Assessing the impacts of shutdown of TEPCO’s nuclear reactors on CO$_2$ emission in the Japan’s electricity sector

Shuichi Ashina
Toshihiko Nakata
Tohoku University, Japan

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Background

Electricity generation in Japan

Total: 902 TW

- KEPCO 17%
- Chugoku 7%
- Shikoku 3%
- Kyushu 9%
- Okinawa 1%
- Chubu 15%
- Tohoku 9%
- Hokuriku 3%
- Hokkaidoh 4%
- TEPCO 32%

Shutdown

- Thermal 41%
- Nuclear 40%
- Others 14%
- Hydropower 5%

122 TW

Can power supply stability be assured?
How much operation cost rise?
How much CO₂ emission increase?
Nuclear power stations in Japan

Number of nuclear power plants: 52
Total installed capacity of nuclear power plants: 45,617 MW
Purpose

- Analyze the impacts of shutdown of nuclear power plants at Tokyo Electric Power Company (TEPCO) on energy systems in Japan.
- Evaluate electricity supply security, operation cost and CO$_2$ emission.
Methodology of the analysis

- Consider the site of power plants and the distribution of regional electricity consumption.
- Separate Japan into sixty regions.
- Include transmission grids and its capacity limits.
Schematic structure of the Multi Node Model

- Electricity demand
- Power generation plant
- Transmission grid
- Interconnection line
Objective function

\[ \min TC = \sum_{P,T,R} (V(P,T,R)) \]

- TC: Total Operation and maintenance cost.
- P: Pattern (1-7).
- T: Time (1-24).
- R: Region (1-60).
- V: Operation and maintenance cost

- Operation and maintenance (O&M) costs are considered according to amount of dispatches.
## Demand patterns

<table>
<thead>
<tr>
<th>Demand pattern</th>
<th>Days in a year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Maximum demand days in Summer</td>
<td>3</td>
</tr>
<tr>
<td>B Weekdays in Summer</td>
<td>98</td>
</tr>
<tr>
<td>C Weekdays in Winter</td>
<td>95</td>
</tr>
<tr>
<td>D Weekdays in Spring and Autumn</td>
<td>97</td>
</tr>
<tr>
<td>E Holidays in Summer</td>
<td>21</td>
</tr>
<tr>
<td>F Holidays in Winter</td>
<td>26</td>
</tr>
<tr>
<td>G Holidays in Spring and Autumn</td>
<td>25</td>
</tr>
</tbody>
</table>
Analyzed scenarios

- Business as Usual scenario (BAU scenario)
  - All 17 nuclear power plants at TEPCO are in operation.

- Shutdown scenario
  - Shutdown of all nuclear power plants at TEPCO.
Result: Changes in electric generation in Japan

- BAU
- Shutdown

Annual electric generation [TWh]

- Pump. hydropower
- Conv. hydropower
- LNG combined
- LNG
- Oil
- Coal
- Nuclear
Result: Mixture of power sources at pattern A (Shutdown case)
Result: Changes in electric generation in TEPCO and Tohoku
Result: Annual operation cost

- BAU
- Shutdown

Bar chart showing the annual operation cost in Billion $. The chart compares different sources of energy: Pump. hydropower, Conv. hydropower, LNG combined, LNG, Oil, Coal, and Nuclear.
Result: Annual CO$_2$ emission in the electricity sector
Results

- The shutdown of nuclear power plants at TEPCO has following impacts:
  - Electricity supply stability is assurable.
  - Electricity generation of coal-fired boiler and LNG-fired boiler in both TEPCO and Tohoku (next to TEPCO) increases.
  - Annual operation cost rises 13%.
  - CO$_2$ emission in Japan’s electricity sector increases from 102 mmTC to 117 mmTC.
Interconnection capacities and peak loads in the year 2001

Kyushu 16,260 MW
  Chugoku 12,002 MW
    Shikoku 5,925 MW
        (5,568 MW)
    (2,400 MW)
  KEPCO 32,330 MW
        (1,100 MW)
    (2,100 MW)
  Hokuriku 5,508 MW
        (300 MW)
    (600 MW)
  Chubu 25,480 MW
      (2,500 MW)
Tohoku 13,410 MW
      (300 MW)
  TEPCO 64,300 MW

