Reflections on the Integration of Wind Energy into the Power Grid

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Abstract

This paper notes that the large scale integration of wind into the power system is likely to have only a minor impact on carbon emissions. It is also noted that wind energy is not inexpensive. There is peer reviewed literature from Europe that the wind turbines can create visual disamenities that are economically relevant. Wind energy is highly variable from hour to hour. The production levels are difficult to forecast and thus its large scale integration into the power grid presents a challenge to electric power reliability.

1. Introduction

According to the United States Energy Information Administration, the share of electricity generation in the United States from wind turbines was approximately 1.8 percent in 2009. Broad political support exists for increasing substantially this share. Some policymakers are in favor of attaining a 20 percent wind penetration level by 2030.[1] Given the magnitude of this proposed expansion, it is prudent to consider seriously its potential consequences.

This paper notes that the large scale integration of wind into the power system is likely to have only a minor impact on carbon emissions. It is also noted that wind energy is not inexpensive. There is peer reviewed literature from Europe that the wind turbines can create visual disamenities that are economically relevant. Wind energy is highly variable from hour to hour. The production levels are difficult to forecast and thus its large scale integration into the power grid presents a challenge to electric power reliability.

2. The Large Scale Integration of Wind Energy into the Power Grid is Expected to have only a Minor Impact on Carbon Emissions.

There are no direct carbon emissions associated with the production of electricity from wind turbines. In contrast, the production of electricity using coal gives rise to approximately two pounds of CO_2 per kilowatt-hour (kWh) while a modern natural gas combined cycle plant has a carbon “footprint” of about 0.80 pounds per kWh.[2] Based on these statistics, the environmental benefits of wind energy are maximized when wind energy displaces coal. However, the operators of power grids dispatch generating plants based on economics, not carbon intensity.

[1] For example, in October 2008, the California Public Utilities Commission and the California Energy Commission recommended a 33 % renewable energy requirement as a key strategy to reduce greenhouse gases. The plan, if implemented, would increase the wind energy capacity available to the California Independent System Operator (ISO) by almost 500 percent by 2020 with wind energy capacity accounting for approximately 18 percent of installed nameplate capacity (Hawkins, 2008). The European Union has a goal of 20 percent renewable energy by 2020 with wind energy serving as a key source of the increase.

[2] Based on data reported by the United States Energy Information (2010).

System operators base the dispatch of nonwind generation on private marginal costs with priority being given to generating units with the lowest private marginal costs (private marginal cost is the change in generation cost paid by the generating firm when output rises by one unit). An increase in scheduled wind energy will therefore reduce expected generation from higher private marginal cost generating units. While natural gas combined cycle plants are more efficient in power conversion than coal plants, the reality is that the short run private marginal costs of generating a MWh from natural gas is generally more than the short run private marginal costs of generating a MWh of electricity from coal because natural gas is more expensive than coal on an energy equivalent basis.[3] Thus, in the absence of a carbon tax or cap-and-trade legislation (either of which would discourage the production of electricity from carbon intensive fuels), an increase in wind energy has the unintended consequence of largely displacing natural gas, the cleanest fossil fuel.[4] One implication of this is that increases in wind energy penetration may have only a modest effect on carbon emissions. A 2008 study by the United States Department of Energy projects that carbon emissions from the electricity sector in 2030 will be substantially above the target level even if the wind penetration level rises to 20 percent (Figure 1).[5]

