Task 4.1

Title

Risk, safety and societal acceptance

Projects (presented on the following pages)

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Induced seismicity risk analysis of the planned geothermal hydraulic stimulation in Geldinganes, Iceland

M. Broccardo, F. Grigoli, D. Karvounis, A. Mignan, A.P. Rinaldi, L. Danciu, S. Wiemer

Motivation

The rapid increase of energy demand in Reykjavik has posed the need for additional supply of geothermal energy. The deep hydraulic (re-)stimulation of the well RV-43 in the peninsula of Geldinganes (north of Reykjavik) is an essential component of the plan implemented by Reykjavik Energy to increase the geothermal supply of energy. Hydraulic stimulation are often associated with fluid-induced seismicity, which can cause damage to the nearby building stock and nuisance to population. This study presents a pre-drilling preliminary probabilistic induced-seismic hazard and risk analysis for the site of interest. The induced-seismic hazard and risk analyses are based on a fully probabilistic framework, with focus on inherent epistemic and aleatory variability. We provide full probabilistically estimated of peak ground accelerations, European Microseismicity intensity, damage, and individual risk for the area of interest.

Site description and planned operations

The well RV-43 is located in the Geldinganes geothermal field in the northeastern part of the city of Reykjavik, Figure 1. Reykjavik Energy (OR) is the main supplier of heat in Reykjavik and has drilled several wells in Geldinganes. OR aims producing hot water from RV-43 to be directly utilized for heating purposes and to meet the increasing energy needs of Reykjavik. RV-43 was drilled in 2001, it is 1832 m long, where the deeper 924 m long are uncased (8½ inches open hole). The well is oriented towards the northeaster of Geldinganes, an area speculated to be exceptionally warm, since it is closer than the rest of the Geldingane's wells to the extinct central volcanic system north of Reykjavik.The locations of both Geldinganes, its wells, its shallow temperature gradient and RV-43 are shown in Figure 1.

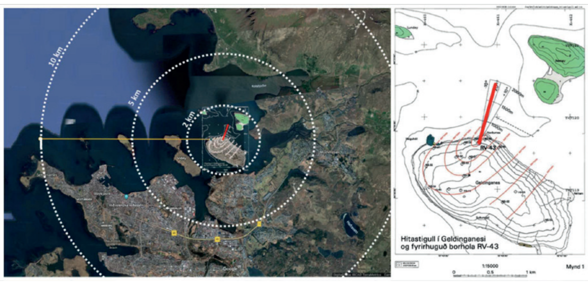

Figure 1 Map view of the Geldinganes island in Reykjavik. On the right, the Geldinganes area is plotted with all its wells, the temperature gradients measured at shallow depths and with the solid red line representing RV-43 at different measured depths (figures extracted from OR's report for the drilling of RV-43).

Probabilistic fluid-induced seismicity seismic hazard and risk analysis in a nutshell

- Classical PSHA analysis, Intensity measures PGA, and EMS-98 scale
- Sources: fixed point source at injection points (data driven, S1) and *Karvounis et al.* physical based model (synthetic catalogue, S2)
- Frequency-magnitude distribution: Truncated Gutenberg Richter
- Epistemic Uncertainties, logic tree (Figure 2): 2 rate models, 7 Ground Motion Predictive Equations (GMPE), 2 Ground Motion Intensity Conversion Equation (GMICE). Number of brunches 120
- Results Hazard curves Figure 3 show larger uncertainty for data driven source model
- Risk computation computed as classical convolution of hazard vulnerability and exposure
- Output Individual Risk (IR), and Damage Risk (DR)
    - IR is defined as frequency at which a statistically person is expected to experience death or a given level of injury
    - DR is defined as frequency at which a statistically average building class is expected to experience light non-structural damage
- Vulnerability models: Macroseismic intensity approach for IR and local mechanical fragility function for DR
- IR threshold 10^{-6} (one micromort), DR threshold 10^{-2}. Figure 4 and 5
- Results of the a-priory risk analysis shows IR and DR bellow the safety limits.
- It is mandatory to update hazard and risk computations during stimulation

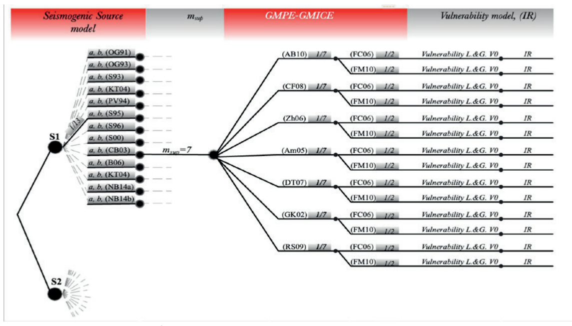

Figure 2 Full logic tree for hazard and risk computation

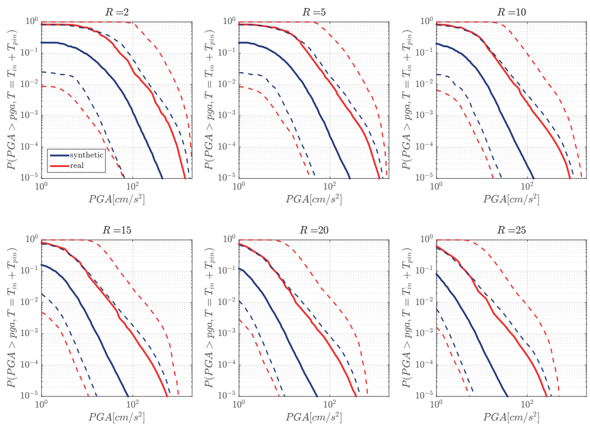

Figure 3 PSHA analysis comparison between source model S1 (Data driven) and S2 (synthetic catalogue). Solid lines: medians; dashed lines 10% and 90% quantiles.

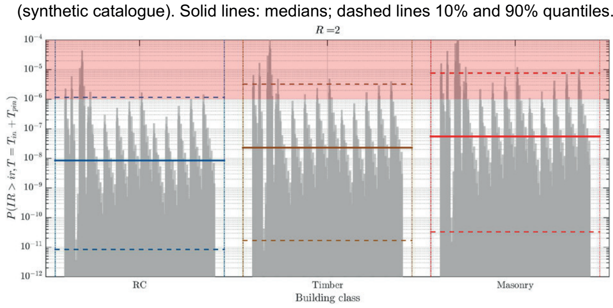

Figure 4 Marginal ***IR*** for 2 km distances. The solid horizontal lines represent the weighted median values of the vertical gray lines. The dashed horizontal lines represent the 10 and 90% epistemic quantiles.

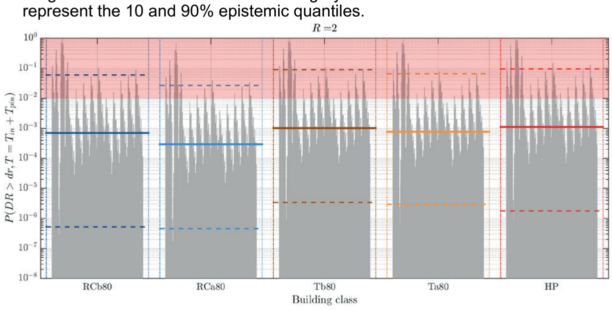

Figure 5 Marginal ***IR*** for 2 km distances. The solid horizontal lines represent the weighted median values of the vertical gray lines. The dashed horizontal lines represent the 10 and 90% epistemic quantiles.

