

The Relationship between Wind Energy and System Operator Actions to Ensure Power Grid Reliability: Econometric Evidence from the 50Hertz Transmission System in Germany

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The Findings of this Study

- The claims that wind energy is “fairly predictable” are based on data where the forecast errors are weighted by capacity.
- The forecast errors are very large relative to the level of wind energy that is actually produced.
- Using data from Germany, wind energy is found to have implications for actions by the system operator to ensure reliability.
- Evidence is presented that the incidence of the reliability actions can be forecasted based on day-ahead information.

The Current Study

- Focuses on the 50Hertz transmission control area in Germany (formerly known as Vattenfall).
- Over the period 1 May 2008 through 31 December 2009 wind energy accounted for approximately 18.5 percent of consumption.
- The installed capacity of wind farms in the control area is about 10,000 MW which is equivalent to 41 percent of Germany's total wind energy capacity.

Electricity Control Areas in Germany



The Integration of Wind Energy into the Power Grid

The ***consensus view*** [*Cali et al. (2006), GE Energy (2010), Giebel et al. (2011), Holttinen, et al. (2006), Kariniotakis et al. (2006), Krauss et al. (2006), Lange, et al. (2006, 2007), Milligan, et al. (2009)*] seems to be that wind energy, though incapable of “upward dispatch”, is ***reasonably predictable*** and therefore ***large scale wind energy penetration should not pose serious challenges to grid stability and reliability.***

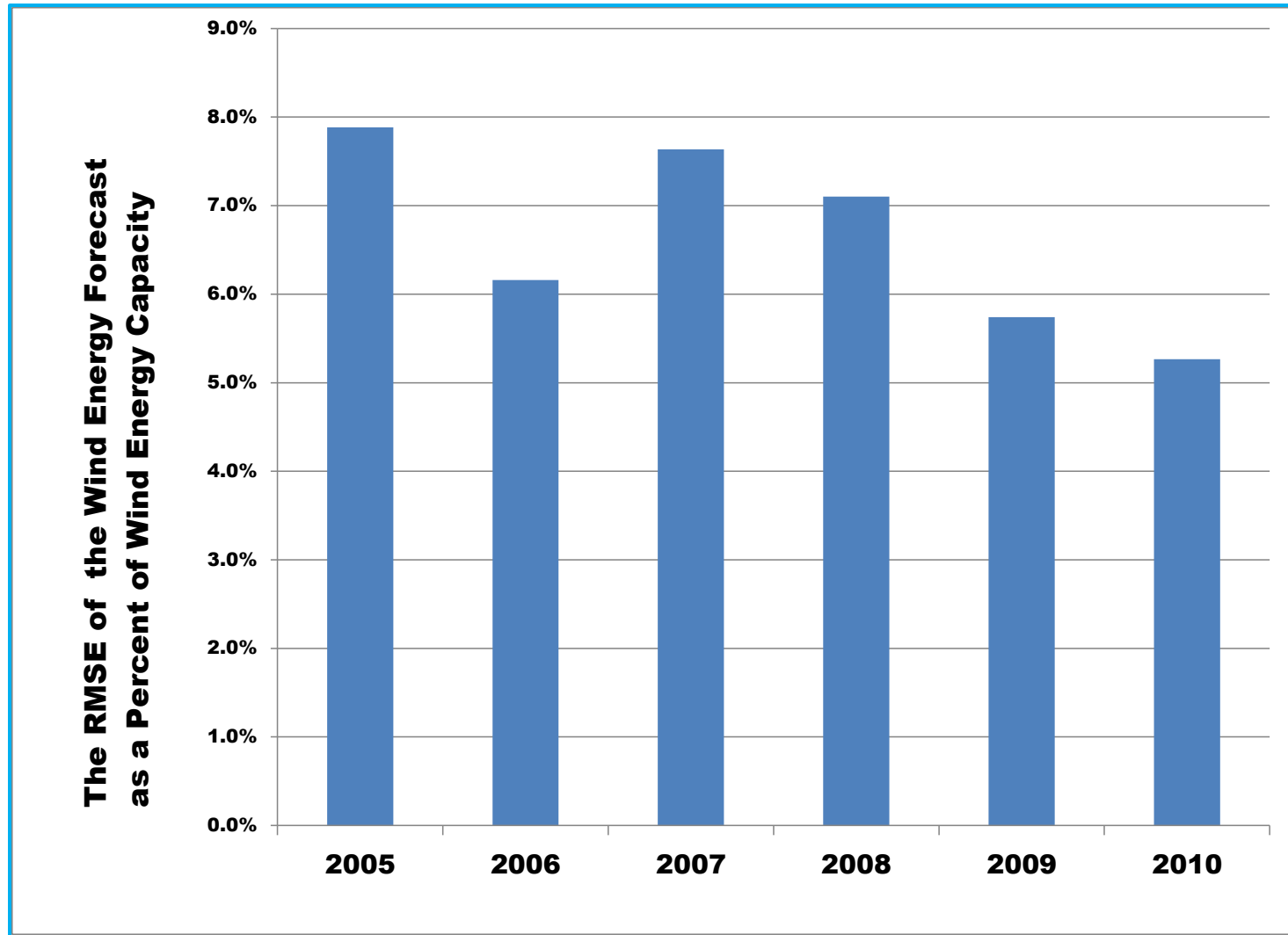
***Are the data consistent
with the consensus view?***

