ENERGY Geo Hackathon
Society of Petroleum Engineers

SPE International
SPE Europe Region

2022 SPE EUROPE ENERGY GEOHACKATHON

Geothermal in energy transition: Cross-fertilisation between geothermal and hydrocarbon industries

Mariane Peter-Borie – CGG's Geothermal team leader

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Today’s speaker

Mariane Peter-Borie

2022-: CGG UK – North Wales
Geothermal team leader

2020: ISOR – Icelandic geosurvey
Hosted researcher
Geothermal system conceptual modelling

2009-2022: BRGM – French geological survey
Geothermal project manager / Researcher / Expert
Geology and geomechanics in geothermal

2008: PhD in geosciences
Univ. Bordeaux (France)

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Headline

Geothermal has good “green” credentials, but we don’t hear much about it from the environmental energy lobby

- Because geothermal had been the forgotten industry in the green energy mix, there is a vast untapped potential!

- But the Geothermal decade is now ongoing!

*“Geothermal technologies have been around since the beginning of 1900s, but the last six years have witnessed an extraordinary growth. By 2030 the sector will be 13 times bigger” (*EGEC, 2022)

Photo credit: Mariane Peter-Borie

Reykjanes Geothermal field (Iceland) where the world’s hottest geothermal well (IDDP2) is sited
An example of a fruitful cross-fertilisation between hydrocarbon and geothermal industries

It’s time sub-surface O&G and green energy entities become aligned!

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Agenda

- Overview of Geothermal
  - –History and uses
  - –Geothermal plays
  - –Exploration and exploitation
- Focus on Europe’s deep* geothermal assets
- Challenges and risks
- Conclusion: The high potential of the cross-fertilization with O&G industry

*Deep geothermal (>200m) as opposed to shallow / ground source heat pump geothermal

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OVERVIEW OF GEOTHERMAL

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Quiz

- When did the first geothermal energy uses start?
  A. 20,000 years ago
  B. 2,000 years ago
  C. 200 years ago

- What are the end uses of geothermal energy?
  A. Bathing
  B. Electricity
  C. Heating
  D. Egg boiling
  E. Too long to be listed here

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Geothermal: a long story

Earth heat has been used by humans for more than 20,000 years!

-Natural hot pools for bathing, cooking, warmth, thermae (Roman, Etruscan)

-Middle ages: few organized uses

-Ex. 1332: “District heating” in Chaudes-aigues (France) – around 40 houses

-19th century – early 20th century:

-first industrial use in Larderello (Italy) to extract the boric acid

-large district heating (Idaho, Iceland, Japan, USA …), greenhouse heating

-1904: first power plant in Italy

-1970s energy crisis: Geothermal takes off

-Development of heat harvesting out of obvious volcanic areas:

-District heating in sedimentary basins (e.g.: Paris)

-1980s: HDR then EGS concepts (Fenton Hill, Soultz, ….)

-Formation of associations to manage and encourage the development of geothermal resources all over the world.

-2010s and later: Rise of geothermal

-High rate of technology improvement and innovations

-Diversification of uses

Hveragerði geothermal exploitation
Water from hot springs has been used for heating in this area since 1929.

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Heat uses

- Tourism and Recreation
  - Bathing, Swimming pools, Thermae
- Agricultural:
  - Greenhouse heating
  - Fish/animal farm heating
- In the house:
  - Heating, Cooling
  - Cooking
- Industrial uses:
  - Drying / dehydration (fruits and vegetables, metal extraction, …)
  - Heating and Cooling for industrial processes
  - Sea water desalinization
- In the city:
  - Building heating and cooling (air-conditioning)
  - District heating
  - De-icing and De-snowing systems under roads, pavements, …
- Power generation
  - Processes: ORC, binary, flash…
- Cascade use
  - e.g.: power → desalinisation → fruits drying → fish farm heating…

District heating (SEMACH, Villejuif, France)

Enjoying a hot pot in the Icelandic cold winter

De-icing system under a road (Reykjavik, Iceland)

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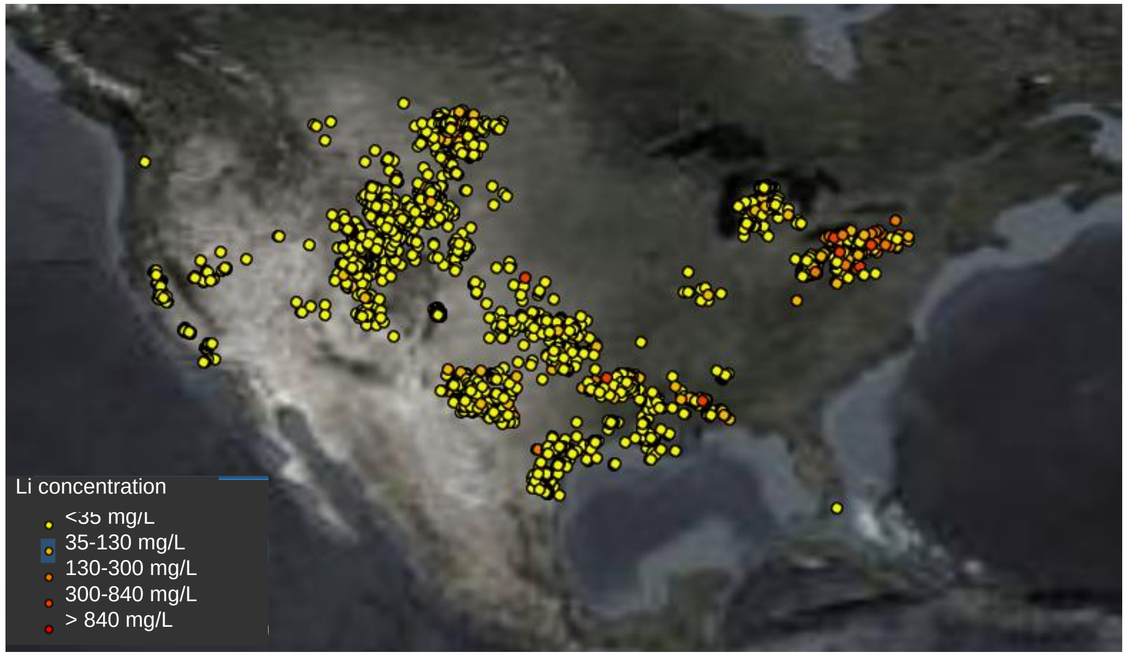
Co-products

The mineralogical composition of geothermal brines can add-value to the operations

