The Total Impact of Wind Energy Variability on Fossil Fuel Emission Rates in Texas

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Secondary Emissions Impacts from Variable Wind Output

- Primary wind emission reductions are calculated using the simple emission rate of the offset unit.
- Variable EGU output may induce ramping in thermal EGUs.
- During ramping periods, thermal unit emission rates are typically higher than their average rates.
Conventional Approach to Modeling Emissions Reductions from Wind

- Recognizes difference between marginal emissions increases and total emissions reductions
- Assumes ‘steady-state’ demand
- Simplified system with only well understood resources

\[
\text{Variable Power} + \sum_{i=1}^{n} \text{Compensating Power} = \text{Power}
\]

- Gas
- Wind

Time
Databases Used for Analysis

• EPA Continuous Emissions Monitoring Data (CEMS)
  – Hourly
  – Updated quarterly
  – Includes ~95% of ERCOT fossil fueled EGU output

• Additional Data & Support
  – ERCOT 15-minute EGU output by fuel type
  – TACC Pecan Street Database
Modeling Emission Rates

- Weighted average hourly emission rates
- CEMS data for Texas, filtered for ERCOT only
- 2008 – 2011

\[
\begin{align*}
\text{CO}_2 &= \frac{\sum_{n=0}^{N} \text{CO}_2_{n,t}}{\sum_{n=0}^{N} \text{Output}_{n,t}} \\
\text{SO}_2 &= \frac{\sum_{n=0}^{N} \text{SO}_2_{n,t}}{\sum_{n=0}^{N} \text{Output}_{n,t}} \\
\text{NO}_x &= \frac{\sum_{n=0}^{N} \text{NO}_x_{n,t}}{\sum_{n=0}^{N} \text{Output}_{n,t}}
\end{align*}
\]

*For \( N = \# \text{ of ERCOT fossil-fuel EGUs, time } t \)*
Basic Regression Model Results

\[ CO_2 \text{ Emissions} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \]

where:

- \( x_1 \) = wind EGU output in MWh
- \( x_2 \) = fossil-fueled EGU output in MWh
- \( x_3 \) = average new fossil-fueled EGU MWh
- \( x_4 \) = fossil-fueled EGU heat rate in Btu/kWh

- **R Square**: .84
- **Coefficients**
  - \( \beta_1 \): \(-1.2 \times 10^{-5}\)
  - \( \beta_2 \): \(-5.1 \times 10^{-6}\)
  - \( \beta_3 \): \(8.99 \times 10^{-8}\)
  - \( \beta_4 \): \(7.7 \times 10^{-5}\)
Two-Part Reduced Form Model

Identifying the Role $\Delta \gamma$ Plays in CO$_2$ Emissions

$$\text{CO}_2 \text{ Emissions} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ldots + \beta_{49} x_{49} + \beta_{50} x_{50}$$

where:

- $x_1 = \gamma$
- $x_2 = \Delta \gamma = \gamma_t - \gamma_{t-1}$
- $x_3 = \Delta \gamma^2$
- $x_4 = \text{system heat rate}$
- $x_5 \ldots x_{10} = \text{day of week}$
- $x_{11} \ldots x_{33} = \text{hour of day}$
- $x_{34} \ldots x_{42} = \text{temperatures for 8 select cities and system average temp}$
- $x_{43} \ldots x_{50} = g \text{ lagging variables for prior 8 periods (2 hours)}$

Identifying the Role Wind EGU Output Plays in $\Delta \gamma$

$$\Delta \gamma = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_{41} x_{41} + \beta_{42} x_{42}$$

where:

- $x_1 = \text{wind EGU output}$
- $x_2 = \Delta \text{wind} = \text{wind}_t - \text{wind}_{t-1}$
- $x_3 = \Delta \text{wind}^2$
- $x_4 = \text{system heat rate}$
- $x_5 \ldots x_{10} = \text{day of week}$
- $x_{11} \ldots x_{33} = \text{hour of day}$
- $x_{34} \ldots x_{42} = \text{temperatures for 8 select cities and system average temp}$
## Results: Identifying the Role $\Delta \gamma$ Plays in Emissions

