Decision Models for Bulk Energy Transportation Networks

Computational modeling:
- integrated fuel, electricity networks
- environmental impacts
- electricity commodity markets
- behavior of market traders
- uncertainty in demand & fuel price
- participatory research and modeling

Link structure & decision-making
Bridge separate fields: Power Engineering, Sociology, Economics, Industrial Engineering
Answer energy-related questions national, regional, local significance

Aggregated Topologies

Production

Transportation & Storage

Aggregated Model

Coal Subsystem

Gas Subsystem

Electric Subsystem
Overall Objectives of the Study

**National Scale (federal government, NERC):**
1. Possible improvements in energy flow patterns
2. Effects of catastrophic events and detection of infrastructure weaknesses
3. Infrastructure enhancements to improve performance
4. Effects of environmental regulations on energy system performance

**Regional Scale (regional independent system operator):**
1. Effects of market design on market performance
2. Sensitivity of market performance to system shocks
3. Potential improvements in market design

**Local Scale (local electric utility company):**
1. Effects of changes in raw fuel production and transportation on the returns from investing in specific types of plants at specific locations
2. Response of energy buyers and sellers to potential new policies designed to improve transparency and ease of trade
What is modeled

- Gas wells & pipelines
- Coal mines & rail/barges
- Storage
- Electricity market
- Electric gen & trans
- Costs, capacities
- SO2 constraints
- Market traders

What is computed

- spatial & temporal energy flows & nodal prices (fuel, electric)
- SO2, allowance price
- total costs
- network attributes
- decision-making of market traders with learning capabilities
- market efficiency and market power outcomes

Decision Models for Bulk Energy Transportation Networks

Structural Model

Behavioral Model
Structural Model: Energy Flows

Case A: 2002 reference, actual generation
Case B: Optimized, no emissions constraint
Case C: Optimized, with emissions constraint
Structural Model: Nodal Prices and Reliability

<table>
<thead>
<tr>
<th>Result</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal deliveries (million tons)</td>
<td>953</td>
<td>1,054</td>
<td>1,048</td>
</tr>
<tr>
<td>Natural gas deliveries (million Mcf)</td>
<td>5,125</td>
<td>3,615</td>
<td>3,615</td>
</tr>
<tr>
<td>Electricity generation from coal (thousand GWh)</td>
<td>1,910</td>
<td>2,117</td>
<td>2,116</td>
</tr>
<tr>
<td>Electricity generation from natural gas (thousand GWh)</td>
<td>607</td>
<td>414</td>
<td>414</td>
</tr>
<tr>
<td>Net electric power trade (thousand GWh)</td>
<td>205</td>
<td>382</td>
<td>367</td>
</tr>
<tr>
<td>Allowance price ($)</td>
<td>98</td>
<td>------</td>
<td>359</td>
</tr>
<tr>
<td>Total costs (billion $)</td>
<td>101.42</td>
<td>98.89</td>
<td>96.96</td>
</tr>
</tbody>
</table>

![Diagram with nodal prices and reliabilities](image)
The national limit on emissions is determined by summing the 2002 vintage unit-level emissions allowances allocated in the CAAA and adjusted to account for net banking and trading activities.

The level of emissions produced depends on the fuel used, pollution control devices installed, and the amount of electricity generated.
Structural Model: Effects of Katrina

Comparison of average nodal gas prices from model with actual gas prices during 2005

Comparison of monthly electric prices at NY-ISO from model with actual NY-ISO prices during 2005
**Structural Model:**

**Stochastic generalized network flow**

\[
\begin{align*}
\min \quad & z = \sum_{i \in T} \sum_{(i,j) \in A} c_{ij}(t) x_{ij}(t) \\
\text{s.t.} \quad & \sum_{(j,k) \in A} x_{jk}(t) - \sum_{(i,j) \in A} r_{ij} x_{ij}(t) = b_j(t) \quad \forall j \in N, \forall t \in T \\
& x_{ij,\min} \leq x_{ij}(t) \leq x_{ij,\max} \quad \forall (i, j) \in A, \forall t \in T
\end{align*}
\]

Fuel cost uncertainty: \( c_{ij}(t) \) random variable for fuel acquisition arcs

Discrete distributions: define a scenario \( s \) for each combination of values, with probability
\[
\pi_s = P(c_{ij}(1) = c_{s1}, c_{ij}(2) = c_{s2}, \ldots, c_{ij}(T) = c_{sT})
\]

