Task 4.1

Title

Risk, safety and societal acceptance

Projects (presented on the following pages)

Reservoir stimulation's effect on depletion-induced seismicity
Barnaby Fryer, Gunter Siddiqi, Lyesse Laloui

Increase of the EGS levelized cost of electricity, or the financial cost of public safety
Arnaud Mignan, Dimitrios Karnouvis, Marco Brocardo

JA IDEA-HG: Initial version of recommendations for regulating & governing DGE seismic risk
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Probabilistic Fatigue Model for predicting plaster cracks on unreinforced masonry walls caused by induced seismic hazard
Giuseppe Abbiati, Marco Broccardo, Adrian Gabbi, Nebojsa Mojsilović, Milos Petrović, Max Didier, Bozidar Stojadinović

From a "steam monster" to energy projects: moving forward to geothermal social acceptance in Chile
Sofía Vargas Payera

Optimal PV and Wind Locations for an Efficient & Renewable Swiss Power System
Bert Kruyt, Annelen Kahl, Stuart Bartlett, Jérôme Dujardin, Michael Lehning

Comprehensive Historical Accident Data for Comparative Risk Assessment of Energy Technologies
Peter Burgherr, Wansub Kim, Matteo Spada, Anna Kalinina, Stefan Hirschberg

Mapping the landscape of participation in Geneva
Franziska Ruef, Michael Stauffacher, Olivier Ejderyan

Semiotic analysis of technoscientific promises in geothermal energy
Olivier Ejderyan

Framing geothermal energy in the UK: a media analysis
Xue Xu, Olivier Ejderyan, Michael Stauffacher

Application of the Polynomial Chaos Expansion for uncertainty quantification of the flood wave propagation resulting from a concrete dam break
Anna Kalinina, Matteo Spada, Peter Burgherr, Christopher T. Robinson

Quantitative assessment of uncertainties and sensitivities in life loss estimates due to an instantaneous dam-break
Anna Kalinina, Matteo Spada, Peter Burgherr, Christopher T. Robinson

Toward a new framework for chemical risk assessment in the context of accidental events in deep geothermal energy (DGE) systems
Matteo Spada, Peter Burgherr

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Reservoir stimulation's effect on depletion-induced seismicity

Barnaby Fryer, Gunter Siddiqi, Lyesse Laloui

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Motivation

Fluid production can induce earthquakes by inducing total stress changes [1]. In the conservation of momentum equation, it is the gradient of pore pressure which induces these stresses. A smaller pore pressure gradient leads to smaller induced stresses. Darcy's Law tells us that higher permeabilities will require smaller pore pressure gradients to produce an amount of fluid. Therefore, can we manipulate permeability to reduce the pore pressure gradient required to produce fluid and thereby reduce the induced stresses and seismicity associated with fluid production?

In this work, we will be using a hydraulic fracture near the well to reduce the seismicity rate far from the well.

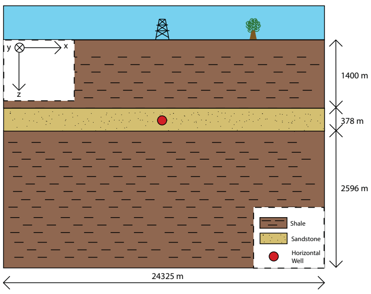
Methods

Poroelastic reservoir simulator

Seismicity rate predicted based on [2,3] using:

$$\frac{dR}{dt} = \frac{R}{t_a}\left(\frac{\dot{\tau}}{\dot{\tau}_0} - R\right)$$

Hydraulic fracture simulated using standard field results from literature. Results in high permeability region near well



Stimulation's effect on seismicity

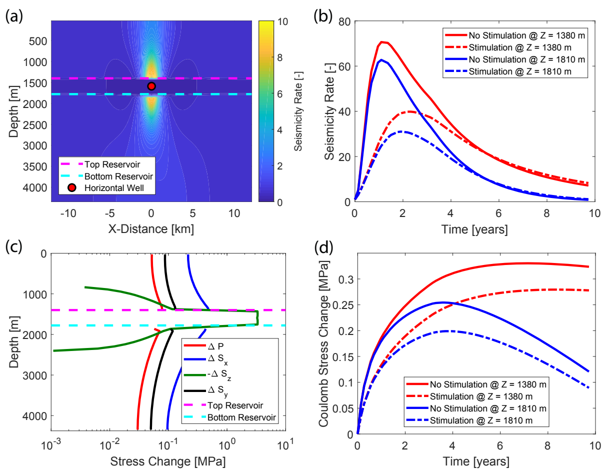
Reverse faulting stress regime example ($S_{Hmax} > S_{hmin} > S_v$):

a) Seismicity rate with no hydraulic fracturing

b) Seismicity rate comparison above and below reservoir for the case with and without hydraulic fracture

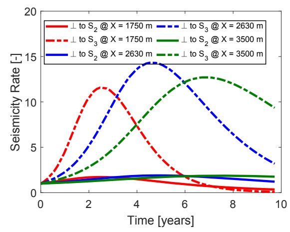
c) Stress changes in-line with well when no fracture

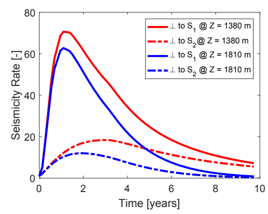
d) Difference in Coulomb stress when fractured



Wellbore orientation

Because stress changes are not independent of direction, there are implications for horizontal well orientation. On the right it is clear that drilling a well parallel to S_{Hmax} in a normal faulting stress regime would result in a higher seismicity rate. This is because the stress changes are larger perpendicular to the well. If S_3 is perpendicular to the well, a larger amount of tension in this direction increases differential stress, worsening seismicity rate.





The same reasoning applies to reverse faulting stress regimes. Drilling parallel to S_{Hmax} in this case would reduce the seismicity rate. This is because the largest compression above and below the reservoir is happening in the direction perpendicular to the well. S_1 is horizontal in this case, and so it is not ideal to large amount of induced compression in the direction of S_{Hmax}.

Discussion & Conclusion

The reduction of the pore pressure gradient required to produce fluid has been shown here to reduce the induced stresses and seismicity associated with production. This effect is significant for reverse and strike-slip faulting stress regimes and moderate for normal faulting stress regimes.

Care should be taken, however, as hydraulic fracturing is generally not well accepted publically and there have been instances of the process itself inducing seismicity.

Additionally, hydraulic fracturing is not the only way to reduce required pore pressure gradients and it may be that there are other, less controversial, ways of achieving similar results.

The optimal orientation of a horizontal well was also found (in the case fracturing was not considered). In terms of induced seismicity, it was found that the optimal orientation of a horizontal well is:

- Parallel to S_{hmin} in a normal faulting stress regime
- Parallel to S_{Hmax} in a reverse faulting stress regime
- In a strike-slip faulting stress regime well direction changes the likely location of seismicity from above and below the reservoir (parallel to S_{hmin}) to the outskirts of the reservoir (parallel to S_{Hmax})

References & Funding

[1] Segall, P. (1989), Earthquakes triggered by fluid extraction, Geology, 17, 942-946.
[2] Dieterich, J. (1994), A constitutive law for rate of earthquake production and its application to earthquake clustering, Journal of Geophysical Research, 99, 2601-2618.
[3] Segall, P., S. Lu (2015), Injection-induced seismicity: Poroelastic and earthquake nucleation effects, Journal of Geophysical Research: Solid Earth, 120, 5082-5103.

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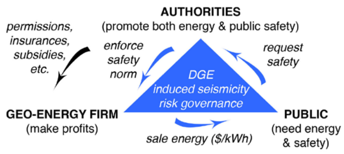
Increase of the EGS levelized cost of electricity, or the financial cost of public safety

Arnaud Mignan, Dimitrios Karnouvis, Marco Broccardo

Rationale

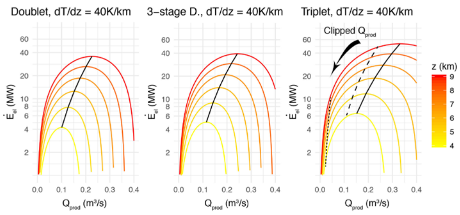
A multitude of models exist that compute the levelized cost of electricity (LCOE) for Enhanced Geothermal Systems but none take into account the costs associated with induced seismicity, although seismic risk remains the main problem facing the EGS industry today.



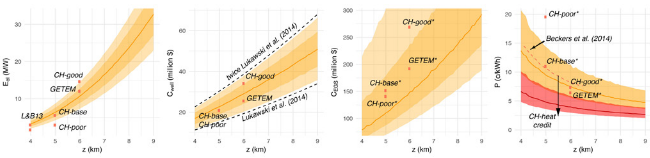
We present a meta-model that quantifies the LCOE taking into account the "cost of public safety", i.e., the cost of mitigation measures against induced seismicity. This is implemented within a Deep Geothermal Energy (DGE) seismic risk governance framework where a trade-off must be decided between public safety & energy safety.