References

Broccardo et al. (2019). *A-priori seismic risk study for the stimulation of well RV-43 in Geldinganes, Iceland.* Internal risk report

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Risk Assessment of Accidents in the Energy Sector for Selected Long-Term Scenarios

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P. Burgherr[1], M. Spada[1], L. Vandepaer[1,3], A. Kalinina[1], W. Kim[2], P. Lustenberger[2]
[1]Laboratory for Energy Systems Analysis (LEA), Paul Scherrer Institut, Villigen PSI, Switzerland
[2]Future Resilient Systems (FRS) , Singapore-ETH Centre, Singapore, [3]Sherbrooke University, Sherbrooke, Québec, Canada.

Introduction

The comparative risk assessment of accidents in the energy sector is well established to evaluate the performance of technologies [1]. In recent years, it has become an essential component within the broader concepts of sustainability, energy security and resilience [2].

This study focuses on how the overall accident risk of a country's electricity supply mix is affected by long-term energy projections like the World Energy Outlook (WEO) scenarios [3]. It includes several novel elements: (1) average and marginal electricity supply mixes for today and 2030; (2) updated accident risk indicators until 2016; and (3) coverage of 11 country groups / countries (three shown here).

PSI's ENSAD Database

The Energy-related Severe Accident Database (ENSAD) comprises a comprehensive global coverage of full energy chains, and focuses on severe accidents (e.g. ≥5 fatalities) that are a major concern to industry, authorities and the public. Recently, it has been transformed in a spatial database with comprehensive GIS functionality, running on a Platform as a Service (PaaS) cloud environment [4].

Normalized fatality risk indicators were calculated for fossil energy chains (coal, oil, natural gas), hydropower, nuclear power and new renewable technologies. Figure 1 shows fatality rates per energy chain and country group (i.e. OECD, EU28, non-OECD). Generally, OECD and EU28 countries perform better than non-OECD for fossil and hydropower energy chains. Compared to the 1990s, the Chinese coal chain is only slightly higher than the rest of non-OECD. Hydropower is most deadly in non-OECD countries, but the difference becomes substantially smaller if the most extreme dam failure in China (Banqiao/Shimantan, 1975, 26'000 fatalities) is excluded. For nuclear, fatality rates are among the lowest, particularly for the new generation III reactors. Finally, new renewables have clearly lower fatality rates than fossil chains (except biogas).

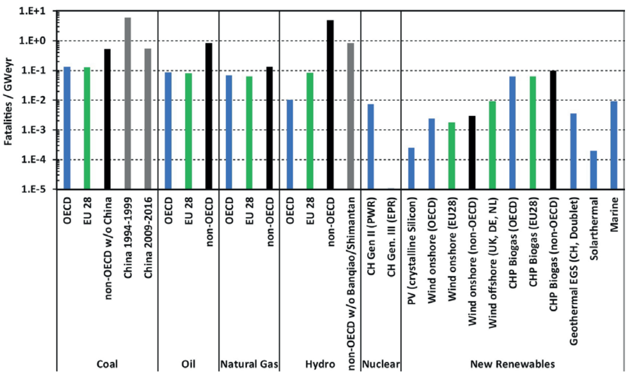

Figure 1: Severe (≥5 fatalities) fatality rates for fossil, hydro, nuclear and new renewables in OECD, EU28 and non-OECD countries for the period 1970-2016. PWR: Pressurized Water Reactor, EPR: European Pressurized Reactor, CHP: Combined Heat and Power, EGS: Enhanced Geothermal Systems.

Risk Indicators in Long-Term Scenario Modeling

Three core scenarios from the WEO were considered [3]:

- **Current Policies Scenario** (CPS) takes into account only those policies and measures that are confirmed and legally consolidated.
- **New Policies Scenario** (NPS) illustrates the general direction in which the most recent policy ambitions could lead the energy sector.
- **Sustainable Development Scenario** (SDS) is fully aligned with the goal of the Paris Agreement to keep global average temperature rise well below 2 °C above pre-industrial levels.

The current mix (2017) for each scenario is compared against the corresponding 2030 average (attributional) electricity mixes, and the 2017 and 2030 marginal (consequential) mixes (see [5] for details). Fatality rates for 2030 were approximated using data for the period 1990-2016 as presented in [6].

Figure 2 shows the overall accident risk for the current and future average and marginal electricity supply mixes per scenario for OECD, EU28 and non-OECD countries. The former two country groups clearly perform better, but all three groups exhibit a similar pattern: (1) overall accident risk becomes smaller for scenarios with increasingly ambitious climate targets; (2) improvements become larger for 2030 compared to 2017; (3) the overall accident risk is consistently lower for the marginal mix than the corresponding average mix, indicating that renewable technologies increasingly replace large, centralized power plants, especially coal and to a large extent also natural gas.

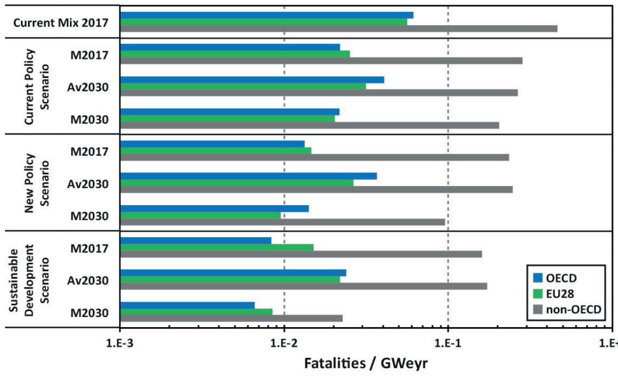

Figure 2: Overall accident risk for the current mix (2017) and scenario-specific average (Av) and marginal (M) electricity supply mixes in 2017 and 2030 for OECD, EU28 and non-OECD.

Conclusions

Among centralized, large-scale technologies, fossil energy carriers have the highest fatality rates, whereas hydro and nuclear perform best in industrialized countries. Decentralized, new renewables are less sensitive to the issue of severe accidents, and geothermal is clearly better than natural gas and biogas.

The implementation of more stringent climate policies often leads to a reduced overall accident risk as exemplified by the current scenario analysis. Furthermore, results showed the impact of the increasing penetration of new renewables on the average electricity supply mixes, but also reflected their growing importance for marginal mixes, replacing particularly coal and to a lesser extent natural gas until 2030, which further reduces overall accident risks.

Acknowledgements

This work has been carried out within the **Swiss Competence Center for Energy Research (SCCER) – Supply of Electricity** (concept, data management and scenario analysis), and the **Future Resilient Systems (FRS) program** of the Singapore-ETH Centre (SEC) (database development and implementation).

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Geothermal Exploration Chance Of Success

UNCERTAINTY REDUCTION

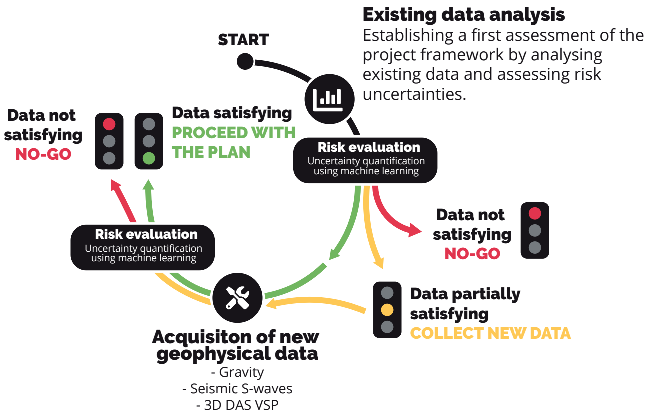
Acquisition of cost-effective, quick and high resolution geophysical data such as 3D DAS VSP, S-waves seismic and high resolution gravity can help to improve the understanding of the subsurface.

