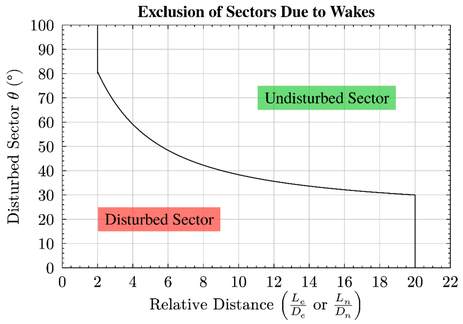
Sector informed analysis of small wind turbine power production

Zachary Selzman[1], Consuelo Wells[2]
[1]California Polytechnic State University, San Luis Obispo, CA, [2]National Wind Technology Center at the National Renewable Energy Laboratory, Arvada, CO,

Introduction

- Small wind turbine performance is evaluated using the International Electrotechnical Commission standard (IEC 61400-12-1)[1]
- The standard requires a lengthy site assessment to normalize the test terrain and obstacles to account for wake effects on power performance, which is determined by:



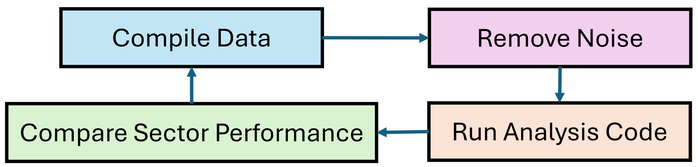
$$D_E = \frac{2 l_h l_w}{l_h + l_w}$$

where:
D_E is the equivalent rotor diameter;
l_h is the height of the obstacle;
l_h is the width of the obstacle as seen from the turbine

Figure 1: Site assessment methodology for determining valid sectors

- Small turbines (less than 200 m^2 swept blade area) are less influenced by large-scale terrain and obstacle effects
- Wake effects require a site calibration with six hours of data per wind speed bin (wind speeds within 0.5 m/s width)
- A revised site assessment would cut down on test time and cost

Methods



- Raw power performance data was compiled for the turbines involved in NREL's small distributed wind projects from 2008-2010
- The data was cleaned to avoid grid fault, icing, and data acquisition error, and invalid sector events
- The data was run through an IEC-verified code that outputs power performance and annual energy production values
- Performance was compared between turbines with data from obstructed (all directions) and unobstructed sectors (determined in the site assessment and published in the IEC report)

Results

All Sector estimated annual energy production				
Hub height annual average wind speed (Rayleigh)	AEP-measured MWh	Standard Uncertainty in AEP-measured		AEP-extrapolated
m/s	MWh	MWh	%	MWh
4	3.926	1.264	0.322	3.926
5	9.939	1.527	0.154	9.939
6	16.790	1.708	0.102	16.807
7	22.989	1.807	0.079	23.120
8	27.779	1.842	0.066	28.275
9	30.970	1.831	0.059	32.176

Valid Sector estimated annual energy production				
Hub height annual average wind speed (Rayleigh)	AEP-measured MWh	Standard Uncertainty in AEP-measured		AEP-extrapolated
m/s	MWh	MWh	%	MWh
4	4.045	1.280	0.317	4.045
5	10.132	1.535	0.151	10.132
6	17.011	1.711	0.101	17.028
7	23.211	1.808	0.078	23.243
8	27.991	1.843	0.066	28.487
9	31.166	1.831	0.059	32.372

Figure 2: Viryd annual power production estimates for All Sector and Valid Sector

- Viryd was the most consistent turbine case study, with all invalid events (icing, faults, etc.) being controlled conditions
- The Valid direction data has a left shift compared to the All direction because the Valid Sector is bin-averaging unobstructed wind data
- Change in expected annual energy production between tests is minimal, and equivalent when rounded to two decimals (common practice in IEC test reports)