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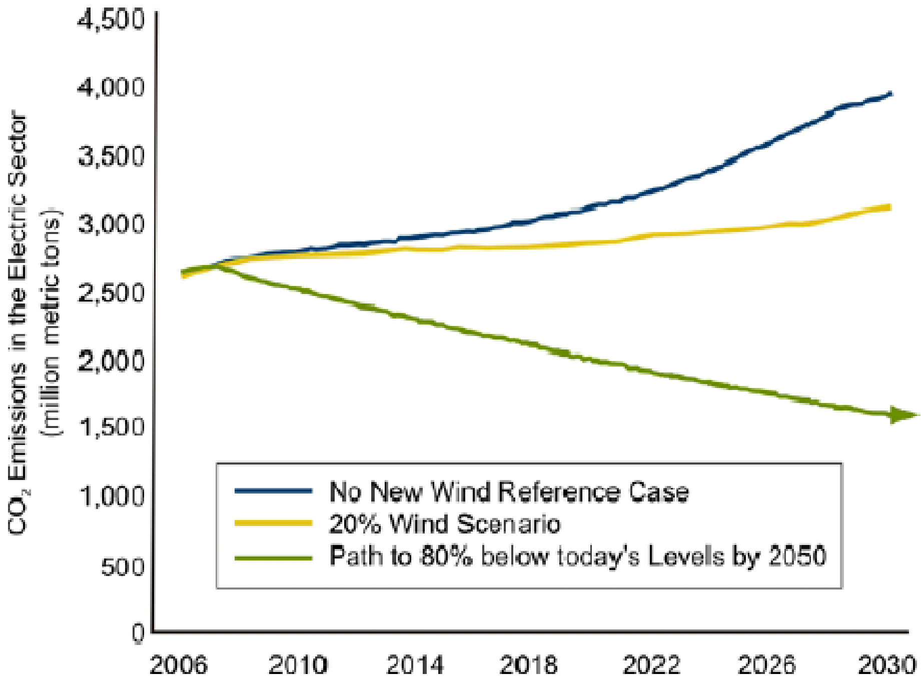
[3] For evidence on this point, see Figure 4 of the 2008 Midwest State of the Market.

[4] This point about wind displacing natural gas has also been made by a recently released study by MIT. The study can be downloaded at
http://web.mit.edu/ceepr/www/publications/Natural_Gas_Study.pdf
One caveat of this point is that wind levels less than forecasted may induce the system operator to dispatch turbines fueled by natural gas.

[5] Department of Energy, 2008, p. 8.

Figure 1. Wind Energy Scenarios and Carbon Emissions



Source: DOE (2008), p. 15.

3. Wind Energy is not Cheap

When the cost of electricity transmission is ignored, the United States is believed to have more than 8,000 Gigawatts (GW) of wind resources that the industry estimates can be developed at a cost of less than or equal to approximately $80 per MWh. [6] When transmission costs are factored in, only about 600 GW of resources could be available at a delivered price less than $100 per MWh with the vast proportion of this amount requiring a price of more than $60 per MWh (Figure 2).[7] To put these supply prices in perspective, the 2008 average day-ahead wholesale

[6] Department of Energy, 2008, p. 9.

[7] This estimate excludes the effect of the production tax credit and renewable energy credits on the supply price.

price in the Wisconsin-Upper Michigan area of the Midwest Independent System Operator (ISO) was $54.30 per MWh.[8]

One dramatic example of the economics of wind energy is the offshore Cape Wind project in Cape Cod, Massachusetts. Cape Wind and National Grid have filed a contract with the Massachusetts Department of Public Utilities under which National Grid would purchase from Cape Wind 50 percent of the project's output for $207 per MWh.[9] This is almost five times the Massachusetts' 2009 wholesale price of approximately $42 per MWh and thus represents a very high cost approach to reducing carbon emissions.[10] A cheaper approach to reducing carbon emissions would be to stimulate the substitution of natural gas for coal.[11]

