DEEP GEOTHERMAL – STATE-OF-THE-ART AND OPPORTUNITIES & CHALLENGES

Jan-Diederik van Wees

TNO innovation for life

Universiteit Utrecht

GEOTHERMAL ENERGY – UNLOCKING GEOTHERMAL POTENTIAL

CHALLENGES

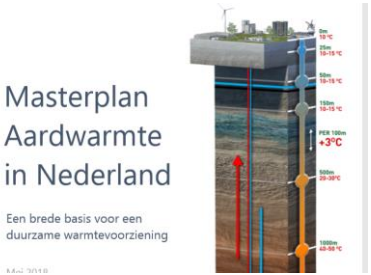
- Extending the resource base for urban heating
- lowering LCOE
- Ensuring safety and sustainability

METHODS

- Geothermal reservoir characterization based on Geological Survey data
- Play based portfolio development
- Thermal models

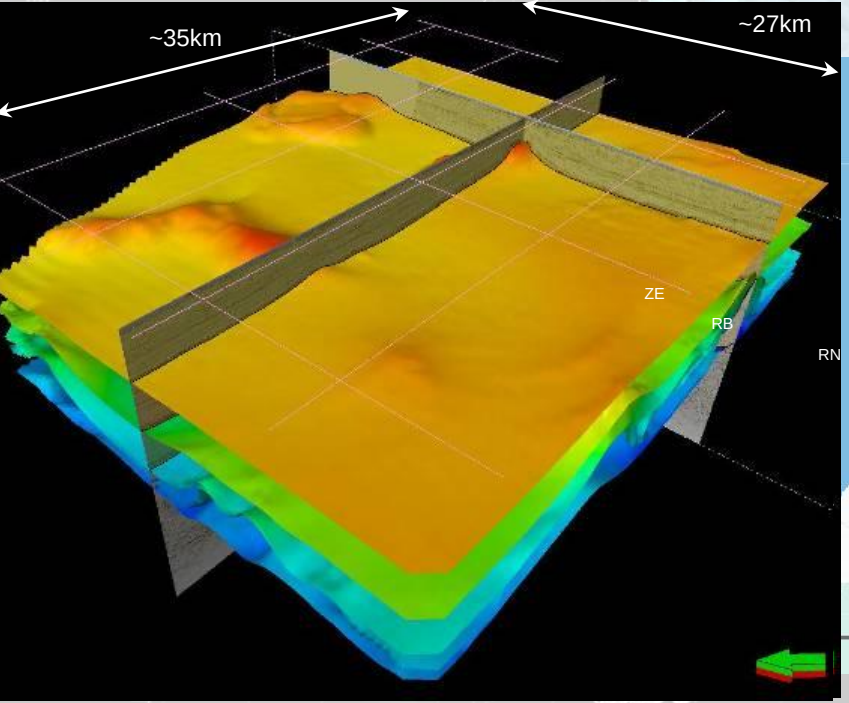
IMPACT

- 90% success rate of wells
- 75mln+ Public Private Partnerships in the development of geothermal energy for urban heating
  - LEAN
  - RESULT
  - WARMING UP

