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System Adequacy Study

Carried out by University of Basel and ETH Zürich for SFOE
Strommarkttreffen Schweiz, Zürich, 15.06.2018
Motivation and background

• Swiss electricity system subject to changes on many levels
  • Shift to renewables
  • Nuclear decommissioning
  • Hydropower under revenue pressure

• What are the consequences for security of supply?

• System adequacy vs. generation adequacy

• Prior studies regarding system adequacy in Switzerland
  • PLEF
  • ENTSO-E
  • Elcom (shorter time horizon)

• SFOE looks at longer time horizon than Elcom
This study

• Modelling of the system adequacy of the Swiss electricity sector
• Taking into account neighboring countries developments
• Scenario based electricity future until 2035
• Two models:
  • Deterministic model: Focus on detailed representation of transmission and hydro system
  • Stochastic model: Aggregated to regions but with higher number of scenarios (Monte Carlo)
Model

Focus here: Deterministic model
Model: Swissmod

Swissmod is a DC load flow, dispatch, cost-minimization model with particular detail on hydropower

Transmission System Model:
- ca. 230 nodes (150 in Switzerland)
- ca. 400 lines

Neighboring countries included in simplified representation
Model: Hydropower representation
Modelling of lost load

• Lost load is modeled as a “very expensive power plant” for each node (10,000 EUR/MWh, based on literature estimates of VoLL)

• “Ultima ratio” if load cannot be served by other means (imports, power plants)

• Loss of load (LOL): Number of hours in which the “loss of load power plant” is used

• Energy Not Served (ENS): Energy produced by the “loss of load power plant”
Probabilistic model

• Similar model, but more aggregated
  • Zonal model with 7 nodes for Switzerland and 14 for neighboring countries
  • Load, production and storage aggregated per region

• Less variables enables use of probabilistic Monte Carlo approach
Scenarios and Data
Base scenarios for Switzerland

Policy
- Demand policy
- Supply policy

Weather
- Demand weather
- Renewables weather

Years
- 2017
- 2020
- 2025
- 2030
- 2035

Supply policy
- CuE
- C
- EuI

Demand policy
- NEP
- POM
- WWB

Renewables weather
- std
- min
- max

Weather Demand
- std
- min
- max

Renewables Demand
- std
- min
- max

Policy Weather Demand
- std
- min
- max

Policy Weather Demand
- std
- min
- max

Policy Weather Demand
- std
- min
- max

Policy Weather Demand
- std
- min
- max

Policy Weather Demand
- std
- min
- max

Policy Weather Demand
- std
- min
- max
Scenario groups

• Base scenarios
  • Represents developments according to reference scenarios
  • Combinations of policy and weather scenarios for 5 target years

• Fast EU transformation scenarios
  • What if EU transitions faster towards renewables?
  • Takes assumptions from different national studies from TSOs and regulators
  • Based on NEP/EuI and all weathers

• Extreme scenarios
  • 15 specifically designed scenarios of special circumstances
  • From singular capacity reductions (on top of regular assumed availability factors) to large-scale outages across Europe and Switzerland
  • Based on WWB/EuI/cold/RESmin
Data for Base Scenarios

- Europe
  - EU Reference Scenario for Energy (2016)

- Switzerland
  - Prognos Energy Strategy to 2050 (2012)
Results
Results: Base scenarios

- **LOL**: Number of loss of load events
  - Zero for all scenarios

- **ENS**: Energy not served in GWh
  - Consequently, also zero for all scenarios

- **RCM**: Reserve capacity margin
  - All scenarios have at least 2.97 GW reserve capacity (min: WWB-Eul-2035) at all points in time
Results: Fast EU transformation scenarios

- Faster transition in neighboring countries
  - Decline of thermal capacities
  - Increase of renewables
Results: Fast EU transformation scenarios

Switzerland

• Loss of load events
  • 2030: 2h
  • 2035: 163h

• Energy not served
  • 2030: 0.86 GWh
  • 2035: 105 GWh

• Reserve capacity margin
  • All scenarios have at least 2.89 GW reserve capacity (min: 2035) at all points in time