- In-demand minerals critical for the energy transition: lithium & cobalt
- Other economic minerals: boron, rubidium, caesium, potassium…
- White (Natural) and green Hydrogen
- CO_2 for greenhouses to facilitate the photosynthesis process
- …



Lithium concentration in underground waters of USA (modified from Blondes et al., 2019)

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Quiz

- In which geological contexts can earth energy be extracted?
  A. Volcanic areas
  B. Sedimentary basins
  C. Old plutonic cratons
  D. Rift zones
  E. Foreland basins

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Geothermal play types

Geothermal play types definition based on geology and the heat transfer process *(from Moeck, 2014, modified)*

Intracratonic sedimentary basins
Example:
Paris basin, France

Orogenic belts and other tectonically deformed basins
Example:
Molasse basin, Germany

Plutonic cratons
Example:
Cooper basin, Australia

Active volcanic area
Example:
Hellisheidi, Iceland

Recent plutonic intrusion
Example:
Larderello, Italy

Extensional domains
Example:
Landau, Germany

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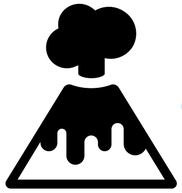
Geothermal play types vs Hydrocarbon play types



Geothermal

- Heat is considered a renewable resource
- Geological context: all
- Permeability control: matrix porosity, and/or fault and fractures (potentially in almost impermeable rock mass)
- Resource storage: in the rock skeleton (minerals) and/or in the fluid. Cap or Seal importance
- Resource transport: convection, conduction, *advection, radiation*

Hydrocarbon

- Not a renewable resource
- Geological context: mainly sedimentary
- Permeability control: mainly matrix porosity, but fractures in certain cases
- Resource storage: porosity. Cap or Seal importance
- Resource transport: migration if any

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EXPLORATION AND EXPLOITATION

Quick overview

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Quiz

- Which geophysical method is the most appropriate for geothermal exploration?
  A. Active Seismic Surveys
  B. Magneto-telluric surveys
  C. It depends on the play type

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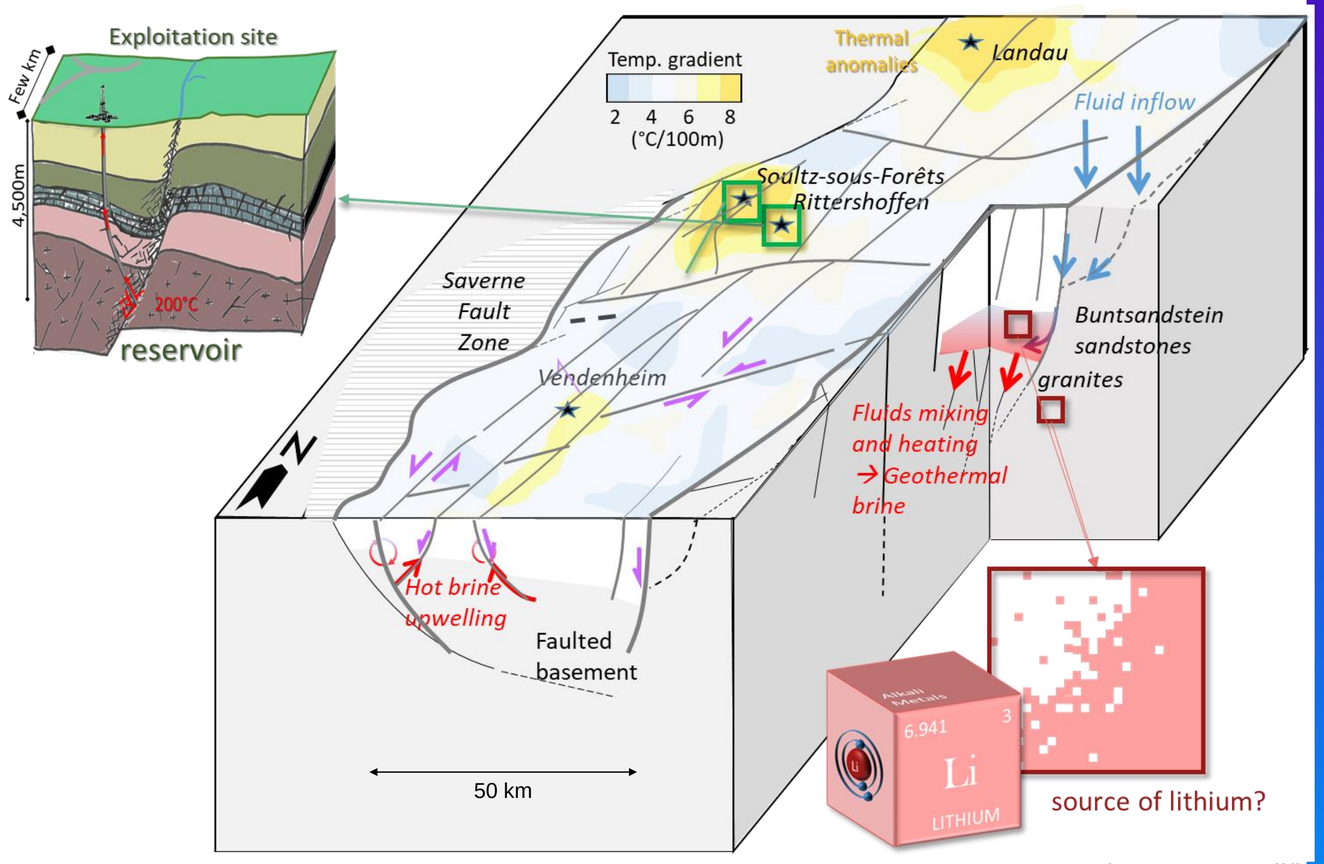
Disciplines involved in geothermal exploration

- Geology
- Petrophysics
- Geochemistry
- Geophysics
- Geomechanics
- Hydrogeology
- Reservoir engineering
- …



From Peter-Borie, 2020, modified

Non-geothermal wells (research, oil & gas industry) can provide useful information!