A meta-model for EGS LCOE computation

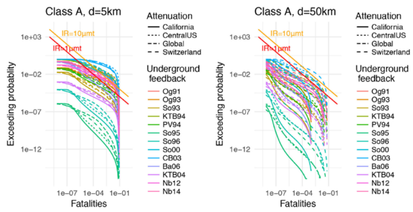
(1) *Energy model*: Composed of EGS, conversion cycle & district heating | Fully analytical | Optimizes injection production rate Q_{prod} to maximize electricity produced | Heat loss based on exponential decline along supply pipe



(2) *Economic model*: LCOE = tot. energy produced / tot. costs | Function of distance *d* to EGS plant because of heat loss | In agreement with existing models (MIT GETEM, TA-Swiss CH-*, *etc.*)



(3) *Seismic risk model*: Computes induced seismicity risk [1] to be compared to safety norm (individual risk IR in micromort μmt) | Tectonic maximum magnitude assumed | Same method for traffic light system (TLS) [2,3]



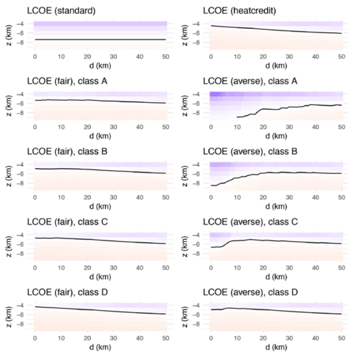
(4) *Behavioural model*: probability *p* of safety norm failure = probability reservoir stimulation would be stopped by TLS = probability of losing the injection well for foreseeing future | LCOE translated into null expectation following Bernoulli trial (*P*: price, E: energy, C: costs) | Cumulative Prospect Theory (CPT) risk aversion & loss aversion included (π: distorted probability, *v*: utility function) [4]

$$(1-p)(P_{fair}E - C) + p(-C_{TLS}) = 0 = \mathbb{E}[X] = (1-p)x_1 + px_2$$

$$\pi^+ v^+(P_{averse}E - C) + \pi^- v^-(-C_{TLS}) = 0 = \mathbb{E}[v(x)]$$

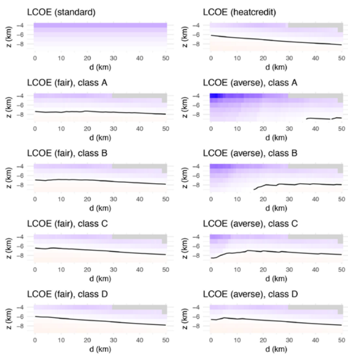
Results

(1) Mitigating seismic risk during reservoir stimulation (via TLS):

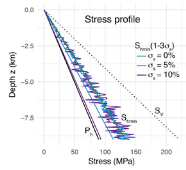


- Black curve: break-even price, red: competitive price, for building classes A to D
- Impact of safety norm limited on the fair price
- However the small probability *p* of losing a well leads to risk aversion, which amplifies the price
- Benefit of heat credit at small distances *d* from EGS plant lost by cost of seismic risk mitigation
- Best EGS plant siting = *d*(min LCOE)

(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
- The safety-norm-based TLS could also be used during the production phase



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

(4) How to decide from the public-safety/energy-safety trade-off?
- Public-safety prone (zero-risk policy): LCOE becomes too high & EGS industrial potential collapses
- Energy-safety prone (high risk tolerance): EGS projects prosper
- Must find right balance putting it into the perspective of the climate change existential risk & the need to quickly find energy solutions

References

[1] Mignan et al. (2015), Induced seismicity risk analysis of the 2006 Basel, Switzerland, EGS project: Influence of uncertainties on risk mitigation, *Geothermics*, 53, 133-146
[2] Mignan et al. (2017), Induced seismicity closed-form TLS for actuarial decision-making during deep fluid injections, *Sci. Rep.*, 7, 13607
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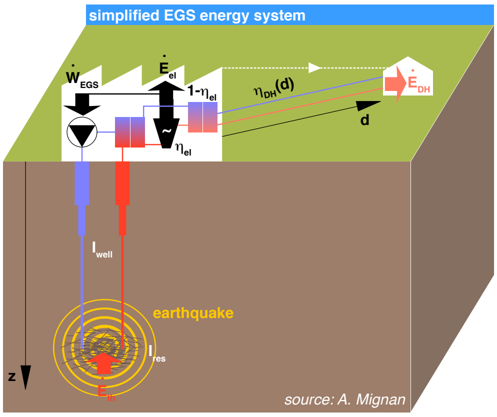
JA IDEA-HG: Initial version of recommendations for regulating & governing DGE seismic risk

With Deep Geothermal Energy (DGE) remaining at the demonstration level in Switzerland, we provide an initial set of recommendations on how the legislative framework and the governance structure related to DGE's main risk, induced seismicity, could be enhanced to facilitate the resolution of conflicts among stakeholders and thus increase investments in DGE via a reduction of project risk. Our approach is twofold: (1) We develop a regulatory sandbox for induced seismicity risk governance based on a transparent meta-model with DGE electricity price (or levelized cost of electricity; LCOE) as main metric. (2) We do a Q&A, assessing the existing problems and envisioning possible legislative solutions, considering existing laws, risk transfer, etc., hence merging SCCER-SoE and SCCER-CREST knowledge towards one comprehensive governance framework.

DGE seismic risk regulatory sandbox

Based on a quantitative & transparent meta-model

- *Energy model*: both electricity & heat
- *Economic model*: Levelized Cost of Electricity (LCOE)
- *Seismic risk model*: Safety-norm-based mitigation
- *Behavioral model*: Risk-averse & loss-averse decision



Trade-off between public safety & energy safety

- *Traffic light system*: safety norm verified on average
- *Cost of public safety*: LCOE increases due to possible loss of wells & investor's fear of uncertainty

Initital recommendations

In the short-term

- *Existing safety norms must be adapted*: (i) Vibration norms (construction industry) & risk-based norms (chemical industry) to be combined for full risk spectrum; (ii) Maximum earthquake magnitude ambiguity to be considered, by assuming the worst-case scenario (tectonic M_{max}) based on minimax, or mean risk to be used instead of median risk if an M_{max} logic tree is still preferred.

In the medium-to-long-term

- *Creation of a DGE catastrophe fund*: in the case of a large earthquake occurrence, losses would be beyond the DGE insurance cover. Would allow risk transfer from firm (possibly bankrupted) and canton/state to dedicated fund.
- *Proposal of a legislative framework:* to allow the federal legislator to set a nationwide DGE safety norm to best deal with the public-safety/energy-safety trade-off, finding a balance between 2 extremes: public-safety prone (very conservative safety norm that hampers all DGE projects) and geo-energy industry-prone (loose or no safety norm, likely leading to public opposition).

Research Partners

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Probabilistic Fatigue Model for Predicting Plaster Cracks on Unreinforced Masonry Walls Caused by Induced Seismic Hazard

ETH zürich *Abbiati, G., Broccardo, M., Gabbi, A., Mojsilovic, N., Petrovic, M., Didier, M., and Stojadinovic, B.*

Abstract

In Basel and St. Gallen, CH, two pilot enhanced geothermal systems projects caused sequences of induced earthquakes with magnitudes up to 3.5. In Basel, non-structural damage that arose from the events stooped the project. Thus, prediction and quantification of non-structural damage due to long sequences of repeated induced ground motions is central for estimating the related financial risk.

Test Protocol

To investigate plaster cracking on plastered URM walls caused by induced ground motions, a fatigue test campaign was recently conducted at ETH Zurich (Figure 1). Ten URM walls were constructed using modern techniques. The first nine URM walls were subjected to constant amplitude horizontal displacement sequences of 3, 5 or 7 mm (Table 1). An additional wall was tested considering a combination of cycles with different amplitudes. Digital Image Correlation (DIC) was used to measure the strains and displacements on the plaster surface. Further image processing was used to detect and quantify the induced cracks in the plaster.

Table 1. Summary of fatigue tests.

Wall IDs	Displacement amplitude (A)	Applied number of cycles
	[mm]	[-]
1,4,8	3	200, 200, 200
2,5,7	5	100, 100, 70
3,6,9	7	50, 80, 42
10	2.4, 3.6, 4.8	70, 15, 13

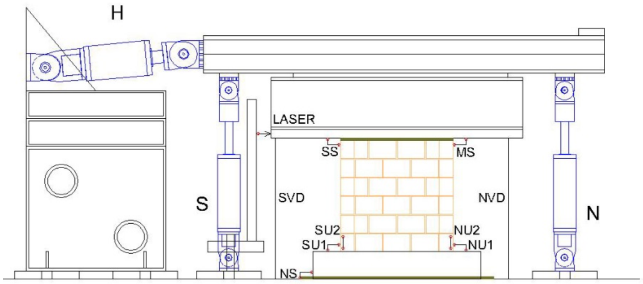

Figure 1. Experimental setup.

Damage Quantification

The Normalized Cumulate Cracked Area (NCCA) was calculated to quantify the area of cracked plaster. The NCCA corresponds to the percentage of the total plaster area A_w affected by cracks:

$$NCCA\,[\%] = \frac{A_c}{A_w} \cdot 100$$

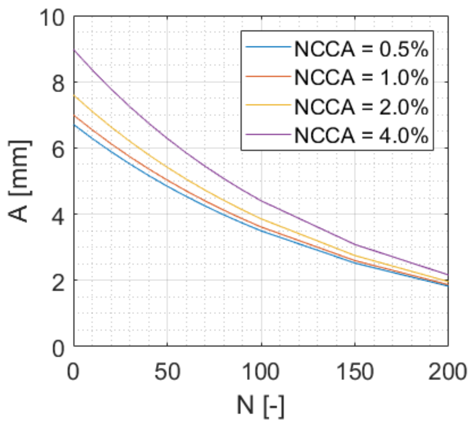

Figure 2. Evaluation of the probabilistic fatigue model for different values of NCCA.

Plaster Fatigue Model

Recorded NCCA histories were sampled at predetermined NCCA values and corresponding numbers of cycles were used to calibrate a logarithmic fatigue model:

$$\ln(A|NCCA) = a + bN + \varepsilon|NCCA$$

- A: displacement amplitude of the cyclic test [mm]
- N: number of cycles corresponding to the specific NCCA value [-]
- $\varepsilon \sim N(0, \sigma|NCCA)$: regression error, assumed Gaussian with zero mean and standard deviation $\sigma|NCCA$.
- a, b: regression parameters

The regression parameter a and b are:

$$a = NCCA\, m_a + q_a ;\, b = NCCA\, m_b + q_b$$

Figure 2 shows the mean value of the displacement amplitude for different NCAA values: for a given NCCA level and displacement amplitude A_i (i represents the index of a cycle bin) the curve provides the average number of cycles $N_{max,i}^{ave}$ that are needed to reach a target NCCA value associated with the plaster failure limit state.

