Wind Energy, the Price of Carbon, and Carbon Emissions: The Case of Ireland

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Trends in Public Policy

- Broad political support exists for increasing substantially the share of electricity generation from wind.
- Some have advocated that policymakers should strive to have 20 percent of generation be accounted for by wind by 2030.
- In contrast, there is almost no chance that the United States Congress will pass either a carbon tax or cap-and-trade legislation any time soon.

This Study Addresses the Following Questions

1) What is the relationship between wind energy and carbon emissions?

2) What is the relationship between the price of carbon and carbon emissions?

We address these questions using data from the power grid in Ireland

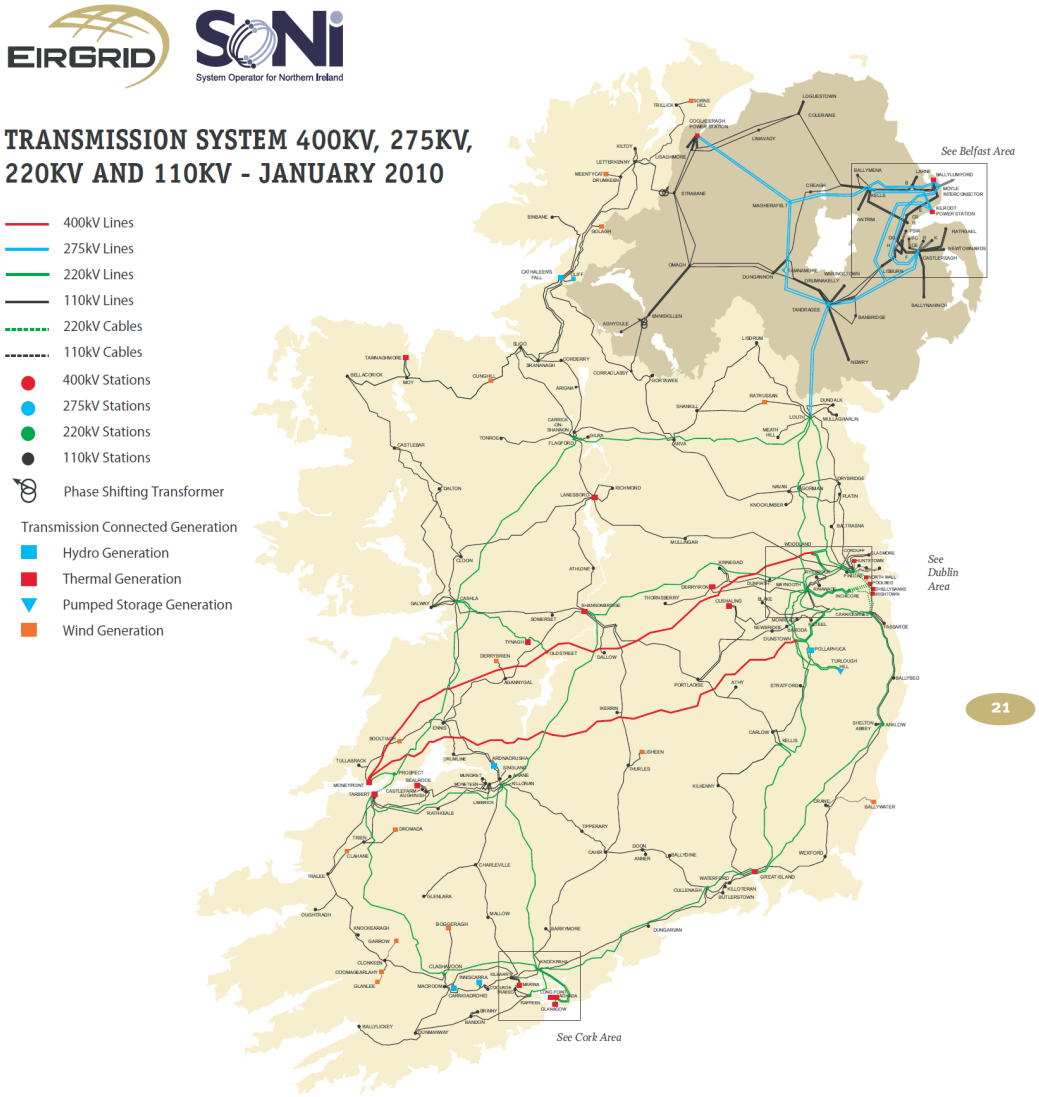
Irish Government targets for renewable energy are:

- 15% of electricity supply by the end of 2010 and
- 40% by 2020

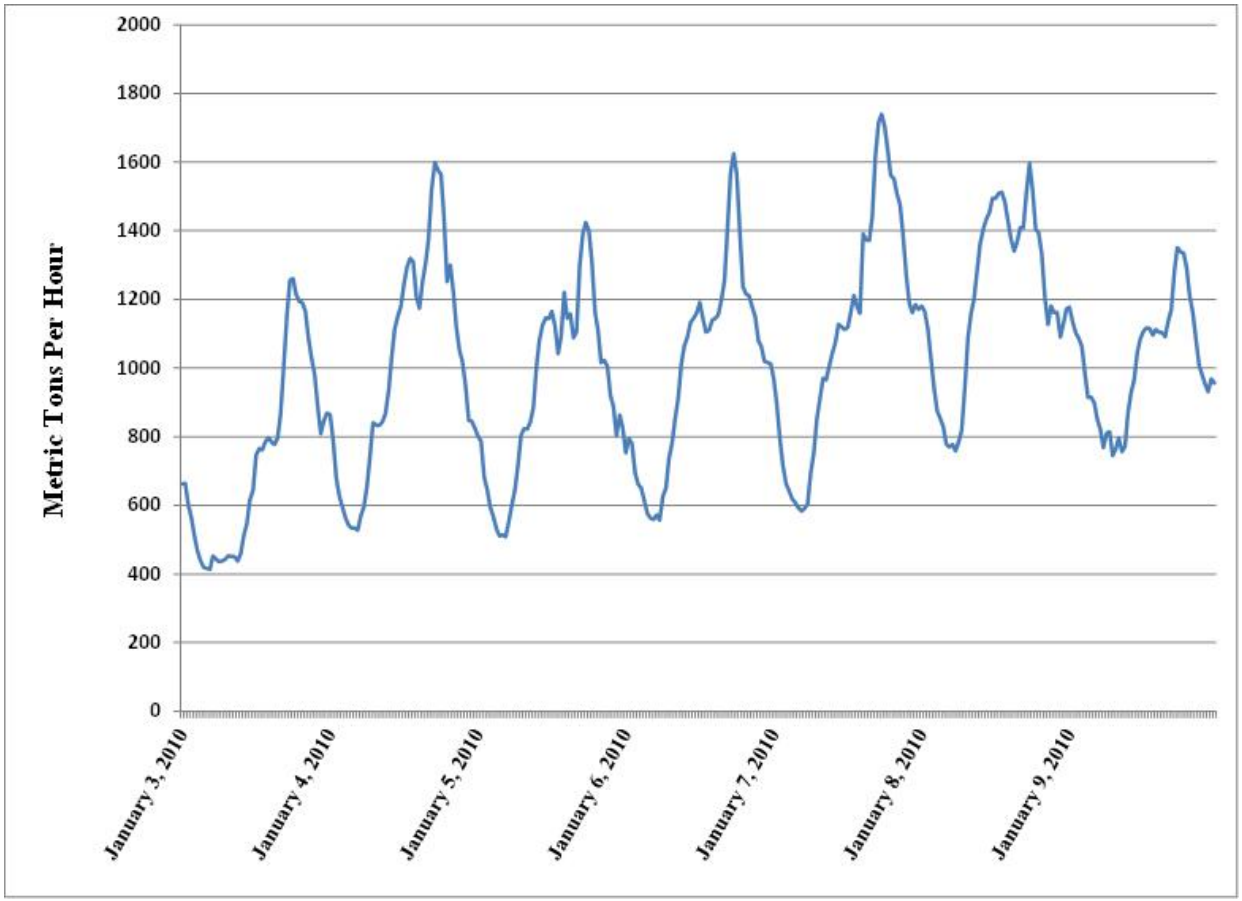
- At the end of 2009 there was a total of 1562 MW of wind generation capacity on the island, accounting for 14.1% of total capacity.