The Capacity Weighted Root Mean Squared Error (*CWRMSE*)

$$CWRMSE = \frac{\sqrt{\sum_{t=1}^T \frac{(Actual_t - Forecast_t)^2}{T}}}{Installed Capacity}$$

For all of Germany, *Milligan, et al. (2009)* calculate *CWRMSE values of between five and seven percent.*

Capacity Weighted Day-Ahead Wind Forecast Errors in 50Hertz 1 January 2005 to 31 December 2010

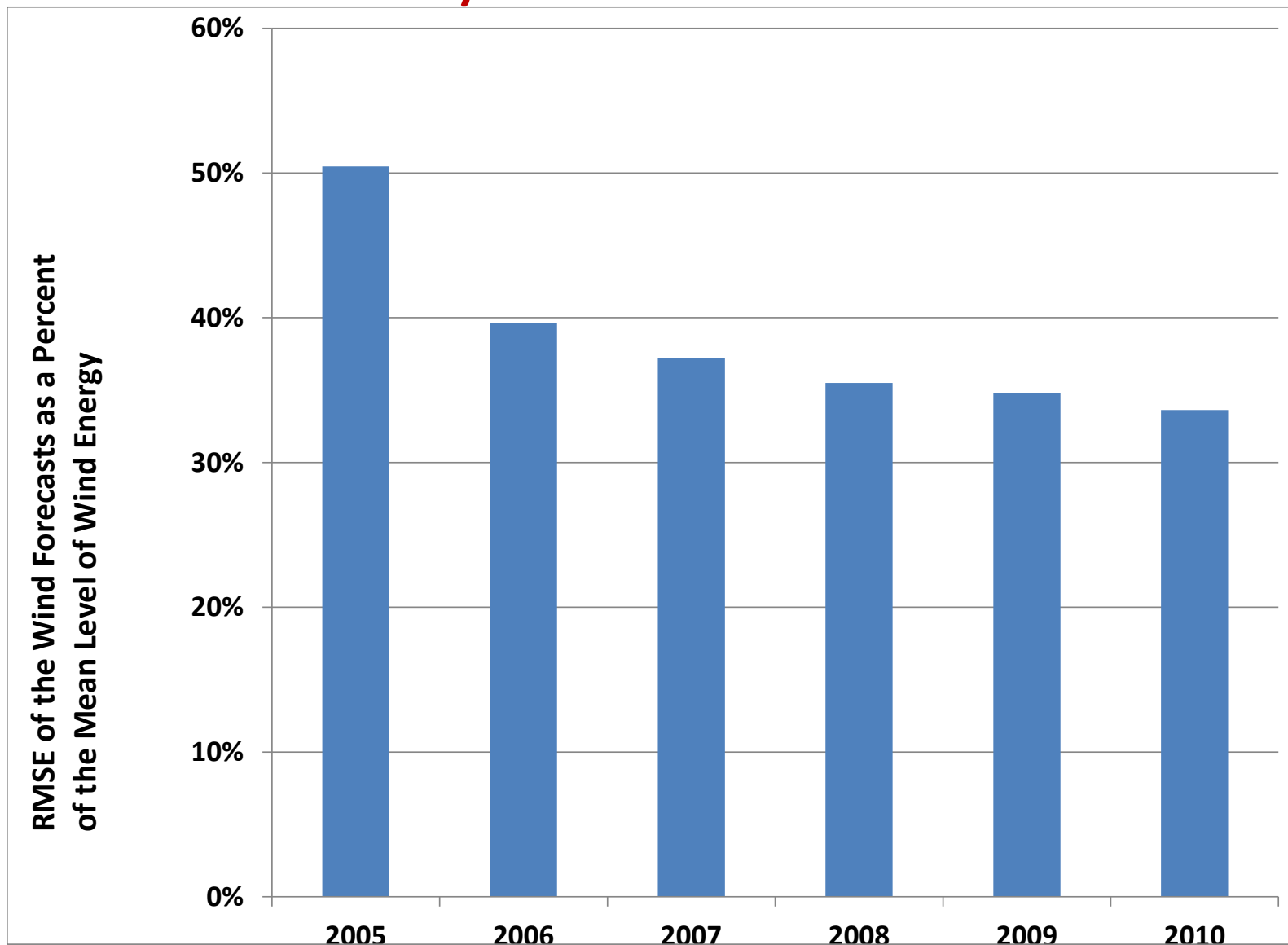