Conceptual modelling of the Upper Rhine Graben geothermal system (aborted rift system)

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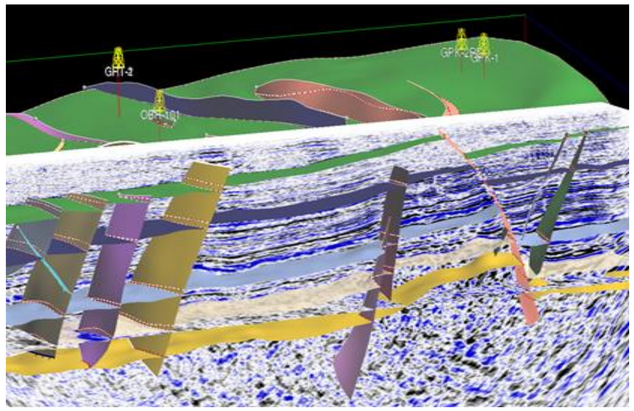
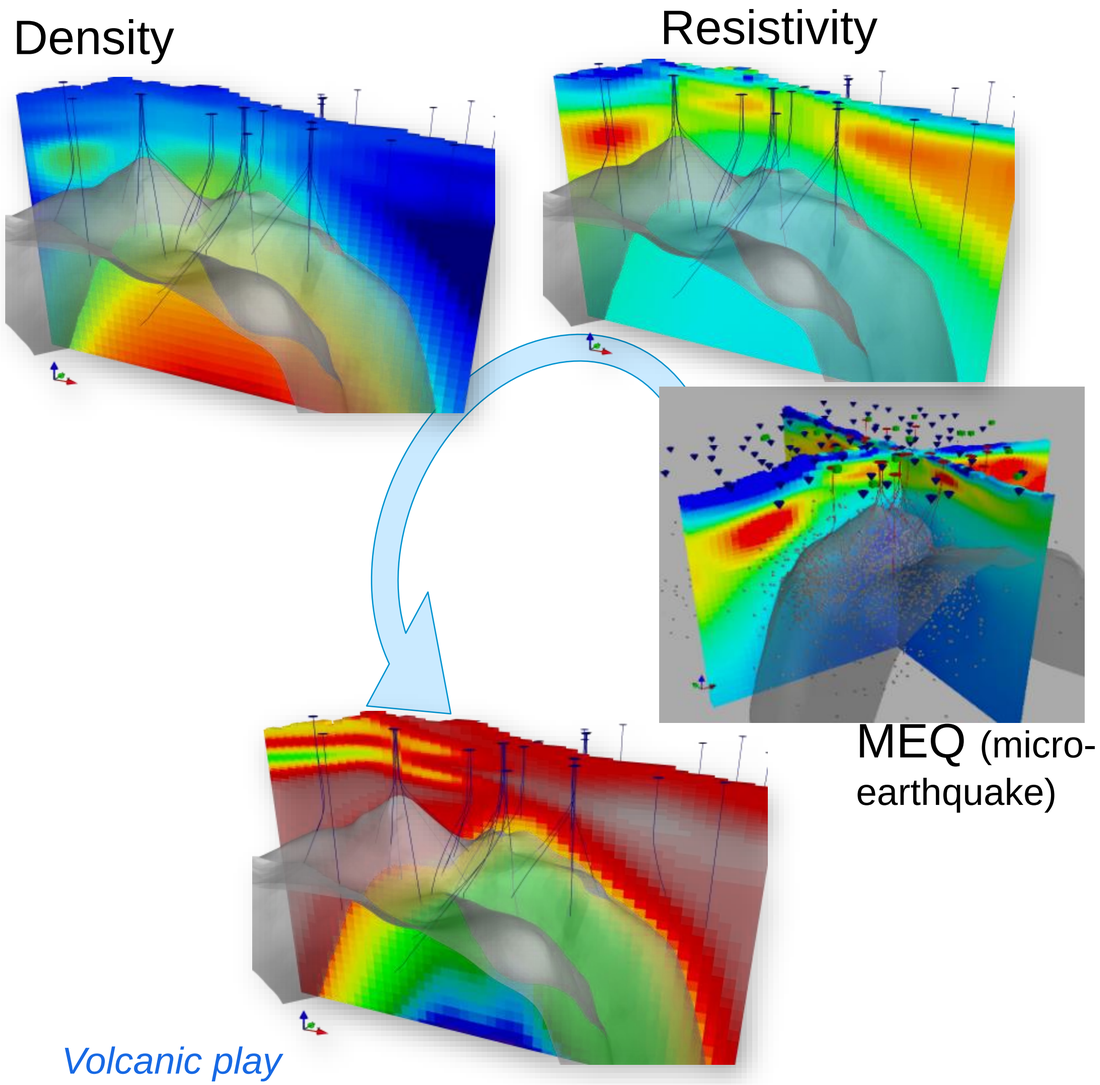
Example of geophysical method applications



CGG Upper Rhine Graben study



Extensional domain

Seismic surveys (but not only)

interpretation and mapping of layers and faults
seismic inversion to characterize geothermal reservoirs and estimate porosity and permeability.

→ High cross-fertilisation potential!

Multi-physics plays a key role in geothermal exploration: gravity, magnetics, density, resistivity

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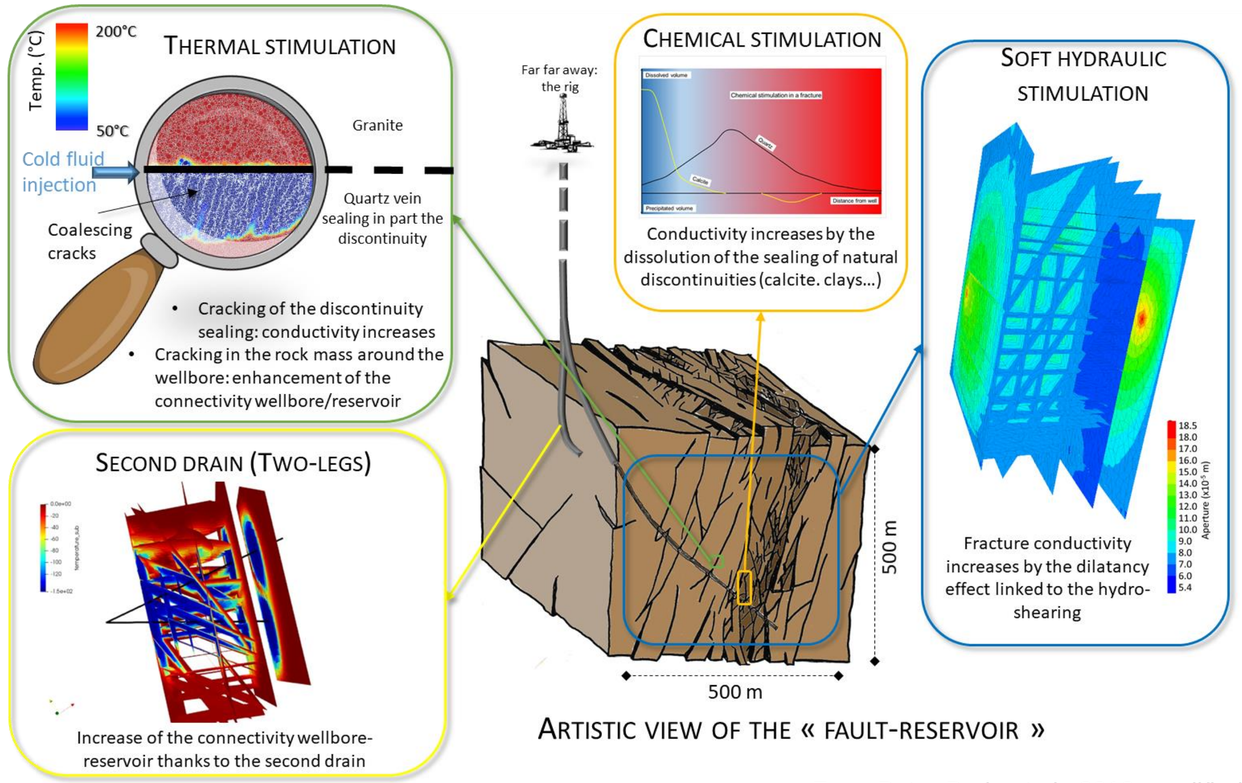
Exploitation technologies: innovations still ongoing!