- Wind energy accounted for about 9.3 % of mean Load over the period March 2008 - September 30, 2010

Ireland's Power Grid



Carbon Emissions from the Republic of Ireland's Power Grid, January 3 – 9, 2010

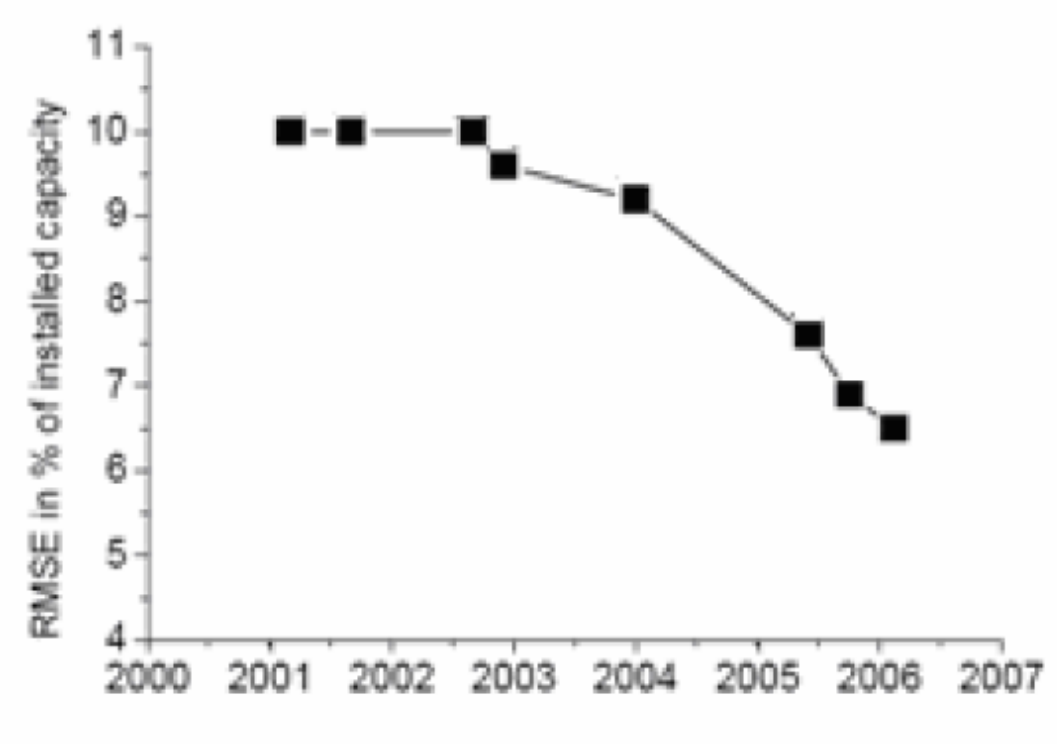


Source: Eirgrid

The “Consensus” View of Wind Energy:

It is widely believed that the many advances in forecasting wind in Europe over the past decade that makes it possible to reduce carbon via high levels of wind integration

There is evidence from Germany that day-ahead wind energy forecast errors have been declining



Source: Lange, *et al.* (2006)

Is the evidence compelling?

- While the forecasting error relative to installed wind energy capacity may have declined, is such a metric even relevant?
- The necessary balance between electricity supply and demand is in terms of MW of energy, not capacity, or MW of energy weighted by capacity.
- In the case of wind energy, it is not uncommon for the mean level of wind energy production to be less than 30 percent of wind energy capacity and hence, weighting the forecasting error by capacity will always make the error appear small relative to the level of energy that is actually produced.
- We note that load forecasting errors are not weighted by the capacity of the equipment that consumes electricity.

