Locational Analysis for Zonal Siting of New Capacity Additions in Large Interconnected Systems

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Case Study: Where to Locate the First Nuclear Plant in Poland?

- The expansion analysis determined that nuclear power in Poland will be needed from 2017.

- The locational analysis was performed using simplified zonal representation of the Polish power grid and interconnections with neighboring countries.

- 5 potential locations in zones/regions of Poland.

- 1 potential location outside of Poland (in Lithuania) was also considered.
Analysis Showed that Early Nuclear Plants Should Be Sited in the Northern or Western Regions of Poland

- In a completely deregulated market, locational marginal prices (LMPs) can be calculated to determine the economic strain on the grid. The analysis examined the impacts on LMP electricity prices resulting from locating new nuclear plant into different zones.
- Average LMP price reduction for different locations of new nuclear plant:

<table>
<thead>
<tr>
<th>Location of New Nuclear Plant</th>
<th>Average Price Reduction ($/MWh)</th>
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<tbody>
<tr>
<td>Central</td>
<td>13.47</td>
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<tr>
<td>Lithuania</td>
<td>15.54</td>
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<tr>
<td>Eastern</td>
<td>20.34</td>
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<tr>
<td>Southern</td>
<td>37.07</td>
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<tr>
<td>Western</td>
<td>65.82</td>
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<tr>
<td>Northern</td>
<td>66.12</td>
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</table>
A Nuclear Plant Located in the Northern or Western Regions Significantly Reduces Electricity Price Volatility

Average monthly LMP price volatility index by zone for different locations of new nuclear plant:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Without Nuclear (%)</th>
<th>Northern Zone (%)</th>
<th>Western Zone (%)</th>
<th>Central Zone (%)</th>
<th>Eastern Zone (%)</th>
<th>Southern Zone (%)</th>
<th>Lithuania (%)</th>
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<tr>
<td>North</td>
<td>621.10</td>
<td>7.49</td>
<td>47.56</td>
<td>618.39</td>
<td>570.95</td>
<td>356.68</td>
<td>688.61</td>
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<td>West</td>
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<td>Central</td>
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<td>3.02</td>
<td>26.18</td>
<td>201.95</td>
<td>173.78</td>
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</table>
EMCAS uses an agent-based modeling approach to represent multiple market participants (agents) with decentralized decision-making under uncertainty.

- Alternative company strategies can be simulated.
- Incorporates learning and adaptation.
- Allows testing of market rules.
- Allows market monitoring for price manipulation.

Locational Analysis Has Been Applied to the Long-Term Expansion Module of Argonne’s EMCAS Model.
The Long Term Capacity Expansion Analysis in EMCAS Can Be Performed Using Two Possible Decision Algorithms

1. Centralized system-level decision-making (DP Model)
   - Least-cost based investment planning
   - Uses dynamic programming (DP) to optimize the expansion of the entire power system
   - Includes locational analysis for siting of new generating units

2. Decentralized profit-based company-level decision-making (Market-Based Model)
   - Profit-based investment planning in a competitive market
   - Independent decision-making by each generation company (GenCo)
   - Based on GenCo’s profit expectations under multiple uncertainties
The Purpose of the DP Model is to Provide the Least-Cost Capacity Expansion Option for EMCAS

- DP Model combines:
  - Production cost (dispatch) model
  - DP optimization model (to find the least-cost expansion path for the system)
  - Locational analysis model (for siting of new capacity additions).
- The production cost model simulates the operation of the power system for each identified state (system configuration) in each year of the study period.
- The DP model finds the expansion path with the minimum NPV of all investment and operating costs that meets the demand and satisfies all reliability and other constraints.
- The locational analysis model finds best locations for new capacity additions on zonal basis.

