ASSESMENT OF HIGH ENTHALPY OF GEOTHERMAL RESOURCES AND PROMISING AREAS OF CHILE

D. Aravena, M. Munoz, D. Morata, A. Lahsen, M. Angel Parada, P. Dubosn, 2015

Presented by Quentin Mesot and Albane Gibon Guilhem

Intro: Computing geothermal power potential in identified high enthalpy areas in the Chilean Andes

GOAL: Improve and gather geothermal knowledge and promoting its use in the Andeans countries.

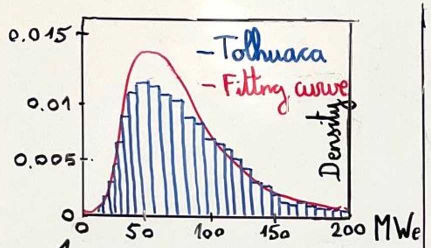
Methods:

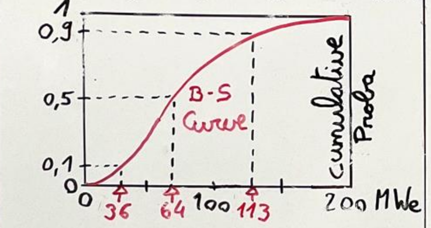
Inferred	Indicated	Measured
reservoir features constraind but not reached	reservoir confirmed by exploratory wells	wells with proven deliverability

Ranking of geological confidence

Main formulas:

1. Volumetric heat content: $q_R = \rho \bar{C} . V . (T_R - T_r)$
2. Recovery factor: $q_W = R_g . q_R$
3. Steam fraction for single flash system: $m_{stm} = \frac{q_W}{h_{gl}(T_{sep})}$
4. Power Output: $W_{Aflash} = m_{stm} [h_{stm}(T_{sep}) - h_W(T_C) - T_C . k (s_{stm}(T_{sep}) - s_W(T_C))]$





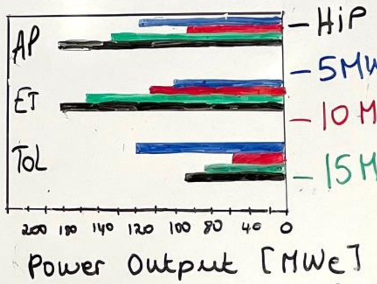
Heat in P. Param	min	m.l.	max
$\bar{C}$ [kJ/m³.K]	–	2700	–
T_r [°C]	–	151	–
R_g [%]	0	–	20
T_c [°C]	–	40	–

Variability of BC → Monte Carlo (100'000 iterations)

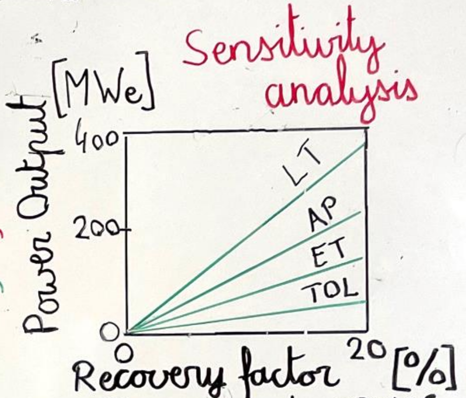
Results:

System	Area [m²]	Thickness [m]	T° [°C]	Results Mean	Results Std	Fit to Distrib P10	P50	P90
Apacheta	4 - 25	880-1120	212-250 -256	99 [MWe]	58 [MWe]	185 [MWe]	81 [MWe]	72 [MWe]

Discussion:



Sensitivity analysis



- Comparison of Heat in Place and power density method for power potential calculat.
  → HiP overestimates power output for high power density sites due to recovery factor not taking permeabity into account.
- Large systems → higher variability in V or T → higher std
  ↗ Higher power potentiae: 97-128 MWe
- ↘ Medium power potential: 32-70 MWe

Conclusion

→ Ranking
→ 9 high enthalpy reservoirs
→ 8 highly favorable res.
→ 57 high enthalpy potential geotherm. res.

{ Indicated 228 MWe Std 119 MWe
Inferred 431 MWe Std 321 MWe } ⇒ ~ 4,4% of total installed electric capacity

The thermal structure and temporal evolution of high-enthalpy geothermal systems.