Validation and Conclusion

Wall #10 was subjected to a displacement sequence with non-homogeneous amplitude to test the fatigue model. A NCCA threshold value of 1.00 % was selected to denote the plaster failure. According to the fatigue model, Wall #10 fails as the NCCA measured is equal to 1.57%>1.00%.

This suggests that the proposed URM wall plaster fatigue model is suitable for predicting the damage caused by long sequences of induced earthquakes.

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From a "steam monster" to energy projects: moving forward to geothermal social acceptance in Chile

Sofía Vargas-Payera – Andean Geothermal Center of Excellence

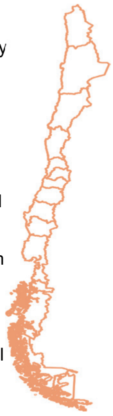
Context:

In Chile there is an urgency to adopt the use of renewable energy sources due to the high level of air pollution, the country's high dependency on oil imports and severe droughts that have affected the country, and there has been an increase in social resistance movements.

After 100 years of geothermal explorations, in 2017, the first geothermal power plant was inaugurated in Chile and South America along with the world's first large-scale facility of this kind to be built at 4,500 meters above sea level.

In 2018, the exploitable potential of the explored areas goes from approximately between 1,300 MW to 3,800 MW.

The direct use of the energy by geothermal heat pump is represented by 8.6MWth (83% of which goes to the services, industries and public buildings sector, and only 17% in residential use).



Methodology:

To illustrate the state of art of geothermal energy after 100 years of explorations, this work includes the analysis of secondary sources of information, including.

- Ministry of Energy reports (4)
- Indigenous consultation reports (5)
- Geothermal research center annual report (1)
- Chilean scientific publications (3)

Data analysis: **Thematic Analysis**

The main goal is to describe the big picture of the Chilean geothermal development, paying attention to public engagement strategies and social aspects.

Chilean geothermal Milestones

1920´s – Italian pioneers started the first geothermal exploration program in Antofagasta

1960's Chilean State starts to promote geothermal exploration

1979 Geothermal explorations were paralyzed

1995 The research of the geothermal resources were carried out solely by the University of Chile

2000 A new law renewed interest in geothermal exploration and exploitation (Geothermal Licences Act, Statute No.19657)

2009 El Tatio incident took place. This geothermal field is a major tourism destination in northern Chile.

2010 Ministry of Energy is founded

2011 The Andean Geothermal Center of Excellence, CEGA, was founded.

2016 Decreasing concession numbers

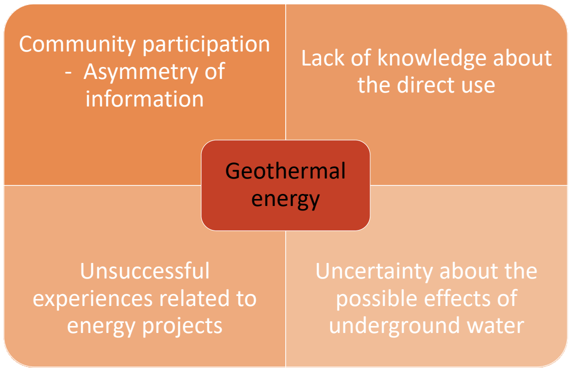
2016 – 2018 5 indigenous consultation processes have been carried out in Chile

2017 The first geothermal plant – located at Cerro Pabellón in Antofagasta region –started its operation. It has an installed capacity of 48 Mwe.

2017 The Geothermal Roundtable was created. Its role was to identify geothermal progress and challenges to analyze the systemic impact of its participation in the energy matrix

2018 Mariposa from Energy Development Corporation and el Valle from Transmark are most advance explorations projects.

Social aspects that affect the resource acceptance* :



* According to indigenous consultation reports.

Main conclusions:

- There is no mechanism to promote geothermal heat pump systems beyond general renewable energy measures.
- The most common communication material among all organizations involved in geothermal energy development is the brochure with general information describing this energy source.
- The energy policy 2018-2022 promotes the direct use of geothermal energy, but the mechanisms are not clear.
- The current geothermal law did not include the social worries, such as underwater owner and environmental impact (the law is under revision).
- The lack of citizen engagement in early stages of energy projects affects the social perceptions. Currently, the social demands of participation in exploratory stage is not reflected in the geothermal law.
- Environmental impact assessment is developed in the exploitation phase. The late relationship between energy companies and community promotes distrust among them.
- The mechanism to promote geothermal energy for the Andean Geothermal Center of Excellence since 2015 has been to interact with communities through workshops in territories with high geothermal potential.
- Although Chile is a territory with a great geothermal potential, this energy development is still emerging, characterized by up and down moments.
- Geothermal developments are still located at a technical level. The discussions and efforts have been made to overtake economic barriers, but the discussion about social strategies to increase public acceptance is still underdeveloped.
- High enthalpy projects have been the most important focus to the Ministry of Energy and companies in Chile. The direct use of the energy is still emergent.

References

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Optimal PV and Wind Locations for an Efficient & Renewable Swiss Power System

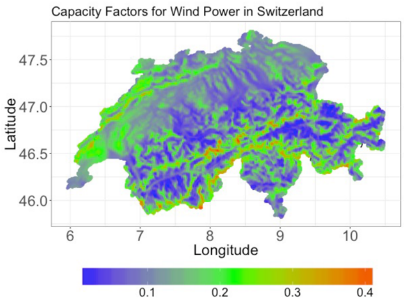
Bert Kruyt, Annelen Kahl, Stuart Bartlett, Jérôme Dujardin, Michael Lehning

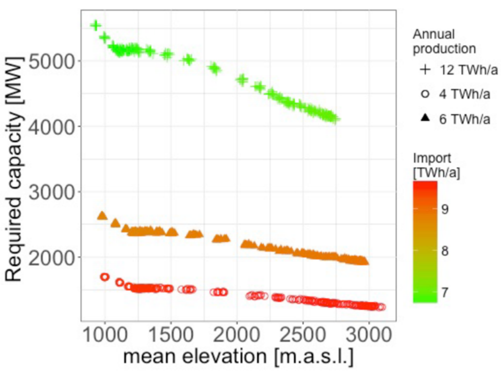
Highlights

- We demonstrate that it is possible to **shift PV production to winter** without compromising total annual production by making use of:
  - **higher albedo** due to snow cover
  - **low cloud cover** in winter at high elevations
  - increased **panel tilt** to account for lower sun angles in winter
- We calculate **the wind turbine capacity required to reach the ES2050 target** (4TWh), and show that this target can be reached with minimal capacity if we allow for high elevations to be used:
  - 1230 MW when selecting optimal locations
  - 1596 MW when limited to the locations in 'Konzept Windenergie Schweiz'.
- Line use is investigated in scenarios with varying degrees of renewables, and it is found **the current transmission network is capable of supporting a fully renewable power system**. (Line use is actually lower for a fully renewable Swiss power system than for the current system).

Wind turbine capacity required to produce 4, 6, or 12 TWh

We used 100m wind speeds from the COSMO-1 model and the Enercon E82 power curve to calculate power time series and capacity factors for each 0.01° pixel in Switzerland. Using locations with the highest capacity factors, capacity was located until annual production reached 4, 6, or 12 TWh.

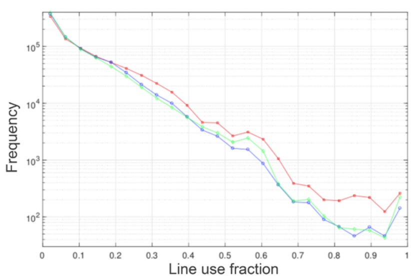




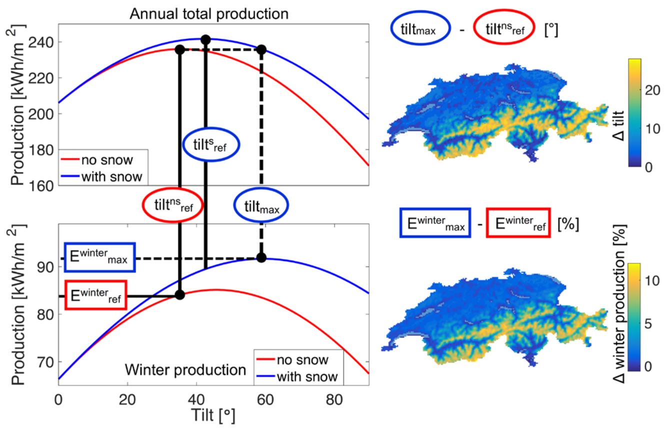
This was repeated while varying the maximum elevation at which turbines are allowed to be located, resulting in the graph on the left.

Line use

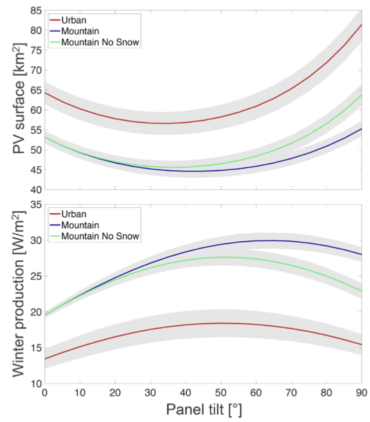
Line use under 3 scenarios (Current, Intermediate, Renewable) with varying shares of renewables. The frequency of high line use fractions is actually lower under high renewable scenarios.