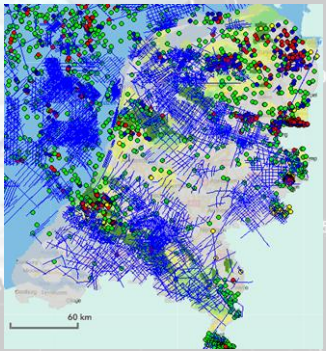


GEOTHERMAL ENERGY: THERMOGIS

100 YEARS OF GEOLOGICAL MAPPING

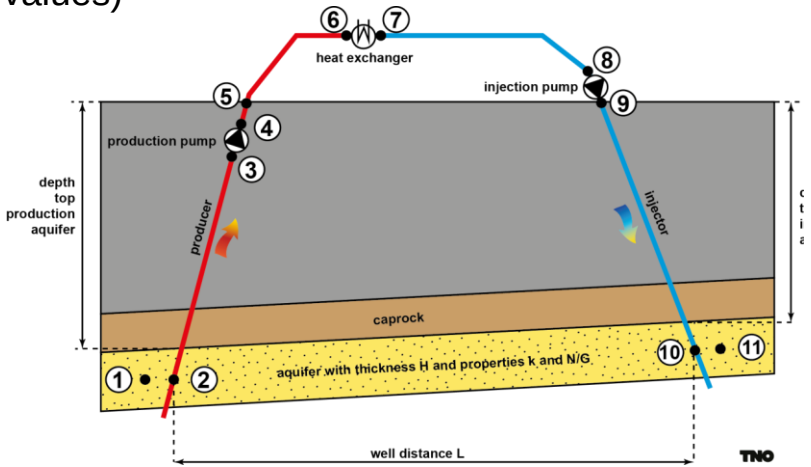


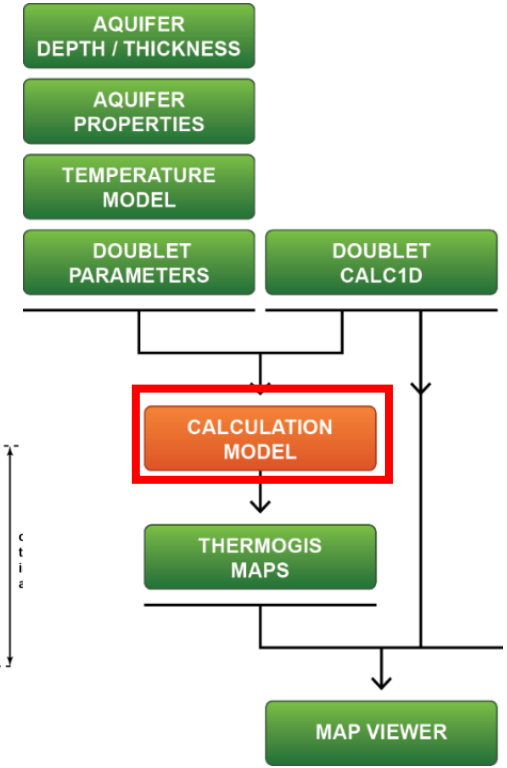
ThermoGIS/doubletcalc



DOUBLETCALC: STOCHASTIC TECHNO-ECONOMIC MODEL

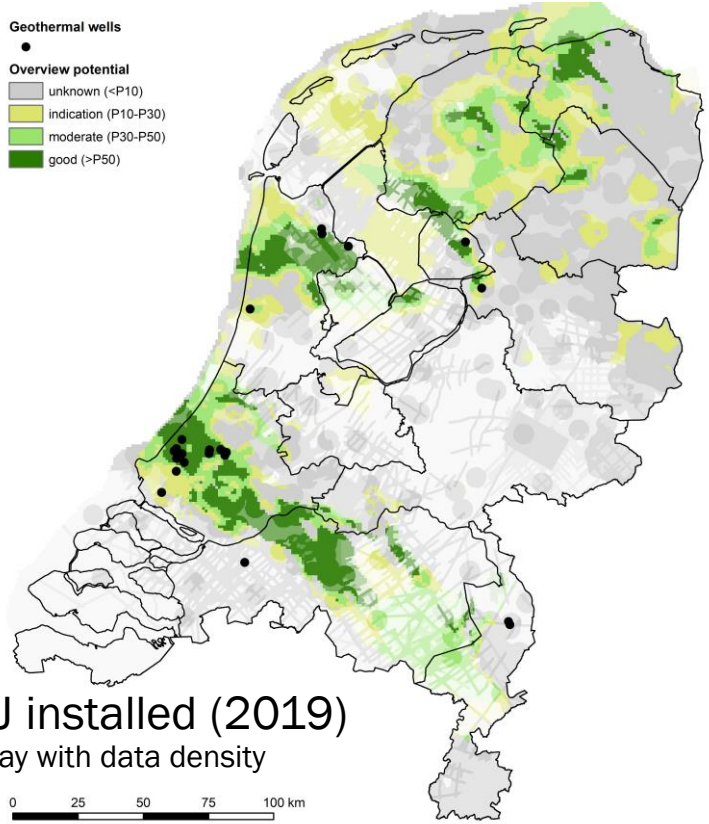
- Techno-economic analysis per XY location on a 1kmx1km grid
- Technical model:
  - Optimization of well distance
  - Pump pressure optimization
  - Batch run of DoubletCalc1D (for different transmissivity p-values)
- Most important output
  - geothermal power
  - flow rate
  - production temperature
  - LCOE

