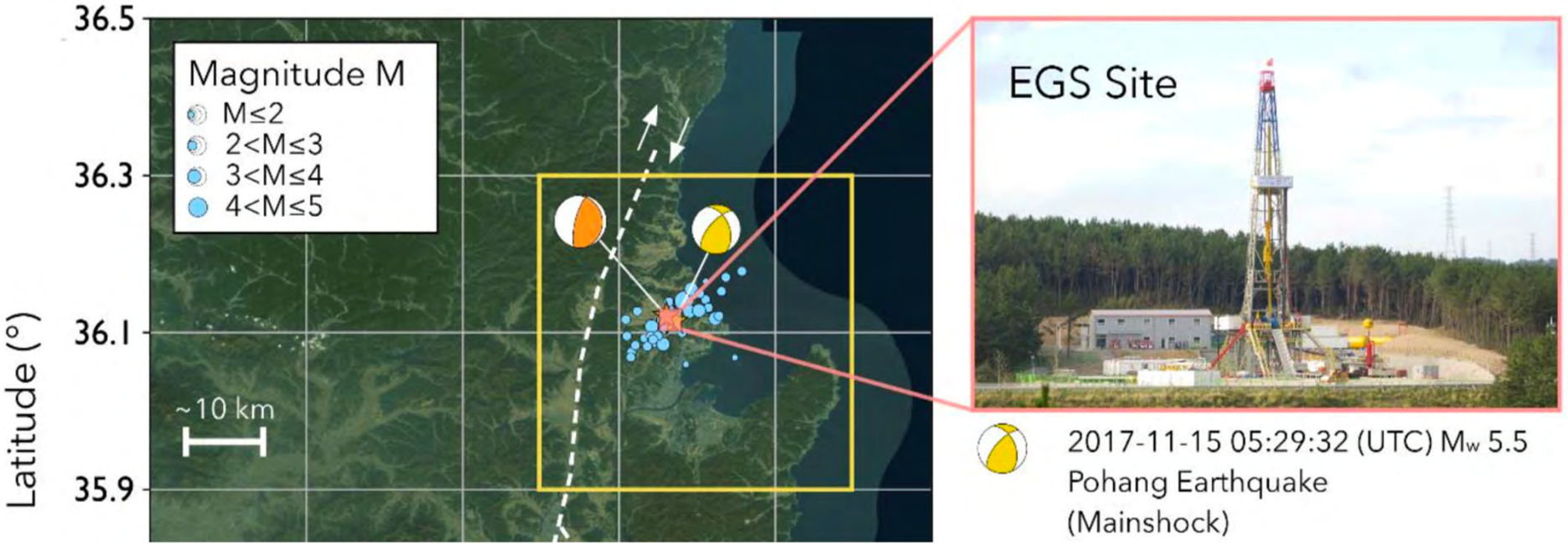
Induced Seismicity Risk

Its Governance involving scientists, authorities, and the public

Arnaud Mignan & Olivier Ejderyan
ETH Zurich
SCCER SoE Annual Conference 2019, 3 Sep. 2019, Lausanne

Seismic risk is the main risk faced by EGS projects

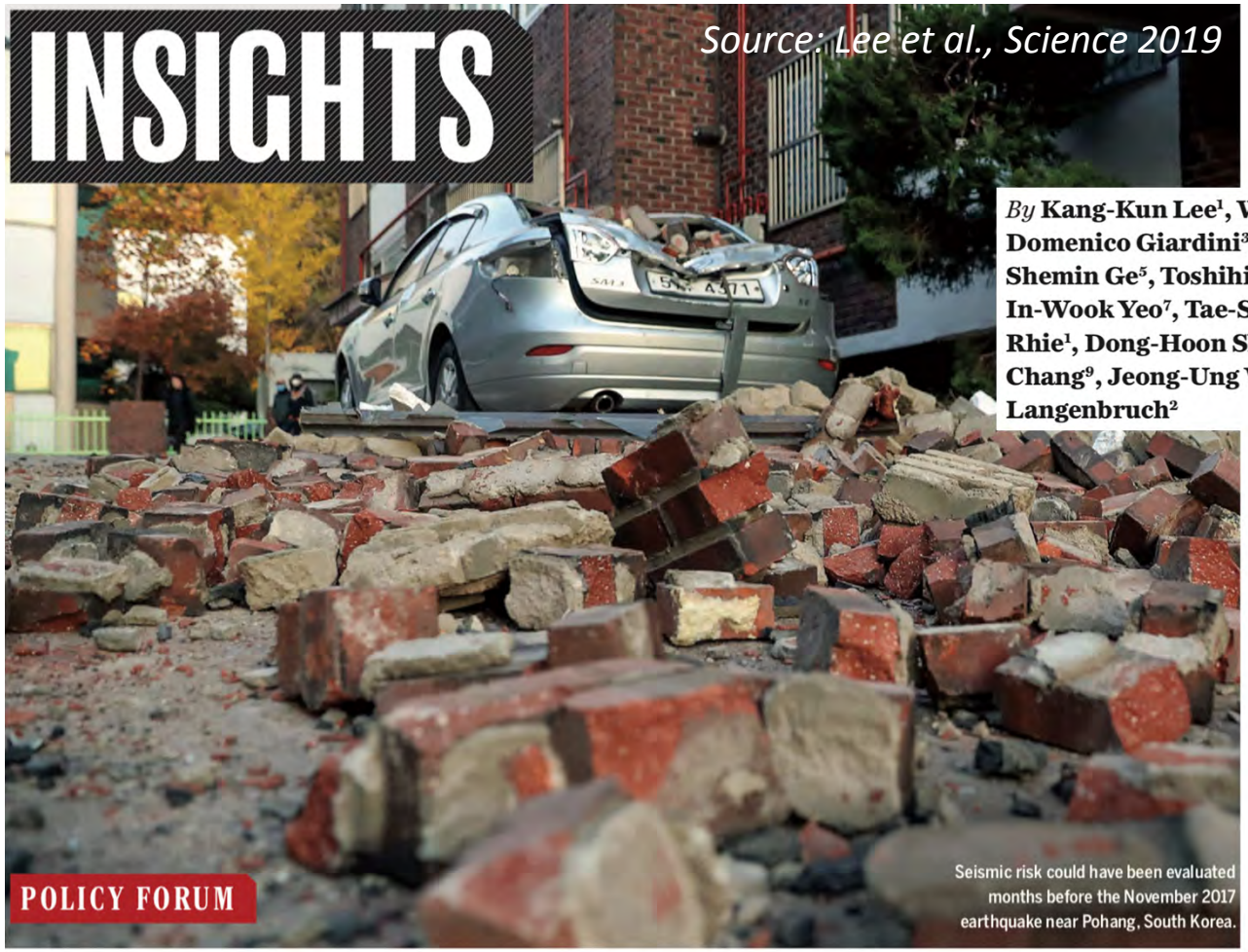
- In Switzerland, 2 stimulation projects terminated due to occurrence of M3+ earthquakes, Basel in 2006 and St Gallen in 2013 – Led to minor, non-structural damage
- In South Korea, EGS project suspended due to 2017 Pohang M5.5 earthquake, potentially triggered by EGS operations (Grigoli et al., Science 2018) – Led to 10,000s structures being damaged & 100+ injuries
- We are in a **post-Pohang environment**, requiring "*new methods to assess and manage evolving risks*" (Lee et al., Science 2019), i.e. **risk-based & dynamic/adaptive**