- Open loop: Heat extraction through warm to hot natural geothermal fluid extraction
  - –Vertical or deviated wells
  - –1 hole or multilaterals (same diameter or not)
  - –Stimulation processes:
    - –Thermal stimulation
    - –Hydraulic stimulation
    - –Chemical stimulation
    - –Explosive stimulation
- Closed loop (demonstration ongoing): Heat extraction through a working fluid via conduction.
Examples: Eavor-Loop™, Fongeosec concept © Fonroche



From Peter-Borie et al., 2019, modified

Geothermal wells: flagged difficulties (non-exhaustive list)

- Reservoir characteristics:
  - –Hard rocks quite common (Granites, basalts, …)
  - –High temperature (up to 500 deg C: IDDP2, Iceland)
  - –High pressure
  - –Fault targeted!
  - –Steam cap (blow out risk)
  - –Corrosive geothermal fluids
- Exploitation design:
  - –Injection wells necessary:
    - –Mandatory from regulations in several countries
    - –To cool down the reservoir in order to avoid steam cap formation
    - –To maintain the pressure of the reservoir (in particular in self-flowing-well areas)
- Well type/trajectory:
  - –Vertical wells: routine
  - –Deviated wells: routine
  - –multilaterals: few
  - –horizontal drains: few
- Well design:
  - –Diameter: large diameter required to extract enough geothermal fluid
  - –Casing: scaling and corrosion issues
- Innovative designs: Closed loops (isolated from the environment) to limit the geological hazard

Drilling rig in Vendenheim (France).
Two wells:
- Well 1: 5.4 km MD , Well 2: 5.3 km MD
- Around 200 deg C
- Target: major fault in granite
- Bottom hole diameter: 8”1/2

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EUROPEAN ASSETS

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Quiz

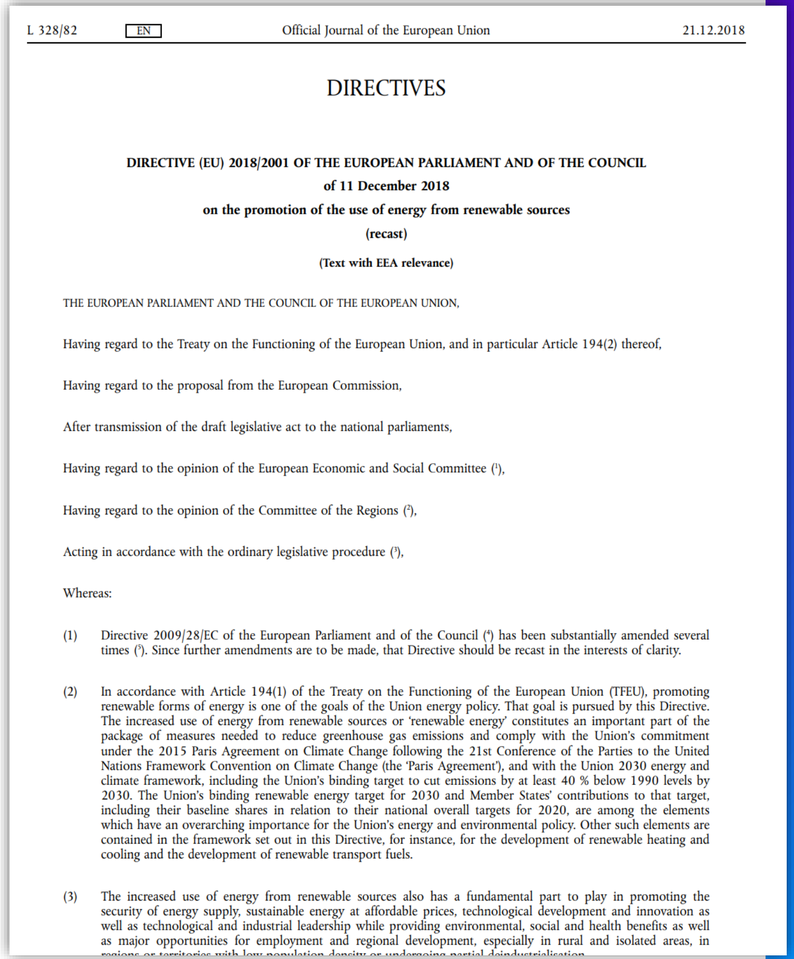
- What is the renewable share of energy consumption in European Countries?
  A. Less than 15%
  B. Between 30 and 40%
  C. More than 65%

- Which countries use geothermal energy for district heating?
  A. France
  B. Germany
  C. Poland
  D. Greece

- Which countries use geothermal energy for electricity?
  A. France
  B. Germany
  C. Poland
  D. Greece

The Clean Energy for all European Package

- Adopted in 2019, will help to decarbonise EU's energy system in line with the European Green Deal objectives
- Aims at delivering on the EU's Paris Agreement commitments for reducing greenhouse gas emissions
- Ambition:
  - **Renewable energy :** 32% binding target on renewable energy by 2030 at the European level
  - **Energy efficiency :** increasing energy efficiency over current levels by at least 32.5% by 2030;
  - **Greenhouse gases emission:** at least 40% of reduction by 2030 at the European level.
- First steps toward the EU's long-term strategy of achieving carbon neutrality (net-zero emissions) by 2050



L 328/82 EN Official Journal of the European Union 21.12.2018

DIRECTIVES

DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 11 December 2018
on the promotion of the use of energy from renewable sources
(recast)

(Text with EEA relevance)

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty on the Functioning of the European Union, and in particular Article 194(2) thereof,