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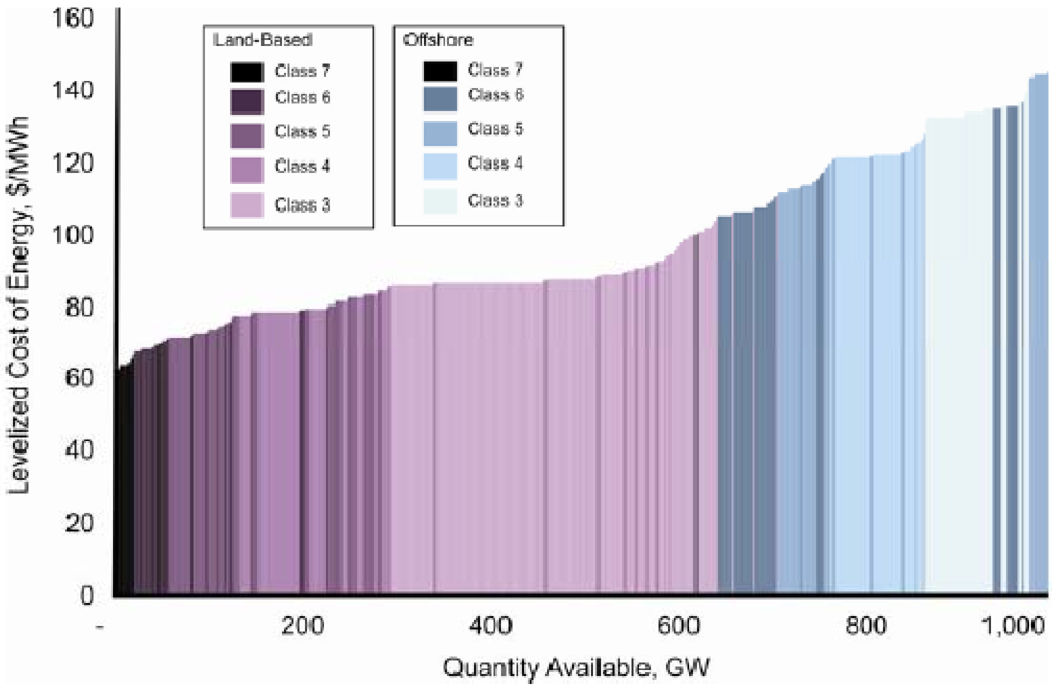
8 Midwest ISO 2008 State of the Market, p. 37.

9 http://www.windtoday.net/articles/National_Grid_and_Cape_Wind_Sign_Power_Purchase_Contract_-93520.html

10 The price of $42 per MWh is based on 2009 hourly price data reported by ISO England. This data are available at http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html

11 Minimizing the total cost of abatement for a desired level of emissions reduction from the power sector requires that marginal abatement costs be equalized across emission sources. There is no reason to believe that this technical condition for cost minimization is satisfied when renewable fuel mandates are imposed. Given the differences in carbon intensity between natural gas and coal, a cost minimizing abatement policy implies a substitution of natural gas for coal. For more on this point see the recently released study by MIT which is available for download at http://web.mit.edu/mitei/research/studies/report-natural-gas.pdf

Figure 2. The Supply Costs of Wind Energy



Source: DOE (2008), p. 9

Note: the "Classes" in the figure are categories of wind intensity. For information on wind classes, please see http://www.eia.doe.gov/cneaf/solar.renewables/page/wind/wind.html

4. Wind Turbines can Create Visual Disamenities.

There is published peer-reviewed evidence from Europe that a significant number of individuals would be willing to pay for wind turbines to be less visible. For example, Bergmann et al. (2006) have reported evidence that respondents in a survey in were willing to pay 12 Euros/year for reducing landscape impacts. Ladenburg and Dubgaard (2007) have reported evidence that there are significant preferences in Denmark for reducing the visual disamenities from offshore wind farms. Specifically, they report an average willingness to pay of 46, 96, and 122 Euros/household/year for having a wind project located at 12, 18 and 50km from the coast of Denmark as opposed to 8 km.

These results are not consistent with a recent study by Hoen et. al, (2009) that found no evidence of any adverse impact of wind energy development on property values in the United States. However, their results are open to question given that the wind projects were selected for analysis based in part on the advice of wind energy stakeholders.[12] Consistent with the suspicion that the sample was not representative, there are no observations in the sample in which the house in question had a premium view in the absence of the wind turbines and an extreme view of the wind turbines.[13]

There are other issues with the study by Hoen et. al. (2009) For example, in one of their models (pages 52-54 of the report) the natural logarithm of the sales price was regressed on a number of control variables and two series of binary variables. The first series of binary variables represent the intensity of the view of the wind turbines while the second series represent the quality of the view from the house in the absence of the wind turbines. The authors report evidence that the quality of the view from the house in the absence of the wind turbines affects the sales price but that intensity of the view of the turbines does not. One acknowledged shortcoming of this model is that it presumes that the impact of wind turbines on the dependent variable is independent of the quality of the view in the absence of the wind turbines. The authors attempt to address this shortcoming by creating an interaction variable which equals the product of the two series of binary variables. This is akin to multiplying apples and oranges since the product of the two series does not represent a unique combination of the two measures. The coefficient on this improperly constructed variable is negative and statistically significant at the 10 percent level indicating modest statistical support for the hypothesis that wind turbines can have an adverse impact on property values. One can only wonder what the statistical significance would be if the sample were representative and the interaction effect were properly modeled.

