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A Methodology for Resource assessment and application to core countries

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Integrated over volume V

Practical potential

Realistic **Technical Potential [MW]**
UR2=1-2%

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

Theoretical **Technical Potential [MW]**
UR1=12.5%

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

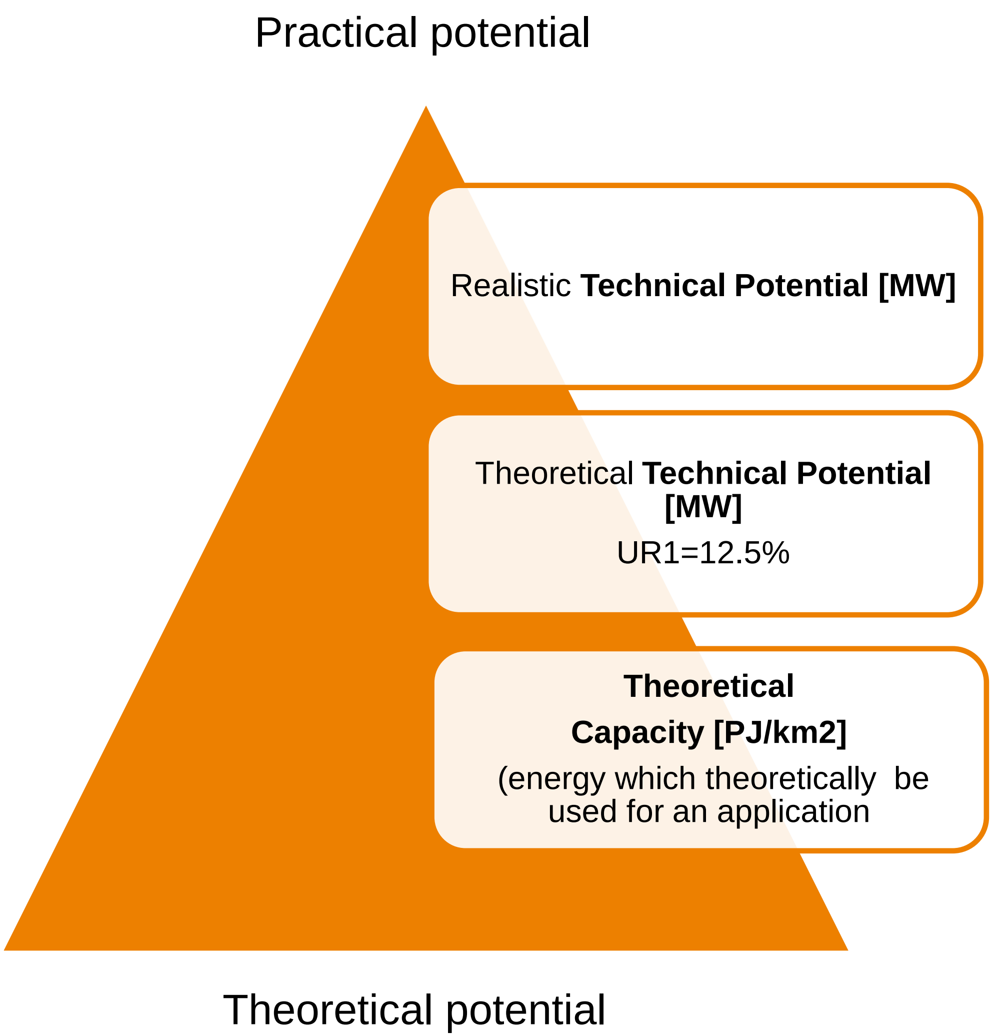
Theoretical Capacity [PJ/km2]
(energy which theoretically be used for an application

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

Theoretical potential

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

Economic potential



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

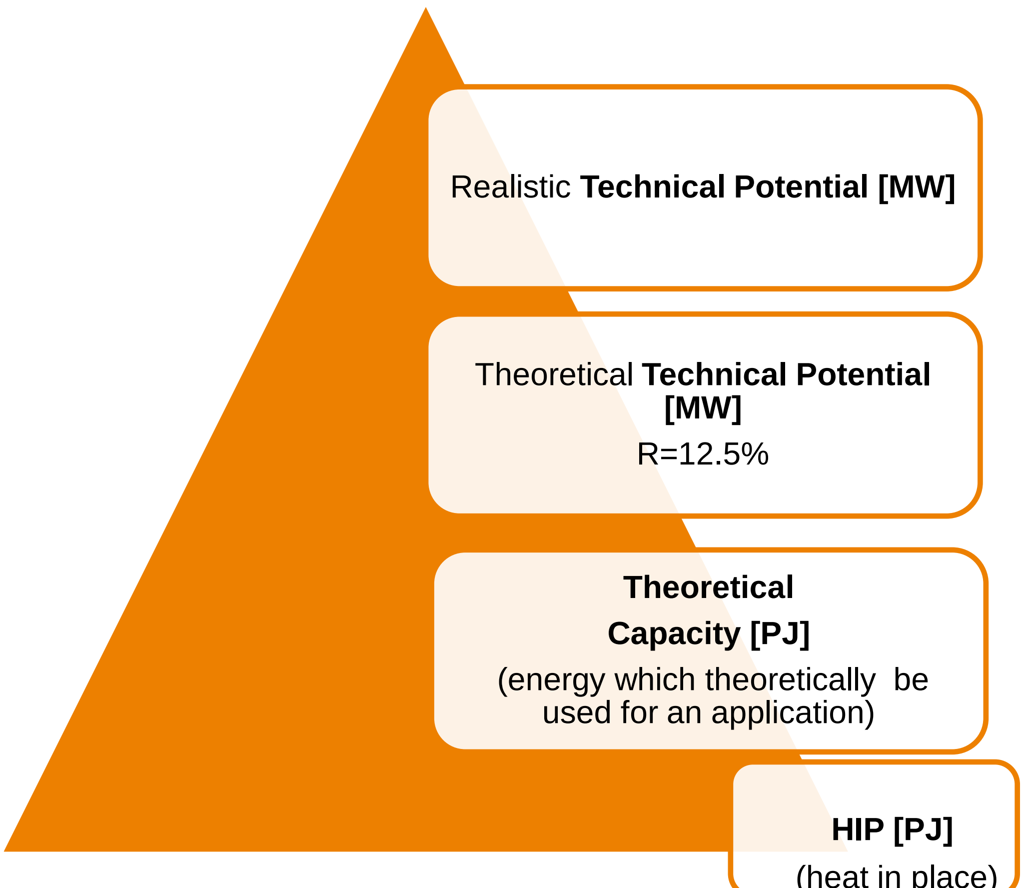
$$\text{TPplaylevel} = \frac{TC}{lifetime} UR1$$

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

Used here

Practical potential

Economic potential



Theoretical potential

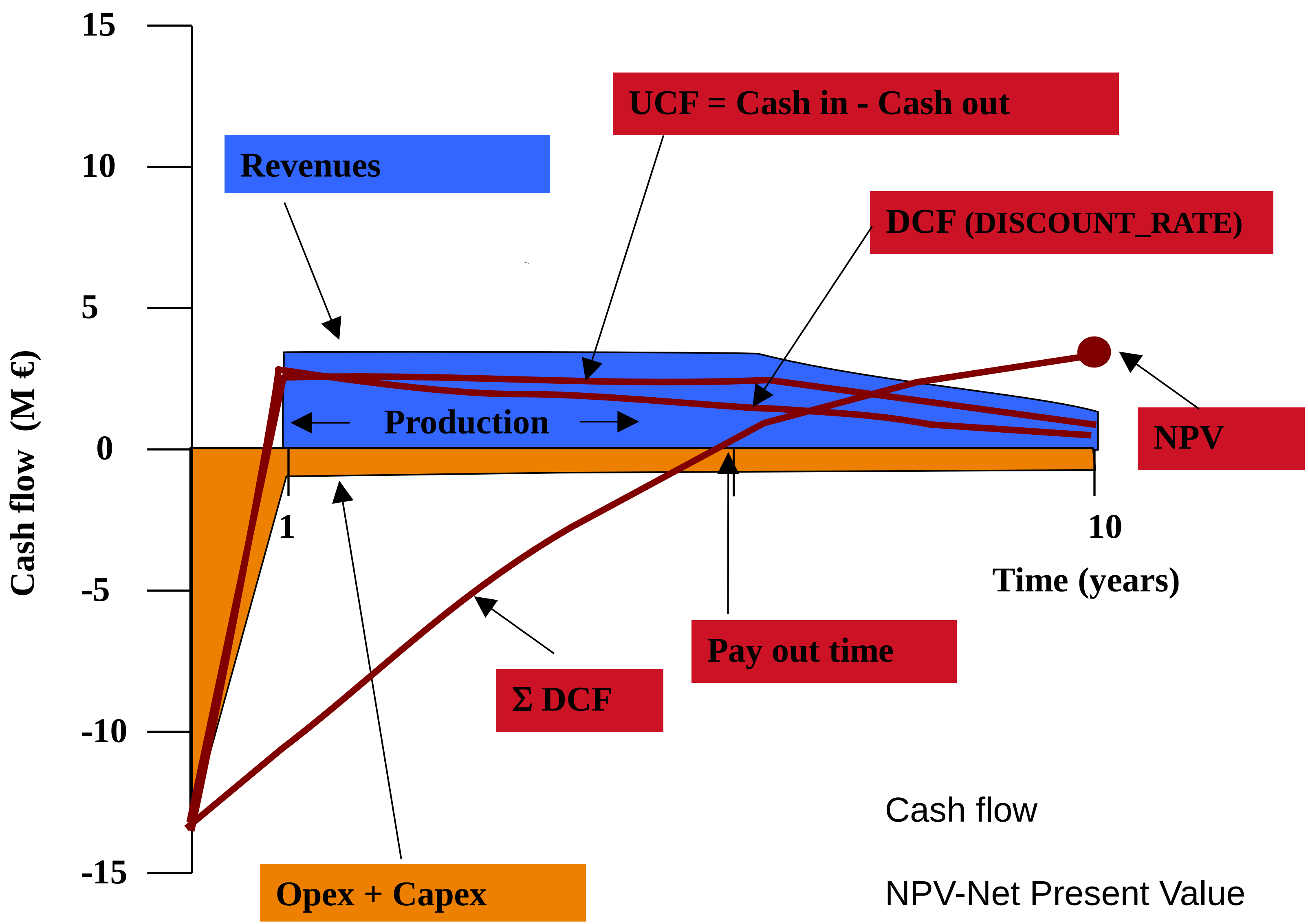
Tplcoe_c [MW/km2] = TP, if LCOE<c

TP[MW/km2] = 1.057* TC* R

$$TC\ [PJ/km2] = \square z \rho_{rock} C_{rock} (T_x - Tr) \eta\ 10^{-9}$$

HIP $[PJ/km2] = \square z \rho_{rock} C_{rock} (T_x - Ts)\ 10^{-9}$

parameter	Name	Unit
HIP	Heat in place	PJ/km2
TC	Theoretical capacity	PJ/km2
TPtheory	Theoretical Technical Potential (R=1)	MW/km2
TPbm	Technical Potential according to Beardsmore et al., 2010 (R=0.01)	MW/km2
TPreal	Technical Potential (R=0.125)	MW/km2
TPlcoe_c	Economic Technical Potential (LCOE<c) C=50,100,150,200 €/MWh	MW/km2
LCOE_c	Minimum Levelized Cost of Energy	€/MWh (electricity)
DEPTHLCOE_c	Minimum depth of LCOE_c	km



Cash flow

NPV-Net Present Value

Levelized Cost of Energy

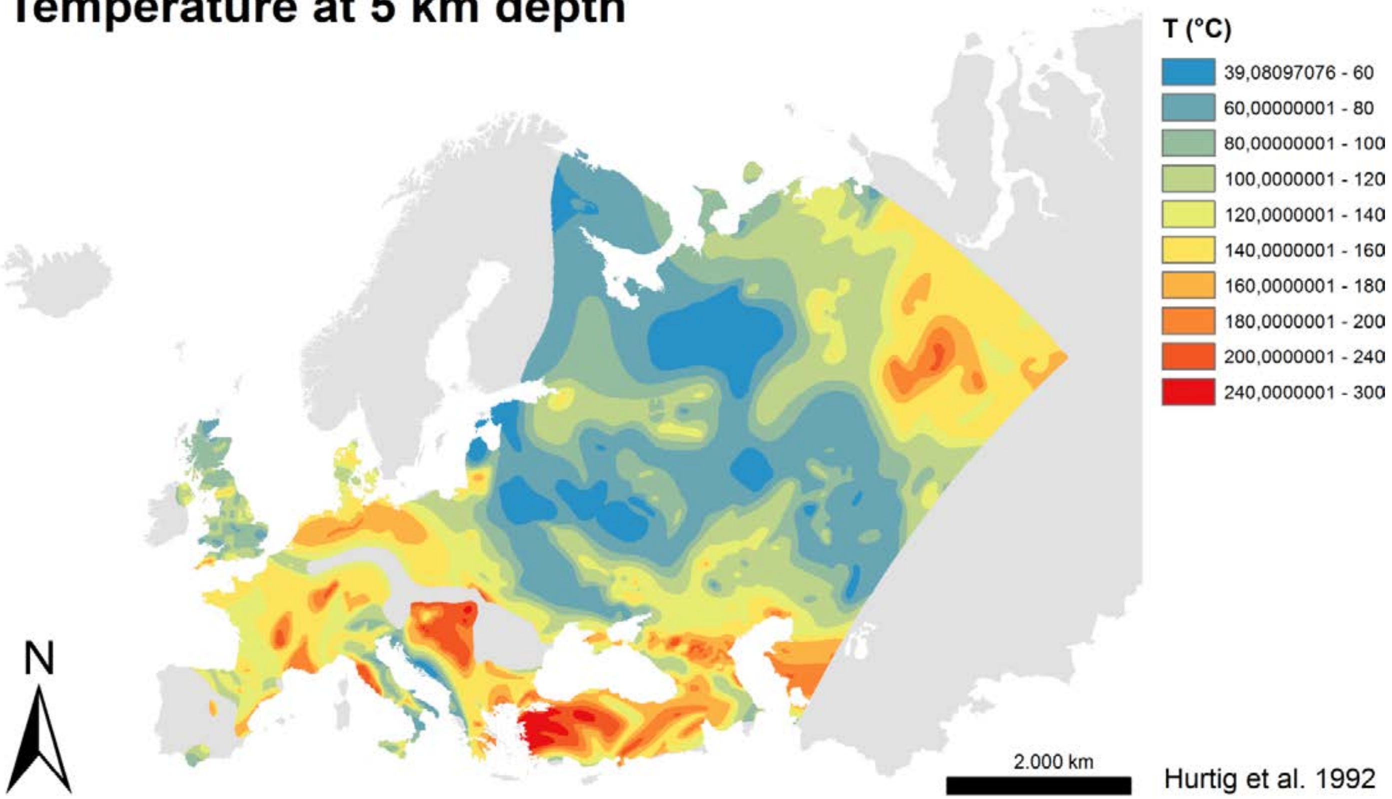
- Discounted energy produced [MWh, GJ]
- Discounted cash out [EUR]

- LCOE = discounted cash-out / discounted energy produced

Do we have access to key information?

