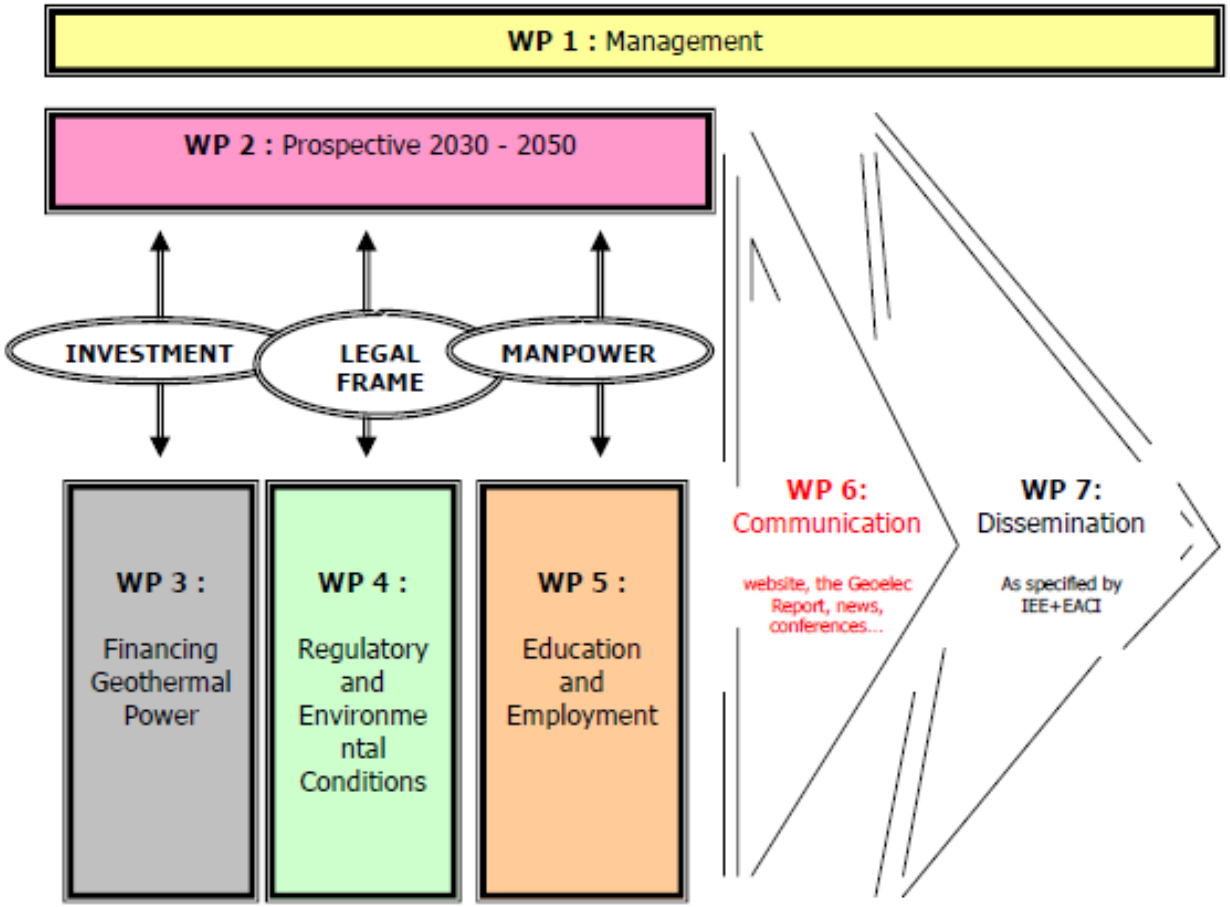
# D2.3 GEOELEC web-service database on resource assessment



# Content

- Resource assessment philosophy + methodology
- Data assessment- workshops
- Temperature model and resource potential
- Future of geothermal energy in EU

# A Methodology for Resource assessment and application to core countries

Writing team:

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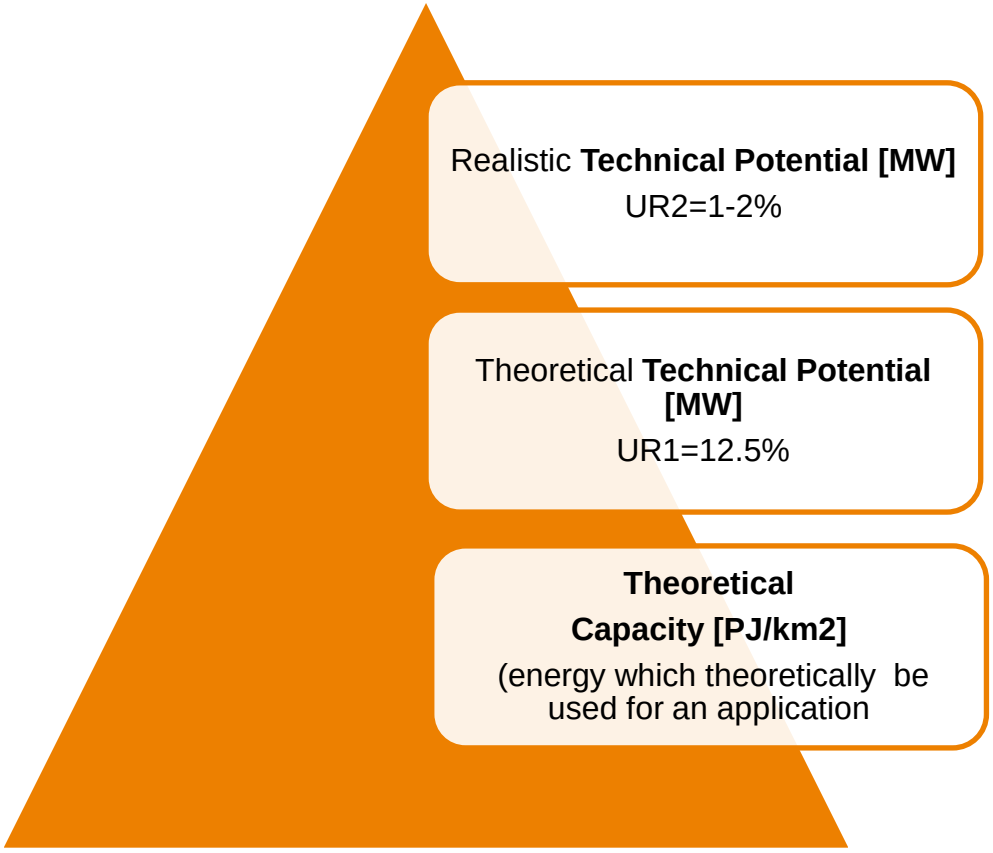
Phillipe Calcagno, Chrystel Dezayes (BRGM),
Christian Lacasse (Mannvitt),
Adele Manzella (CNR)

Integrated over volume V

Practical potential




$$\text{TPvolume} = \frac{TC}{lifetime} UR2$$

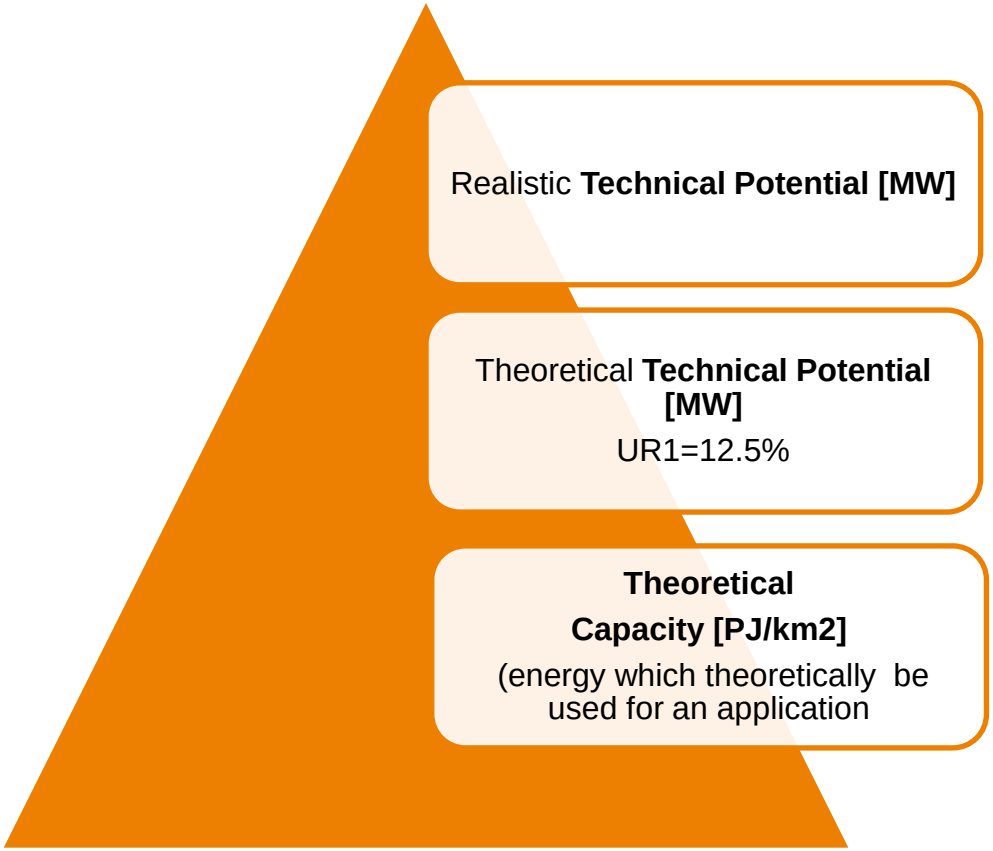
$$\text{TPplaylevel} = \frac{TC}{lifetime} UR1$$

$$\text{TC} = V * \rho_{rock} * Cproc_k * (T_x - Tr) * \eta$$

Theoretical potential

Beardsmore et al., 2011.
philosophy used In IPCC and IEA roadmap

Practical potential




Theoretical potential

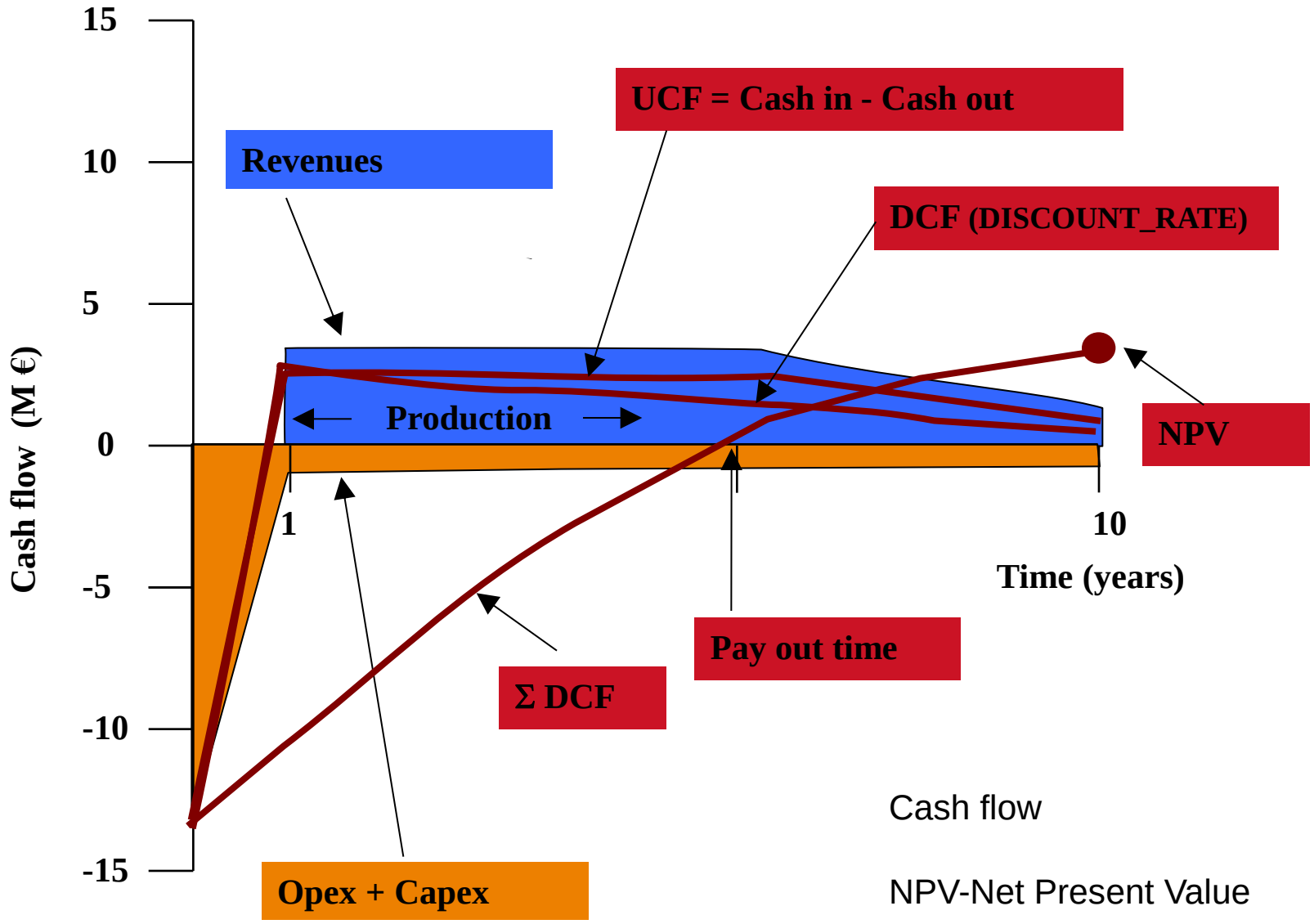
Economic potential

$$\text{TPvolume} = \frac{TC}{lifetime} UR1, if\ LCOE < c$$

$$\text{TPplaylevel} = \frac{TC}{lifetime} UR1$$

$$\text{TC} = V * \rho_{rock} * Cpr_{ock} * (T_x - Tr) * \eta$$

Used here




Cash flow

NPV-Net Present Value

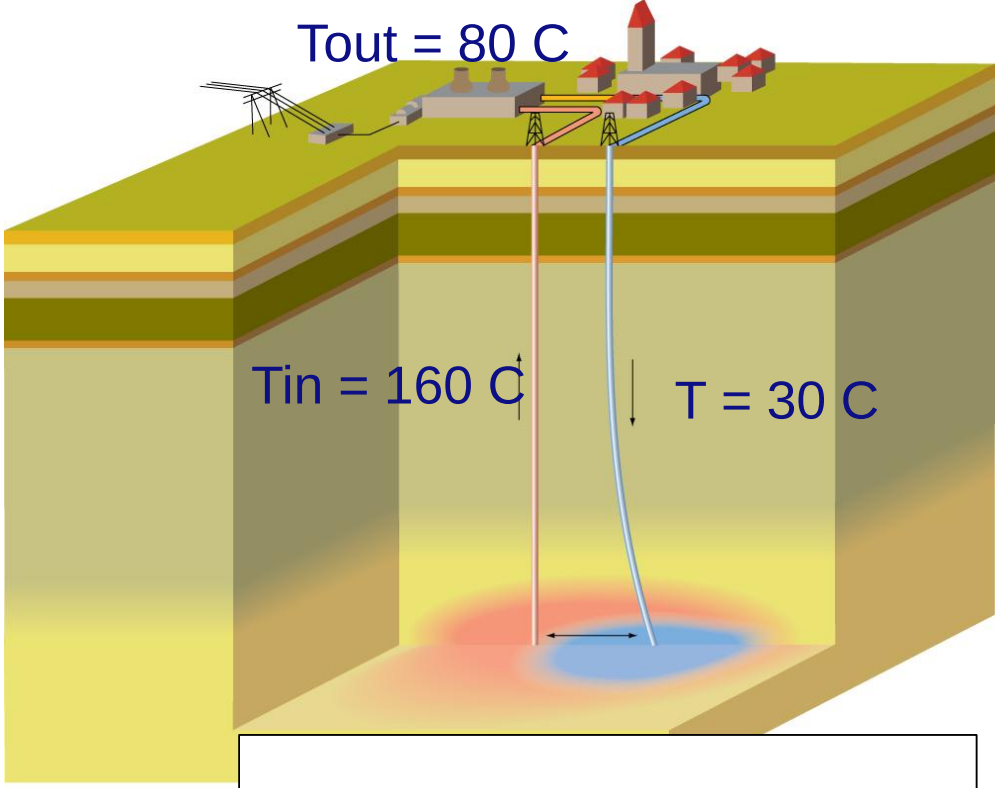
# Levelized Cost of Energy

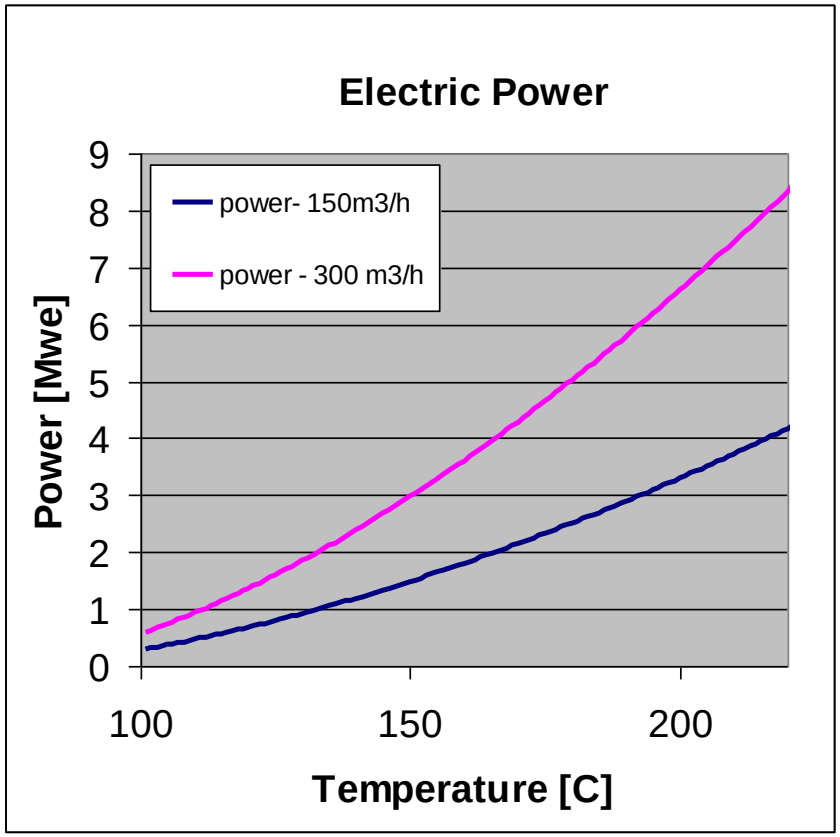
- Discounted energy produced [MWh,  GJ]
- Discounted cash out [ EUR ]