Hoen et. al. (2009) also examine whether wind turbines create a "nuisance stigma" in the sense that sound and shadow flicker may depress the values of homes that are in close proximity to wind turbines. In one of the models aimed at testing for this, they create a number of binary

[12] This point is acknowledged on page 11 of Hoen et. al. (2009)

[13] The authors concede this point in footnote 90 on page 53.

variables to represent the distance between the house and the closest wind turbine. The categories are as follows: distance < 3000 feet, 3000 feet ≤ distance < one mile, one mile ≤ distance < three miles, three miles ≤ distance < five miles, distance ≥ five miles. The coefficients on the first two binary variables are negative but are statistically insignificant. Given this statistical insignificance, the authors report that there is no evidence of "nuisance stigma."

Closer inspection of these results is warranted. There are 4,937 observations in the sample but there are only 67 observations in the first distance category, i.e. distance < 3000 feet. This is the category that one would expect nuisance stigma, if it exists, to be evident. The authors chose 3000 feet as a cutoff for this category "because it was the closest cutoff that still provided an ample supply of data for analysis." [14] Given that sound and shadow flicker may be irrelevant when distance exceeds say, 2000 feet, one can only wonder what the statistical significance of the estimated coefficient would be if more data had been employed and the cutoff of the first distance category were 2000 feet as opposed to 3000 feet.

Hoen et. al. (2009) examine whether wind turbines create "area stigma," which they define as "as a concern that the general area surrounding a wind energy facility will appear more developed, which may adversely affect home values in the local community regardless of whether any individual home has a view of the wind turbines."[15] The authors test for area stigma using a number of econometric specifications. In each of these specifications, area stigma is tested for using variables that represent distance of the house from the nearest wind turbine. No evidence of "area stigma" is obtained.

A few remarks are in order. Suppose there are two identical houses, ABC and XYZ located in two different counties. They are both located one mile from the nearest turbine. But the turbine corresponding to ABC is part of a 100 turbine wind energy facility while the turbine corresponding to XYX is part of a three turbine facility. The models estimated by Hoen et. al. (2009) would treat these two observations as identical when in fact they are not in terms of wind turbine density. Accordingly, the reported tests for "area stigma" are not convincing.

The solution to this problem would to include turbine density (e.g. turbines per square mile for the zip code) as an explanatory variable. When including this variable, one would want to test for threshold effects since area stigma may only be evident once a certain level of turbine density is attained.

[14] footnote 38 on page 15.

[15] Heon(2009), p 69.

5. Wind Energy is Difficult to Forecast and thus its Integration into the Power Grid Presents a Challenge to Electric Power Reliability

Under currently technology, it is not economically viable to store large quantities of electricity. Moreover, the stability of a power grid requires that the supply of electricity equal demand, on a near-instantaneous basis, at all times. Given these realities, wind energy can represent a challenge to operations because production levels are largely uncontrollable.[16] There is also evidence in the case of ERCOT (Electric Reliability Council of Texas), the system operator for the vast proportion of Texas, that wind energy production levels are difficult to forecast. This is quite apparent in the case of January 2010 (Figure 3). Figure 4 presents a histogram of the forecast errors over the period 13 June 2009 through 28 February 2010. Observe that the forecasts are biased in the sense that the forecasting system tends to overpredict the actual level of wind energy.