RISK MITIGATION

Stochastic and machine learning approach are perfectly shaped to integrate and analyse different types of geodata to mitigate the risk of developing geothermal project projects.

EXPLORATION COST REDUCTION

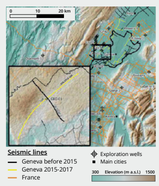
High-resolution acquisition and integration of data from different sources using machine learning allow improving the probability of success of new geothermal projects.



GECOS WORKFLOW

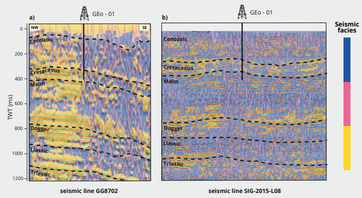
This workflow can be replicated at any stage of a geothermal project. From the early stages when only scarce data are available, during exploration when new data will be collected and when large new investments (i.e. 3D seismic and drilling) need to be planned, and during production to monitor the reservoir and eventually design new drilling operations. Predictive machine learning models are updated as far as new data are available.

Machine learning on seismic en borehole data



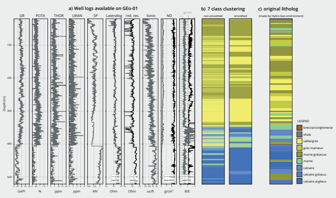
About 200 km of 2D seismic lines are available over the Geneva Basin, corresponding principally to 4 acquisition campaigns undertaken from 1987 to 2015, as well as a selection of unitary lines issued from earlier acquisition campaigns (1972-1977) to complete the seismic dataset toward the Northeast of the studied area.

Two time-migrated, 2D seismic reflection profiles intersecting the well GEo-01 have been retained to apply the proposed methodology, highlighted in the bottom left box of the left figure. Lines GG87-02 and SIG 2015-L08 are oriented NW-SE and NE-SW, covering approximately a distance of 4630 m and 8039 m, with a trace spacing of 15 m and 10 m respectively. Vertically, the profiles were recorded down to 4000 ms and 2000 ms respectively.

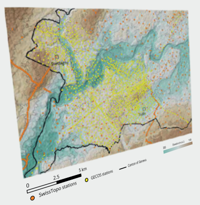


Machine learning allows classifying the seismic data into 3 facies that can be interpreted as unfractured intervals zone (yellow facies), especially visible in the left part of the GG8702 section; a likely occurrence of fractures zone (blue facies), which cover the most of the seismic line SIG-2015-L08 and a region of likely occurrence of fractures and small offset faults (pink facies).

Automatic classification of facies in GEo-01 well, using a K-means algorithm that allows to identify similar group of clusters (or facies) within a dataset of different wireline logs measurements. Figure (a) shows the 14 the geophysical logs used with the proposed approach, figure (b) shows the result of K-means algorithm with the number of clusters fixed to 7 for the lithofacies classification compared to the original lithology (c).

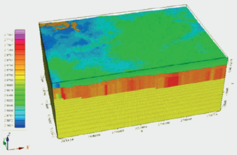


Gravity Data

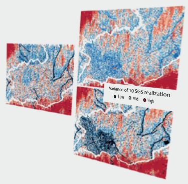


Location of the survey area and the Gravimetric Atlas of Switzerland stations and the stations collected in the framework of the GECOS project. The survey was carried in 71 days adopting an approach aimed at optimizing at most the quality and the time of the acquisition. This was achieved by running cycles between control stations and by using the Geneva Canton cadastral points as reference for the coordinates XY of each station and the DPGS or the Geneva Canton LiDAR DTM for the Z coordinate.

3D density model resulting after inversion processing. The inversion processing allows to reconstruct the density distribution in the subsurface according to gravity data observed on the field. The GM-SYS 3D toolset in Geosoft Oasis Montaj was used in this task. The inversion processing can provide accurate results when geometrical constraints (i.e. from a 3D geological model) and/or density data for the lithology of interest are available, therefore reducing the uncertainty of the resulting density model



One objective of the new acquisition campaign is to improve the knowledge of the subsurface density and better quantify its uncertainty. Starting from a gravity survey, we are able to produce a map of the complete Bouguer anomaly (CBA) that is a result of an interpolation of the observed anomaly at each survey location. However, since the distribution of the acquisitions stations could be more or less dense, we need to quantify the uncertainty related to the resulting interpolated map realizations.



For this purpose, we propose a stochastic approach to produce several sequential Gaussian simulation of the CBA over the studied area, before and after the new gravimetric acquisition. First order statistics are then applied to estimate the variance at each pixel of the interpolated grid to evaluate uncertainty of the resulting interpolated map. Adding the new GECOS stations allowed to reduce the uncertainty on the CBA map.

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Martin F
Meyer M
Nawratil De Bono C
SIG

The present study is part of GECOS (Geothermal Exploration Chance Of Success), a project (no. 26728.1 PFIW-IW) co-funded by INNOSUISSE and by Services Industriels de Genève and GEO2X SA.

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Public perception of hydrogen technologies combined with CCS in Switzerland

Lisa Hämmerli, Michael Stauffacher

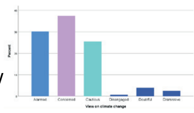
Limiting global warming and technology perception

- A majority of the climate scenarios considers negative emission technologies (NET) to reach a long-term climate stabilization under 2°C (Fuss et al., 2014)
- Bioenergy with carbon capture and storage (BECCS) is a NET
- There are few economic driver for the commercial deployment of carbon capture and storage (CCS). The introduction of hydrogen (H_2) as a low-carbon fuel for transport, industrial processes, heating and cooling could be a driver for the development of CCS or BECCS.

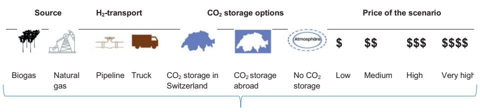
→ **How does the public perceive the options fossil fuel to H_2 and biogas to H_2 with carbon storage in Switzerland, abroad or no storage?**

→ **Is CCS more accepted when it is used in combination with hydrogen for the mobility sector?**

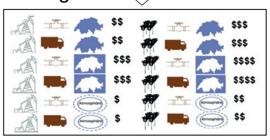
Quantitative Online Survey (N = 923)



- April to May 2019, quota on gender & age
- Audience segmentation: climate change view
- Vignettes design study

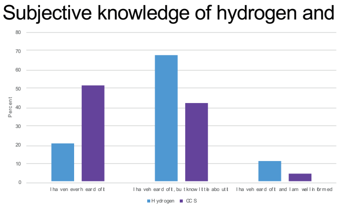


12 Vignettes

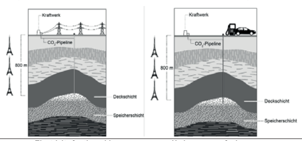


Results

- Subjective knowledge of hydrogen and CCS (N = 923)