Samuel Scotta, Jhomas Driesnera and Philipp Weis (ETHZ & GFZ 2016)

Intuoduction:

The aim of this study is to model the long term evolution of undisrurbed geothermal systems with a variation of several param-eters.

Field measurements of pressure, temperature, flow rates and enthalpies were used to calibrate the model

Methodology:

Variation of parameters:

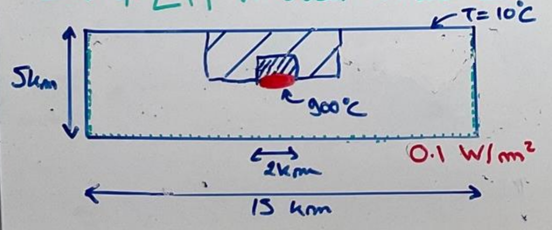
k : $10^{-14} - 10^{-16}$ m^2

Intusion depth : 2-3 km

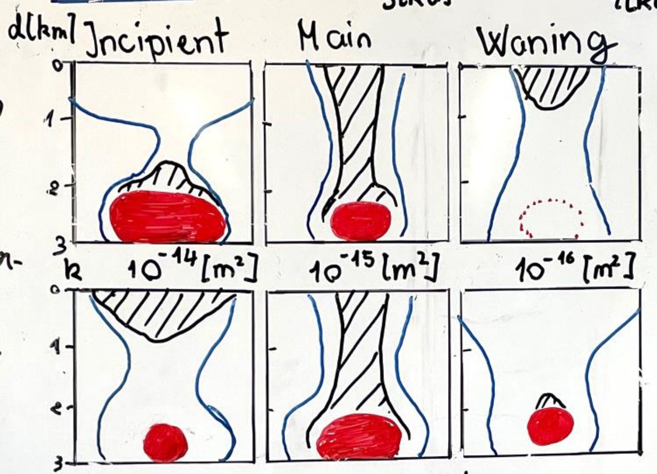
T_{BDT} : 360; 450; 550°C

Geometry : Large / prolate

→ FEM model 14 000 e



Results



effects of k

low k no plume developpement. Moreover k influences the width of the plumes and the formation of the boiling zone.

effects of other parameters

- depth of the intrusion influences the paths of upflow plumes and boiling zone
- geometry of the intrusion widths and number of plumes
- T_{BDT} supercritical & boiling zone

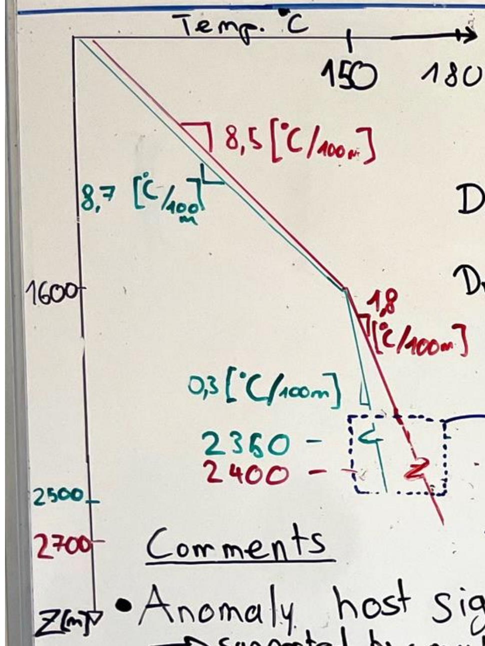
Discussion

- Enables geothermal exploration based on field measurements: plumes, boiling zone, T gradient.
- Highlights the life cycle.
- Showed the presence of supercritical geothermal resources.
- Highlights that convection decreases life span.

Conclusion

- k = 10^{-14} [m²] "shallow" boiling zones
  k = 10^{-15} [m²] extensive vertical ones
- Intrusion depth controls extent of boiling zones
- higher T_{BDT} in k = 10^{-14} [m²] creates deeper boiling zones. For 10^{-15} [m²] creates supercritical water near the intrusion.
- There are characteristic ∇p, ∇T and entalpy → position of heat source

HYDROTHERMAL CHARACTERIZATION IN RITTERSHOFFEN

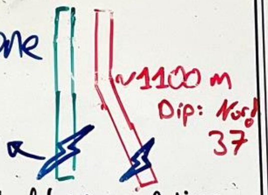


Wellbore description

Loca.: Alsace (FR)