It is sometimes suggested that the uncertainty in wind power forecasting is not necessarily greater than the uncertainty in forecasting load, i.e. consumption. Analysis of the data does not support this view. For example, the root-mean-squared errors of the day-ahead wind forecasts in ERCOT were more the 50% percent of mean wind energy production over the period 13 June 2009 through 28 February 2010. [17] To put this measure in prospective, the root-mean-squared errors of the load forecasts in the Midwest ISO are approximately 3.5 percent of mean load.[18]

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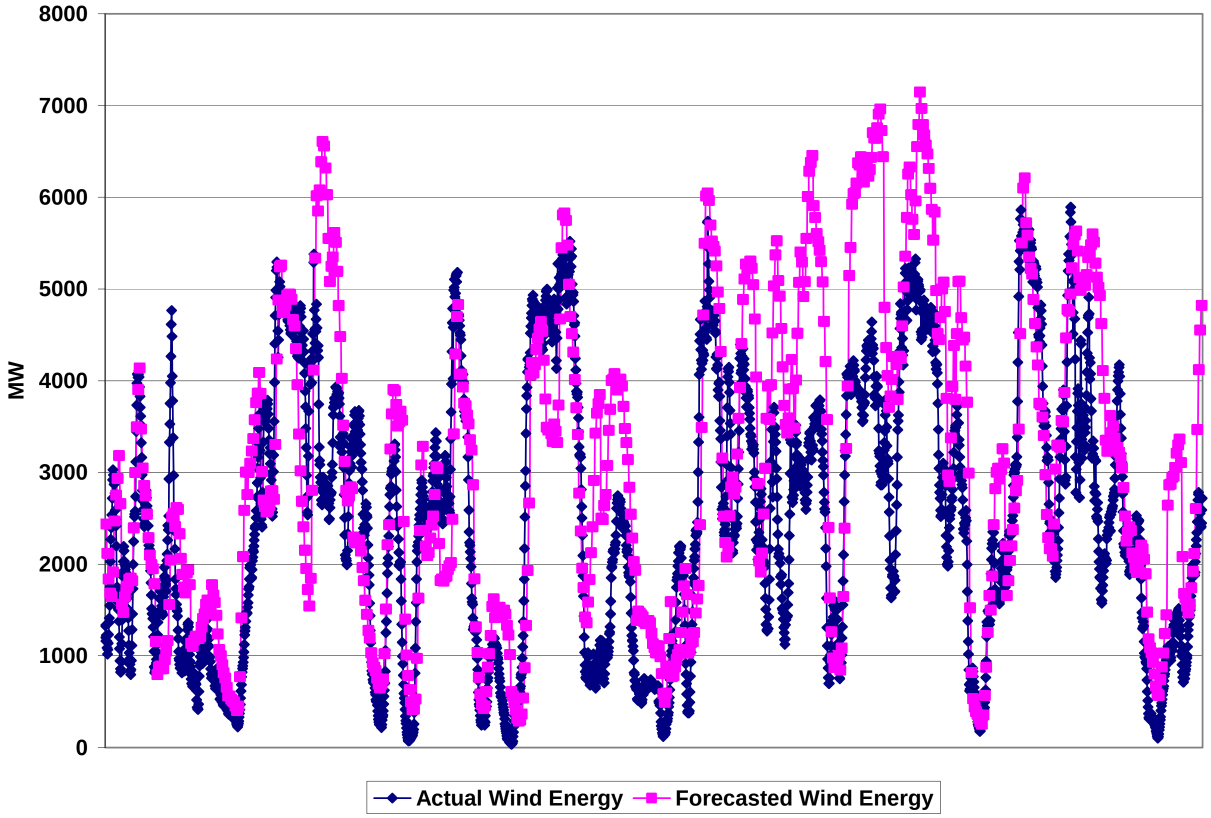
[16] Wind generation can be reduced but the system operator cannot direct that wind generators increase their output.

[17] The root-mean-square-error is a measure the average of the square of the "error”. Specifically, it equals the squared root of the average squared error.

