ALETHEIA
The Alpha Chi Journal of Undergraduate Scholarship

Volume 3 | Issue 2 | 2018

Wind-for-Water Trade: Mathematical Validation of a Novel Policy Initiative in Wind Energy

Parker LaMascus, Abdullateef Shodunke, Dr. Ruth Douglas-Miller

Oklahoma Christian University
Kansas State University

Vol. 3(2), 2018
Title: Wind-for-Water Trade: Mathematical Validation of a Novel Policy Initiative in Wind Energy
DOI:
ISSN: 2381-800X
Keywords: distributed wind, applications of wind energy, wind-water nexus, policy initiatives, broader perspectives, resource assessment
This work is licensed under a Creative Commons Attribution 4.0 International License.
Author contact information is available from tlindblom@alphachihonor.org or kvosevich@alphachihonor.org

Aletheia—The Alpha Chi Journal of Undergraduate Scholarship

- This publication is an online, peer-reviewed, interdisciplinary undergraduate journal, whose mission is to promote high quality research and scholarship among undergraduates by showcasing exemplary work.
- Submissions can be in any basic or applied field of study, including the physical and life sciences, the social sciences, the humanities, education, engineering, and the arts.
- Publication in *Aletheia* will recognize students who excel academically and foster mentor/mentee relationships between faculty and students.
- In keeping with the strong tradition of student involvement in all levels of Alpha Chi, the journal will also provide a forum for students to become actively involved in the writing, peer review, and publication process.
- More information can be found at www.alphachihonor.org/aletheia. Questions to the editors may be directed to tlindblom@alphachihonor.org or kvosevich@alphachihonor.org.

Alpha Chi is a national college honor society that admits students from all academic disciplines, with membership limited to the top 10 percent of an institution's juniors, seniors, and graduate students. Invitation to membership comes only through an institutional chapter. A college seeking a chapter must grant baccalaureate degrees and be regionally accredited. Some 300 chapters, located in almost every state, induct approximately 11,000 members annually. Alpha Chi members have been "making scholarship effective for good" since 1922.

Volume 3 | Issue 2 | 2018

Article Title: Wind-for-Water Trade: Mathematical Validation of a Novel Policy Initiative in Wind Energy
DOI:
ISSN: 2381-800X
This work is licensed under a Creative Commons Attribution 4.0 International License.

ALETHEIA
The Alpha Chi Journal of Undergraduate Scholarship

Wind-for-Water Trade: Mathematical Validation of a Novel Policy Initiative in Wind Energy

Parker LaMascus, Abdullateef Shodunke, Dr. Ruth Douglas-Miller

Oklahoma Christian University
Kansas State University

Abstract

Western Kansas farmers depend on water from the Ogallala Aquifer to irrigate their crops; however, this water is a limited resource and will become depleted without intervention. State legislators proposed a policy solution called wind-for-water trade: farmers would be able to generate wind energy on their land to offset the costs of reduced irrigation. Recognizing that the efficacy of this wind-for-water trade would be limited in part by the quantity of wind energy produced, our team investigated the feasibility of such a program through analysis of National Weather Service data and the latest theory of wind energy estimation. We concluded that Southwest Kansas and geographical locations like it are ideal places for the institution of wind-for-water trade. We further concluded that larger wind turbines (WTs) were more cost-effective long term, despite their greater upfront cost, so we make recommendations for which types of turbines to use in wind-for-water trade. We also discuss obstacles to the implementation of wind-for-water trade from scientific and legislative perspectives.

Keywords: distributed wind, applications of wind energy, wind-water nexus, policy initiatives, broader perspectives, resource assessment

Problem Statement

We required a quantitative evaluation of the feasibility of a wind-for-water incentive program, using such metrics as Annual Energy Production, payback times, and the value of one year's energy. We prioritized accessibility in our units (USD/year, for example) since we knew that farmers and legislators would be the "end users" of our study. We also knew that long-term programs such as wind-for-water trade would necessitate study of annual and regional variation in wind speeds.