Having regard to the proposal from the European Commission,

After transmission of the draft legislative act to the national parliaments,

Having regard to the opinion of the European Economic and Social Committee [1],

Having regard to the opinion of the Committee of the Regions [2],

Acting in accordance with the ordinary legislative procedure [3],

Whereas:

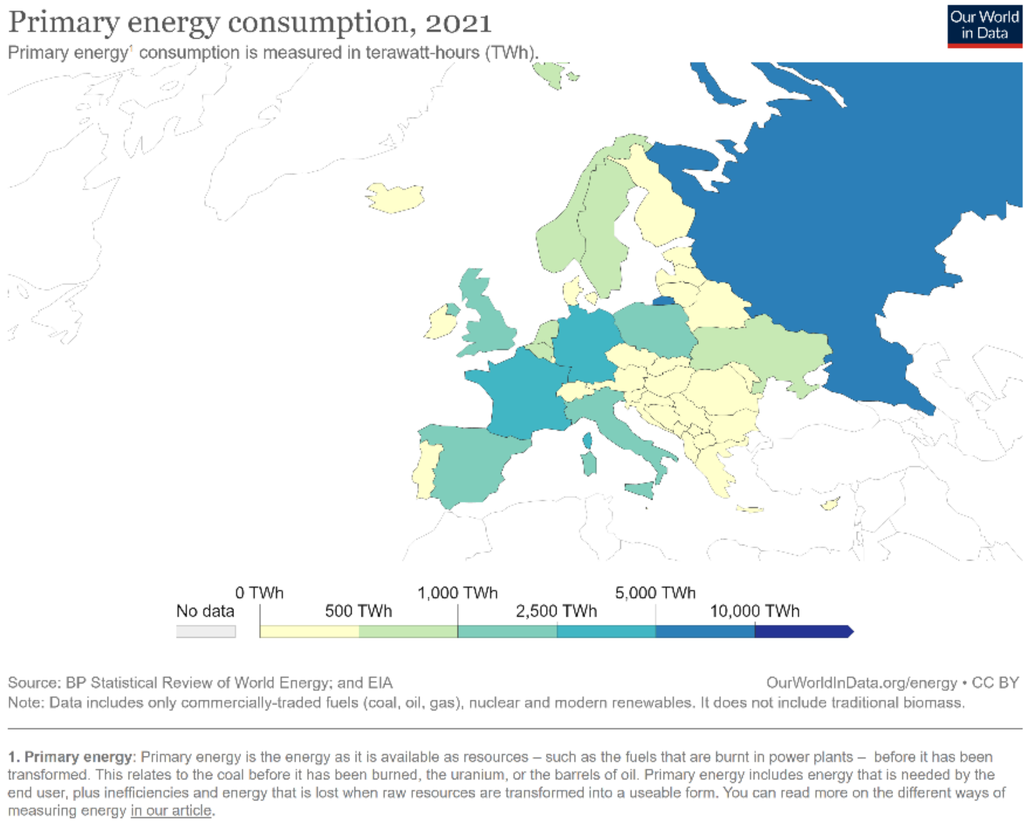
(1) Directive 2009/28/EC of the European Parliament and of the Council [4] has been substantially amended several times [5]. Since further amendments are to be made, that Directive should be recast in the interests of clarity.

(2) In accordance with Article 194(1) of the Treaty on the Functioning of the European Union (TFEU), promoting renewable forms of energy is one of the goals of the Union energy policy. That goal is pursued by this Directive. The increased use of energy from renewable sources or 'renewable energy' constitutes an important part of the package of measures needed to reduce greenhouse gas emissions and comply with the Union's commitment under the 2015 Paris Agreement on Climate Change following the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (the 'Paris Agreement'), and with the Union 2030 energy and climate framework, including the Union's binding target to cut emissions by at least 40 % below 1990 levels by 2030. The Union's binding renewable energy target for 2030 and Member States' contributions to that target, including their baseline shares in relation to their national overall targets for 2020, are among the elements which have an overarching importance for the Union's energy and environmental policy. Other such elements are contained in the framework set out in this Directive, for instance, for the development of renewable heating and cooling and the development of renewable transport fuels.

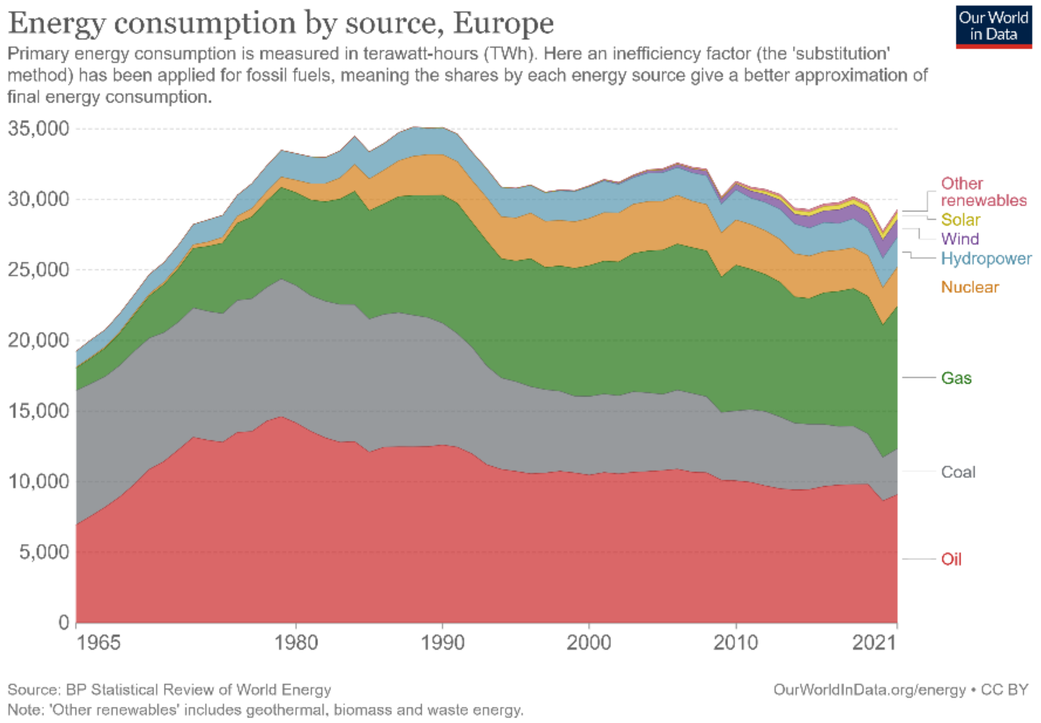
(3) The increased use of energy from renewable sources also has a fundamental part to play in promoting the security of energy supply, sustainable energy at affordable prices, technological development and innovation as well as technological and industrial leadership while providing environmental, social and health benefits as well as major opportunities for employment and regional development, especially in rural and isolated areas, in

DIRECTIVE (EU) 2018/ 2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 11 December 2018 - amending Directive 2012/ 27/ EU on energy efficiency (europa.eu) (screen shot)

Energy consumption in Europe



1. Primary energy: Primary energy is the energy as it is available as resources – such as the fuels that are burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil. Primary energy includes energy that is needed by the end user, plus inefficiencies and energy that is lost when raw resources are transformed into a useable form. You can read more on the different ways of measuring energy in our article.



