Potential impact of post Fukushima nuclear policy on the future role of CCS in climate mitigation scenarios in Switzerland

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Outline

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References
Overview Swiss energy system

Primary and final energy consumption

Swiss primary and final energy consumption 2010

- Agriculture / stat. Diff
- Transport
- Services
- Industry
- Residential
- District heat
- Electricity
- Other renewables
- Nuclear
- Hydro
- Gas
- Oil products
- Oil
- Waste
- Coal
- Wood
Overview Swiss energy system

Electricity generation mix (2010)

- Total: 239 PJ
- Run-of-river hydro (24.2%)
- Dam hydro (32.3%)
- Nuclear power (38.1%)
- Conventional thermal (5.4%)

- Power sector nearly decarbonised
- Self sufficiency in annual electricity generation but still dependent on import for seasonal demands
- Electricity trading is important (power system balance, revenue)
Overview Swiss energy system

Challenges for the future Swiss energy system

- Development of future electricity demand (population/GDP growth increase, electrification)
- Nuclear phase-out
- Climate policy
- Energy security
- Future availability of technologies supporting low carbon energy system
Objective

- Analyze how uncertainties may affect future Energy system and cost-effectiveness of technologies
- Identify robust combinations of technologies and fuels
- Potential role of low carbon electricity sources (new renewables, CCS) under nuclear and climate constraints

Scenario analysis

- Uncertainties → Definition of scenarios
- Scenarios analysed using Swiss MARKAL energy system model
Swiss MARKAL model

Description of modeling framework

- Technology-rich bottom-up energy system model of entire Swiss energy system (single region model)
- Extensive representation of end-use efficiency technologies
- 40-years time horizon (2010-2050)
- Calibration to years 2000-2010
History of Swiss MARKAL model

- Model development initiated by M. Labriet at the University of Geneva (Labriet, 2003)
  - Building up first version of the model including five end-use sectors, conversion and supply
- Further developments and analyses by T. Schulz (Schulz, 2007; Schulz et al., 2007, 2008)
  - Implementation of extensive end-use technology options in transport and residential sector (including energy saving options based on marginal cost curves)
- and N. Weidmann (Weidmann, Turton, and Wokaun, 2009; Weidmann, Kannan, and Turton, 2011; ETS, 2009)
  - Further development of the model in all end-use sectors
  - Calibration of the entire model to 2010 data and demand update
  - Development and implementation of CCS module
Swiss MARKAL model

CCS module

Swiss MARKAL CCS Module

Natural gas

Electricity

- ENGACCSS0 Powerplant + capt.
- ENGACCSS50 Powerplant + capt.
- ENGACCSSR10 Powerplant
- ENGACCSSR50 Powerplant
- CHPNGCSS30 CHP Powerplant
- CHPNGCSS50 CHP Powerplant
- CHPNGCSSR10 CHP Powerplant
- CHPNGCSSR50 CHP Powerplant

- CCS_CONV_1 Combine captured CO2 streams
- CCS_CONV_2 Combine captured CO2 streams
- CCS_COMB_1 Combine captured CO2 streams
- CCS_COMB_2 Combine captured CO2 streams

- CCS_TRANS Transport of CO2
- CCS_STG Storage of CO2

- IMPSTGPOT1 Import of STGPOT (storage potential 1)
- IMPSTGPOT2 Import of STGPOT (storage potential 2)

- User-defined constraint: A_CCS_A
  \[ \sum \text{Activity}_i \text{(CCS_COMB_1, CCS_COMB_2, CCS_CAP)} = \text{Activity}(\text{CCS_TRANS}) \]

- User-defined constraint: A_CCS_1
  \[ \sum \text{Activity}_i \times \text{ENVACT}_{\text{capt},i} \text{(ENGACCS tech)} = \text{Activity(\text{CCS_COMB_1})} \]

- User-defined constraint: A_CCS_3
  \[ \text{Activity(\text{CCS_CONV_2})} = \sum \text{Activity}_i \times \text{ENVACT}_i \text{(CCSCAPTHxx)} \]

- User-defined constraint: A_CCS_5
  \[ \text{Activity(\text{CCS_CONV_2})} = \sum \text{Activity}_i \times \text{ENVACT}_i \text{(CHPNGCCS tech)} \]

- User-defined constraint: A_CCS_1x
  \[ \text{Activity(ENGACCSR)} \times \text{EFF(\text{CCSCAPTE})} \geq \text{Activity(\text{CCSCAPTE})} \]

- User-defined constraint: A_CCS_2x
  \[ \text{Activity(ENGHCCSR)} \times \text{EFF(\text{CCSCAPTH})} \geq \text{Activity(\text{CCSCAPTH})} \]

- User-defined constraint: A_CCS_6
  \[ \sum \text{Activity}_i \times \text{ENVACT}_{\text{capt},i} \text{(CHPNGCCS tech)} = \text{Activity of CCS_COMB_2} \]
Scenario definitions

- **Ref**: Reference scenario (nuclear replacement, no (climate) policies)
- **NoNuc**: Nuclear phase-out
- **Clim**: Climate target (domestic CO$_2$ reductions by 20% by 2020, 60% by 2050)
- **Cumul A**: Cumulative CO$_2$ target
- **Cumul B**: Cumulative CO$_2$ target with fixed end point
- **CCS**: Carbon Capture and Storage technologies available

General model assumptions

- Oil, coal, and geothermal based power generation are fully restricted
- Hydro assumed to follow a fixed production path (34.8 TWh$_{el}$ in 2035, 33.0 TWh$_{el}$ in 2050)
- Renewable potentials (Solar PV: 13.7 TWh$_{el}$, Wind: 4 TWh$_{el}$, Biomass: 28.1 TWh$_{th}$)
- Discount rate: 3%
Reference scenario

Primary energy supply

![Primary energy - Ref graph](image)
Climate scenario

Primary energy supply

![Primary energy - Ref vs. Clim.](chart.png)

- Geo
- Solar
- Wind
- Biomass
- Hydro
- Nuclear
- Gas
- Oil
- Coal

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Electricity and CO₂ emissions

Electricity gen. - *Ref vs. Clim*

![Graph showing electricity generation across different years and scenarios.]

