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System Adequacy Study

Carried out by University of Basel and ETH Zürich for SFOE
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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

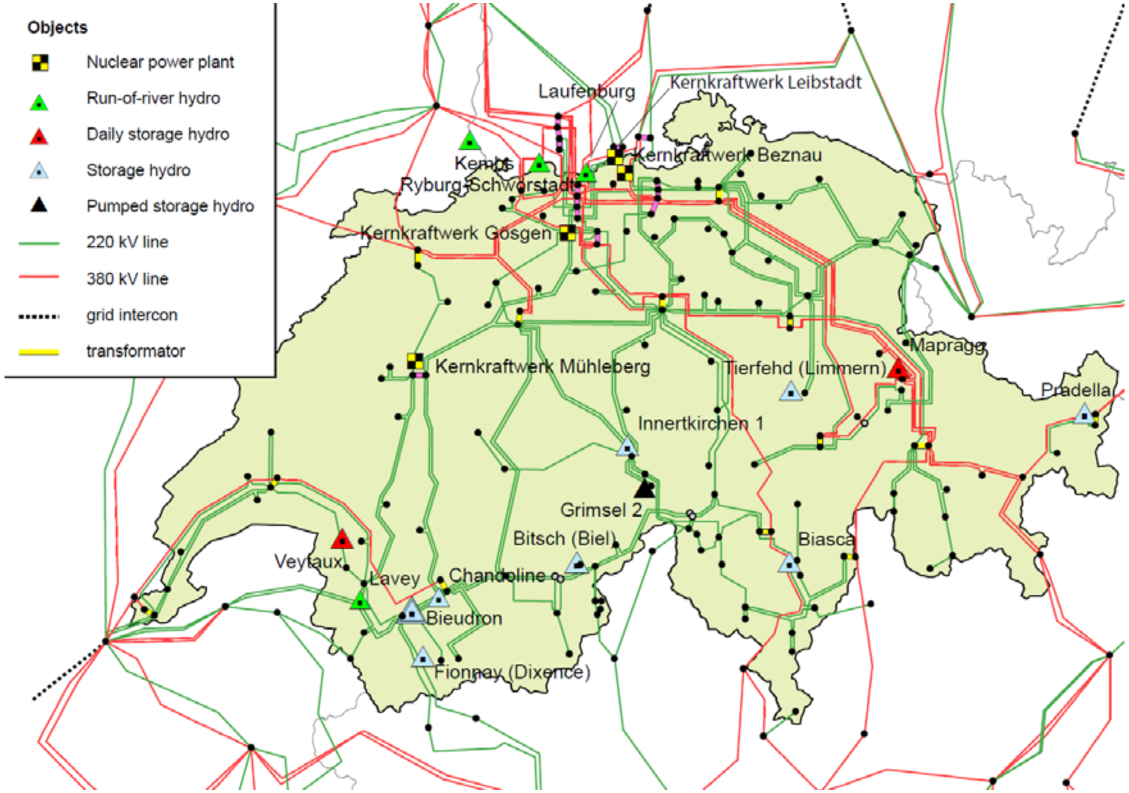
This study

- 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



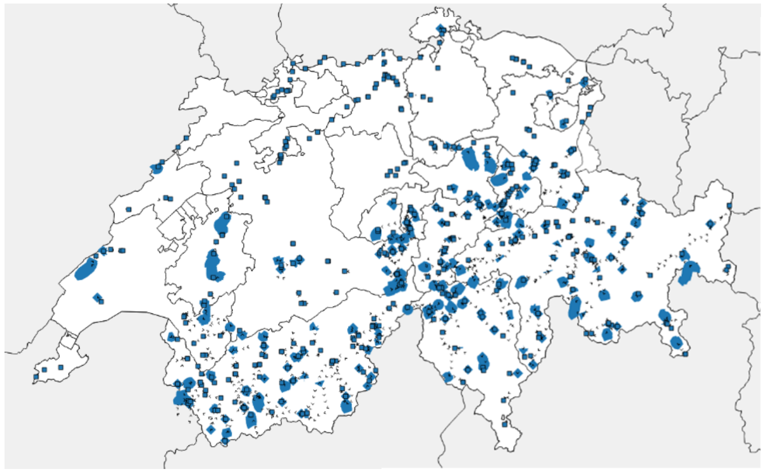
Transmission System Model:

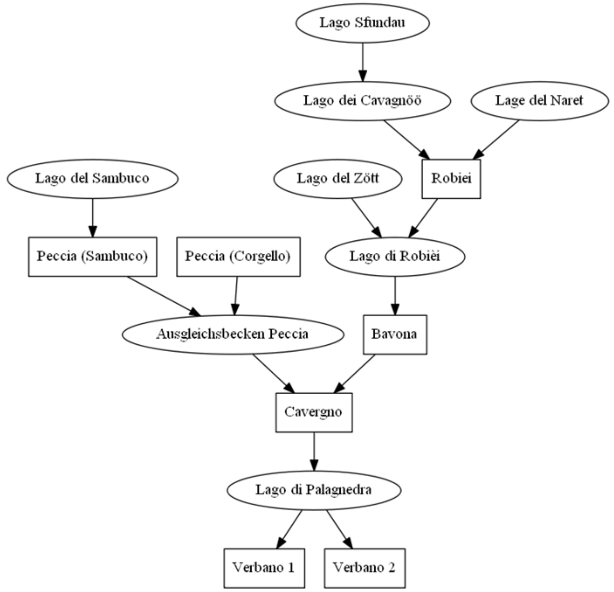
- ca. 230 nodes (150 in Switzerland)
- ca. 400 lines

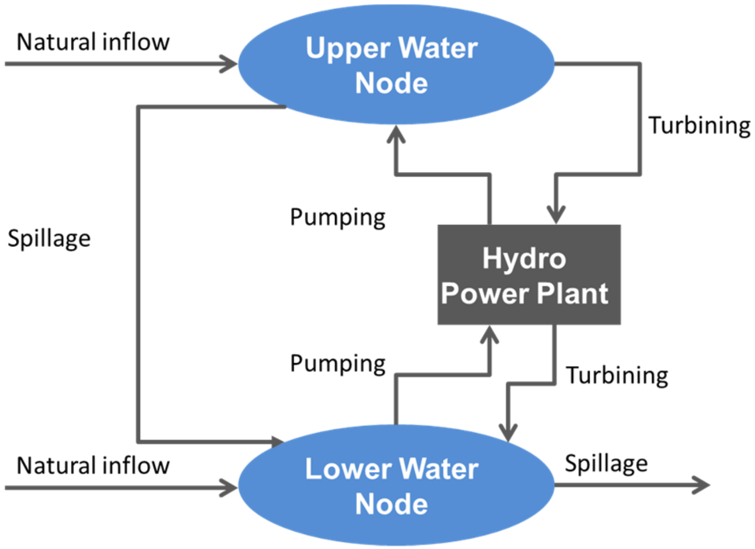
Neighboring countries included in simplified representation

