Implications of Climate Change for Regional Air Pollution, Health Effects and Energy Consumption Behavior: Selected Emissions Results*

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Outline

• Project components
• Health effects of pollution emission from utilities sector
• Climate change effects analyzed
• Analytical framework
• Results
The project involves four modeling efforts:

- Hourly Electricity Load Modeling and Forecasting (GWU)
- Electricity Generation and Dispatch Modeling
- Regional Air Pollution Modeling
- Health Effects Characterization
Significant Public Health Threats of Emissions from Utility Sector

- In US, utility sector accounts for 22% and 67% of total emission of NO\textsubscript{x} and SO\textsubscript{2} emission (NET, 2002)

- Reactions of primary pollutants (NO\textsubscript{x} and SO\textsubscript{2}) with other chemicals forming secondary pollutants, i.e., PM\textsubscript{10}, PM\textsubscript{2.5} and O\textsubscript{3}, which pose substantial threats to public health
  - Every 10 ppb increase in daily maximal ozone concentration results in the death of all causes (except accidents) increases by 0.36% (Thurston et al. 99) and 0.41% (Samet et al. 2000)
  - Every 100ppb increase in the previous week O\textsubscript{3} leads to an increase of 0.52% and 0.64% in daily mortality rate and cardiovascular and respiratory mortality, respectively (Bell et al. 2005)
Climate Change Effects Analyzed

- Mobile Sources
- Power Sector
- Other Point Sources
- Biogenic Sources

Air Pollutant Transport & Transformation

Health Effects
Climate Change Effects Analyzed

- **Climate Change**
  - Wind, temperature, humidity changes
  - Demand: higher summer, lower winter
  - Lower capacity & efficiency
  - Generator Efficiency, Capacity
  - Long run demand - capacity mix interactions

- **Mobile Sources**
- **Power Sector**
- **Other Point Sources**
- **Biogenic Sources**

- Ozone alerts
- Biogenic VOC changes

- Air Pollutant Transport & Transformation

- Health Effects
Effects of Climate Change on Components of Power System

Power Demands:

- \( \Delta \) Use of equipment (e.g., air conditioner hours)
- \( \Delta \) Mix of equipment (e.g., #, size of air conditioners)

Generator Characteristics:

- \( \Delta \) Thermal capacity & efficiency (e.g., Carnot)
- \( \Delta \) Water supply
- \( \Delta \) Mix of generators (fuel sources, peak vs. baseload)

Result: Changes in Amounts, Timing, & Location of Emissions
The Largest Emissions Uncertainty:
Size of Emissions Cap and New Source Review Policy

Source: www.rff.org
Given a cap, climate warming:

- *might* alter distribution of emissions over year (2\textsuperscript{nd} order compared to cap size?)
- *will* increase electricity generation and emissions control costs
PJM Interconnection

• Largest wholesale electricity market in the world
• Power from coal, oil, gas, nuclear and hydroelectric resources
Simulation of Power Sector Emission Responses

• *First*, Short-run analysis:
  – fixed generation capacity
  – short-run load response to temperature

• Impact of 2 °F warming upon PJM market:
  – Year 2000 demands
  – 879 generating units (from EPA, DOE data bases)
  – Year 2000 ozone season, with detail on ozone episode Aug. 7-9, 2000

• Assumptions:
  – Statistical models of electricity demand
    • as \( f(\text{day, hour, lagged demand, temp}) \)
  – Thermal plant efficiency from literature, Carnot calculations, *e.g.*,
    • Gas turbine heat rate increases 0.07% / 1° F increase
    • Steam plants heat rate increases 0.06% / 1° F increase
  – Capacity using reported winter and summer capacities:
    • Average 0.23% decrease / 1° F increase
Simulation Summary

• Approach: LP Market simulation (perfect competition)
  – Generators compete to sell electricity, subject to markets for NO$_x$ allowances and transmission
  – Considers existing generating units load, NO$_x$ cap (SIP call), and transmission network (Kirchhoff’s Voltage and Current Laws)
  – Hourly simulation of Aug. 7-9; ten-period approximation for remainder of season

• Results for entire season:
  – 4.3% increase in average hourly demand in ozone season
  – No change in total NO$_x$ (due to cap)
  – Fuel cost increases:
    – 21% due to load increase alone
    – 0.4% due to generator efficiency decrease
    – 22% total
2 °F Increase: Electricity Demand & Generator Performance Impacts

**Aug. 7-9, 2000**

<table>
<thead>
<tr>
<th>Base Case</th>
<th>Generator Performance Impact Alone</th>
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<tbody>
<tr>
<td>Tons NO(_x)</td>
<td>Tons SO(_x)</td>
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<td>2,691</td>
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+5.1% Demand Impact Alone

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<th>Tons NO(_x)</th>
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**Joint Generator & Demand Impact**

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<th>$M FuelCost</th>
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<td>+4.9%</td>
<td>+5.4%</td>
<td>+20.3%</td>
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Total PJM Load, Aug. 7-9

$(\Delta Load = +5.1\% \text{ due to } 2^\circ F \text{ increase})$
PJM Emissions, Aug. 7-9
($\Delta NO_x = +4.9\%; \Delta SO_2 = +5.4\%$)
- $\Delta NO_x$ in southern part of region; $\Delta SO_2$ in eastern (populous) part
Long-Run Analysis

• Shifts in electricity demand distributions as a result of changes in air conditioner penetration and use in residential and commercial sectors (NEMS Electricity Market Model demand modules)

• Shifts in generation mix as a result of changes in generator efficiencies and load shapes (peakier loads imply proportionally more combustion turbines)

• Sitting scenarios for emissions sources in Mid-Atlantic/Midwest region
Long Run Emission Responses in PJM

• Impact of 2 °F warming upon Pennsylvania-Jersey-Maryland (PJM) market, using 2025 projected demands and generation mix
  – Unretired existing units
  – Year 2025 ozone season, with detail on ozone episode Aug. 7-9, 2025

• Assumptions:
  – Future capacity mixture
    • Screening curve analyses using NEMS data, subject to existing units
    • Impose generation proportions in LP siting & dispatch model
      – Like Short Run Model: considers NO\textsubscript{x} future cap, transmission network (Kirchhoff’s Voltage and Current Laws)
  – Hypothetical electricity demand
    • Higher increment in peak period and lower in off peak period with an average of 5%
    – Thermal plant efficiency and capacity losses (as in short run)
2025 Load Duration Curve

Average 5%
Simulation Summary

• Load blocks:
  – Hourly simulation of Aug. 7-9
  – Ten-period approximation for remainder of season
  – Ten-period approximation for nonozone season

• Results for entire ozone season:
  – 5.4% increase in average demand in ozone season
  – No change in total NO\textsubscript{x} (due to cap)
  – Fuel cost increases:
    – 5.7% due to load increase alone
    – 5.8% total, including efficiency losses
Three-day Episode Load

Hours of Aug. 7-9, Avg Load Increase 8.6%
Three-day Episode $\text{NO}_x$ Emission Profile

Hours of Aug. 7-9, Avg Load Increase 8.6%
Next Steps - Regional Air Pollution Modeling

- Incorporation of synthetic met observations into MM5 (within Models-3) and produce future load scenarios
- Execute climate change-driven scenarios to produce ozone concentration field
- Estimate health impact based on epidemiological dose-response relationships