- Solar
- Biomass CHP
- NGA CHP
- NGA CC
- Hydro
- Wind

*CO₂ emissions - Ref vs. Clim*

![Graph showing CO₂ emissions across different years and scenarios.]

- Electricity
- Residential
- Industry
- Transport
- Service
- Agriculture
- Other
- Upstream
Climate scenario

Final energy in residential heating and car sector

Final energy res. heat. - Ref vs. Clim

Final energy car sector - Ref vs. Clim

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Primary energy supply

Primary energy - Clim. vs. Clim.+NoNuc

Graph showing the primary energy supply from 2010 to 2050 for different scenarios: Ref, Clim, and Clim + NoNuc. The graph compares the energy supply from various sources including Geo, Solar, Wind, Biomass, Hydro, Nuclear, Gas, Oil, and Coal. The y-axis represents PJ (petajoules) ranging from 0 to 1200, and the x-axis represents years from 2010 to 2050.
Electricity supply

Electricity gen. - Clim. vs. Clim + NoNuc

- Solar
- Wind
- Biomass CHP
- NGA CHP
- NGA CC
- NGA CC CCS
- Nuclear
- Hydro
- Other
CO\textsubscript{2} emissions

CO\textsubscript{2} emissions - \textit{Clim vs. Clim+NoNuc}

- Million tons of CO\textsubscript{2}
- Years: 2010, 2020, 2035, 2050
- Categories: Electricity, Transport, Residential, Industry, Service, Agriculture, Upstream
Nuclear phase-out under climate constraint

Final energy in residential heating and car sector

**Final energy res. heat. - Clim vs. Clim+NoNuc**

**Final energy car sector - Clim vs. Clim+NoNuc**

- **Savings**
- **Electricity**
- **District heat**
- **Natural gas**
- **Oil**
- **Biomass**

- **Battery**
- **Hydrogen**
- **Natural gas**
- **Gasoline**
- **Diesel**

- **Ref Clim Clim + NoNuc**
Electricity supply

Electricity gen. - **CCS in nuclear replacement and nuclear phase-out**
Final energy in residential heating and car sector

**Final energy res. heat. - CCS w/ & w/o Nuclear**

- **2010**: Ref, Clim + NoNuc, Clim + NoNuc + CCS
- **2020**, **2035**, **2050**: Savings, Electricity, District heat, Natural gas, Oil

**Final energy car sector - CCS w/ & w/o nuclear**

- **2010**: Ref, Clim + NoNuc, Clim + NoNuc + CCS
- **2020**, **2035**, **2050**: Battery, Hydrogen, Natural gas, Diesel, Gasoline
Alternative CO₂-reduction pathways

CO₂-emissions

CO₂ emissions - CO2 reduction pathways

CO₂ emissions - CO2 reduction pathways with CCS

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System costs

Incremental total discounted system costs (rel. to Ref)

- no CCS
- CCS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Ref</th>
<th>Clim</th>
<th>Clim + NoNuc</th>
<th>Cumul A + NoNuc</th>
<th>Cumul B + NoNuc</th>
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<td>0.5%</td>
<td>1.0%</td>
<td>1.5%</td>
<td>2.0%</td>
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</table>

Notes:
- Ref Clim Clim +
- NoNuc
- Cumul A + NoNuc
- Cumul B + NoNuc
Summary and conclusion

- Changes over time across entire energy system (supply and end-use). Climate- and nuclear policy constraints have system-wide effects (e.g., interplay between end-use and power sectors).

- Car sector: Trends towards higher efficiency (across all scenarios) and low carbon intensity (climate scenarios). However, fossil fuels will play a major role during the next 40 years.

- Residential heating: Implementation of energy saving options and low carbon heating systems attractive across a wide range of scenarios (with and without climate targets).
New renewables become attractive towards the end of time horizon. Climate targets and nuclear phase-out promote earlier deployments.

CCS only attractive under nuclear phase-out and stringent climate targets. First, new renewables are deployed.

CCS has effects on end-use sectors:
- Residential heating: Electrification of energy system → more heat pumps, less saving measures
- Car sector: Decarbonisation of electricity sector → lower efficiency and more fossil fuels in car sector

Costs: Nuclear phase-out → increase in system costs. CCS could reduce costs for climate mitigation under nuclear constraint (dependent on stringency of climate target).
Outlook

- Improvements and extension of technology detail in services and industrial sectors (including energy efficiency options)
- Sensitivity analysis on crucial model input parameters (technology costs, discount rate)
- Extension of CCS module in Swiss MARKAL model and analysis of additional CCS scenarios
- Energy service demand update (to be implemented in Swiss MARKAL and Swiss TIMES models)


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