11.5, and 7.3 percentage points, respectively.” We believe the addition of GWA3 to be highly beneficial to the validation study and are very grateful for your suggestion.

While we lack the obstacle information required to investigate the obstacle modelling capabilities, we did perform a wind resource comparison of GWA1 and GWA3 at 10 m and 50 m (Fig. 6c, 6d in the revised draft). Across the 55 turbine locations, GWA1 is on average 0.5 m s^{-1} faster than GWA3 at 10 m and only 0.1 m s^{-1} faster than GWA3 at 50 m. At 10 m, the 55 wind speeds from GWA1 range from 2 m s^{-1} to 9 m s^{-1} while the speeds from GWA3 range from 2.5 m s^{-1} to 6 m s^{-1} . At 50 m, the 55 wind speeds from GWA1 range from 3 m s^{-1} to 9 m s^{-1} , while the 55 wind speeds from GWA3 range from 4 m s^{-1} to 8 m s^{-1} .

Responses to Reviewer #2

General Comments:

The paper reports on a well-reasoned and performed piece of work related to wind speed and wind energy assessment for small, distributed wind turbines. The approach taken, data used, and results presented are useful and needed, and the work represents a step forward. Identification of the source data is useful, especially for any that would like to use the wind simulation data from the sources listed. Typical proposed small wind turbine installations do not have good met tower or weather data from nearby sources, so the use of simulation data is very practical, and thus the some understanding of its ultimate accuracy in predicting AEP is critical.

Thank you, Dr. Acker, for your time, positive feedback, and suggestions for improvement of our article. We are very grateful and have addressed your comments in the revised draft as outlined below. Thank you again!

Specific Comments:

The wind speed bias errors are only positive for the smallest wind speed bin plotted in Fig. 5 (0-5 m/s), yet the wind turbine capacity factors are almost all overpredicted (Fig. 7). This seems to imply that the wind speed spends most of its time in the lowest wind speed bin. However, most of the wind power curves shown in Fig. 2 show little production in this wind speed range. Would it be possible to add to Fig. 5 the percent of time that the wind speed was in each wind speed bin? That could help in interpreting the results. Moreover, if they possess sufficient time resolution in the wind turbine production data, it would be helpful if the authors provided an explanation for the overestimate of capacity factor... at which wind speeds (or wind speed bins) does the overestimate of energy occur?

We appreciate the suggestion to add the percentage of time spent in each wind speed bin, and have transformed Fig. 5 into Fig. 5a, which shows the frequency of occurrence for each wind speed bin, and Fig. 5b, which depicts the wind speed bias according to each wind speed bin. The frequency analysis reveals that the wind speed does spend most of its time in the lowest wind speed bin. Model wind speed overestimation of observed wind speeds in the 0 – 5 m s⁻¹ range can lead to significant production overestimation, given the transition from zero power to the steep portion of the power curve around cut-in speeds.

While a subset of the turbines do possess high-resolution (10-second) production data, a lack of on-site hub height wind speed measurements presented the first hurdle to directly correlating wind speed to simulated energy production under/overestimation. The authors considered using bias-corrected reanalysis wind speeds, based on the results of Sect. 3.1, in conjunction with the production data rolled up to an hourly resolution, but encountered a final hurdle with the lack of similar temporal resolution and overlap within the tools. For example, the APRS World collection began outputting 10-second production data within the last few years (monthly kWh total production values are available prior to that), while the latest year that SAM provides hourly production simulations for is 2013. We wish that we could incorporate this analysis for this collection of turbines and tools, and hope to revisit the concept as tools increase temporal coverage and resolution.

The (simulated – actual) capacity factors for 55 turbines are presented in Fig. 7, split up by region of the country. Another interesting categorization would be by “surface roughness” or something similar that provides an indication of whether the area in the vicinity of the turbine is forest, fields, etc. It would also be nice to sort by complex terrain vs non-complex, and to provide some suggestion of how to distinguish between the two. Have the authors considered looking at the data in these ways?