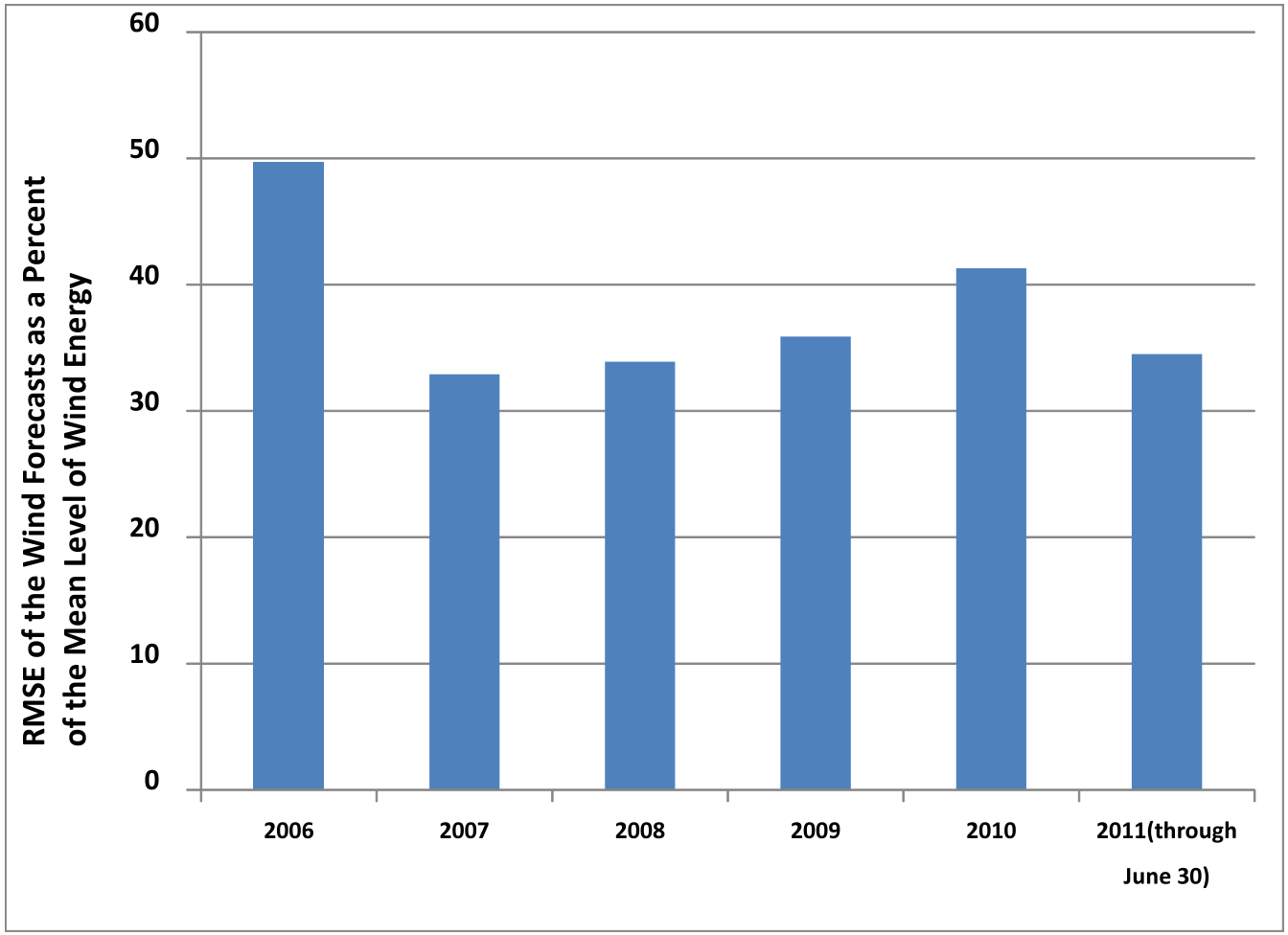
Forecasting Errors in Western Denmark

- The RMSE of the Day-Ahead Load Forecasts were about **4.5 percent** of mean Load over the period 14 September 2009 – 26 October 2010

- The RMSE of the Day-Ahead Wind Forecasts were about **28.5 percent** of the mean wind energy levels over the period 14 September 2009 – 26 October 2010

Based on data reported by Nordpool

Day-Ahead Wind Forecast Errors in the TenneT System in Germany, 2006 – June 30 2011



