

Induced Seismicity Risk

Its Governance involving scientists, authorities, and the public

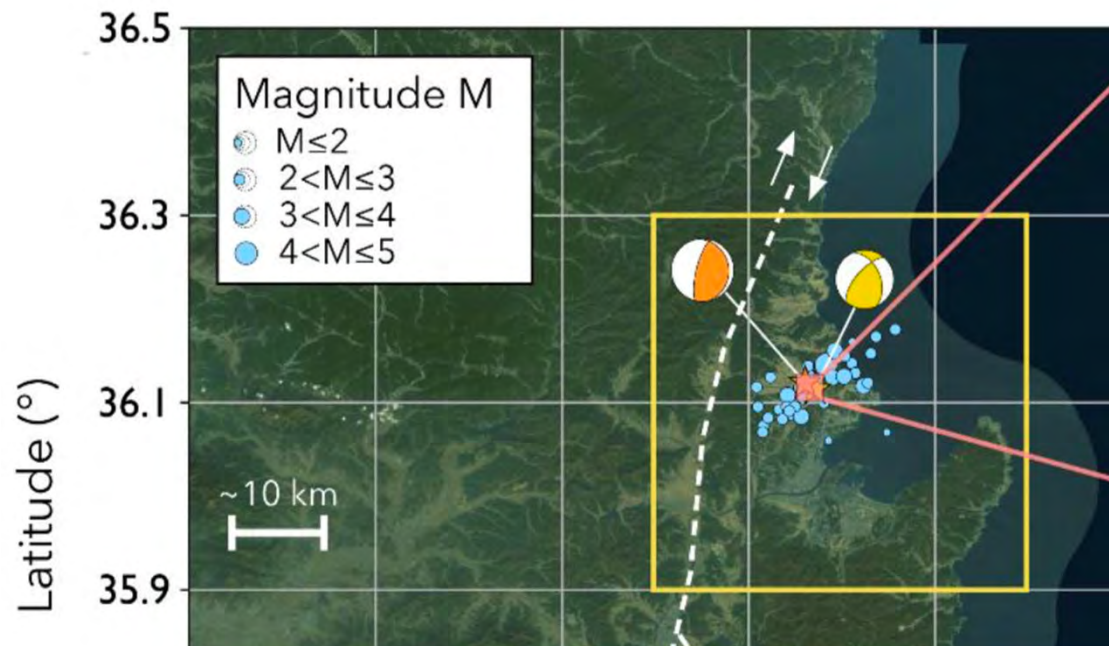
Arnaud Mignan & Olivier Ejderyan

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



2017-11-15 05:29:32 (UTC) M_w 5.5
Pohang Earthquake
(Mainshock)

INSIGHTS

Source: Lee et al., Science 2019



By Kang-Kun Lee¹, William L. Ellsworth²,
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In-Wook Yeo⁷, Tae-Seob Kang⁸, Junkee
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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

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

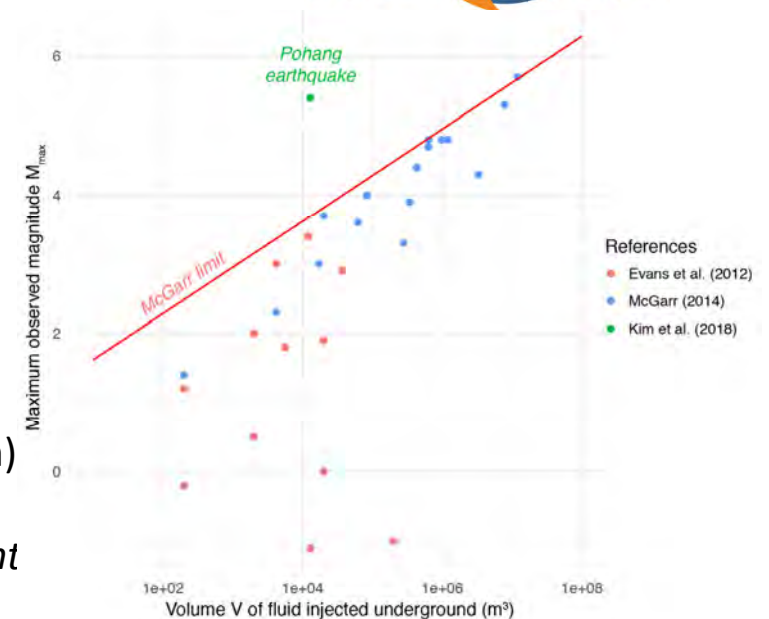
The Pohang earthquake violated the volume hypothesis, as the injected volume was less than 1/500th of the amount expected to produce an earthquake of M_w 5.5. Once initiated, the Pohang earthquake grew through the release of tectonic strain rather than being limited by the pressure perturbation induced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