We are thankful for the excellent suggestions on different ways to visualize the capacity factors errors. Fig.7 now includes Fig. 7d, which examines the capacity factor errors according to the land cover categories provided by the Copernicus Global Land Cover dataset (<https://lcviewer.vito.be/>). The turbines in this collection fall into the following categories: herbaceous vegetation/shrubland, cropland, forests, and built up. By including this analysis, we learned that the highest energy production overestimation occurs in forested locations. We appreciate the suggestion, and the discussion can be found on lines 375-384 of the revised draft.

We also created Fig. 7e, which estimates terrain complexity by considering the difference in maximum and minimum elevation within a 2 km radius of each turbine using the ASTER Global Digital Elevation Model V003 (https://cmr.earthdata.nasa.gov/search/concepts/C1575731655-LPDAAC_ECS.html). One of the tools (MyWindTurbine.com) showed an average trend of increasing error with increasing terrain complexity. The remaining tools exhibited no such average trends in capacity factor error according to terrain complexity, however, extreme tool underestimation outliers were found in accordance with complex terrain. The discussion can be found on lines 385-393 of the revised draft.

Fig. 10 shows availability statistics for 9 turbines of varying ages. Why were only nine turbines used? Also, did the authors sort the availability by turbine age?

The nine turbines were originally selected to provide a geographically-diverse overview of availability. Your question encouraged us to present the entire suite of turbines with availability information (36 of the 55 turbines), the discussion of which can be found on lines 457-485 of the revised draft. Additionally, Fig. 10 was reimaged to sort the availability data according to turbine age, per your suggestion.

Thanks to your encouragement to further develop this section, we learned that the annual *average* percent of time missing or spent in a stopped/fault state ranged from 14% to 30%, and only SAM's loss assumption falls within this range (18%). The annual *median* percent of time missing or spent in a stopped/fault state ranged from 4% to 18%, and the loss assumptions from all the tools falls within this range.

For the conclusions: Do the authors have any recommendation about how a person whose job is estimating small wind turbine AEP/capacity factor should account for interannual variability, given its significant influence on capacity factor?

We are grateful for this suggestion to tie the findings together and provide recommendations for the small wind community. We have added the following text to lines 522-528 in the conclusions:

“Given the significance of interannual variability on turbine production estimates, the authors recommend that small wind turbine production estimators utilize a tool that provides a range of annual production possibilities in order to set expectations for average, high, and low wind resource years. For currently deployed small wind turbines, an owner can estimate whether the wind resource during the current or near future time period will be above or below average by considering climate oscillations, such as the El Niño-Southern Oscillation. Hamlington et al. (2015) correlates La Niña events with faster wind speeds and El Niño events with suppressed wind speeds across the U.S. Great Plains.”

Hamlington, B. D., Hamlington, P. E., Collins, S. G., Alexander, S. R., and Kim, K-Y., Effects of climate oscillations on wind resource variability in the United States, *Geophysical Research Letters*, 42, 145-152, doi:10.1002/2014GL062370, 2015.

Technical Corrections:

Page 6 Line 148: Should read “2.1 kW to 56 kW” NOT “8.9 kW to 56 kW”

Thank you for catching this error! We have made the change to “2.1 kW.”

I believe the Southwest WindPower Skystream is now owned by Xzeres. Perhaps some mention should be made of this when introducing the turbine?

A footnote has been added to Table 2, stating that “Southwest Windpower closed in 2013 and the remaining Skystream assets were acquired by the now-defunct XZERES Corporation. The Skystream turbine models included in this analysis were installed in 2008 through 2012.” Thank you for the suggestion!

Response to Community Reviewer #1

Lines 483-484: Wind Report is not available by subscription, though some of the old New Roots pages and links do indicate that it is. Wind Report is offered free of charge to dealers, key accounts and friends of Bergey Windpower. We will try to clean up the incorrect pages and links.

Mike Bergey, President, Bergey Windpower Co.

Thank you, Mike! We have altered lines 569-570 to read: “Wind Report is freely available at http://www.newrootsenergy.com/page/wind_report to dealers, key accounts, and friends of Bergey WindPower Co.”

Regards, Lindsay