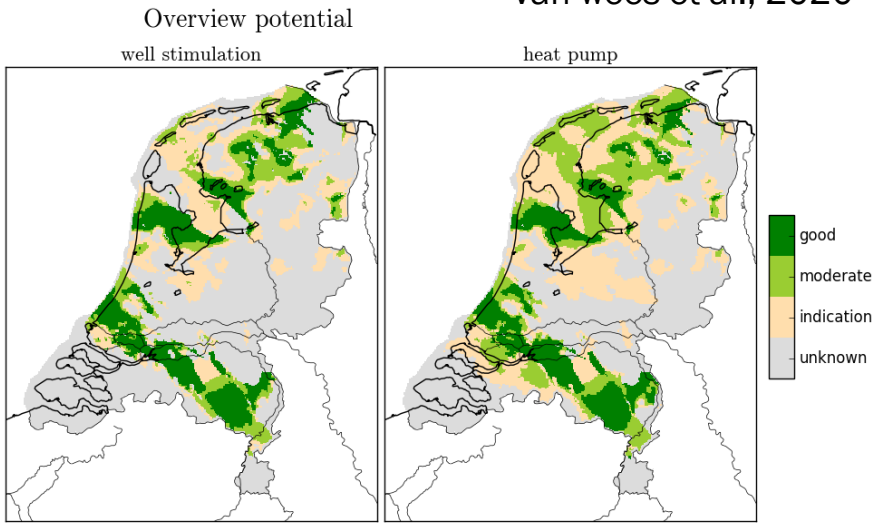




OVERVIEW GEOTHERMAL POTENTIAL

Van wees et al., 2020





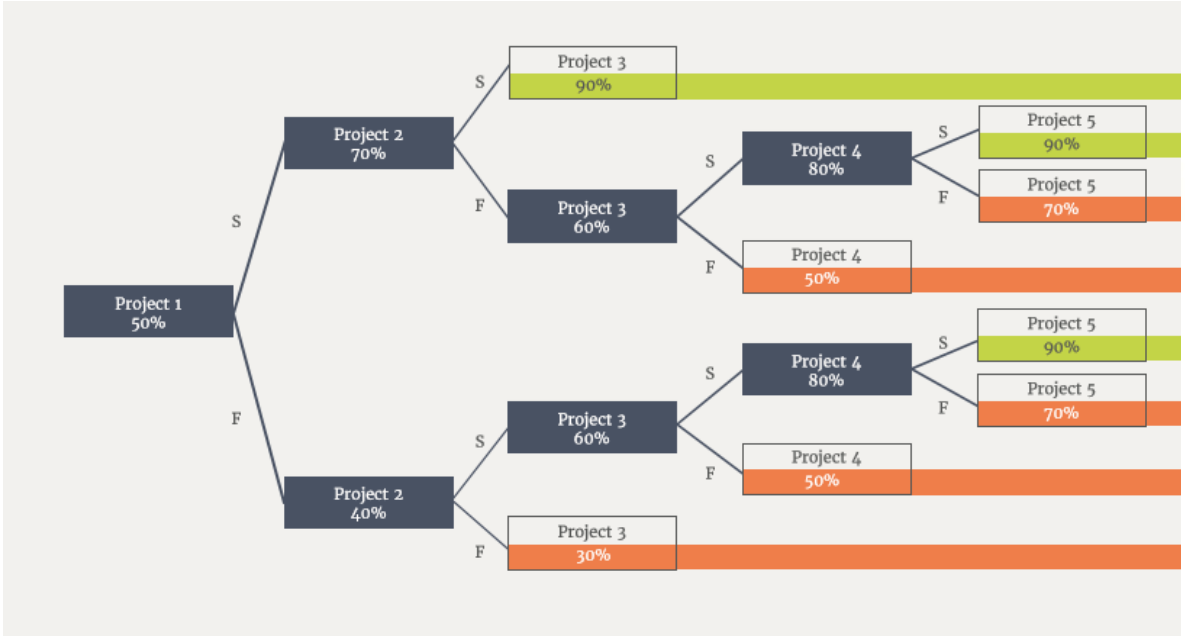
- *Unknown*: UTC P10 > reference price
- *Indication*: UTC P10 < reference price
- *Moderate*: UTC P30 < reference price
- *Good*: UTC P50 < reference price

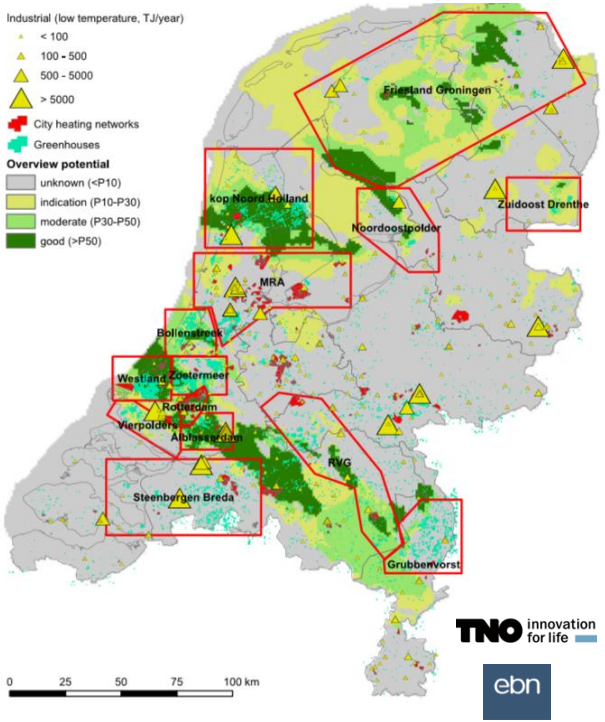
3 PJ installed (2019)