Inputs:
- Demand forecast
- Load profiles
- Existing units
- Candidate technologies
- Economic data
- Reliability parameters and constraints

Results:
- NPV of investment and operating costs
- Timing and schedule of new capacity additions
- Operating costs
- Investment costs by year
- Reliability results

Inputs:
- Zonal information
- Transmission links
- Firm purchases/sales
- Siting constraints

Results:
- Locations of new capacity additions by zone
Argonne’s Approach for Optimal Zonal Locations of New Capacity Additions in Interconnected Power Systems

- Locational analysis can be applied to several interconnected systems or to a single system consisting of several zones.
- Each system or zone may have a number of generating units, loads, or both.
- Firm bilateral contracts or exchanges can also be taken into account when calculating available transfer capabilities.
In Principle, Multiple Decision-Making Criteria Can Be Identified and Used for the Locational Siting of New Capacity

- Technical and reliability criteria (in each system/zone by period and/or annual):
  - Reserve margins:
    - Without interties
    - With interties
  - The expected price of electricity supply:
    - Based on the intersect of supply and demand curves (firm bilateral contracts can also be taken into account)
    - Based on the results of the probabilistic simulation of each system
    - Price volatility index and average price reduction by zone
  - The expected loss-of-load probability (LOLP) and energy-not-served (ENS):
    - Without interties
    - With interties
  - The flows on the interties in and out of the system/zone. This also provides an assessment of line congestions (e.g., if one system/zone has a significant shortage of capacity, the power flows to that system/zone will be close to the maximum transfer capability of transmission interties).
Multiple Decision-Making Criteria Can Be Identified and Used for the Locational Siting of New Capacity (cont’d)

- Economic criteria
  - Historical market clearing prices in each system/zone (e.g., LMPs, SMPs, etc.)
  - Government incentives/subsidies for the construction of new capacity (e.g., wind energy credits, green energy credits, etc.)
  - Prices and availability of emission allowances (if they vary by system or zone)

- Resource and site availability criteria
  - Availability of primary energy resources in each system zone (e.g., lignite fired power plants can only be located in zones with lignite reserves).
  - Availability of natural gas or LNG facilities may restrict some candidate options
  - Availability of adequate locations, cooling water, etc.

- Environmental and social criteria
  - Public acceptance of various candidate technology options (e.g., nuclear power plants may not be allowed in certain systems/zones because of public opposition or because of existing government regulations).
All or some of these Criteria Can Be Used in Decision-Making Analysis for Siting of New Generating Units

- The user provides the weight coefficients for each of the parameters (in most general case they may change over time)

- The weight coefficients can be different for each generation company, depending on GenCo’s preferences and risk profile

- The algorithm for choosing the best location may be represented as an optimization problem maximizing the Location Utility Function (LUF):

  \[
  \text{Maximize } \text{LUF}\{\text{RM}(x), \text{MCP}(x), \text{LOLP}(x), \text{ENS}(x), \ldots; \text{etc.}\}, \quad x=1, \ldots, N
  \]

  subject to environmental, resource, and social constraints

Where: \( N = \text{Number of systems or zones} \)
Decision Parameters Can Be Calculated for Each System or Zone

RM = LOLP = ENS = MCP = Economic Resource Environmental

Status in 2007 (Base Year)
Decision Parameters Change over Time

A

RM = LOLP = ENS = MCP = Economic Resource Environmental

B

RM = LOLP = ENS = MCP = Economic Resource Environmental

C

RM = LOLP = ENS = MCP = Economic Resource Environmental

D

RM = LOLP = ENS = MCP = Economic Resource Environmental

E

RM = LOLP = ENS = MCP = Economic Resource Environmental

F

RM = LOLP = ENS = MCP = Economic Resource Environmental

Status in 2015

Updated parameters!

New generating units built between the base year and 2015!

Reinforcement of this line from 2009!

Updated supply and demand curves!

New line from 2012!

Updated environmental regulations!

Updated social parameters!
Case Study for Three Interconnected Systems

By varying the weight coefficients $a$, $b$, and $c$ in the equation below, the user may put more or less importance on certain criteria that maximize the locational utility function (LUF):

$$\max \ LUF[RM(x), RMi(x), ZP(x)] = f[a \times RM(x), b \times RMi(x), c \times ZP(x)]$$

subject to resource, social, and other constraints

$RM = $ Reserve margin  
$RM_i = $ Reserve margin with interties  
$ZP = $ Isolated zonal price
Resource, Social and Other Siting Constraints Are also Observed

- Some resource, social, environmental, and other constraints may restrict the siting of certain generating technologies in some zones.
- A matrix of these exclusion constraints is provided to the model to take into account the zonal restrictions over the study period.

**Example:**

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0 = siting not allowed in this year
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The results of siting analysis are summarized in a table:

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0, 1, 2,.. = Number of units commissioned in this year