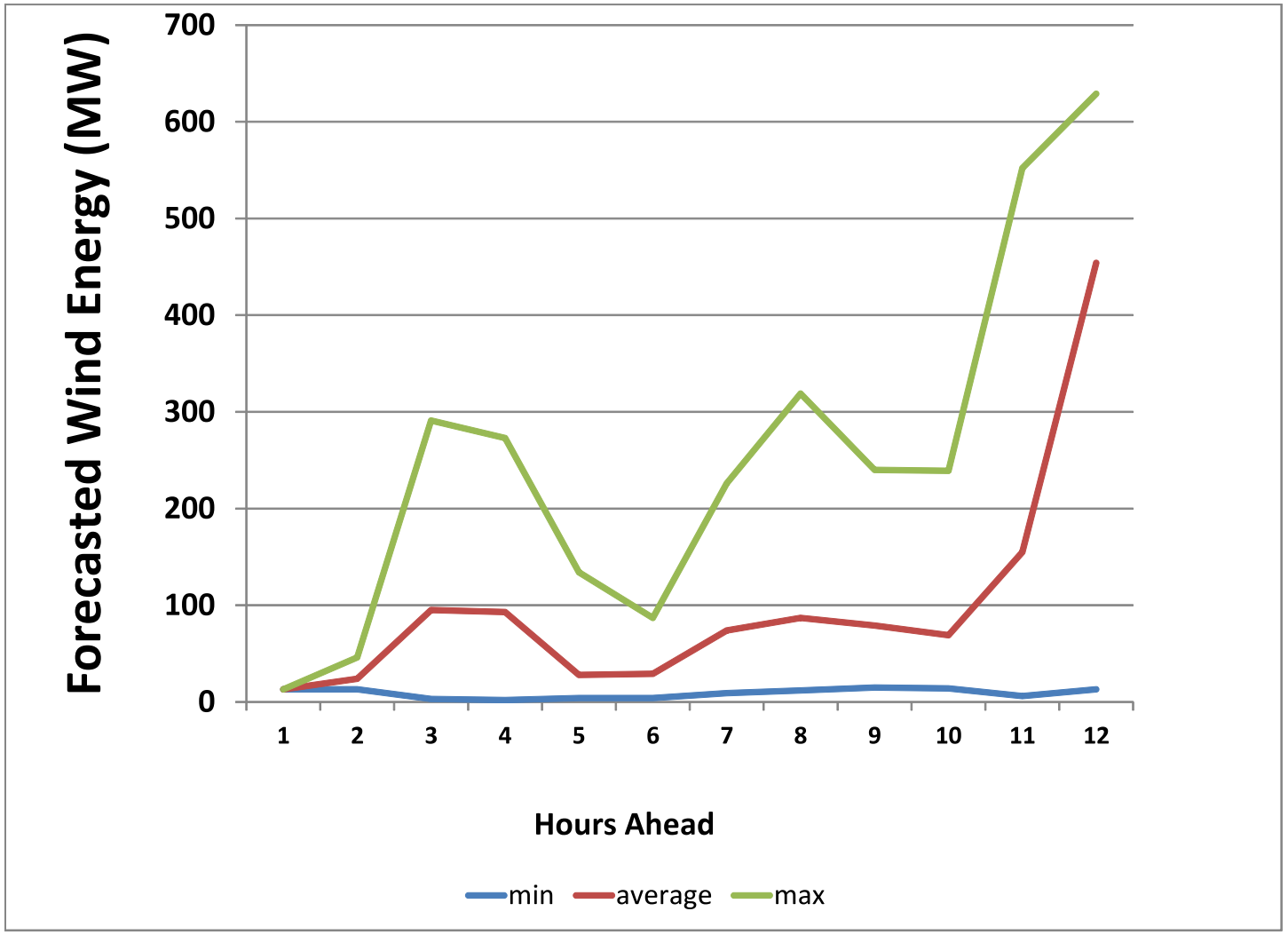
TenneT was formerly known as E.ON Netz and Transpower