	GRT-1	GRT-2
Depth/length	2580/2580	2708/3196
Drill date	[Sept. 2012 - Dec 2012]	[Mars 2014 - July 2014]

:Faultzone
N°355
a = 45°

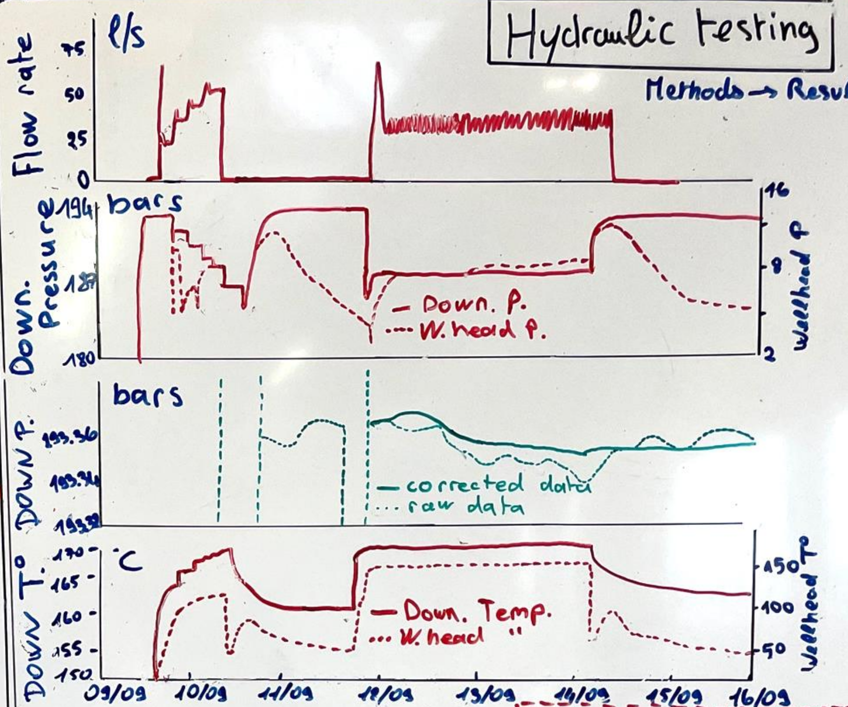


Comments

- Anomaly host significant natural fluid circulation
  - —▷ supported by mud loses during drilling
  - —▷ permeability/heterogeneity
- Clear conductive/convective transition
  - →▷ existance of caproch

Hydraulic testing

Methods → Results



GRT-2 production test

① Short production test
- → P_0 = 191.8 bars P_1 = 190 bars
- → Flow ↗ ⇒ P ↘ ⇒ T ↗
- → Difference can be explained by a change of density of the water column

② Long production test
- → 28 [l/s], pressure stabilizes quickly: 186.1 ⇒ 190.1 [bars]
- → Maximum recorded T°: 169 °C
- → We see a correlation with GRT-1: Pressure ↘ when we pump at GRT-2

GRT-1 Test EGS

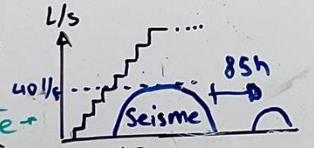
① Clean-up/Prelminary testing
- → ⚠ censor problem but 0,45 [L/s/bar]

2.1 Thermal simulation
- 6 dif flow rate [5-25 l/s]
- Temp: 12°C
- → 113 microseism impact: 1,3

Final result: → 2,3-2,5 [l/s/bar]

2.2 Chemical stimulation
- to disolve calcite
- Flowrate 5 l/s
- → No seism impact: 2

2.3 Hydraulic stim
- 8 stage flow rate ↗
- → Seism if F > 40 l/s Impact: 1,5



Circulation test
- 3 weeks
- 28 l/s
- Two tracer
- → 14 days recovery
- → No seismicity

Conclusion

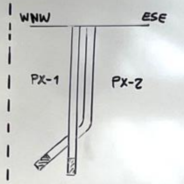
- GRT-1 and GRT-2 are connected
- EGS is a success: 5x better productivity
- High injectivity and productivity → economic threshold for exploitation ✓
- Permeable structure and natural fluid
- No hydraulic fracturing observed
- No seismicity above 1.7 magnitude

Baujard / Genter / Dalmais / Maurer / Hehn / Rosilette / Vidal / Schmittbuhl in 2017.