Source: Grigoli et al., Science 2018

INSIGHTS

Source: Lee et al., Science 2019



POLICY FORUM

Seismic risk could have been evaluated months before the November 2017 earthquake near Pohang, South Korea.

INDUCED SEISMICITY

Managing injection-induced seismic risks

The Pohang quake shows the need for new methods to assess and manage evolving risk

By **Kang-Kun Lee[1], William L. Ellsworth[2], Domenico Giardini[3], John Townend[4], Shemin Ge[5], Toshihiko Shimamoto[6], In-Wook Yeo[7], Tae-Seob Kang[8], Junkee Rhie[1], Dong-Hoon Sheen[7], Chandong Chang[9], Jeong-Ung Woo[1], Cornelius Langenbruch[2]**

the number of earthquakes, the higher the odds of one of them being large (*13*).

The Pohang earthquake violated the volume hypothesis, as the injected volume was less than 1/500th of the amount expected to produce an earthquake of M_w 5.5. Once initiated, the Pohang earthquake grew through the release of tectonic strain rather than being limited by the pressure perturbation induced by the injected fluids or confined

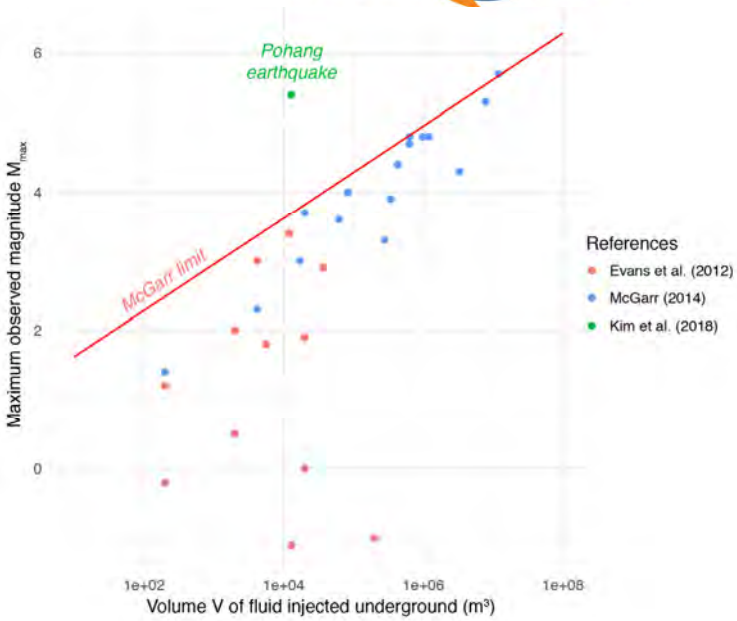
recognized nor communicated. It is essential that EGS and related stimulation activities use a risk-based TLS that adapts to evolving hazards such as fault activation from multiple stimulations.

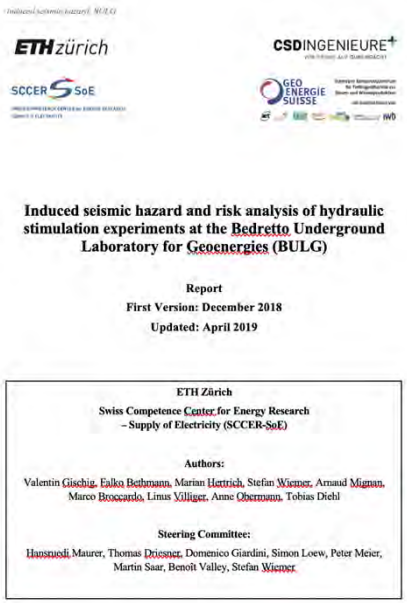
Earthquakes are heavy-tailed phenomena, with the hazard concentrated in the large-magnitude, low-probability events (*14*). However, the risk that this hazard poses depends on exposure and vulnerability. The siting of the Pohang EGS project close to a major population and industrial center should have emphasized the need to consider risk rather than simply hazard. Such considerations are

