The Interface of Infrastructures, Markets, and Natural Cycles: Innovative Modeling and Control Mechanisms for Managing Electricity, Water and Air Quality in Texas

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How can a smart electrical grid balance water use, regional air quality, carbon emissions, and electricity demand and cost?

**Infrastructures**
- Power Plants
- Electricity Grids
- Waterworks

**Natural Cycles**
- Air Quality
- Water Availability

**Markets**
- Retail Power Markets
- Wholesale Power Markets
- Retail Water Markets
- Air Quality Markets

**BEFORE:** Today’s Electricity Dispatching Decisions Are Based on Price and Availability of Power

**AFTER:** Integrated Electricity Dispatching Decisions Also Include Advanced Markets, Infrastructure Resiliency, Air Quality Impacts and Water Availability
Why Texas?

• Grid entirely contained within the state
• Water-rich east, water-poor west
• Air quality limits in the east but not in the west
• A diverse base of Electricity Generating Units (EGUs), including more installed wind power than any other state
Agenda

• General Background on the UT-MIT Integrated Model

• Case Studies of the Response of the Electricity-Water System
  
  Air Quality and Water Use Impacts of Increased Natural Gas Production and Use in Texas

  Response to drought
Flexibility in Grid Operation

- Electricity Reliability Council of Texas (ERCOT)
- Installed Capacity: 74,000 MW
- Average Generation: 38,200 MW
- Minimize the cost of meeting demand

Image courtesy of ERCOT

General Background  Conceptual Model  Case Studies
Flexibility in Grid Operation

Image courtesy of ERCOT

Image courtesy of ERCOT
Generation Choices Matter

Conceptual Model

General Background
UT-MIT Integrated Model

- Cost of Grid Operation to Meet Demand
- Hourly-Resolved EGU Generation (MWh)
- EGU Greenhouse Gas and Water Usage
- EGU Primary Emissions of SO$_2$, CO, NO$_x$, and VOC
- CAMx Regional Photochemical Model
- Daily Effect on Regional Ozone and PM Concentrations

General Background  Conceptual Model  Case Studies
Extension to Multiple Days

Cost of Grid Operation to Meet Demand

Hourly-Resolved EGU Generation (MWh)

EGU Greenhouse Gas and Water Usage

EGU Primary Emissions of SO₂, CO, NOₓ, and VOC

CAMx Regional Photochemical Model

Monthly Effect on Regional Ozone and PM Concentrations

Power World Electricity Generation Model

Consumer Demand Fuel Price Emissions Price

General Background Conceptual Model Case Studies
Natural Gas Supply and Price Effect

Cost of Grid Operation to Meet Demand

Power World Electricity Generation Model

Consumer Demand Fuel Price Emissions Price

Hourly-Resolved EGU Generation (MWh)

EGU Greenhouse Gas and Water Usage

EGU Primary Emissions of SO₂, CO, NOₓ, and VOC

CAMx Regional Photochemical Model

Monthly Effect on Regional Ozone and PM Concentrations

Regional Natural Gas Supply and Price

General Background Conceptual Model Case Studies
Full Supply Chain Integration

- Cost of Grid Operation to Meet Demand
- Hourly-Resolved EGU Generation (MWh)
- Regional Natural Gas Supply and Price
- EGU Greenhouse Gas and Water Usage
- EGU Primary Emissions of SO₂, CO, NOₓ, and VOC
- CAMx Regional Photochemical Model
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General Background  Conceptual Model  Case Studies
CASE STUDY 1:
AIR QUALITY AND WATER USE IMPACTS
OF INCREASED NATURAL GAS
PRODUCTION AND USE IN TEXAS
How resilient is system to these changes in fuel prices?
Natural Gas in Texas

% Growth Since 2010 (Texas Railroad Commission)

General Background  Conceptual Model Change  Case Studies
Effect on Electricity Generation

MWh
- Coal
- Natural Gas

Average Daily Generation over Episode

Natural Gas Price
($)/MMBTU

1.89

General Background  Conceptual Model Change  Case Studies
Effect on Electricity Generation

- **Coal**
- **Natural Gas**

Average Daily Generation over Episode

Natural Gas Price ($/MMBTU)

- 2.88

General Background  Conceptual Model Change  Case Studies
Effect on Electricity Generation

- Coal
- Natural Gas

Average Daily Generation over Episode

Natural Gas Price ($/MMBTU)

- 3.87
Effect on Electricity Generation

Average Daily Generation over Episode

- Coal
- Natural Gas

Natural Gas Price
($/MMBTU)

7.74

General Background  Conceptual Model Change  Case Studies
Effect on Electricity Generation

Monthly Percentage of Generation by Fuel Type

Natural Gas Price ($/MMBTU)