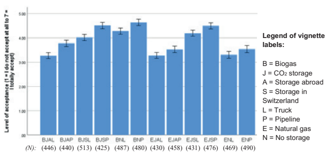


- Affective perception of different end-use options



Affective perception (1 = very negative to 7 = very positive)	Electricity for the grid Mean value (SE)	Hydrogen as a fuel Mean value (SE)
Biogas	4.41 (.064)	4.40 (.065)
Natural gas	4.16 (.060)	4.14 (.065)

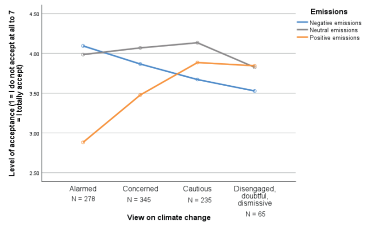
- Preferences of the vignettes



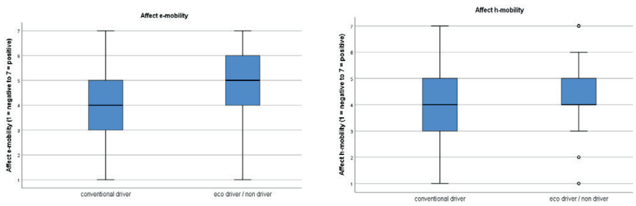
1. *Biogas without CO_2 storage & H_2 transportation via pipeline*
2. *Biogas with CO_2 storage in Switzerland & H_2 transportation via pipeline*
3. *Natural gas with CO_2 storage in Switzerland & H_2 transportation via pipeline*

- Perception regarding storage

- Climate change view on different emission options



- Affect of h-mobility and e-mobility



Summary and Discussion

- Affective response to hydrogen is more positive than to CCS.
- Affective response to both end-uses (hydrogen in the mobility sector or electricity for the grid) is similar.
- To accept negative emission technologies (BECCS in this case), you need to be alarmed by climate change.
- The study showed no clear preference towards scenarios with negative emissions.
- There is a significant preference of pipelines over transport by trucks. But rresults from Wallquist et al. (2012) suggest, that options without pipeline are preferred over options with a (CO_2) pipeline.
- There is a preference towards storing CO_2 in Switzerland compared with storing options abroad. There is also a clear preference using biogas in comparison with natural gas.
- There is no significant difference in the perception of h-mobility between conventional drivers and eco- and non-drivers.

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Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., Jackson, R. B., Jones, C. D., Kraxner, F., Nakicenovic, N., Le Quéré, C., et al. (2014). Betting on negative emissions. *Nature Climate Change*, 4, 850.

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The spatial diffusion of solar PV in Switzerland:
an interdisciplinary approach

Léon F. Hirt[1], Marlyne Sahakian[2], Evelina Trutnevyte[1]

[1]Renewable Energy Systems group, Faculty of Science, Department F.-A. Forel for Environmental and Aquatic Sciences, Institute for Environmental Sciences, University of Geneva, Switzerland
[2]Institute of Sociological Research (IRS), Institute for Environmental Sciences (ISE), University of Geneva, Switzerland

INTRODUCTION

Solar photovoltaic (PV) systems and spatial technology diffusion approaches

Switzerland is seeking to increase its share of renewable electricity to meet its Energy Strategy 2050 targets. Due to its high technical potential, solar PV could have an important role to play [1, 2, 3]. Cumulative installed capacity of solar PV has been increasing in the last decade (Fig. 1), but in a spatially uneven way (Fig. 2 and 3) [1, 2]. Therefore, a better understanding of how solar PV diffused in the past could help define measures to increase the uptake of this technology.

The literature on solar PV diffusion has focused on finding quantitative socio-technical/economic variables (e.g. feed-in tariffs) to predict the uptake of solar PV, whereas theoretical frameworks have only rarely been used [4]. Transitions studies more broadly have studied transitions using theoretical frameworks [5,6] but they were only rarely quantified [7].

Aim and approach

Our overall aim is to contribute to a better retrospective understanding of solar PV diffusion in Switzerland by linking the *Multi-level perspective (MLP)* on socio-technical transitions framework [5, 6] with quantitative indicators (n=36, e.g. population density). More specially, we aim to gain a better understanding of the spatial diffusion of solar PV which may contribute to helping Switzerland meet its energy targets.

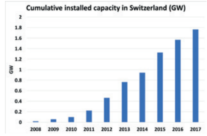

Figure 1. *Cumulative installed capacity in Switzerland (GW). Temporal perspective. Source: own analysis of the Pronovo dataset of registered solar PV projects [8]*

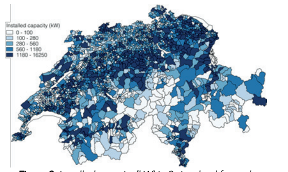

Figure 2. *Installed capacity [kW] in Switzerland for each municipality in 2017. Source: own analysis of the Pronovo dataset of registered solar PV projects [8]*

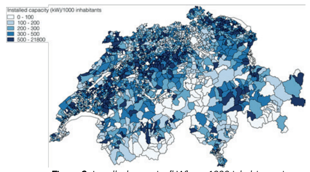

Figure 3. *Installed capacity [kW] per 1000 inhabitants in Switzerland for each municipality in 2017. Source: own analysis of the Pronovo dataset of registered solar PV projects [8]*

METHODOLOGY

The *Multi-level perspective (MLP)*

The MLP framework is a heuristic tool to study long-term socio-technical transitions. A transition is conceptualised as the destabilisation of a socio-technical regime, triggered by interactions between 3 hierarchical levels: a *Landscape* level (macro), a *socio-technical regime* level (meso) and a *niche-innovation* level (micro) level [5, 6] (Fig.3). The MLP has predominantly been used to study transitions at the national level [9]; here, we apply it to the municipality scale (N=2212) and focus on the regime level. Broadly speaking, a regime can be defined as the rules and regulations embedded in institutions and infrastructures which characterize a society's trajectory.

Theory and quantitative indicators

We selected quantitative indicators (n=36) based on the literature on solar PV uptake and the MLP framework (Fig. 3). We aimed to select indicators that quantitatively describe regimes of municipalities.

Statistical methods

We use a dataset of PV systems in Switzerland (includes projects e.g. that received federal subsidies, are on a waiting list; M=76'587). We used *cluster analysis* and *principal component analysis (PCA)* to identify and analyse clusters of municipalities which have similar regimes. We statistically described the growth of solar PV in each of these clusters and linked the findings to broader qualitative insights from the MLP framework.