Observations and analyses of the first two hydraulic stimulations in the Pohang geothermal development site

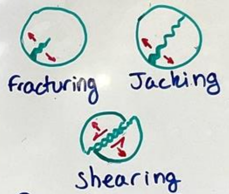
INTRODUCTION:

- Localisation: Pohang, South Korea
- Context: EGS is a technology that enhance and/or create geothermal re-sources in hot dry rock by producing or reopening fractures. This paper pre-sents the observations and analyses for PX1 and PX2 stimulations.
- Goal: Improve understanding of hydro-mechanical and induced seismic charac-teristic



THEORY:

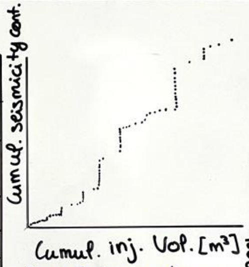
- 3 conceptual models:



- Reservoir performance evaluted with:
  - Injectivity [L/sMPa]
  - Transmissivity [m³/s]

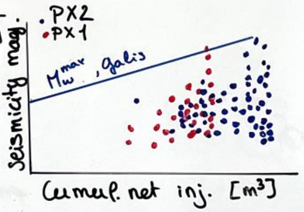
RESULTS/ANALYSES

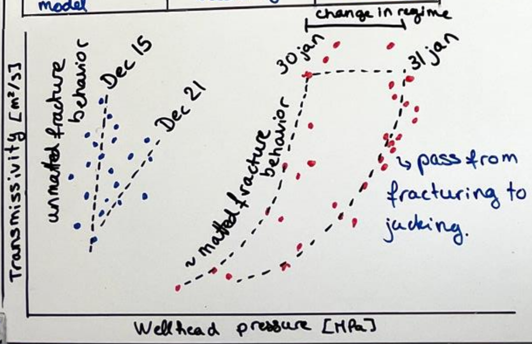
Parameter	PX2	PX1
Injected Volume	1970 m³ mud loss	3907 m³
Max wellhead pressure	89.2 MPa	27.7 MPa
Max inj. rate	46.8 L/s	18 L/s
Pressure peaks	64-67 MPa	15-17 MPa
Injectivity evol.	-12%	+10%
Transmissivity evolution	Reversible, non-lin pressure dependant	Less pressure dep more gradual
Conceptual model	Fracturing Jacking	Shearing Jacking



- Correlation observed between injected volume and seismic magnitude.

- During the shut-in phases the number of seismic events is greater than during the injection phase.





CONCLUSION:

- Different hydraulic response between PX1 and PX2.
- Possibly caused by mud loss in PX2...

2016, Park, Kim, Xie, Yoo, Min, Kim, Yoon, Kim, Zimmermam, Guinot, Meier. Fation Krasniqi, Odile Montarnal

MINERAL SCALING IN 2-PHASE GEOTHERMAL PIPELINES

C. BLANCO
J. ENGLER

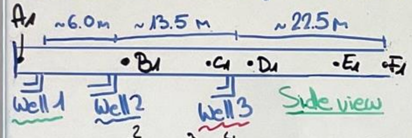
Jansell Jamero, Sadiq Zarrouk, Ed Mroczek, 2017

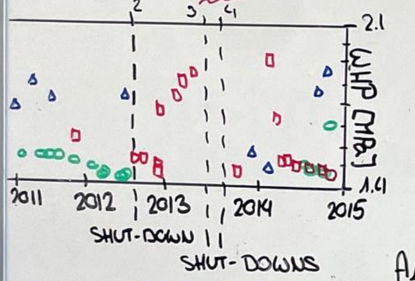
Scaling: Mineral deposition due to oversaturation of the fluid. Limits flow in equipment → ↓ efficiency

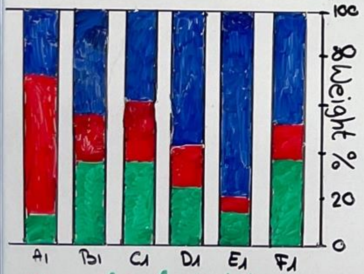
This work focuses on 2phases geothermal pipelines, when fluids w. high enthalpy and under-saturated w. respect to amorphous silica mix in common pipes/headers.