Procedure and Data

We selected likely sites for WT installation by juxtaposing a NOAA wind map of Kansas with Google Earth images, targeting rural farming sites in areas that had high annual wind averages. We identified three Kansas cities -- Dodge City, Garden City, and Liberal -- as ideal sites for WTs that also demonstrated a wide enough geographic distribution for the purposes of this research.

We gathered hourly wind speed data for the three cities from NOAA databases for the years 2011-2015 to provide a sufficient range of data to represent the actual wind resource of southwest Kansas. The NOAA data were only available at 10 m, whereas most commercial WTs have a hub height around 80 m, so we used Windographer software to extrapolate 80m wind speed (WS) from the 10 m raw data. Windographer is an academic platform for manipulating large amounts of wind-related data much more easily than another program such as MS Excel. The wind profile power law given in Equation 1 provided the mathematical basis for this extrapolation (Emeis, 2012).

$$u = u_R\,(z / z_R)^\alpha \qquad (1)$$

In Equation 1, the wind shear exponent α was assumed to be a constant 0.20 based on the flat geography of our sites, which matched the number Emeis (2012) gave for surfaces covered in low shrubbery. Our other variables, however, were known: z_R was the reference height (10m), u_R was the reference wind speed at each time step given from NOAA data, z was the desired hub height of extrapolation (80m), and u was the resultant wind speed at the reference height. Because α is usually determined for each location by taking two data sets at the same point and solving for it, we were unable to perform that analysis ourselves; therefore, we needed to prove that our assumptions for the value of α were valid.

Analysis

To validate the accuracy of our extrapolation using Windographer, we used an additional data set from Kearny County, Kansas (a county as little as 30 miles from our nearest site, which makes the geographies similar), for the year 2004, from an analogous study based on tall-tower wind measurements (Chapman et al.; King, 2005). This data set, which was obtained at 80 meters in ten-minute increments, has no inaccuracies introduced by extrapolation and could, therefore, serve as a benchmark for estimating the accuracy of our assumptions. As 2004 was the only year for which tall-tower data were available, we collected this wind history data for the three southwestern Kansas cities (King 2005). We compared the 2004 data between the Kearny tower and the three cities by plotting probability distribution functions for all four sites and by plotting monthly averages for 2004 across all four sites. These graphs were evaluated to provide a means of establishing the validity of using Equation 1 as the basis of 80 m wind speeds for Dodge City, Garden City, and Liberal. The validation was necessary because of our assumptions concerning our alpha value -- if we were wrong about the geography of our sites, our extrapolated data would also be incorrect. Figures 1 and 2 contain the graphical representations of this analysis, which led to the conclusion that our assumptions were conservative.