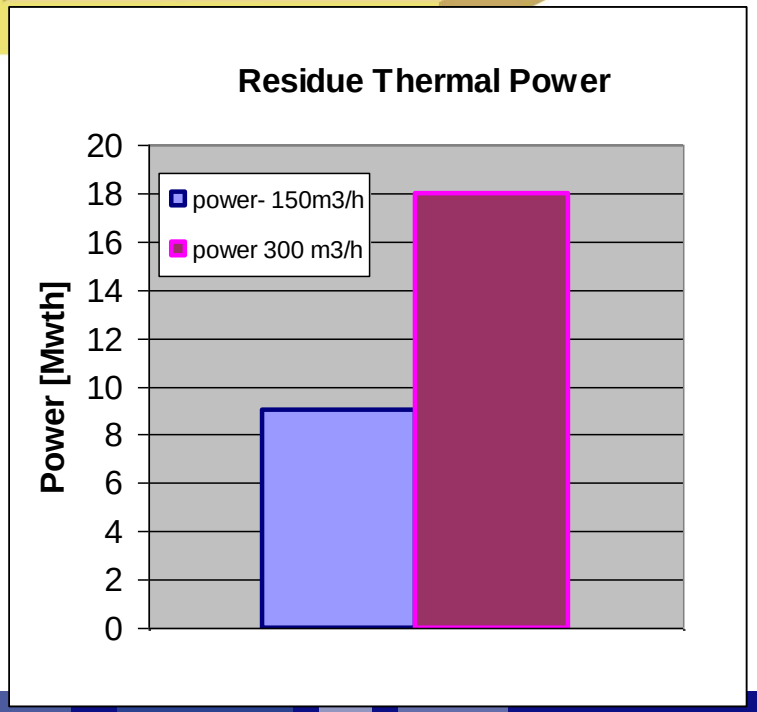
- LCOE = discounted cash-out / discounted energy produced

**Power ~**

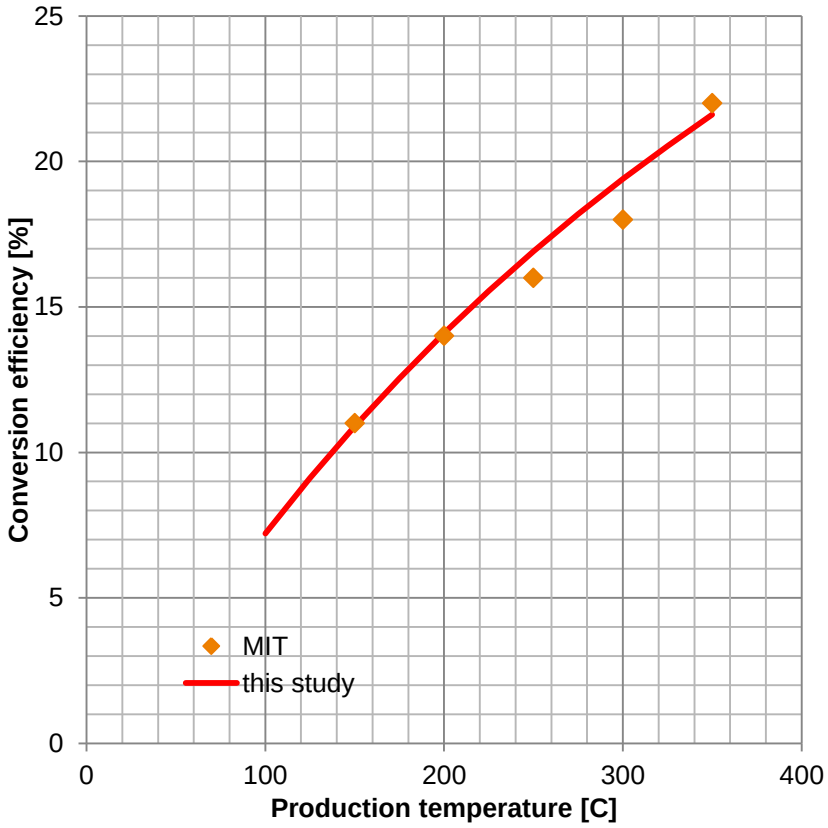
**(Tin-Tout) * conversion efficiency * flow rate**

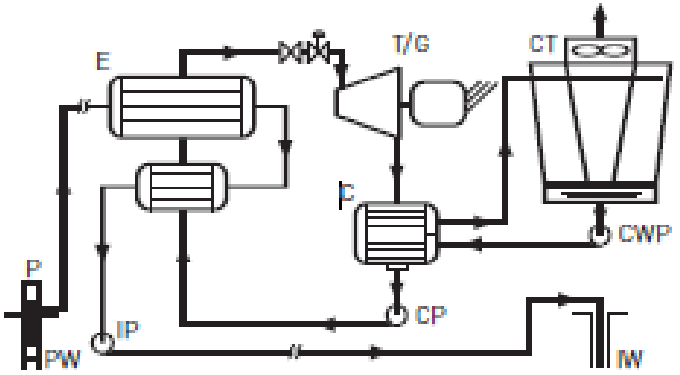


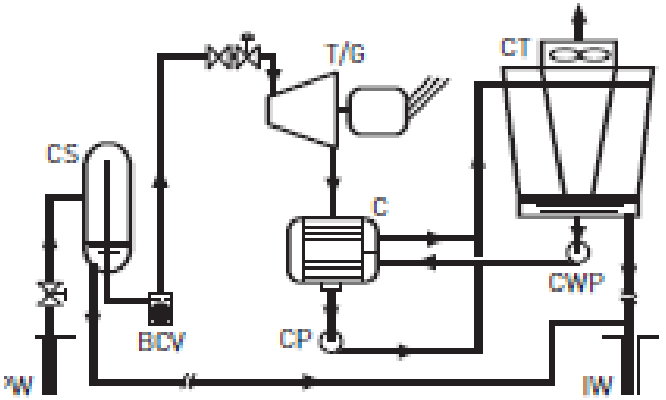



# Geothermal power: Conversion Efficiency




binary




flash

MIT report , 2007: Future of geothermal energy

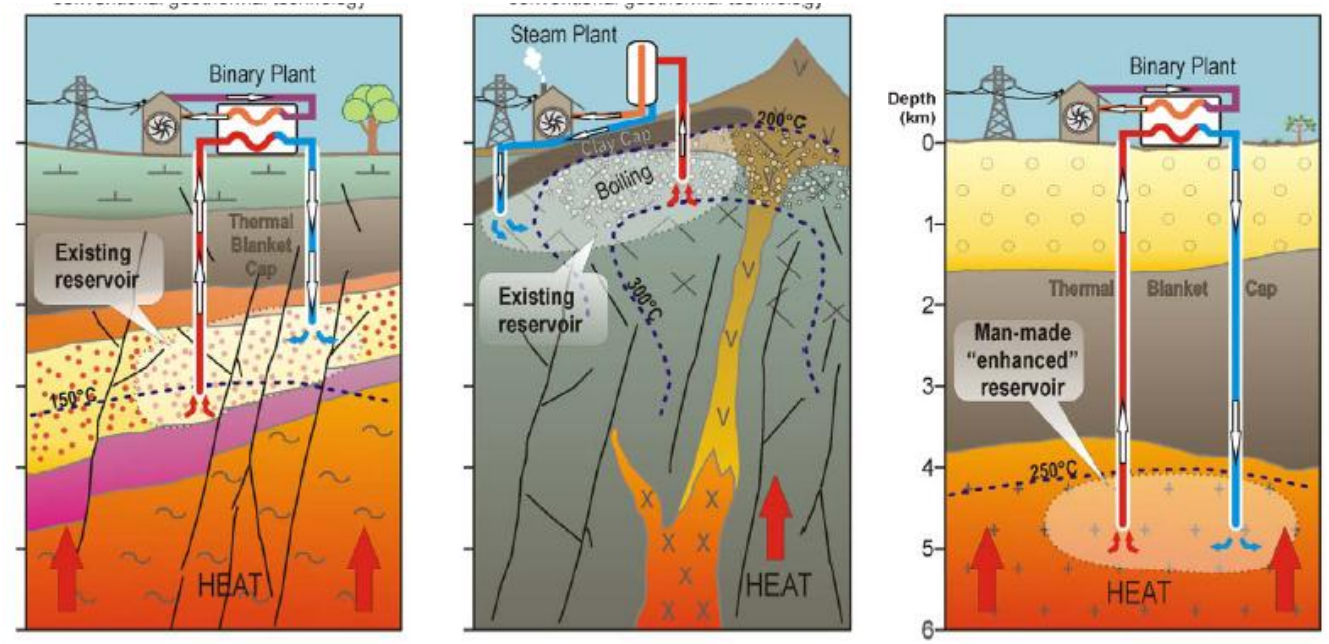



*Figure 2: example of different play types for geothermal systems (modified from Hot Rock ltd). Hot sedimentary aquifers and magmatic plays can be mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. Magmatic plays can generally produce very high temperatures at shallow depth. Low permeable rock plays are located in regions of elevated temperatures (caused by radiogenic heat production, elevated tectonic heat flow, or vertical heat advection trough deep fault zones).*

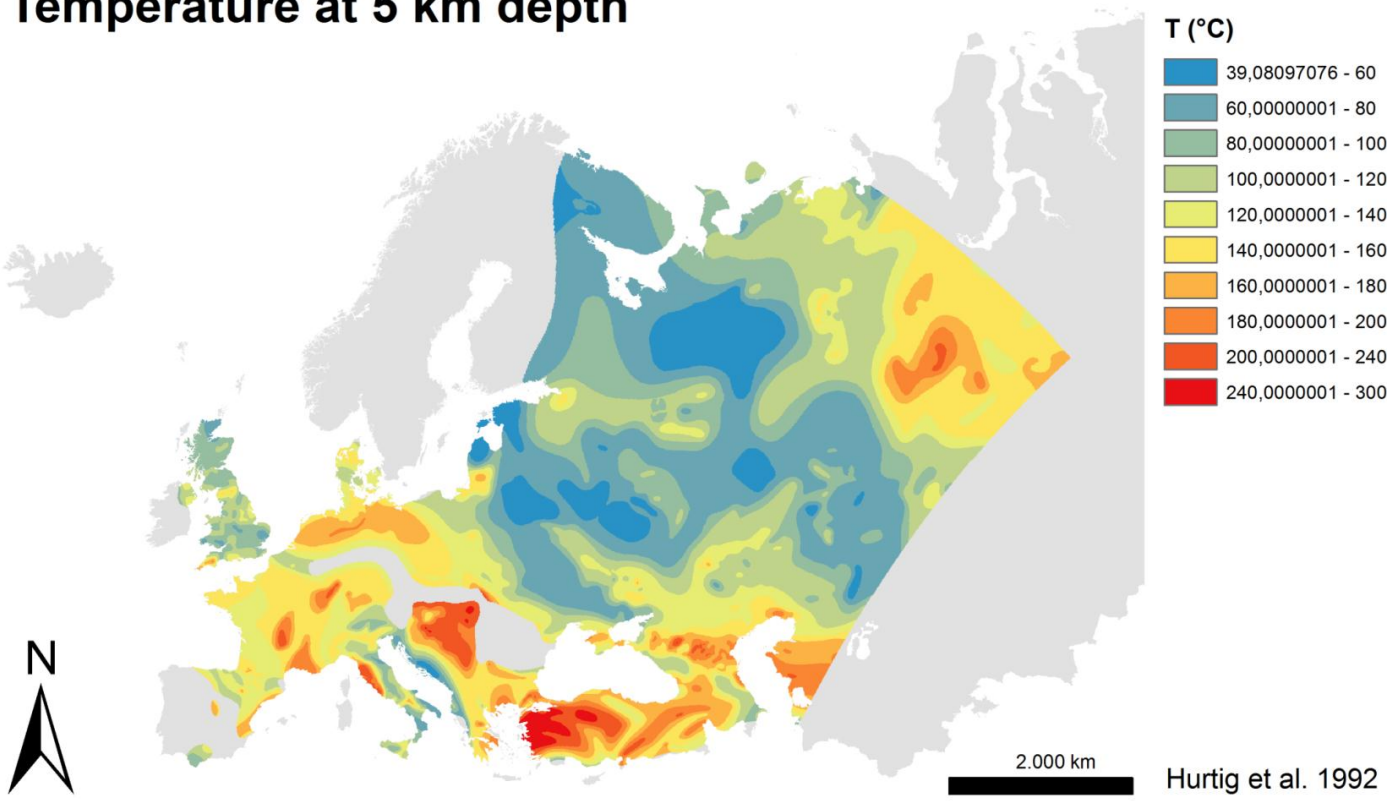
# Levels in resource assessment

| | |
|---|---|
| 1. Global European prospective resource assessment for EGS | European wide assessment (cf. Beardsmore et al., 2010). Determine technical potential for different depth ranges for EGS, key input are base maps of temperature, and rock type to identify theoretical potential. Filter maps with information on natural reserve areas etc. Assume relatively low ultimate recovery in agreement with whole depth column (cf. IPCC, 2011). distinguish relative attractiveness, low, mid, high estimates according to drilling depth required to reach temperature |
| 2. Prospective undiscovered resource assessment for different play types | Identify delimited areas with a particular play type (e.g. Hot Sedimentary Aquifer (HSA), magmatic convective). Include data relevant to exploration of particular play types and exploration outcomes (cf. AGEA-AGEC, 2010) for exploration data relevant to resources assessment |
| 3. Contingent (discovered) resources and reserves | From industry and government reporting obtain information on drilled prospects and producing reserves, play types, development type |

# Do we have access to key information?

## Temperature compilations date from over 20 years ago, only exists in a paper report

### Temperature at 5 km depth




Hurtig et al. 1992

**Data information sheet for LEVEL 1 and (partly) LEVEL 2**

For the GEOELEC, we would kindly request you to fill in the questionnaire below. Note that the provider of the information is not responsible for the delivery of the information. However, the provider is requested to correctly report the source of the information.

It is further assumed that the owner of the data is responsible for storing and distributing the underlying data, or alternatively you may identify data or key publications which have originated from you or affiliated institutes

Digital = Database in any accessible form (*.xls, *.mdb, etc)
Paper = Either printed or in PDF
#... = Number of ...

Please indicate whether the information provided is/will be publically available

---

1. Name of institute:
2. Country:
3. Contact person:
4. Contact details:

5. Known data of the temperature in the subsurface (e.g. oil and gas BHT/DST)
   a. #.... Uncorrected BHT data

      Publically available — Yes ☐ No ☐

      Data available on: Digital ☐ Paper ☐

      (Internet) source location:

   b. #..... Corrected BHT data

      Publically available — Yes ☐ No ☐

      Data available on: Digital ☐ Paper ☐

      (Internet) source location:

   c. #..... DST data

      Publically available — Yes ☐ No ☐

      Data available on: Digital ☐ Paper ☐

      (Internet) source location:

6. Surface heat flow measurements and map interpretation
   a. # .... measurements

      Publically available — Yes ☐ No ☐

      Data available on: Digital ☐ Paper ☐

      (Internet) source location:

   b. map coverage

      Publically available — Yes ☐ No ☐

      Data available on: Digital ☐ Paper ☐

      (Internet) source location:

10. If applicable: basin layout and sediment-basement interface depth
    a. Basin contours

       Publically available — Yes ☐ No ☐

       Data available on: Shape ☐ Paper ☐

       (Internet) source location:

       .... % of country/ region name: .....

    b. Sediment thickness

       Publically available — Yes ☐ No ☐

       Data available on: Raster ☐ Paper ☐

       (Internet) source location:

       .... % of country/ region name: .....

11. If applicable: outlines of granitic formations:

    a. granite outlines

       Publically available — Yes ☐ No ☐

       Data available on: Digital ☐ Paper ☐

       (Internet) source location:

       .... % of country/ region name: .....

    b. granite thickness (thickness map or 3 classes <3km, >3 km, >6km)

       Publically available — Yes ☐ No ☐

       Data available on: Digital ☐ Paper ☐

       (Internet) source location:

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# WORKSHOPS

**WORKSHOP 1: UK, IRELAND AND ICELAND, 26TH SEPTEMBER 2011, LONDON**

The first regional workshop was undertaken in September 2011. Participants were invited based on their expertise and experience in geothermal resource assessment, or project development.

- AGENDA
- PRESENTATIONS

**WORKSHOP 2: SPAIN & PORTUGAL, 10TH NOVEMBER 2011, VALENCIA**

The second regional workshop was undertaken in November 2011. Participants were invited based on their expertise and experience in geothermal resource assessment, or project development in Spain and Portugal

- AGENDA
- PRESENTATIONS

**WORKSHOP 3: FRANCE, SLOVENIA AND THE BALKANS, 5TH DECEMBER 2011, MILAN**

The third regional workshop was undertaken in December 2011. Participants were invited based on their expertise and experience in geothermal resource assessment, or project development.

- AGENDA
- PRESENTATIONS

**WORKSHOP 4: GREECE, CYPRUS, MALTA, BULGARIA, ROMANIA AND TURKEY**

The fourth regional workshop was undertaken on 20th December 2011. Participants were invited based on their expertise and experience in geothermal resource assessment, or project development.

- AGENDA
- PRESENTATIONS

**WORKSHOP 5: THE NETHERLANDS, BELGIUM, DENMARK, LUXEMBOURG, SWEDEN AND NORWAY**

The fifth regional workshop was undertaken in Utrecht on January 24th 2012. Participants were invited based on their expertise and experience in geothermal resource assessment, or project development.

- AGENDA
- PRESENTATIONS

**WORKSHOP 6: GERMANY, POLAND, CZECH REP., SLOVAKIA, HUNGARY, AUSTRIA, SWITZERLAND**

The sixth regional workshop was undertaken on February 29th 2012 in Offenburg, Germany. Participants were invited based on their expertise and experience in geothermal resource assessment, or project development.