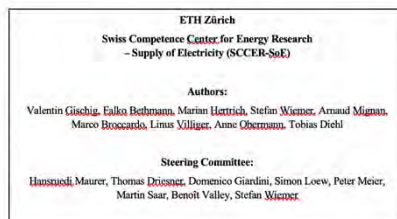
From R&D to application of the new risk method

- **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 Geoennergies (BULG)

Report
First Version: December 2018
Updated: April 2019



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

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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 Kavounis, Arnaud Mignan, Antonio Pio Rinaldi, **Laurentiu Danciu**, and Stefan Wiemer (ETH Zurich)

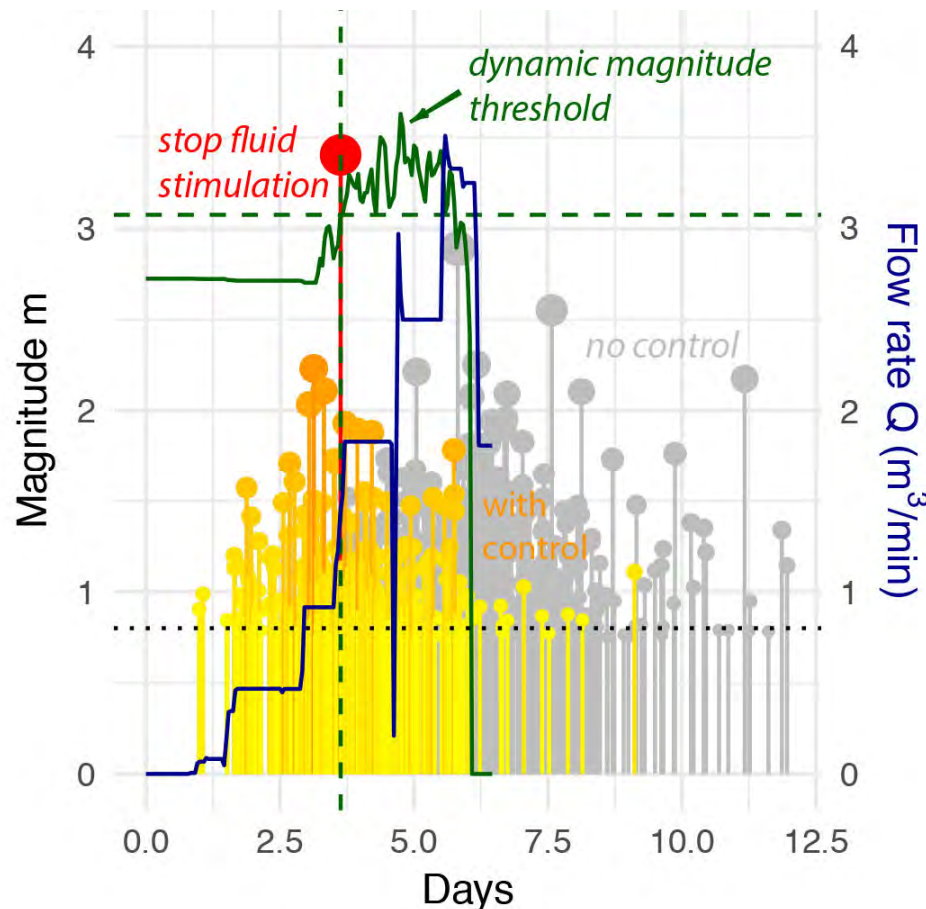
With input from Hannes



Figure 1 The city of Reykjavik as it can be seen from the well HV-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)