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>All Fossil Fuels</th>
<th>Natural Gas EGUs</th>
<th>Coal EGUs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO2 tons/MWh</td>
<td>Nox lbs/MWh</td>
<td>CO2 tons/MWh</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.8204</td>
<td>0.5941</td>
<td>0.7157</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>-1.16E-05</td>
<td>-6.03E-06</td>
<td>-1.80E-04</td>
</tr>
<tr>
<td>$\Delta \gamma$</td>
<td>6.50E-06</td>
<td>2.14E-05</td>
<td>1.85E-04</td>
</tr>
<tr>
<td>$\Delta \gamma^2$</td>
<td>-1.32E-10</td>
<td>-7.39E-10</td>
<td>-2.42E-08</td>
</tr>
<tr>
<td>system heat rate</td>
<td>1.10E-04</td>
<td>2.84E-04</td>
<td>7.24E-04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>CO2 tons/MWh</th>
<th>Nox lbs/MWh</th>
<th>SO2 lbs/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted R Square</td>
<td>0.4755</td>
<td>0.2796</td>
<td>0.2358</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>-1.69E-07</td>
<td>-1.66E-05</td>
<td>-9.63E-05</td>
</tr>
<tr>
<td>$\Delta \gamma$</td>
<td>1.14E-06</td>
<td>3.28E-05</td>
<td>2.14E-04</td>
</tr>
<tr>
<td>$\Delta \gamma^2$</td>
<td>3.70E-10</td>
<td>4.51E-09</td>
<td>-5.81E-09</td>
</tr>
<tr>
<td>system heat rate</td>
<td>3.07E-05</td>
<td>1.79E-04</td>
<td>6.07E-04</td>
</tr>
</tbody>
</table>

Table 1: Regression analysis results from equation 4, showing model fit and correlations for key independent variables. The results show a relatively good fit (“Adjusted R Square”) for the CO$_2$ “All Fossil Fuels” model. Directionality of independent variables in the CO$_2$ “All Fossil Fuels” model show that increasing $\gamma$ correlates with lower emission rates, while increasing $\Delta \gamma$ correlates with lower emission rates.
Results: Wind Output, Wind Variability and System Variability

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Full Model</th>
<th>Wind Variables Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted R Square</td>
<td>0.566</td>
<td>0.115</td>
</tr>
<tr>
<td>Wind EGU MWh</td>
<td>9.22E-03</td>
<td>2.98E-02</td>
</tr>
<tr>
<td>Δwind</td>
<td>-8.58E-01</td>
<td>-1.22E+00</td>
</tr>
<tr>
<td>Δwind^2</td>
<td>1.88E-04</td>
<td>6.10E-04</td>
</tr>
</tbody>
</table>
Identifying the Secondary Emissions Impact of Wind EGU Output

\[ \gamma_{\text{wind}} = \gamma(\text{wind}) = \beta_{1,\text{wind}}(\text{wind MWh}) + \beta_{2,\text{wind}}(\Delta \text{wind}) + \beta_{3,\text{wind}}(\Delta \text{wind}^2) \]

\[ \Delta E_{\text{wind}} = \beta_{1,g}(\gamma_{\text{wind}}) + \beta_{2,g}(\Delta \gamma_{\text{wind}}) + \beta_{3,g}(\Delta \gamma_{\text{wind}}^2) \]

| \(\Delta\text{CO}_2\) (tons/MWh) | 0.03 |
| \(\Delta\text{SO}_2\) (lbs/MWh)  | 0.47 |
| \(\Delta\text{NO}_x\) (lbs/MWh)  | 0.16 |
Secondary Wind Impact as Percentage Primary Emissions Offset by Wind

- CO2
- NOx
- SO2

Secondary Wind Impact as a % of Emissions Offset by Wind

Apr-07 Nov-07 Jun-08 Dec-08 Jul-09 Jan-10 Aug-10 Feb-11 Sep-11 Apr-12
Thank you!

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