An Alternative Metric: The Energy Weighted Root Mean Squared Error (*EWRMSE*)

$$EWRMSE = \frac{\sqrt{\sum_{t=1}^T \frac{(Actual_t - Forecast_t)^2}{T}}}{Mean\ Energy\ Produced}$$

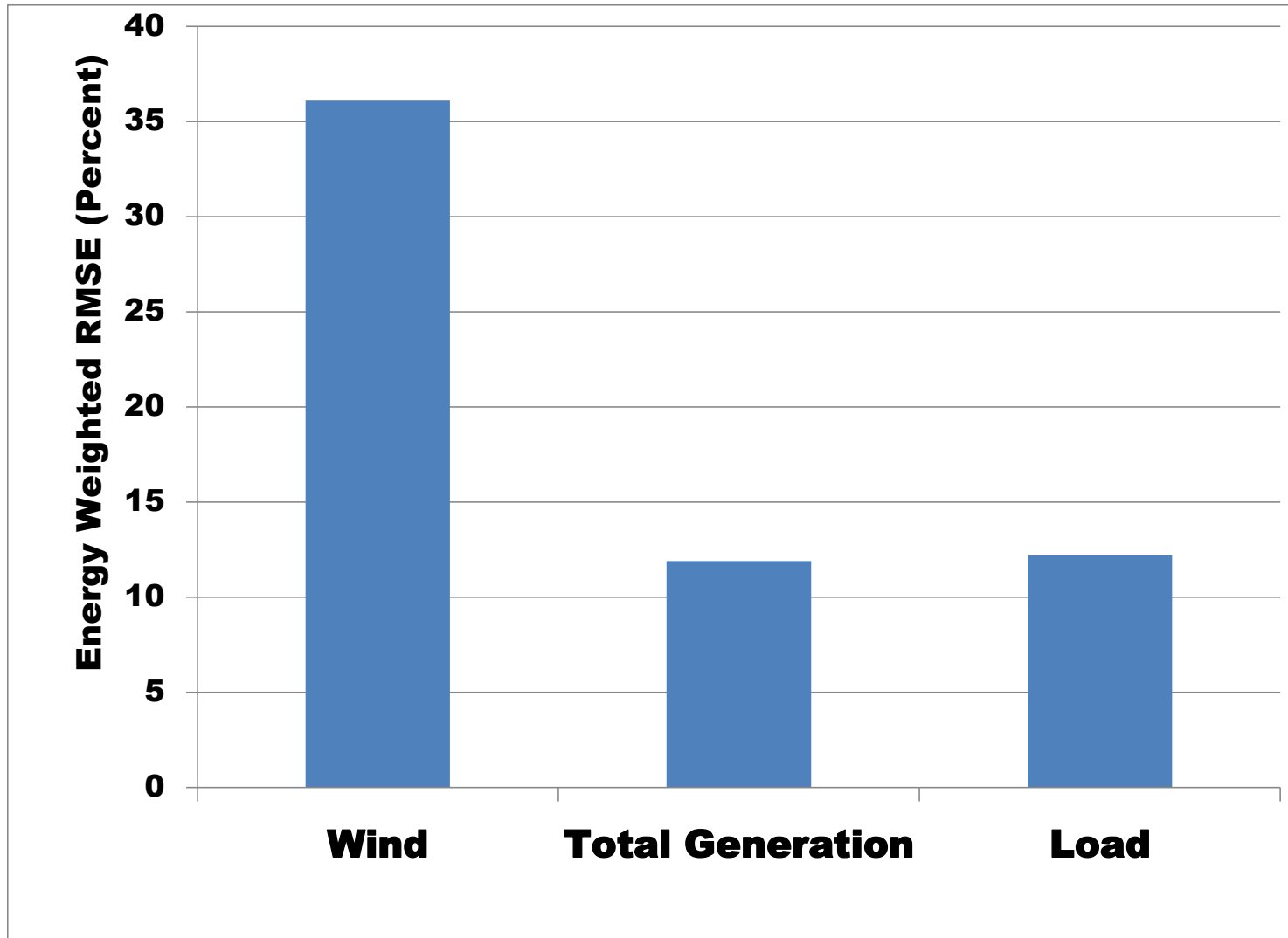
Observe that the RMSE of the forecast is measured *relative to the mean of the variable that is actually being forecasted*. The *EWRMSE* can be *fairly* compared to load forecasting errors which are *analogously weighted by mean load*.