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

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

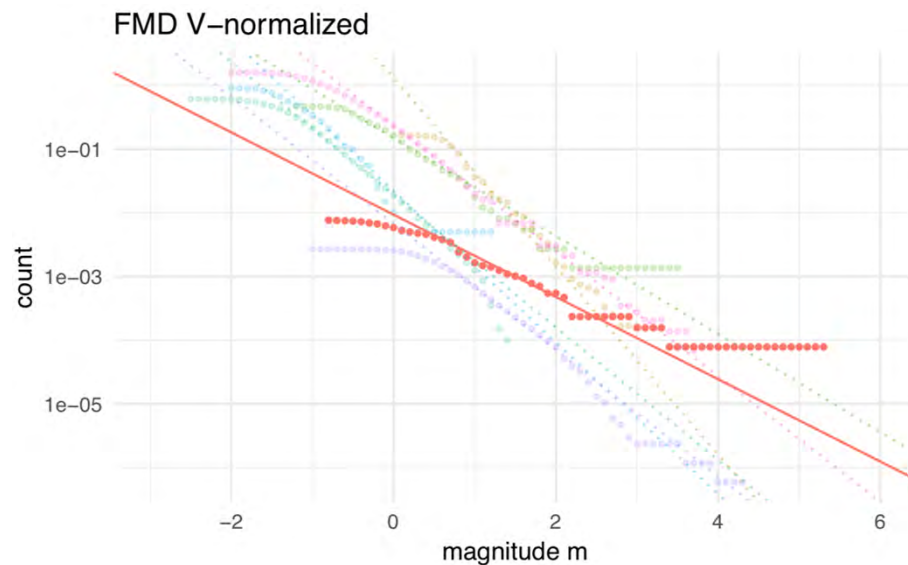


Mignan et al., *Sci. Rep.* 2017; Broccardo et al., *GRL* 2017; Mignan et al., *Energy Geotech.* 2019

From R&D to application: Adaptive TLS



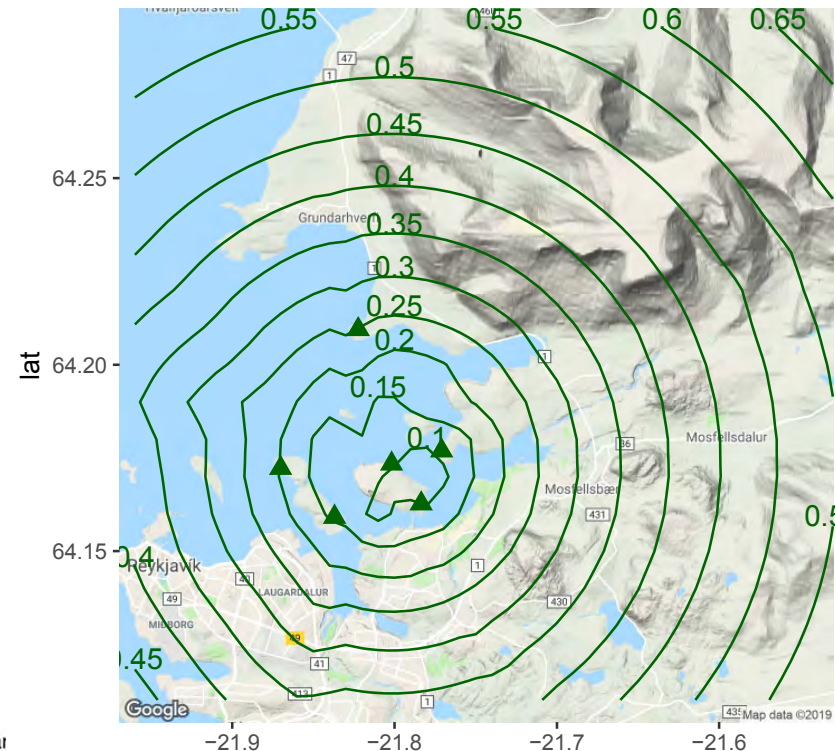
- Practical aspects for proper ATLS application
 - ✓ Seismic monitoring level can be inferred from the ATLS magnitude threshold
 - ✓ Innovation in **seismic network planning** based on a Bayesian approach
 - ✓ Pohang experience: Critical role of the b -value (ratio in event magnitude) in increased likelihood 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