Overlay with data density

GEOTHERMAL ENERGY: PLAY-BASED PORTFOLIO APPROACH

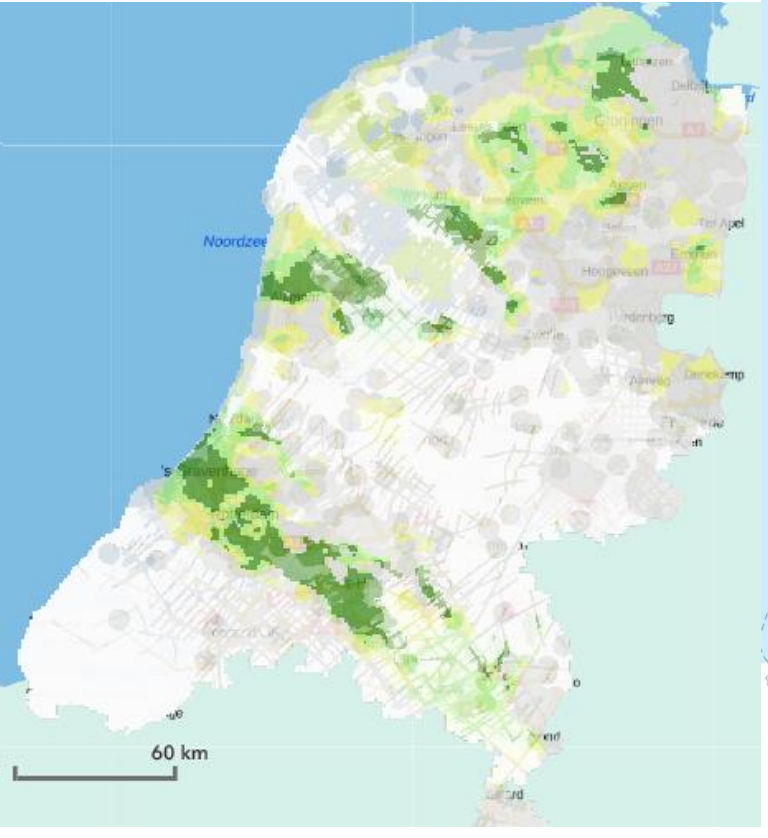
Van wees et al., 2020



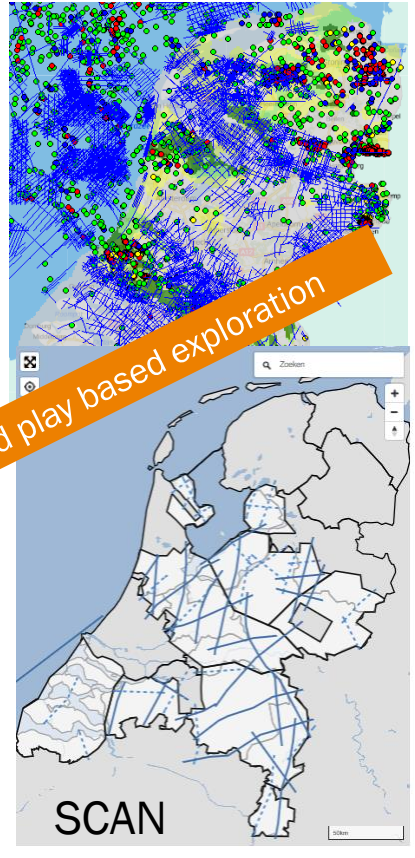


Ca 2 BLN Euro savings vs stand-alone for ca 500 doublets, 100-300PJ potential

WHITE SPOTS

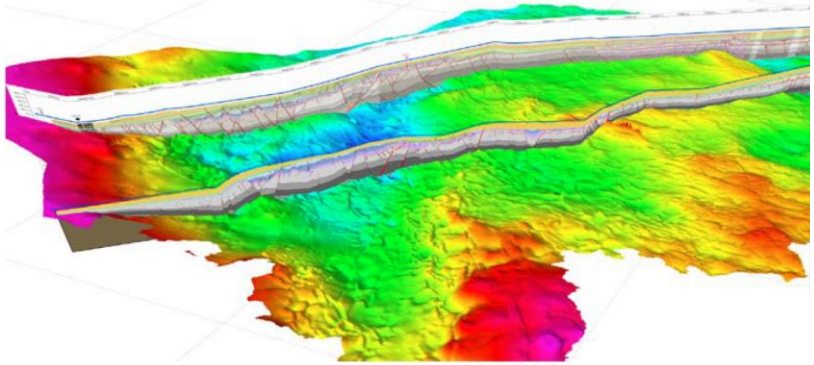


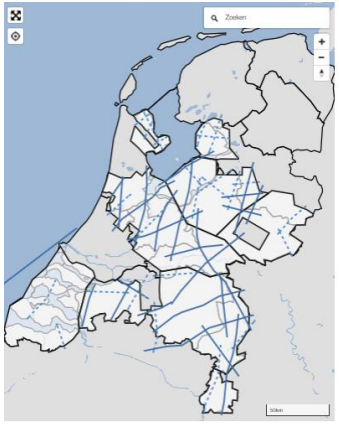
IMPACT: >30 mln invested in a concerted play based exploration

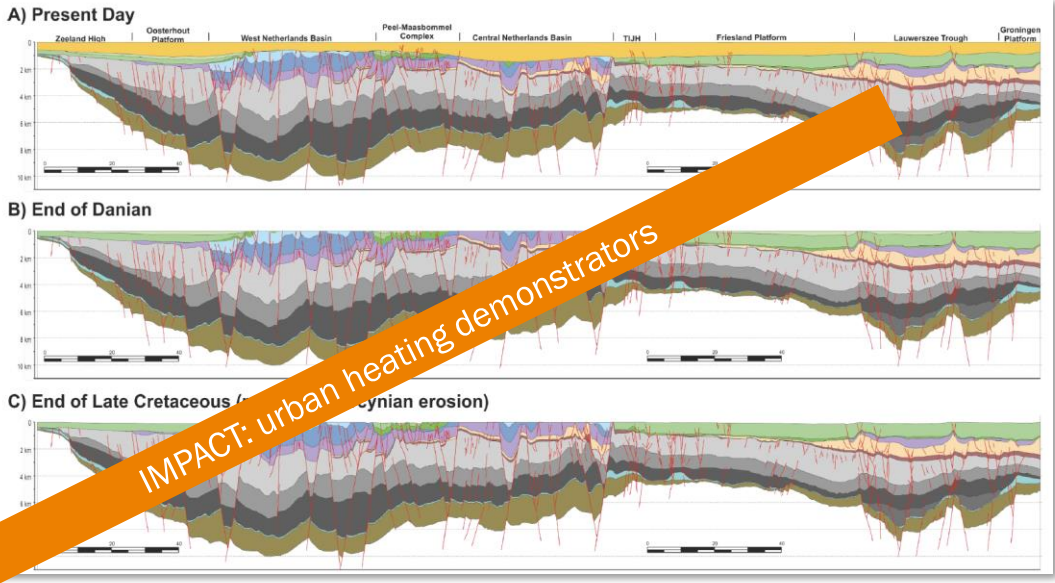


GEOTHERMAL ENERGY: SCAN EXPLORATION AND DRILLING CONCEPTS

Bouroullec et al., 2019







LEAN: Low cost Exploration and derisking in urbAN areas

RESULT

Enhancing **RES**ervoirs in **U**rban deve**L**opmen**T**: smart wells and reservoir development