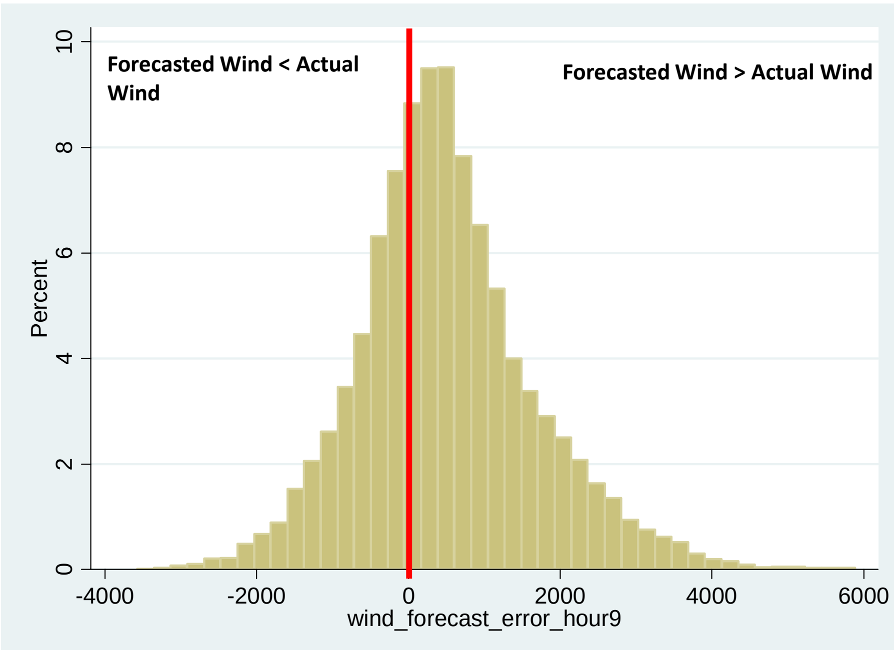
[18] This measure was calculated by the author using hourly data from the Midwest ISO over period 1 January 2009 through 30 December 2009.

Figure 3. Forecasted and Actual Wind Energy Production Levels in ERCOT, January 1-31, 2010



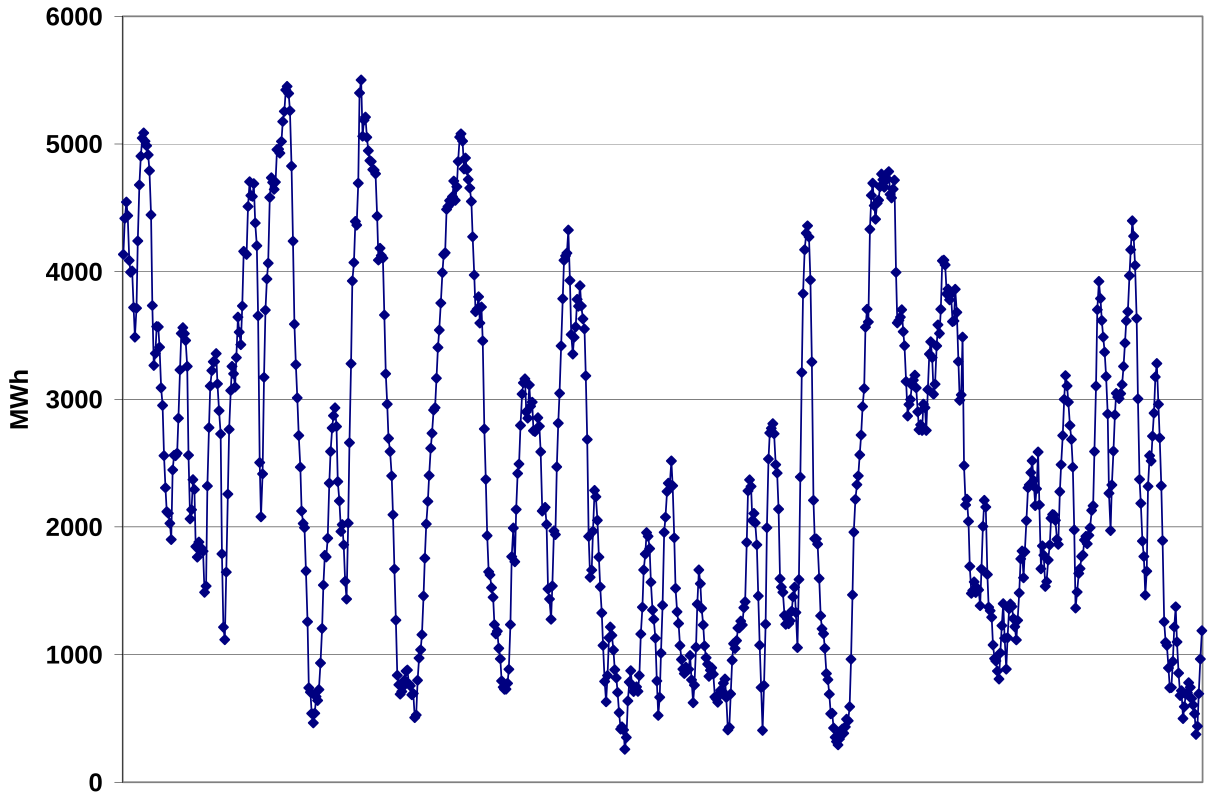
Source: Based on data reported by ERCOT. Note: the day-ahead forecasts in the figure are ERCOT's 9:00 AM forecast.