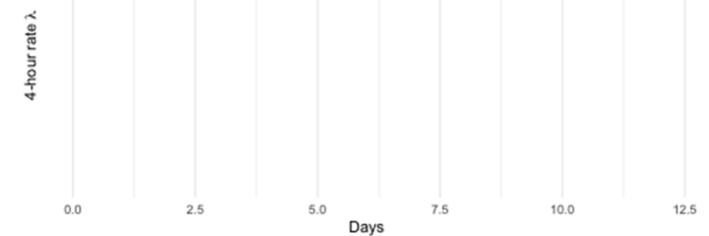
site

- Pohar
- Basel
- StGallen
- Soultz93
- KTB94
- ParadoxV
- Cooper Basin

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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^a Swiss Federal Institute of Technology, Zurich, ETHZ, Institute of Geophysics, NO Building, Sonneggstrasse 5, CH-8092 Zurich, Switzerland

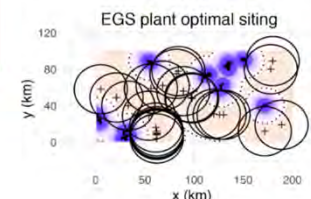
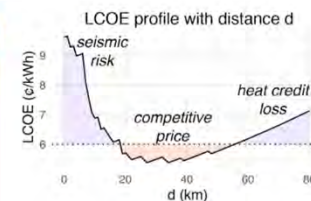
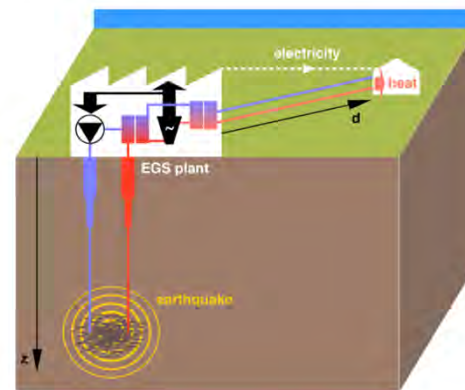
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HIGHLIGHTS

- 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



potential subsidies

INSURANCE FIRM
(make profits)

GEO-ENERGY FIRM
(make profits)

AUTHORITIES
(promote both energy & public safety)

enforce
ATLS
(safety
norm)