Rijswijk Center for Sustainable Geo-energy

TNO innovation for life

ebn

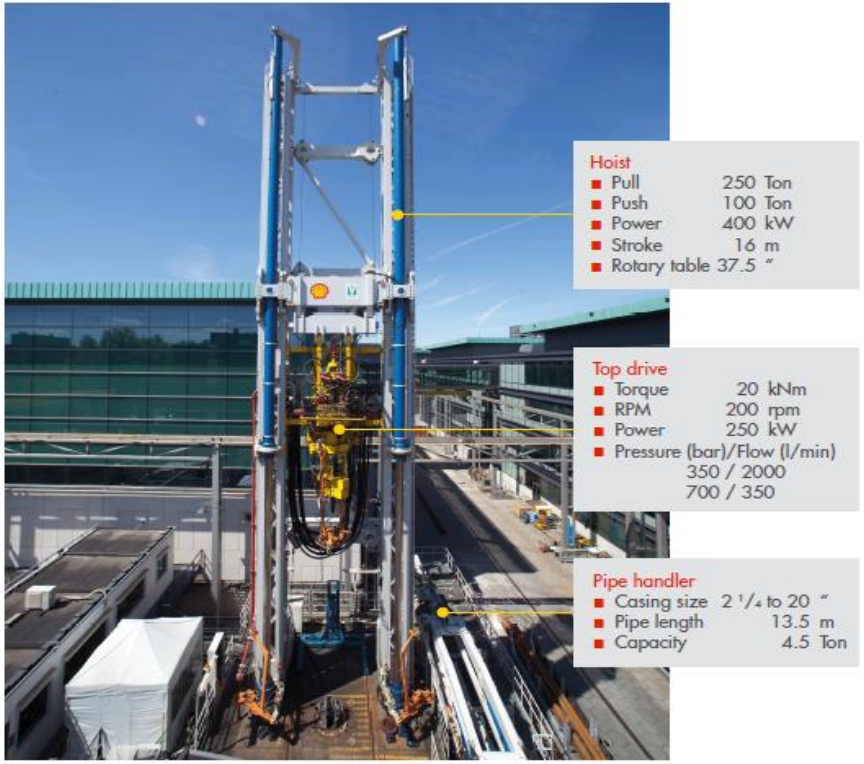
TU Delft

Universiteit Utrecht

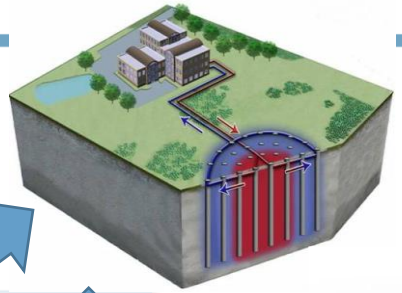
Rijswijk

provincie Zuid Holland

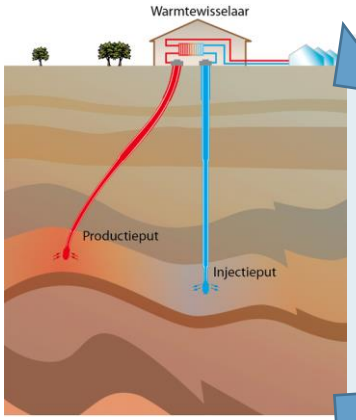
Ministry of Economic Affairs and Climate Policy



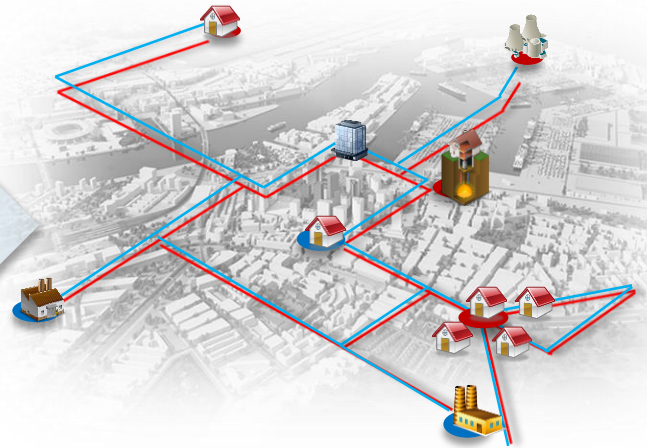
GEOTHERMAL HEAT FOR THERMAL GRIDS: SYSTEM INTEGRATION



- Thermal energy storage



- Production

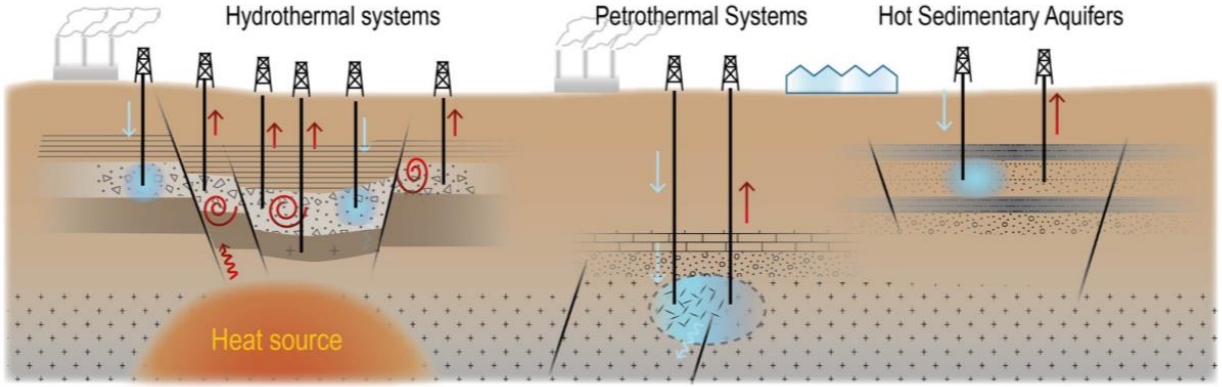


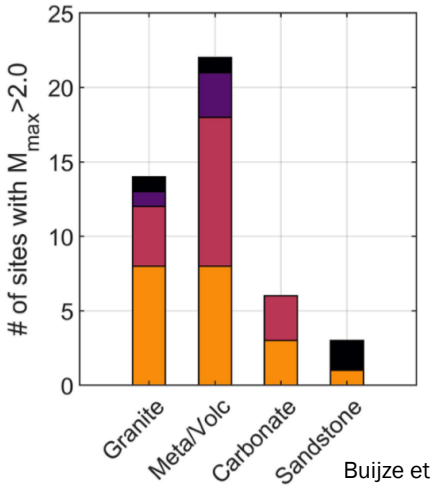
- Optimization of KPIs
  - costs
  - sustainability
  - flexibility