Energy Weighted Day-Ahead Wind Forecast Errors in 50Hertz 1 January 2005 to 31 December 2010

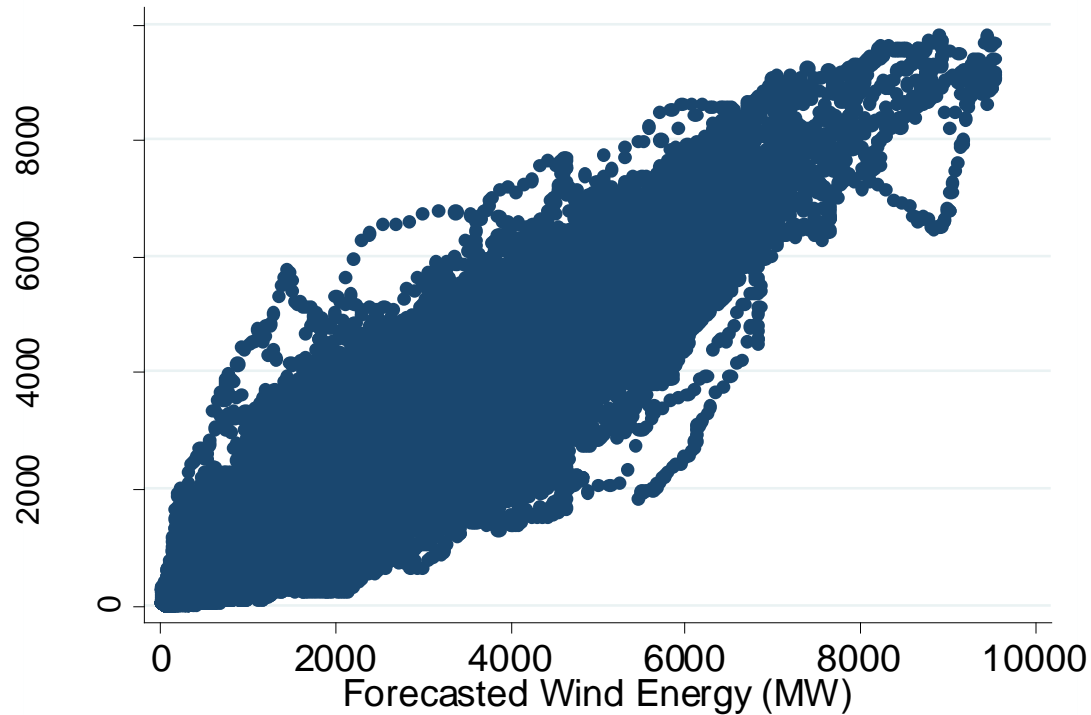


Energy Weighted Forecasting Errors in 50Hertz

1 May 2008 – 31 December 2010



Forecasted and Actual Wind Power in 50Hertz 1 May 2008 -31 December 2010



What is Wrong with the *CWRMSE* as a Metric of Energy Production Forecast Accuracy?

