WP 4: Future Supply of Electricity - Highlights, Impacts and Outlook

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WP4: Tasks, Activities, Objectives

Risk, Safety & Societal Acceptance
- Assist & enable upcoming P&D projects in DGE
- Move to risk-cost-benefit analysis and MCDA
- Validate & extend approaches and tools
- Engage with industry and cantonal regulators
- “Export” methodologies

Global Observatory of Electricity Resources
- Technology monitoring; contributions to ES2050
- Sustainability Assessment using (spatial) MCDA
- Electricity Market in Europe and impacts in CH
- Electricity capacity expansion in CH, incl. Europe
- Stochastic dispatch optimization of hydropower
- Scenarios for fully renewable CH

Future Supply of Electricity

Socio-Economic–Political Drivers
- Economic, social, and political boundary cond.
- Assessment of different policy futures for Swiss electricity supply
- JA IDEA with CREST

JA S&M
(G. Guidati)
T4.1 – Risk, Safety and Societal Acceptance
Haute-Sorne DGE risk analysis validation

- Benchmarking of Haute-Sorne DGE risk analysis (in Matlab, R, Python OpenQuake)
- Aggregate probabilistic risk curves corrected for spatial correlation aspects

Local losses & individual risk

Aggregate losses via simulations

Broccardo et al., to be submitted
DGE energy/risk governance meta-model

- **Energy model**: analytical, both electricity and heat production modelled
- **Economic model**: LCOE reformulated to include “cost of public safety” (financial losses linked to seismic risk mitigation, such as loss of injection well during TLS)
- **Seismic risk model**: Probabilistic, safety-norm in risk space, safety-norm-based TLS
- **Behavioural model**: Cumulative Prospect Theory to model risk/loss aversion
- Maps optimal trade-off between public safety (via norm) & energy safety (via LCOE spatial minimization) to improve governance

Mignan et al., injecting seismic risk mitigation measures into the Levelized Cost Of Electricity of Enhanced Geothermal Systems, in revision
Identifying spaces of participation

- Research with the GEothermie 2020 program
- Worked on the different implicit assumptions about what is participation
- 6 focus groups with inhabitants and participatory observation management meetings
- Result indicate that program managers see participation as classical formats of information provision and site visits;
- Invited/internal participation that is exclusive is important in managers’ view.
- Focus group participants see information provision as one important format
- They often referred to individual actions and awareness on an individual level.
Landslide risk model in Alpine context

- Cellular Automaton for landslide initiation and propagation tested in simulated fractal topographies & retrieves the same power law scaling as literature
- Application to Alpine context with frequency-size distribution refined for hazard

Jafarimanesh et al., Origin of the power-law exponent in the landslide frequency-size distribution, in revision
Jafarimanesh et al., Application to the Swiss Alps of the Landslide Generic Cellular Automaton, in prep.
Uncertainty Quantification (UQ) in the Modeling of Dam-Break Consequences

- **Metamodelling** for UQ and sensitivity analysis of consequences of the potential failure of a hydropower dam, with particular focus on relevant Swiss conditions;

- The metamodel of the computational model was built using the polynomial chaos expansion (PCE) technique on the experimental design of only 2,000 sample points;

- 10^6 realizations of the PCE metamodel helped to build distributions describing the variability of the model outputs (see below examples for the peak discharge, $Q_{peak}$);

- No additional sampling was required to calculate Sobol’ sensitivity indices.

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**Step B**
Quantification of sources of uncertainties

**Step A**
Computational model

**Step C**
Uncertainty Propagation

$$M_{i}^{PCE} = \sum_{\alpha \in A} y_\alpha \Psi_\alpha (X)$$

**Step D**
Sensitivity Analysis

$M_{i}^{PCE}$ - PCE response

$X_i$ - input vector

$y_\alpha$ - coefficient

$\Psi_\alpha$ - polynomials

- Modified from Sudret (2017)

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**First order Sobol’ sensitivity indices**

Kalinina et al. (in prep.)

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**Computation, $y_{i,ED}$, and PCE meta model response, $M_{i}^{PCE}$**

**Frequency**

0 5 10 × 10^5

0 500 1000

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**Kalinina et al. (in prep.)**
Quantitative Assessment of Uncertainties and Sensitivities in Life Loss estimates due to an Instantaneous Dam Break

- Adapt and integrate the HEC-LIFESim life-loss (LL) modeling tool with a metamodeling approach, including UQ and GSA.
- Application to a hypothetical, instantaneous dam break with conditions relevant for CH.
T4.2 – Global Observatory of Electricity Resources

Future Supply of Electricity

Graphs and charts illustrating electricity price and capacity vs. turbine mean elevation, along with maps and other visualizations related to energy resources and sustainability.
Potential, Costs and Environmental Effects of Electricity Generation Technologies