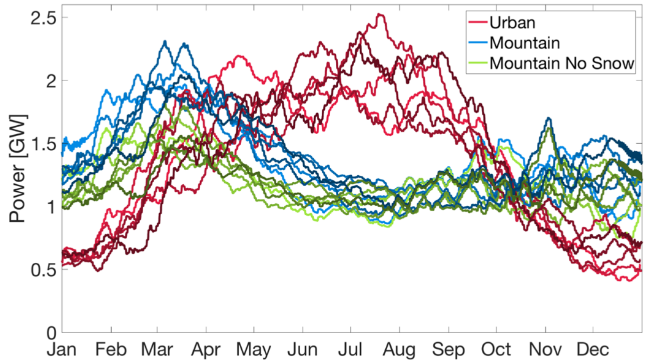


Increase Winter PV Production



<u>Top Left</u>: example location at 2500m: Annual and winter production as function of panel tilt. Equal annual production can be maintained while simultaneously shifting a part of production to winter.
<u>Top Right</u>: Increase in tilt and winter production with equal annual total.
<u>Right</u>: 3 Scenarios that all produce 12TWh/a: required panel surface (top) and winter production (bottom) as function of tilt.





<u>Above</u>: 5 years (increasing darkness) of PV production for the 3 scenarios. A clear **shift to winter** production is observed when moving from Urban to Mountain PV allocation.

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Comprehensive Historical Accident Data for Comparative Risk Assessment of Energy Technologies

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(FRS) FUTURE RESILIENT SYSTEMS 未来韧性系统

Introduction

The **systematic and consistent, comparative risk assessment of energy technologies** is a central element both in the comprehensive evaluation of the performance of energy technologies, as well as in the broader context of **sustainability**, **energy security** and **critical infrastructure protection**, ultimately contributing to a more **resilient energy system** (*Burgherr et al., 2017; Burgherr & Hirschberg, 2014*). PSI's Energy-related Severe Accident Database (ENSAD) provides the most complete and authoritative source for historical accidents in the energy sector worldwide. With the development of ENSAD v2.0 an updated and significantly extended, web-based version is available that builds upon cutting-edge, open source technologies.

Structure and Implementation of ENSAD v2.0

The newly established **ENSAD v2.0** is a **spatial database** with fully integrated **GIS capabilities**. Its design and implementation was driven by simplifying the database structure compared to ENSAD v1.0, and to ensure full **scalability and flexibility** in view of potential future extensions. The overall structure of the database is shown in Figure 1. The core table, i.e. the **general accident information**, is linked through a 1:n relationship to the **consequences information** ensuring that information from different primary information sources is stored individually in the consequence table. **Infrastructure-dependent information** is stored in separate tables for each infrastructure type (e.g. dam, pipeline, power plant) and linked through a 1:1 relationship to the core table. Furthermore, reference **background data** and additional infrastructure information (e.g. third party databases) can be directly linked through the infra-dependent tables. Finally, the **user and data history information** tables provide important information about a user's role and activities, and what changes have been made to accident records and fields over time.

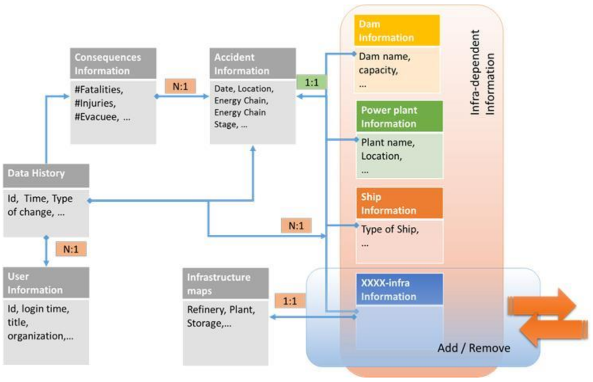

Figure 1: Overall structure of an accident record in ENSAD v2.0. (*Kim et al., 2018*).

ENSAD v2.0 has been developed as a **responsive web application**, based on a **cloud server** and **open-source technologies**. Depending on a user's role (e.g. Basic, Editor, Admin, Public) and the device used (e.g. PC, smartphone, tablet) the corresponding version is selected on the client side and displayed in the web browser. Figure 2 shows the three dedicated ENSAD versions that are available.

The main interface of the **desktop viewer** has a **similar layout to a typical GIS software** (Figure 2a). The layer panel is located on the left, and the preview panel for information sources is on the right of the map. The main menus and buttons are placed on the top, whereas the query form and the attributes table are on the bottom.

The **mobile viewer** has three main functions (Figure 2b): (1) "**Search**" for a location, (2) "**Locate**" accidents around the current user, and (3) select "**Layers**" to display (2b, left). The layer panel manages accident and base maps (2b, middle). When the user selects an accident on the map by touching its symbol, the corresponding attribute information for this accident is displayed as a popup window (2b, right).

The **ENSAD Visual Explorer (EVE)** (Figure 2c) has a **filtering panel** that allows choosing energy chains, chain stages and damage types. If at a location more than one accident occurred, they are displayed on the map as a pie chart with one slice per energy chain, and the total number of accidents is also indicated. The user can also select from several **predefined chart options to generate summary graphs**.

Numerous case study applications with ENSAD v2.0 data highlight its usefulness and versatility, including: (1) Bayesian hierarchical modeling to assess the **risk of dam accidents** (*Kalinina et al., 2018*), (2) risk assessment of energy **accidents in the natural gas sector** (*Cinelli et al., 2017*), and (3) **network analysis of the European natural gas infrastructure** (*Lustenberger et al., 2018*), among others.

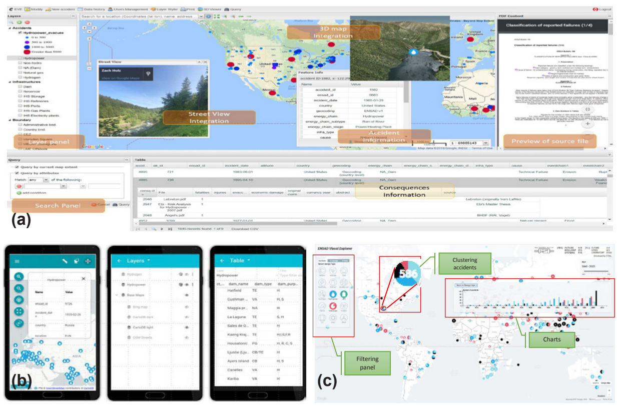

Figure 2: (a) Desktop viewer layout with full database access and functionality. (b) Mobile viewer with reduced features: main interface, layer selection and attribute table. (c) ENSAD Visual Explorer (EVE) for public users focuses on visualization with less detailed information (*Kim et al., 2018*).

Acknowledgements

This work has been carried out within the **Swiss Competence Center on Energy Research – Supply of Electricity** (concept, data management and preparation of data migration), the **Energy Turnaround National Research Programme (NRP70)** of the Swiss National Science Foundation (dam accident prototype), and the **Future Resilient Systems (FRS) program** of the Singapore-ETH Centre (SEC) (tool development and implementation, data migration).

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Mapping the landscape of participation in Geneva

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

Research Context and Objectives

This study takes place in the context of the Geneva program for geothermal energy, **GEothermie 2020**, which is funded by the public utilities SIG and the canton of Geneva. We accompany the program in its work on participation and the public.

This study maps participatory experiences of GEothermie 2020 program managers and inhabitants, and confronts those to their expectations and ideal types of participation.

The goal is to analyze the interplay between the different formats of participation used in GEothermie 2020 and identify potential misalignments between what is expected by participation and what specific formats can deliver.

Research Questions

How can the landscape of participation be drawn for geothermal in the Geneva context?

Does this landscape differ for program managers of the geothermal program and for local inhabitants? And if so, in what way?

Methods – two different perspectives on participation

We conduct a qualitative analysis in order to identify preferences about participation in the actors' own words.

Participant observation in strategic management meetings:
- Attendance to weekly sessions during 18 months
- Internal meetings with their project partners and public events
- *Data: observation notes, Memos and documentation.*

Focus groups with inhabitants:
- 6 focus groups in different municipalities and neighborhoods
- 5-10 participants in each group
- Same structure for all groups
- *Data: focus group transcripts and Memos.*

Framework for Analysis

We analyze the data using a framework that focuses on 3 aspects of the participatory process:
- Formats of participation: the ideal format for participation that leads to the implementation of a specific participatory process
- Subjects: the actors that participate in the given format
- Objects : the issues that are addressed in the given format

Each of these aspects is related to a wider space that influences the content of a specific participatory format and is simultaneously affected by what happens during participation. These relationships constitute a landscape of participation.