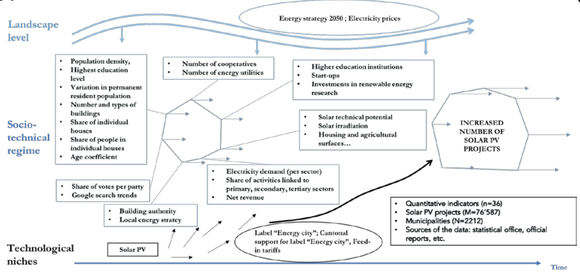

Figure 3. *The MLP framework is used to explore solar PV uptake in Switzerland. Quantitative indicators are defined based on the theory of the MLP [5, 6] and the existing literature on solar PV uptake (see examples of indicators in blue boxes). Indicators have municipality-level resolution and are chosen as to identify different socio-technical regimes across Switzerland.*

PRELIMINARY RESULTS

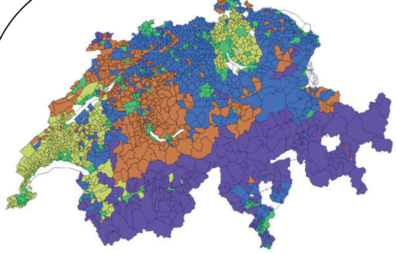

Figure 4. *Using the MLP and quantitative indicators, we did cluster analysis and PCA and identified five main clusters of regime configurations in Switzerland. Cluster of municipalities names: see legend.*

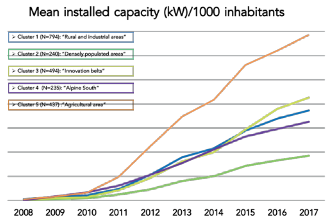

Figure 5. *Growth of solar PV in each cluster measured here using the mean installed capacity (kW) per 1000 inhabitants. Cluster of municipalities names: see legend.*

"Regimes" across Switzerland

- At least 5 main types of different regimes across Switzerland were identified (Fig. 3) . For example, a higher share of agricultural and primary sector activities (values above the national average) characterize cluster 5 (orange).
- Growth rates of solar PV are different between clusters: the mean installed capacity per capita is highest in cluster 5 (orange, "Agricultural activities") and lowest in cluster 2 (blue, "Densely populated areas") (Fig. 5). The 3 remaining clusters have similar growth rates (Fig. 5). We obtained similar results using other metrics (e.g. number of projects per capita).

Analysis of clusters of municipalities with similar regimes

- We identify outliers (municipalities) in most clusters that drive the growth of solar PV. For example, in cluster 5 (orange, "Agricultural activities"), 27 municipalities show a faster growth of solar PV (Fig. 6, 7 and 8).
- The 27 municipalities show in particular, a higher electricity demand than the other municipalities in the same cluster, stemming from the agricultural activities. Similar results (i.e. a small number of municipalities driving solar PV growth) are found in other clusters.
- Further analysis should determine whether these municipalities are front-runners or perhaps benefited from more favourable conditions facilitating PV growth.

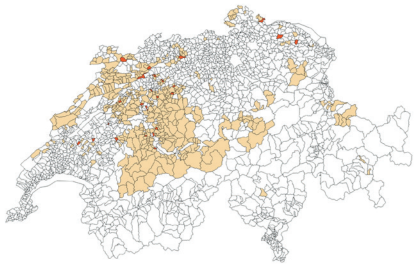

Figure 6. *In-depth analysis of each cluster identified in Fig. 4. Here, the example of cluster 5 (N=437, "Agricultural area"). Twenty-seven municipalities (red) were identified as outliers and show faster-growing solar PV in terms of installed capacity (kW) per capita.*

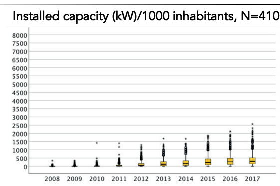

Figure 7. *Installed capacity for N=410 municipalities in cluster 5 (see Fig. 6).*

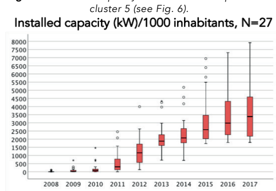

Figure 8. *Installed capacity for N=27 outlier municipalities in cluster 5 (see Fig. 6).*

Summary

We carried out a spatial analysis of solar PV uptake in Switzerland :

- In terms solar PV diffusion, we find that specific regimes may influence solar PV uptake.
- In terms of methodological findings, we suggest that an MLP analysis may be refined using quantitative methods by providing more quantitative context-driven indications. Correspondingly, we can place quantitative analysis into a broader context using the MLP.
- Finally, our results may potentially provide helpful insights to local governments to elaborate tailored policies for solar PV diffusion according to the dominant regime identified in their area.

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Uncertainty quantification and global sensitivity analysis in life loss estimates due to an instantaneous dam-break

Anna Kalinina[1], Matteo Spada[1], Peter Burgherr[1] & Christopher T. Robinson[2]

[1] Technology Assessment Group, Paul Scherrer Institut, Villigen PSI, Switzerland;
[2] Department of Aquatic Ecology, Eawag, Dübendorf, Switzerland

Research objectives

1. Application of the HEC-LIFESim life-loss (LL) modeling software to a case study with conditions relevant for Switzerland;
2. Application of metamodeling for quantification of uncertainties in the estimation of life loss provided by HEC-LIFESim;
3. Global analysis of the model sensitivities.

Framework for uncertainty quantification (UQ) & global sensitivity analysis (GSA)

Modeled input uncertainty is propagated through the surrogate model created using Polynomial Chaos Expansion (PCE) (Figure 1):

$$M^{PCE} \stackrel{\text{def}}{=} \sum_{\alpha \in N^M} y_\alpha \Psi_\alpha(X_j)$$

M^{PCE}: PCE response, X_i: input vector, y_α: coefficient, Ψ_α: polynomials.

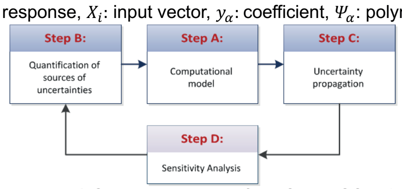

Figure 1 Global Framework for UQ and GSA [1]

Global Sensitivity Analysis is performed in this study by calculating two indices for comparative reasons:

- Sobol' indices, S_i, define individual contributions of each model input to the total variance D. Sobol' indices are calculated from the coefficients of the PCE-metamodel [2], such that:

$$S_i = \sum_{\alpha \in A_i} y_\alpha^2 / D,\ A_i = \{\alpha \in N^M : \alpha_i > 0, \alpha_{j \neq i} = 0\}$$

- Borgonovo index [3], δ_i, which is a measure of the expected shift in the probability distribution of the model output when a random input variable X_i is set to a fixed value. If the expected shift is close to zero, then the variable is not important, otherwise for more important variables it takes a larger value:

$$\delta_i = \frac{1}{2} E_{X_i}\left[\int \left| f_Y - f_{Y|X_i} \right| dy\right]$$

Where f_Y is the probability distribution of the model output and $f_{Y|X_i}$ is the conditional distribution of X_i.

Step A: Computational model

The HEC-LIFESim software [4] is a spatial dynamic system for modeling LL of a flood event. It is a modular system consisting of four modules (Red boxes in Figure 2). These modules are built around databases and exchange data through geo-layers. HEC-LIFESim estimates the number of LL by redistributing the initial Population At Risk (PAR), i.e., the number of people living in the inundated area, based on different information, e.g. flood severity, warnings, etc..

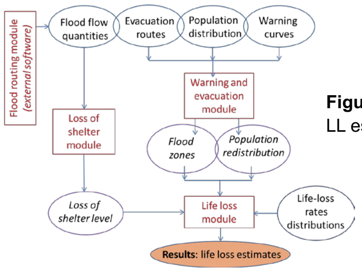

Figure 2 HEC-LIFESim approach for LL estimation (modified from [5])

In this study, the LL is estimated for a generic locality downstream of a large concrete arch dam over 100 m height located in Switzerland.