request
safety

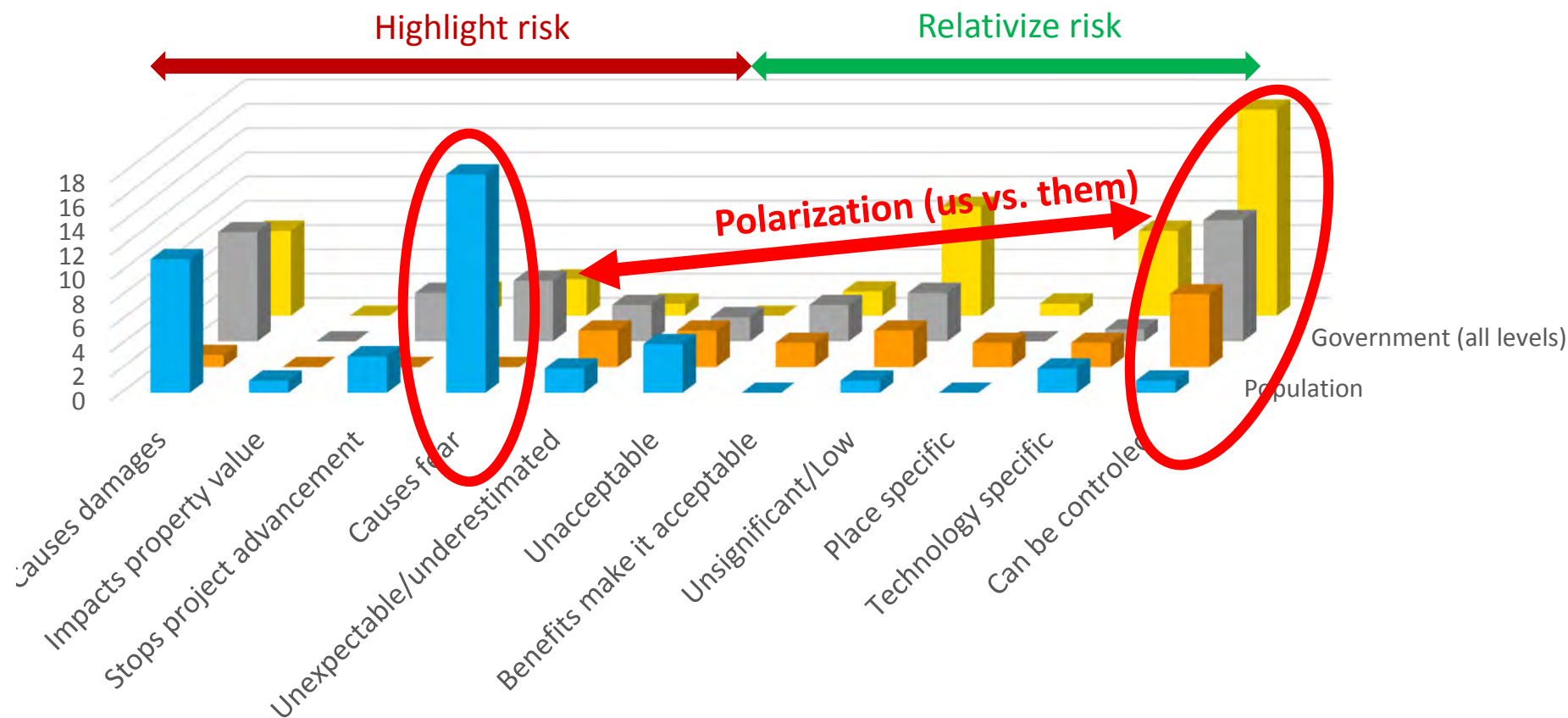
autonomous
induced seismicity
risk governance

sale energy (\$/kWh)

PUBLIC
(need energy
& safety)

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?

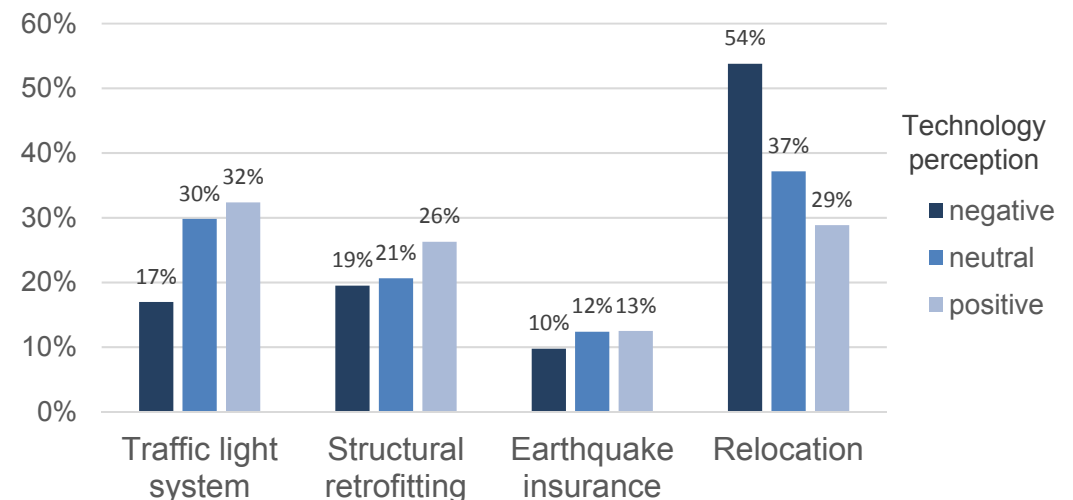
Risk mitigation perception	DGE <i>N</i> = 209	SG <i>N</i> = 200	CPG <i>N</i> = 198	CCS <i>N</i> = 200	
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>F</i> (3, 803)
Traffic light system	4.62 (1.27)	3.99 (1.30)	4.54 (1.30)	4.10 (1.37)	12.029***
Structural retrofitting	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

