Modeling of Power Generation Pollutant Emissions Based on Locational Marginal Prices for Sustainable Water Delivery

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Project Overview

- Reduce energy consumption and environmental impact of water distribution systems
- Develop a real-time pump optimization (RPO) software tool
Pilot Study: DWSD

- Detroit Water & Sewerage Department (DWSD)
  - 4 million customers
  - ~300 Million KW-Hours annually
  - 220 billion gallons annually
- DTE Energy footprint
- MISO dispatch
Methodology

- Energy Optimization
- Economic Optimization
- **Environmental Optimization**
  - Link pump power consumption to pollutant emissions associated with energy generation
  - Shift pumping loads to advantageously utilize clean generation units
Linking Consumption to Emissions

1. Source Identification
   • Dispatch adjusted every 5 minutes within MISO

2. Emissions Quantification
   • Function of generator type
LMPs are determined for thousands of Commercial Pricing Nodes (CPNodes).

LMP Curve can be developed for all CPNodes on any given day.

Harbor Beach Price Curve for August 17, 2008
Linking Consumption to Emissions

Sources could be derived by:

**Energy Bid Price OR Generator Type**

- MISO bid prices are confidential
- Identify *type of generation units*
  - Calculate marginal cost for each generator type
- Calculate pollutant emissions per unit of power generation
From LMP to Gen Type

- Find the LMP (real time, hour-ahead, or day-ahead)
- Map the LMP to the type of generation unit

![Diagram showing price ($/MWh) and types of generation units: Hydro & Nuclear, Coal, Natural Gas, Oil. LMP at time $t_i$.]
Identify Power Generation Units

- Step 1: Calculate the heat rate

\[
Heat Rate \left( \frac{MMBtu}{MWh} \right) = \frac{Fuel \ Quantity \ Consumed \ for \ Electricity \ (MMBtu)}{Electricity \ Net \ Generation \ (MWh)}
\]

- Step 2: Determine average monthly fuel price
- Step 3: Calculate variable cost of electric generation

\[
Electric \ Generation \ Fuel \ Cost \left( \frac{\$}{MWh} \right) = Heat \ Rate \left( \frac{MMBtu}{MWh} \right) \times Price \ of \ Fuel \left( \frac{\$}{MMBtu} \right)
\]

- Step 4: Compute electric generation cost statistics
- Step 5: Define generation type LMP ranges
Key Assumption

- Pilot study - DWSD
- DTE Energy network is unconstrained
  - The next incremental change in demand will be supplied by the cheapest generator inside the network or the same source outside
  - Use LMPs to model pollutant emissions
- Check Assumption
  - 97.7% of DTE LMPs are within 1 standard deviation of the mean
Calculate Locational Marginal Price (LMP) range at which each type of generator will be producing power on the margin

<table>
<thead>
<tr>
<th>Marginal Generator Type</th>
<th>LMP Range ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear / Renewable</td>
<td>&lt;19.25</td>
</tr>
<tr>
<td>Coal</td>
<td>19.25 - 78.88</td>
</tr>
<tr>
<td>Combined Cycle NG</td>
<td>78.88 - 128.58</td>
</tr>
<tr>
<td>Other Natural Gas</td>
<td>128.58 - 140.28</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>140.28 - 202.20</td>
</tr>
<tr>
<td>Simple Cycle NG</td>
<td>202.20 - 277.11</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>&gt;277.11</td>
</tr>
</tbody>
</table>
Results – Time on Margin

- Calculate percentage of time generators were on the margin using LMP ranges
- All generators in DTE system for 2008

<table>
<thead>
<tr>
<th>Fuel/Generator Type</th>
<th>Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear/Renewable</td>
<td>85,699 (10.02 %)</td>
</tr>
<tr>
<td>Coal</td>
<td>556,107 (65.01 %)</td>
</tr>
<tr>
<td>Combined Cycle NG</td>
<td>147,007 (17.18 %)</td>
</tr>
<tr>
<td>Other Natural Gas</td>
<td>23,386 (2.73 %)</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>30,247 (3.54 %)</td>
</tr>
<tr>
<td>Simple Cycle Natural Gas</td>
<td>13,012 (1.52 %)</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>2,158 (0.25 %)</td>
</tr>
</tbody>
</table>
Results – LMP Ranges