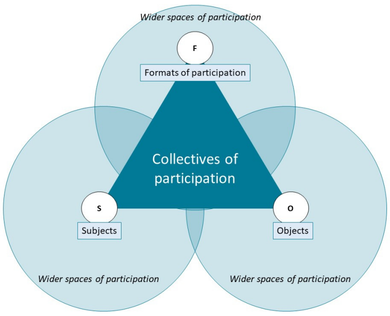

Fig. 1 Relational co-productionist framework adapted from Chilvers, Pallett, & Hargreaves, 2018

Preliminary Results

Below are first results from an analysis on the formats of participation

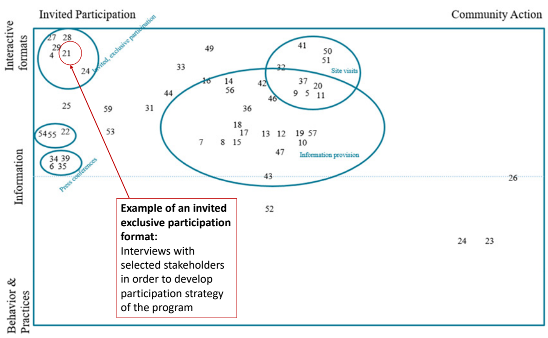

Fig. 2: Wider spaces of participation formats – **program managers' perspective**

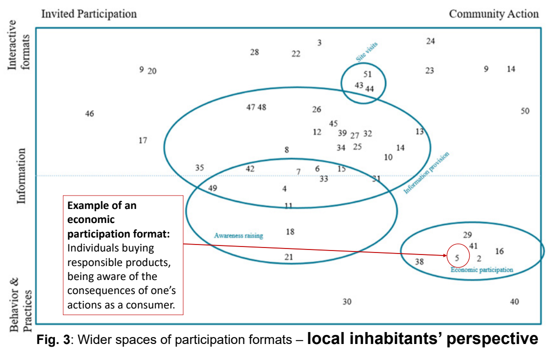

Fig. 3: Wider spaces of participation formats – **local inhabitants' perspective**

- Numbers represent references to participation formats made by the program managers (Fig. 2) and local inhabitants (Fig. 3).
- Blue circles: *wider spaces of participation*, thus a grouping of similar formats of participation.

Discussion

- Program managers see participation formats mostly as classical formats of information provision and site visits; only very few references to participation through behaviour and practices.
- Invited/internal participation that is exclusive in terms of who may participate is important in the program managers' view.
- Focus group participants also see information provision as one important format of participation;
- Focus group participants also often referred to other formats going more into individual actions and awareness on an individual level.

The diversity of participation collectives that could be identified for the Geneva context shows that there are many ways in which participation may be considered for a program like the geothermal one. However, depending on the perspective, these collectives may or may not be part of daily decision making of program managers or local inhabitants.

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Semiotic analysis of technoscientific promises in geothermal energy

Olivier Ejderyan (ETH Zürich, D-USYS TdLab)

Background

Future oriented statements and discourses projecting potential uses and benefits of a new technology are a common feature of innovation paths. Such statements and discourse can take various forms such as imaginaries, visions, scenarios or promises (Borup et al. 2006).

Promises are a specific form of future oriented statements: they formulate an engagement to deliver in a given time frame. They seek to secure research funds and investments and mobilize supporting actors (Audétat 2015; Joly 2010). They are characteristic of *performative statements* aimed to enact what they enounce.

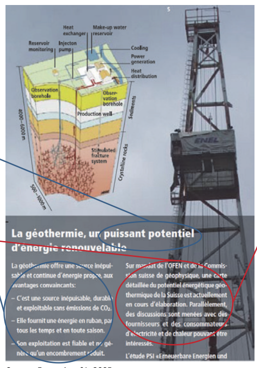
This study analyses the structure of promises related to geothermal energy development in Switzerland and evaluates their performative features. The goal is to focus how these promises might influence social siting and public engagement.

Methods

We conducted a semiotic analysis on promises about geothermal energy development in a corpus composes of:

- Newspaper articles
- Public relations material from energy operators and public authorities (flyers, pamphlets, websites…)
- Project presentation materials from developers

"By promises we mean **optimistic expectations sketching the potential and assumed benefits** which may be achieved by a technology, but nevertheless **require work to be done**." (te Kulve et al. 2013)

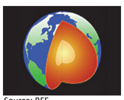


Source: Energeia, n°1, 2005

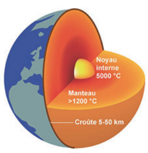
"Promises are not just a matter of discourses and representations. They also involve practices of exploration and experimentation; they are **related to investment, and to mobilization, circulation, and accumulation of resources.**" (Joly 2010)

We analysed the explicit content of the promises (what is to be delivered, when and how) and their audience (direct and indirect).

Insights



Source: BFE



Source: Geo-Energie Suisse

A common feature of promises about deep geothermal energy is to start from statements about the abundance of heat available in the earth. Images of a earths section depicting the mantle in a glowing orange are a popular visual trope.

Such pictures are instrumental in backing up one of the main arguments in favour of the development of EGS, that is the possibility to be deployed "anywhere".

Exemplary features of promissory statements:

Source: Hot Dry Rock, Geo-Energie Suisse

"Thanks to this we will have unlimited access to geothermal resources. This announces, already today, a guaranteed and serene energetic future"

«[HDR] These three letters, initials of « Hot Dry Rock », name a technique that enables to use geothermal energy independently from the availability of hot springs or hot aquifers.» (*Tribune de Genève* 29.12.2003)

Source: www.geothermie2020.ch

«In a near future, geothermal energy will enable us to heat whole neighborhoods, and possibly produce electricity. Well hidden in the underground, this promising renewable energy must first be ferreted out in places where it can be exploited. (…). Since traditional water-divining rods are not of a big use in this case, the SIG are betting on techniques elaborated to dig up oil» (*Tribune de Genève* 23.08.2010)

Table: Performative features of promises of Swiss geothermal energy

	Petrothermal/ EGS	Hydrothermal / conventionnal
Development formulated as…	Necessity	Opportunity
Reference to science	«top» science Pushing back frontiers Connexion au désir scientifique	Exploration Adding knowledge Reference to luck and vernacular knowledge
Source of funding	National states Research agencies International organisation Investors	Public bodies Local utilities End users Local universities
Future	Far but already here and clearly defined	Close but uncertain
Space	Delocalised Top down site selection Power for the network	Anchored Locally identified potential Resource justifies site Local direct use of heat
Vision of the public	Abstract Challenge to overcome Needs to be educated	Local Needs to be mobilised

Discussion

- Differentiated structure of promises for EGS and hydrothermal
- Performative effects of promises relate to specific features of the siting process (principles for site selection) or and public engagement (framing potential participants to involve)
- Project managers must take into account these effects when developing communication and public engagement strategies.

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Framing geothermal energy in the UK: A media analysis

Xue Xu, Michael Stauffacher, Olivier Ejderyan (ETH Zürich, D-USYS TdLab)

Goals of the study

- Identifying how UK's mass media frames geothermal energy
- Providing a foundation for analysing the social acceptance and for public communication of geothermal energy in the UK

Background

- No mature development of geothermal energy and no sufficient social analysis on geothermal energy in the UK
- Media frames impact public perception and social acceptance
- Sound social analysis including media analysis on geothermal energy in other countries(e.g. Switzerland, Australia)
- Social analysis on other energy technologies in the UK (e.g. shale gas, wind power)

Method: Media framing analysis

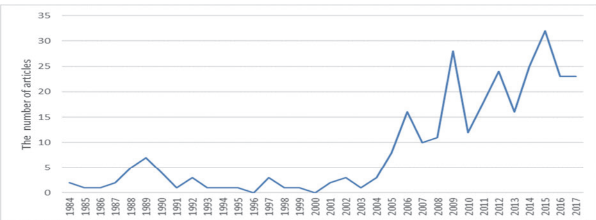
We conducted a qualitative content analysis to identify the framing on geothermal energy of two British newspapers with national audience

- Corpus: *The Independent* (1989-2017, n = 97 articles) & *The Guardian* (1975 - 2017, n = 192 articles)
- Statements about geothermal energy were coded using NVivo by combining deductive codes (predefined by literature and theoretical framework) and inductive codes (interpretation of salient statements)
- Exploring the relations between categories of codes, for example, actors and their attitudes, actors and the topics they relate to

Results

Frequency

- The number of articles per year increases over time, especially after 2000
- Peaks in reporting are not attributed to specific events related to geothermal energy but to an increase of reporting about energy related issues



Number of articles mentioning geothermal energy published per year (*The Guardian* and *The Independent*)

Identified frames

- Ordering the codes into categories of related topics enabled to identify following frames
- These frames are the main angles through which geothermal is discussed in the UK press

Name	Sources	References
Environment	168	260
Technology	105	199
Energy	113	153
Finance	73	101
Politics	52	74
Risk	17	30

Main frames of geothermal energy identified in *The Independent* and *The Guardian*

Actors, their frames, and attitudes

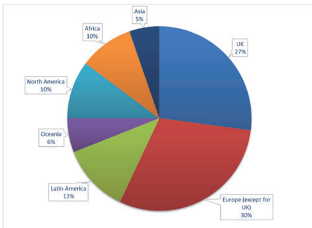
- Some actors appear more strongly associated to specific frames:
  - Scientists and experts with technology
  - UK's government with environment and energy
  - Geothermal operators with finance
- Actors' arguments were evaluated through interpretation. Arguments were classified as:
  - Positive: potential benefits of geothermal, financial and political support, successes
  - Neutral: facts without evaluative statement
  - Negative: drawbacks or nonsupport for geothermal
- Most quoted actors with more positive arguments
- NGOs and inhabitants are quoted with more negative ones

Actor	Negative	Neutral	Positive
UK's government	7	4	40
Other countries' governments	3	1	19
Business companies	5	5	19
Geothermal operators	3	4	19
Scientists & experts	3	2	32
Intergovernmental organizations	1	1	15
NGOs	8	2	5
Inhabitants	4	1	0

Attitudes towards geothermal energy of the actors mentioned in *The Independent* and *The Guardian*

Area of reporting

- Only a quarter of the articles report about geothermal in the UK as a source of energy discussed or under development



Countries mentioned in relationship to geothermal energy in *the Guardian* and *the Independent*.