- Heat pump technology

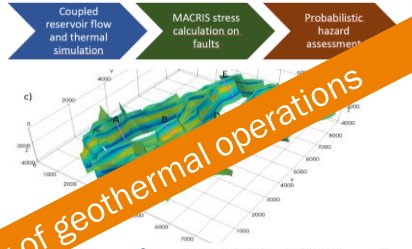
WARMINGUP

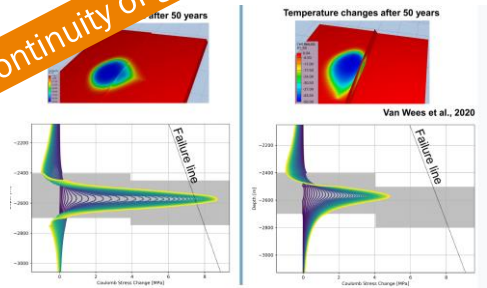
GEOTHERMAL ENERGY: UNDERSTANDING INDUCED SEISMICITY





Buijze et al., 2020





- **pore pressure and temperature changes**
- seismic hazard prediction → practical (public) tools
- Identification of regions & reservoirs that need 'more' or 'less' attention
- Build confidence: How good are our predictions?

IMPACT: ensuring continuity of geothermal operations

GEOTHERMAL ENERGY RESEARCH

INTERNATIONAL ▼

NATIONAL ▼

1926 – 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | ...

KAWAH KAMOJANG

1926 First Indonesian geothermal test well, now biggest geothermal field in Indonesia.

EERA: WORLD AQUIFER VIEWER

2011 European Energy Research Alliance

GEISER: INDUCED SEISMICITY MODELS

GEISER

2012 EU research into seismicity

GEOELEC: EUROPEAN GEOTHERMAL RESOURCE ASSESSMENT

2012 Resource assessment in Europe. Prospective study on the Geothermal electricity potential in the EU.

GEOTHERMAL ATLAS (EUROPE)

1988–2002 Inventory and mapping of geothermal potential.

ENGINE

IEA TECHNOLOGY ROADMAP GEOTHERMAL ENERGY 2011-2050

IMAGE: INTEGRATED METHODS FOR ADVANCED GEOTHERMAL EXPLORATION

Develop reliable exploration and assessment methods

SURE

Radial jet drilling

DESTRESS

Reservoir stimulation

GEOWELL

High temperature wells

GEMEX

Cooperation Mexico

GEOCAP: GEOTHERMAL CAPACITY BUILDING

Education and research

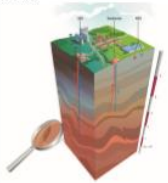
GEOTHERMICA

GEOTHERMICA

- CAGE (composite casing)
- Perform (reservoir performance), HeatStore (ATES)
- GeConnect (tight casing connections)

RESOURCE MAPPING FOR GEOTHERMAL IN THE NETHERLANDS

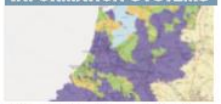
1982–1987 Mapping of potential aquifers for geothermal in the Netherlands.



ASTEN-2 GEOTHERMAL WELL

1986 First geothermal exploration well in the Netherlands.

ThermoGIS / DUTCH GEOTHERMAL AQUIFER INFORMATION SYSTEMS

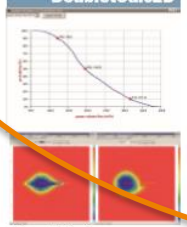


2010 Public tool for pre-drill geothermal capacity estimate.

VAN DEN BOSCH-1 GEOTHERMAL WELL

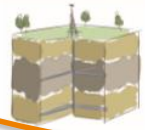
2007 First successful geothermal doublet in the Netherlands.

DoubletCalc2D



1D and 2D performance assessment tool

HIPE



Field application of radial jet drilling.