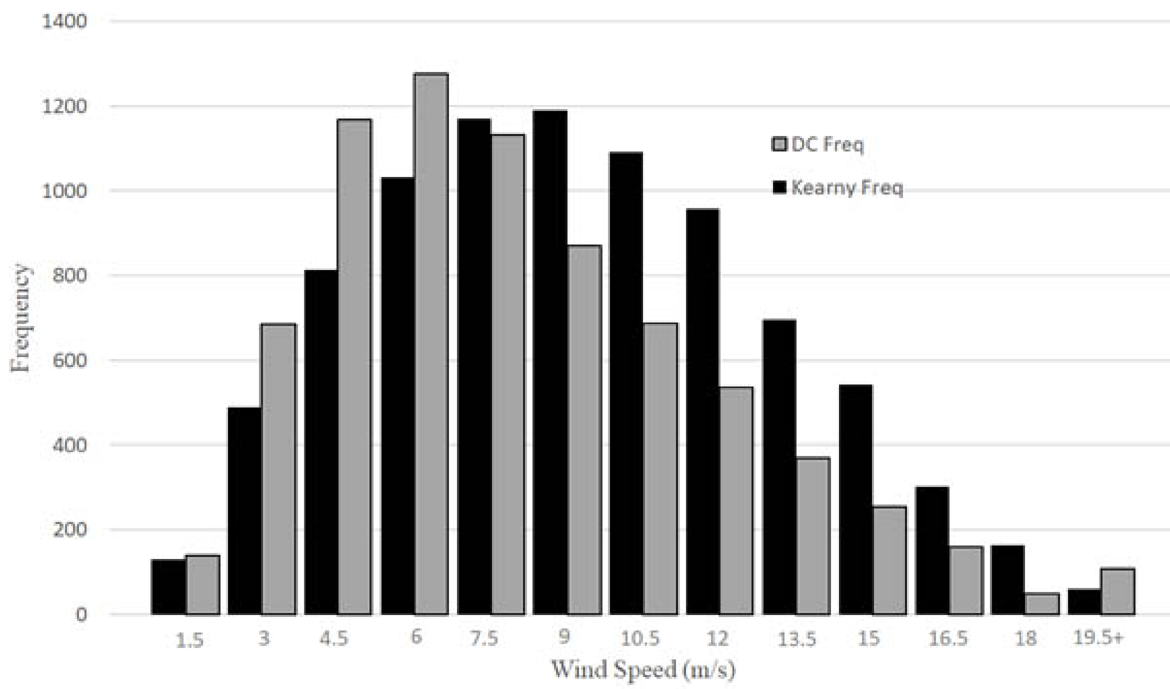

Figure 1: Histogram Comparisons Between Actual and Estimated Data

The histograms between Dodge City and Kearny matched well (for the sake of legibility, only Dodge City data are shown, but all studied cities exhibited this similarity). If anything, the use of the power law was conservative, since the extrapolated data were below the data obtained at 80m at higher wind speeds.