- The necessary balance between electricity demand and electricity supply is in terms of *megawatts of energy, not installed capacity or energy weighted by installed capacity*.
- Capacity weighted wind errors *cannot/should not be compared to load forecast errors because the latter are weighted by mean load and not by the capacity of the equipment that consumes electricity*.
- This issue is discussed in more detail in an article scheduled to be published in the April 2012 Electricity Journal

Actions Undertaken by the System Operator to Ensure Reliability

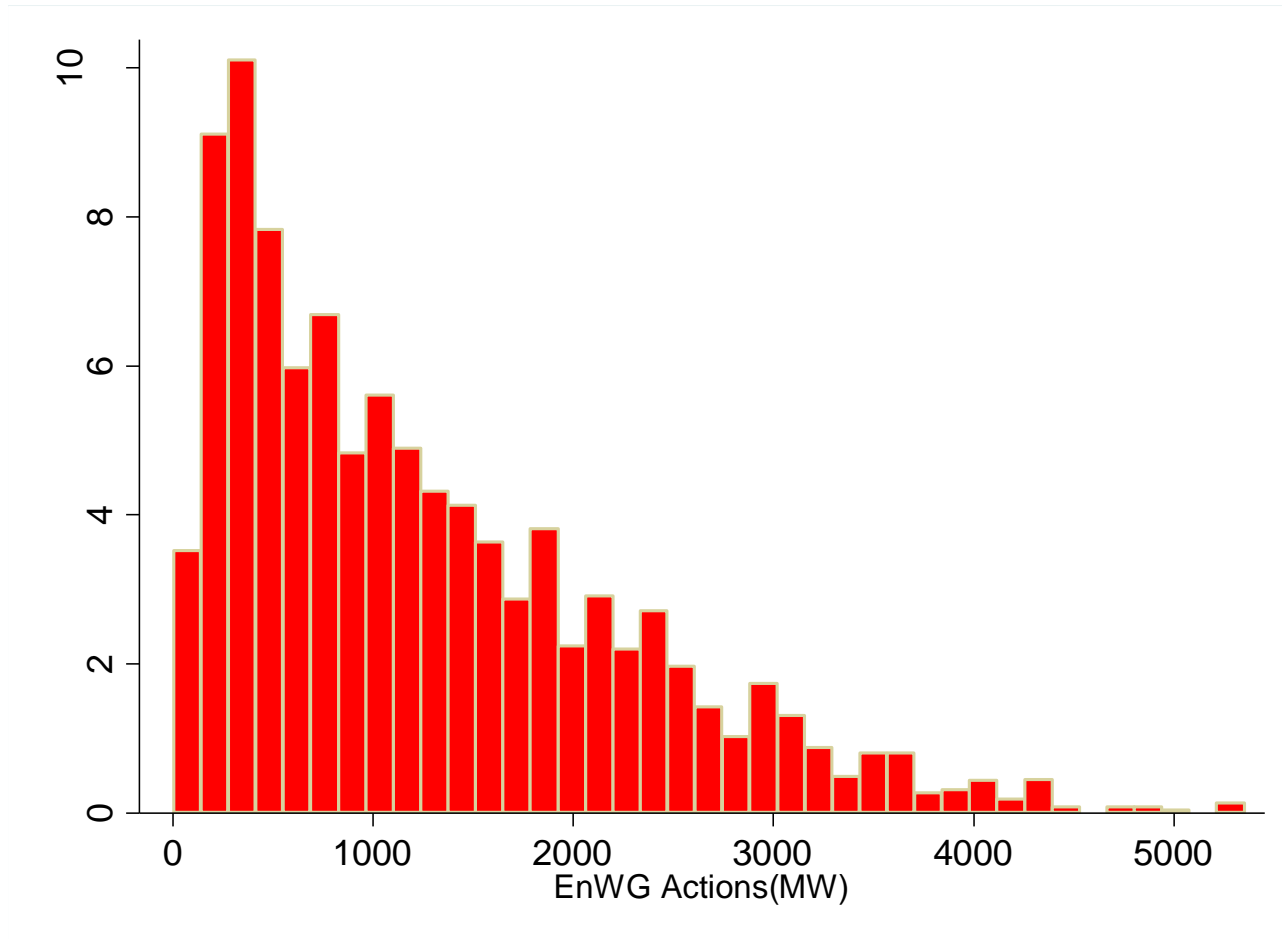
- We consider the possible effect of wind energy on the need to take actions under S.13.1 and S.13.2 of the German Energy Industry Act (EnWG) to ensure “safe, secure, and reliable operations.”
- These actions include redispatch of generating units and modification of power feed-ins.
- The actions are relatively infrequent but can be large in magnitude.