- AGENDA
- PRESENTATIONS

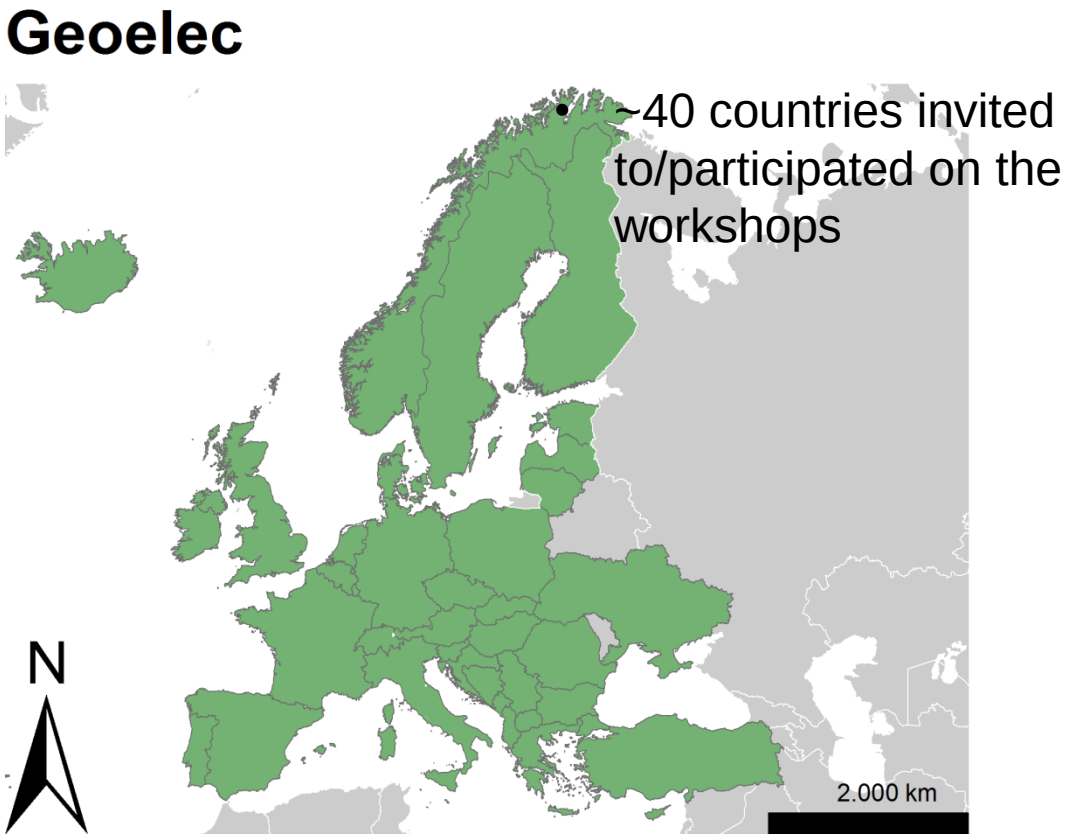
**WORKSHOP 7: LITHUANIA, LATVIA, ESTONIA, FINLAND, UKRAINE**

The seventh regional workshop was undertaken on March 22nd in Vilnius, Lithuania.

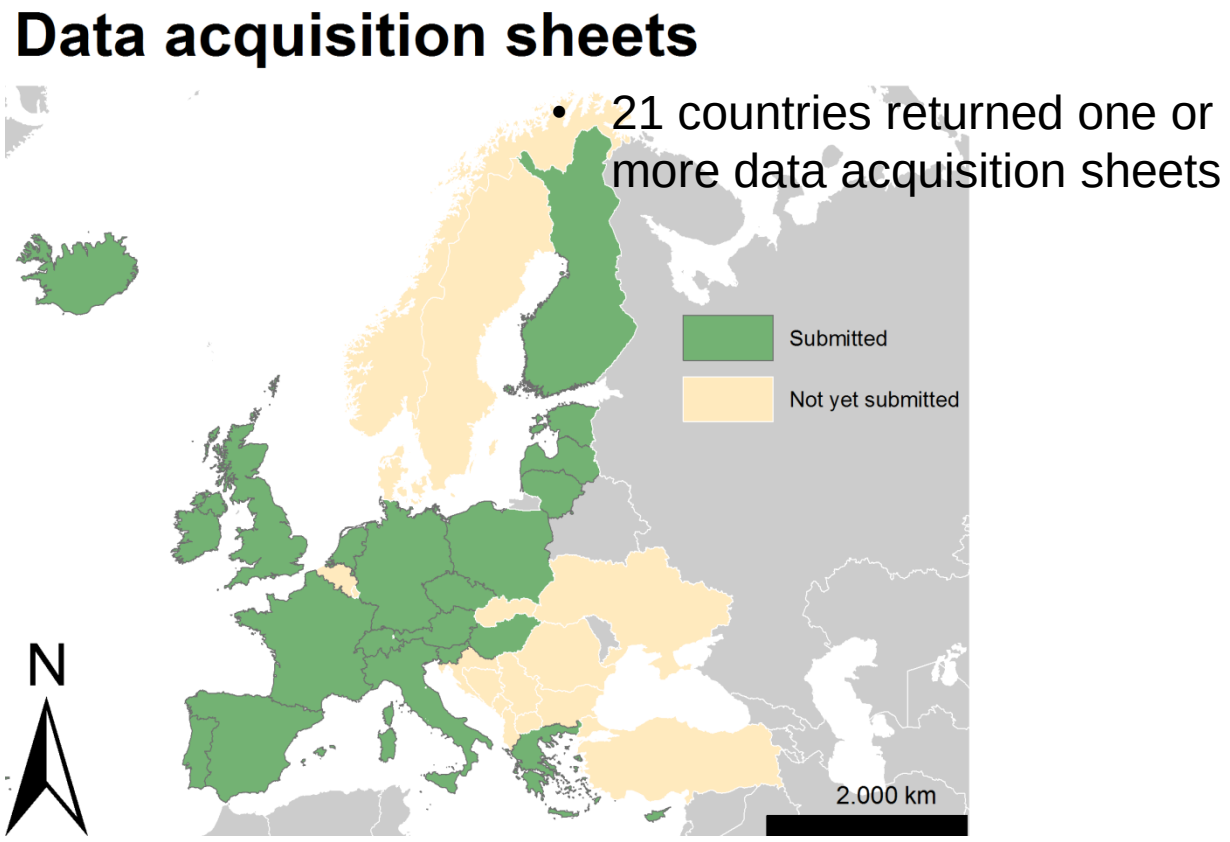
- AGENDA
- PRESENTATIONS

http://www.geoelec.eu/

# Data acquisition sheets



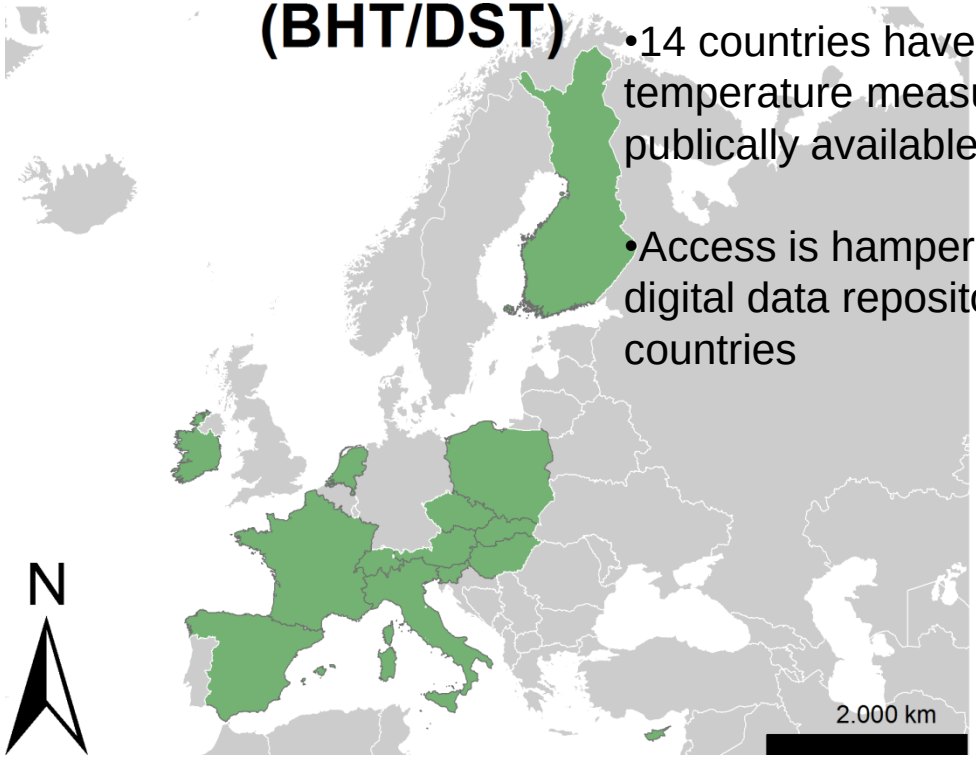
# Data acquisition sheets



# Can stakeholders access key information?

**Legislation to access key information differs. In many countries temperature measurements are not public**

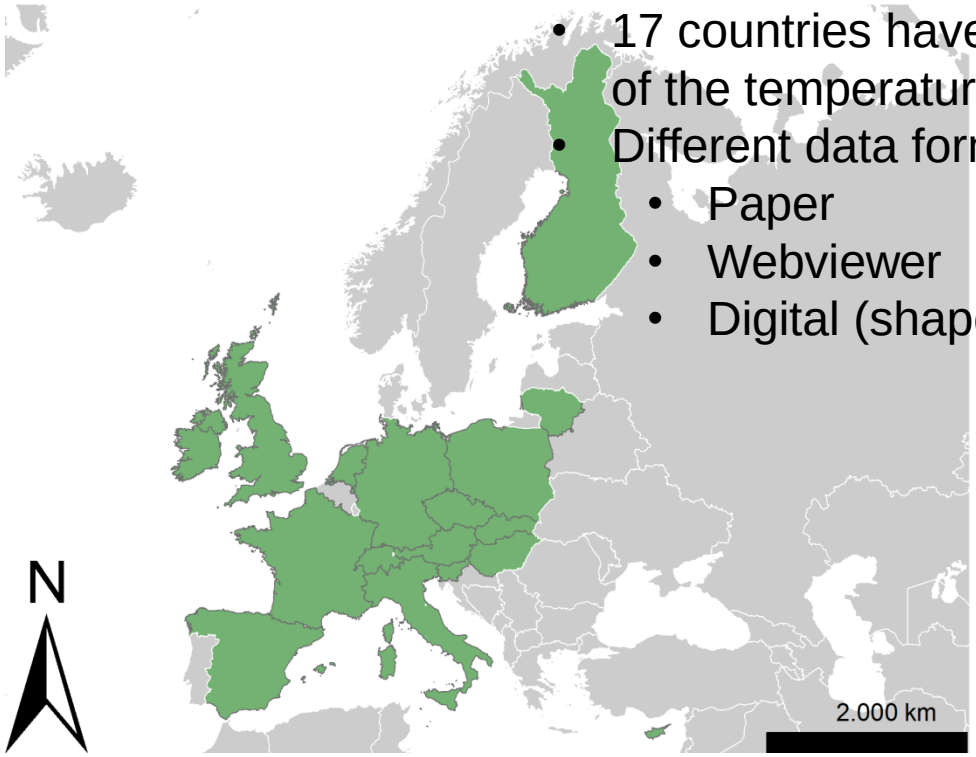
## Temperature Measurements (BHT/DST)




- 14 countries have indicated that temperature measurements are publically available at no cost
- Access is hampered by lack of digital data repositories in most countries

# Data acquisition sheets

## Temperature maps at depth

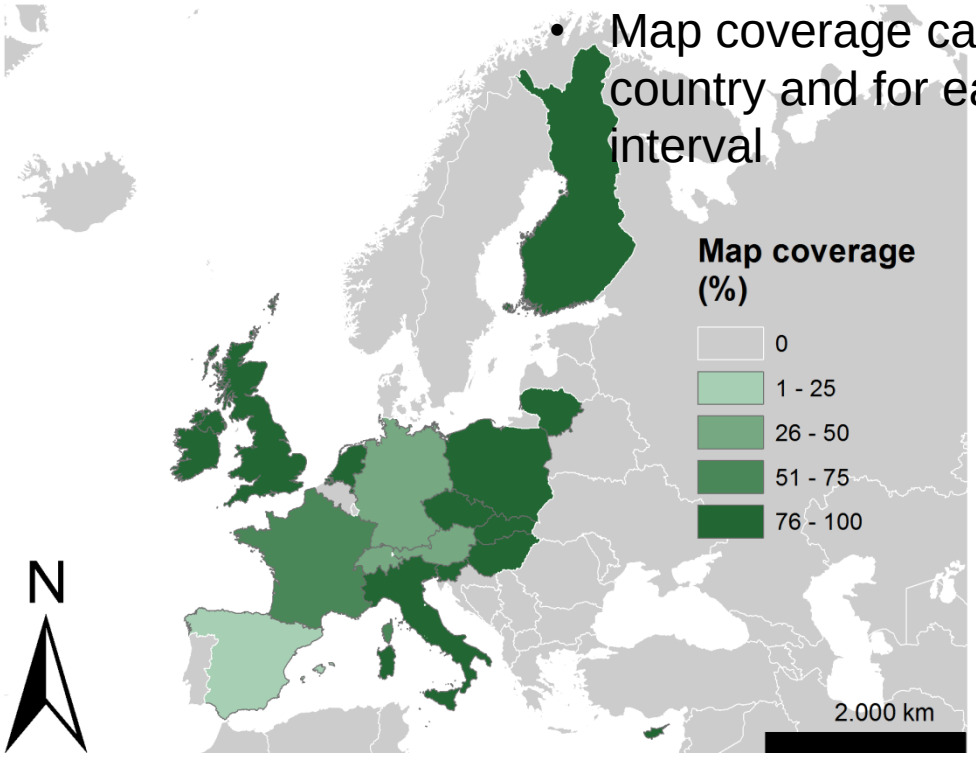



- 17 countries have (partial) maps of the temperature at depth
- Different data formats:
  - Paper
  - Webviewer
  - Digital (shapefile/grid)

# Data acquisition sheets

## Temperature maps at depth

- Map coverage can vary for each country and for each depth interval

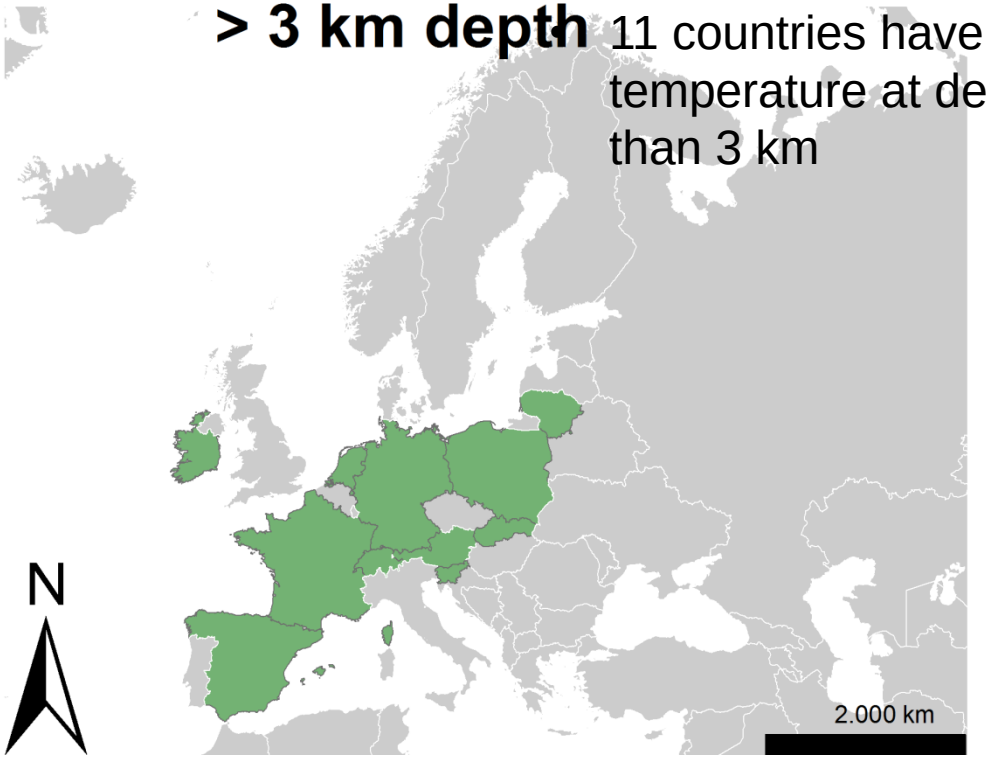


# Data acquisition sheets

## Temperature maps at depth

### > 3 km depth

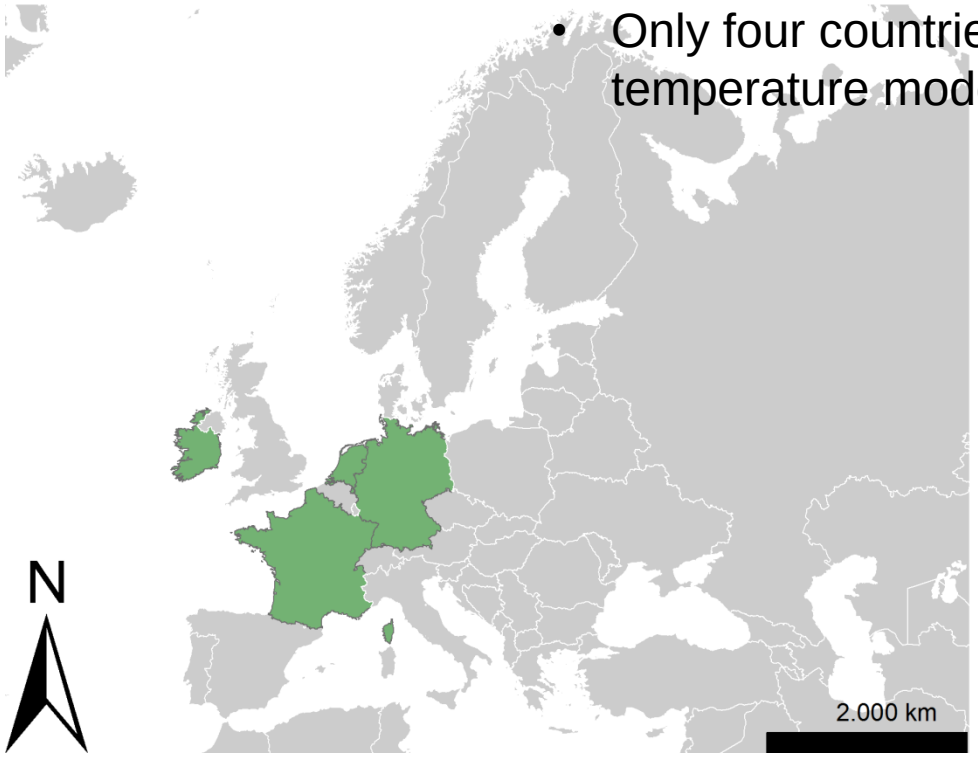
11 countries have maps for the temperature at depths greater than 3 km