- Consistent evaluation of electricity generation technologies that are potentially relevant for Swiss supply until 2050
- **Funded by** SFOE and SCCER SoE; **Additional contributions from** SCCER Biosweet
- **Report supports:** «Energieperspektiven 2017» and SFOE technology monitoring
- Final report including executive summary with technology “fact sheets”. [https://www.psi.ch/ta/PublicationTab/Final-Report-BFE-Project.pdf](https://www.psi.ch/ta/PublicationTab/Final-Report-BFE-Project.pdf)
- SCCER SoE Blog: “Can renewables fill the power gap?”
Potential, Costs and Environmental Effects of Electricity Generation Technologies

- Key input to JA Scenario & Modeling for several modeling teams
- Update of current electricity generation costs (until Jan 2019)
- Similar analysis will be carried out for electricity storage technologies
### Modeling Activities of Energy Economic Group (PSI)

<table>
<thead>
<tr>
<th>Elec. generation capacity</th>
<th>Electricity prices</th>
<th>Optimal profit against prices</th>
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<td>European capacity</td>
<td>Electricity market</td>
<td>Hydropower stochastic</td>
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<tr>
<td>expansion modeling</td>
<td>modeling</td>
<td>dispatch modeling</td>
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- **Elec. generation capacity**
  - Long-term capacity expansion in Europe under policy scenarios
  - Scope: CH + EU

- **Electricity prices**
  - Future wholesale price ranges under policy scenarios
  - Scope: CH + surrounding countries

- **Optimal profit against prices**
  - Optimal production and pumping thresholds under exogenous prices
  - Scope: Single utility
EU production capacity expansion modeling

- Multi region, cost-optimization model of electricity system of Europe: Long time horizon (2050), hourly time resolution (typical days)
- Near-term EU energy polices implemented (with new electricity storage options)

Electricity supply in 2015, 2035, and 2050

- **Gas power** becomes transitional technology in short-/mid-term
- **Baseline scenario**: EU polices reduce power sector’s CO₂ emission in 2050 by 60% (w.r.t. 2010)
- **Further decarbonization** requires high share of renewable (> 40% of generation) and gas-based CCS technology. In 2050, the new renewables require 250-450 TWh (=5-10% of electricity load) shifted daily by **storage with 125-355 GW capacity**
Fully Renewable Swiss Power System

Inputs:
- Strategic Grid 2025
- Renewable Placement

Algorithm: Match Supply and Demand

Results: Generation and Demand

- Current Scenario
- Intermediate Scenario
- Renewable Scenario

• Switzerland has the resources to be fully renewable.
• Transmission grid may be similarly or less stressed with increasing renewable penetration.
• Large scale foreign exchange or significant new storage facilities would be required.
• Alpine solar and wind resources could play a significant role in a future renewable Switzerland.

Bartlett et al. (2018)
T4.3 – Socio-Economic-Political Drivers
Framing HP in Swiss Newspapers

- Media analysis in collaboration with ZHAW
- Complementing media analysis on DGE
- Providing a basis to test impacts of media frames on public acceptance
- Analysis completed

**First results**
- Predominantly framed as an economic issue
- Main actors are operators and federal offices
- Technical risk and periglacial dams are non issues

Most frequent topics in relationship to HP (n=170)
Cantonal views on challenges to HP

- Collaboration with Uni Basel
- Assess the challenges encountered by cantons to expand HP
- Qualitative interviews with 9 Cantonal officers in charge of HP (covering 83% of Swiss HP production)
- Qualitative content analysis
- Analysis ongoing

First results
- Goal conflicts between BFE and BAFU appears as the most limiting factor for HP
- Economic issues are perceived as conjunctural
- Cantons have little to no leverage to plan for HP
- They do not see wider public engagement as necessary. Information is enough
- Increasing discussions with operators about maintenance and safety costs.
Case study Lago Bianco

Case study to assess stakeholder engagement during the concessioning process of the Lago Bianco pump-storage dam

- Collaboration with University of Geneva (not JA CREST partner)
- Social network analysis (SNA) to assess nature of relationships of actors involved in the participatory process that led to the re-design of the project
- SNA completed with qualitative interviewing to identify the type of resources (legal, financial, expertise, legitimacy, social capital...) used by actors to assert their position
- Data collection is currently ongoing.
Policy Pathways

- The Climate Policy group at ETH is analysing the value of the flexibility that hydropower provides, as this depends on the policy pathways in neighbouring and nearby countries.
- So far, they have developed representative scenarios for Germany, based on literature review and stakeholder interviews.
- Similar scenarios for Italy, France, and Spain are currently being developed.
WP4 – Poster Pitches

1. Arnaud Mignan (ETHZ): Increase of the EGS levelized cost of electricity, or the financial cost of public safety

2. Matteo Spada (PSI); A preliminary sustainability analysis of potential areas for deep geothermal energy (DGE) systems: Application to Switzerland

3. Michael Lehning (WSL/EPFL): Heterogeneity of Swiss environmental condition and its possible impact on the electrical system

→ WP4 has a total of 31 posters
What is the price of electricity produced by EGS plants?