**Stage 1:** Long term coal contracts  
**Stage 2:** Natural gas purchases, generation, transmission

**2-stage stochastic recourse model**

- Stage 1 decisions \( z \) made with knowledge of distributions, before scenario realization:
- Stage 2 decisions \( y \) made after scenario realizations known
- Deterministic equivalent \( x = (z, y) \) has \( y(s) \) for each scenario
Structural Model: Stochastic Recourse Results

- Wait and See (WS): solve the deterministic problem with actual gas cost
- Expected Value (EV): solve the deterministic problem with expected value of gas costs
- Recourse Problem (RP): solve the stochastic problem with a rolling horizon

<table>
<thead>
<tr>
<th>Result</th>
<th>Actual</th>
<th>EV</th>
<th>RP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal deliveries (million tons)</td>
<td>976</td>
<td>1,071</td>
<td>1,018</td>
</tr>
<tr>
<td>Natural gas deliveries (million Mcf)</td>
<td>5,398</td>
<td>3,861</td>
<td>5,011</td>
</tr>
</tbody>
</table>

Generation mix under stochastic costs is more like actual than deterministic optimum!

![Natural gas storage level graph]

![Electric energy exports at transmission centers EV vs. RP graph]
Behavioral Model: Key Objectives

- Research/teaching/training-grade electricity market test-bed permitting:
  - Dynamic testing with learning traders
  - Intensive sensitivity experiments
  - Full access (free open-source Java code)
  - Easy modification (extensible/modular architecture)
  - Integration with structural model

- Targeted Users
  - Academic researchers (qualitative understanding)
  - Industry stakeholders (learn rules, test business strategies)
  - Policy makers (efficient and reliable market design)
Behavioral Model: Background

- In April 2003, U.S. FERC proposed a Wholesale Power Market Platform (WPMP) for common adoption by all U.S. wholesale power markets.

- About 50% of electric power generating capacity in the U.S. is now operating under some version of the WPMP market design (e.g. ISO-NE, MISO, PJM, NYISO, CAISO).

**Initial Goal Accomplished:** Development of an agent-based test bed ("AMES") for dynamic wholesale power markets operating under core features of the WPMP market design.

AMES = Agent-based Modeling of Electricity Systems
www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm
AMES Market Test Bed

- JReLM learning module
- DC-OPF solver module
- Working dynamic wholesale power market model

Traders

Transmission Grid

Markets

ISO

Reliability Commitment Dispatch Settlement

Buyers

Sellers

Load Serving Entities

Generators

Bilateral

FTR

Day-Ahead

Real-Time

Re-Bid Period
Illustration of Interactions in AMES: (No-Shock 5-Node Test Case)
Trader Learning in AMES

Trader learning and decision-making are implemented in AMES by means of a Java reinforcement learning module (JReLM) that incorporates insights from human-subject experiments and that permits a flexible representation of human learning and decision-making.
Potential Acceptance and Efficacy of New Policies for Energy Trade

Research Question: How might buyers & sellers of energy respond to potential new policies and market design features introduced to improve transparency and ease of trade?

Methodology: Acceptance of selected potential policies suggested by industry, government, and academic organizations to improve the transparency and ease of trade will be evaluated using both computational and human-subject laboratory experiments. Policy options will be integrated within simulated gaming experiments to determine the extent to which traders recognize the benefits of pursuing these policies for personal as well as social goals. Experiments might also reveal unanticipated costs and benefits of proposed policies.

Anticipated Products: Empirical and test-bed evaluations of the efficacy of policies aimed at maximizing net social benefits from market-based energy trading.
Public Acceptance of Additional High Voltage Line Construction

Research Questions: How might the public respond to plans to build additional high voltage transmission lines in designated national corridors?

Methodology: 1) Surveys of the general public to ascertain their responses to potential issues related to health concerns, environmental concerns, and state-level control over the routing of lines. These surveys also will assess the effect of the source of power generation (e.g., fossil fuels, wind power, nuclear) on public perceptions of transmission capacity building. 2) Face-to-face interviews with persons who attend scheduled public forums to discuss the building and operation of additional high voltage lines.

Anticipated Products: Empirical evaluation of potential public responses and the key determinants of these responses.
Publications