1.89 2.88 3.87 7.74

OTHER NUCLEAR COAL NG

General Background  Conceptual Model Change  Case Studies
Regional Life Cycle Assessment

ERCOT Electricity Generation
Barnett Shale Natural Gas Production
Texas Lignite Mining
Texas Subbituminous Coal Rail Emissions
Barnett Shale Production Vehicle Emissions

Episode Average Emissions (tons per day)

$1.89 $2.88 $3.87 $7.74

NOx VOC CO

Case Studies
Average Ozone Impacts

• Base Case = $2.88 per MMBTU natural gas
• Austin Vehicle Emissions and Inspection Program: 0.35 ppb reduction (Durrenberger et al (2005) A&WMA Conference Proceedings)
Average PM Impacts

- Base Case = $2.88 per MMBTU natural gas
- Average Cross State Air Pollution Rule Reduction for Texas monitors in 2014: 0.8 µg/m³ (EPA Technical Documentation)
Overall water use decreases but increases in some watersheds
Episode

Alternative NG Price of $11.09/MMBTU (July 2008 Price)

Actual NG Price

Price of Natural Gas ($/MMBTU)
Scenarios in Work

Actual NG Price and Production

• Actual NG Price used in ERCOT model
• 2996 horizontal wells with hydraulic fracturing in Haynesville (5.7 million gal/well) and Barnett (2.8 million gal/well) Shales
• Included upstream water use for lignite used at ERCOT power plants

High NG Price and no Hydraulic Fracturing of Horizontal Wells

• Constant $11.09/MMBTU price used in ERCOT Model
• No hydraulic fracturing of horizontal wells in the Haynesville or Barnett Shales
• Included upstream water use for lignite used at ERCOT power plants
Change in total water consumption in Texas water basins during the August 2008 through December 2009 episode related to the drilling of horizontal wells in the Haynesville and Barnett shales as well as modeled changes in the ERCOT and lignite production sectors. Red and orange areas indicate regions with increased water consumption in the scenario with actual natural gas prices compared to the scenario in which natural gas prices in the state remained elevated.
Comparison of the cumulative water consumed in hydraulic fracturing activities in horizontal wells in the Haynesville and Barnett shales to cumulative consumptive water savings in the electricity generation and coal mining sectors since the start of the episode (August 2008).
Selected change in cumulative water consumption (billion gallons) in selected river basins since the start of the episode (August 2008), reported monthly. Note that negative values indicate a net reduction in consumption in the water basin in the scenario with actual natural gas prices compared to the scenario with a constant $11.09 price for natural gas.
EGU Emission Caps

1. Cost of Grid Operation to Meet Demand
2. Hourly-Resolved EGU Generation (MWh)
3. Regional Natural Gas Supply and Price
4. EGU Primary Emissions of \(\text{SO}_2\), \(\text{CO}\), \(\text{NO}_x\), and \(\text{VOC}\)
5. CAMx Regional Photochemical Model
6. Monthly Effect on Regional Ozone and PM Concentrations

- Seasonal NOx

Conceptual Model

General Background  Case Studies
CASE STUDY 1: THE ELECTRICAL GRID AS A WATER PIPELINE
Can an electrical grid be a virtual water pipeline during drought?

Shift generation from regions of extreme and exceptional drought

General Background  Conceptual Model Change  Case Studies
Virtual water pipelines

• Could it be done – yes, with little net change in overall water consumption, even at times of high electricity demand

• At what cost – costs similar to dry cooling technologies
What are the non-monetized costs?

Consider air quality
Virtual water pipelines

- At what cost — increases in SOx, CO₂ and NOx emissions — and in ozone concentrations

General Background  Conceptual Model Change  Case Studies
Case Study Outline

1. Air Quality Impacts of Increased Natural Gas Production and Use in Texas
2. Response to drought
Integrated Model: Many case studies

- Cost of Grid Operation to Meet Demand
- Power World Electricity Generation Model
  - Seasonal NOx
- Consumer Demand, Fuel Price, Emissions Price, Emissions Cap
- CAMx Regional Photochemical Model
- Monthly Effect on Regional Ozone and PM Concentrations
- Changes in Consumer Demand Profiles
- Regional Natural Gas Supply and Price
- EGU Primary Emissions of SO₂, CO, NOₓ, and VOC
- EGU Greenhouse Gas and Water Usage
- Hourly-Resolved EGU Generation (MWh)

General Background

Conceptual Model

Case Studies
Generic observations

• Infrastructures, by their nature, influence and are influenced by most large scale societal decisions*; challenge is to identify the critical interactions; many of the interactions will be place dependent

• Resilience and adaptability in the grid is in (large?) part due to the diversity of power sources and a built capacity that is much greater than average daily needs (due to lack of storage)

*electricity generation choices impact water; fuel availability and transportability impacts electricity generation and materials manufacturing; transportation choices impact electricity generation
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