# Data acquisition sheets

## 3D temperature models

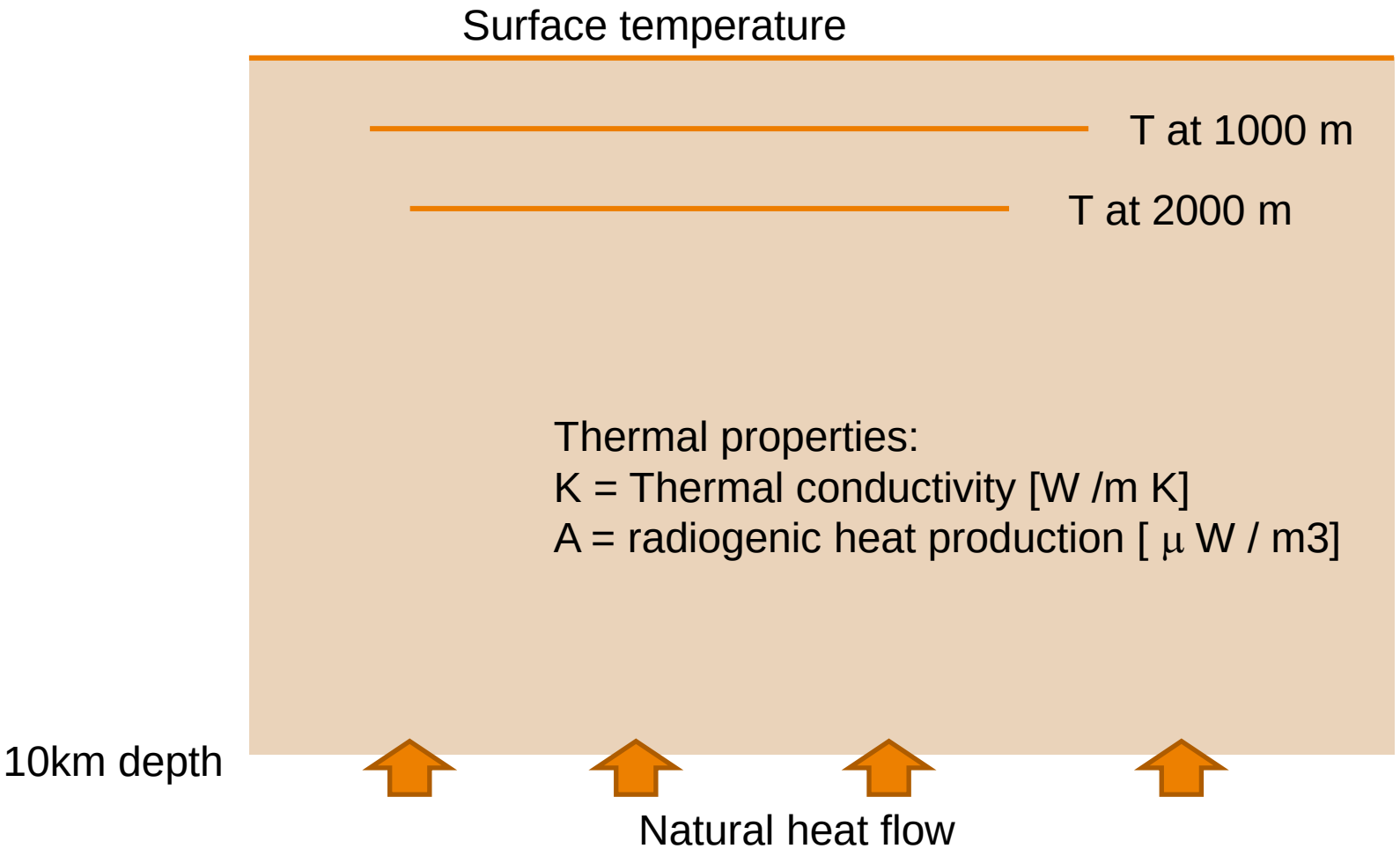
- Only four countries provide 3D temperature models



# Findings

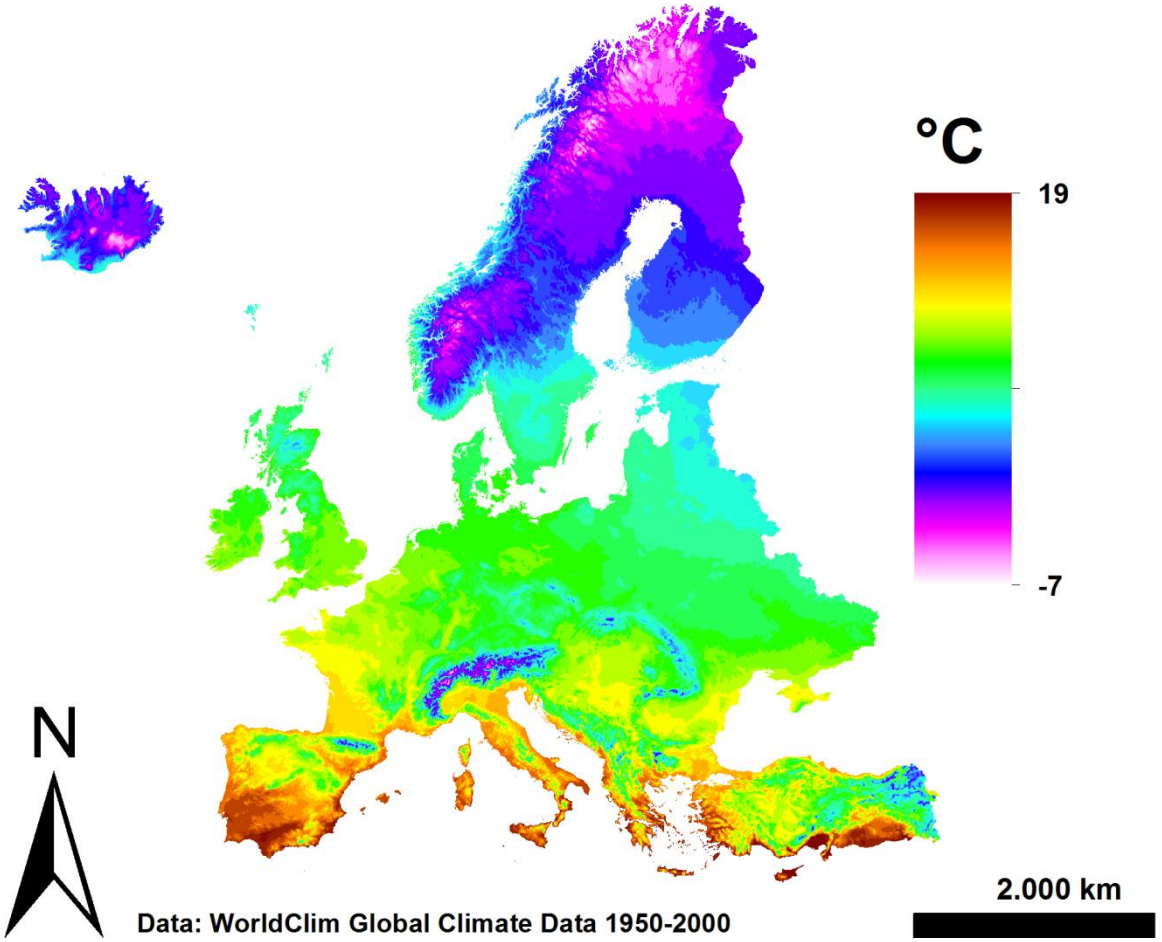
- There are a lot of geothermal data available, however:
  - Fragmented
  - Different format
  - Different correction methods used for BHT
  - Different methodology construction of maps
- Centralised and unified database recommended

# How to construct a temperature model?

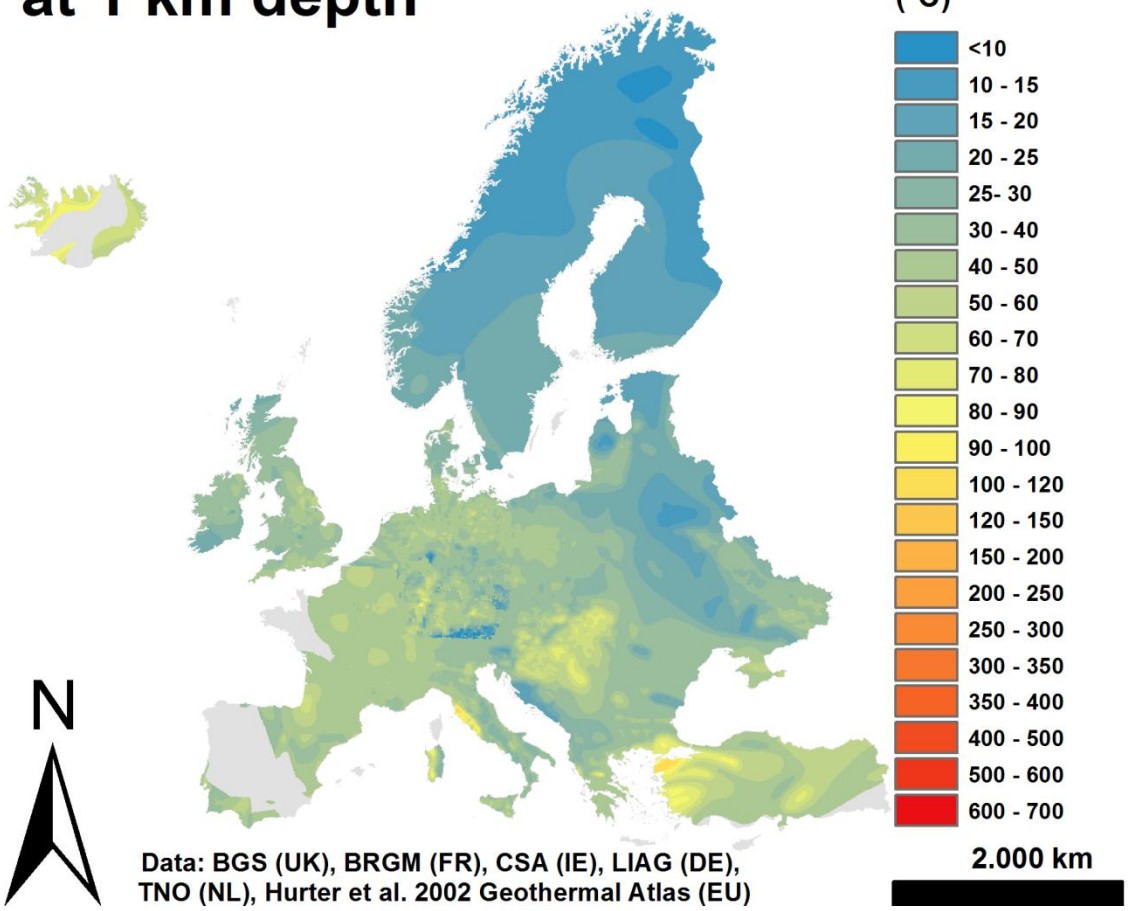


# Boundary conditions

## Mean Annual Surface Temperature

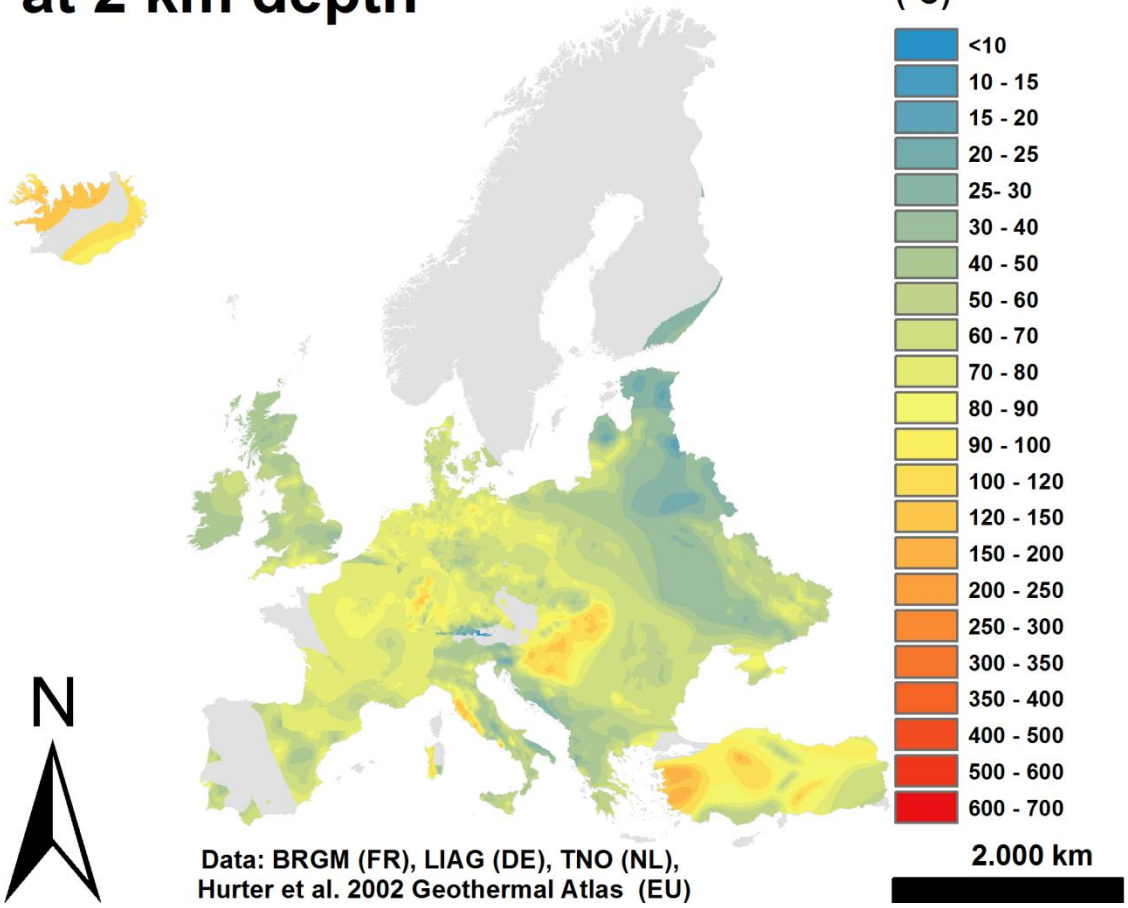


# Temperature Constraints at 1 km depth



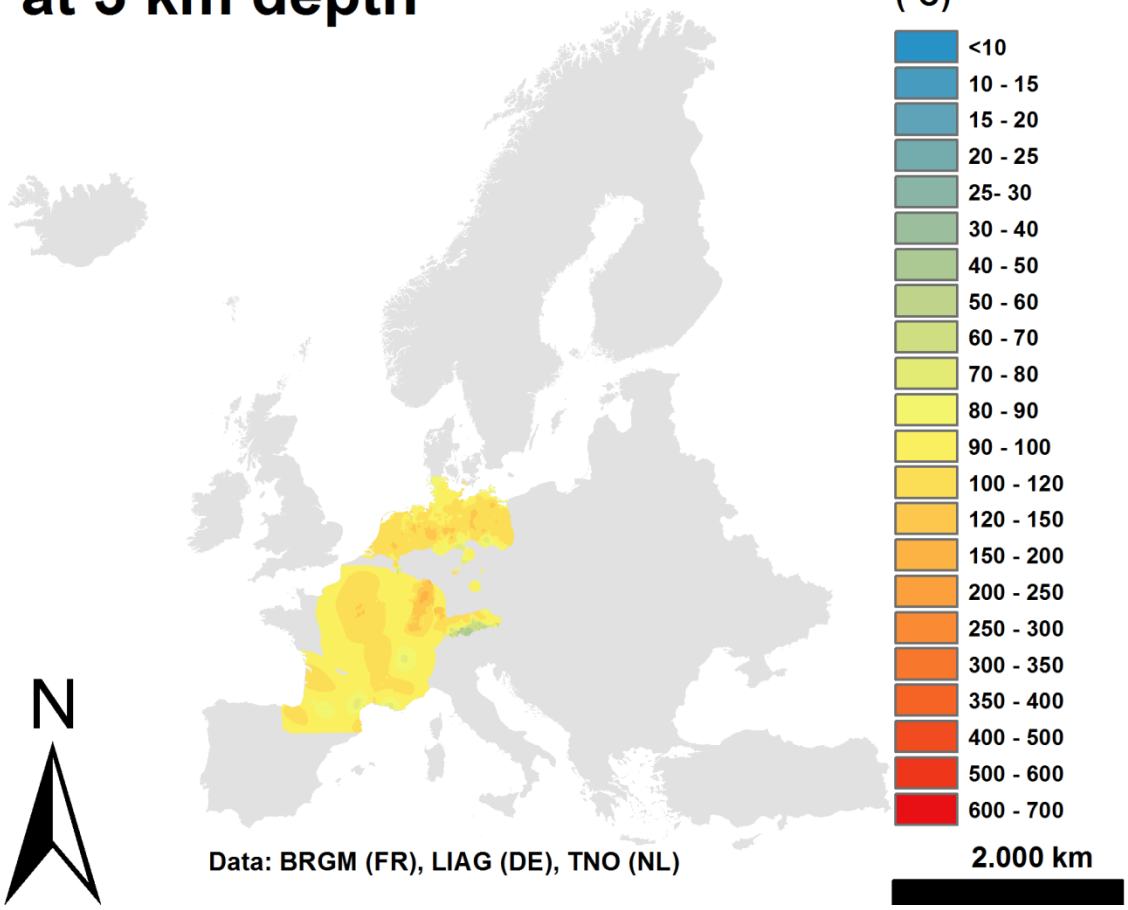

Data: BGS (UK), BRGM (FR), CSA (IE), LIAG (DE), TNO (NL), Hurter et al. 2002 Geothermal Atlas (EU)