Risk mitigation preference across technology perception (N = 807)

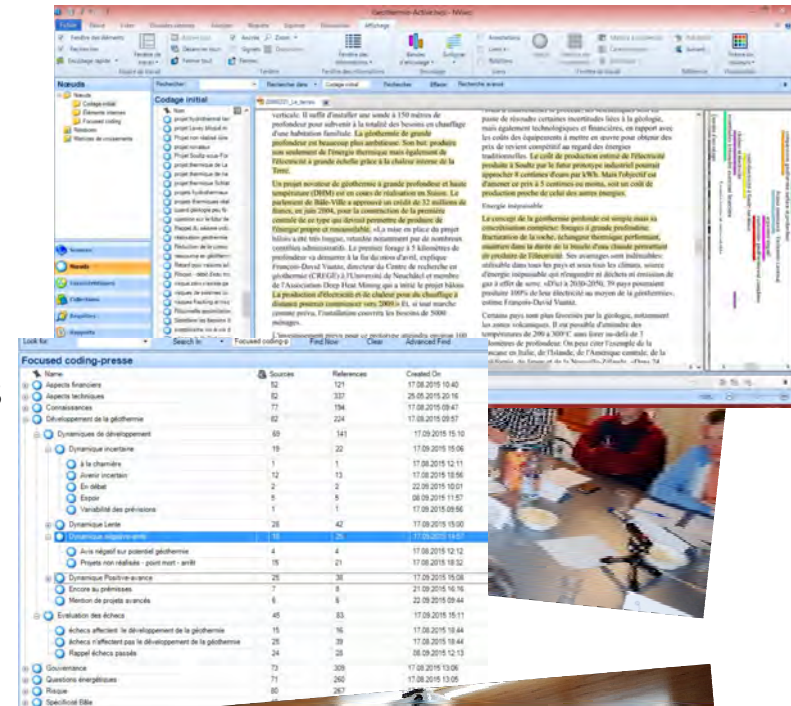


From media discourse to public engagement

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



Source: GEothermie 2020



Codeage initial

Le projet de construire une centrale à 170 mètres de profondeur pour produire de l'électricité à partir d'une habitation familiale. La géothermie de grande profondeur est beaucoup plus ambitieuse. Son but : produire une énergie de l'énergie thermique mais également de l'énergie à grande échelle grâce à la chaleur interne de la Terre.