- Economic models give price/kWh
- None consider the cost of seismic risk mitigation measures
- Seismic risk is the greatest problem that the EGS industry is facing

"Increase of the EGS LCOE, or the financial cost of public safety"

- DGE risk governance framework
- Meta-model (electricity + heat production, economic model, seismic risk model, behavioural model, safety-norm-based TLS)
- LCOE as main metric

Rationale

A multitude of models exist that compute the levelized cost of electricity (LCOE) for Enhanced Geothermal Systems but none take into account the costs associated with induced seismicity, although seismic risk remains the main problem facing the EGS industry today.

Results

(1) Mitigating seismic risk during reservoir stimulation (via TLS):
- Block curve: break-even price, red: competitive price, black: too high
- Impact of safety norm limited on the fair price, however, the small increase in price that a building class A to D would cost to avoid any induced seismicity)
- Benefit of heat credit at small distances from EGS is included in the cost of seismic risk mitigation

(2) Mitigating seismic risk during production phase (via Q_{prod} clipping):
- Strong impact of Q_{prod} clipping to avoid any induced seismicity on LCOE.
- Depends on local stress field, which is very uncertain.

Discussion

(1) Meta-model as regulatory sandbox to improve DGE risk governance & regulation (see poster by Mignan & Seferovic, SCCER SoE-CREST joint activity)

(2) Seismic risk better controlled, via the use of a safety norm. However, the seismic risk being stochastic in nature, the safety norm can only be respected on average.

(3) Public acceptance could be improved via such a transparent approach & their understanding of the trade-off between public safety & energy safety

References

Which are the most sustainable areas for DGE in Switzerland?

- Previous sustainability assessments of new renewables in Switzerland did not consider the spatial variability of criteria (e.g., economic, environmental and social).
- However, it is of great importance for DGE.
- “A Preliminary Sustainability Analysis of Potential Areas for DGE Application to Switzerland”
  - Spatial Multi-Criteria Decision Analysis (sMCDA) framework
  - Stochastic classification to rank 32 areas based on 11 indicators for 2 hypothetical types of DGE plants in Switzerland.
  - Different weighting profiles can influence performance of both plant type and area.

**Table 1:** Key physical parameters of DGE plant capacity cases considered in this study

| Type of Plant | Total Plant Capacity (MWe) | Total Turbine | Total Architectural
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<td>Single Plant</td>
<td>1.47</td>
<td>2.01</td>
<td>3.67</td>
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<tr>
<td>Double Plant</td>
<td>2.94</td>
<td>4.02</td>
<td>7.34</td>
</tr>
<tr>
<td>Triple Plant</td>
<td>4.41</td>
<td>5.97</td>
<td>10.68</td>
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Next, criteria are established to cover all 3 pillars of sustainability (environment, economy, and society). Furthermore, indicators are chosen for each criterion based on availability and potential spatial variability (Table 2).

**Table 2:** Selected criteria and indicators used in this study.

| Type of Plant | Regional Climate | Local Topography | Natural Seismic Risk | Human Activity
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Indicators are then quantified for the hypothetical plants in Table 1 and for a set of 32 potential areas defined using Hot Flue (HF) and Natural Seismic Risk maps. Environmental and economic indicator values have been estimated based on the topographical gradient (UT) in the area of interest, since UT is the ratio between the HF and the thermal conductivity of rocks (on average 3 W/mK in Switzerland) [3]. On the other hand, the non-seismic accident risk indicator considers the output risk and release of selected hazardous chemicals, which are related to the number of drilled wells [2]. The natural seismic risk indicator is considered in this study as a proxy for social acceptance, meaning that high risk is associated with high social acceptance of a DGE system. The induced seismicity indicator is estimated based on the flow rate expected for the stimulation (i.e., higher the flow rate, the higher the risk of induced seismicity) for each of the plant capacities considered in this study.

Conclusions

- Different weighting profiles strongly influence the sustainability profile, which varies by plant type.
- Results can help inform decisions on where to allocate DGE plants in Switzerland.
- Further research is needed to refine the methodology and consider additional indicators.
How to Increase Winter PV Production

1. More radiation in winter
2. More ground reflection in winter
3. Steeper panel tilt
ES2050: Required wind power capacity

![Capacity vs turbine mean elevation graph]

- Required capacity [MW] vs Mean elevation [m.a.s.l.]
- Import [TWh/a] ranges: 7 to 9
- Annual production markers: +12 TWh/a, ○4 TWh/a, ▲6 TWh/a