# Temperature Constraints at 2 km depth

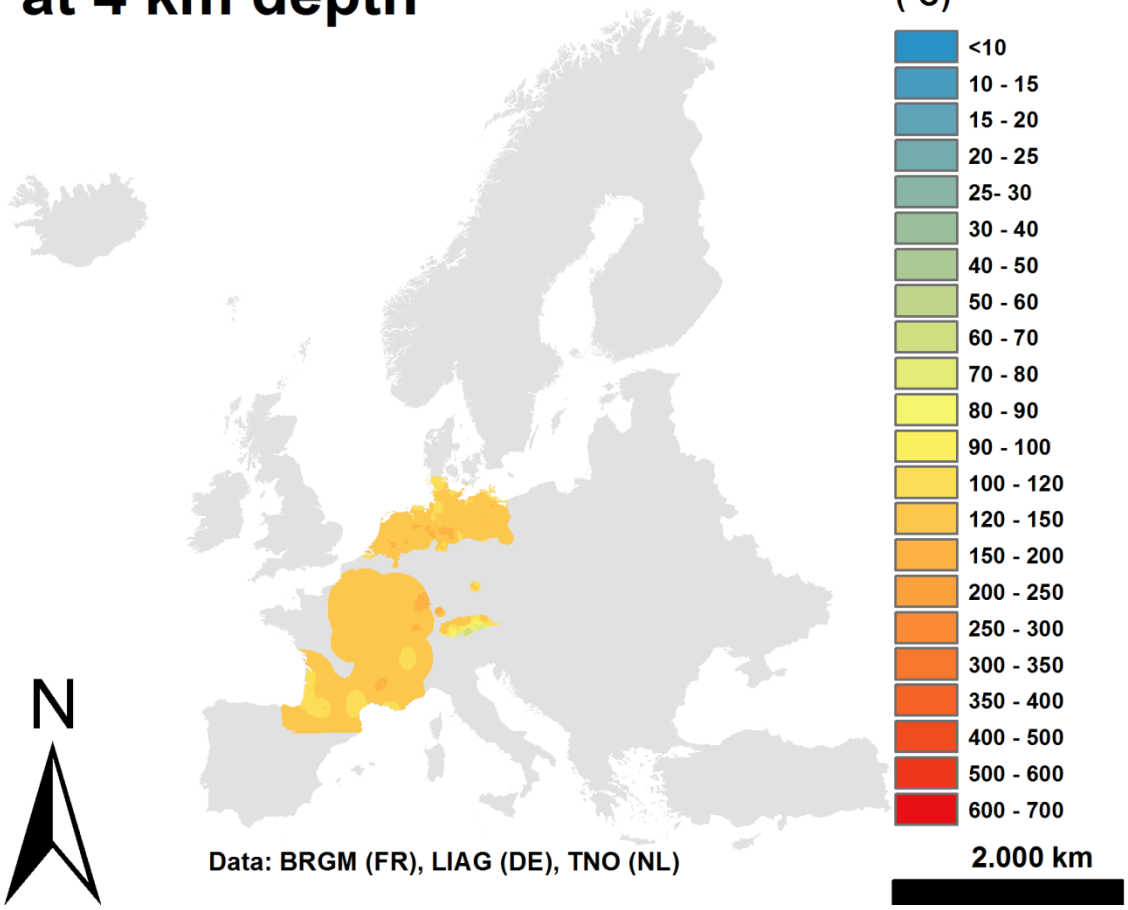



Data: BRGM (FR), LIAG (DE), TNO (NL),
Hurter et al. 2002 Geothermal Atlas (EU)