Step B: Marginal distributions for uncertain model inputs

Parameter	Name	Unit
Inhabited locality		
P_{tot}	Total population	[people]
P_{o65}	Population over 65	[fraction]
H	Building foundation height	[m]
Flood and Warning process		
F_{chance}	Fatality rate in the chance zone	[fraction]
F_{compr}	Fatality rate in the compromised zone	[fraction]
T_{hcd}	Hazard communication delay	[hour]
T_{wid}	Warning issuance delay	[hour]

Table 1 The marginal distributions modeled in this study for the Swiss case used as input for the metamodel

Swiss Data on demographics (P_{tot}, P_{o65}), structural inventory (H), etc. collected from [6-8], data on Warning issuance delay (T_{wid}) provided by [9] and Swiss specific fatality rates (F_{chance}, F_{compr}) estimated in [10].

Step C: Example results for uncertainty propagation

PCE of different degrees are built on the experimental design of 550 samples for the parameter of the model output for 6 different scenarios, based on 3 different flood inflow severity and 2 times in a day (2 a.m. and 2 p.m.) (Figure 3).

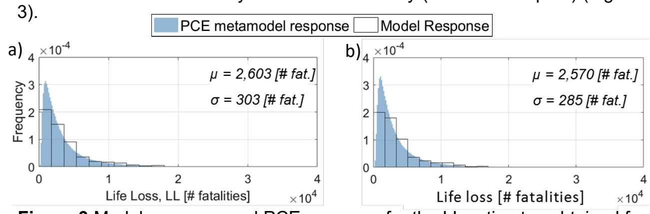

Figure 3 Model response and PCE response for the LL estimates obtained for two selected scenarios. a) daytime – mean flood inflow; b) nighttime – mean flood inflow

Step D: Example results for global sensitivity analysis

Sobol' and Borgonovo indices indicate that the total population, the fatality rate in the chance zone and the warning issuance delay contributed most to the variability of the model output for both day and nighttime (Figure 4). Discrepancies between Sobol' and Borgonovo indices (e.g. T_{hcd}) are related to the fact that the latter provides a relative ranking with respect to the most important parameter (P_{tot}), while Sobol' indices provide absolute values.

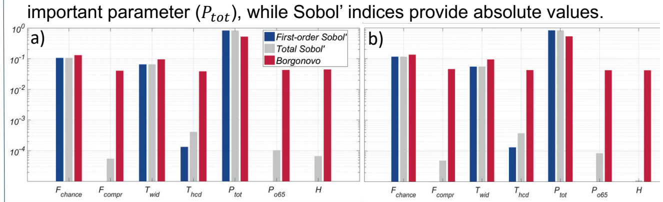

Figure 4 Results for global sensitivity for the LL estimates obtained for two selected scenarios. a) daytime – mean flood inflow; b) nighttime – mean flood inflow

Conclusions

- The applied metamodeling approach is in good agreement with the physical model;
- Application of the constructed metamodel enables reducing computational effort with respect to, for example, Monte Carlo approaches;
- Global sensitivity analysis can help to understand how the variability of each model input affected variability of the LL-estimates;
- The constructed metamodel can support inform ed risk management and reliability-based design for typical Swiss hydropower dams.

Acknowledgements

This research project is part of the National Research Programme "Energy Turnaround" (NRP 70) of the Swiss National Science Foundation (SNSF). Further information on the National Research Programme can be found at www.nrp70.ch. It is also integrated with the activities of the Swiss Competence Center on Energy Research – Supply of Electricity (SCCER SoE). The authors express their sincere thanks to Prof. Dr. Bruno Sudret and Dr. Stefano Marelli, ETHZ, Dr. David Vetsch, ETHZ, and to Dr. Calvin Whealton, PSI, for valuable comments and assistance.

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A tool to visualize different participation formats

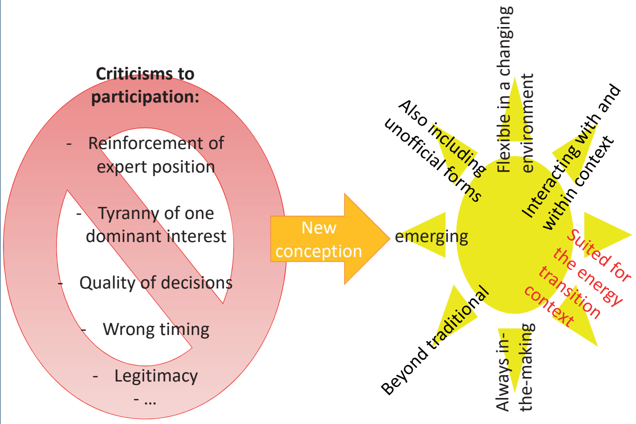
Franziska Ruef, Michael Stauffacher, Olivier Ejderyan – D-USYS TdLab, ETH Zürich

Context of a geothermal energy program – GEothermie2020

The context of our study is the geothermal program GEothermie2020 funded by the public utilities SIG and the canton of Geneva. Launched in 2014, the program started with an extensive prospection and exploration campaign. We accompany the program in its different steps to work on participation and the public. With the program transgressing different phases of development, we adapt our research questions and priorities in order to stay in line with the pressing issues and questions at hand.

GEOTHERMIE 2020 — RÉPUBLIQUE ET CANTON DE GENEVE — SIG

►► Need for a new conception of participation…

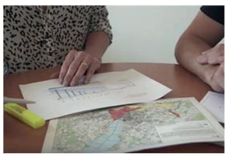


Research Questions and Method

1. How does structuring different formats of participation allow to identify blind spots in a participation context?
2. Which are these blind spots and how do they highlight different understandings of participation?

Two perspectives: the project managers and residents

Aim: grasp participation seen and understood from different perspectives through the lenses of the 2 central actors:
- The ones initiating a participative format: PROJECT MANAGERS
- The ones participating (or not) in it: RESIDENTS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Data

Core findings are based upon a detailed analysis of in-depth qualitative data elicited through **focus groups** with residents and **participant observation** in strategic management meetings of the geothermal project managers in Geneva.

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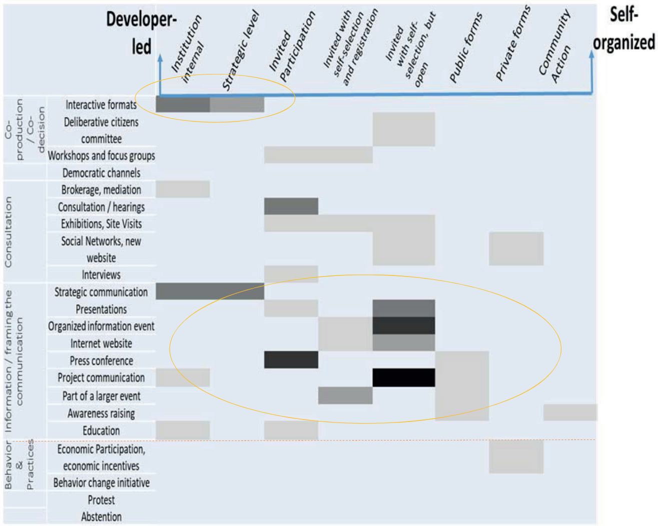
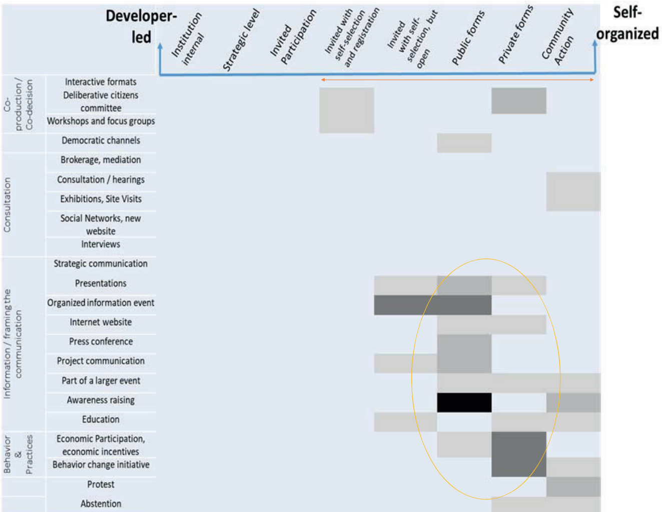
Results

Project Managers' view



The distribution for project managers' references shows that they see participatory formats mostly in the classical sense, ranging from information over consultation to co-production. Rather common governance schemes, as through information provision for example. Lesser-theorized top-down participative models deployed internally or within an invited group were also part of their view.