An Example of Wind Forecasting Uncertainty

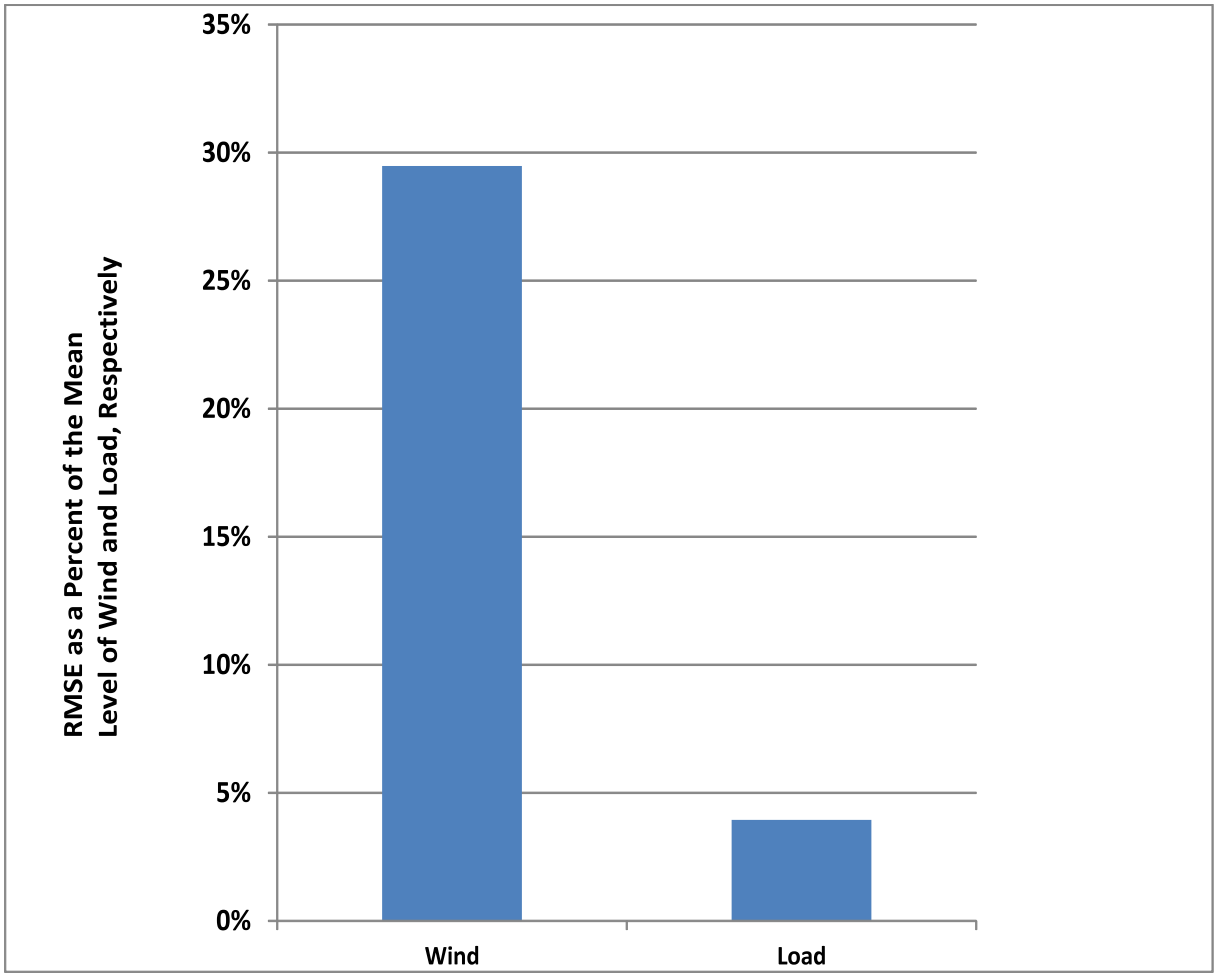
- The Bonneville Power Authority (BPA) in the Pacific Northwest has a new wind forecasting system

- In each hour, three forecasts are produced for the next three days: Average, Minimum, and Maximum

The Uncertainty in one of BPA's forecasts on July 2 2011



Wind vs Load Forecast Errors in Ireland



Possible Implications for Carbon Emissions

- The relative unpredictability of wind energy may have adverse implications on the heat rates of conventional generating units
- This adverse impact may reduce the net carbon reductions from wind energy
- This is consistent with the findings of the Bentek Study of wind energy's impact in Colorado

The Bentek Study

- Used four years of Public Service Company of Colorado (PSCO) hourly operational history
- The study indicates that wind energy required PSCO to “cycle” its conventional plants where “cycling” refers to sudden increases or decreases in power generation.
- Cycling has an adverse impact on heat rates

The Dependent Variable in an Econometric Model of Carbon Emissions

- lnCO2 – the natural logarithm of carbon emissions for each 30 minute market period of the day

- Emissions are measured in metric tons per hour.