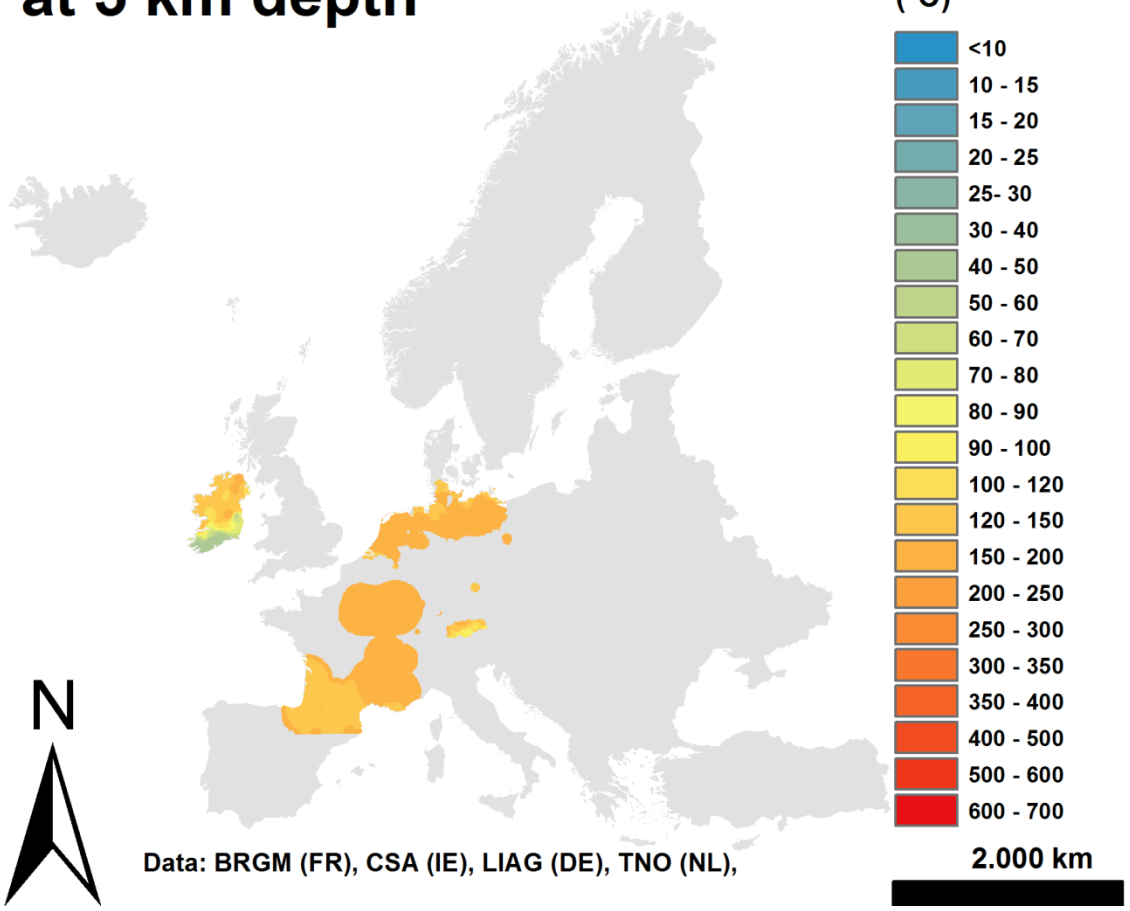
# Temperature Constraints at 3 km depth



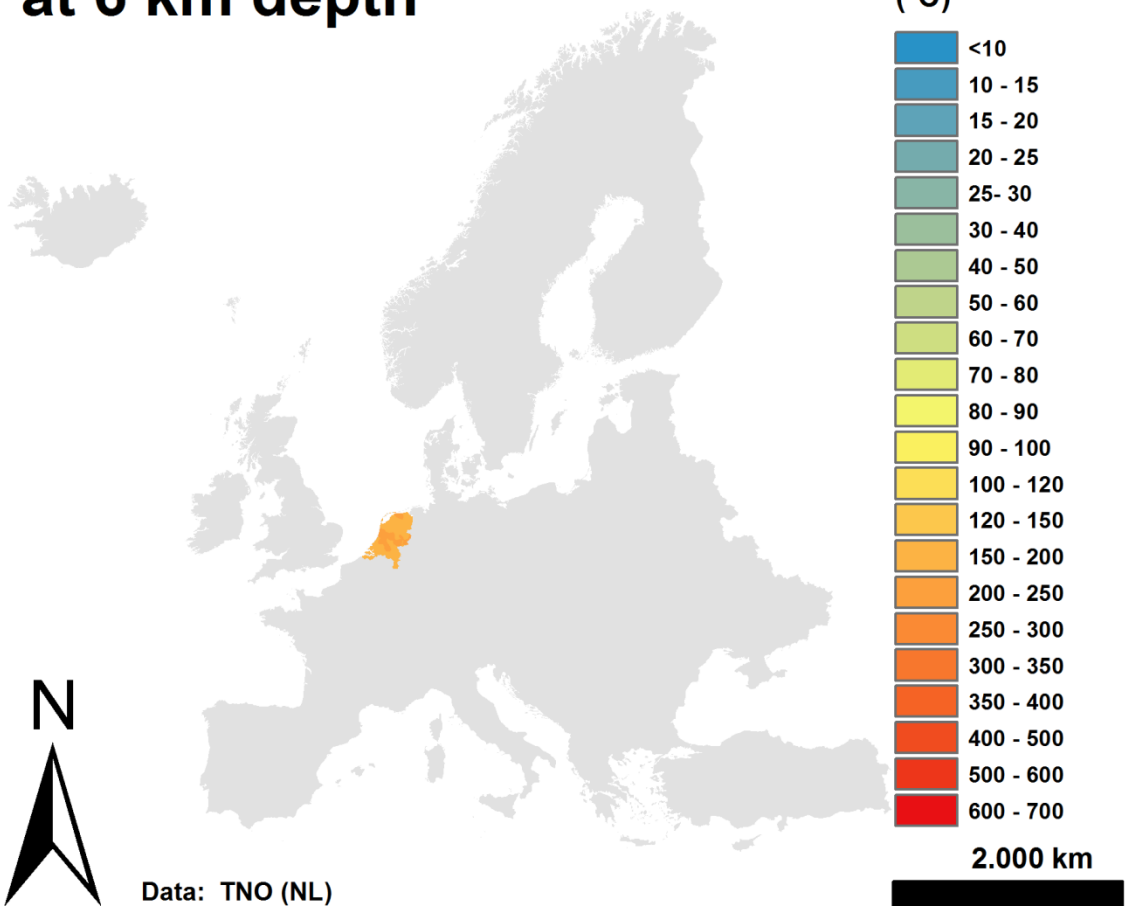
# Temperature Constraints at 4 km depth



# Temperature Constraints at 5 km depth

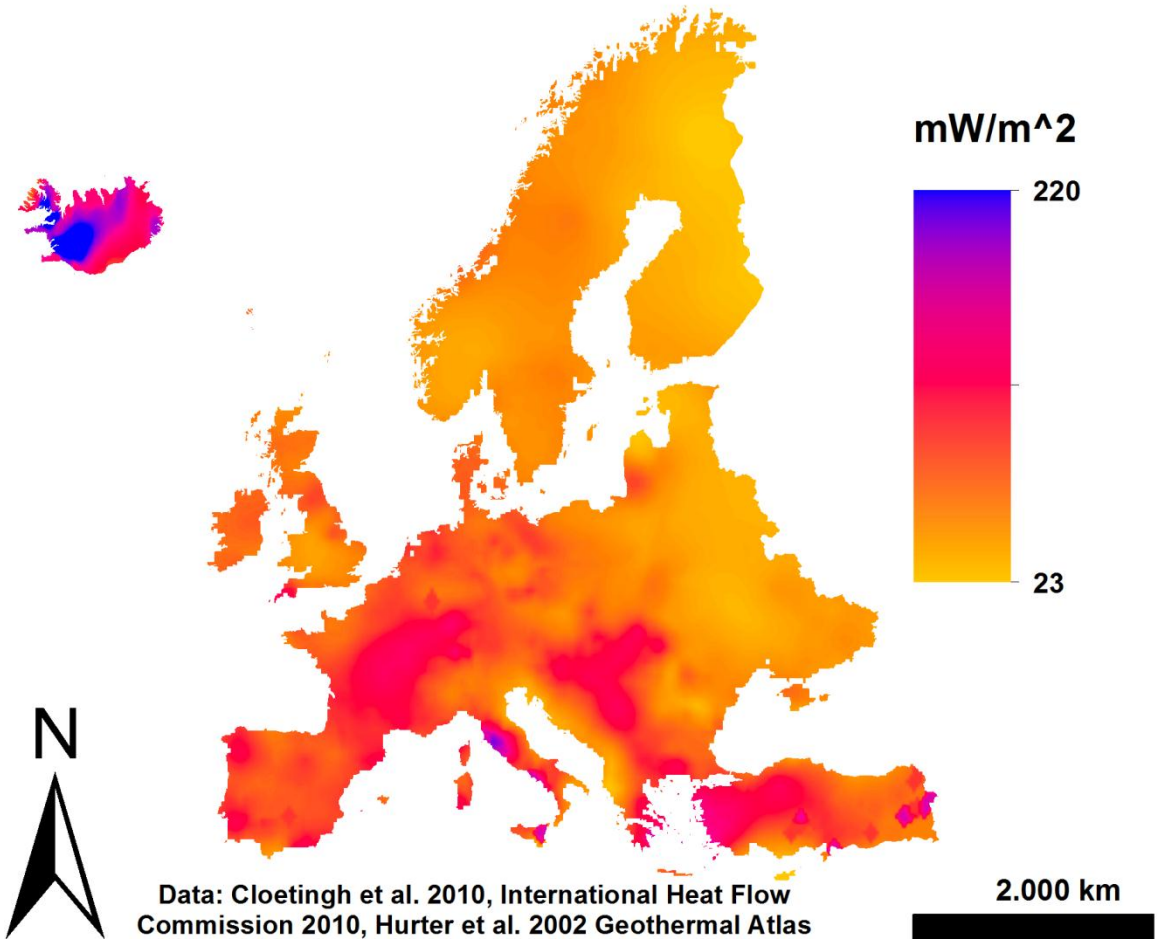


# Temperature Constraints at 6 km depth



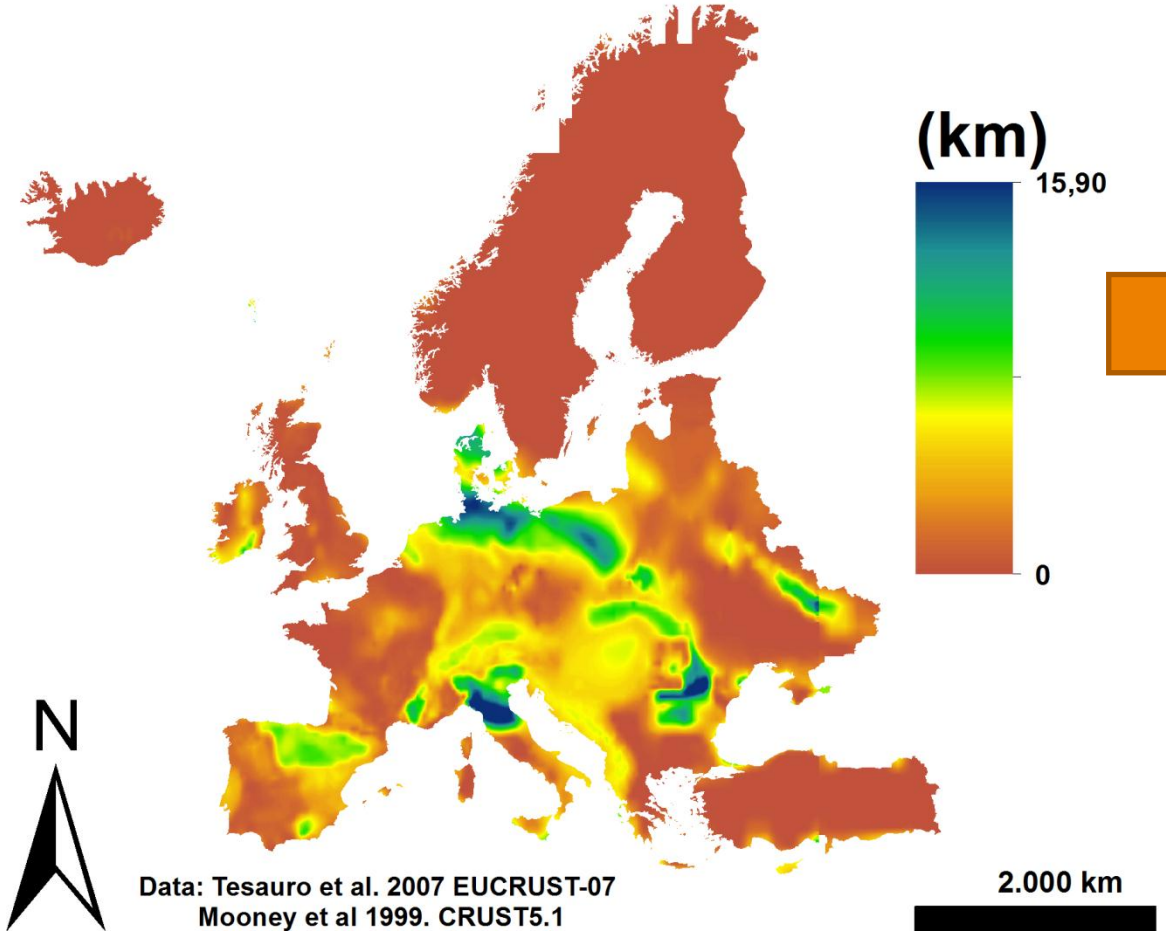
# Boundary condition at Base -->

## Surface Heat Flow



## Populating model with thermal properties (cf. beardsmore, 2011)

# Sediment Thickness




$K_{sed}$ = 2.5

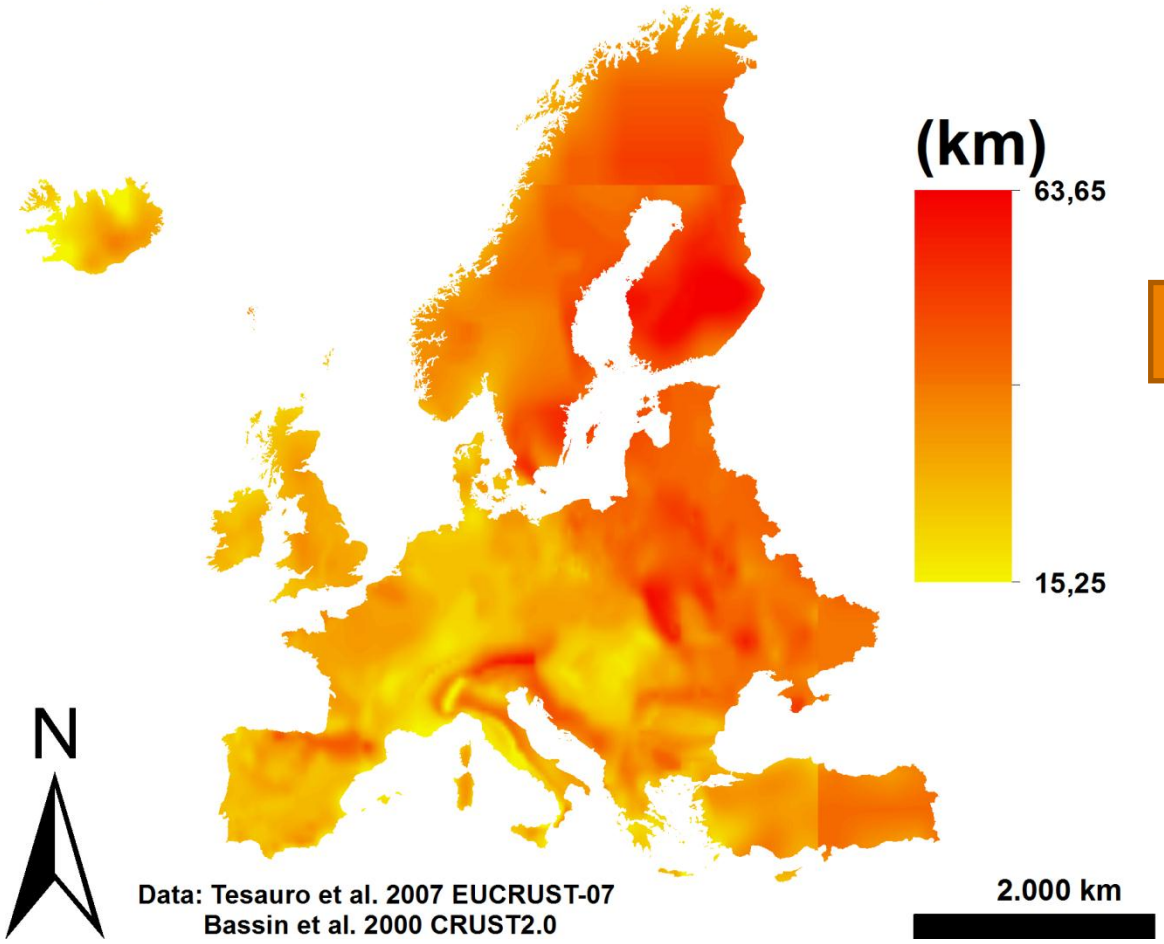
$K_{bsmt}$ = 2.14

$A_{sed}$ = 1

$A_{bsmt}$ = 2.65

## Populating model with thermal properties (cf. Cloetingh et al., 2012)

# Depth of the Moho



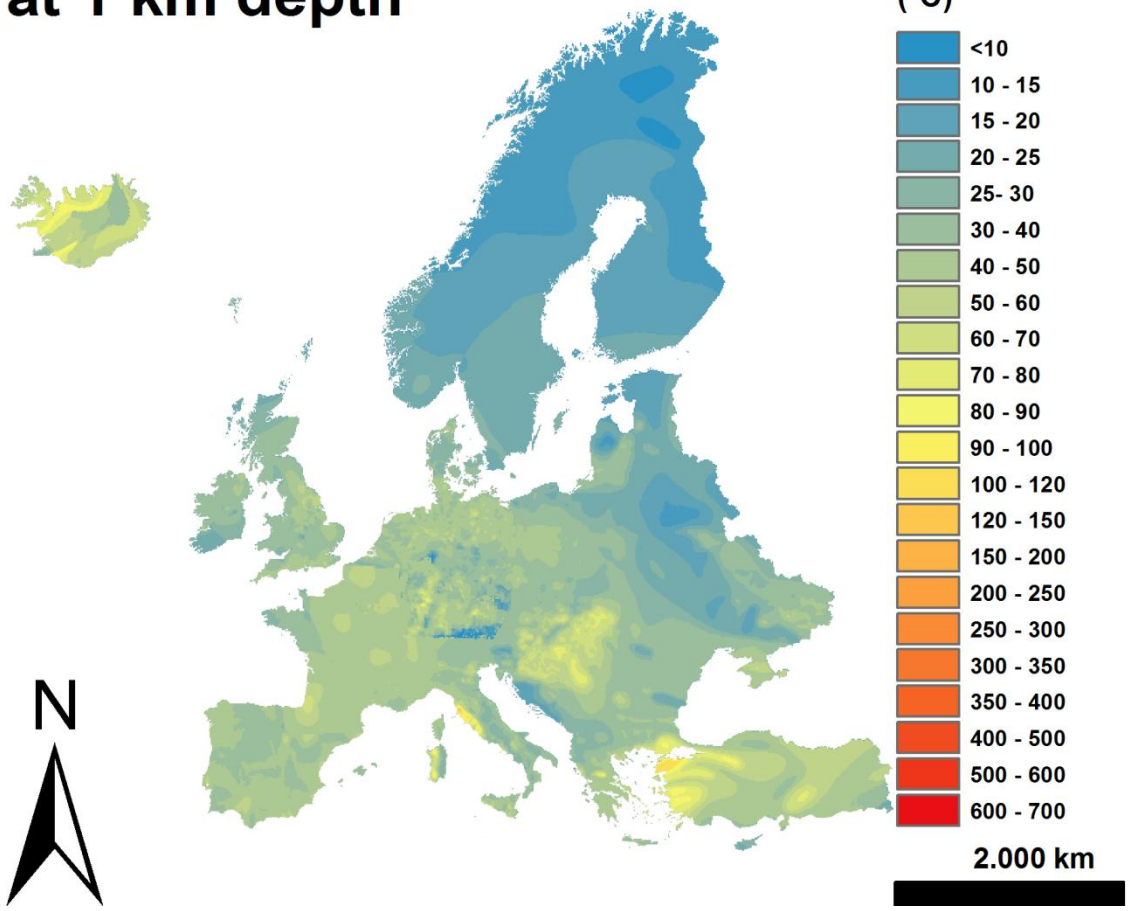

$K_{sed}$ = 2

$K_{bsmt}$ = 2.6

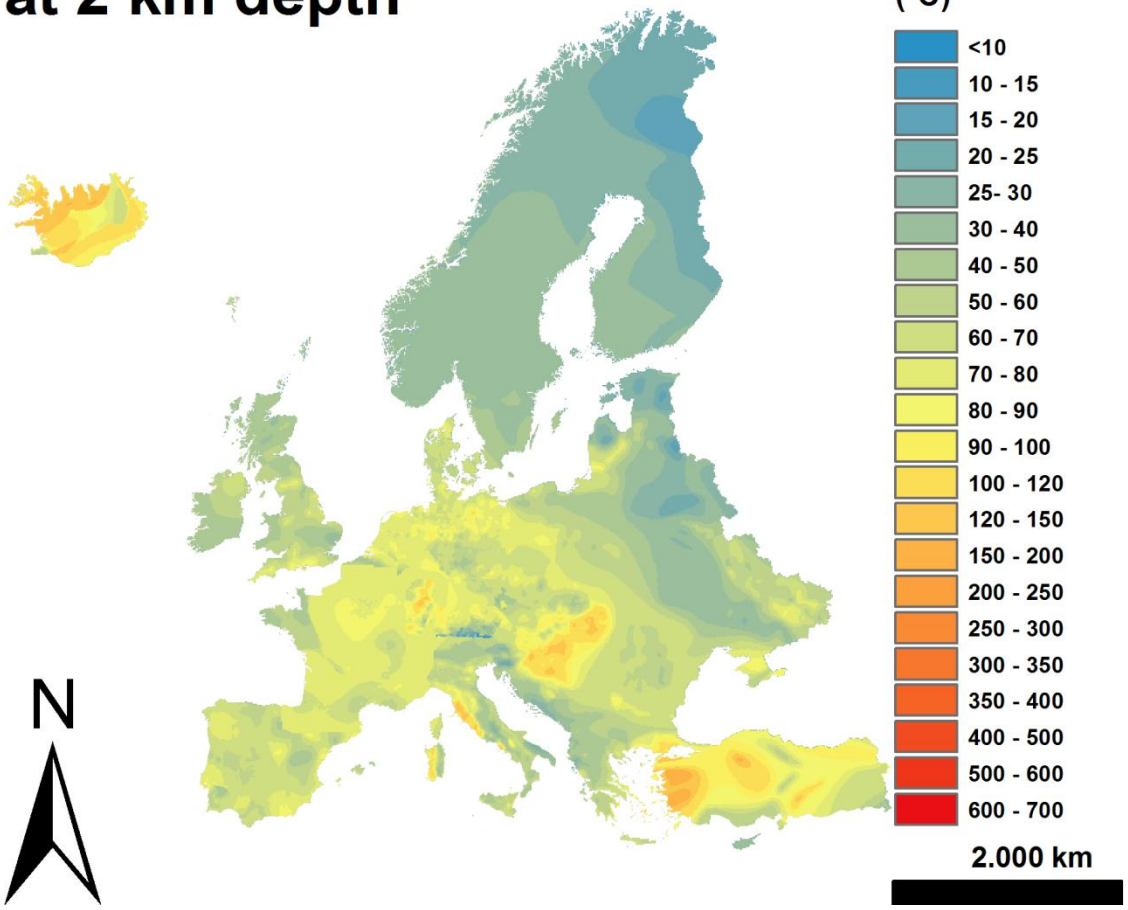