Residents' view



For residents, information provision is also very important. However, more references to self-organized than to institution-led forms of participation. Private forms of participation such as buying responsibly and investing in renewable energy installations came up often.

Discussion – the following blind spots were identified:

- Untypical participation forms are just as important! Such as forms linked to behaviour and practices, abstention and protest.
- What's hot in literature, doesn't need to be relevant on the ground! One example: highly discussed consultative participation, rare in practice.
- "Just" transparent information, please! Residents not necessarily wish for ideal-type participation, but rather transparent information.
- What *exactly* is behind the format? Implicit definitions of different formats are important to use them well!

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Quantitative risk assessment for Deep Geothermal Energy (DGE) systems in Switzerland

Matteo Spada, Peter Burgherr

Technology Assessment Group, Laboratory for Energy Systems Analysis, Paul Scherrer Institut (PSI)

Introduction

This work is built upon the approach developed in the TA Swiss study [1], which is significantly extended since SCCER-SoE Phase 1. Deep geothermal energy (DGE) systems are, like all energy technologies, not risk free. Although the risk of induced seismicity is frequently pointed out, geothermal systems present additional potentially risky aspects such as borehole blowouts or chemical related incidents. In this study, different technological risks associated with deep geothermal energy systems are identified, characterized and quantitatively analyzed. In particular, two major updates have been achieved in this phase:

- the introduction of additional hazardous materials potentially used as working fluids in the operational phase and as part of the matrix acidizing in the stimulation phase;
- the update of historical accidents in the period 1990-2017.

Results are shown in terms of normalized risk indicators (e.g. fatality rate, injury rate, etc.) in order to compare risks of blowouts in the drilling and stimulation phases and the use of hazardous substances in drilling, stimulation and operational phases.

Data

Since DGE systems have not been yet installed at many sites, historical experience in terms of accidents is rather limited. Therefore, the estimation of risk indicators is based on historical experience of other industries that can be considered a meaningful proxy for DGE systems. In all considered cases, accident data for the time period 1990-2017 from OECD countries were used because they can be considered sufficiently representative for Switzerland. However, when dealing with hazardous substances, it was necessary to focus on the chemicals that could be possibly used in Switzerland. In addition to PSI's Energy-related Severe Accident Database (ENSAD) several other databases were used in order to collect accidents related to the use of hazardous substances (Table 1) and blowouts (Table 2), i.e. ERNS, ARIA, FACTS, etc..

Table 1: Summary of the numbers of accidents and associated consequences for the Hazardous Substances analyzed in this study.

Phase	Hazardous Substance	Accidents/Fatalities	Accidents/Injuries
Drilling	Caustic Soda	13/30	142/1149
Stimulation	Hydrogen Chloride (HCl)	2/4	94/697
	Hydrogen Fluoride (HF)	3/3	26/83
	Ammonium Persulphate	2/2	8/76
	Boric Acid	1/1	10/43
Operational	Benzene	3/4	33/562
	Toluene	16/20	66/679
	Methanol	18/43	15/103
	n-Hexane	11/25	20/205
	o-Xylene	8/24	27/415
	Ammonia	16/20	136/1191

Table 2: Summary of onshore blowout accidents in the natural gas industry, collected for USA and Alberta, since no specific historical experience for deep geothermal systems is available.

Blowouts	Accidents/Fatalities	Accidents/Injuries
	5/5	11/25

Method

The risk indicators are normalized to the unit of energy production (i.e. Gigawatt-electric-year, GWeyr) using specific normalization factors for each substance and blowout.

$$NF_{Caustic\ Soda} = \frac{CS_{Well} * WD * NW}{total\ production\ 1990 - 2017} * \frac{1}{P_{GWeyr}}$$

$$NF_{Stimulation} = \frac{HS_{Well} * NW}{total\ production\ 1990 - 2017} * \frac{1}{P_{GWeyr}}$$

$$NF_{Working\ Fluid} = \frac{WF_{Year1} + (kg\ of\ substance\ refilled * LT)}{total\ production\ 1990 - 2017} * \frac{1}{P_{GWeyr}}$$

$$\mathrm{NF}_{\mathrm{Drill+Stim}} = \frac{\mathrm{NW}}{\text{total number of natural gas drilled wells 1990} - 2017} * \frac{1}{\mathrm{P}_{\mathrm{GWeyr}}}$$

$NF_{Caustic\ Soda}$, $NF_{Stimulation}$, $NF_{Working\ Fluid}$ and $NF_{Drill+Stim}$ are the normalization factors for Caustic soda, Stimulation Fluids, Working Fluids, Blowouts, respectively. P_{GWeyr} is the production of the plant in Gweyr. Table 3 summarizes the key physical parameters considered in this study for normalization purposes.

Table 3: Key physical parameters of the capacity cases for DGE plants considered in this study.

		SCCER-SoE/BFE/GEOTHERM-2 Doublets			SCCER-SoE/BFE/GEOTHERM-2 Triplets		
Capacity cases		High	Base	Low	High	Base	Low
Net plant power		3.28 Mw_e	1.45 MW_e	1.18 MW_e	5.21 MW_e	2.73 Mw_e	2.27 MW_e
Production in GWeyr (P_{GWeyr})		6.56e-2 Gweyr	2.99e-2 GWeyr	2.36e-2 GWeyr	1.04e-1 GWeyr	5.46e-2 GWeyr	4.54e-2 GWeyr
Well depth (WD)		5 km					
Number of wells (NW)		2			3		
Surface plant life time (LT)		20 years					
Caustic Soda as additive in the drilling mud per Well (CS_{Well})		1 kg/m					
Additives in Hydraulic Stimulation (total average) per Well (HS_{well})		HCl:3.4E7 kg HF:7.1E6 kg; Ammonium Sulphate: 3.1E5 kg; Boric Acid: 1.2E5 kg					
Working Fluids used at the power plant at year 1 (WF_{Year1})	Ammonia	1415 kg	863 kg	740 kg	1716 kg	1369 kg	1179 kg
	Benzene	1208 kg	737 kg	632 kg	1465 kg	1169 kg	1007 kg
	Toluene, Methanol, n-Hexane, o-Xylene	1197 kg	730 kg	626 kg	1452 kg	1158 kg	998 kg
Yearly losses of the working fluids (YLWF)		8%					

Results: Example for Fatality Rates

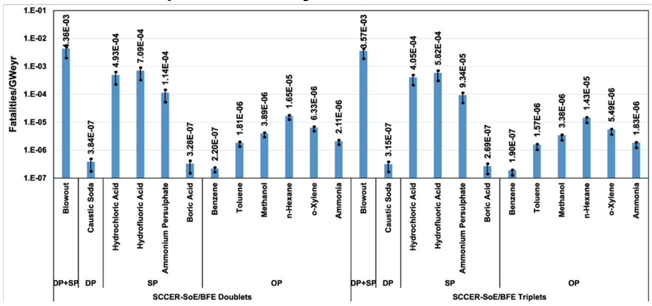

Figure 1: Fatality rate for the drilling, stimulation and operational phases based on accident data for the period 1990-2017. Blue bars: Base Case; Error bars: High and Low Capacity plants (See Table 3). DP: Drilling Phase; SP: Stimulation Phase; OP: Operational Phase.