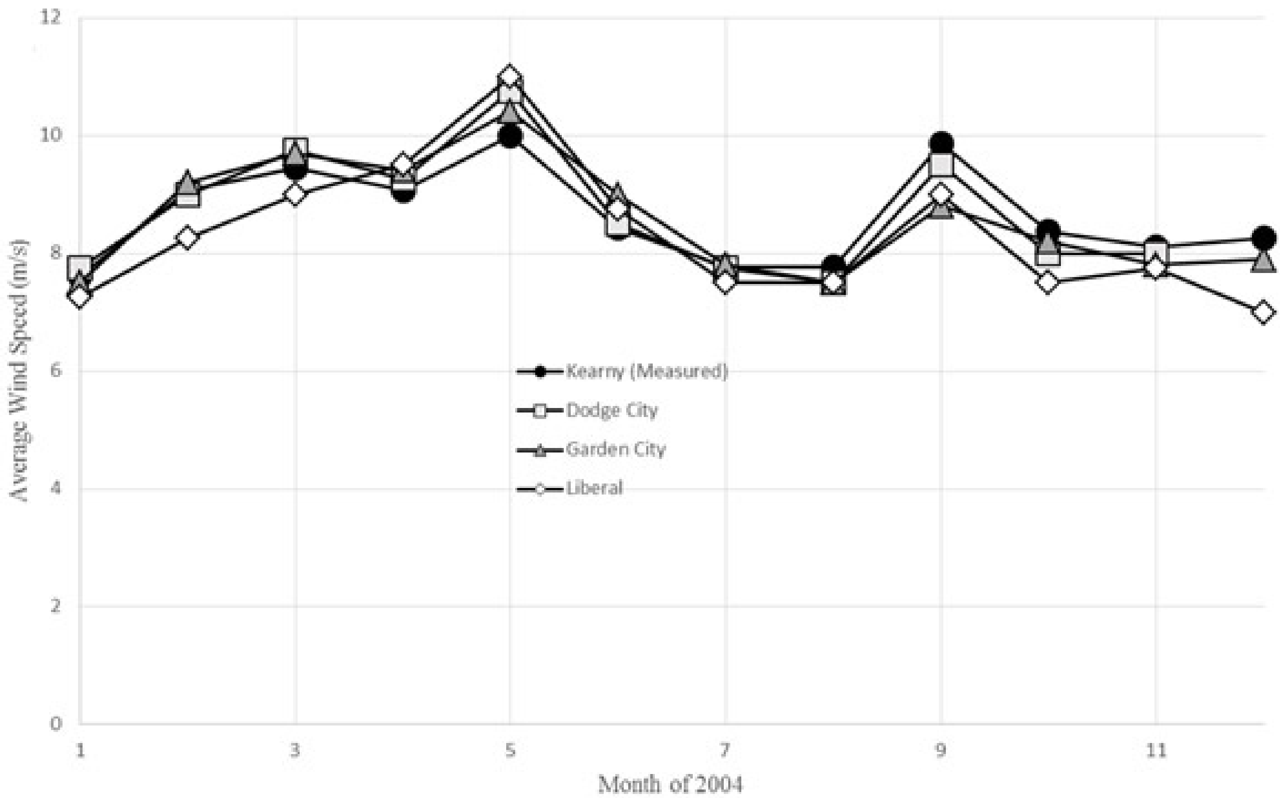

Figure 2: Monthly Wind Speed Averages, Actual versus Estimated

Figure 2 serves as a more generalized corroboration of our assumptions – though it does not display the same levels of precision as Figure 1, monthly averages would necessarily smooth over differences in measurement sensitivities between towers. Since Figure 2 shows that monthly averages are consistent regardless of the precision, we concluded that our assumptions were validated -- 0.2 was an appropriate value for α in southwest Kansas -- and analysis of WT performance could proceed.

Once we obtained 80 m wind speeds for the years 2011-2015 by extrapolating through Equation 1, we used Windographer to calculate Annual Energy Production (AEP) for six WT options: Endurance E3120 50 kW, Northwind 100-24C 100 kW, Endurance E35 225 kW, GE 1.5-77 xle 1.5 MW, Vestas V90 2.0 MW, and Siemens SWT-2.3-82VS 2.3 MW. To calculate AEP, we manually input power versus wind speed curves for each turbine (provided by their respective manufacturers), ensured their hub height were 80m, and used Windographer to multiply that WT power output by the wind histogram. This function yielded a power probability distribution function for each WT's power, which was integrated to give yearly power output. We selected this range of turbines to yield results for both commercial WTs and smaller, cheaper WTs.

In order to establish the efficacy of each turbine relative to one another, we estimated costs for installation price in dollars per watt of capacity, which are detailed in Table 1. We also assumed an estimated wholesale price for electricity, detailed in Table 2, which we based on personal correspondence with a Kansas rural electricity co-op. (Though electricity prices vary with respect to market demand and time of day, the range of wholesale prices we obtained with the backing of industry expertise gives a sufficient estimation for this feasibility study.) Payback time in years and the dollar value of the average year's energy production for each turbine were calculable using these quantities, enabling the analysis and comparison of turbines for each site.

We compared the AEP of each turbine between years and also between sites. Results were designed to illustrate two primary research questions: the payback time for each WT and the average annual revenue a turbine owner could expect from a WT. These results are compiled in a succinct visual format in Figures 3 and 4, respectively, displaying the data about which policy makers and farmers care the most.