$A_{sed}$ = 40% HF

$A_{bsmt}$ = 40% HF

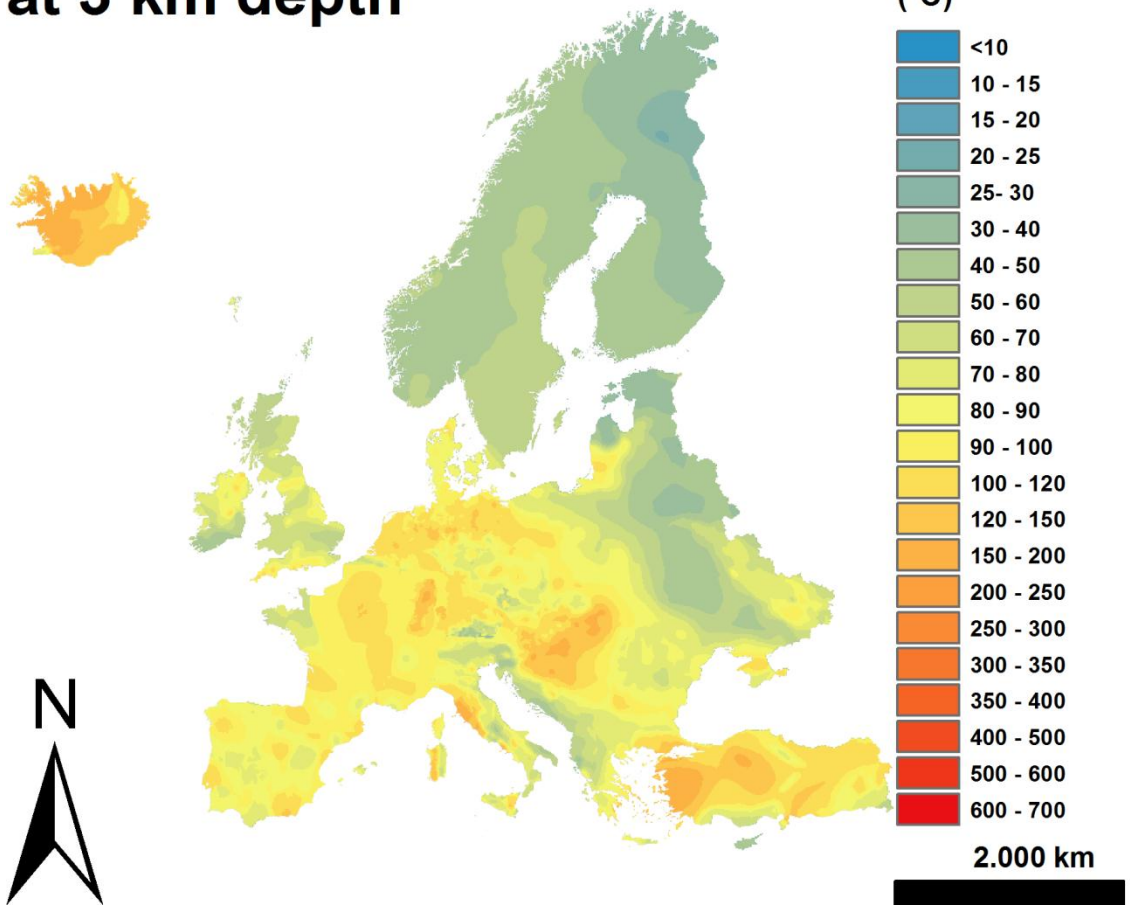
# Modeled Temperature at 1 km depth



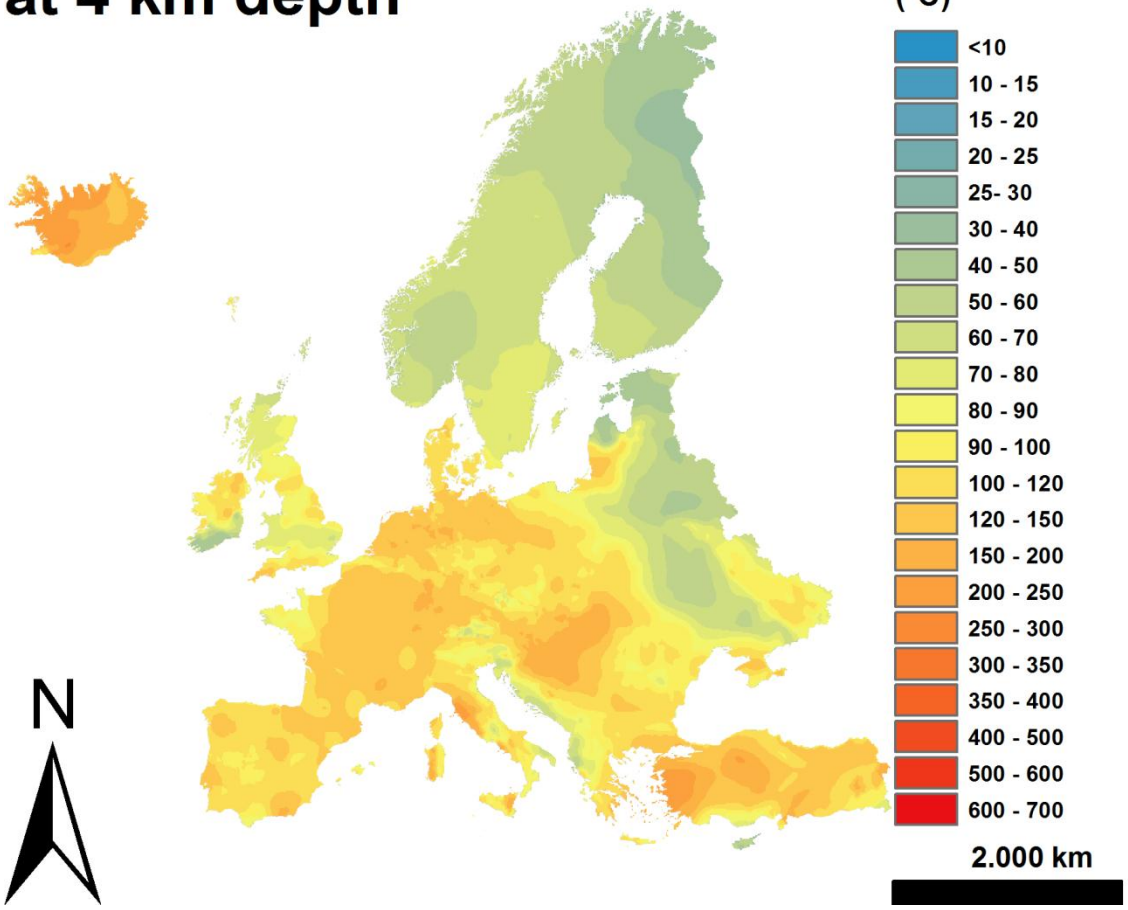
# Modeled Temperature at 2 km depth



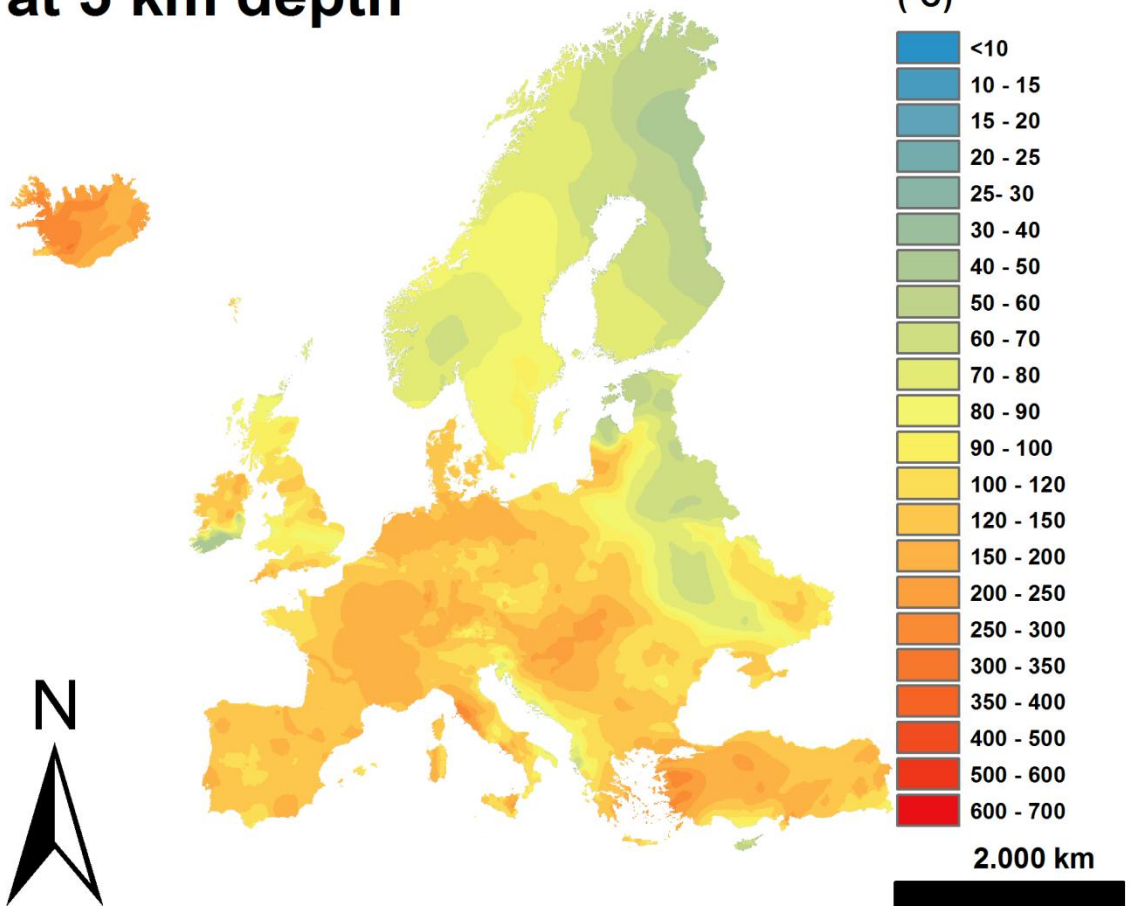
# Modeled Temperature at 3 km depth



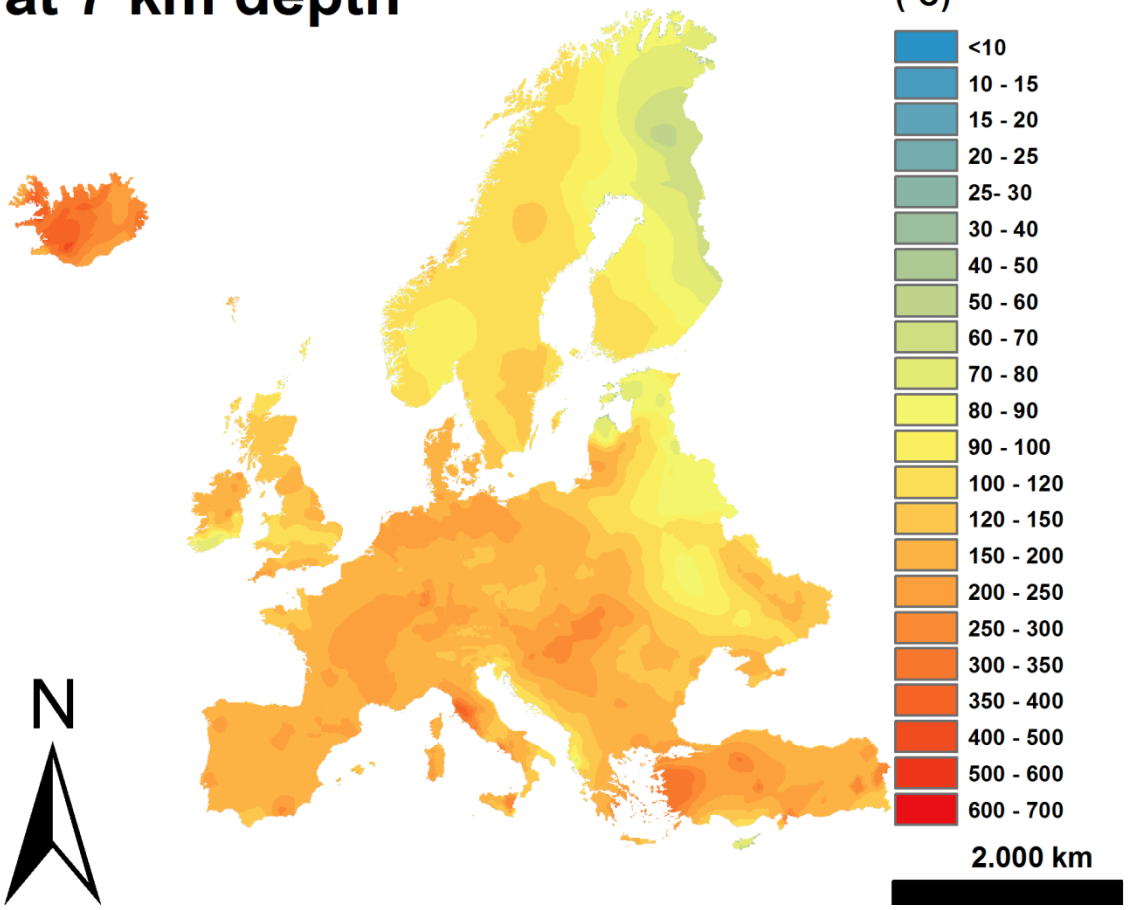
# Modeled Temperature at 4 km depth



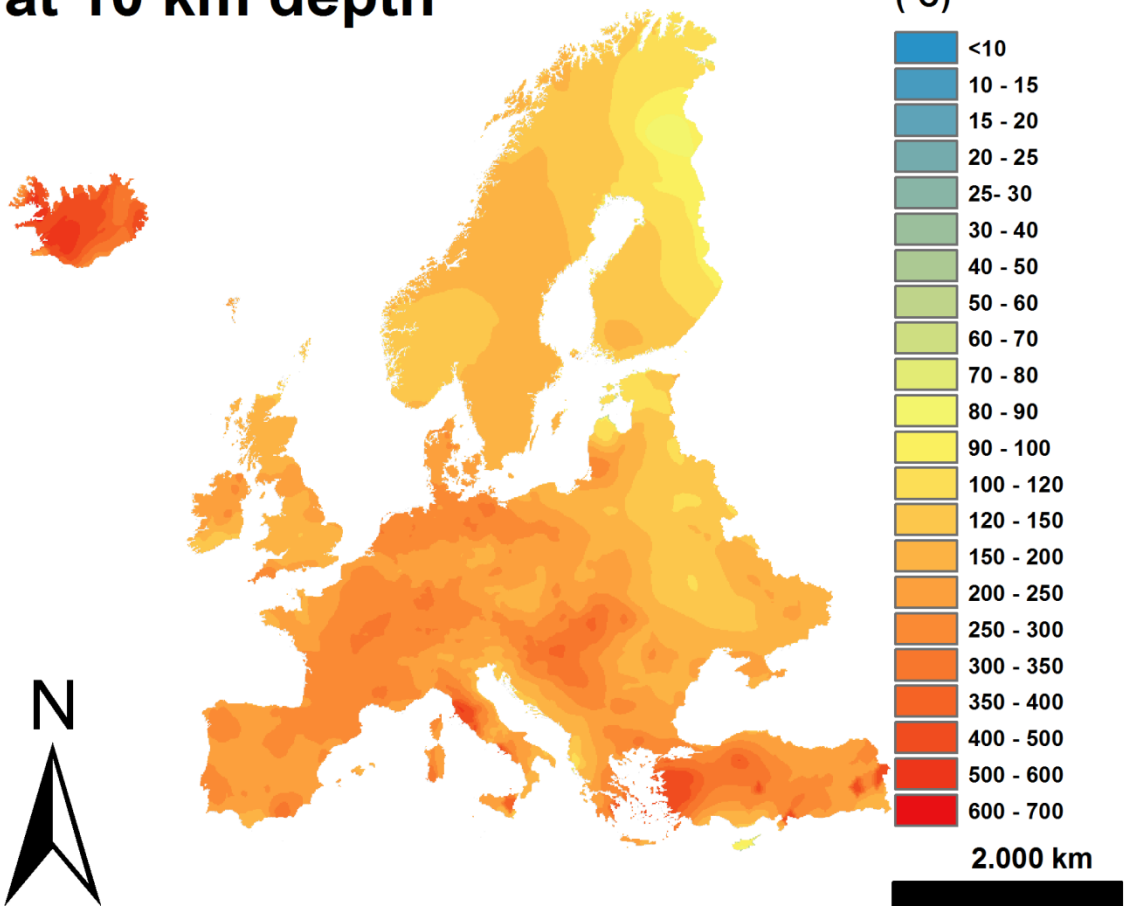
# Modeled Temperature at 5 km depth



# Modeled Temperature at 7 km depth

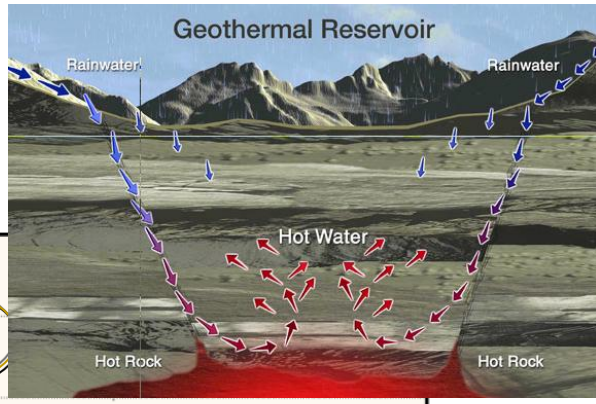


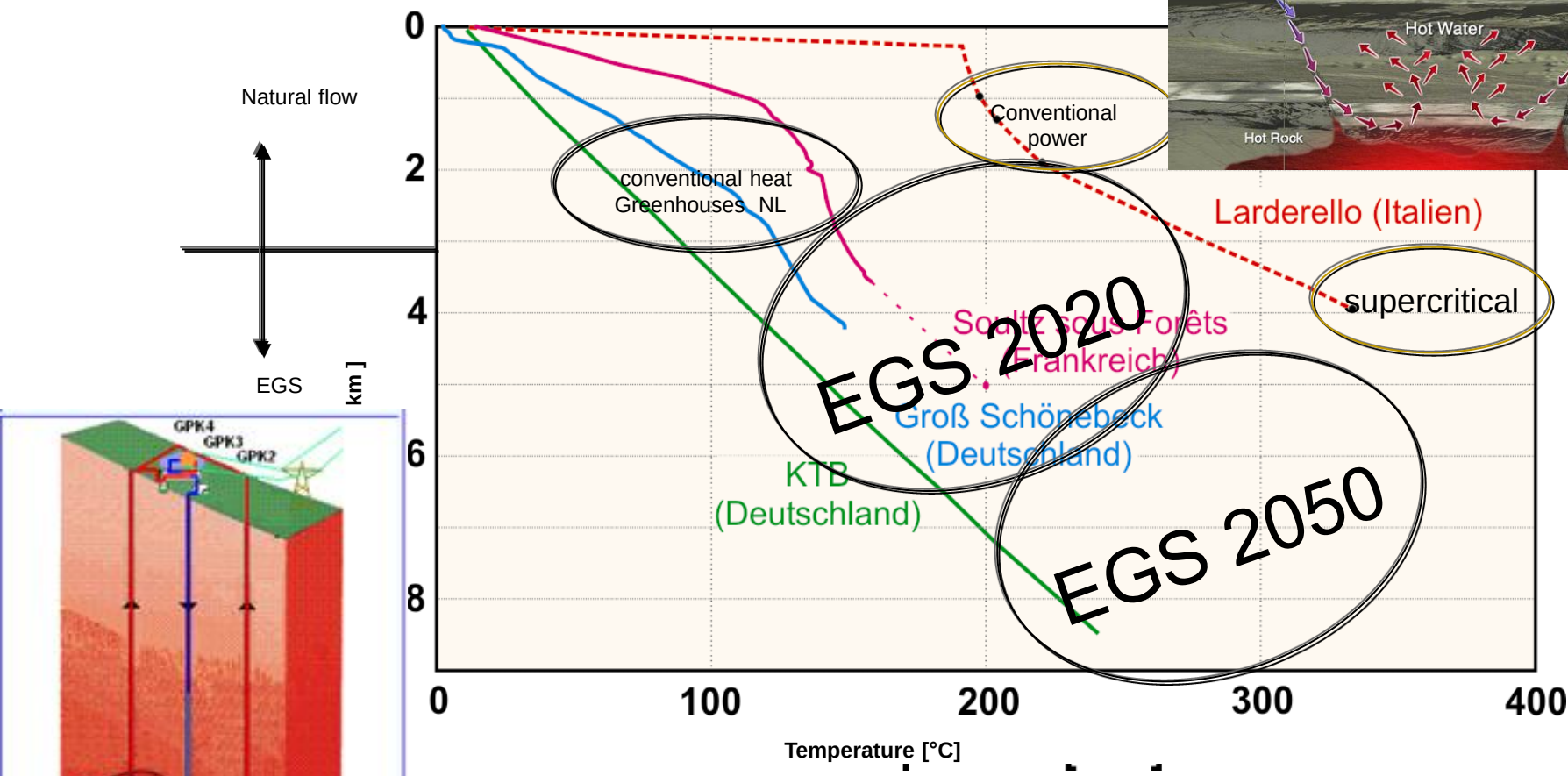
# Modeled Temperature at 10 km depth

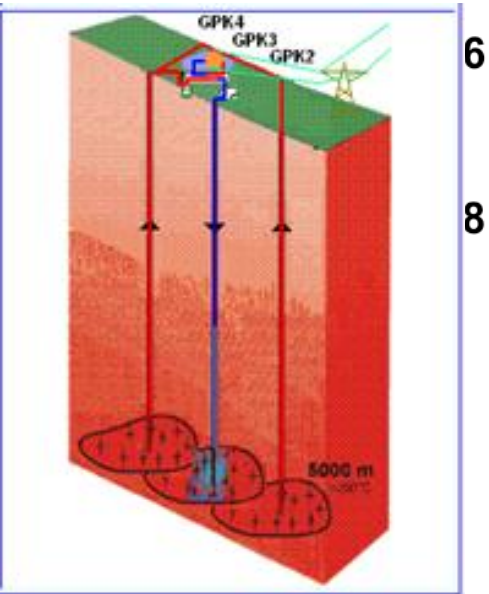


# Geothermal energy:

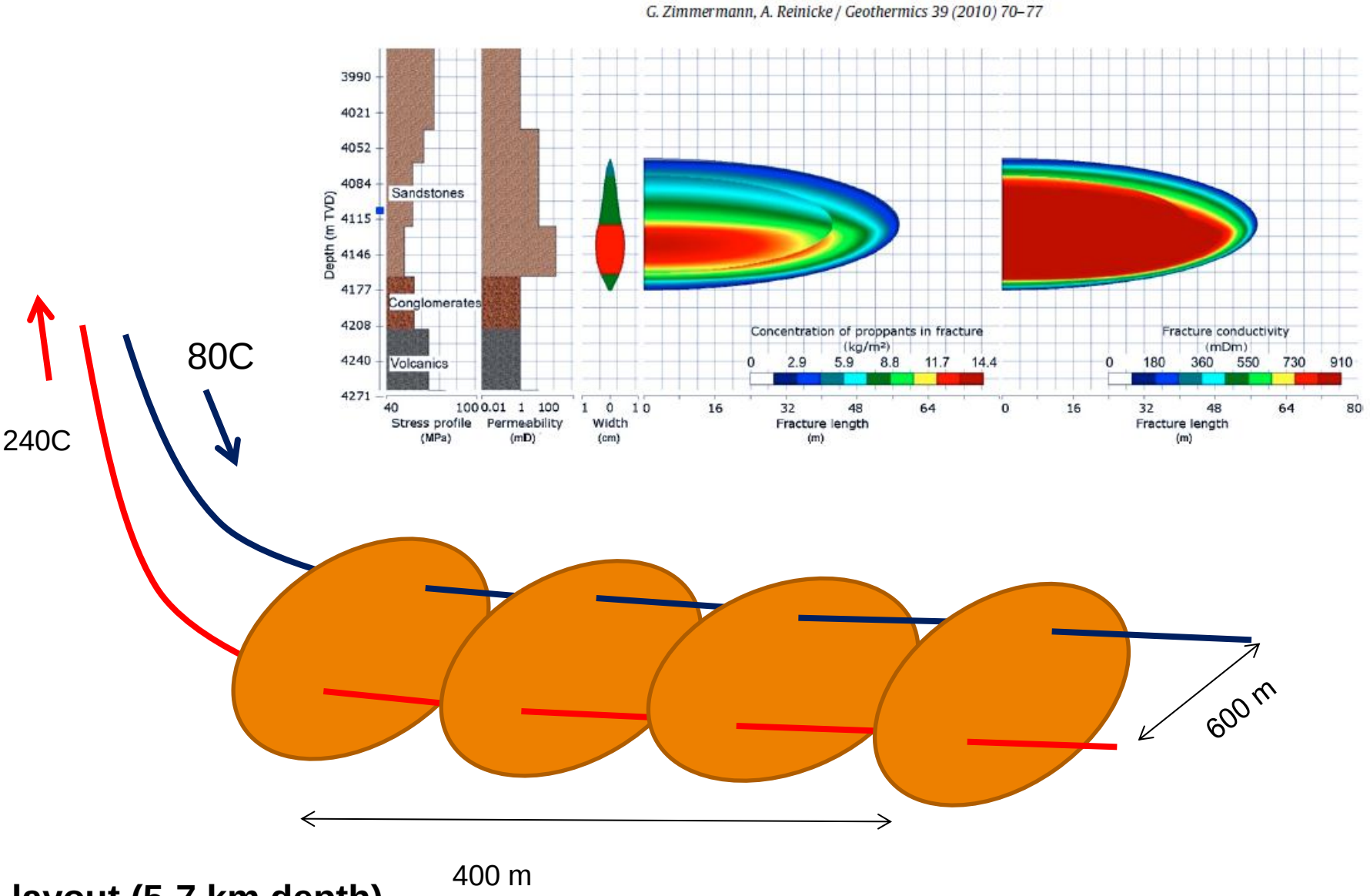
**Conventional:**
2% worldwide electricity 2050
5% RE NL 2020