Hannah Ritchie and Max Roser (2021) – Energy. Published in Our World in Data.
Online at: ourworldindata.org/energy

In Europe, 86% of the consumed primary energy is not renewable

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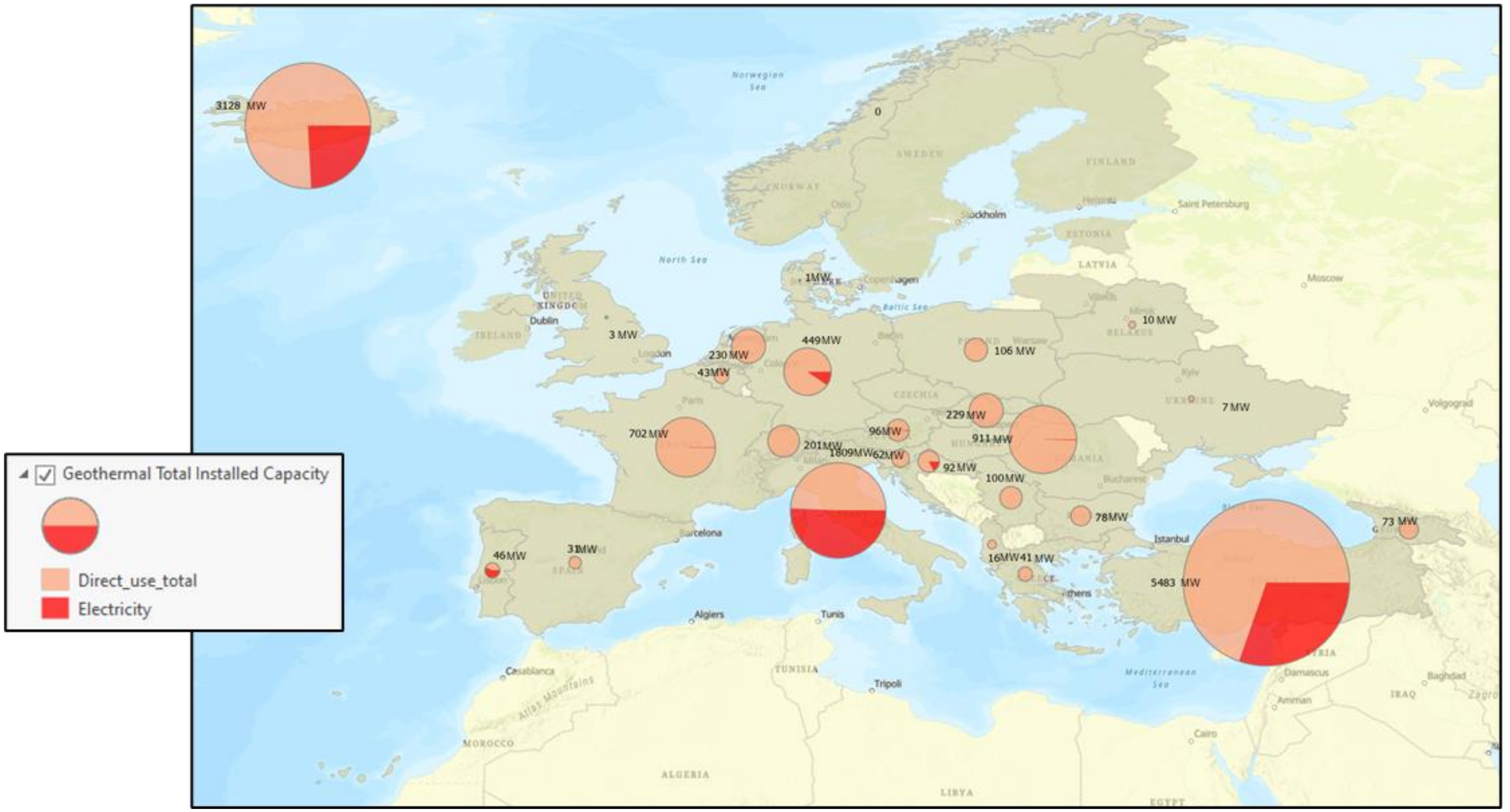
Geothermal energy capacity in Europe in 2020