METHOD: Fluid chemistry analysis + in-situ observations

CASE 1: Mix of steam-dominated + 2-phase fluids







Mineral scale distribution

■ OTHERS ■ MAGNETITE ■ AM. SILICA

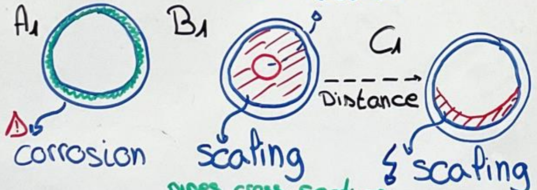
Well	H kJ/kg	Water flow	Steam flow	Well SSI	Mix SSI	SiO_2 mg/kg
1	2790	0	18.5	-	-	-
2	1649	9.5	7.1	0.95	0.95	868
3	1667	14.6	11.3	0.6	0.74	555

Fluid properties

→ Well Head Pressure:

Shut down → SCALING → ↗ WHP

25% available

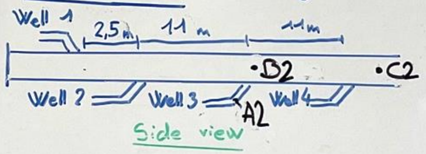


pipes cross-sections

→ Fast scaling at 1st mixing point (B1)

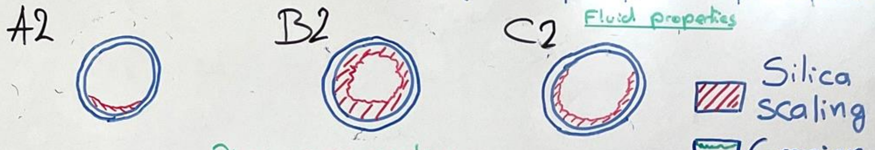
→ Slow scaling at 2nd mixing point (D1)

CASE 2: Mix of low pH high silica + neutral fluids



Well	H kJ/kg	Water flow	Steam flow	SSI well	pH	SiO_2 mg/kg
1	2359	8.5	31.2	0.96	5.49	782
2	1894	3.4	4.2	0.73	3.46	617
3	1538	46,6	27,7	1.3	3,54	1087
4	1989	5.0	7.5	063	5.59	530

Fluid properties

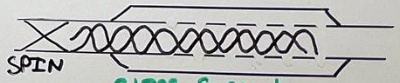


Pipes cross-sections

Well 3 is super-saturated (SSI=1.3) but small scaling due to low pH (A). Mixing w. higher pH fluids allows scaling (B). Adding unsaturated fluid at well 4 reduces scaling (C).

Proposed solutions

- Oversized drained pots (gravity separation)
- Separators (Vortex, BLISS)
- Wet scrubber
- Flux throttling
- pH modifications



BLISS Separator

Conclusion: Mixing of incompatible fluids → Scaling. Uncommon since fluids from same pad usually similar.

Case 1: Higly supersaturated brine saturate the mix. Case 2: Mix increase pH, allowing excess silica to scale.

Lithium-rich geothermal brines in Europe:

An up-date about geochemical characteristics and implications for potential Li resources

Authors: B. Sanjuan, B. Gourcerol, R. Millot, D. Rettenmaier, E. Jeandel, A. Rombaut – 2022

Introduction:

- Assessment of potential unconventional Lithium resources in Europe (i.e. deep geothermal brines)
- Identification of main lithium source in these reservoirs.

Main geothermal sites:

1+2: Cesano and Campi $T \geq 300°C$
3: North German basin
4: Molasse basin Local high [Li]
5: South crofty mine low salinity, $T \approx 52°C$
6: Upper Rhine Graben $T = 120 - 200°C$

Main chemical fluid characteristics:

- High Na-Cl concentration
- Reservoir temperature $T_r > 120°C$

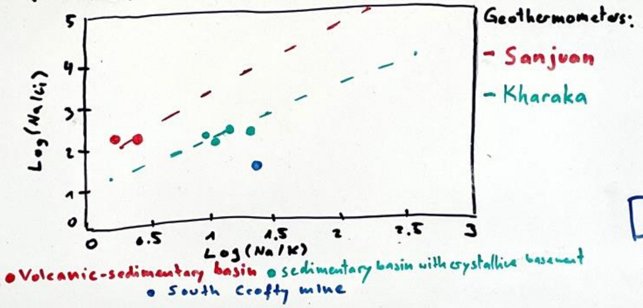
=> not sufficient to explain Li presence eg. UK, USA ...