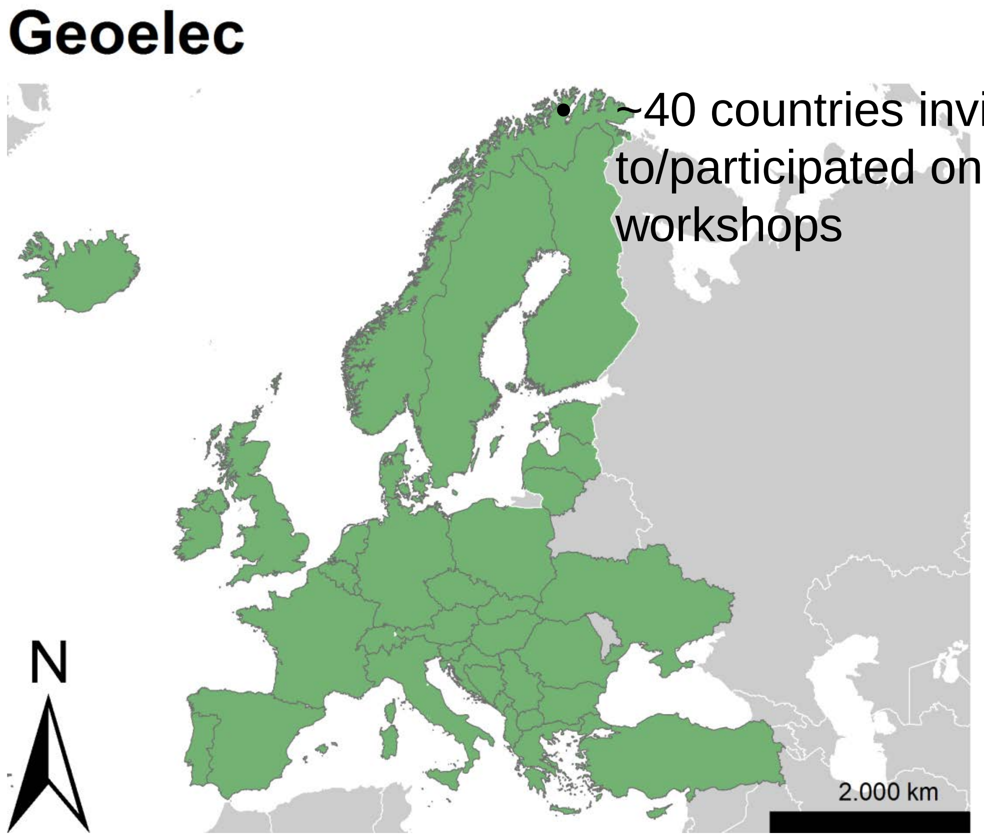
Temperature compilations date from over 20 years ago, only exists in a paper report

Temperature at 5 km depth



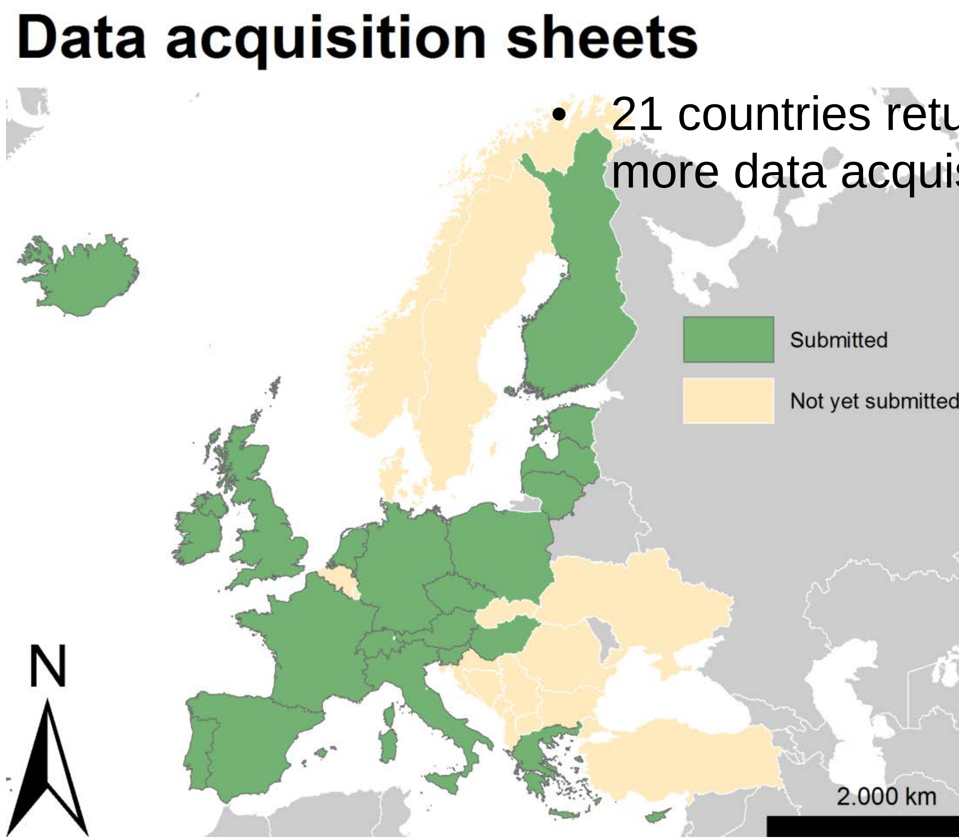
Hurtig et al. 1992

Data acquisition sheets



- ~40 countries invited to/participated on the workshops

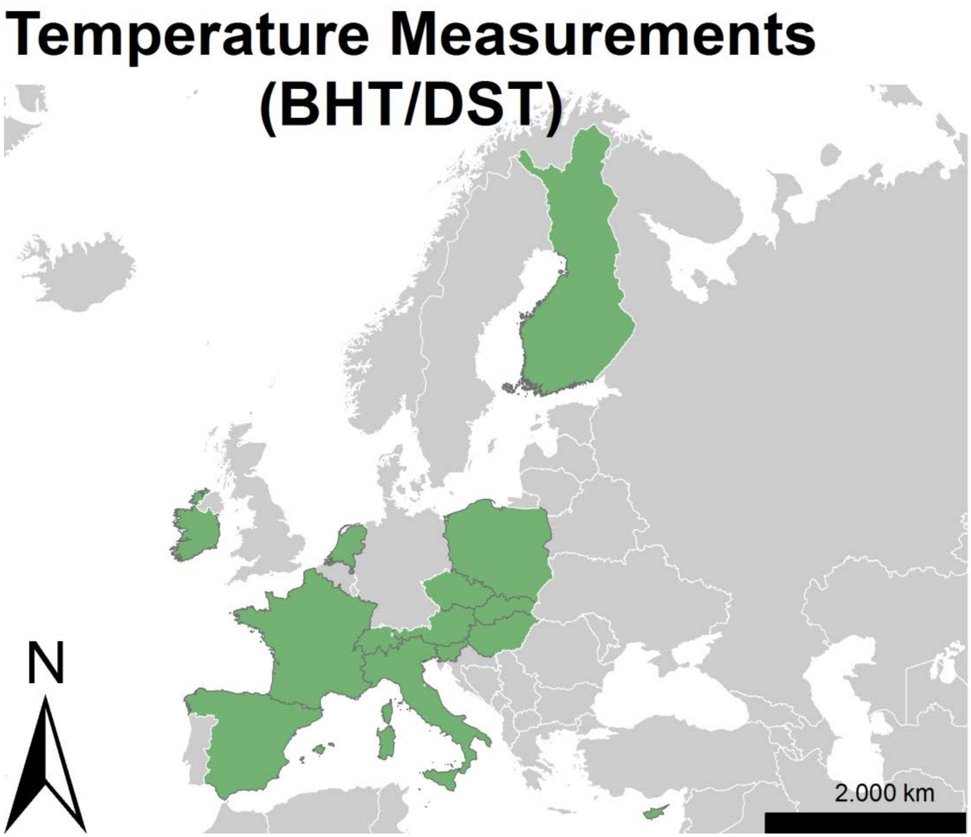
Data acquisition sheets



- 21 countries returned one or more data acquisition sheets

Can stakeholders access key information?

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

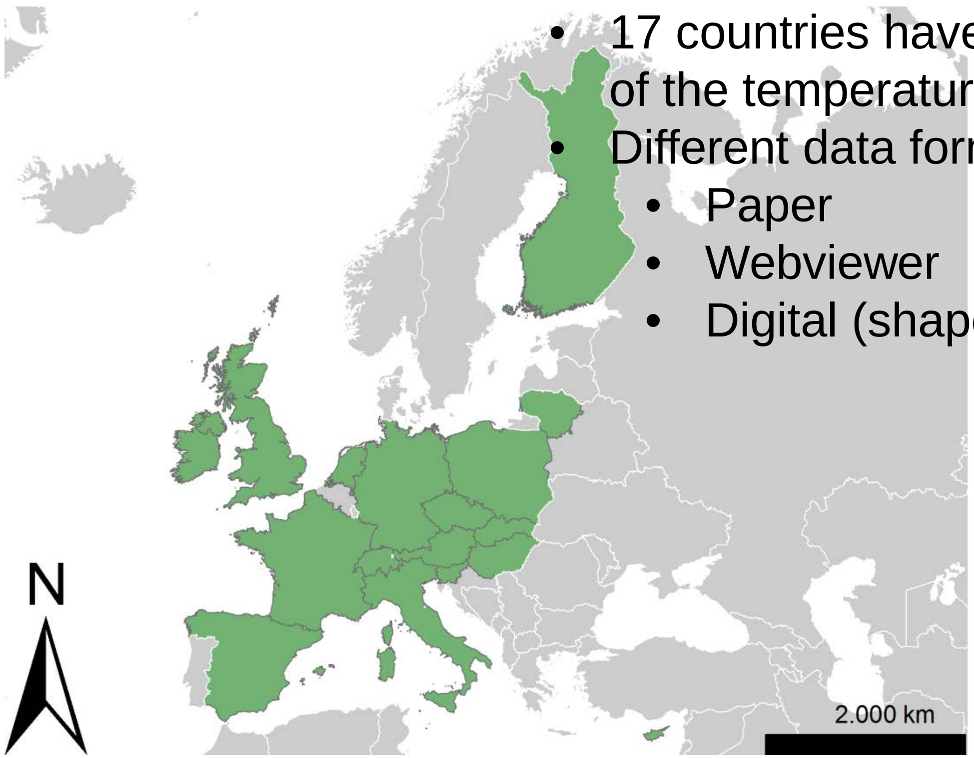


•14 countries have indicated that temperature measurements are publically available at no cost

•Access is hampered by lack of digital data repositories in most countries

Data acquisition sheets

Temperature maps at depth

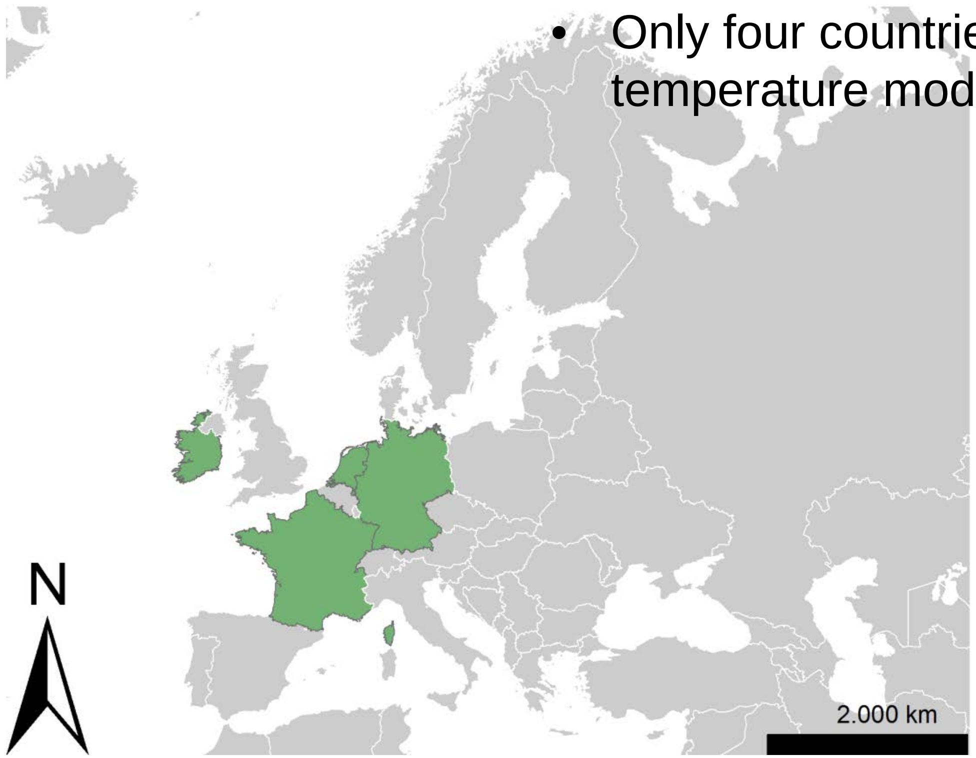


- 17 countries have (partial) maps of the temperature at depth
- Different data formats:
  - Paper
  - Webviewer
  - Digital (shapefile/grid)