From R&D to application of the new risk method

- **Probabilistic risk** assessment method mature
  - ✓ Respects the post-Pohang view on risk, with volume hypothesis weight reduced in logic trees
  - ✓ From **benchmarked** in OpenQuake to systematic use
  - ✓ **Improved best-practice guidelines,** 2019 applications:
    - Bedretto risk report
    - Haute-Sorne manuscript
    - Iceland (Geldinganes) risk report + manuscript
  - ✓ Provides ***a priori* risk quantification** (prior to stimulation)

- *Broccardo et al.'s POSTER on Geldinganes risk assessment*





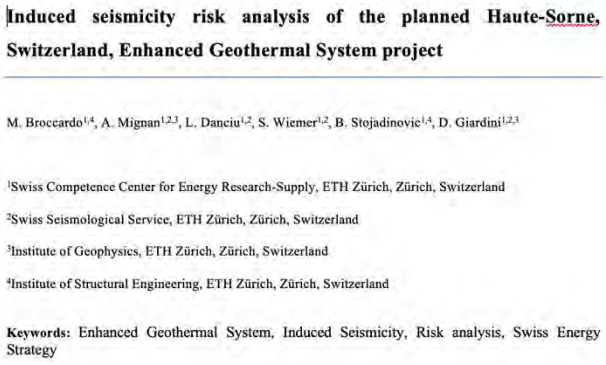
Induced seismic hazard and risk analysis of hydraulic stimulation experiments at the Bedretto Underground Laboratory for Geoenergies (BULG)

Report
First Version: December 2018
Updated: April 2019

ETH Zürich
Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE)

Authors:
Valentin Gischig, Falko Bethmann, Marian Hertrich, Stefan Wiemer, Arnaud Mignan, Marco Broccardo, Linus Villiger, Anne Obermann, Tobias Diehl

Steering Committee:
Hansruedi Maurer, Thomas Driesner, Domenico Giardini, Simon Loew, Peter Meier, Martin Saar, Benoît Valley, Stefan Wiemer



Induced seismicity risk analysis of the planned Haute-Sorne, Switzerland, Enhanced Geothermal System project

M. Broccardo[1,4], A. Mignan[1,2,3], L. Danciu[1,2], S. Wiemer[1,2], B. Stojadinovic[1,4], D. Giardini[1,2,3]

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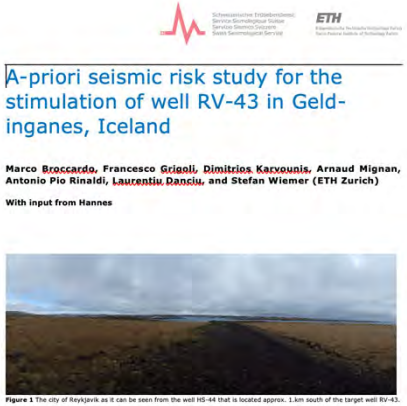
Keywords: Enhanced Geothermal System, Induced Seismicity, Risk analysis, Swiss Energy Strategy



A-priori seismic risk study for the stimulation of well RV-43 in Geldinganes, Iceland

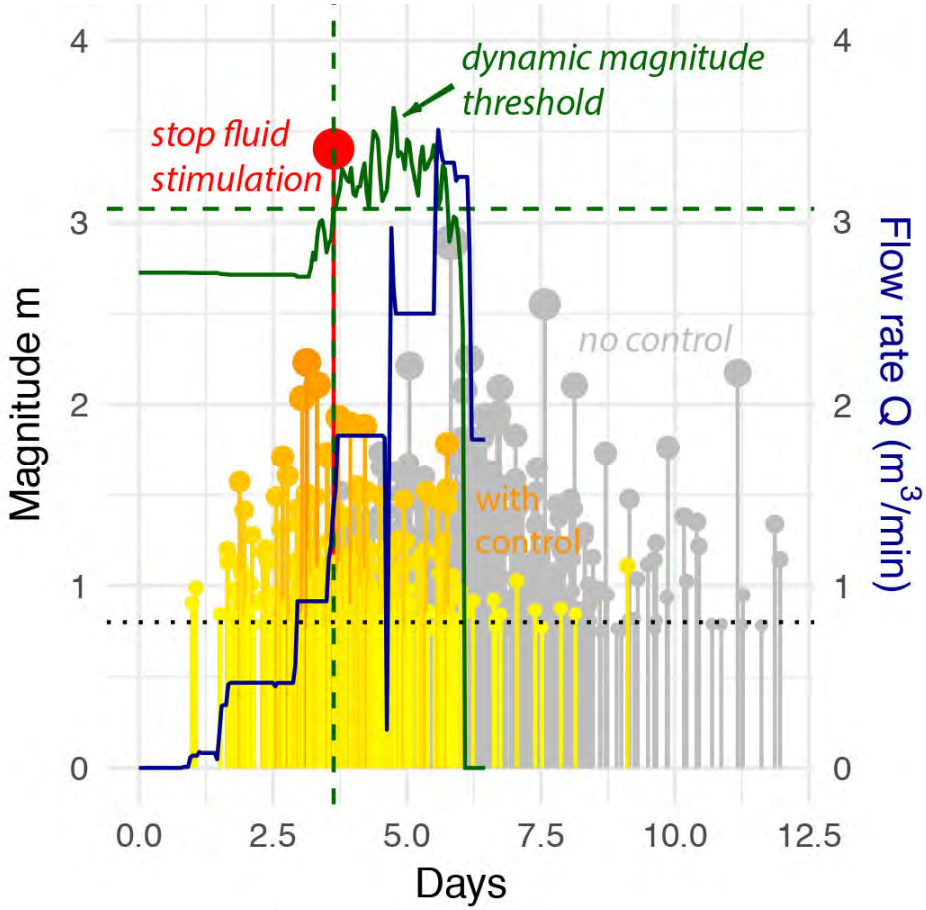
Marco Broccardo, Francesco Grigoli, Dimitrios Karvounis, Arnaud Mignan, Antonio Pio Rinaldi, Laurentiu Danciu, and Stefan Wiemer (ETH Zurich)

With input from Hannes

Figure 1 The city of Reykjavik as it can be seen from the well HS-44 that is located approx. 1.km south of the target well RV-43.