EnWG Actions

- Over the period 1 November 2008 – 31 December 2009, EnWG actions were undertaken in about 22 percent of the reporting periods.
- The median action was 1,000 MW
- In five percent of the cases, the action by the system operator exceeded 3,180 MW
- In one percent of the cases, the action by the system operator exceeded 4,155 MW

Size Distribution of EnWG Actions*

50Hertz



**Note that zero observations have been excluded. The area shown comprises approximately 20 percent of the complete size distribution for EnWG actions in 50Hertz.*

A “Parsimonious” Econometric Model of Reliability for 50Hertz

- Reliability is modeled as a binary variable equal to one if an EnWG action occurred and equal to zero, otherwise.
- Explanatory variables: forecasted load, forecasted wind relative to forecasted load, and the errors in forecasting both load and wind energy
- Estimation Method: Complementary Log-Log

A Multivariate Model of Reliability Actions

Implementation of EnWG procedures is hypothesized to be a function of the following factors: forecasted load, forecasted wind relative to forecasted load, and the errors in forecasting both load and wind energy. The model distinguishes between positive and negative forecasting errors.

$$\begin{aligned} \text{Ln}(-\text{Ln}(1-p)) = & c + \alpha_1 \text{FDemand} + \alpha_2 \text{FWINDShr} \\ & + \alpha_3 \text{NegDemandError} + \alpha_4 \text{PosDemandError} \\ & + \alpha_5 \text{NegWindError} + \alpha_6 \text{PosWindError} \end{aligned} \quad (1)$$

where p_t is the probability of an EnWG event.

The transformation on the left-hand side of (1) is the complementary log-log transformation.

Explanatory Variables

- **FDemand_t** is the forecasted level of load for period t
- **FWindShr_t** is forecasted Wind Energy in period t relative to Forecasted load in period t

Explanatory Variables (Continued)

- **NegDemandError_t** equals the absolute value of the difference between the forecasted and actual level of demand when the forecasted level of demand is less than actual. It is zero otherwise
- **PosDemandError_t** equals the absolute value of the difference between the forecasted and actual level of demand when the forecasted level of demand is greater than actual. It is zero otherwise

Explanatory Variables (Continued)

- **NegWindError_t** equals the absolute value of the difference between the forecasted and actual level of wind energy generation in period t when the forecasted level of wind energy generation is less than actual. It is zero otherwise.
- **PosWindError_t** equals the absolute value of the difference between the forecasted and actual level of wind energy in period t when the forecasted level of wind energy generation is greater than actual. It is zero otherwise.