Data acquisition sheets

3D temperature models

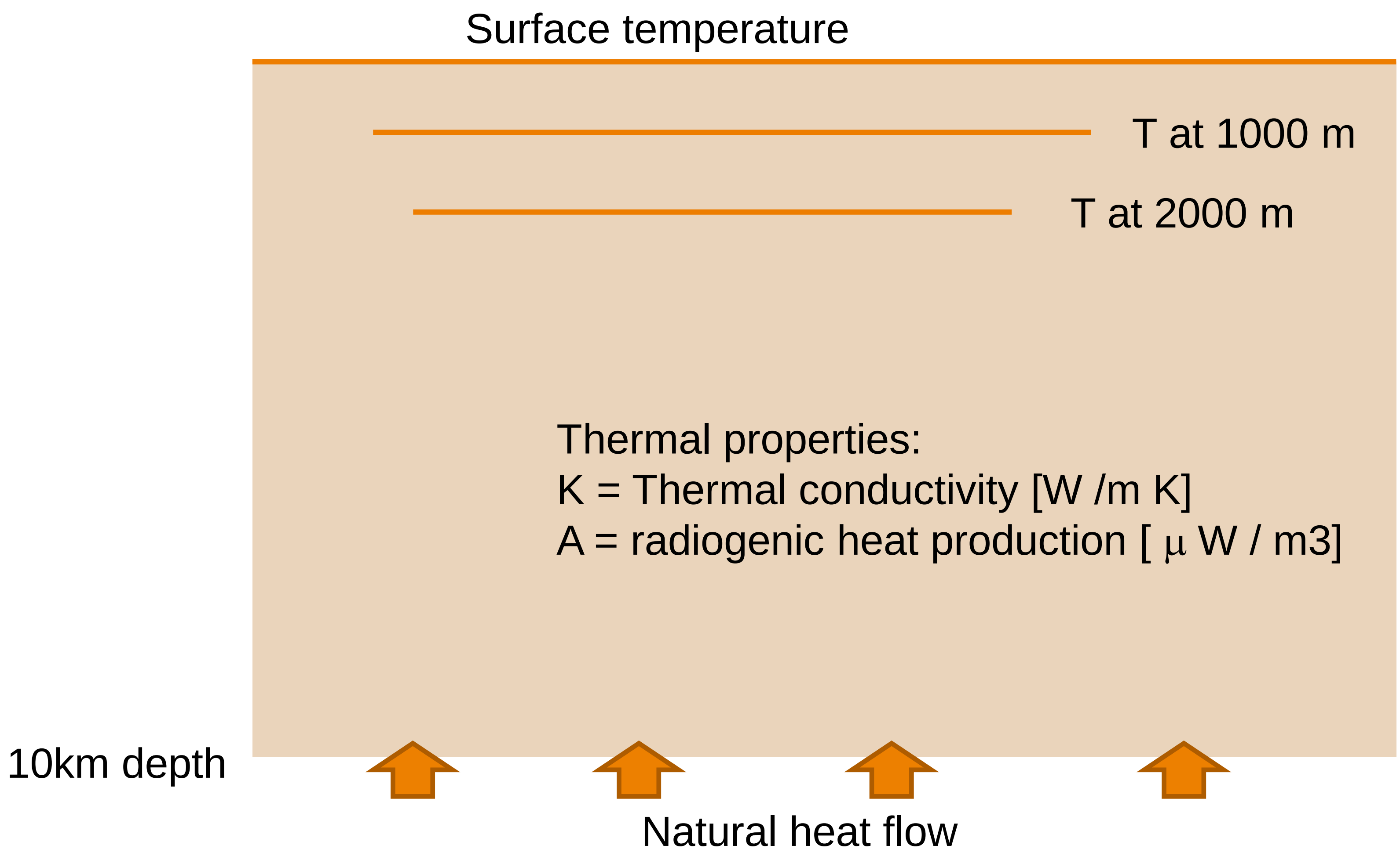
- Only four countries provide 3D temperature models



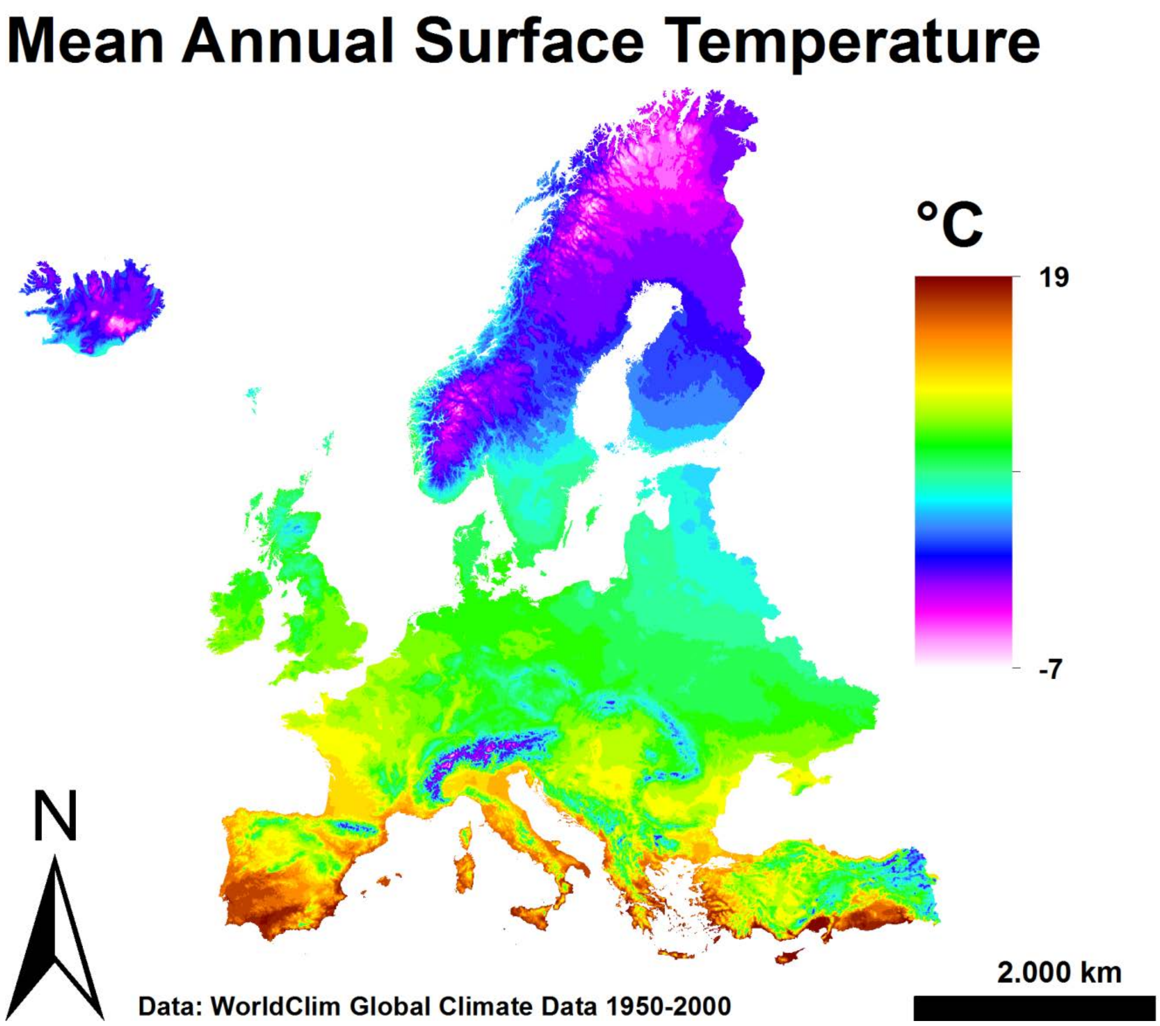
Findings

- 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

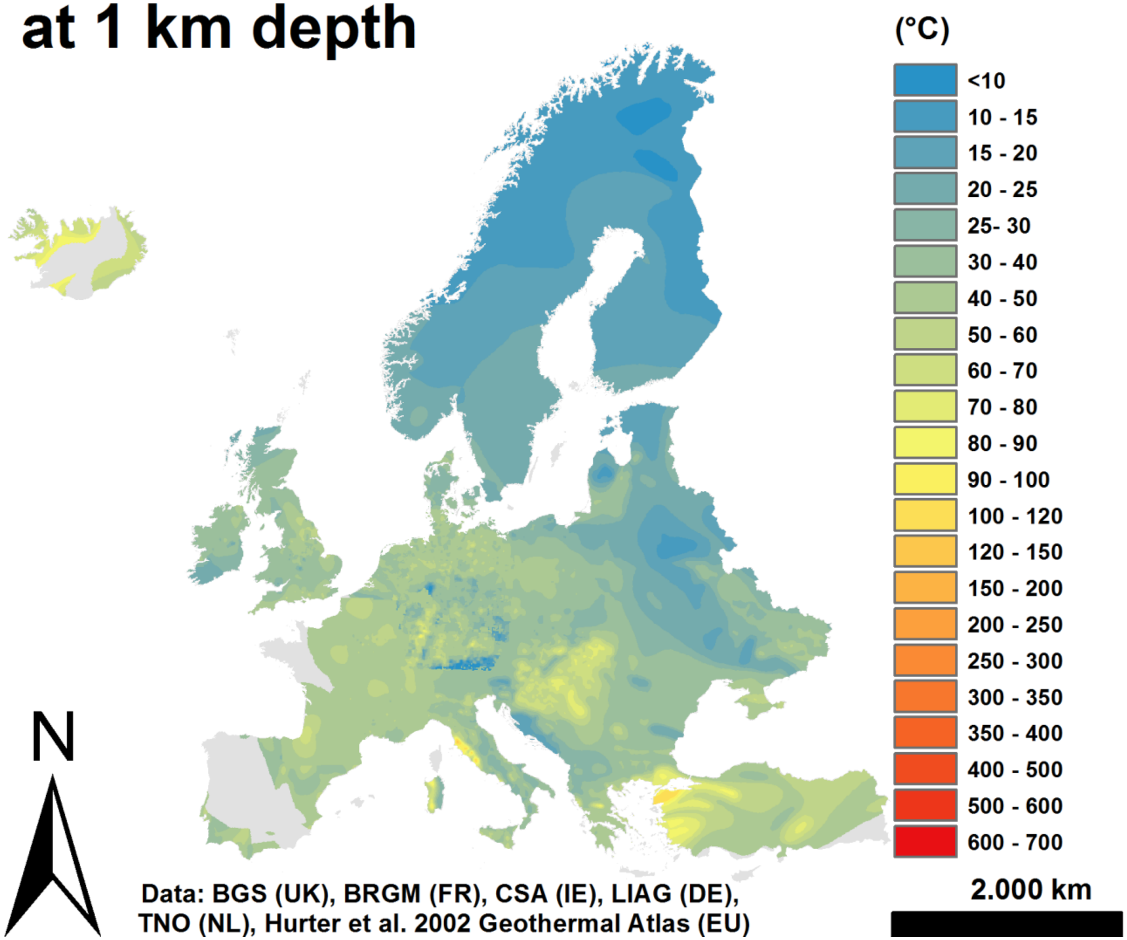
How to construct a temperature model?