Discussion

- The general tone of reporting on geothermal energy in the UK is positive (this does not mean that social acceptance is high!)
- Geothermal is described as a promising energy, but with still lacking governmental funding and political support
- Geothermal mainly appears as an energy source in foreign countries, outside of the UK
- Geothermal is most often treated aside other energy related topics, mainly solar and wind power, shale gas and fracking
- Polarized quotes of actors might make discussions about geothermal energy appear as more controversial than they are: governments and operators are mostly quoted in favor while NGOs and inhabitants are more often quoted to convey negative views of geothermal energy.
- Little discussion of risks. This is a challenge to project developers who will need to develop proactive communication schemes here

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DESTRESS

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Application of the Polynomial Chaos Expansion for uncertainty quantification of the flood wave propagation resulting from a concrete dam break

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

[1]Laboratory for Energy Systems Analysis (LEA), Paul Scherrer Institut, Villigen PSI, Switzerland; [2] Department of Aquatic Ecology, Eawag, Dübendorf, Switzerland

Research Objectives

1. Quantification of flow quantities downstream of a large concrete hydropower dam in case of its failure;
2. Application of Polynomial Chaos Expansion for Uncertainty Quantification (UQ) and Sensitivity Analysis (SA) of the modeled flow quantities;
3. Development of a generic model for Swiss conditions (i.e. >= 100 meters, arch concrete dams located in the Alpine area).

Framework for uncertainty quantification & sensitivity analysis

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

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

M_i^{PCE}- PCE response, X_i - input vector, y_α - coefficient, Ψ_α - polynomials.

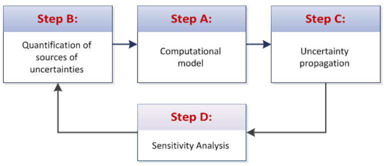

Fig. 1. Global framework for uncertainty quantification (Sudret, 2007)

Sensitivity Analysis is performed by calculating 1st order Sobol' indices of individual contributions of each model input to the total variance D; Sobol' indices are calculated from the coefficients of the PCE-metamodel (Sudret, 2008), such that:

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

The metamodel was built using UQLab (Marelli and Sudret, 2014).

Step A: Computational model of the flood wave propagation

Complete and instantaneous failure of the dam is assumed; thus, the dam-break is treated as a Riemann problem (Fig. 2(a));
The amount of water released from the dam is characterized using 3 parameters: *H, V,* L_{cr}, (Table1), whereas, flood propagation is simulated for a generic model of the downstream valley characterized by 6 parameters: $L_{ch\text{-}rel}$, W, S_b, S_s, M_b & M_s (Table 1).
The model output is given by 6 parameters (Fig. 2(b)): Q_{peak}, t_{peak}, t_{ar}, k, maximal velocity v_{max}, and maximal depth h_{max}.
A 1D model is built in the BASEMENT software (ETHZ).

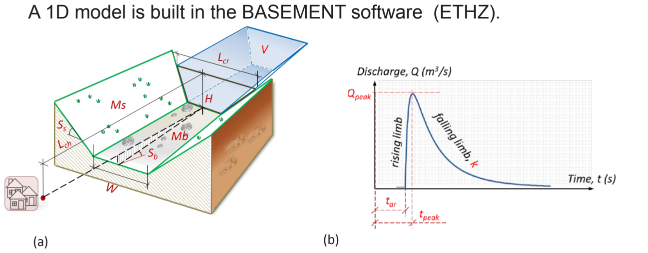

Fig. 2. (a) Parametrization of the input parameters of the dam, reservoir, and valley topography downstream of the dam; (b) Parametrization of the model output

Step B: Marginal distributions for uncertain model inputs

Table 1. The marginal distributions specified for the input of the metamodel

Parameter	Name	Unit	Distribution	Information sources
Physical characteristics of the dam and reservoir				data on large hydropower dams (SwissCOD, 2016)
H	Dam height	[m]	$H \sim Beta(1.3,3,117,250)$	
V	Reservoir volume	[m³]	$V \sim Beta(1.3,3,9200,2E5)$	
Lcr	Length of the dam crest	[m]	$L_{cr} \sim U(256,610)$	
Physical characteristics of the channel				data on slopes from GeoVITE & Rosgen, et al. (2013)
Lch_rel	Relative channel length	[m/m]	$L_{ch\ rel} \sim U(5.9,123.6)$	
W	Channel width	[m]	$W \sim U(1,163.7)$	
Sb	Slope of the channel bed	[-]	$S_s \sim U(28.3,45.9)$	
Ss	Slope pf the channel embankments	[-]	$S_b \sim Beta(3.2,32.5)$	
Characteristics of the environment				Land cover data from GeoVITE
Mb	Roughness coefficient of the channel bed	[s/m$^{1/3}$]	$M_b \sim Beta(0.33,2.1)$	
Ms	Roughness coefficient of the channel embankments	[s/m$^{1/3}$]	$M_s \sim Beta(0.4,1.9)$	

Step C: Results for uncertainty propagation

PCE of different degrees are built on the experimental design of 2,000 samples for the 6 parameters of the model output (Fig.3):

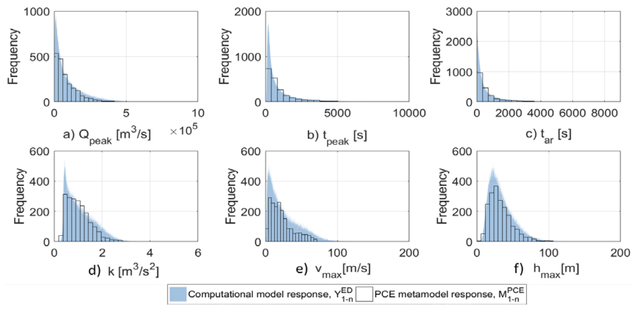

Fig. 3. Model response (Y_{i-n}^{ED}) and PCE response (M_{i-n}^{ED}) for a) Q_{peak} ; b) t_{peak}; c)t_{ar}; d) k; e) v_{max}; f) h_{max}

Step D: Results for sensitivity analysis

Sobol' indices indicate that the reservoir volume, length of the valley, and surface roughness contributed most to the variability of the model output (Fig. 4)

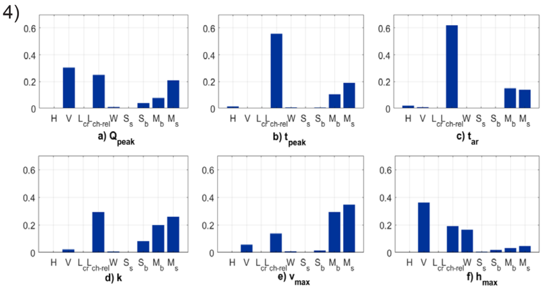

Fig. 4. Results for sensitivity of a) Q_{peak} ; b) t_{peak}, c)t_{ar}; d) k; e) v_{max}; and f) h_{max}

Conclusions

- The applied metamodelling 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;
- Sensitivity analysis can help to understand how the variability of each model input affected variability of the model output;
- The constructed metamodel can support informed risk management and reliability-based design for typical Swiss hydropower dams.

Acknowledgement: 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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Quantitative assessment of uncertainties and sensitivities in life loss estimates due to an instantaneous dam-break

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Research scope

This work focuses on the model that estimates the life loss resulting from the impact of the dam-break flood in the locality downstream of the dam (Block 2 in Fig. 1). The model of the corresponding flood (Block 1 in Fig.1) is presented by the authors in the poster "Application of the Polynomial Chaos Expansion for uncertainty quantification of the flood wave propagation resulting from a concrete dam break".

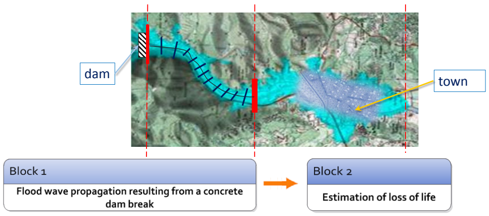

Fig. 1. Essential computational blocks for the modeling of the dam-break event

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 metamodelling 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)

The framework for uncertainty quantification (UQ) and global sensitivity analysis (GSA) in Fig.2 is developed specifically for the model estimating LL due to an instantaneous dam break. The physical model is run with the HEC-LIFESim software and reflects conditions relevant for Switzerland. The framework aims at demonstrating benefits of the use of metamodeling for quantification of uncertainties in comparison with the sampling-based Uncertainty Mode implemented in HEC-LIFESim. The framework also includes calculation of global sensitivity indices for different model inputs in order to understand their contribution to the overall variability of LL estimates.

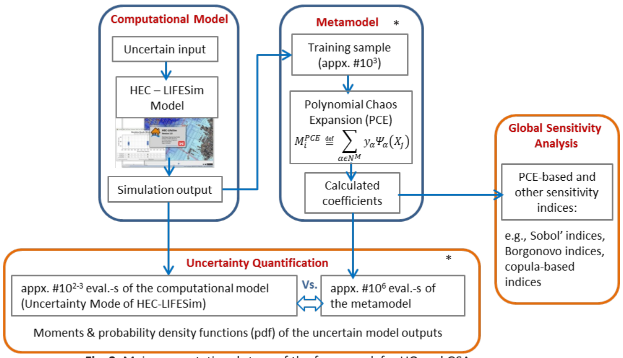

Fig. 2. Main computational steps of the framework for UQ and GSA

* The module is explained by the authors in the poster "Application of the Polynomial Chaos Expansion for uncertainty quantification of the flood wave propagation resulting from a concrete dam break".

The modules on the computational model and GSA are further elaborated in detail in this poster.

Computational HEC-LIFESim model

The HEC-LIFESim software (USACE 2017) is a spatial dynamic system for modeling LL of a flood event. It is a modular system consisting of four modules, namely flood routing module, warning and evacuation module, loss of shelter module, and life loss module. These modules are built around databases and exchange data through geo-layers.