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

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

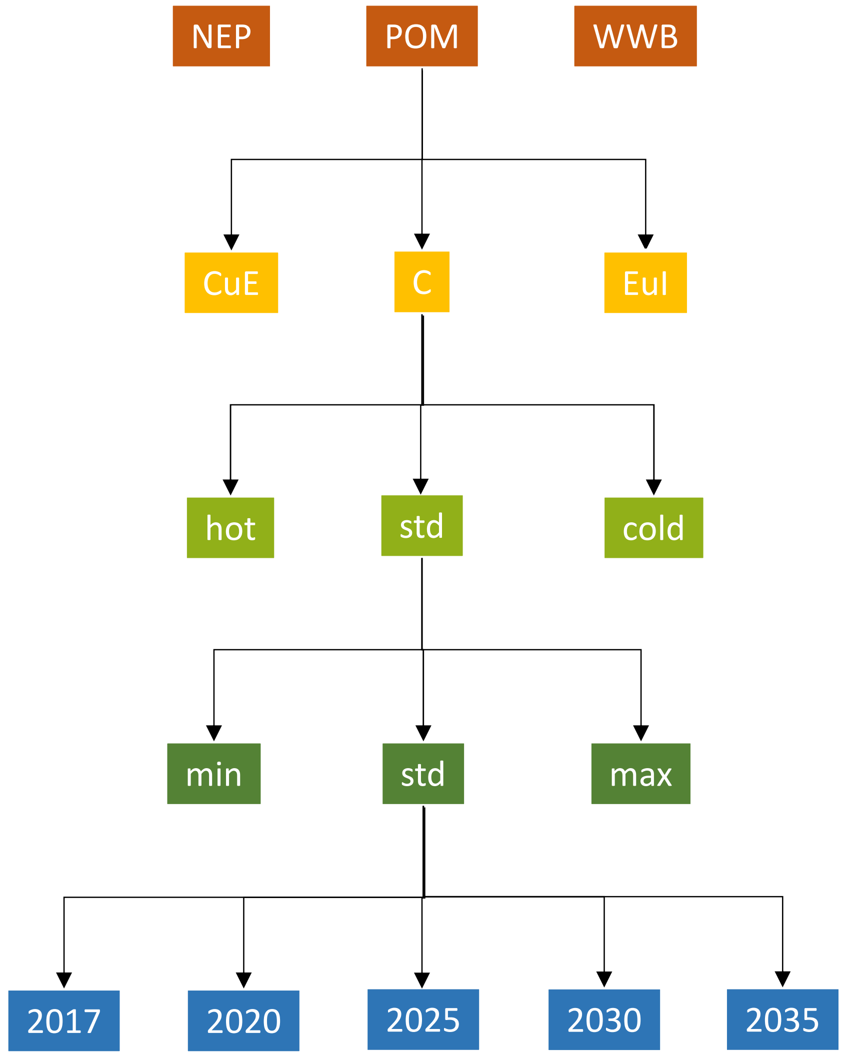
Supply policy

Weather

Demand weather

Renewables weather

Years

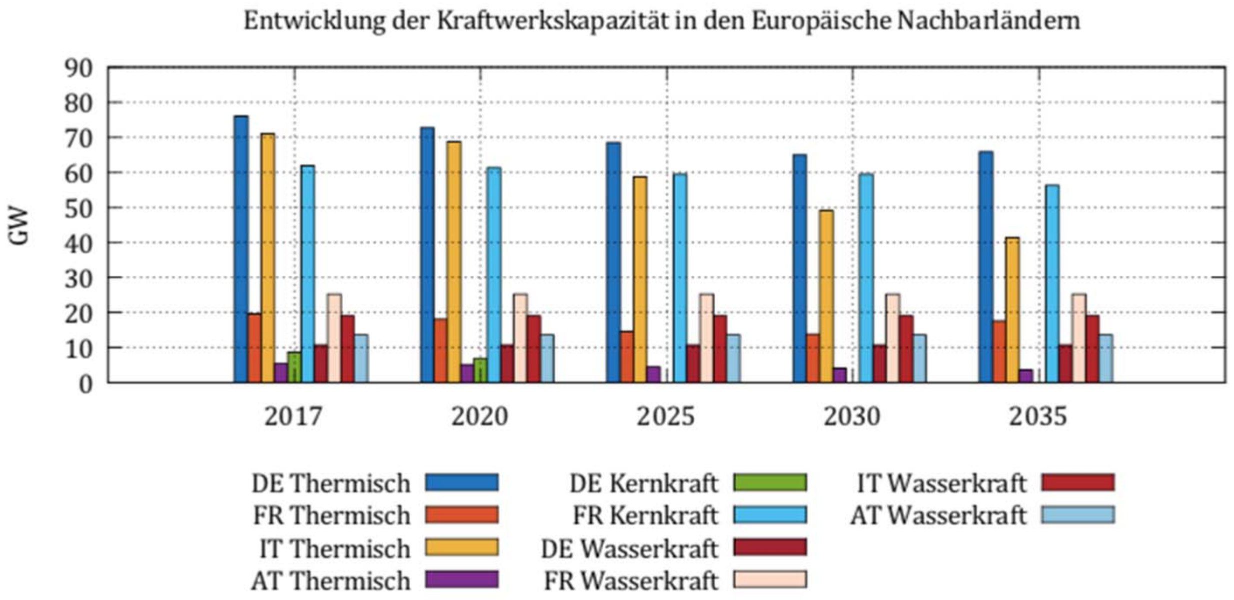


Scenario groups

- 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)