From R&D to application: Adaptive TLS

- Adaptive traffic light system **to be tested/validated in the coming weeks in Geldinganes**
  - ✓ Risk-based: mapping from **fixed safety criterion** to magnitude threshold
  - ✓ Two statistical approaches available: frequentist versus Bayesian
  - ✓ Ongoing work: **dashboard-type risk mitigation system for online decision-making** (from R&D to software for operators)



$$\begin{cases} \mu(t) = 10^{a_{fb}} 10^{-bM_c} \Delta V(t) & ; t \le t_{shut-in} \\ \mu(t) = \mu(t_{shut-in}) \exp\left(-\dfrac{t - t_{shut-in}}{\tau}\right) & ; t > t_{shut-in} \end{cases}$$

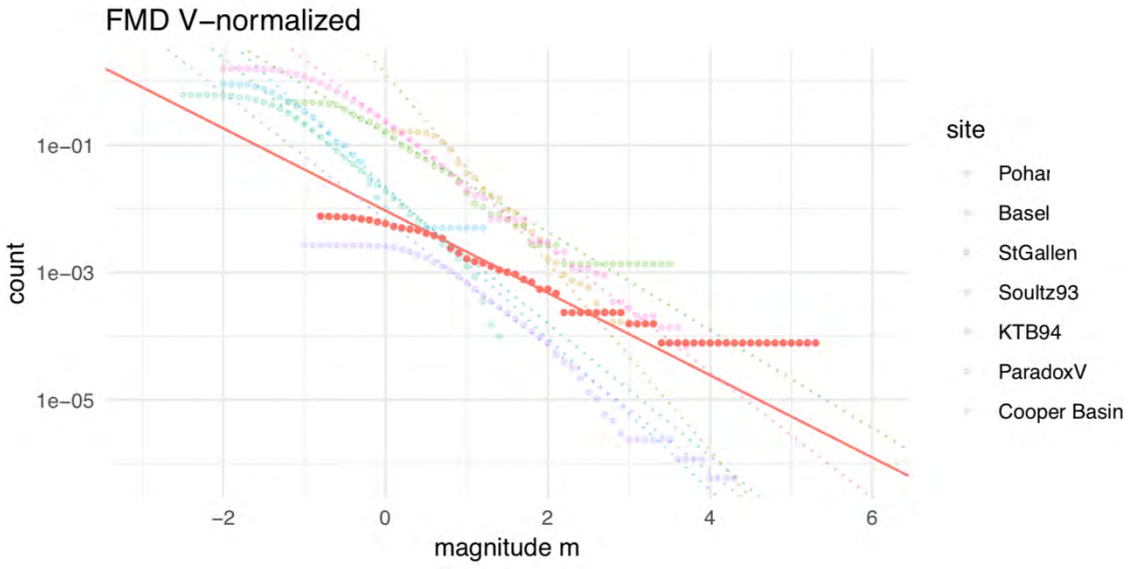
$$m_{th} = \frac{1}{b_{fb}} \log_{10}\left[Y - 10^{a_{fb} - b_{fb} m_{saf}} \tau \dot{V}(t_{shut-in})\right] + m_{saf}$$

TOP 100 - READ ARTICLES - 2017
OFFICIAL AUTHOR
SCIENTIFIC REPORTS

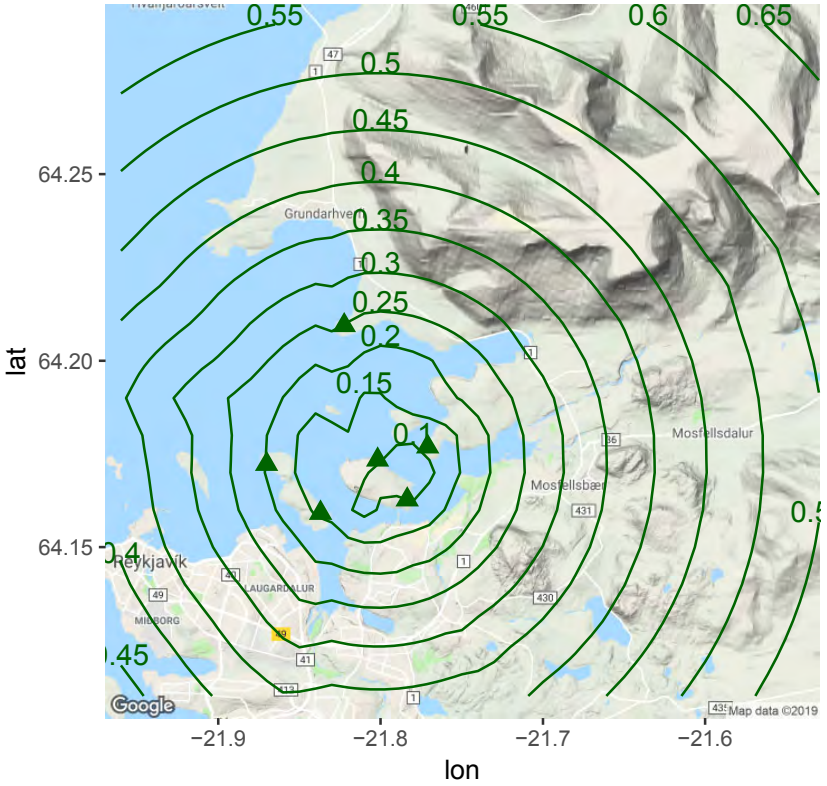
Mignan et al., Sci. Rep. 2017; Broccardo et al., GRL 2017; Mignan et al., Energy Geotech. 2019