Data from the 2020-WGC Country updates

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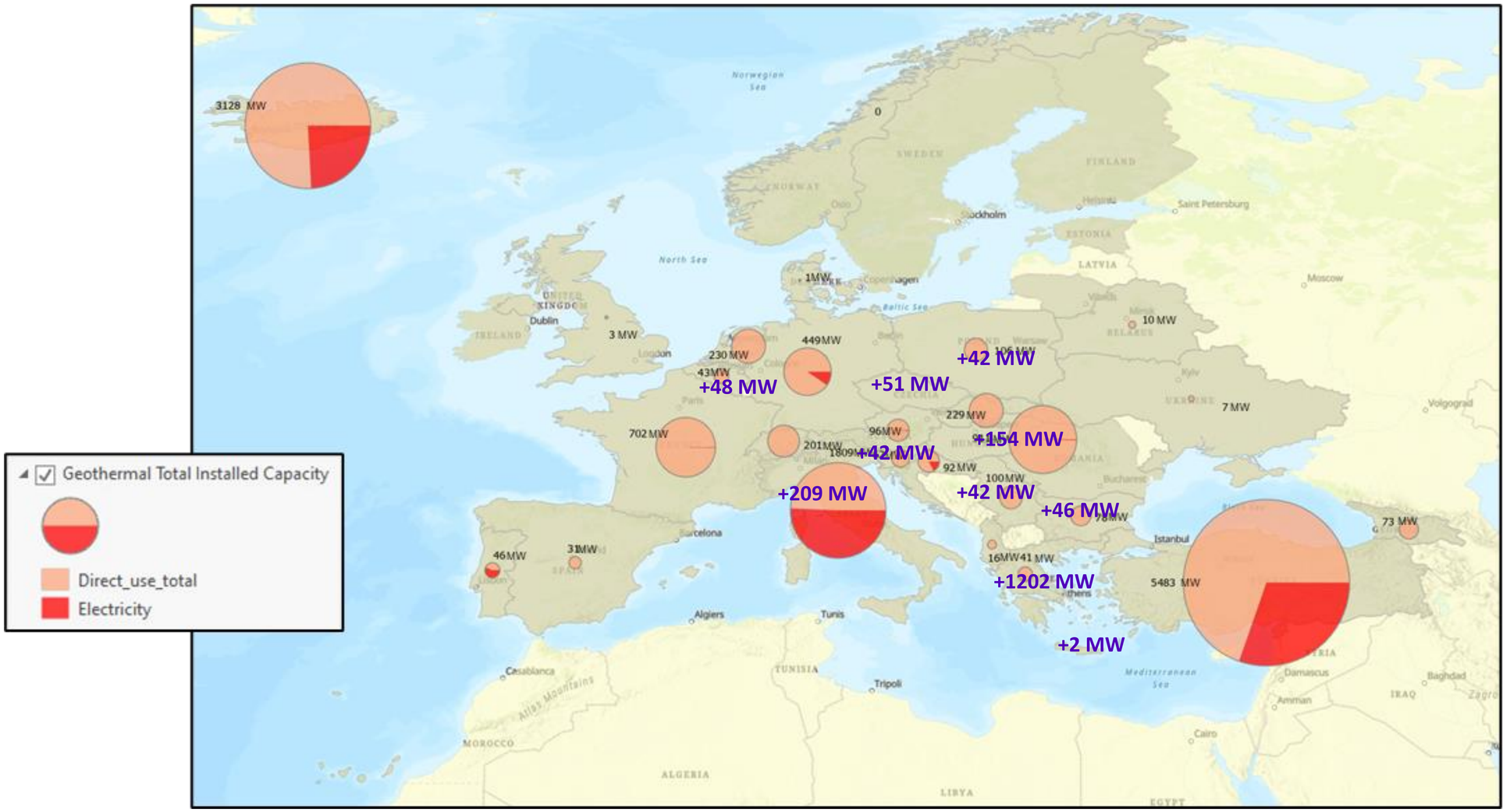
Geothermal energy capacity targets for 2030 (direct use)



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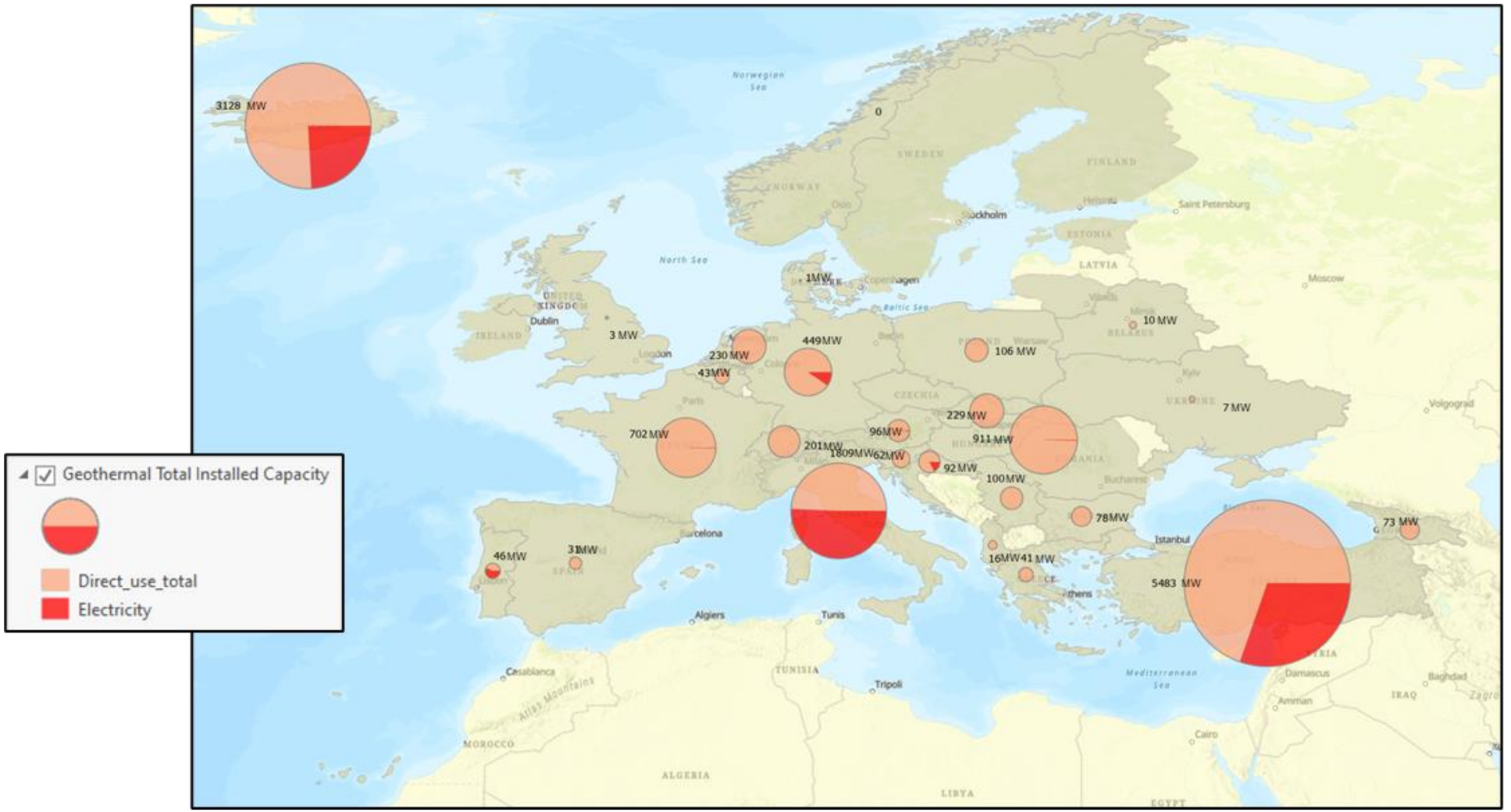
Geothermal energy capacity targets for 2030 (power generation)



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CHALLENGES AND RISKS

And draft of solutions

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Quiz

- What are the main challenges to address for increasing geothermal development?

A. Public perception
B. Lack of regulation
C. Drilling cost and technical challenges
D. Geological hazard resulting in injectivity/productivity too low
E. Induced seismicity
F. Corrosion and scaling
G. Non-Condensable gas emissions
H. Ground motion

Highlight on Drilling challenges

- Challenges: hard rocks, high temperature, complex sedimentary beds.