3 considerations for Lithium presence:

1. Thermodynamic:

method: Geothermometer

results:



-> Li-mica dissolution is the main source of lithium.

2. Minerological:

method: literature review

results:

-> Confirms process of dissolution of white mica and biotite as main source

-> partial incorporation of lithium into illite structures.

3. Isotope:

method: Li-isotope data in the URG

-> $\delta^7Li_{,liq.} \in [-0{,}4 ‰ ; 1{,}7 ‰]$

-> $\delta^7Li_{,liq} - \delta^7Li_{,sol} = \frac{7847}{T(K)} - 8{,}093$

results:

$\delta^7Li_{,sol} \in [-8{,}1 ‰ ; -5{,}2 ‰]$

-> characteristic values for sedimentary rock.

-> Buntsandstein as the main Li source

Discussion:

URG = promising zone for Li mining

+ Li concentration = 155 mg/L
+ host already geothermal projects
- old data (~ 30 years)
- data needed at site scale

-> estimation of 300'000 to 2'200'000 tons of lithium that could be extracted

-> 4000 - 6000 tons/years with the planned geothermal projects

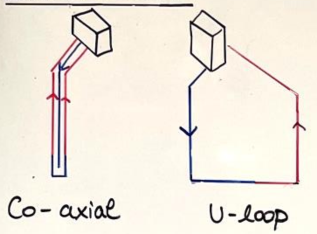
Conclusion:

-> The URG is the most promising of the considered areas

-> The main source of lithium in deep reservoirs are micas.

TECHNO-ECONOMIC PERFORMANCE OF CLOSED-LOOP GEOTHERMAL SYSTEMS

INTRODUCTION:



Benefits:

* no need of permeability
* no reservoir stimulation
→ reduction of induced seismicity
* Usage of pre-existing wells

Challenges:

* Limitated heat transfer area
→ no circulation
* Low rate of heat extraction
* Low temperature for electricity production

METHODS:

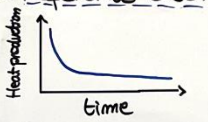
SBT (Slender Body Theory) → complexity → COMSOL (Finite element) / GEOPHIRES (costs)

$$LCOE = \frac{\sum[(I_t + M_t + F_t)/(1+r)^t]}{\sum(E_t/(1+r)^t)}$$

RESULTS AND DISCUSSIONS:

=> Multiple change in parameters tested (40 cases)

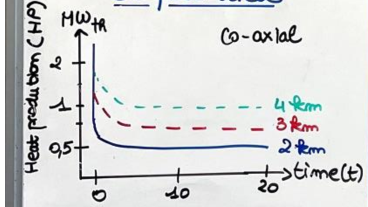
- Reference case:



▸ Same curve behaviour independent of change in parameters
▸ Drop caused by slow replenishement because of low diffusivity / connectivity

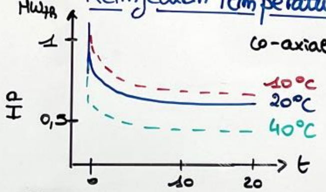
- Presentation of key parameters: Fluid type: ↗ water = better fluid for heat generation; ↘ SCO_2 = 40% lower enthalpy gain

Surface area



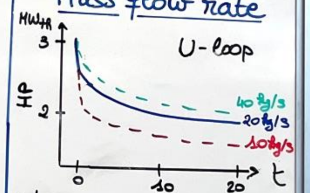
Explains why U-loop has higher production

Reinjection temperature



▸ Idem for U-loop with factor 3
▸ Low injection T° is advantageous for heat production

Mass flow rate



▸ Low rate ↗ production T° but ↘ heat production
▸ Not applicable for co-axial

- Comparison and economics

	AGS	Traditional
Heat production (MWth)	0,6 - 2,1	10 - 50

	AGS	Traditional	Competitiveness
LCOH	37 - 52	15 - 105	✓
LCOE	825 - 1315	60 - 80	✗

$/MWh

CONCLUSION:

- Optimal direct-use not for elect. productio.
- Maximazing surface area
- Low inject T° ⊕ large mass flow rate
- Locations where traditional can't be used

K. Beckers, N. Rangel-Jurado, H. Chandrasekar, A. J. Hawkins, P. M. Fulton, J. W. Tester 2022

Social shaping of deep geothermal projects in Alsace (2018)

(By Chavot, Heimlich, Masseran, Serrano, Zoungrana, Bodin)

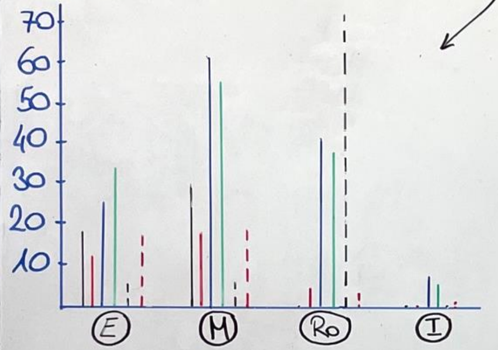
Intro: due to electricity tariff review, geothermal projects becomes viable in Alsace. However, some opposition to the projects occurs.

Goal: examine the social, cultural and political factors that favour or disrupt deep geothermal energy projects in Alsace

Methods: two considered areas,

- Area of public expression → literature review of public inquires
- Area of information → case studies, and social media coverage

Results:



Expressed concerns and cited risks
- urban planning
- local politics
- induced seismicity
- groundwater pollution
-- risk of explosion
-- cumul. eff. close drilling

Contested
- Public informed/consulted only after the main project characteristics had been settled.
- No upstream dialog with locals.
- Opposition of the elected officials to reaffirm the sovereignty of their communities.

Approved
- Residents regularly informed.
- Useful for the future.
- Local authorities takes part in the project.
- In phase with local politics.
- History of the region.

Unbound project
- Definition: developed thanks to a favorable economics and national politics context.
- Imposition of Geothermal Project without prior debate.

Locally anchored project
- Definition: outcome of a long, concerned dialog between operators and local actors.
- Upstream discussion and partnerships between operator and municipal government.

Discussion and conclusion:

In general:
- Disseminating information upstream and encouraging public input is necessary to facilitate the social acceptance of a project.
- Concretization of a GP cannot disregard the social and cultural dimension of the territory.
- Taking into account the social identity of a community sheds light on the meaning that politicians, local associations and residents give to geothermal projects.

Sebastiano & Loïc

Tailor-made risk governance for induced seismicity of geothermal energy projects : An application to Switzerland. E. Trutnevyte, S. Wiemer - 2016

objective: Screening tool: Geothermal Risk of Induced Seismicity (I.S.) Diagnosis

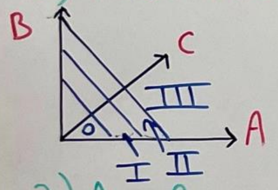
Motivations:
- Worldwide preoccupations
- Lack of guidance
- No federal laws
- No social considerations (S.C.)

GRID Concept

To what extent is I.S. a concern?

1) Assign a value 0→2 to each indicator
   - 3 types:
     - A. Seismic hazard (7 ind.)
     - B. Exposure / vulnerability (7 ind.)
     - C. Social concerns (5 ind.)

2) Plot results : define project category



X-axis: Σ ind. A

y-axis: Σ ind. B

Σ ind. C : +0,5 on x, y per point

3) Apply measures for the project category

Recommended Procedure

- Individual GRID / partie
- Discussion / partie
- Individual GRID review
- Autority decides Final Category (0→3)

→ Project Operator, Autorities, Experts

GRID Method

When : Early stage —evolves→ End of project

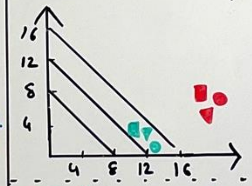
Why : Early assessment with S.C.

→ amplify or reduce risks

⚠ S.C. ≠ "Factual" hazard/risk

Basel-type plant Example:

Low risk & high S.C.



GRID ↗ With S.C. ↘ Without S.C.

Tailor-made risk gov. : includes social groups

8 measures (incl. 3 social)

↳ 4 Levels of app. depending on project category

Conclusion

- Subjective method
- Quick, transferable, transparent & reproductible
- Indicators designed for (pre-) Alpine areas