From R&D to application: Adaptive TLS

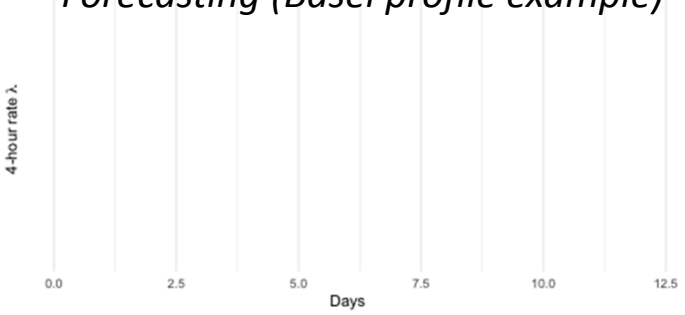
- Practical aspects for proper ATLS application
  - ✓ Seismic monitoring level can be inferred from the ATLS magnitude threshold
  - ✓ Innovation in **seismic network planning** based on a Bayesian approach
  - ✓ Pohang experience: Critical role of the *b*-value (ratio in event magnitude) in increased likelihood of a large earthquake, requiring a very low completeness magnitude (i.e. very good network) to stop injection ASAP in case of anomalous *b*-value



Predicted completeness magnitude
method: BMC Iceland prior



Forecasting (Basel profile example)



Towards algorithmic decision making

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Including seismic risk mitigation measures into the Levelized Cost Of Electricity in enhanced geothermal systems for optimal siting

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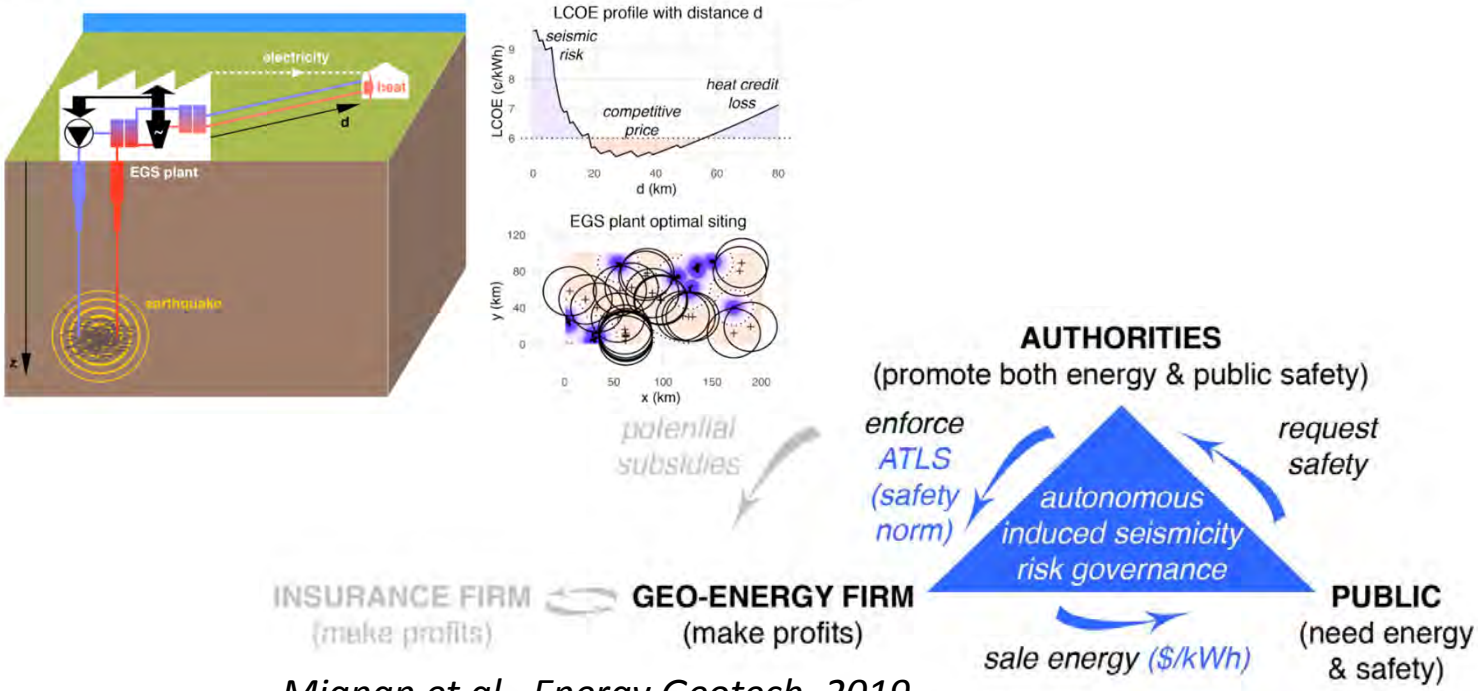
HIGHLIGHTS