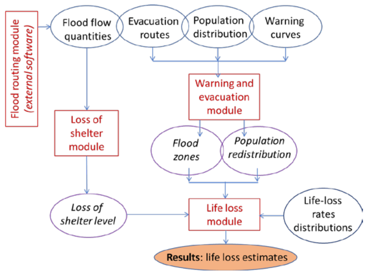

Fig. 3 HEC-LIFESim approach for LL estimation (modified from Bowles, 2007)

HEC-LIFESim estimates the number of LL by redistributing the initial Population At Risk (PAR), i.e., the amount of people living in the inundated area, based on the information about evacuation, warning, flood severity and other factors. Combining further the recalculated PAR in different zones with the historical LL-rates, the total LL caused by a specific dam-break event can be estimated.

Global Sensitivity Analysis (GSA)

A number of different techniques are applied for the purpose of the GSA in this study. They include Sobol' indices, Borgonovo indices, copula-based indices, etc.

For example, Sobol' indices, S_i, define individual contributions of each model input to the total variance D. They can be determined using the PCE coefficients calculated in the previous step (so-called PCE-based Sobol' indices); in this case, GSA requires no additional sampling (Sudret, 2008):

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

The Borgonovo index, δ_i, (Borgonovo, 2007) of a random input variable X_i is a measure of the expected shift in the probability distribution of the model output when 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. Other sensitivity indices used in this study are elaborated in Kalinina et al. (2018).

Status and Outlook

- The dynamic spatial LL-model built in HEC-LIFESim can fully address the risk to which people are exposed in a dam-break flood event.
- Furthermore, it is important to adjust LL-rates to reflect study-specific characteristics of the dam type and failure mode. For Swiss dams, alternative LL-rates had different shapes and frequency ranges than the generic ones used by HEC-LIFESim.
- PCE-metamodeling and GSA allowed for rigorous and computationally efficient assessment of uncertainties in LL estimates.

Acknowledgement: 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).

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Toward a new framework for chemical risk assessment in the context of accidental events in deep geothermal energy (DGE) systems

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Motivation & Objectives

The aim of this study is to move toward a framework for chemical risk assessment of accidental events in Deep Geothermal Energy (DGE) systems. In particular, the scope of this work is to develop a framework for a hypothetical accidental chemical release in the air compartment that considers both uncertainty and variability in the inputs to account for uncertainty and variability in the outputs. Furthermore, a global sensitivity analysis of the model outputs with respect to the inputs will be performed. The focus of this preliminary study is on the presentation of the framework and on a preliminary analysis on the chemical concentration (mg/m^3) in air at different distances from the source of the accident.

A Framework for Chemical Risk Assessment

Chemical Risk Assessment (CRA) is estimated as the product between the exposure duration and concentration to a chemical under interest (Exposure Assessment (EA)) and the maximum level of acceptable concentration (i.e. without consequences) within a period of time by the receptor under interest (e.g. humans and/or the environment) (Hazard Assessment (HA)) [1], see **Figure 1**.

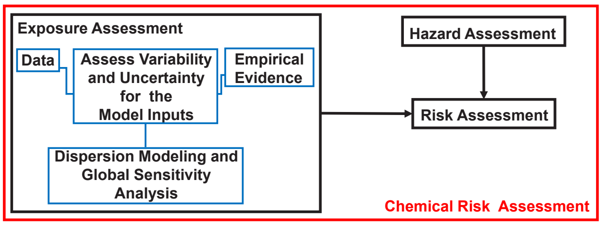


Figure 1: Scheme of the proposed framework for Chemical Risk Assessment with uncertainties

The HA is given by laboratory experiment results, which can be found in the literature for the most common chemicals [2]. Therefore, the focus of this study is on the EA. As shown in **Figure 1**, the proposed framework for the EA could be subdivided into four major steps. First, empirical evidence from historical accidental releases of the chemical under interest needs to be collected along with other crucial information (data) for different parameters that could affect the chemical dispersion (e.g., wind speed, wind directions, etc.). Second, variability and uncertainty of the abovementioned information are assessed to be used as inputs for the model. Third, a dispersion model (e.g. Gaussian Plume model [3]) for chemicals is used in a stochastic environment (e.g. Monte-Carlo sampling, etc.) to assess the chemical concentration in air including its uncertainty at different distances and times from the source. Furthermore, a Global Sensitivity Analysis (GSA) of the model outputs is performed to assess the effect of the inputs of the model to the outputs. Finally, the results of the concentrations under uncertainty at different distances and times are used as exposure vales for the estimation of the risk on human health and/or the environment.

Case Study

Hazardous substances are used in different phases of the life cycle of a deep geothermal power plant [4]. In here, the focus is on the most common chemicals used for the matrix acidizing treatment during the stimulation phase (e.g. Hydrogen Chloride (HCl) and Hydrogen Fluoride (HF)), see **Figure 2**.

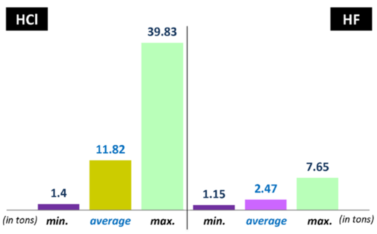
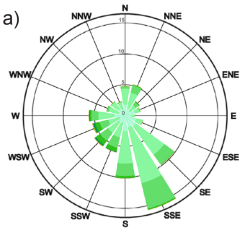


Figure 2: Average, minimum and maximum quantities of the most common hazardous chemicals used in the stimulation phase for deep geothermal energy systems [5].

The analyzed accident scenario is defined as a leak from a circular hole (of variable size: 0.5, 1, 2.5, 4, 8, 15 cm) located at 25 cm from the tank bottom, in a 100% full horizontal cylindrical storage tank (length = 7 m; diameter = 0.95 m; volume = 5 m^3) located at the plant.

Weather data (temperature, dew point, humidity, wind speed, wind direction, etc.) have been collected for a hypothetical location in the Molasse Basin in Switzerland from 2010 to 2018 (**Figure 3**).

a)



b)

Observed Values		Minimum	Average	Maximum
Temperature	°C	-12	8.5	31
Wind Speed	Km/h	1	6	16
Wind Direction			SSE	
Relative Humidity	%	26	77	98

Figure 3: a) Average distribution of Wind Speed and Direction at a hypothetical location in Switzerland; b) Selected weather data used as inputs in the chemical dispersion model (www.wunderground.com).

Weather information and hole size in the storage tank have been sampled 10'000 times with a Monte-Carlo algorithm and input in ALOHA® (https://www.epa.gov/cameo/aloha-software), the chemical dispersion model used in this study, to assess the EA with uncertainty (**Figure 4**).

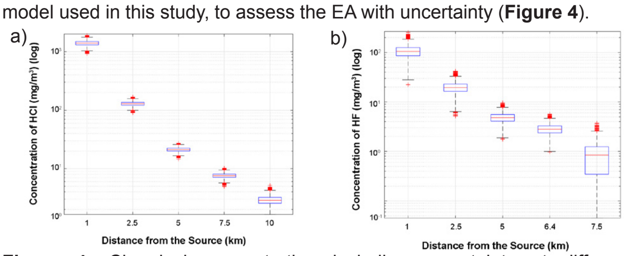


Figure 4: Chemical concentration including uncertainty at different distances along the axis of the main wind direction from the source. a) HCl; b) HF.

A preliminary sensitivity analysis has been carried out by allowing only one parameter to vary per ALOHA® run, keeping all the other parameters fixed (**Figure 5**).

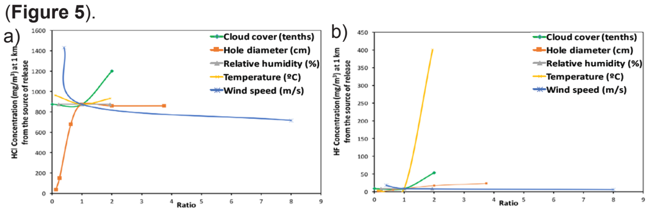


Figure 5: Sensitivity analysis for different model parameters. a) HCl; b) HF

Summary & Outlook

- A new framework for Chemical Risk Assessment including uncertainty quantification and sensitivity analysis has been proposed.
- Along the axis of the main wind direction, uncertainties for the emitted chemical concentrations appear relatively small in general, except for the most distant sample in the HF case.
- The preferential role of some parameters, e.g. wind speed and hole diameter (and also cloud cover for HF), on the atmospheric dispersion of the selected hazardous chemicals is evidenced.
- Further developments of the model framework are needed. On the one hand, by including reactions of the chemicals with the ambient humidity, the deposition process of the chemicals, etc. in the EA model. On the other hand, to optimize and automatize the process along with including the GSA.

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Understanding social perception of geothermal energy in Chile

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[†]*Swiss Federal Institute of Technology Zurich*, [Ψ]*Andean Geothermal Center of Excellence.*

Motivation

Caring for a positive social perception of geothermal energy is necessary to foster this technology in Chile. By 2030, the Chilean portfolio is planning to add up to 5.2 GW, from a 16 GW total capacity, to the current 48 MW installed capacity [1,2,3]. However, there are social and political barriers that have prevented projects to succeed [4]. One can learn from these cases to identify firms' practices on stakeholders engagement and understand how such strategies may trigger a positive and negative social perception. Few studies have addressed this problem worldwide.

Focus and objectives

This study was focused on a geothermal exploration project in southern Chile, in which community stakeholders were approached to inform and create trust. The goal of this study was to disentangle such approach and explain the resulting social perception.
Three objectives were addressed:

- To evaluate actors perception of the project in the past.
- To disentangle the company's stakeholder engagement strategy and understand how it influenced perception.
- To identify external variables that influenced perception and explore how.

Method for data collection

The testimonies of 27 stakeholders were collected from: tourism companies (TR), local authorities (LA), indigenous communities (IN), neighbor associations (DC/NC), landowner (LO), and NGOs.