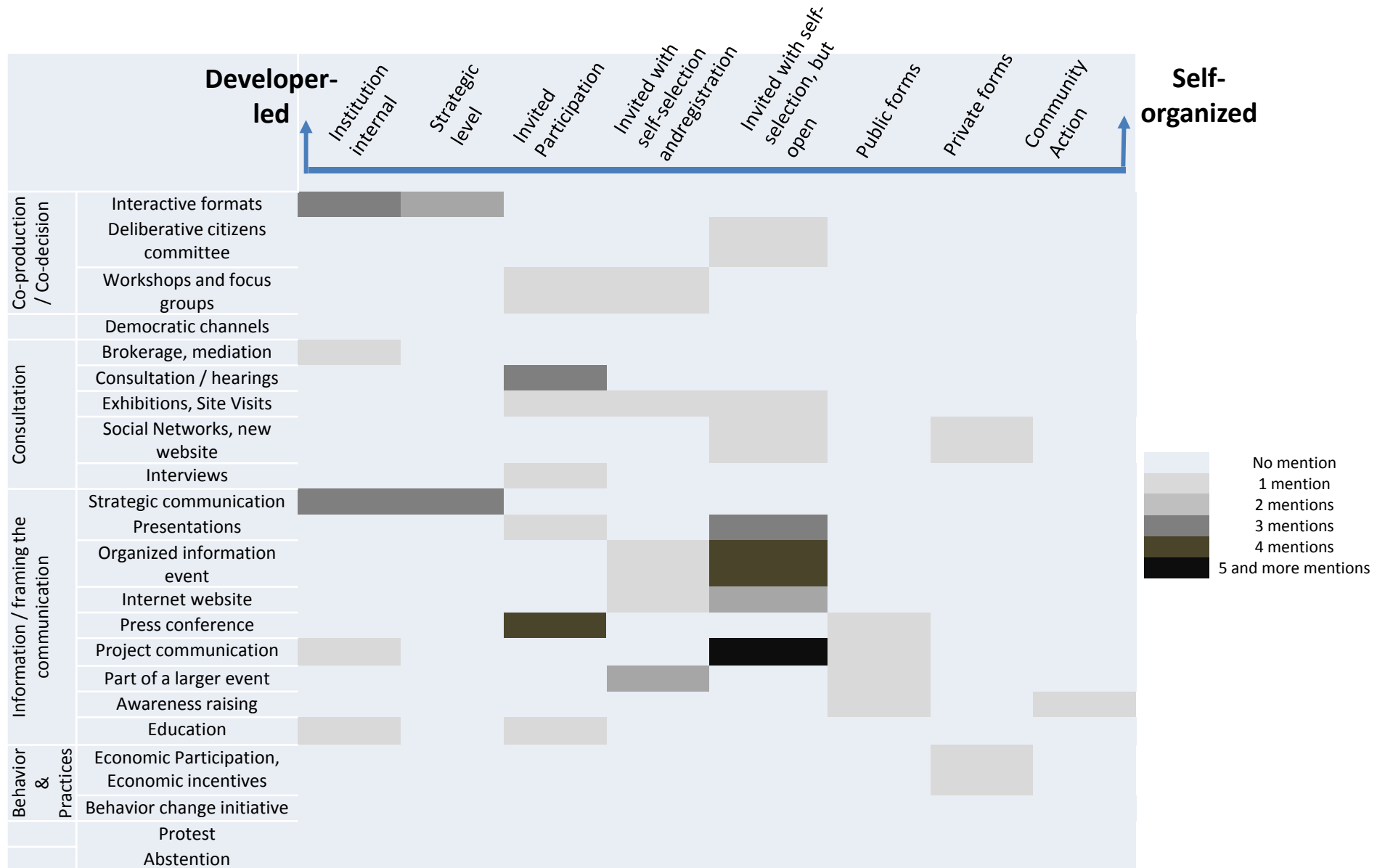
Un projet novateur de géothermie à grande profondeur et haute température (GHT) est en cours de réalisation en Suisse. Le projet de la ville de Yverdon est un projet de 12 millions de francs, en juin 2014, pour la construction de la première centrale de ce type qui devrait permettre de produire de l'énergie propre et renouvelable. «Le projet est en phase de projet à 100% très long, beaucoup plus long que les autres, beaucoup plus long. Le premier étage à 5 kilomètres de profondeur va durer à la fin du mois d'août, explique François David Vautin, directeur du Centre de recherche en géothermie (CREG) à l'Université de Neuchâtel et membre de l'Association Deep Heat Mining qui a lancé le projet. La production effective de la centrale sera de 100 MW et devrait commencer vers 2020-21, ce qui permettra de produire, à l'exception des coûts de construction, les besoins de 20000 logements.