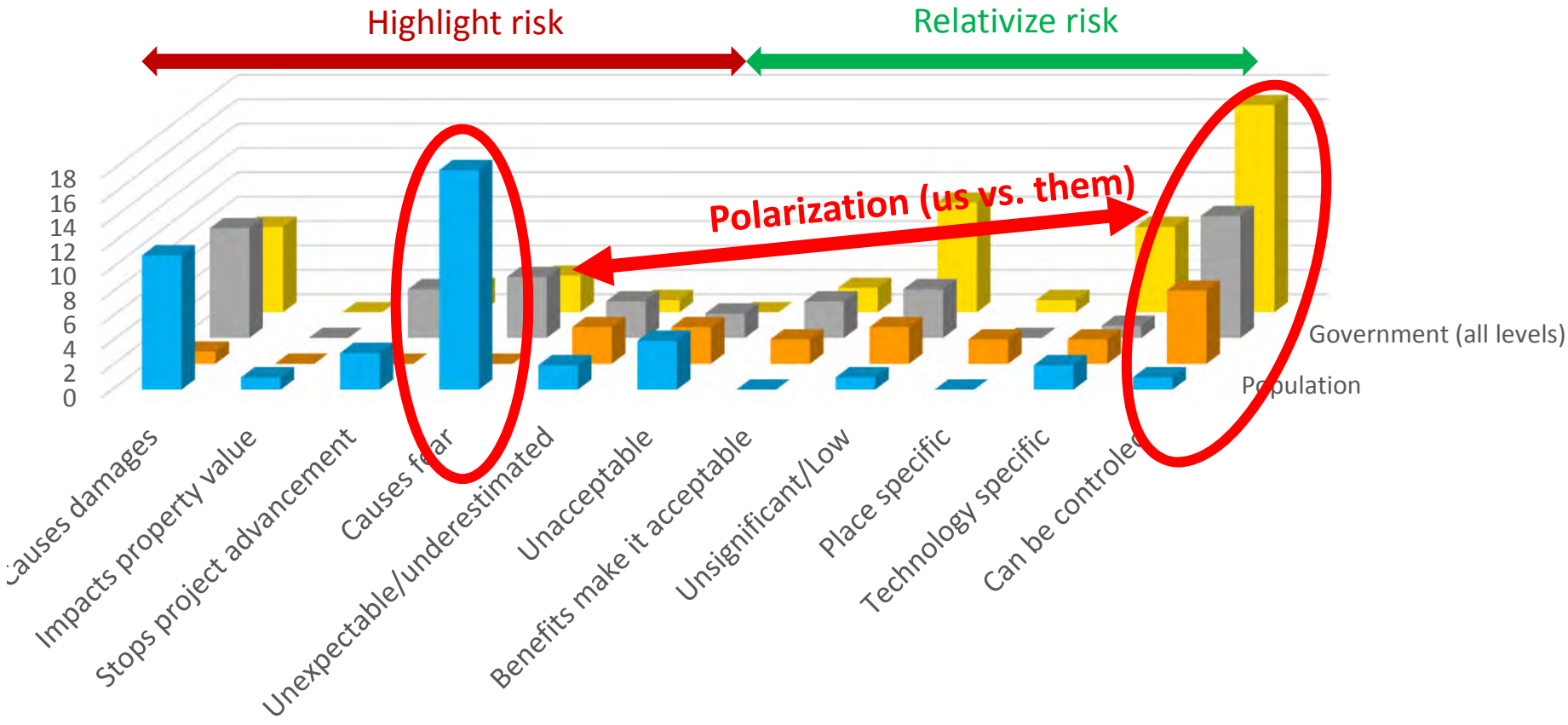
- Seismic risk mitigation cost combined to the heat credit creates a spatial tradeoff.
- The geo-energy pricing increases locally due to induced seismicity risk aversion.
- Safety standards play a central role on spatial optimisation of geo-energy plants.

GRAPHICAL ABSTRACT



Mignan et al., Energy Geotech. 2019

Statements qualifying seismic risk by type of actor in media discourse (f-CH)



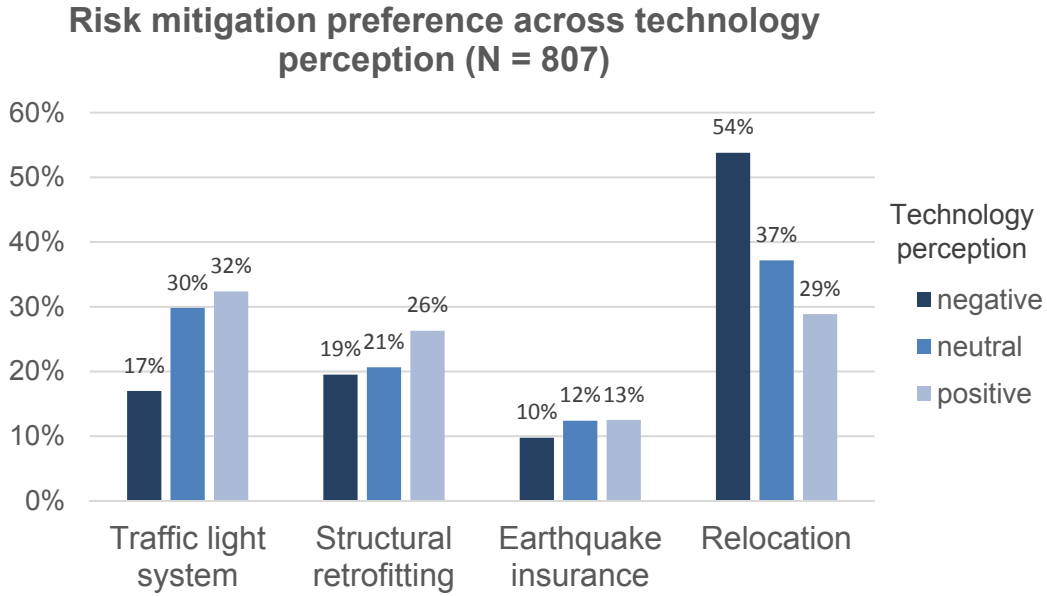
How are measures to mitigate seismic risk perceived?