- Accident risks of blowouts are significantly higher than the risk related to the use of hazardous substances.
- Among hazardous substances, HF exhibits the highest risk followed by the use of HCl and Ammonium Persulphate at the geothermal site.
- In the operational phase, n-Hexane performs worst with respect to the other potential working fluids.
- Doublets (2 production wells) and triplets (3 production wells) plant types show similar results in terms of risk related to the considered phases.

Conclusions

- Results for the use of hazardous substances in drilling, stimulation and operational phases point towards low risk levels.
- Based on these results, the drilling and stimulation phases in deep geothermal systems exhibit higher risks compared to the operational phase.
- Deep geothermal systems compare favorably to, for example, natural gas (7.19E-2 fatalities/GWeyr for OECD countries, according to [2]).

References: [1] Spada, M., Burgherr, P. (2015). Chapter 6.1: Accident Risk. In Hirschberg S., Wiemer S. and Burgherr P.: Energy from the Earth. Deep Geothermal as a Resource for the Future? TA-SWISS Study TA/CD 62/2015, vdf Hochschulverlag AG, Zurich, Switzerland, pp. 229-262. http://dx.doi.org/10.3218/3655-8
[2] Burgherr, P. & Hirschberg, S. (2014) Comparative risk assessment of severe accidents in the energy sector. *Energy Policy,* 74 (S1), S45-S56.

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Using GIS to discuss place factors for CCS projects siting

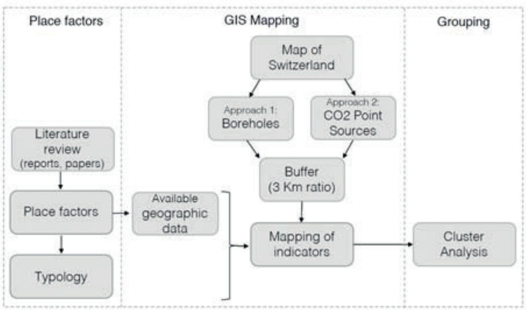
Juanita von Rothkirch, Olivier Ejderyan, Michael Stauffacher

Motivation

Geological CO2 storage is a key technology for facilitating the removal of carbon dioxide from the atmosphere. However, the progression of CO2 storage has been hindered by public opposition to some proposed projects, once storage sites had been selected. As numerous experiences on contested technologies have shown, public participation processes determine whether communities become a door or barrier for the emplacement of projects in local contexts. Yet there is much literature on the importance of early public engagement for normative, substantive and instrumental reasons, there are no tools for integrating social aspects early on in the site selection process.
This poster presents an exploratory study of the upstream inclusion of social characteristics and concerns in the site selection process for CO2 storage in Switzerland.

Methods

Relevant place factors were identified through a literature review. These factors were mapped for potential CO2 storage sites. A cluster analysis was conducted to identify categories of sites for which similar public engagement procedures might apply.



Results

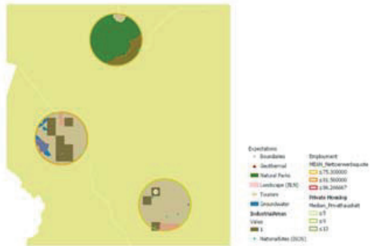
Place factors are the social characteristics and concern linked to specific places (Peterson et al, 2015). The table below lists the relevant place factors for CO2 storage projects and the indicators used to map them in the Swiss context.

Place factor	Indicator	Unit
Industrial zone	Industrial areas. Land use statistics NOAS04 2013-2018. (FSO, 2018b)	ha
Employment	Employment rate per district 15- 64 years old. (FSO, 2018a)	% (mean)
Tourism	Hotel industry: supply and demand of open establishments in 100 municipalities in 2018. (FSO, 2019)	Number
Natural Parks	Swiss National Park and parks of national importance. (FOEN, 2019)	m2
Geothermal energy	Present and future projects of geothermal energy. (Swisstopo, 2019)	Number
Landscape	Federal Inventory of Landscapes and Natural Monuments. (FOEN, 2019a)	m2
Groundwater	Groundwater protection zones. (Swiss Cantons, 2019)	m2
Private housing	Private housing. (FSO, 2017)	Number (median)
Cultural Areas	Heritage sites of national importance. (FOC, 2019)	Number
CO2 from a different political unit	Cantonal boundaries. (Federal Office of Topography (Swisstopo), 2019a)	Number
CO2 emission points	Industrial CO2 emissions > 10 Mtonnes. (PRTR, 2017)	-
Oil and gas extraction or storage	Energy raw materials: Deposits. (Swisstopo & SGTK, 2019)	-

Mapping place factors relevant for CO2 storage sites

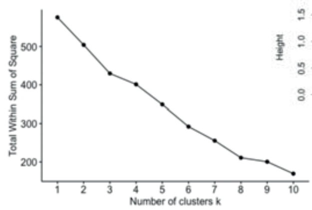

Map based on existing boreholes as proxy for potential sites


Map based on CO2 emission point sources (≥ 10 Megatons) as proxy for potential sites

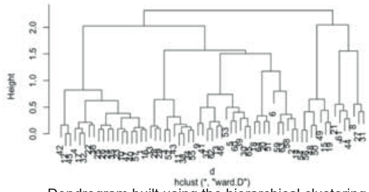


After mapping all the factors in the buffers using the first approach (Boreholes), the statistics of the different indicators per location were extracted to conduct cluster analyses to group sites with similar place factors into categories.

Cluster Analyses
The cluster analyses presented in this section show that there are no clusters of locations, according to the indicators used. Therefore, it is not possible to structure the discussion based on a systematic classification of locations.



Elbow method for identifying the optimal number of clusters, using K-means.



Dendrogram built using the hierarchical clustering method Ward.

Discussion

The typology of place factors allows to understand the logic behind the success or failure of projects in relation to the locations. Our typology indicates that benefits and familiarity can contribute to the positive response to a project. Negative experiences, conflicting expectations, technology-related concerns, status-quo bias and distributive fairness issues can contribute to a negative response.

Our results indicate that maps can help to get a first approximation to place characteristics and people's concerns in potential CO2 storage sites. We found that several geographical indicators exist which partially or completely represent place factors. Therefore, visualization of place factors on maps allows to cope with complex information and make non-technical aspects of sites explicit.

The clustering analyses conducted show that our data does not contain distinct groups of locations with the same set of indicators. Therefore, it is not possible to design strategies to approach locations according to categories. This is the result of having a small ratio of observations and variables: there are only few observations and several variables

References

Peterson, T. R., Stephens, J. C., & Wilson, E. J. (2015). Public perception of and engagement with emerging low-carbon energy technologies: A literature review. MRS Energy & Sustainability, 2, E11. https://doi.org/10.1557/mre.2015.12