Figure 4. A Histogram of Day-Ahead Wind Forecasting Errors in ERCOT, 12 June 2009-28 February 2010.



Source: Based on data reported by ERCOT. Note: the day-ahead forecasts in the figure are ERCOT's 9:00 AM forecasts.

Figure 5. Hourly Wind Energy Production in the Midwest ISO, May 1-31 2010



Source: Midwest ISO

There is evidence that both the variability in wind energy production and the forecast errors in ERCOT have adverse operational impacts.[19] This may be tolerable when the wind energy's share of total generation is low but may represent a major challenge to operations when higher penetration levels are attained.

It is sometimes asserted that the advances in forecasting wind in Europe over the past decade makes it possible to achieve high levels of wind integration with little or no effort.[20] Unfortunately, the data from Germany, a country with one of the world's highest levels of wind integration, does not entirely support this view. True, the errors have declined but they remain quite large. As recently as 2005, the root mean squared errors in 50Hertz, one of Germany's

[19] See Forbes, Stampini, and Zampelli (2010a).
[20] For example, see EWEA, (2007).

largest power grids (formerly known as Vattenfall) were approximately 50 percent of mean wind energy production. The root mean squared errors in 2009 were approximately 35 percent of mean wind energy production.[21] The 2009 wind forecasting errors in the Amprion and Transpower systems (formerly known as RWE and E.ON Netz), the other two major transmission systems in Germany, are of the same order of magnitude. The wind forecasting errors in the Republic of Ireland are also approximately 35 percent of mean wind energy production. [22]

The Midwest ISO does not release sufficient data to be able to meaningfully report on the wind forecasting errors within its control area.[23] It is unlikely that the wind forecasting errors are significantly less than those in Germany. In any event, consistent with the view that the errors are probably very large, the wind energy production levels are highly variable (Figure 5).

Wind energy production levels in the Midwest ISO averaged 1,678 MWh per hour in 2009 which was approximately equivalent to 2.7 percent of average system load. This level of wind energy production was approximately 74 percent higher than in 2008. Production during the first five months of 2010 was 2,416 MWh per hour, up approximately 35 percent over the period in 2009 and almost three times the levels during the same period in 2008.[24] Much of this increase is believed to be driven by renewable energy requirements by the various states and the 2.1 cent per kWh production tax credit from the Federal government during the first 10 years of production.[25]

There are operational challenges arising from the boom in Midwest wind energy production. As in ERCOT, wind generation is often negatively correlated with load and thus the value of the additional generation is open to question. Moreover, in the Midwest ISO, wind generation resources are currently exempt from all Revenue Sufficiency Guarantee (RSG) costs, including must-run, deration, excessive energy, and deficient energy deviations.[26] Ironically, it is believed

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[21] Despite the decline in the relative error, there is evidence that wind energy remains a challenge to operations. Please see Forbes, Stampini, and Zampelli(2010b).

[22] Calculated by the author based on data downloaded from Eirgrid, the system operator in the Republic of Ireland.

[23] Using freely available data from the website of the Midwest ISO, the author has been able compare hourly forecasted wind energy levels with actual hourly levels for 14 days in June 2010. Based on these data, which may not be representative given that there are only 336 observations, the root-mean-squared error of the wind forecasts is approximately 34 percent of mean wind energy production.