Boundary conditions

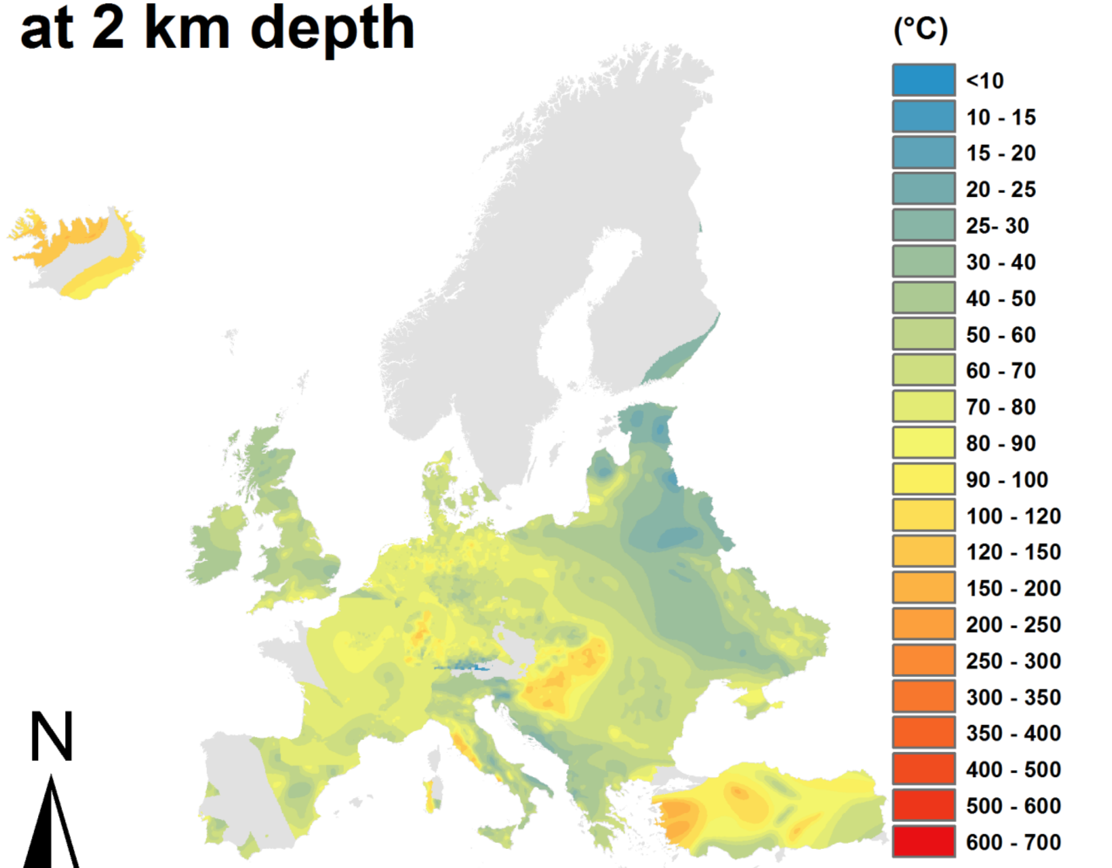


Temperature Constraints at 1 km depth



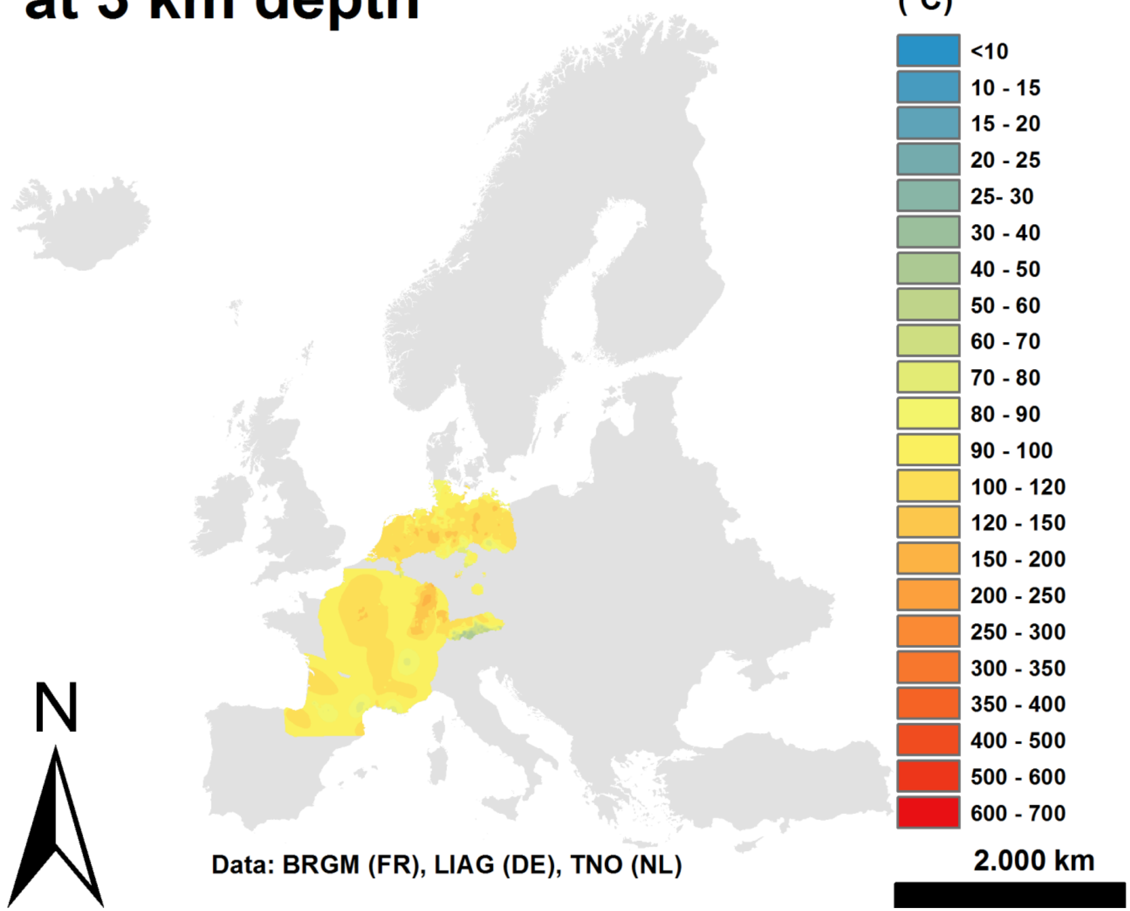
Data: BGS (UK), BRGM (FR), CSA (IE), LIAG (DE), TNO (NL), Hurter et al. 2002 Geothermal Atlas (EU)

Temperature Constraints at 2 km depth

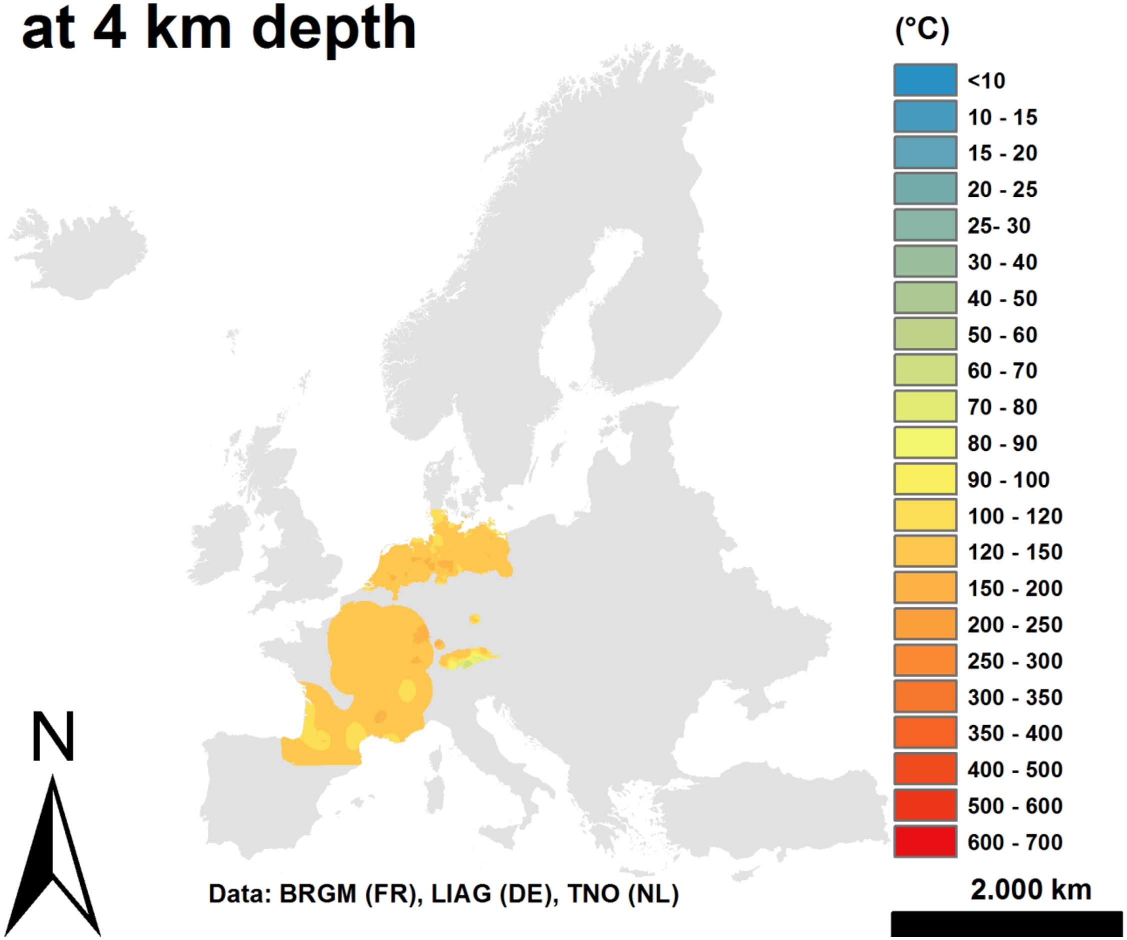


Data: BRGM (FR), LIAG (DE), TNO (NL),
Hurter et al. 2002 Geothermal Atlas (EU)