Europe

• Loss of load events
  • 2030: 72h
  • 2035: 219h

• Energy not served
  • 2030: 256 GWh
  • 2035: 1’003 GWh

• Reserve capacity margin
  • All scenarios have at least 2.02 GW reserve capacity (min: 2035) at all points in time
## Extreme Scenarios

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Name</th>
<th>Anpassung</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC01</td>
<td>DE weniger Braun-/Steinkohle</td>
<td>-15 GW weniger Braun/Steinkohlekapazität</td>
</tr>
<tr>
<td>SC02</td>
<td>FR weniger Kernenergie</td>
<td>-15 GW weniger Kernenergiekapazität</td>
</tr>
<tr>
<td>SC03</td>
<td>IT weniger Gas</td>
<td>-10 GW weniger Gaskraftwerkskapazität</td>
</tr>
<tr>
<td>SC04</td>
<td>CH weniger KKW</td>
<td>Frühzeitige Abschaltung Kraftwerk Leibstadt</td>
</tr>
<tr>
<td>SC05</td>
<td>CH weniger SpKW</td>
<td>- 4 GW weniger aus flexiblen Speicherkraftwerken (Turbinenleistung reduziert)</td>
</tr>
<tr>
<td>SC06</td>
<td>CH weniger PSKW</td>
<td>-1 GW PSKW Leistung vom Netz</td>
</tr>
<tr>
<td>SC07</td>
<td>CH Füllstände Speicher</td>
<td>Speicherfüllstände auf 75% Anfang Oktober</td>
</tr>
<tr>
<td>SC08</td>
<td>FR und DE weniger konv. KW</td>
<td>Kombination aus Szenario (SC01) und (SC02)</td>
</tr>
<tr>
<td>SC09</td>
<td>CH weniger KKW und Speicher KW</td>
<td>Kombination aus Szenario (SC04) und (SC05)</td>
</tr>
<tr>
<td>SC10</td>
<td>CH weniger KKW, SpKW und PSKW</td>
<td>Kombination aus Szenario (SC04), (SC05) und (SC06)</td>
</tr>
<tr>
<td>SC11</td>
<td>FR und DE weniger konv. KW, CH weniger KKW, SpKW und PSKW</td>
<td>Kombination (SC08) und (SC10)</td>
</tr>
<tr>
<td>SC12</td>
<td>CH kein KKW</td>
<td>Frühzeitige Abschaltung aller Kernkraftwerke</td>
</tr>
<tr>
<td>SC13</td>
<td>CH kein KKW und SpKW</td>
<td>Kombination aus Szenario (SC12) und (SC05)</td>
</tr>
<tr>
<td>SC14</td>
<td>CH kein KKW, SpKW und PSKW</td>
<td>Kombination aus Szenario (SC12), (SC05) und (SC06)</td>
</tr>
<tr>
<td>SC15</td>
<td>FR und DE weniger konv. KW, CH kein KKW, SpKW und PSKW</td>
<td>Kombination aus Szenario (SC08) und (SC14)</td>
</tr>
</tbody>
</table>
Results: Extreme scenarios

• Loss-of-load events especially with German lignite and coal capacity decommissioning (both with and without parallel French capacity shortage)

• Only French nuclear or Swiss hydropower decommissioning yield nearly no consequences for Swiss system adequacy

• The minimal reserve capacity margin (RCM) is -1.94 GW for 2030 in SC11 and SC15

• Worst case in 2030:
  • Large neighboring capacities down (SC08)
    • ENS 0.02 TWh in CH; 0.9 TWh in Europe
  • Swiss only capacities down (SC14)
    • ENS 0.00004 TWh in CH, 0.00034 TWh in Europe
  • Swiss and neighboring capacities down (SC15)
    • ENS 0.6 TWh in CH; 1.6 TWh in Europe
Timing of hydro storage and SA indicators:
Example of SC15 extreme scenario
Limitations

• Perfect foresight hypothesis
  • Agents in our model know in the beginning of the year that it will be a hard year