Sample

- 27 March 2008 – 15 August 2010
- The are 48 observations for each day.
- There are 43,671 observations

Explanatory Variables in an Econometric Model of Carbon Emissions

- **Forecasted Load**
- **The Error in the Load Forecast**
- **Forecasted Wind Energy**
- **The Error in the Wind Forecast**
- **The Price of Natural Gas Relative to Coal**
- **The price of a carbon allowance relative to the ex ante system price of electricity**
- **Binary variables for the month of the sample**
- **Binary variables for the hour of the day**

Econometric Issues

- **The Issue of Functional Form-** The relationship is unlikely to be linear

- **ARCH Effects-** Time series regression with high frequency data are often be plagued by the problem of time-varying volatility, more commonly referred to as Autoregressive Conditional Heteroscedasticity (ARCH).

The Issue of Functional Form

- The model was estimated using the multivariable fractional polynomial (MFP) model, a useful technique when one suspects that some or all of the relationships between the dependent variable and the explanatory variables are non-linear (Royston and Altman, 2008), but there is little or no basis, theoretical or otherwise, on which to select particular functional forms.

- The analysis provided support for including nonlinear forms for three of the explanatory variables: **load, the gas/coal price ratio, and the carbon/electricity price ratio**

The Econometric Model

$$\begin{aligned}\ln CO_2 = {} & \beta_0 + \beta_1 \ln(\textit{forecasted load}) + \beta_2(\textit{one hour ahead wind forecast}) \\ & + \beta_3(\textit{positive wind forecast error}) + \beta_4(\textit{negative wind forecast error}) \\ & + \beta_5(\textit{positive load forecast error}) + \beta_6(\textit{negative load forecast error}) \\ & + \beta_7(\textit{gas / coal price ratio})^{3.0} + \beta_8(\textit{carbon/electric price ratio})^{-0.5} \\ & + \sum_{h=2}^{24} \gamma_h hour_h + \sum_{m=2}^{12} \phi_m month_m\end{aligned} \tag{2}$$

ARCH Effects

- ARCH effects were detected
- The Model was re-estimated using the Generalized ARCH (GARCH) procedure

Results

GARCH(1, 1) Estimates--MFP Functional Form

Variable	Est. Coef	Std. Error	Z-Value	P-Value
ln(f orecasted load)	1.414419	0.001709	775.72	0.000
one hour ahead wind f orecast	-0.00047	1.62E-06	-293.25	0.000
positive wind f orecast error	0.000476	7.15E-06	65.15	0.000
negative wind f orecast error	-0.00056	6.77E-06	-87.48	0.000
positive load f orecast error	-0.00056	4.47E-06	-126.04	0.000
negative load f orecast error	0.000496	6.28E-05	120.45	0.000
$(gas/coal\ price\ ratio)^{3.0}$	0.012141	7.14E-05	117.8	0.000
$carbon\ price\ ratio^{-0.5}$	0.015668	0.000922	25.38	0.000
Constant	-4.65938	0.023626	-197.22	0.000
GARCH(1, 1)				
lagged squared error	0.894295	0.017338	51.58	0.000
lagged variance	0.044384	0.00562	7.9	0.000
Constant	0.001006	1.94E-05	52	0.000

Results

- The estimated coefficient on LnLoad suggests that a 10 percent increase in load increases carbon emissions by about 14 percent
- The estimates indicate that a 10 percent increase in wind energy reduces carbon emissions by about 1.1 percent
- The estimates suggest that a one percent decline in the relative price of natural gas reduces carbon emissions by about 1.4 metric tons per hour
- A one percent increase in the relative carbon price reduces emissions by 0.11 metric tons per hour

Conclusions

- The data from Ireland, Germany, and Western Denmark indicate that the errors in forecasting wind energy are very large.

- Wind energy reduces carbon but the relationship at the margin appears to be small. Future increases in wind energy penetration levels in Ireland may have a disappointing effect on emissions.

Conclusions (Continued)

- The elasticity of carbon emissions with respect to the carbon price is negative. The relationship is inelastic which is not surprising given the low carbon price.

- Carbon emissions are sensitive to the price of natural gas relative to the coal price.