[24] Calculated by the author based on hourly data downloaded from the Midwest ISO.

[25] The American Recovery and Reinvestment Act provides a three-year extension of the production tax credit (PTC) through December 31, 2012. Under the act, wind project developers can choose to receive a 30% investment tax credit (ITC) in place of the PTC for facilities placed in service in 2009 and 2010, and also for facilities placed in service before 2013 if construction begins before the end of 2010.

[26] Midwest ISO 2008 State of the Market, p. 60. RSG payments are payments made to generators committed by the Midwest ISO when the market revenues are not sufficient to cover the generators' as-offered production costs. Generation resources that are not committed in the

that the variability in wind output can increase RSG costs since additional conventional generation resources are required to manage the variability.[27]

The Midwest ISO is well aware of the operational challenges associated with higher wind penetration levels. In its words,

> "Although wind provides substantial environmental benefits relative to most conventional generation, it also presents significant operational challenges that need to be addressed before larger amounts of wind generation can be integrated into the market."[28]

The Midwest ISO is to be applauded for its candor. However, given the strong political support in favor of increased wind energy penetration, it may be difficult for the ISO to impose a moratorium on new wind energy projects even if the operational challenges are not resolved. It is more likely that the system operator will seek to impose rules that would penalize wind energy producers for the variability and relative unpredictability of wind energy.[29] Such rule changes have already been proposed in Texas.[30] This is also the reality in Denmark, a country where wind energy accounts for approximately 20 percent of load.[31] This could significantly adversely affect the economics of wind energy production for wind generating units that are no long eligible for the production tax credit (the production tax credit only applies for the first ten years), especially in states such as Wisconsin where the wind resources are marginal.[32] Some wind energy projects could prematurely cease production as a result. If the financial resources available for

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day-ahead market but must be dispatched to maintain reliability (gas turbines) are the most likely recipients of these payments.

[27] Ibid.

[28] Midwest ISO 2008 State of the Market, p. 61.

[29] The market monitor in the Midwest ISO has in fact recommended that "…payments for RSG and other services (e.g., reserves, regulation) should be assessed to wind generators in accordance with the costs that such generators cause in order to provide these suppliers efficient operating and investment incentives." (Midwest ISO, p. 64)

[30] See Gold (2009)

[31] In Denmark, wind producers offer their production for sale in the day-ahead spot market and are penalized for the difference between actual and scheduled output depending on the overall market imbalance. For example, if there is a shortage in the overall market and generation from wind power plants is lower than offered, then upward regulating power will need to be dispatched by the system operator in order to maintain the overall power balance. In this case, the wind producer will receive a price that is less than the day-ahead spot market price (other producers who are in deficit will also be penalized). For more on this point, see http://www.wind-energy-the-facts.org/en/part-3-economics-of-wind-power/chapter-5-wind-power-at-the-spot-market/power-markets.html

[32] According to the EIA, the vast proportion of Wisconsin has class 2 wind resources. This category of wind resources is considered marginal. (http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig13.html)

the decommissioning of inactive turbines are inadequate, this could leave some communities with views of abandoned or largely inactive wind turbines.[33]

6. Conclusion

The integration of wind energy into the power grid is perceived as an important metric of action to reduce carbon emissions. However, simply having more wind energy on the power grid may not result in cost effective reductions in carbon emissions. To reduce carbon at the least cost to society, firms need incentives to reduce emissions from the most carbon intensive fuels. It is not a socially desirable outcome to have carbon reductions undermine the reliability of the power grid. At a very minimum, consideration should be given to slowing the rapid pace of wind energy development before the operational challenges that the Midwest ISO faces become intolerable. Absolutely no weight should be attached to the findings of Hoen (2009) who report no relationship between wind turbines and property values. Instead, following from Ladenburg and Dubgaard (2007), consideration should also be given to mitigating the impacts of turbines on the welfare of individuals in the surrounding communities.

[33] There are of course requirements in Wisconsin that totally inactive turbines be decommissioned. However, it may be possible for the owner of an unprofitable turbine to delay the decommissioning costs by running the turbine at a low level.

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