**Enhanced geothermal systems (EGS):**
2% worldwide electricity 2050




**Well layout (5-7 km depth)**

Calculation of LCOE of renewable heat and electricity

# Geothermal Energy

Operational choice: power

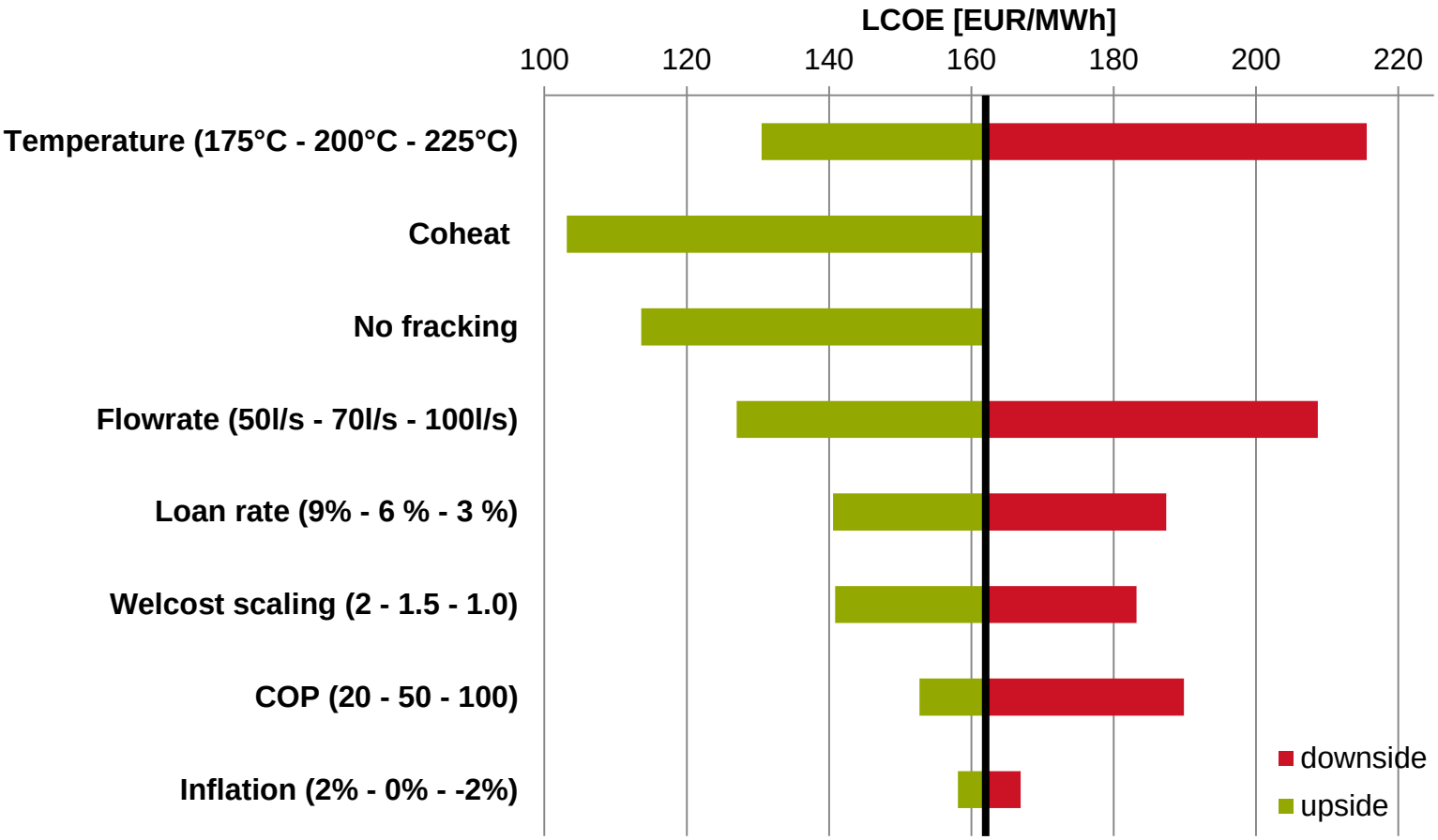
| INPUTVARIABLES | used | Value | Unit | Comment |
|---|---|---|---|---|
| Flowrate | 1 | 50 | L/s | total flow rate which is achieved from the subsurface (measured at surface conditions) |
| along hole depth of a single well | 1 | 5000 | m | along hole depth (total length) of a single borehole in the subsurface |
| Surface temperature | 1 | 11 | C | average yearly surface temperature |
| production temperature (Tx) | 1 | 166 | C | production temperature (reservoir temperature, corrected for temperature losses) |
| Economic lifetime | 1 | 15 | Years | lifetime for cash flow calculations |
| **subsurface** | | | | |
| well cost scaling factor | 1 | 1.2 | - | scaling factor for calculating well costs |
| well costs | 1 | 11 | mln euro/Well | calculated costs for drillling the wells |
| Stimulation and other Cost | 1 | 1 | mln euro/Well | additional well costs for stimulation (and other costs) of the reservoir |
| Pump investment | 1 | 0.6 | Mln euro/pump | pump investements. Workover is assumed every 5 years at installment costs |
| Number of wells | 1 | 2 | - | number of wells in the reservoir |
| subsurface capex | 1 | **23.6** | mln euro | calculated subsurface capex for wells, stimulation and pumps |
| **subsurface parasitic** | | | | |
| COP | 1 | 15 | - | coefficient of performance (MWth/MWe) to drive the pumps. Ratio of thermal and electric power |
| electricity price for driving the pumps | 1 | 110 | euro /MWhe | electricity price for the power consumed by the subsurface pumps |
| Variable O&M | 1 | 7.333333333 | euro/MWhth | calculated variable O&M per unit of heat produced (1MWhth=3.6GJ) |
| **power temperature range used** | | | | |
| (co) heat relative starting temperature | 0 | 0% | % | relative value (100%= Tx,0%=Tbase) for upper limit of temperature range for heat |
| outlet temperature power plant (Toutlet) | 1 | 91 | C | upper limit of Temperature for (co)heat use |
| **power surface facilities** | | | | |
| thermal power for electricity | 1 | **17.181** | MWth | net power produced, taking into account the relative efficiency recorded by operating binary and |
| electric power | | 2.209 | MWe | net power produced, taking into account the relative efficiency recorded by operating binary and |
| power Loadtime | 1 | 8000 | hours/year | effective load hours in a year for electricity production |
| power Plant investment costs | 1 | 2.000 | mln Euro/MWe | costs for power conversion system |
| power Distance to grid | 1 | 5000 | m | distance for the connection to the power grid |
| power Grid investment | 1 | 80 | Euro/kWe | grid connection cost per unit of power installed |
| power Grid Connection Variable | 1 | 100 | Euro/m | grid connection cost per unit of distance |
| power plant capex | 1 | **5.095** | mln Euro | calculated capex for power plant and grid connection |
| power Fixed O&M rate | 1 | 1% | % | O&M costs as percentage of caclulated capex for (sub)surface facilities |
| power Fixed O&M | 1 | 29 | kEuro/MWe | calculated O&M costs per unit of power installed |
| power Variable O&M | 1 | 57.0344086 | Euro/MWhe | calculated variable O&M costs (dependent on COP, and efficiency of conversion) |

| (co)heat surface facilities | | | | |
|---|---|---|---|---|
| direct heat reinjection temperature(Treinject) | 0 | 40 | C | reinjection temperature (effective temperature range is Toutlet..Treinject) |
| direct heat production | 0 | 0.000 | MWth | heat production |
| direct heat load hours | 0 | 5500 | hours/year | effective load hours in a year for heat production |
| direct heat plant investment costs | 0 | 150.000 | kEuro/MWth | heat surface installation costs per unit of heat production |
| direct heat capex | 0 | **0.00** | mln Euro | calculate capex for heat production surface facilities |
| direct heat Fixed O&M rate | 0 | 3% | % | O&M costs as percentage of caclulated capex for (sub) surface facilities |
| direct heat Fixed O&M | 0 | 59 | kEuro/MWth | calculated O&M costs per unit of heat production installed |
| direct heat Variable O&M | 0 | 7.333333333 | Eur/MWHth | calculated variable O&M costs (dependent on COP) |
| **complementary sales** | | | | |
| complementary electricity sales | 1 | 0.00 | Euro/MWh | complementary revenues from electricity sales |
| complementary heat sales | 1 | 0 | euro/GJ | complementary revennues from heat sales |
| **fiscal stimulus** | | | | |
| fiscal stimulus on lowering EBT | 1 | **yes** | yes/no | apply fiscal stimulus on lowering earnings before tax (EBT) of the project developer |
| percentage of CAPEX for fiscal stimulus | 1 | 42% | % | percentage of CAPEX which can be deducted from EBT |
| legal max in allowed tax deduction | 1 | 63 | mln Euro | legal maximum in tax benefit |
| NPV of benefit to project | 1 | 2.8 | mln Euro | effective benefit to project |
| | | | | |
| Inflation | 1 | 3% | % | inflation for costs and benefits in project cash flow |
| loan rate | 1 | 6.0% | % | interest rate on debt |
| Required return on equity | 1 | 15% | % | required return on equity |
| Equity share in investment | 1 | 20% | % | share of equity in the effective investment |
| Debt share in investment | 1 | 80% | % | share of debt(the loan) in effective investment |
| Tax | 1 | 25.5% | % | tax rate for company |
| | | | | |
| Term Loan | 1 | 15 | Year | number of years for the loan |
| Depreciation period | 1 | 30 | Year | number of years for depreciation (linear per unit of production) |

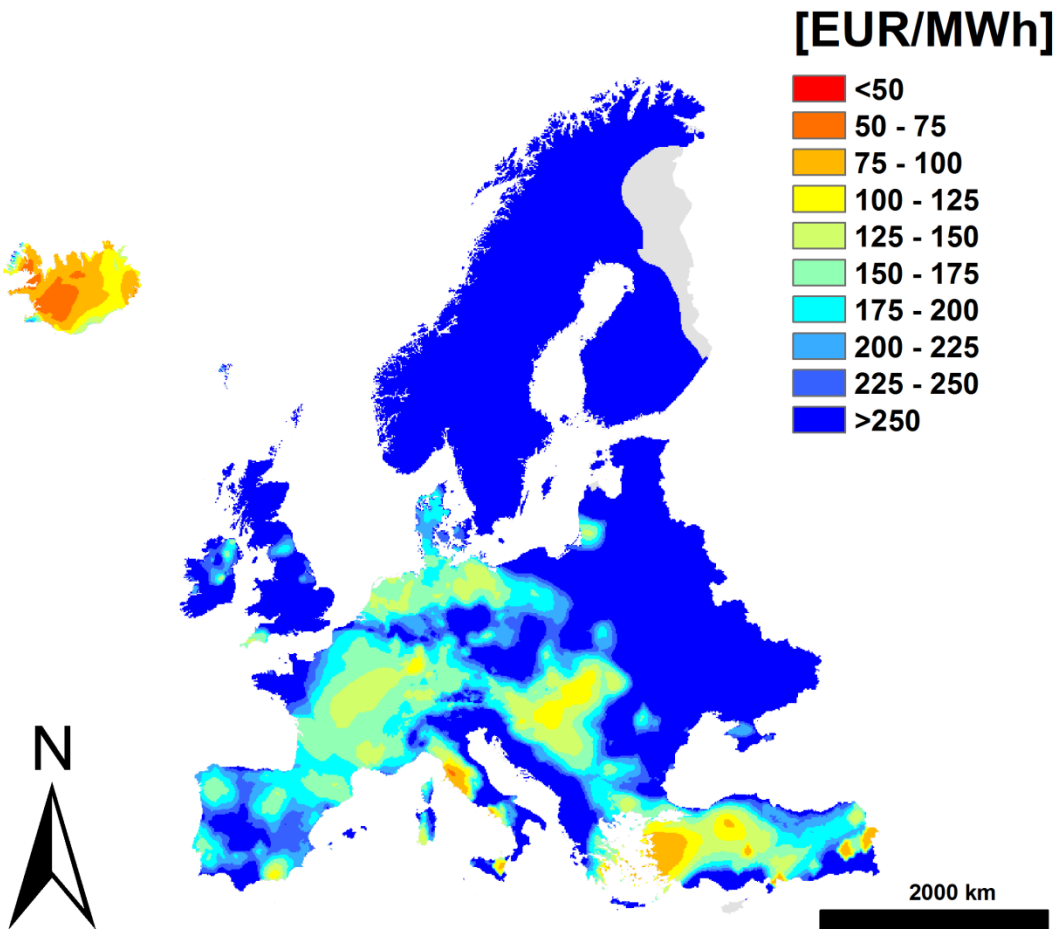
| POWER (power,co-heat) | used | Value | Unit |
|---|---|---|---|
| levelized cost of energy (LCOE) | 1 | 267.48 | Euro/Mwhe |

| HEAT SHEET (heat) | | Value | Unit |
|---|---|---|---|
| levelized cost of energy (LCOE) | 0 | 0.00 | Euro/GJ |
| | | | 1MWhth=3.6GJ |

# Sensitivity Analysis LCOE: upper rhine Graben



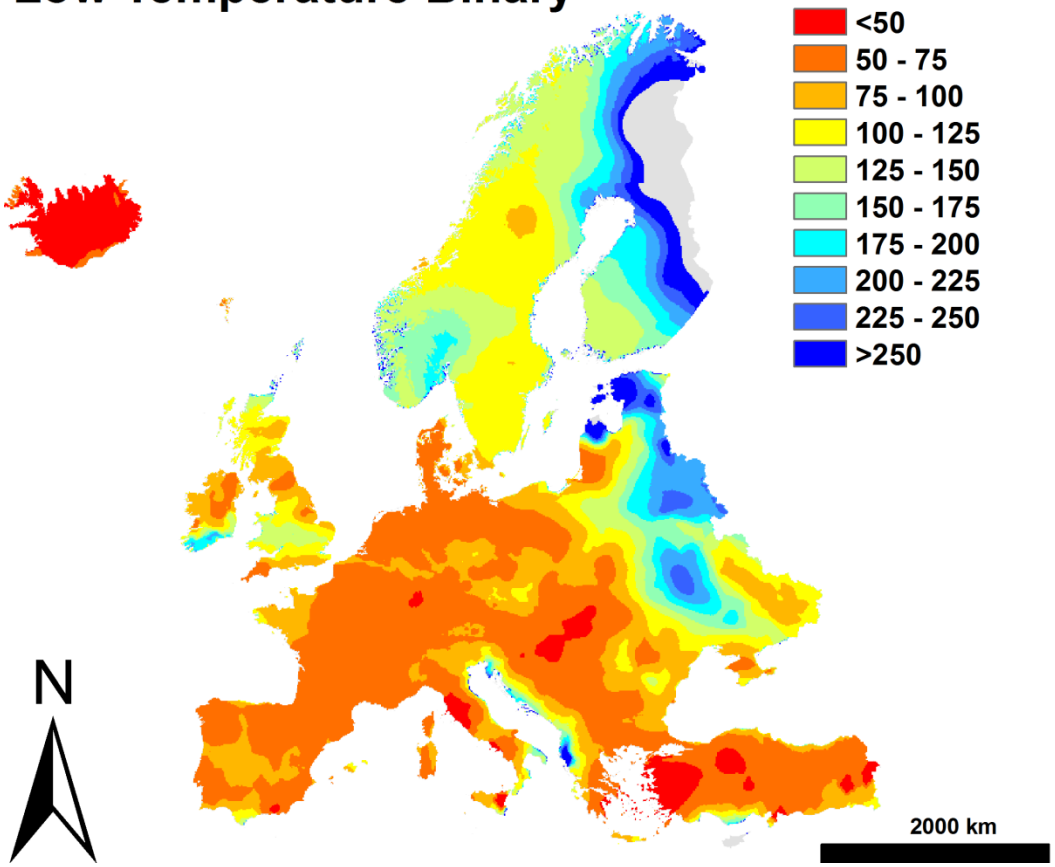
## Minimal LCOE EGS 2020




Assumptions:

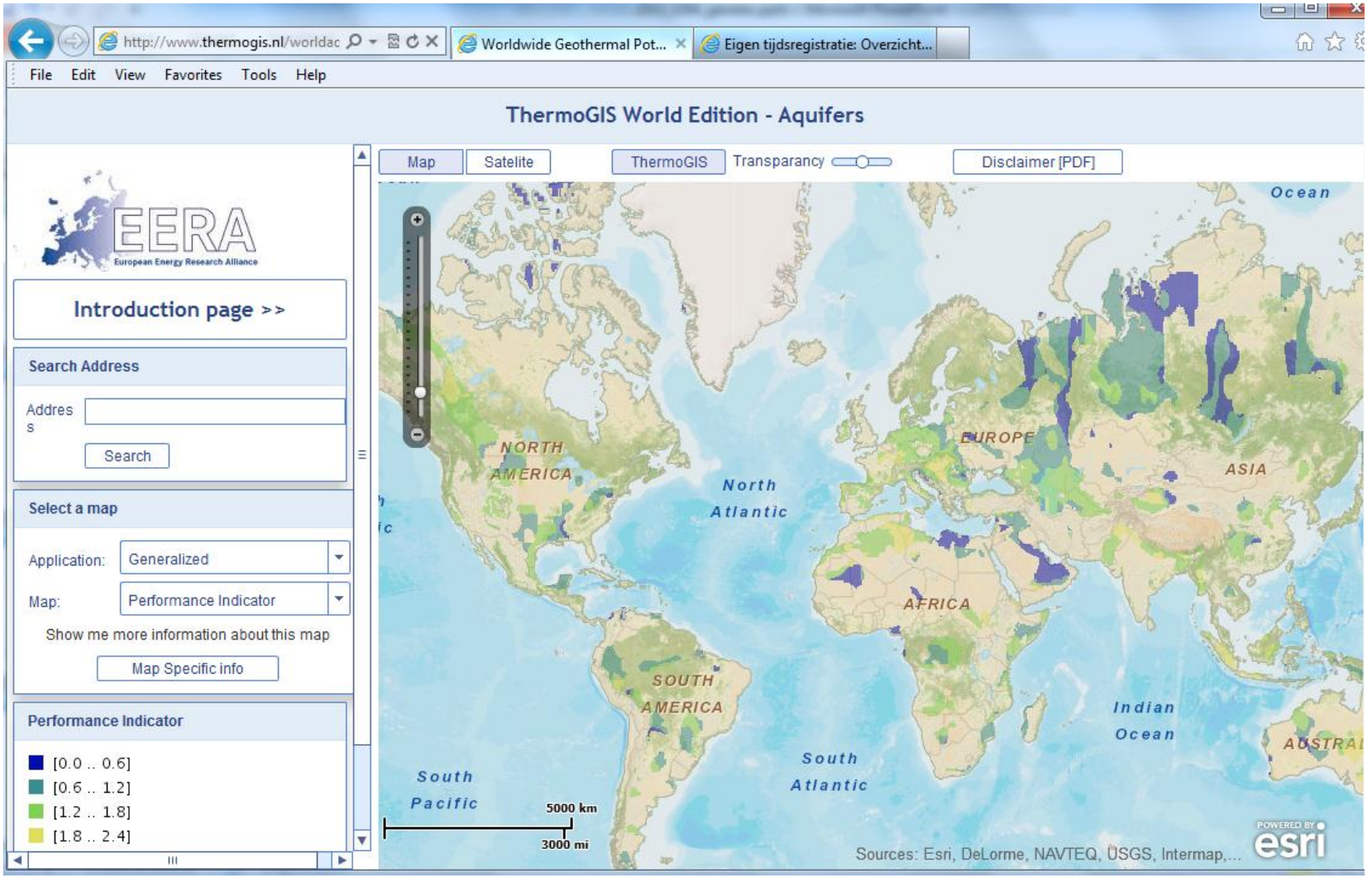
- Doublet
- COP = 50
- Tmin = 100°C
- Flow rate = 70 l/s
- Welcost scaling = 1.5
- Zmax = 7km
- Stimulation costs = 20M euro

## Minimal LCOE EGS 2050: Flame Drilling and Low Temperature Binary




Assumptions:

- Doublet
- COP = 1000
- Tmin = 100°C
- Flow rate = 100 l/s
- Welcosts = €1.500/m
- Zmax = 10km
- Stimulation costs = 20M euro
- Carnot efficiency = 70%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Map: Performance Indicator
Show me more information about this map
Map Specific info
Performance Indicator
[0.0 .. 0.6]
[0.6 .. 1.2]
[1.2 .. 1.8]
[1.8 .. 2.4]
Ocean
NORTH AMERICA
North Atlantic
EUROPE
ASIA
AFRICA
SOUTH AMERICA
Indian Ocean
South Atlantic
South Pacific
5000 km
3000 mi
Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap,...
POWERED BY esri

# The resource assessment and exploration

- Public access to relevant data is important
- Access to data is not harmonized in EU
- Public access to other datasets than discussed here is very important to improve exploration and production (level 1 and level 2)
  - Oil and gas exploration and production data in general
  - Rock Properties (thermal, flow, chemical, …)
  - Stress
  - Fault and fractures
  - Natural seismicity
  - Structural and compositional models