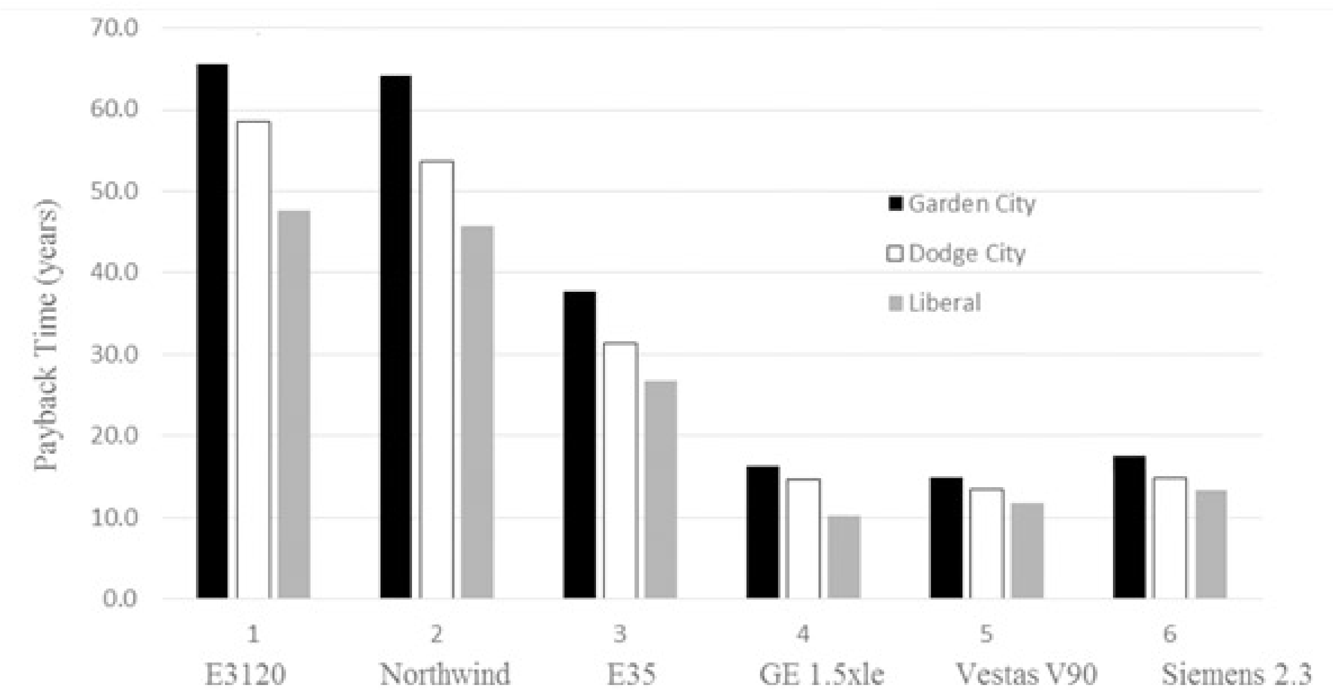

Figure 3: Estimated Payback Time for Six WTs

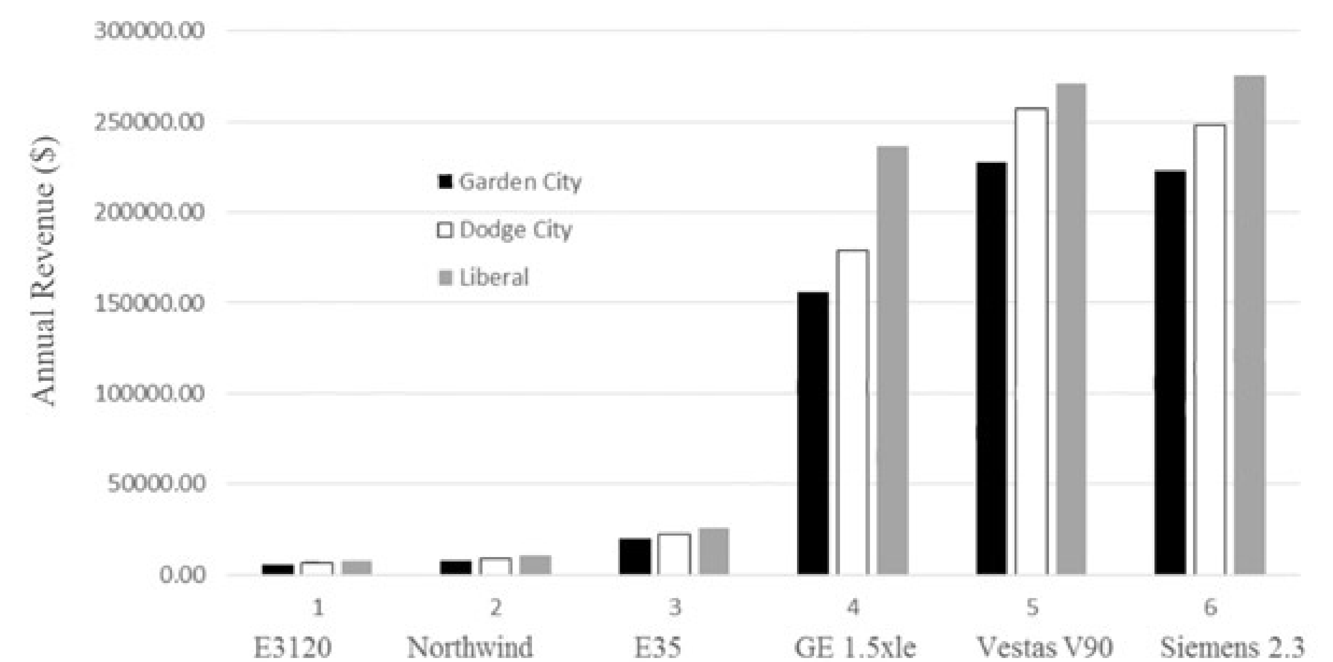

Figure 4: Estimated Annual Revenue for Six WTs

Further corroboration of our results was conducted by comparing our estimated AEPs with actual AEPs gathered by extant wind farms at Spearville, Central Plains, and Butler County ("Kansas Wind Energy," 2016). Though measured data were only available for GE and Vestas turbines, we discovered that our estimates for AEP were actually often 30% smaller than actual measurements, which is shown in Table 3. We concluded that our AEP estimates were conservative and that our assumptions did not compromise the health of our analysis.

Results

From Figures 1 and 2, we concluded that the 80m data were sufficiently similar to the measured data to warrant their use as the basis of further analysis.

Figures 3 and 4 display crucial data concerning the financial feasibility of creating a wind-for-water project. The difference between the highest and lowest outputs for a single turbine was calculated to be 38.2%, which was taken to be a reasonable upper bound for variation between turbines. When evaluating payback times and the revenue of the six turbines in question, it was observed that the WT with the lowest payback time was generally the Vestas V90 2.0 MW turbine, with a maximum payback time of 14.9 years. Generally, the service lifetime of such a turbine is 20 years, so the larger WTs would be able to pay themselves off during their lifetimes. However, the greatest annual revenue from any turbine was from the Siemens 2.3 MW WT, with a minimum revenue of approximately $223,000. In general, it was seen that turbines with low output will take longer to pay off (in some cases more than twice as long!), even though their initial install costs are lower. Larger capacity WTs, by contrast, were more cost-effective to construct, because their greater outputs helped to generate more annual revenue.