- Consequences: wellbore stability issues, side-tracking, premature tool wear, lost time and money

- Potential solutions: New adapted drilling tools, improving geomechanical investigations before and during drilling, numerical simulations

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Highlight on Injectivity/productivity issues

- Challenges: insufficient productivity/injectivity
- Consequence: currently, need to resort to EGS technologies – but not always successful!
- Potential solutions:
  - Better knowledge and characterization of the reservoir
  - Numerical modelling: better anticipation of the short-and long-term reservoir behaviour
  - AGS (Advanced Geothermal Systems) technologies (closed-loop) for limiting the impact of the (hydro-) geological hazard?

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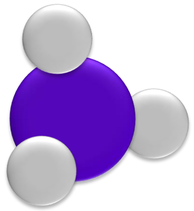
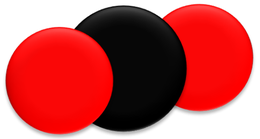
Highlight on Non-Condensable Gas issues

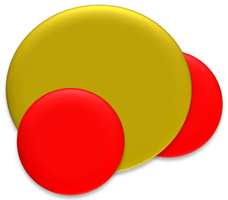
- Challenges: Geothermal brines may contain Non-Condensable Gas (mainly in volcanic plays)
- Consequence:
  - Decrease the power output from the turbine due to gas accumulation in the condenser which causes an increase in the turbine back pressure
  - Air pollution if released in the atmosphere
- Potential solutions:
  - NCG gas reinjection (research in progress)
  - Other use: CO_2 for vegetable feeding in greenhouses, …



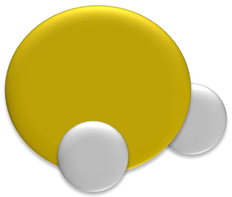
ammonia



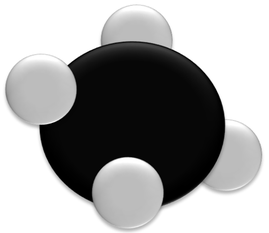
carbon dioxide



sulfur oxide



hydrogen sulfide



Methane

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Highlight on societal challenges – not the least!

- Causes:
  - Problematic induced/triggered seismicity (felt by the population, ML>2.0)
  - Land expropriations
  - Visible pipes
  - H2S Smell
  - …
- Consequences:
  - Cancellation or suspension of operations (e.g. Vendenheim)
  - Increased fear from the population & local authorities, falling confidence in geothermal, strong opposition, protests
- Mitigation plan, perspective and recommendations:
  - Perhaps need to revisit operation integration model in the territories
  - Education
  - Define good practices to limit the impacts. *Ex. In France: Good Practice Guide for deep geothermal op. to minimize seismic risk (commissioned by the State services)*
  - Better communication and involvement of the different stakeholders
  - …

"Earthquake in Alsace: Fear of the neighbouring residents and geothermal issues" © France Ouest Newspaper

Residents of the Orhanlı Valley, located in Orhanlı Village of Seferihisar district of Izmir (Turkey) protesting against geothermal projects (© Bianet newspaper).

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CONCLUSION

The high potential of cross-fertilization with O&G industry

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Europe: the geothermal Promise-land ?

- Geothermal energy:
  - –Everywhere under our feet, whatever the geological context, not dependent on the weather
- Numerous end-use possibilities, making earth heat potentially useful whatever the extracted temperature!
  - – For power generation in Europe:
    - –few volcanic areas but EGS technologies demonstrated in other play types
    - –Progress of the technology: toward lower temperature required to produce electricity
  - –For heat direct use in Europe:
    - –Heating/cooling almost everywhere
    - –District heating in large sedimentary basins in Europe
    - –…
- Pairing with other critical resources for energy development: lithium, hydrogen….
- Technology moving quickly forward to reduce the cost, mitigate the risks and increase the heat recovery efficiency
- European Political will to move toward
  - –Concrete objective for 2030 and 2050!
  - –Urgency to decarbonise energy systems are providing new momentum to the geothermal industry: Geothermal energy has a real place in the green energy mix!

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And now?

- Geothermal energy and O&G exploitations have similarities, but also differences.
- Cross-fertilization of the experiences and know-how would help in geothermal development!

Examples of differences to consider when reorienting its activity!

Geothermal	O&G
Broad geological contexts	Mainly sedimentary basins
Different size of exploitations / plants / operations	Large fields – several wells
Operations for heat direct use close to the use zone (potentially in urban area)	No constraints on the location due to the need
Renewable resource	Not renewable
Drilling hard rocks	Drilling softer rocks
High temperature	Temperature generally lower

Examples of cross-fertilization potential

Common issues	Cross-fertilisable skills
Derisking exploration	Exploration process, in particular seismic acquisition, processing and interpretation. Well targeting …
Drilling issues	Experience in drilling unconventional reservoir, wellbore stability, steering, logging, fishing,…
Productivity/injectivity increase	Deviated wells, Steering capabilities, Multilaterals, stimulations, …
Induced seismicity mitigation	Process knowledge, stimulation and circulation control, mitigation process implementation,…
Public perception	Societal approaches
Regulation	Socio-Political sciences

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References

- Blondes, M. S., Gans, K. D., Engle, M. A., Kharaka, Y. K., Reidy, M. E., Saraswathula, V., Thordsen, J. J., Rowan, E. L., & Morrissey, E. A. (2019). U.S. Geological Survey National Produced Waters Geochemical Database v2.3 [Data set]. U.S. Geological Survey. https://doi.org/10.5066/F7J964W8
- Hannah Ritchie, Max Roser and Pablo Rosado (2020) - "Energy". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/energy' [Online Resource]
- Moeck I.S., Beardsmore G., 2014, A new ‘geothermal play type’ catalog: Streamlining exploration decision making, PROCEEDINGS, Thirty-Ninth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 24-26, 2014, SGP-TR-202
- Peter-Borie M., 2020, A conceptual model of the Geothermal System of the Upper Rhine Graben, Geothermal energy in rift basins, Rift and Rifted Margins Online Seminar, https://www.youtube.com/watch?v=CXWDRJci9is
- Peter-Borie et al., 2019, Thermal stimulation of the deep geothermal wells: insights from the H2020-DEEPEGS project, European Geothermal Congress 2019, Den Haag, The Netherlands, 11-14 June 2019 (picture from the oral presentation)

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Q&A

Geological Survey of Denmark and Greenland | accenture | CGG | MathWorks | Microsoft | NVIDIA | Oilfield International | SAMSUNG | TNO innovation for life | TRE ALTAMIRA

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