River Rouge Peaker Day-Ahead LMPs with Marginal Generator Type for July 16, 2008
Emissions Quantification

**Emissions factors**

- Describe the mass of pollutant per amount of energy generated (e.g. lbs/MWh)
- Serve as transfer function

\[ EF = HR \times WFF \]

\[ lbs / MWh = \frac{Quantity}{MWh} \times lbs / Quantity \]

- An emissions model is created for various pollutants
  - Track individual pollutants or group of pollutants
Results – Emissions Model

The graph illustrates the emissions model for ammonia (NH₃), methane (CH₄), lead (Pb), and NOx (NOx) over the course of the day, measured in pounds per million British thermal units (lbs/MWh). The y-axis represents the emissions values, and the x-axis represents the hour of the day from 1 to 21.

Key observations:
- Ammonia emissions are consistently low across the day, with a notable peak at around 10 AM.
- Methane emissions are relatively stable throughout the day, with a slight increase in the afternoon.
- Lead emissions are notably high at 11 AM and 2 PM, indicating peak emissions times.
- NOx emissions show a significant peak at 11 AM and a smaller peak at 2 PM, with other low points in the day.

The graph highlights the importance of monitoring emission levels at specific times to optimize energy efficiency and environmental impact.
Results – GHG Emissions Model

20-yr GWP * Emissions
River Rouge Peaker July 16, 2008

(lb/MWhr*20yr GWP) of Pollutant

Hour of the Day

0 2 4 6 8 10 12 14 16 18 20 22

CO2 * 20-yr GWP
CH4 * 20-yr GWP
N2O * 20-yr GWP
This emissions model could be **updated every 5 minutes** using real-time MISO pricing.

**Shifting of pumping loads**

- Times of the day when overall emissions will be minimized.
- Utilizing in-line and raised storage.
Conclusions

- Can use Locational Marginal Price (LMP) to determine pollutant emissions
  - Represents best possible estimate using publicly available data

- Model can be used to determine marginal generator type/emissions in real-time

- Model can be implemented into an RPO tool to optimize water distribution systems (e.g., DWSD) based on pollutant emissions
Questions / Comments

Project Team:

- Wayne State University College of Engineering
- Civil and Environmental Engineering
- Tucker, Young, Jackson, Tull, Inc. Consulting Engineers
- University of Dayton
- Commonwealth Associates, Inc.

Project Partners:

- Water & Sewerage Department
- DTE Energy
- City of Monroe, Michigan
## Results – Emissions Factors

<table>
<thead>
<tr>
<th>Marginal Generator Type</th>
<th>July Ammonia Emission Factor (lbs/MWh)</th>
<th>July Methane Emission Factor (lbs/MWh)</th>
<th>July NOx Emission Factor (lbs/MWh)</th>
<th>July Lead Emission Factor (lbs/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear / Renewable</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Coal</td>
<td>0.0003168</td>
<td>0.02803</td>
<td>12.3345</td>
<td>0.003846</td>
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<tr>
<td>Combined Cycle NG</td>
<td>0.02870</td>
<td>0.02063</td>
<td>1.5246</td>
<td>4.484E-6</td>
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<tr>
<td>Other Natural Gas</td>
<td>0.1633</td>
<td>0.02087</td>
<td>4.1925</td>
<td>4.537E-6</td>
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<tr>
<td>Residual Fuel Oil</td>
<td>0.06582</td>
<td>0.02304</td>
<td>5.5126</td>
<td>0.0001613</td>
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<tr>
<td>Simple Cycle NG</td>
<td>0.04689</td>
<td>0.03370</td>
<td>4.1030</td>
<td>0</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>0.07440</td>
<td>0.02604</td>
<td>6.2313</td>
<td>0.0004353</td>
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</tbody>
</table>