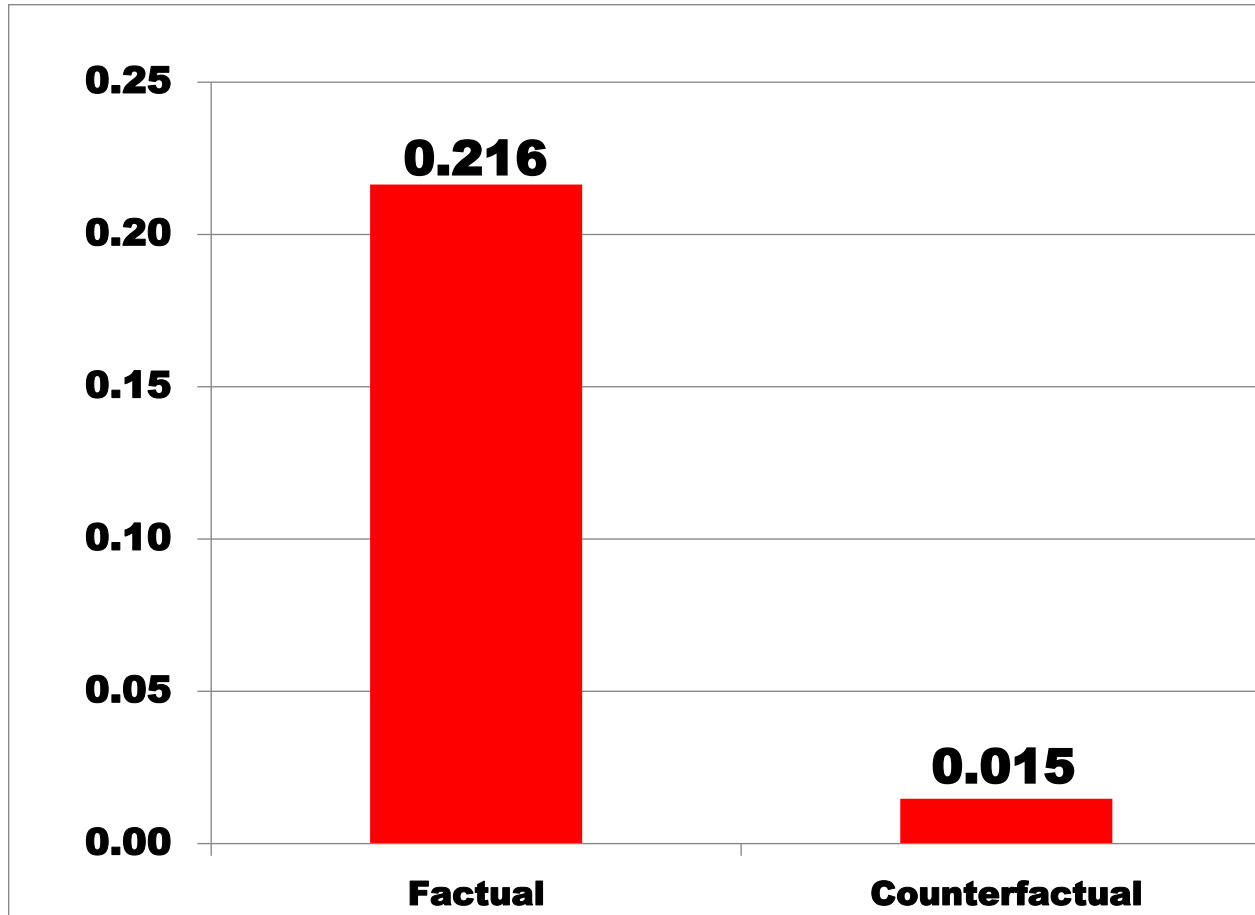
Estimation Results for Equation 1

Variable	Estimated Coefficient	T-Statistic	P-Value
C	-6.3545	54.8	~0
FDemand	0.0002	17.4	~ 0
FWindShr	10.0881	85.0	~ 0
PosDemandError	-0.7459	5.5	~ 0
NegDemandError	4.7995	22.0	~ 0
PosWindError	-0.0002	5.4	~ 0
NegWindError	0.0009	29.6	~ 0
Number of observations	40,594		
Number of Nonzero Observations	8,912		
McFadden's R²:	0.508		
Percentage of Correct Predictions when EnWG actions are predicted	86.65 %		
Percentage of Correct Predictions when normal system status is predicted	90.71 %		