ATES

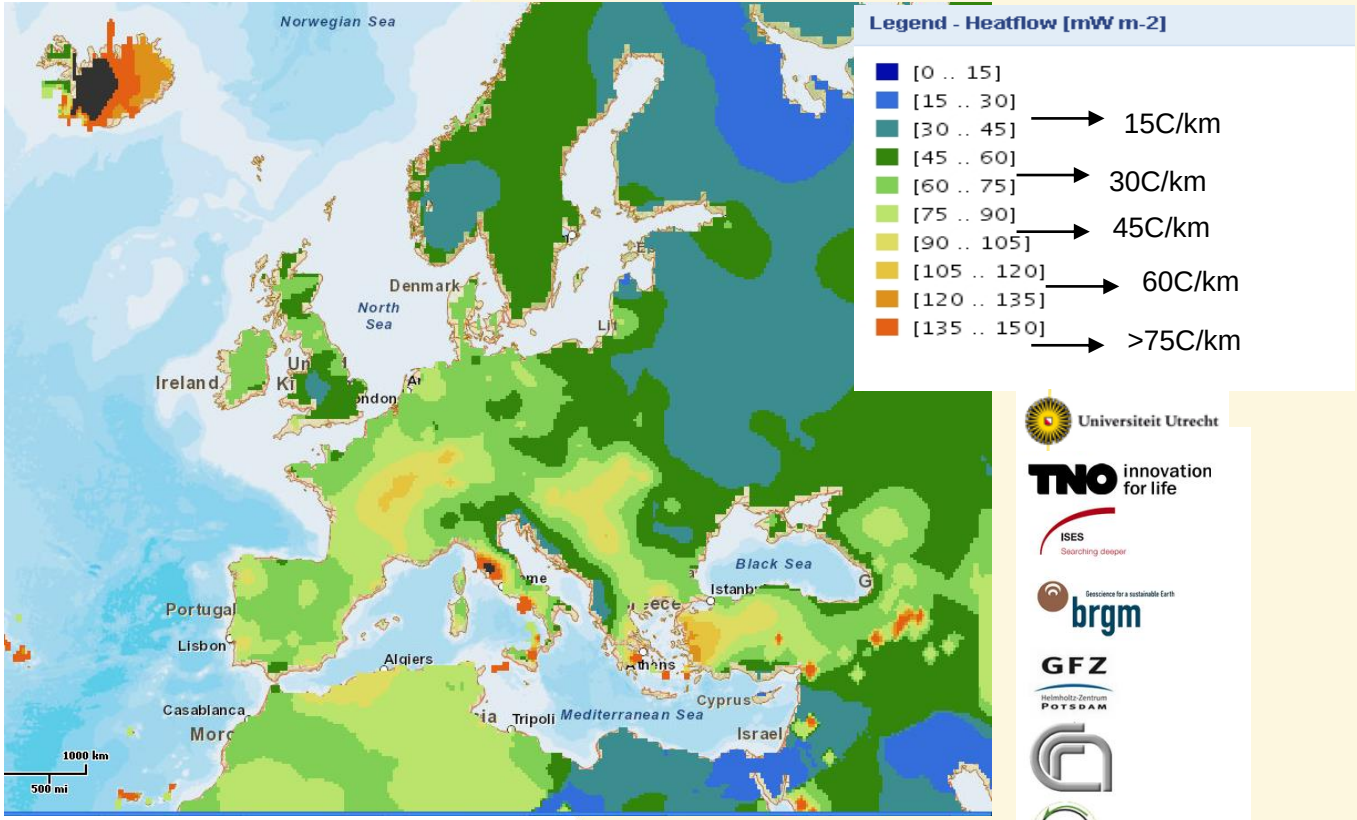
Resource mapping and assessment for high temperature aquifer thermal energy storage

ULTRADEEP GEOTHERMAL

Development ultradeep geothermal play in the Netherlands

A CENTURY OF DEDICATION TO GEOTHERMAL ENERGY

Surface heat flow as indicator for deep temperature



Legend - Heatflow [mW m-2]

- [0 .. 15]
- [15 .. 30]
- [30 .. 45] → 15C/km
- [45 .. 60] → 30C/km
- [60 .. 75] → 45C/km
- [75 .. 90]
- [90 .. 105]
- [105 .. 120] → 60C/km
- [120 .. 135]
- [135 .. 150] → >75C/km

$$q = -k\frac{dT}{dz}$$

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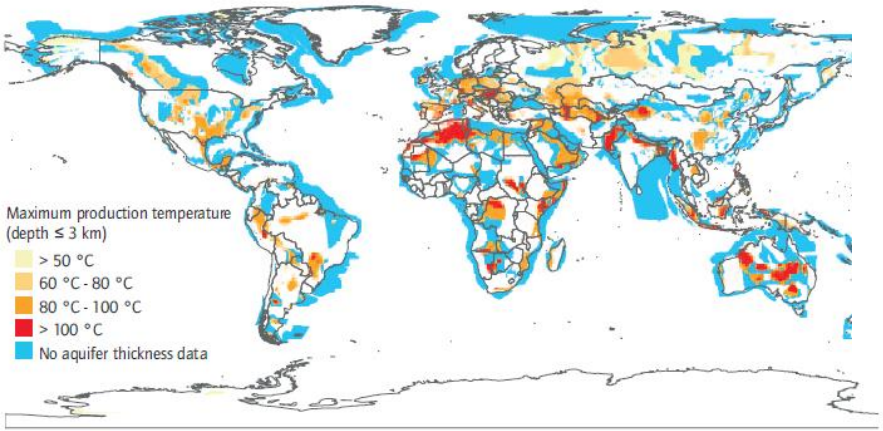
TNO innovation for life
ISES Searching deeper
brgm
GFZ Helmholtz-Zentrum Potsdam
CEGL
IAG