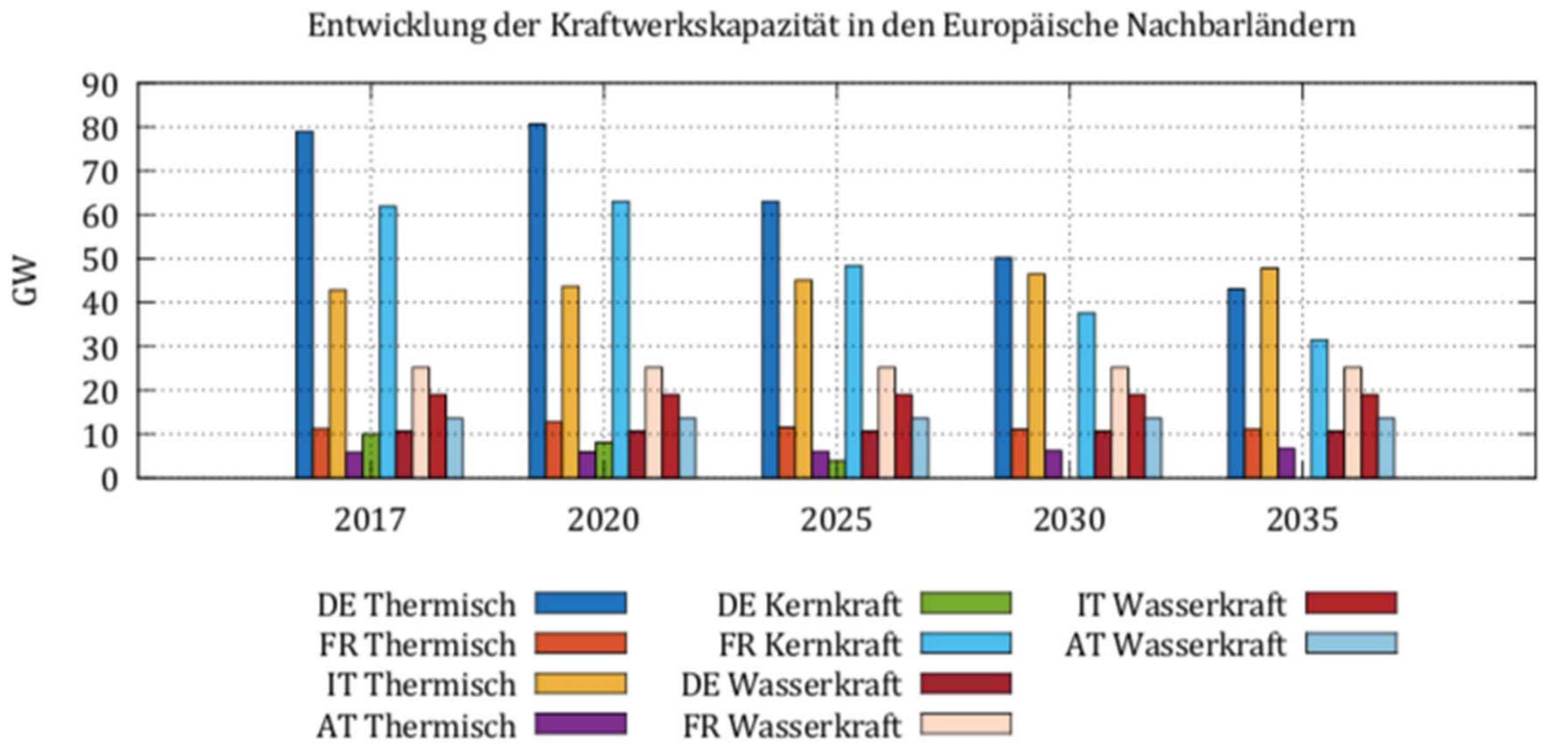


Results

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-EuI-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

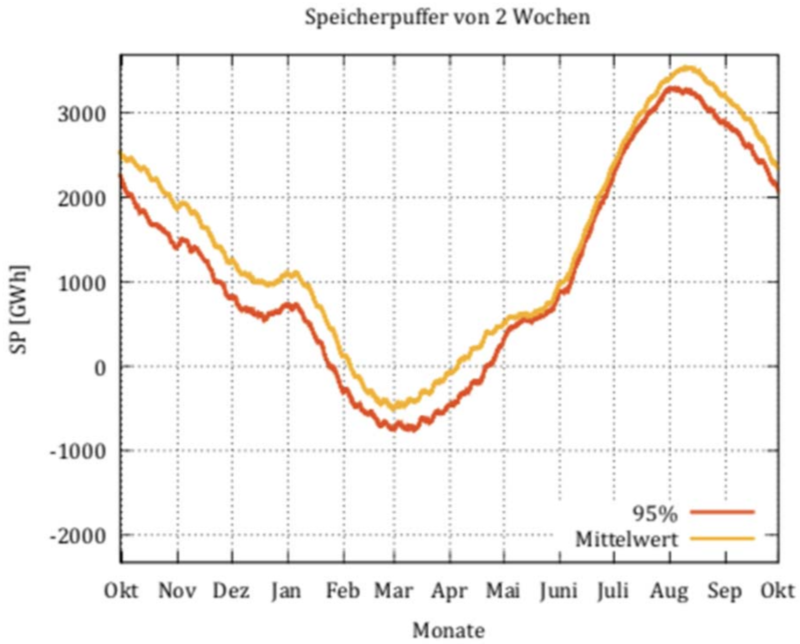
Extreme scenarios

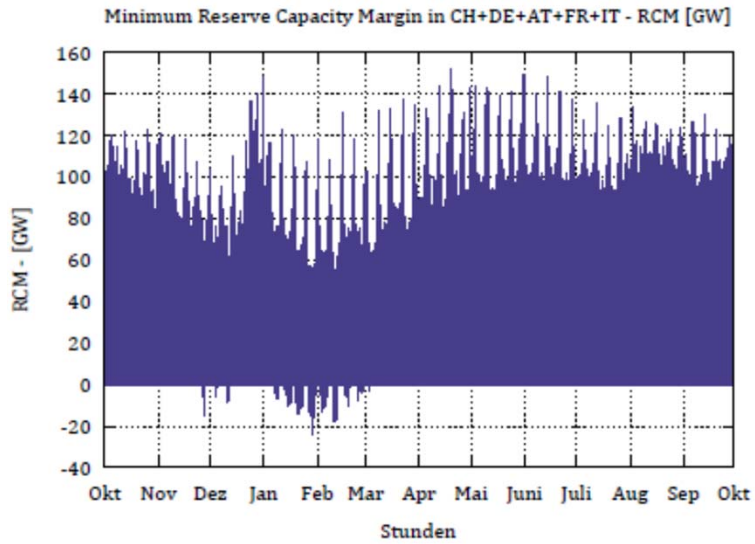
Nr.	Name	Anpassung
SC01	DE weniger Braun-/Steinkohle	-15 GW weniger Braun/Steinkohlekapazität
SC02	FR weniger Kernenergie	-15 GW weniger Kernenergiekapazität
SC03	IT weniger Gas	-10 GW weniger Gaskraftwerkskapazität
SC04	CH weniger KKW	Frühzeitige Abschaltung Kraftwerk Leibstadt
SC05	CH weniger SpKW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