Reported t-statistics are robust to heteroskedasticity

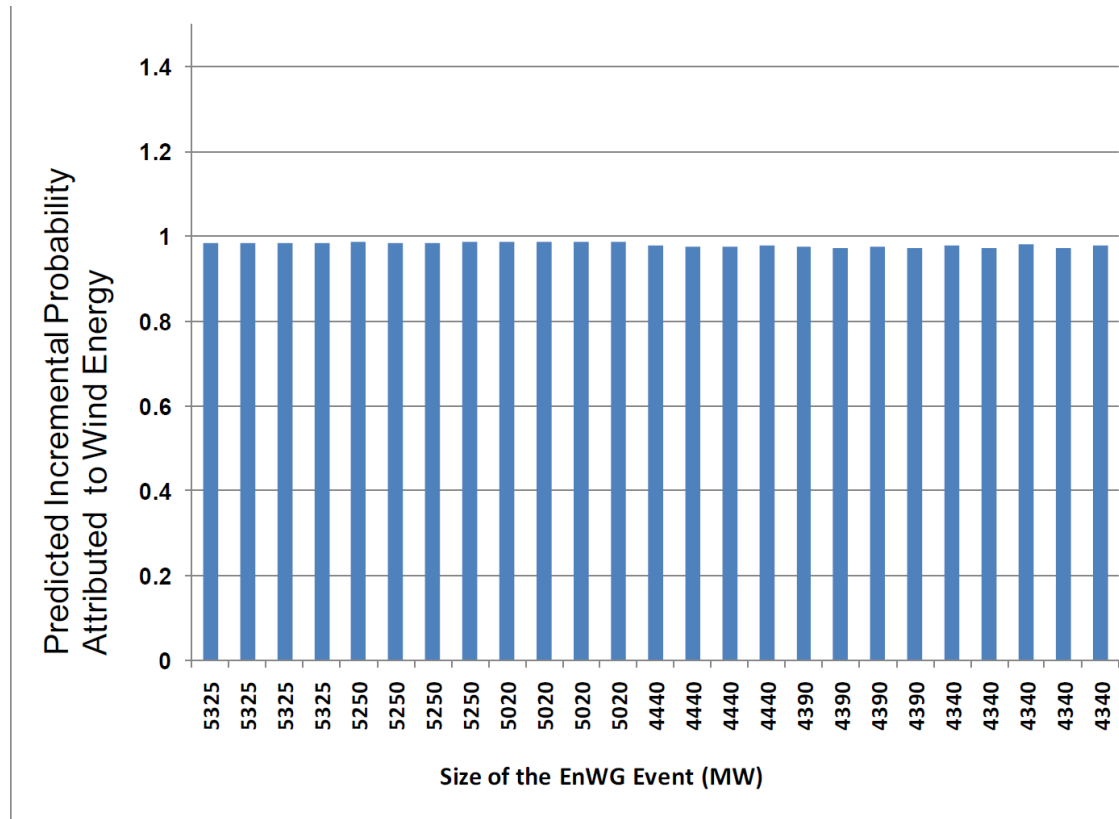
Predicted Incidence of EnWG Actions

Factual vs. Counterfactual



Note: In the counterfactual, forecasted and actual wind energy production levels are set equal to zero.

Predicted Wind Related Incremental Probabilities for 25 Large EnWG Events



Note: In each case in the above figure, an EnWG event occurred and the calculated probability of an EnWG event occurring is equal to 1.00. The predicted wind related incremental probability is the portion of the predicted probability that the model attributes to wind energy.

Further Analysis

- Can the reliability events be forecasted based on day-ahead information???
- Based on the forecasts, additional variables were created.
- The new model was estimated over the period 1 November 2008 – 31 December 2009. The new model only contains day-ahead information.
- An out-of-sample forecast for each market period in 2010 was created.

2010 Out-of-Sample Forecasting Results

- For each period, a predicted probability of an EnWG action was calculated based on the day-ahead information and the estimated coefficients.
- Percent of correct predictions when the predicted probability of an EnWG event is greater than or equal to 0.5: **75 Percent**
- Percent of correct predictions when the predicted probability of an EnWG event is less than 0.5: **97.55 Percent**

Summary and Conclusions

- Wind forecasting errors in 50Hertz are very large relative to the mean of the variable that is actually being forecasted
- The econometric results indicate that forecasted and actual levels of wind power substantially increase the likelihood of actions needed to ensure “safe, secure, and reliable operations” in 50Hertz.

Summary and Conclusions (continued)

- The results presented here are consistent with the findings of a 2011 conference held by 50Hertz: ***“The new energy era presents enormous challenges for the security of the electrical system”***
- The results presented here also indicate that the challenges can be addressed through improved modeling and forecasting.

Related Research

- It has been observed that the errors in forecasting load are not “white noise”
- Modeling of the systematic component can yield more accurate forecasts
- The root-mean-squared-error of the forecasts was approximately 23 percent lower in a recent 8,700 hour out-of-sample analysis.
- A provisional patent application has been filed.