It was also noted that annual wind variation tended to be more important than geographic variation in the same region; in other words, our three cities varied more year-to-year among themselves than they did between each other. Also, a maximum 40% annual output variation (the highest annual variation for any single city that we studied) should be expected and built into calculations, but this variation will smooth out in aggregate throughout the WT's lifetime.

Opportunities for Further Study

There remain several opportunities and obstacles facing successful implementation of wind-for-water trade.

Since wind-for-water trade is primarily construed as a policy solution to aquifer depletion, it was necessary to include legal and market considerations in our analysis. The Kansas net-metering laws for distributed wind were introduced by the Net Metering and Easy Connection Act of 2009. DSIRE, a website managed by the NC Clean Energy Technology Center, summarizes net metering as a system that requires entities that sell electricity to be recognized as electric utilities ("Net Metering Program Overview 2016," 2016). Owners of renewable-energy generators must use either of the two following systems under net-metering:

The first system is known as net-metering. In this Kansas system, the generator owner sells excess electricity at retail rate within a month; excess generation at the end of the month is credited to the owner at wholesale rate. In Kansas, the maximum generator size for net-metering is 15kW residential, 100kW non-residential, and 150kW schools. Any utility can deny net-metering if the total net-metered capacity exceeds 1% of its peak electricity demand ("Net Metering Program Overview 2016," 2016).

The second option is called parallel generation. Under parallel generation, the generator owner sells excess electricity at 150% of the wholesale rate. This electricity is determined instantaneously, not over a day or month. The maximum generator size for parallel generation is 25kW residential and 200kW commercial. All utilities must allow parallel generation from any customer/member who requests it, up to 4% of its peak electricity demand ("Net Metering Program Overview 2016," 2016).