Risk mitigation perception	DGE *N* = 209	SG *N* = 200	CPG *N* = 198	CCS *N* = 200	
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*F*(3, 803)
Traffic light system	4.62 (1.27)	3.99 (1.30)	4.54 (1.30)	4.10 (1.37)	12.029***
Structural retrofitting	4.63 (1.24)	4.08 (1.23)	4.63 (1.19)	4.28 (1.34)	9.690***
Earthquake insurance	4.58 (1.35)	3.84 (1.32)	4.29 (1.46)	4.09 (1.47)	10.216**
Relocation	4.73 (1.32)	4.21 (1.32)	4.51 (1.40)	4.50 (1.36)	4.988**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Note: Values range from 1 = low, 7 = high.

Hämmerli & Stauffacher (2019 – in review). The neglected role of risk mitigation perception in the risk governance of underground technologies – the example of induced seismicity

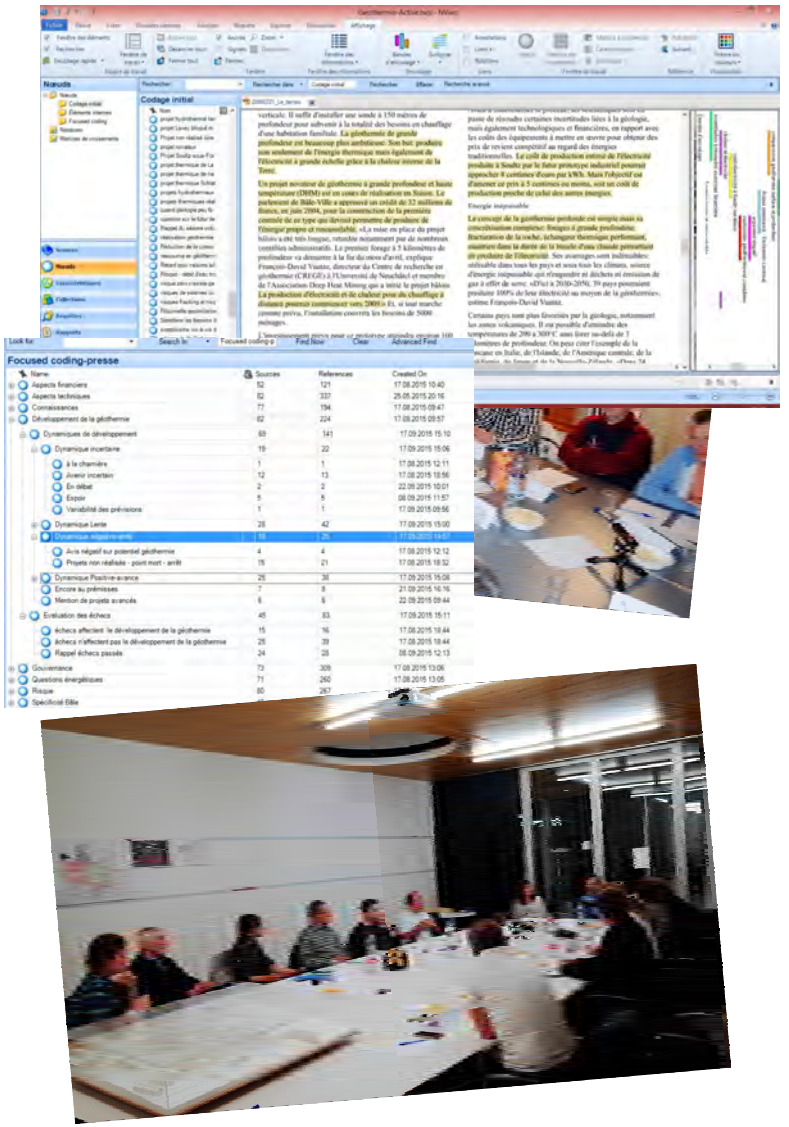


From media discourse to public engagement

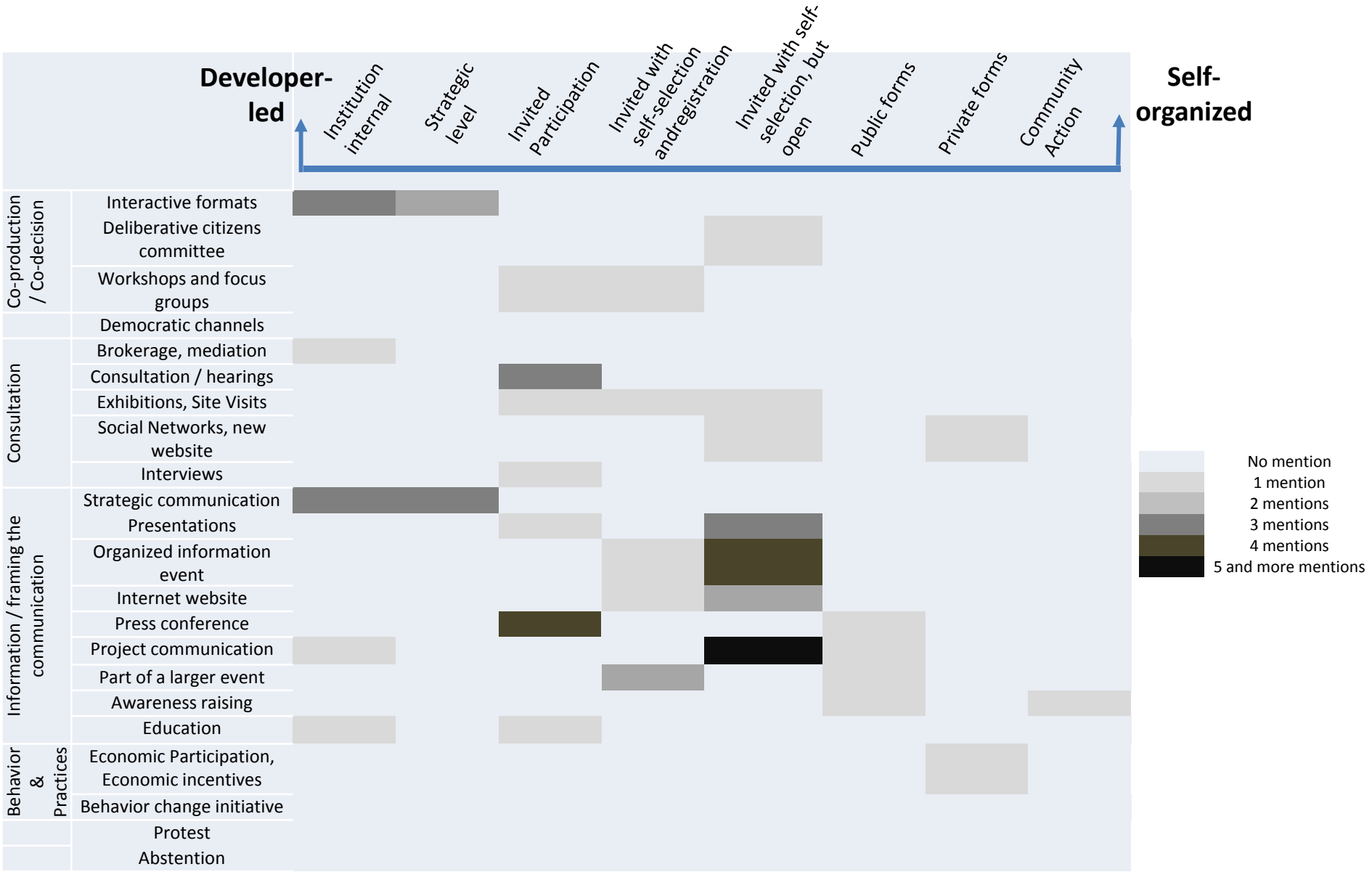
- What do the media frames mean for engaging the public?
- Focus group research
- Participant observation of management meetings

→ Analysed qualitatively

Source: GEothermie 2020