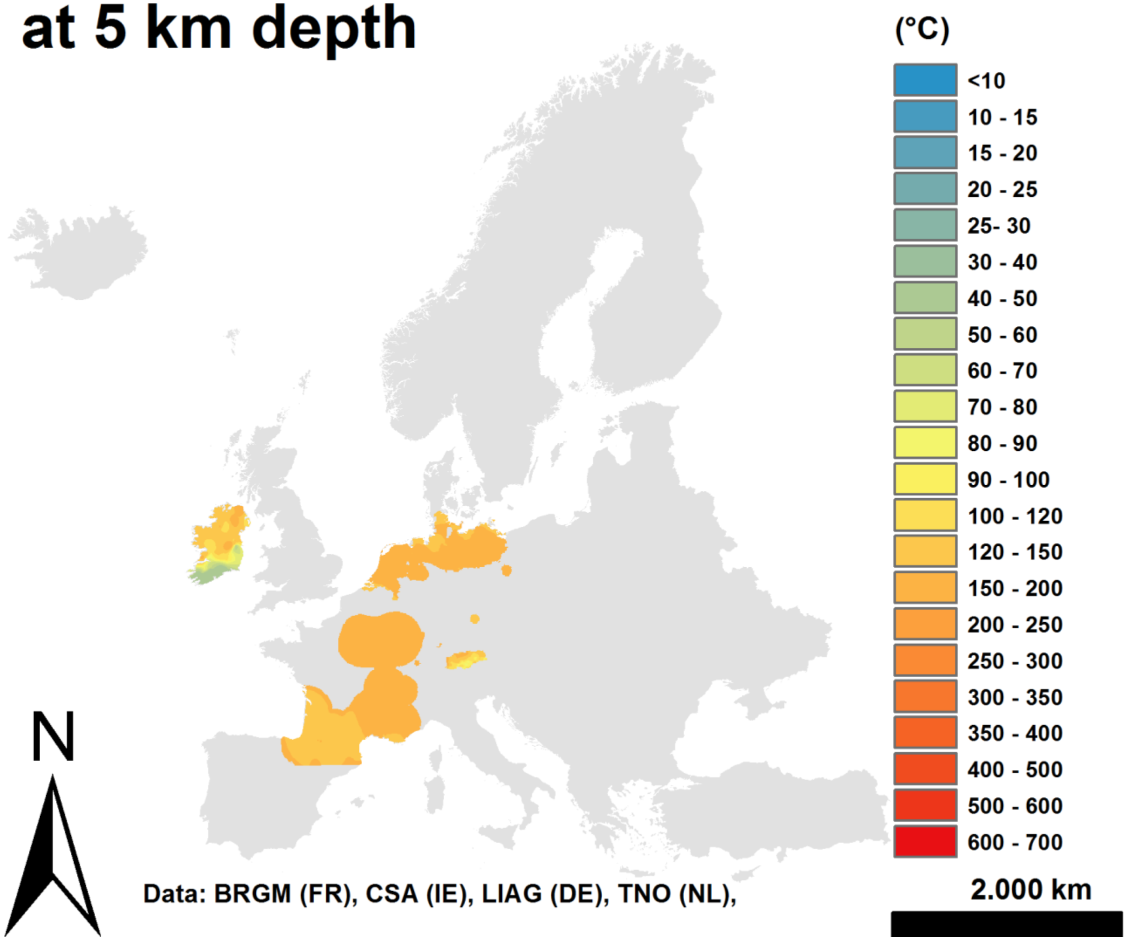
Temperature Constraints at 3 km depth



Temperature Constraints at 4 km depth

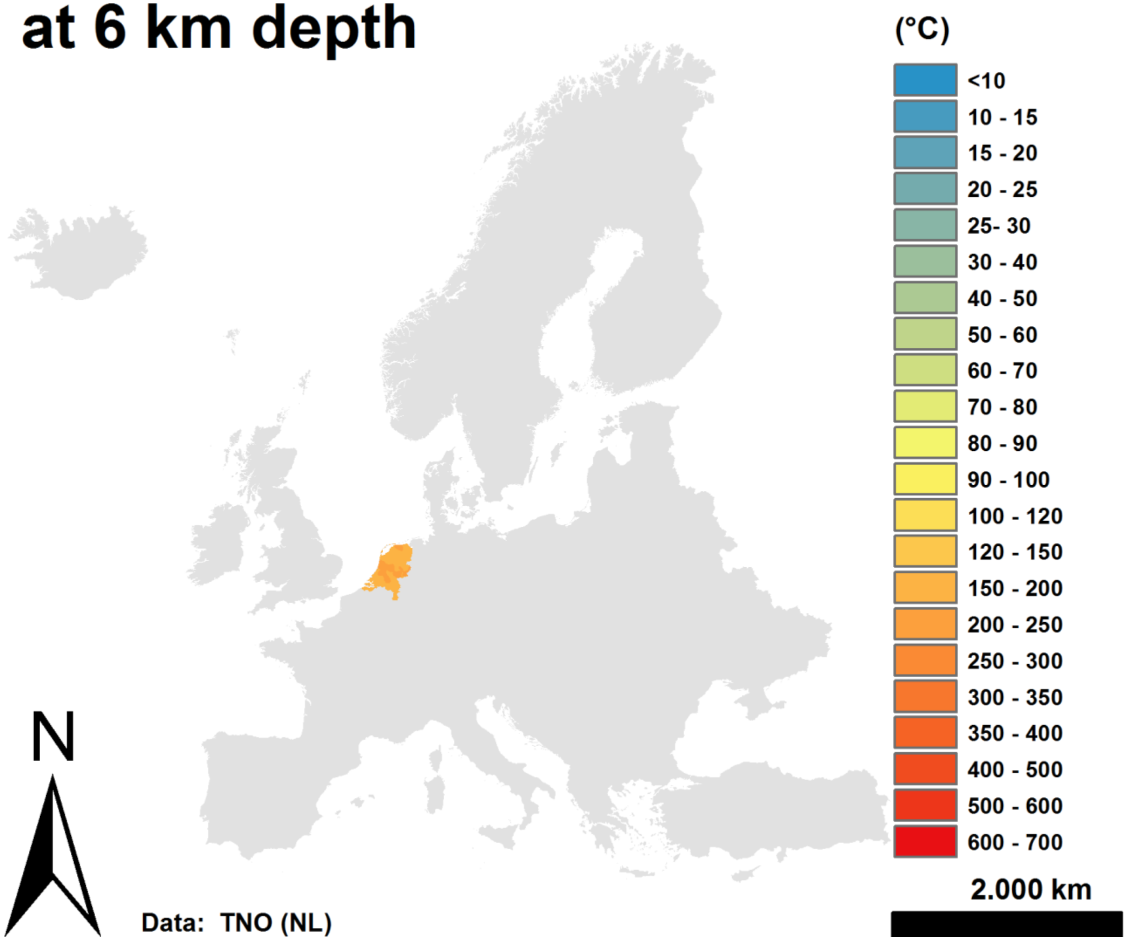


Temperature Constraints at 5 km depth

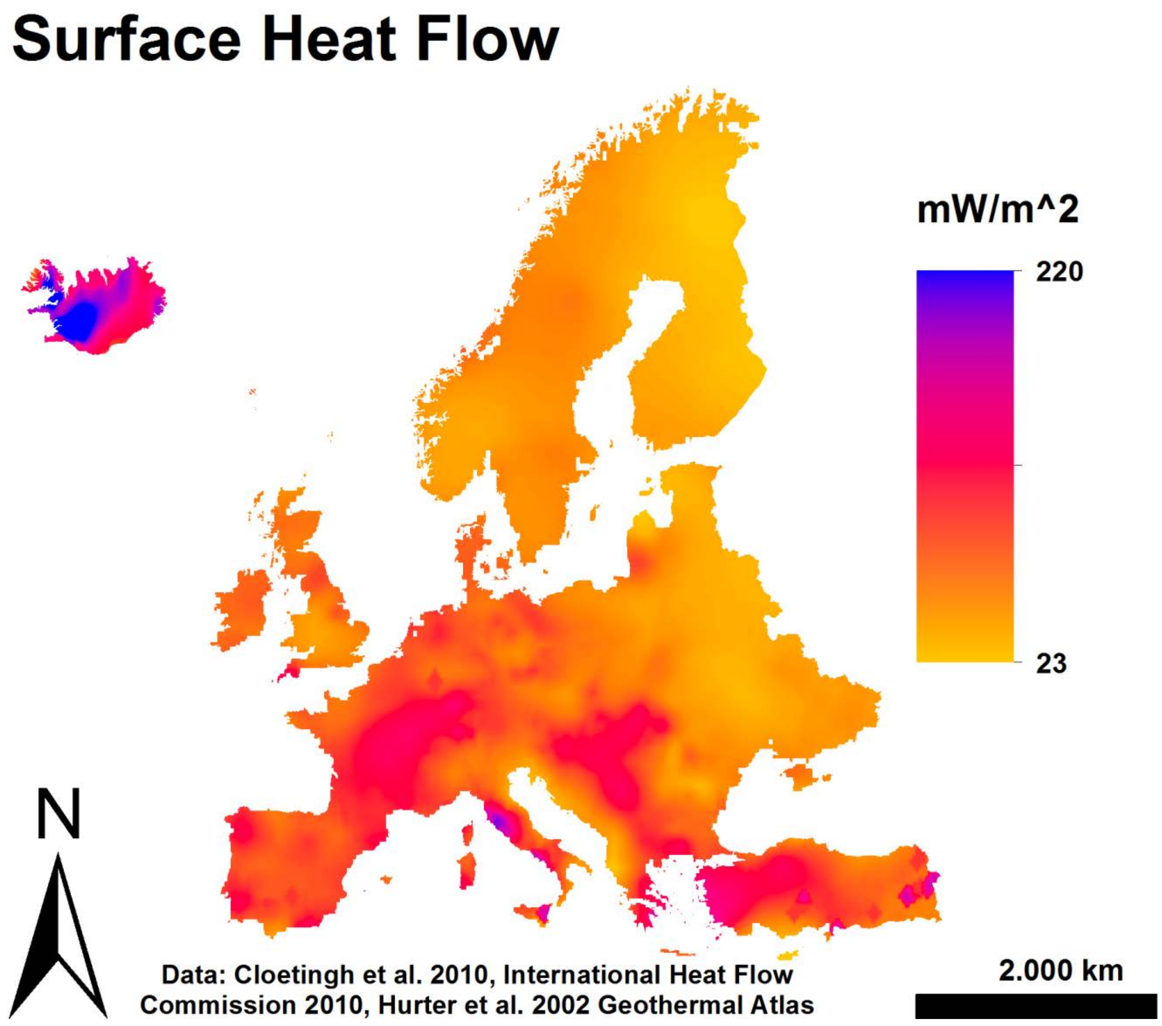


Data: BRGM (FR), CSA (IE), LIAG (DE), TNO (NL),

Temperature Constraints at 6 km depth

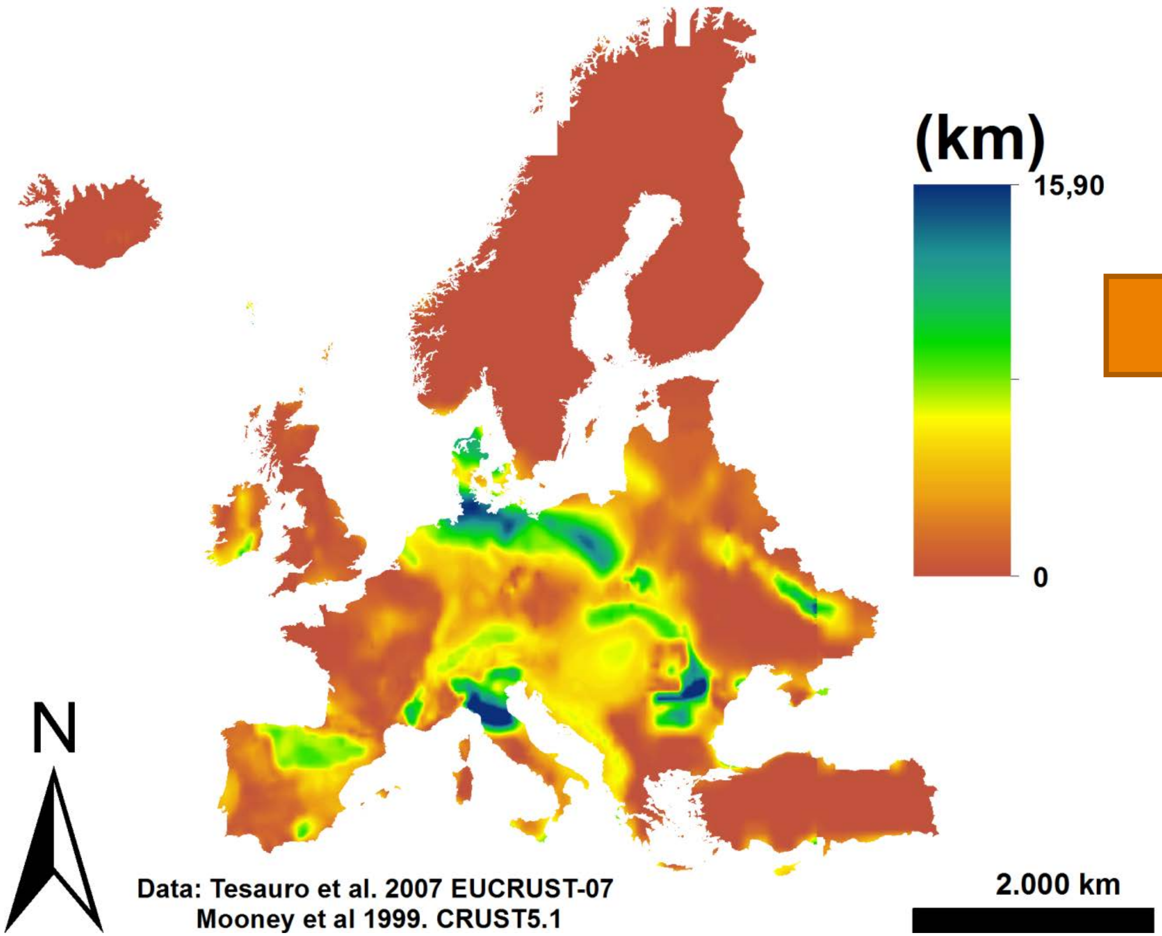


Boundary condition at Base -->



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