Interconnection line
DC power transmission
Frequency converter

60 Hz  50 Hz

(600 MW)
(5,000 MW)
Capacity constraints of power plants

\[ \text{CAPLO}(P, T, RP) \leq \text{POW}(P, T, RP) \leq \text{CAPUP}(P, T, RP) \]

- P: Pattern (1-7).
- T: Time (1-24).
- RP: Region (1-60).
- POW: Electricity generation.
- CAPUP: Upper limit of generation.
- CAPLO: Lower limit of generation.
Supply constraint of electricity

\[ \sum_{R} (X(P,T,R) - S(P,T,R)) = \sum_{R} D(P,T,R) \]

- **R**: Region (1-60).
- **X**: Supply of electricity.
- **S**: Supply to the pumped hydropower plant.
- **D**: Electricity demand.
Constraints of load-following capability

\[ POW(P, T, RP) \leq FUP(RP) \times POW(P, T - 1, RP) \]
\[ POW(P, T, RP) \geq FLO(RP) \times POW(P, T - 1, RP) \]

FUP: Upper limit of load-following capability.
FLO: Lower limit of load-following capability.
Constraint of transmission capacity

\[ \text{TRANS}(P,T,R_1,R_2) \leq \text{TRUP}(R_1,R_2) \]

TRANS: Transmission power from region \( R_1 \) to \( R_2 \).

TRUP: Upper limit of Transmission capacity from region \( R_1 \) to \( R_2 \).
Nuclear power plants at TEPCO

- Total installed capacity of nuclear power reaches 17,308 MW.
  - The capacity corresponds to 38.8 percent of total installed capacity of nuclear power in Japan.
- All of this nuclear power plants has suspended operations at April 14, 2003.
- TEPCO has restarted 8 reactors, which capacity is 8,680 MW.
Assumptions of the analysis

- Power generation plants include:
  - Nuclear
  - Thermal power (coal-fired boiler, LNG-fired boiler, LNG combined cycle, oil-fired boiler)
  - Hydropower (conventional, pumped).
- Electricity transmission is supposed to lose 1% of its power per 100km.
- The capability margin of electricity supply is set at 8%.
## Characteristics of power plants

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Capital cost(^1) ($/kW)</th>
<th>Fixed O&amp;M(^1) (cents/kW-yr.)</th>
<th>Variable O&amp;M(^1) (cents/kWh)</th>
<th>Fuel cost(^1) (cents/kWh)</th>
<th>Thermal efficiency(^2) (H.H.V.) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear power</td>
<td>2,950</td>
<td>2.84</td>
<td>0.042</td>
<td>1.26</td>
<td>32.10</td>
</tr>
<tr>
<td>Coal-fired</td>
<td>2,167</td>
<td>2.36</td>
<td>0.338</td>
<td>2.08</td>
<td>38.98</td>
</tr>
<tr>
<td>Oil-fired</td>
<td>1,667</td>
<td>1.37</td>
<td>0.010</td>
<td>5.83</td>
<td>37.04</td>
</tr>
<tr>
<td>LNG-fired</td>
<td>1,583</td>
<td>1.44</td>
<td>0.010</td>
<td>5.48</td>
<td>38.13</td>
</tr>
<tr>
<td>LNG combined</td>
<td>1,000</td>
<td>1.53</td>
<td>0.052</td>
<td>4.73</td>
<td>43.27</td>
</tr>
<tr>
<td>Hydropowered pumping</td>
<td>5,000</td>
<td>8.33</td>
<td>0.000</td>
<td>0.00</td>
<td>None</td>
</tr>
<tr>
<td>Conventional hydropower</td>
<td>2,500</td>
<td>2.50</td>
<td>0.000</td>
<td>0.00</td>
<td>None</td>
</tr>
</tbody>
</table>


Result: CO$_2$ emission in TEPCO and Tohoku