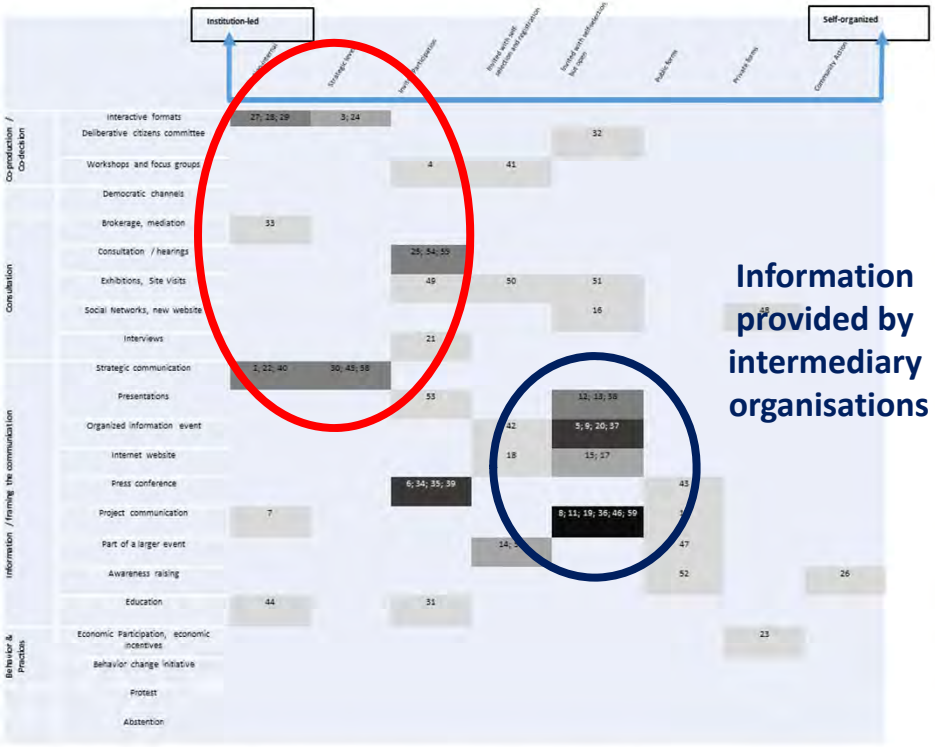
Forms of public engagement preferred by project managers



Forms of public engagement preferred by project managers

State led, invited highly interactive

"Managers"



Information provided by intermediary organisations

References made in strategic management meetings – update with new attributions 20.11.18

"Communities"

Information provided by intermediary organisations

Trust !!!

References made in focus groups – update with new attributions 20.11.18

Embedded in everyday activities

No mention
1 mention
2 mentions
3 mentions
4 mentions
5 and more mentions

Outlook

- Fitting communication & engagement measures;
- Embedding geothermal energy through the use of heat ?

Ejderyan, O., F. Ruef, M. Stauffacher (accepted, 2020) The entanglement of top-down and bottom-up: socio-technical innovation pathways of geothermal energy in Switzerland. *Journal of Environment and Development*. Special issue on Low Carbon Energy Transitions in Federal Systems, March 2020.