Sediment Thickness



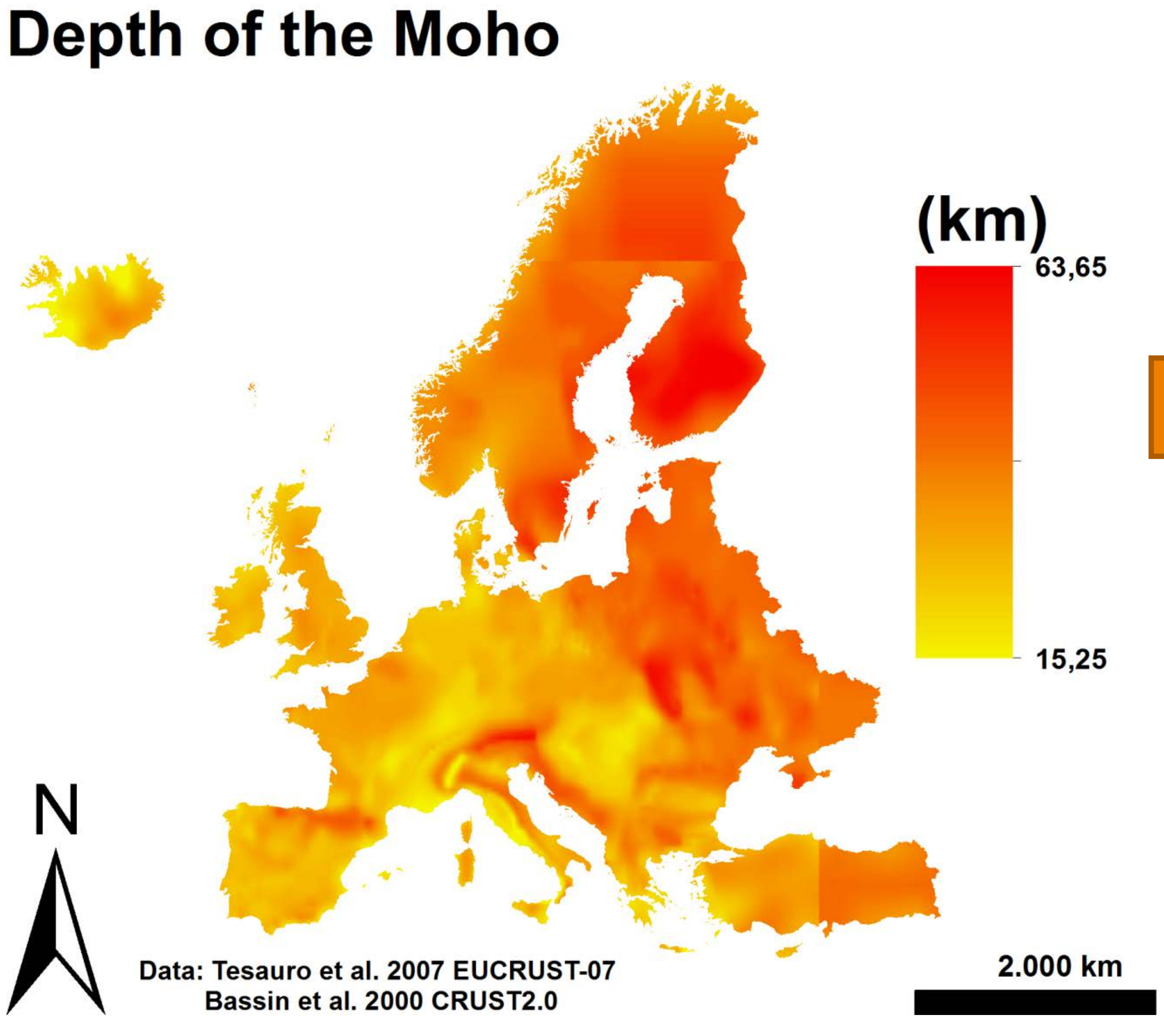
$K_{sed} = 2.5$

$K_{bsmt} = 2.14$

$A_{sed} = 1$

$A_{bsmt} = 2.65$

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



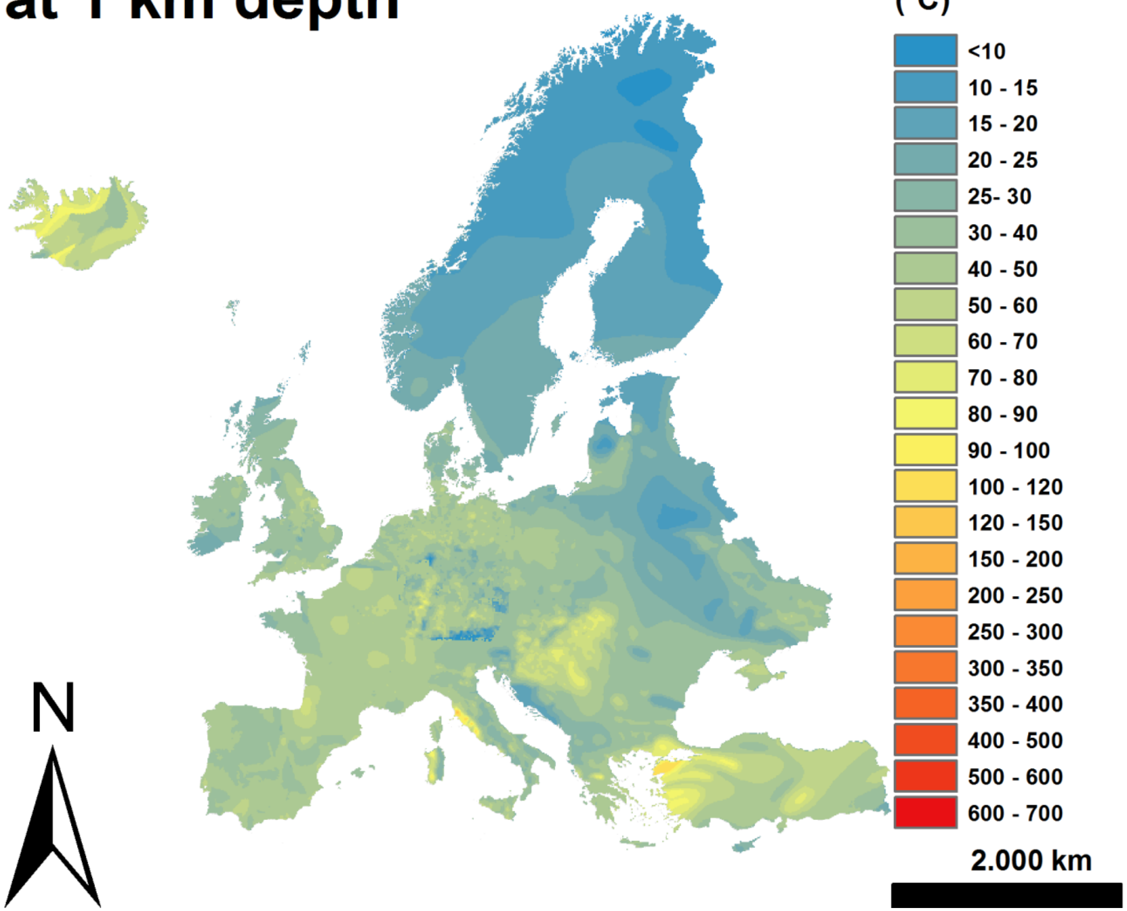
$K_{sed} = 2$

$K_{bsmt} = 2.6$

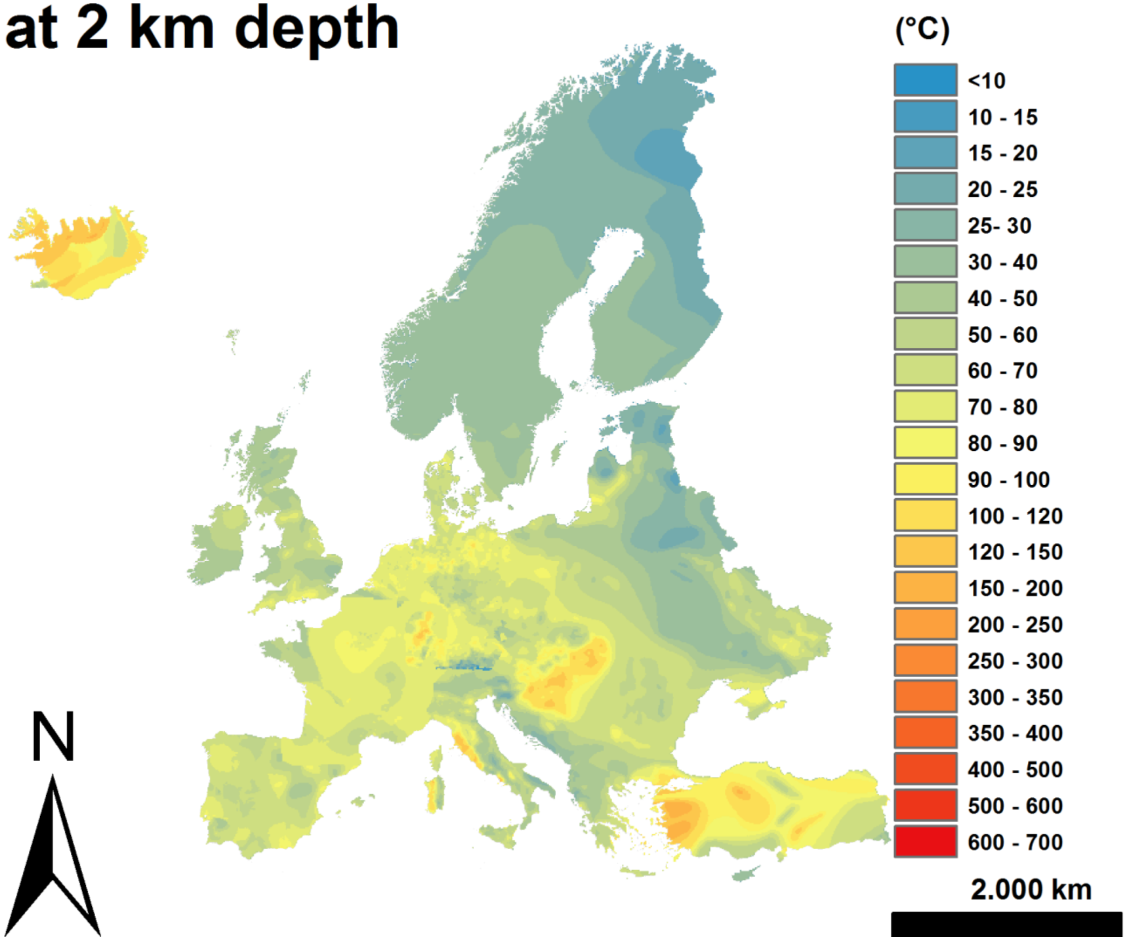
$A_{sed} = 40\%$ HF

$A_{bsmt} = 40\%$ HF

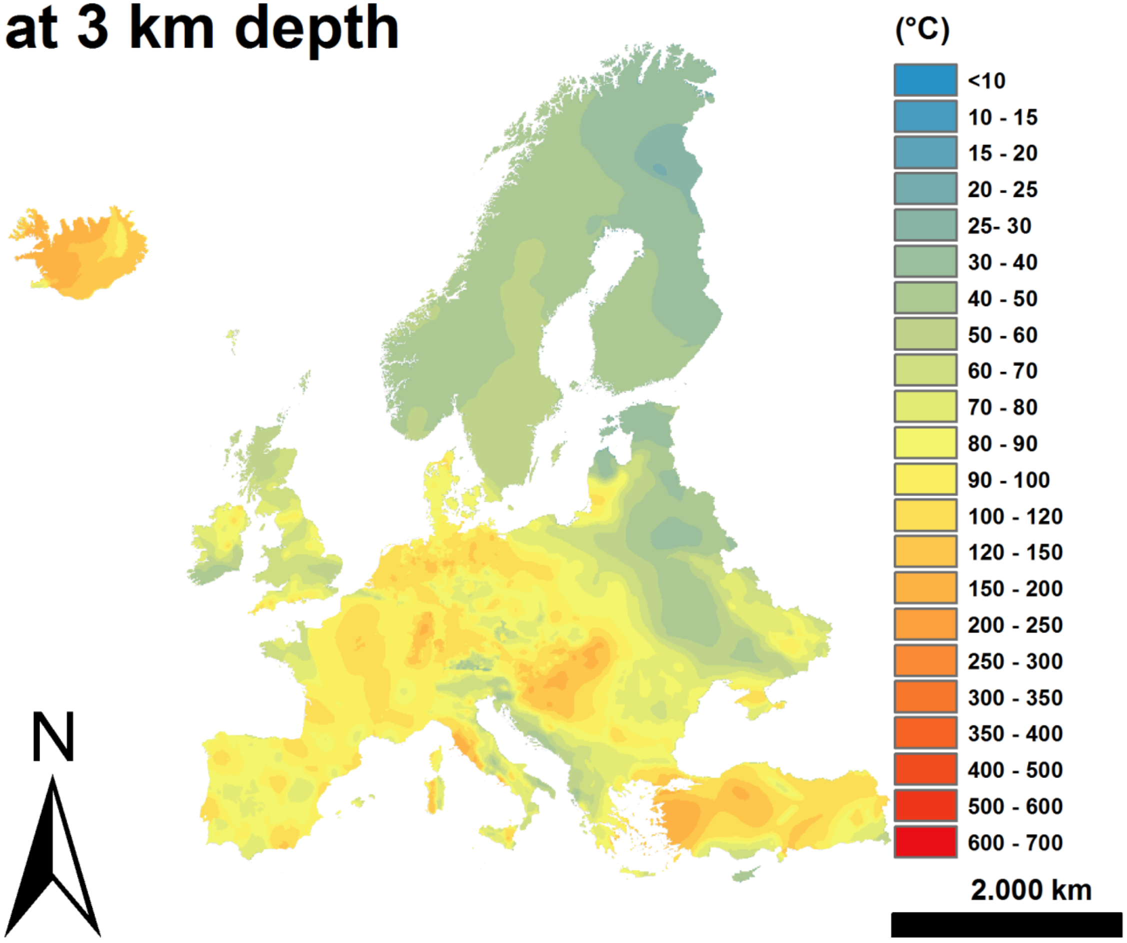
Modeled Temperature at 1 km depth



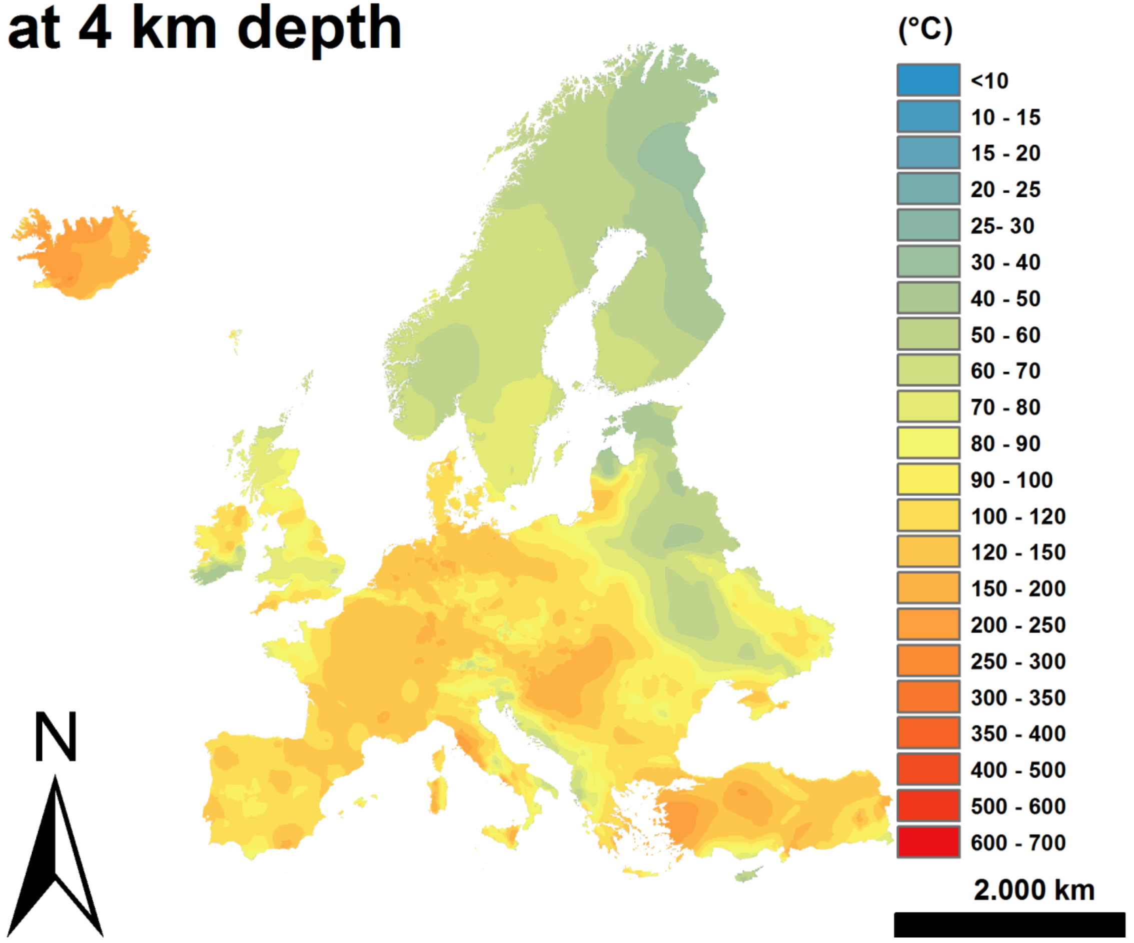