• Global optimization
  • “Everyone helps everyone” hypothesis
  • In reality likely: Helping only if surplus available
  • Swiss RCM remains positive in all base and fast EU transformation scenarios, so likely study over-estimates loss of load problems in Switzerland by counting events, in which Switzerland helps neighboring countries

• Limitation to neighboring countries
  • Including further EU countries could change results
    • The more countries are considered, the more they can compensate for individual short-term supply problems
  • Domestic structures in neighboring highly aggregated
Conclusions

• Important role of international exchanges
  → Coordination with Europe important

• Significant over-capacities in Europe
  → Lost load only occurs if substantial capacities decommissioned

• Switzerland typically less affected by problems than Europe
  → Neighboring countries are likely to react by increasing own capacity
Backup
Indicators

• RCM
  Reserve capacity margin

• LOL
  Number of loss of load events

• ENS
  Energy not served in MWh

• SSD
  Storage Supply Duration. Indicates for any time period how long the contents of the hydro storages are sufficient for supplying Switzerland without any imports.

• SSB
  Storage Supply Buffer. Shows by how much the storage content exceeds (or falls short of) the energy needed to supply Switzerland without imports for a target time span.
Model: Swissmod

\[
\min_{c_{11},c_{12},c_{13}} \left\{ C = \sum_t \sum_{c_{11}} u_{c_{11}} E_{11}^{c_{11}} \right\}
\]

Node Balance

\[
E_i^n = \sum_{c_{11}} c_i^{c_{11}} E_{i1}^{c_{11}} + \sum_{h_{11}} h_{i1}^{h_{11}} E_{i1}^{h_{11}} - \sum_{h_{11}} h_{i1}^{h_{11}} E_{i1}^{h_{11}} - d_i^n
\]

Line Flow

\[
E_i^l = \theta^l \sum_n i_{i,n} X_i^n
\]

Classical dispatch model:

- Cost minimization (QP due to linear increasing generation costs)
- DC-Load flow, node balance, capacity restrictions
- Detailed hydro representation with endogenous determination of water value
Model: Swissmod

Capacity Restrictions

\[ E_{\downarrow t}^{\text{hpp}} = \alpha_{\text{hpp}} W_{\downarrow t}^{\text{hpp}} \]
\[ E_{\uparrow t}^{\text{hpp}} = \frac{\alpha_{\text{hpp}} W_{\uparrow t}^{\text{hpp}}}{\beta_{\text{hpp}}} \]
\[ E_{\downarrow t}^{\text{hpp}} < e_{\downarrow}^{\text{hpp}} \]
\[ E_{\uparrow t}^{\text{hpp}} < e_{\uparrow}^{\text{hpp}} \]

Water Storage Balance

\[ WO_{t}^{wn} = WI_{t}^{wn} - \Delta WS_{t}^{wn} \]
\[ \Delta WS_{t}^{wn} = WS_{t}^{wn} - WS_{t-1}^{wn} \]

Inflow/Outflow Definitions

\[ WI_{t}^{wn} = \bar{w}_{t}^{wn} + \sum_{hpp} lwr_{hpp} W_{\downarrow t}^{hpp} + \sum_{hpp} upr_{hpp} W_{\uparrow t}^{hpp} + \sum_{wn} \theta_{wn} \bar{W}_{t-\text{lag}}^{wn} \forall wn, t \]
\[ WO_{t}^{wn} = \sum_{hpp} upr_{hpp} W_{\downarrow t}^{hpp} + \sum_{hpp} lwr_{hpp} W_{\uparrow t}^{hpp} + \sum_{wn} \theta_{wn} \bar{W}_{i}^{wn} \forall wn, t \]
Extensions

• Hydro specific indicators
  • DSS: Duration of Storage Supply
    • Indicates for any time period how long the contents of the hydro storages are sufficient for supplying Switzerland without any imports.
  • BSS: Buffer of Storage Supply
    • Shows by how much the storage content exceeds (or falls short of) the energy needed to supply Switzerland without imports for a target time span.

• Extension: Grid delay

• Extension: DSM