Five focus groups

Eight semi-structured interviews

Review of written documents:

Two local newspapers

Company's documents

Chilean Geothermal Energy Law

Environmental Impact Assessments

Method for analysis

The software NVivo 12 Plus was employed to arrange data. The next steps were followed:

1. Transcription of collected data.
2. Timeline of project's milestones.
3. Coding into nodes of variables, topics and categories. One node for perception.
4. Allocation of nodes in timeline.
5. Matrix crossing of nodes from point 3 with perception.
6. Explanation of perception by reading the references of overlaps of point 5.

Results

The stakeholders' perception along the geothermal project's lifetime varied due to the influence of different variables. These variables were arranged in 3 categories: Stakeholder Engagement Strategy, Project Activities, and Context. Such influence is explained and shown in Figure 1 and 2, respectively. Overall, 5 stakeholders had a negative perception, 2 a positive and 2 a neutral.

Influence of variables on stakeholders' perception

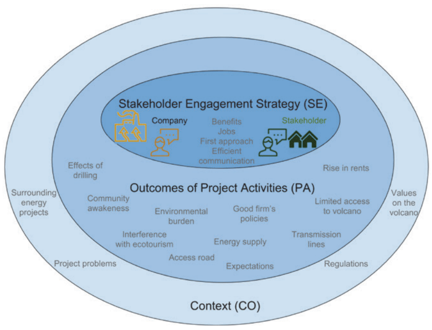

Figure 1. Variables that influenced perception. The engagement process cannot be isolated from the project activities and context.

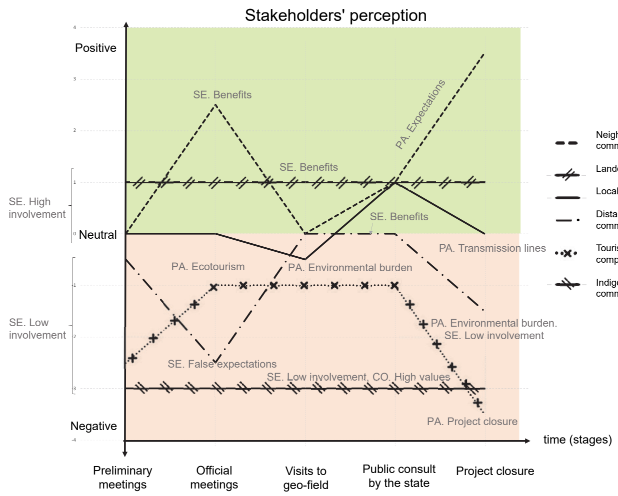

Figure 2. Stakeholders' perception over time. The variables that influenced perception are shown.

Conclusions

- Not only the company's engagement strategy, but also the project activities and context influenced social perception. It varied for each stakeholder.
- Both, Chilean regulations and the company did not promote the realization of an environmental impact assessment from the beginning (exploration). Thus, distrust was built.
- Stakeholders were involved differently, so that different attitudes toward the project were developed.
- The novelty of this study was the description of different stakeholders' views on geothermal energy in the Chilean context, and the development of a methodology that allowed to study the perception of a project that occurred 9 years before.

References & Acknowledgements

Financially supported by own resources from ETHZ USYS Transdisciplinarity Lab. Special acknowledgements to the Andean Geothermal Center of Excellence (CEGA) for their enthusiastic support

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Application to the Swiss Alps of the Landslide Generic Cellular Automaton (LSgCA)

Ahoura Jafarimanesh and Arnaud Mignan

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Abstract:

The scaling exponent α of the power-law in the frequency-size distribution of landslides is a critical parameter in landslide hazard assessment. A recent study by Jafarimanesh et al. (NHESS, 10.5194/nhess-2018-167) proposed a generic cellular automaton approach (LSgCA) to retrieve the range of α values observed in the literature. While LSgCA was applied to simulated topographies with a wide range of possible soil characteristics, this study is the first to apply the method to a real case study with site-specific parameters.

Our site is located in the Illgraben catchment of the Swiss Valais Alps, a very active catchment which potentially produces large sediment discharge that surpasses the average alpine rate. A multi-temporal record of the landslide process in the study slope has been previously quantified by Bennett et al. (2012) with α values observed in the range of α = 1.7-2, in the low range compared to the α = 2.21±0.53 of the literature. We verify that a similar α distribution is retrieved when using the site-specific characteristics of the Illgraben catchment to validate the application of LSgCA in real case conditions and demonstrate the importance of rheology for a refined landslide hazard assessment.

Method: Landslide Generic Cellular Automaton (LSgCA):

A. Initiation phase: Landslide initiate when the factor of safety (Fs) is ≤ 1.

$$FS = \frac{c+h(\gamma_t-\gamma_w)\cos\theta\tan(\emptyset)}{h\gamma_t\sin\theta}$$

c stands for the cohesion of soil, ∅ is the angle of friction angle, θ is the slope gradient, γ_t is the total material unit weight, γ_w is the water unit weight, and h stands for the slope normal thickness of the failure slab.

B. Propagation phase: Input parameters are the initial topography (*z*, *h*) and soil properties (c, γ_t, θ, ∅). The maximum slope θ_{max} is calculated based on the Moore neighbourhood nomenclature (Toffoli and Margolus 1988) and defines the direction of the landslide flow. The mass movement is defined by :

$$\Delta h = [z(x,y) - z(dir_{Moore}[\theta_{max}(x,y)]) - \Delta s\tan(\theta_{stable})]/2$$

Case study: Illhorn peak, Illgraben catchment, Swiss Valais Alps

- ~ 1 km² surface area.
- The Illhorn peak is 2716 meters above the sea levels.
- Quarzitic dominated slope with the layer of dolomite and schist intersecting.
- The size of the past slope failures are measured with the photogrammetric analysis of historical aerial photographs from 1986 to 2005 by Bennett et al. (2012).

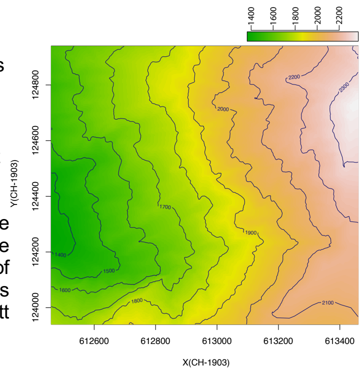


Fig.1: The topography of the case study in the Swiss coordinate system.

Table 1: The range of the typical soil characteristics involved in this study (Swiss standards).

	Min	Max
Cohesion (kPa)	5	20
Soil unit weight (kN/m³)	11	18
Water unit weight (kN/m³)	9.8	-
Internal friction angle (deg)	11	30
Soil thickness (meters)	1	10
Slope gradient (deg)	15	85

The application of LSgCA to the case study: The FS contour and the propagated landslide map:

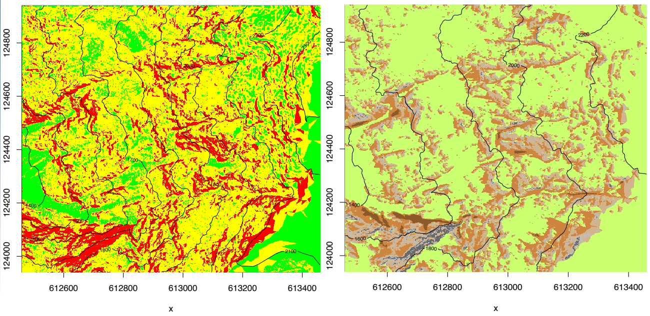


Fig. 2 : (a) The factor of safety (FS) contour map before the application of LSgCA, red patches indicating the unstable cells (FS ≤1). (b) Propagated landslide after the application of LSgCA; brown patches represent the landslide thickness; Scarps are shown in dark grey color.

Results :

- Comparison of the frequency size distributions (FSD), observed and simulated:

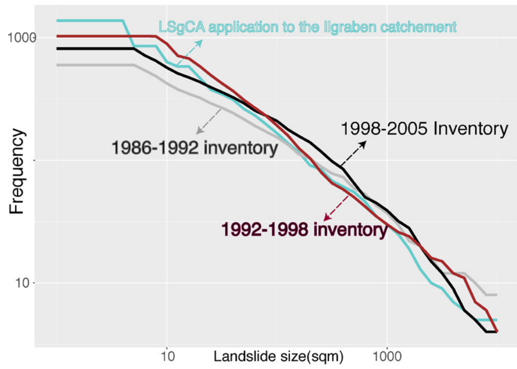
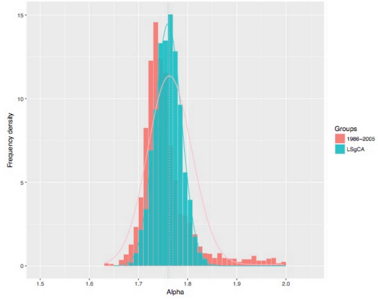


Fig. 3: The comparative FSD of the application of LSgCA in the study slope versus the FSD of the landslide inventories in the periods of 1986-1992 (A), 1992-1998 (B), 1998-2005 (C). We obtained the average non-cumulative scaling exponent α of the power-law equal to ***α=1.8*** for n=50 simulations similar to α_A=1.7, α_B=2, α_C=1.9 for the three time periods.

- Uncertainty analysis on the power-law α range for the resampled landslide size datasets with 10,000 bootstraps.

Fig. 4: The distribution of the power law exponent α on the resampled landslide size data (n=10,000). The green fit demonstrates the distribution of LSgCA with the α_{avg}=1.76, whereas the red fit shows the α range in 1986-2005 landslide inventory with the α_{avg}=1.77.



Reference

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- Jafarimanesh, A., Mignan, A., and Danciu, L.: Origin of the power-law exponent in the landslide frequency-size distribution, Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2018-167, in review, 2018.