Modeled Temperature at 2 km depth



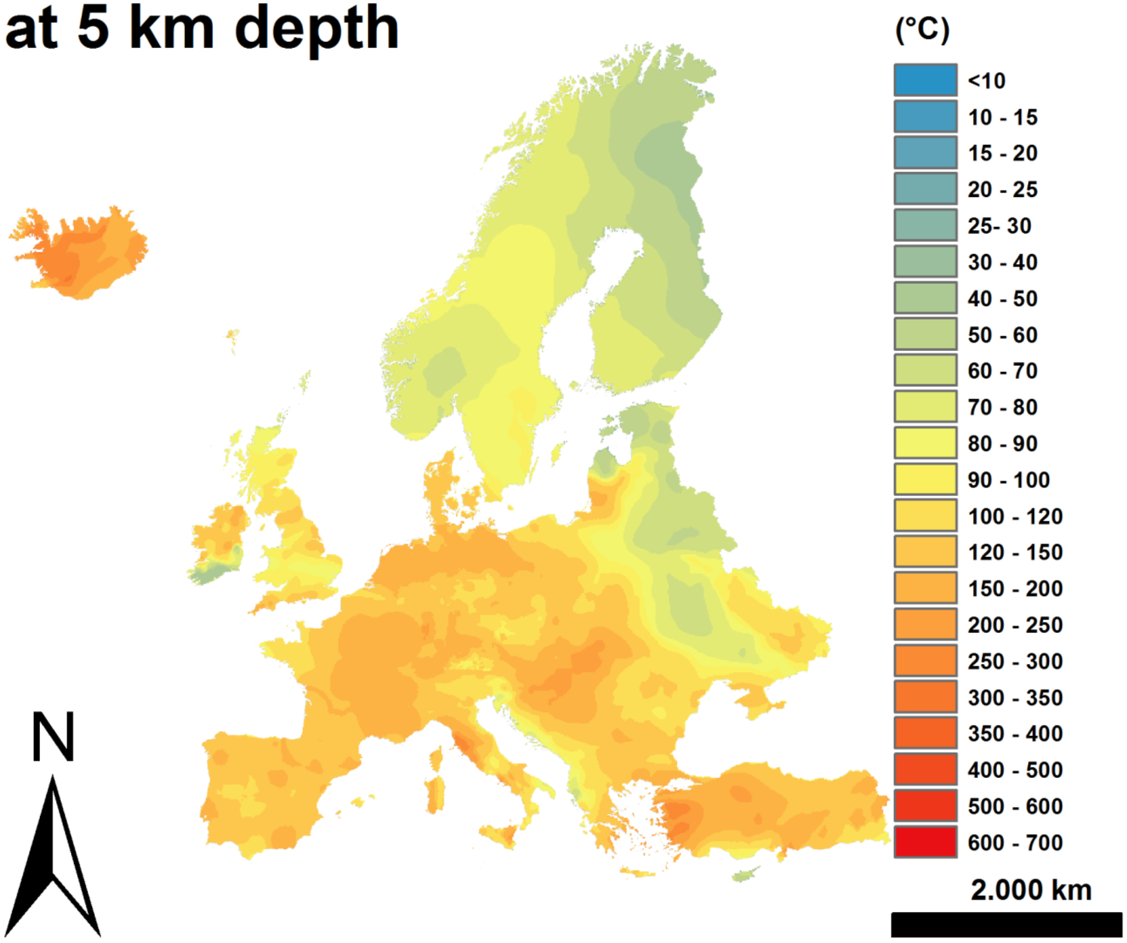
Modeled Temperature at 3 km depth



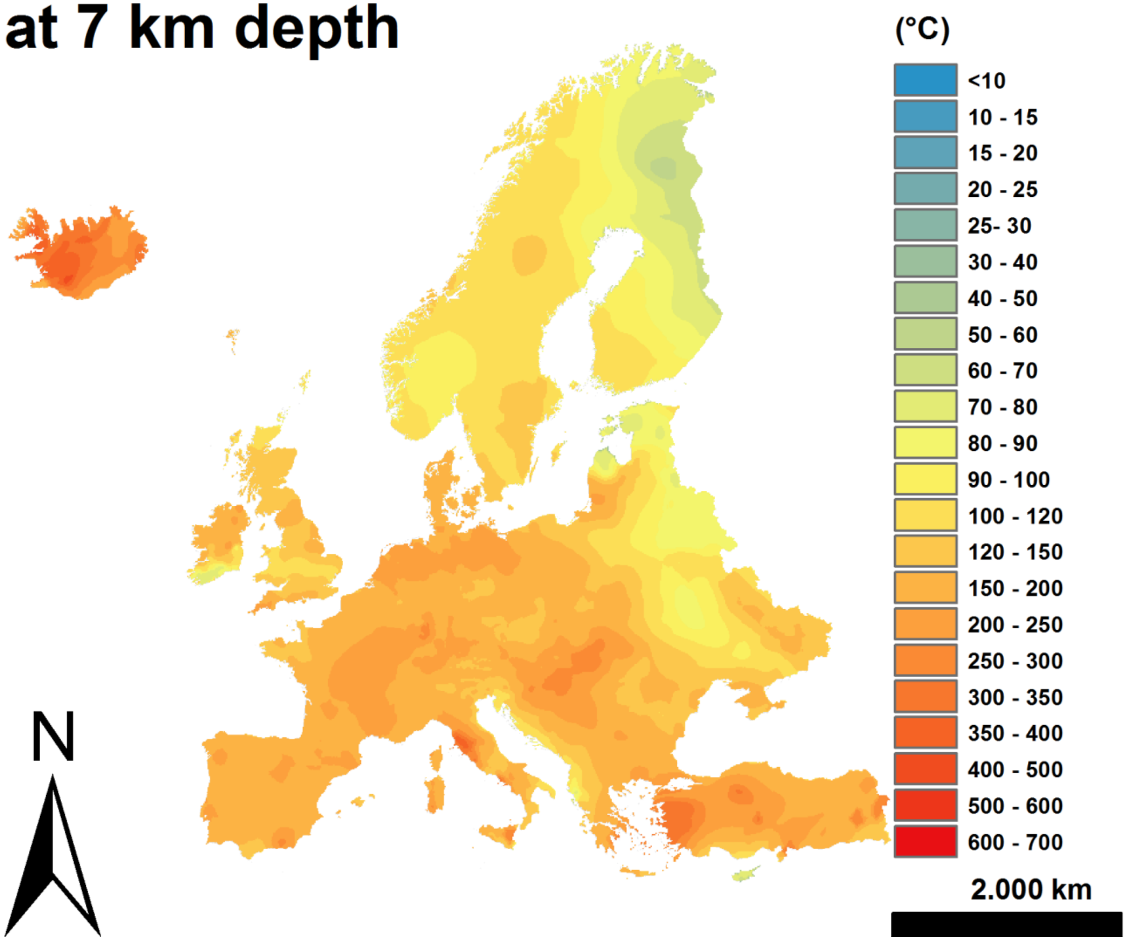
Modeled Temperature at 4 km depth



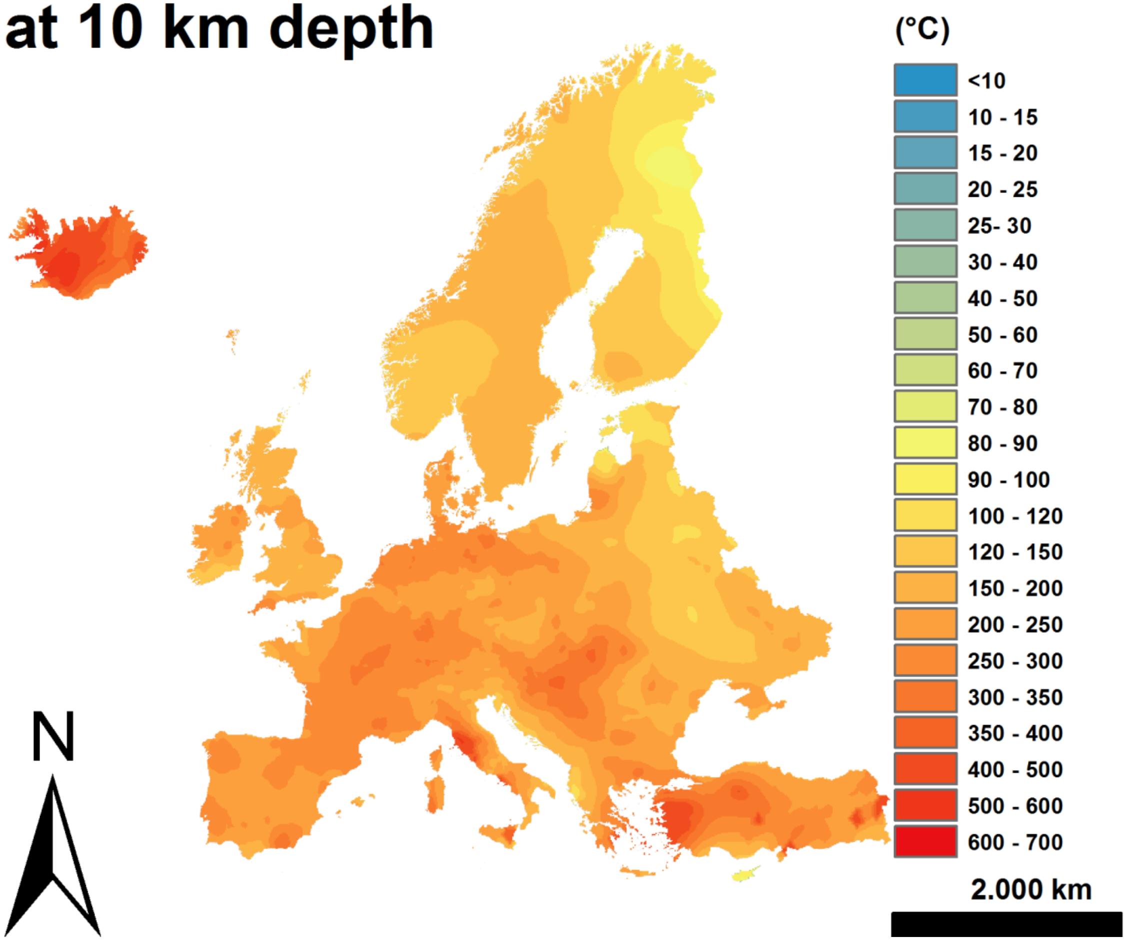
Modeled Temperature at 5 km depth



Modeled Temperature at 7 km depth

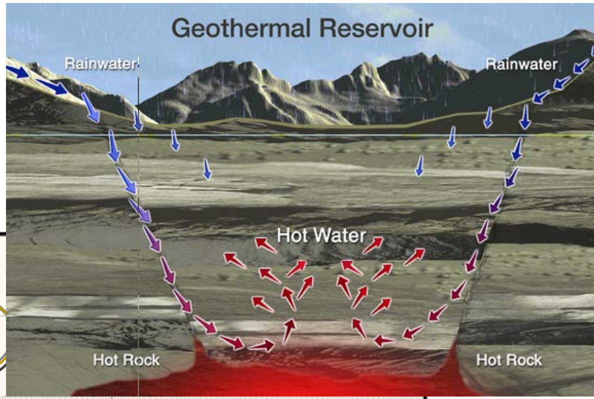


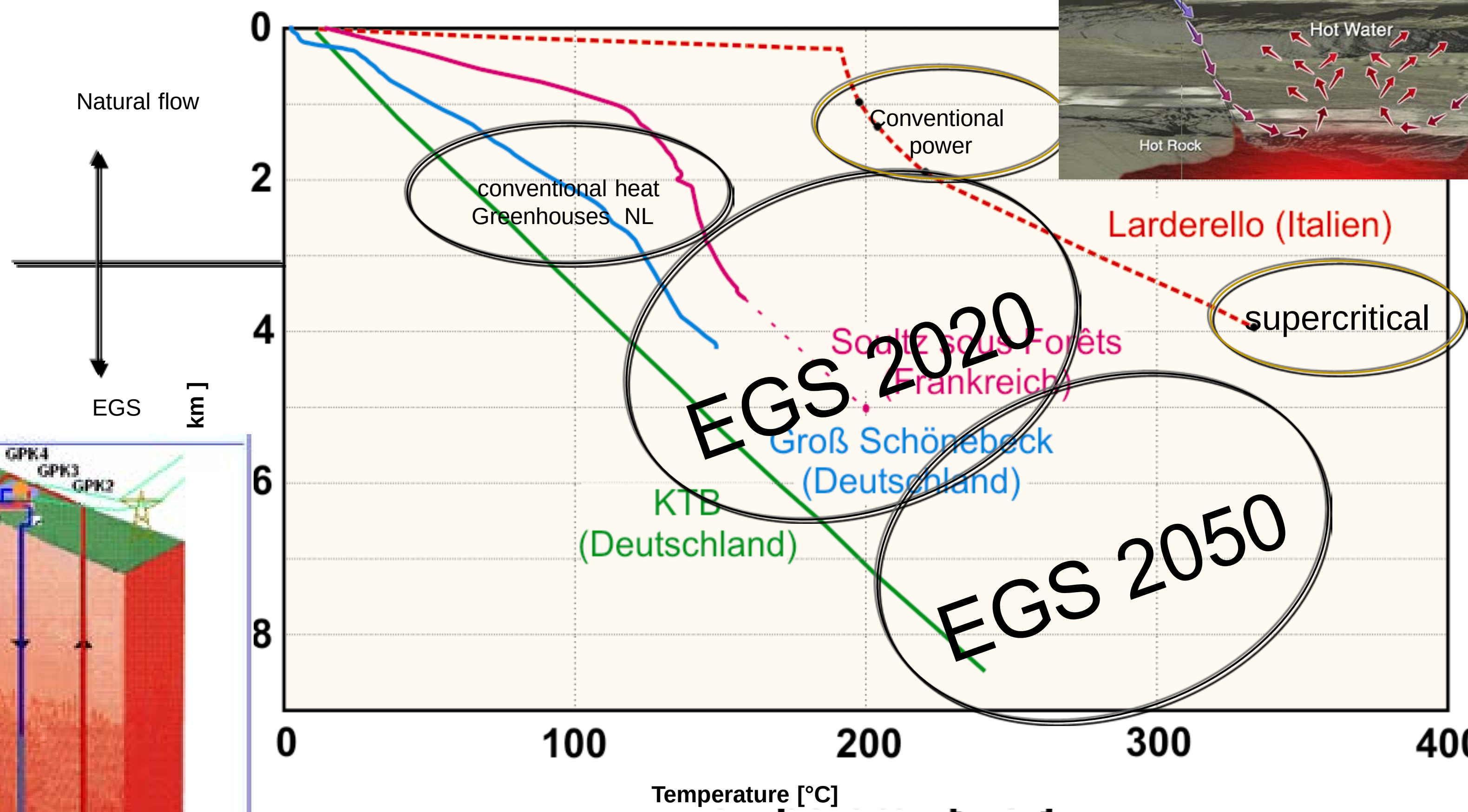
Modeled Temperature at 10 km depth

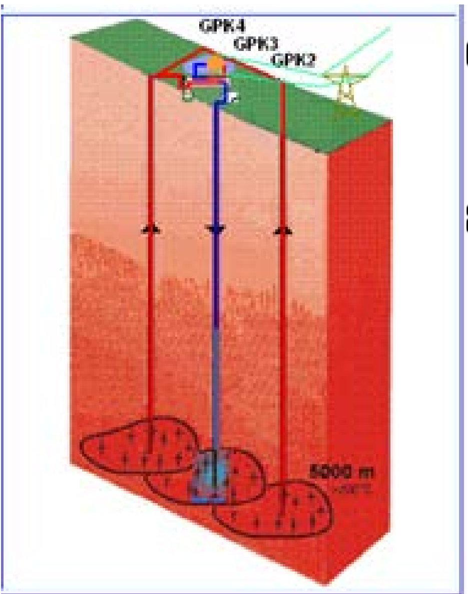


Geothermal energy:

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

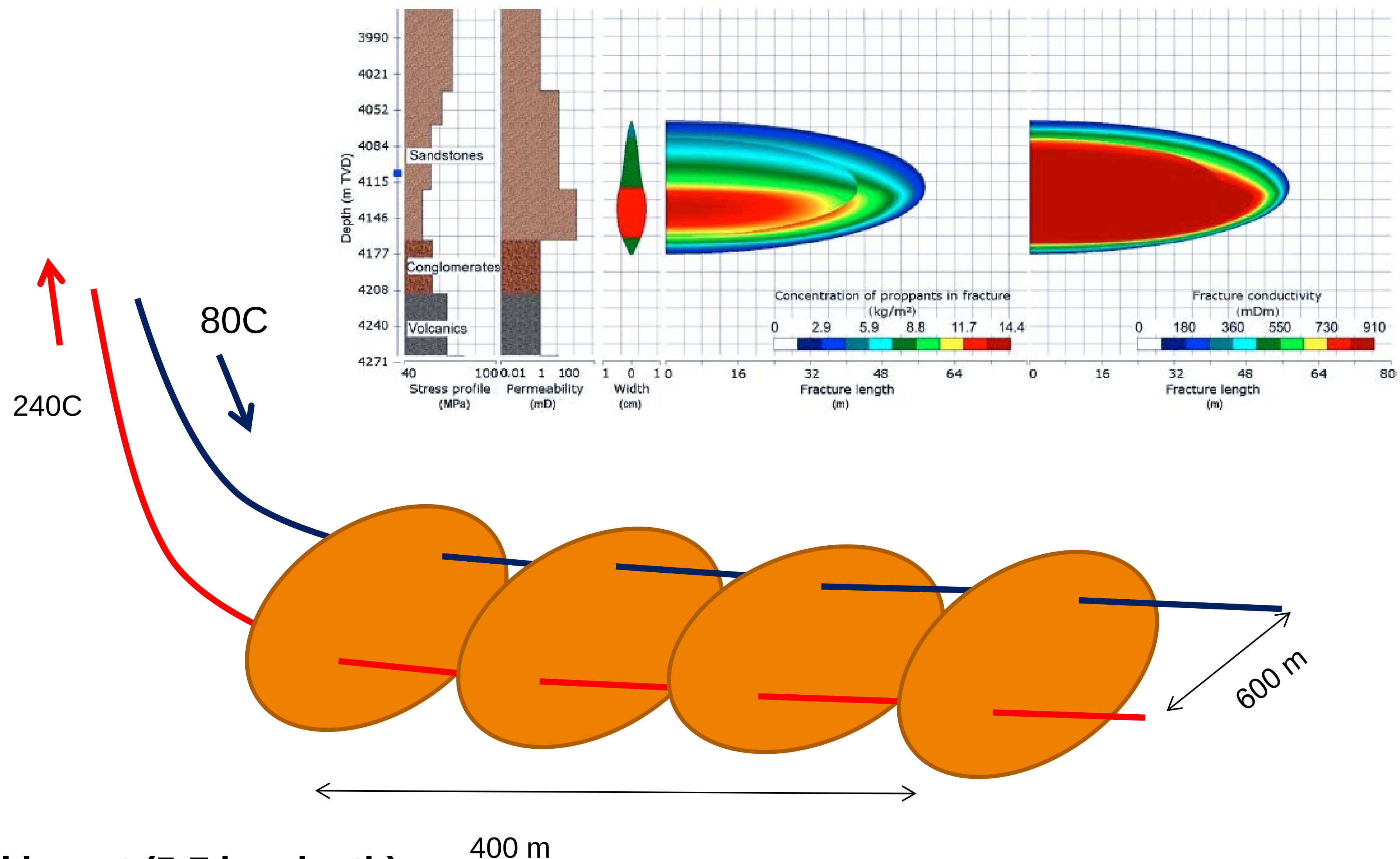






Enhanced geothermal systems (EGS):
2% worldwide electricity 2050

G. Zimmermann, A. Reinicke / Geothermics 39 (2010) 70–77



Well layout (5-7 km depth)

Calculation of LCOE of renewable heat and electricity

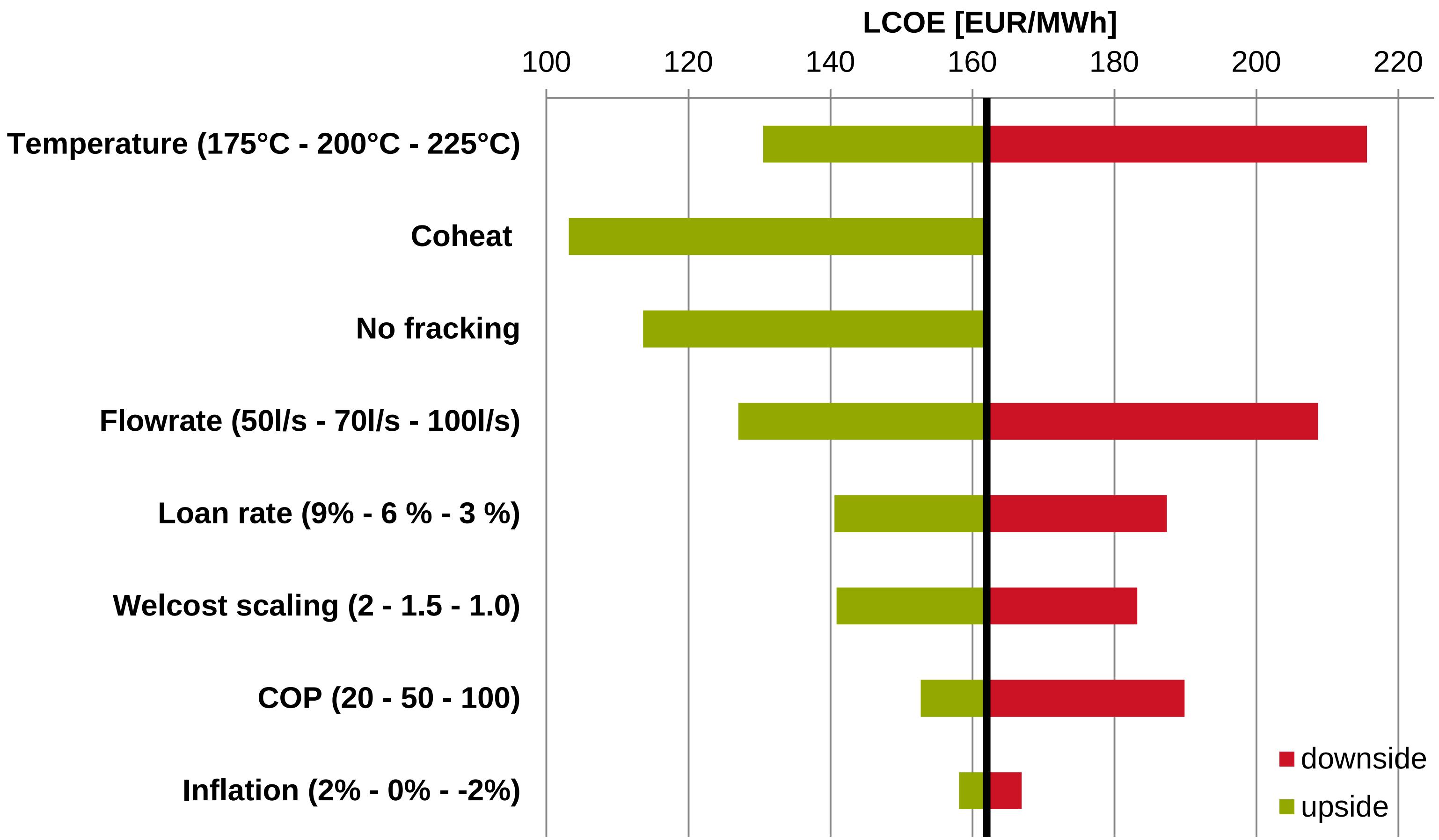
Geothermal Energy			Operational choice	power
INPUTVARIABLES	**used**	**Value**	**Unit**	**Comment**
Flowrate	1	50	L/s	total flow rate which is achieved from the subsurface (measured at surface conditions)
along hole depth of a single well	1	5000	m	along hole depth (total length) of a single borehole 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)

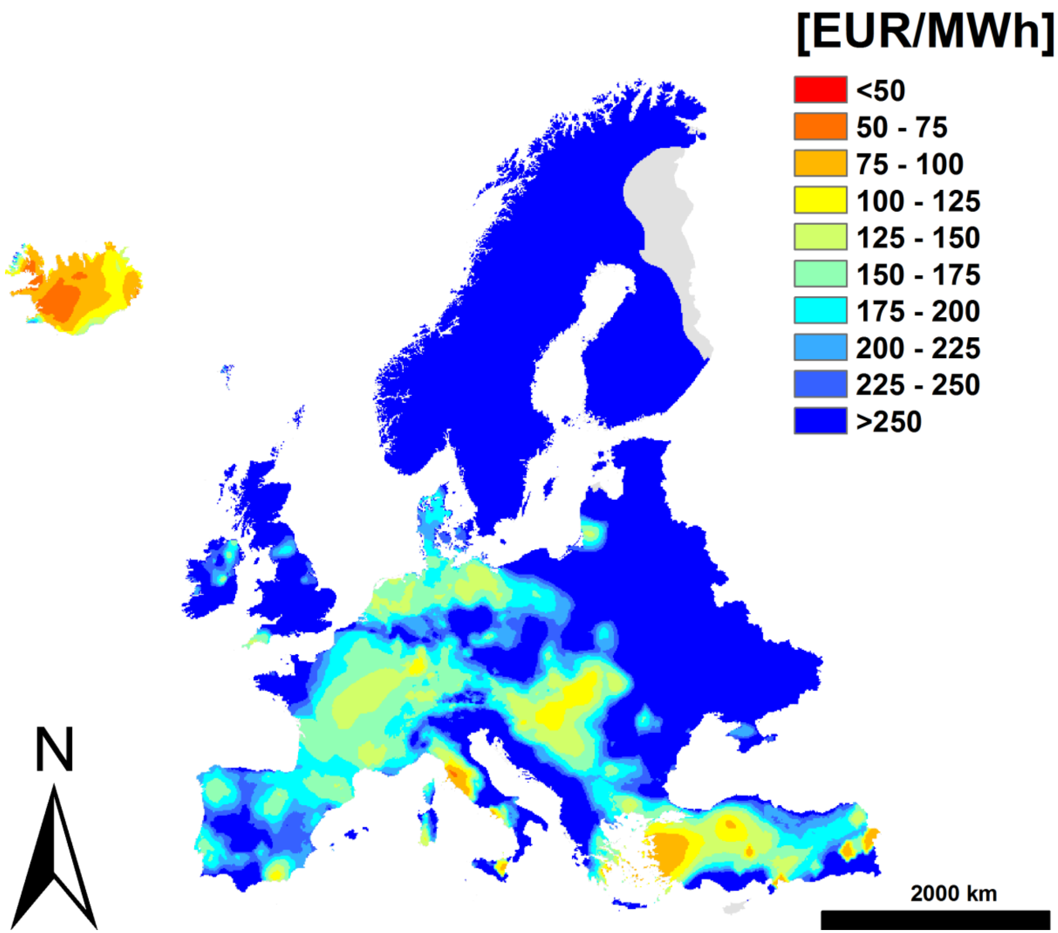
POWER (power,co-heat)	**used**	**Value**	**Unit**
levelized cost of energy (LCOE)	1	267.48	Euro/Mwhe

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

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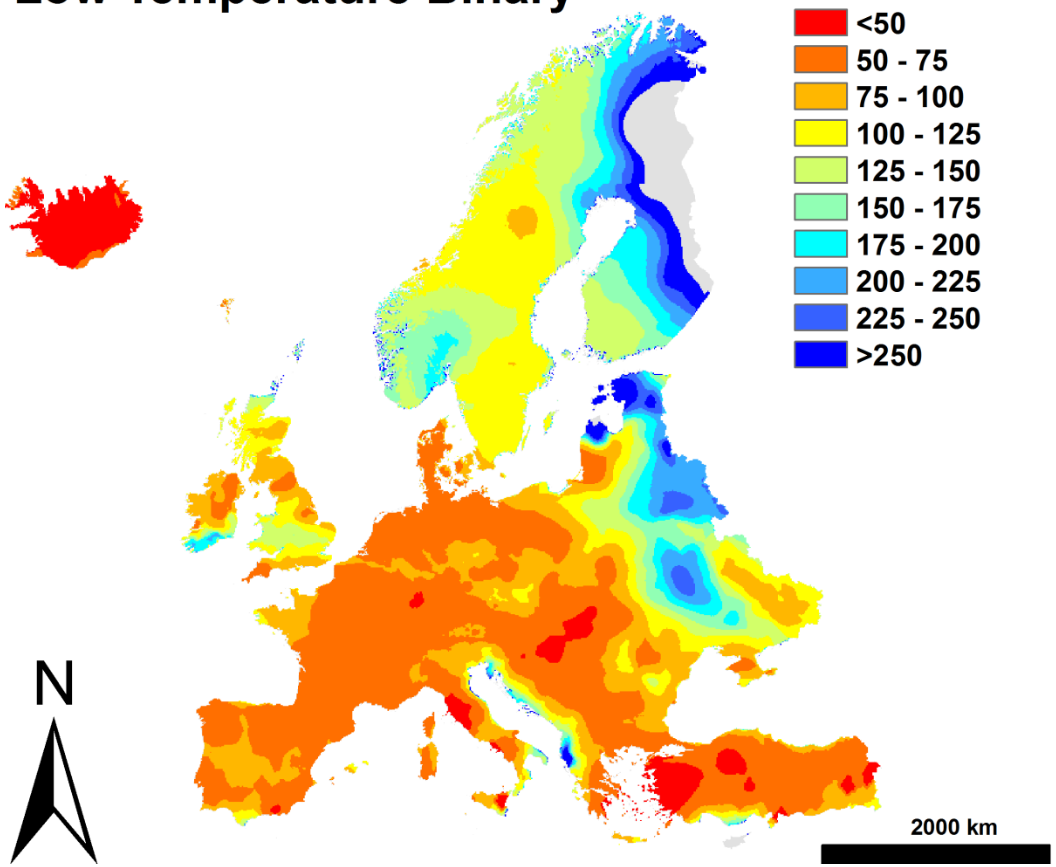
TNO innovation for life

Minimal LCOE EGS 2050: Flame Drilling and Low Temperature Binary

[EUR/MWh]



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%