Focused coding-presse

Thème	Sources	Relevances	Created On
Aspects financiers	52	121	17.08.2015 10:40
Aspects techniques	62	337	26.09.2015 20:16
Connaissances	77	194	17.08.2015 09:47
Développement de la géothermie	62	224	17.08.2015 09:57
Dynamiques de développement	69	141	17.09.2015 15:10
Dynamique incertaine	19	22	17.09.2015 15:06
à la chambre	1	1	17.08.2015 12:11
à l'essai	12	13	17.08.2015 15:56
Essai	2	2	22.09.2015 10:01
Essai	5	5	08.09.2015 11:57
Validité des prévisions	1	1	17.09.2015 09:56
Dynamique Lente	28	42	17.08.2015 15:06
Dynamique lente	1	1	17.08.2015 15:10
à la géothermie	4	4	17.08.2015 12:12
Projet non réalisé - point mort - arrêt	18	21	17.08.2015 18:32
Dynamique Positive-avance	26	38	17.09.2015 15:08
Erreur au prévisions	7	8	21.09.2015 14:16
Motivations de projets avortés	6	8	22.09.2015 09:44
Évaluation des échecs	45	83	17.09.2015 15:11
échec affectant le développement de la géothermie	15	16	17.08.2015 10:44
échec n'affectant pas le développement de la géothermie	26	39	17.08.2015 18:44
Rappel échec passé	24	28	08.09.2015 12:13
Gouvernance	73	309	17.08.2015 13:06
Questions énergétiques	71	262	17.09.2015 13:05
Risque	80	257	
Spécificité Éthique			

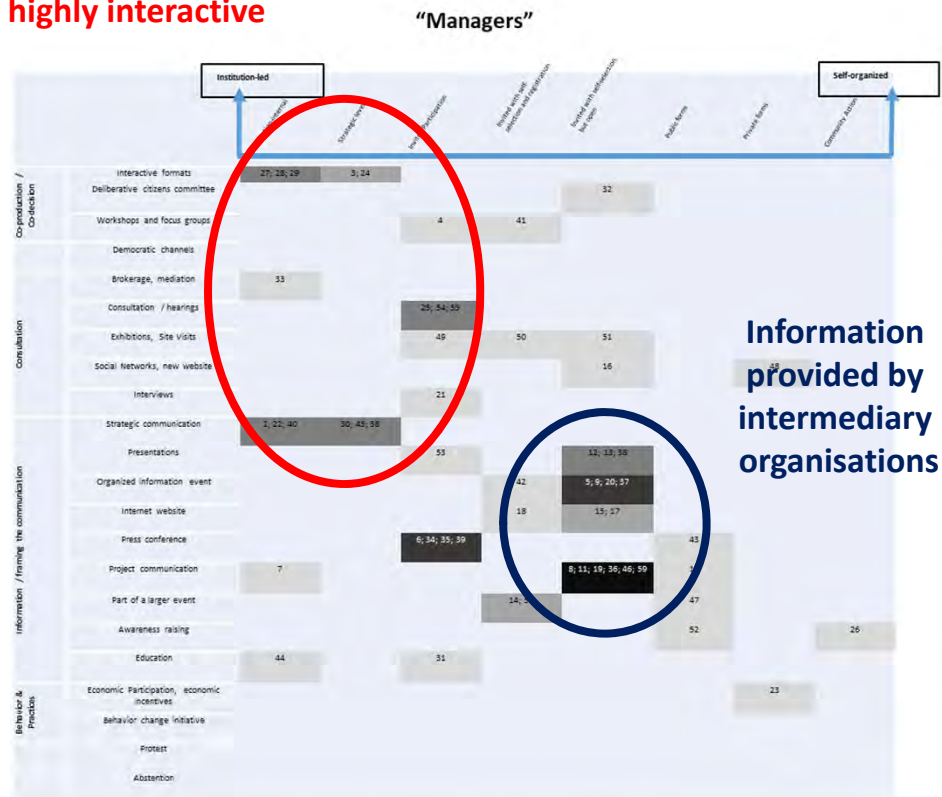


Forms of public engagement preferred by project managers



Forms of public engagement preferred by project managers

State led, invited
highly interactive



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



"Communities"



References made in focus groups – update with new attributions 20.11.18

Embedded in
everyday
activities

- 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.