Investor-owned utilities must allow the owners of generators to have the option between net-metering and parallel generation. On the other hand, electric cooperatives are not required to allow net-metering, though most do. These legal considerations will not only inform the final feasibility of the project, but also inform the way in which wind-for-water trade is implemented in Kansas. For distributed wind owners, it appears that the higher-capacity WTs (the same WTs that are most feasible for wind-for-water trade) are not allowed under *either* system. Therefore, before the pursuit of wind-for-water policies can proceed, policymakers must evaluate locally distributed power generation systems, including the consideration of whether systems that emphasize options are optimal for distributed power in the first place.

In addition to policy solutions for net-metering laws, analysis is needed to eliminate some assumptions and determine the point of equilibrium between wind profit and irrigation loss. During our summer 2016 study, we lacked the expertise to assess the costs of decreased irrigation for individual farmers, so we have yet to prove that wind revenue will indeed outweigh a meaningful cut to irrigation water. Further study is warranted to determine if farmers currently over-irrigate, meaning that wind-for-water trade will be able to incentivize even deeper irrigation cuts; the decreased annual irrigation necessary to equal the revenue from wind-for-water trade; the effects of irrigation on local food production (if any) and any associated costs; and the effects of decreased irrigation on the Ogallala Aquifer in the long term. There are also significant implications in other renewable energy industries -- whether similar programs will work in solar energy, for instance.

Finally, there is significant study needed to determine other locations similar to southwest Kansas that will be ideal locations for wind-for-water trade, especially if the policy differences in those regions increase the likelihood of wind-for-water trade becoming reality. Since our process is easily generalized (even to other types of renewables like solar), other states interested in wind-for-water trade should find it simple to investigate the feasibility of their own programs and initiatives.

These scientific questions and others fuel this study, so one of its effects may be to increase dialogue between policymakers and scientists for the mutual benefit of constituents and the environment they inhabit. It is the hope of the authors that the potential benefits of wind-for-water trade pique interest and further scientific and political inquiry into its potentialities. We have learned that Kansas is not the only geographic area appropriate for wind-for-water initiatives, and our hope is that wind-for-water trade and other programs like it spread throughout the Midwest as its implications are furthered in southwest Kansas.

Acknowledgements

This research was made possible in part by NSF Grant 1460776 and NREL Subcontract AEV-6-62009-01. The authors would also like to thank Bud Estes, Kansas State Representative, and Bob Johnson, retired engineer, for their leadership in wind-for-water trade.

References

Chapman, J., Manuel, L., Morse, S., Slavens, R., Swift, A., & Walter, K. (2006). The use of tall tower field data for estimating wind turbine power performance. *The University of Texas at Austin.* Retrieved from http://www.ce.utexas.edu/prof/manuel/papers/SwiftManuel_AWEA2006.pdf.

Emeis, S. (2012). *Wind energy meteorology: Atmospheric physics for wind power generation*. Berlin: Springer Science & Business Media.

Kansas Wind Energy. (2016). *Kansas Energy Information Network*. http://kansasenergy.org/wind_projects.htm

King, J.E. (2005). Kansas tall tower wind resource data: Final report. Coriolis Architecture and Energy, for Wind Powering America. Golden, CO: National Renewable Energy Laboratory, US DOE.

Net metering program overview 2016. (2016). *DSIRE*. Retrieved from http://programs.dsireusa.org/system/program/detail/3403.

Appendix A: Supplemental Tables & Figures

Table 1: Estimated Installation Costs

Wind Turbine	**Cost ($/W)**
Endurance 50 kW	8
orthwind 100 kW	5.5
Endurance 225 kW	3.5
GE 1.5 MW	1.80
Vestas 2.0 MW	1.80
Siemens 2.3 MW	1.80

Table 2: Estimated Wholesale Electricity Rates

City	**Wholesale Electricity Price ($/kWh)**
Garden City	0.0978
Dodge City	0.1040
Liberal	0.1124

Table 3: AEP Comparison, Estimated AEP Versus Actual AEP

	2011 (kWh/yr)	**2012 (kWh/yr)**
Estimated AEP, GE WT	7,391,324	6,401,312
Actual AEP, GE WT	8,408,433	6,179,045
Estimated AEP, Vestas WT	6,803,755	7,395,435
Actual AEP, Vestas WT	8,939,152	8,919,152