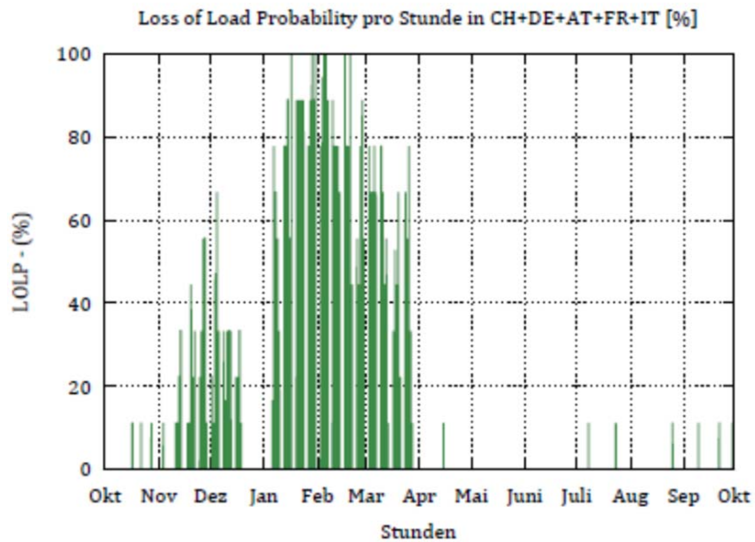
Results: Extreme scenarios

- 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

$$\min_{e_t^{cpp}, e\uparrow_t^{hpp}, e\downarrow_t^{hpp}} \left\{ C \quad = \quad \sum_t \sum_{cpp} vc^{cpp} E_t^{cpp} \right\}$$

Node Balance

$$E_t^n = \sum_{cpp} \mathbf{cpi}_{cpp}^n E_t^{cpp} + \sum_{hpp} \mathbf{hpi}_{hpp}^n E\downarrow_t^{hpp} - \sum_{hpp} \mathbf{hpi}_{hpp}^n E\uparrow_t^{hpp} - d_t^n$$

Line Flow

$$E_t^l \quad = \quad b^l \sum_n \mathbf{i}_{l,n} X_t^n$$

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

$$E{\downarrow}_t^{hpp} = \alpha^{hpp} W{\downarrow}_t^{hpp}$$

$$E{\uparrow}_t^{hpp} = \frac{\alpha^{hpp} W{\uparrow}_t^{hpp}}{\beta^{hpp}}$$

$$E{\downarrow}_t^{hpp} < \overline{e{\downarrow}}^{hpp}$$

$$E{\uparrow}_t^{hpp} < \overline{e{\uparrow}}^{hpp}$$

$$WS_t^{wn} < \overline{ws}^{wn}$$

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

$$WI_t^{wn} = \mathring{w}_t^{wn} + \sum_{hpp} \mathbf{lwr}_{hpp}^{wn} W{\downarrow}_t^{hpp} + \sum_{hpp} \mathbf{upr}_{hpp}^{wn} W{\uparrow}_t^{hpp} + \sum_{uwn} \theta_{wn}^{uwn} \overrightarrow{W}_{t-\mathbf{lag}_{wn}^{uwn}}^{uwn} \quad \forall \quad wn, t$$

$$WO_t^{wn} = \sum_{hpp} \mathbf{upr}_{hpp}^{wn} W{\downarrow}_t^{hpp} + \sum_{hpp} \mathbf{lwr}_{hpp}^{wn} W{\uparrow}_t^{hpp} + \sum_{lwn} \theta_{lwn}^{wn} \overrightarrow{W}_t^{wn} \quad \forall \quad wn, t$$

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