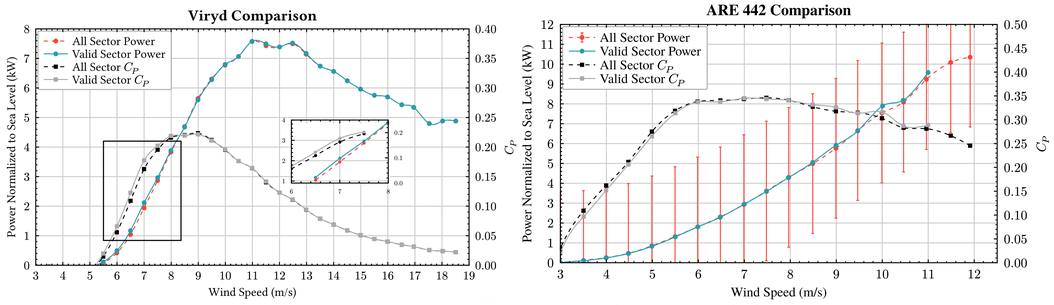


Figure 3 : Viryd comparison and ARE 442 comparison with combined uncertainty

- Alternatively, ARE 442 was a rapid test that failed to complete a full IEC test (wind bins)
- The ARE IEC sector performance is within the combined uncertainty margin for the All-Sector test

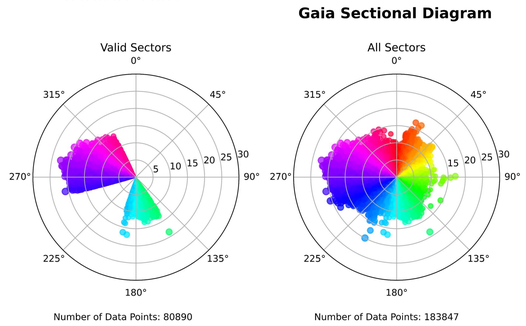


Figure 4: Gaia wind rose scatter plot

- The analysis of Gaia included corrupt data, sector iterations were performed to reduce noise
- Foregoing a site assessment increases the size of the data set, meaning the 60 hours of data required to complete the IEC test in a shorter time

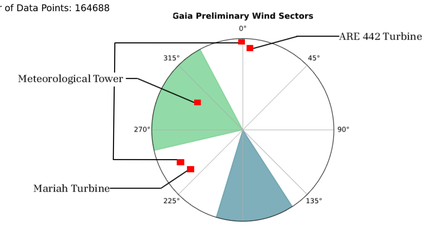


Figure 5: Gaia site primary obstacles

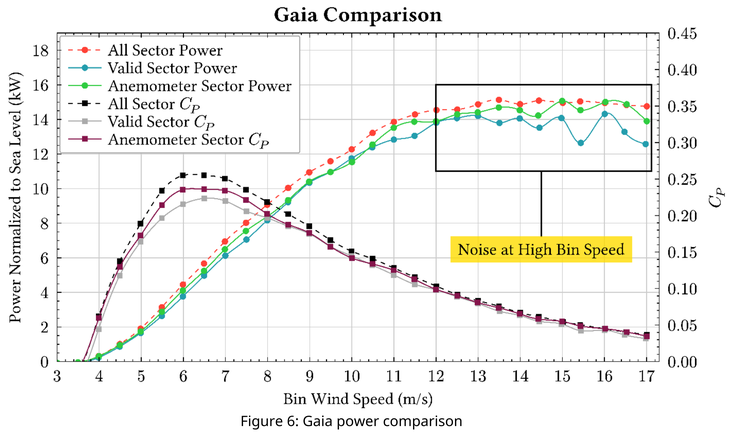


Figure 6: Gaia power comparison

- High wind bins are filled from ~292 (° True), which is included in all analysis, implying terrain effects are unlikely to be the reason for the noisy behavior
- Removing the anemometer sector improved convergence, however, the results are outside of the uncertainty margin (average 0.42 kW) at the higher wind speed bins

Conclusions

- Obstacles in disturbed measurement sectors have a marginal influence on small turbine power performance
- A revision to Annex H of the IEC 61400-12-1 (special considerations for small turbines) could potentially reduce test time and cost at the expense of some uncertainty
- Data was parsed via the engineer's logbook; thus, results may have not removed corrupted data.
- However, all results apart from Gaia place the results within the uncertainty margins calculated by the code

Future Work

- Code updates should follow any changes made to Annex H of the standard
- IEC committee should weigh the costs of site assessments with respect to the decrease in uncertainty

Acknowledgements

I would like to recognize Consuelo Wells, Arlinda Huskey, Jason Roadman, Brynne Hall, and the entire Manufacturing and Characterization group at the NWTC for their guidance, mentorship, and efforts to create a welcoming and nurturing atmosphere. My internship was a valuable and enjoyable experience!

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internship (SULI) Program.

References:
[1]International Electrotechnical Commission (IEC), *Wind energy generation systems-part 12: Power performance measurements of electricity producing wind turbines. ANSI, 2022.*