EERA European Energy Research Alliance
Universiteit Utrecht

SEDIMENTARY BASINS - GLOBAL POTENTIAL INDICATORS

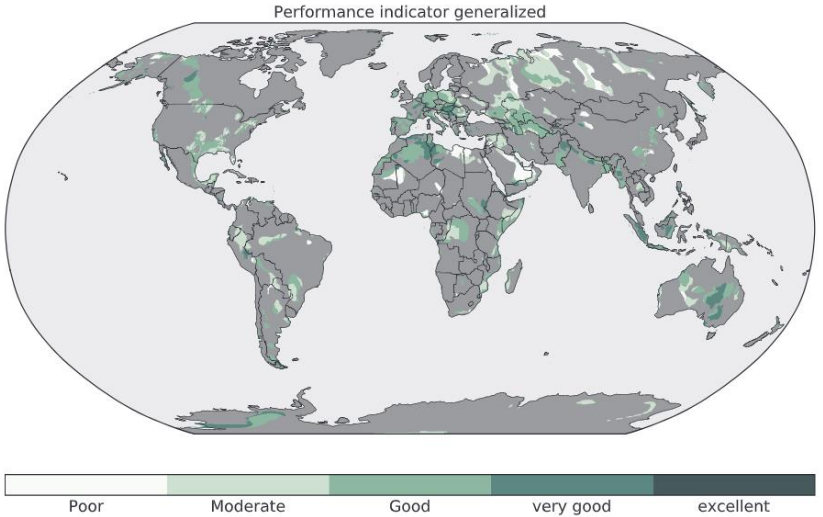
Figure 3: World map of deep aquifer systems



Note: World map of deep aquifer systems modified from (Penwell, 1984). Overlain are expected average production temperatures for a depth interval starting at excess temperatures of 40°C relative to surface, and ranging to a maximum depth of 3 km. The map is based on heat flow data from Artemieva (2006) and sediment thickness information from Laske and Martens (1997). Local performance strongly depends on natural heat flow conditions and surface temperature.

Source: TNO, www.thermogis.nl/worldaquifer.

IEA, 2011



Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization

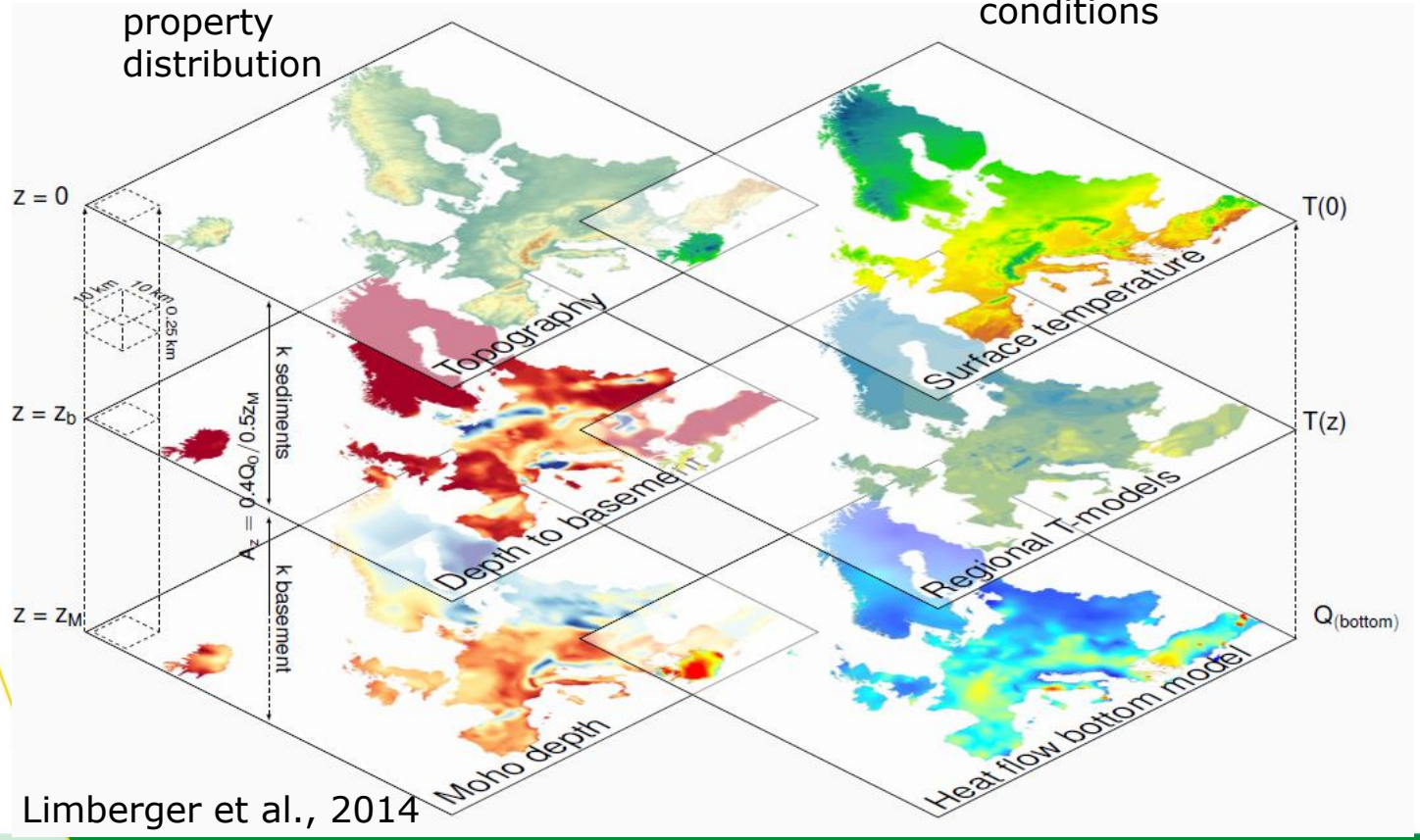
Jon Limberger[a,*], Thijs Boxem[b], Maarten Pluymaekers[b], David Bruhn[c,d], Adele Manzella[e], Philippe Calcagno[f], Fred Beekman[a], Sierd Cloetingh[a], Jan-Diederik van Wees[a,b]

[a] Utrecht University, Department of Earth Sciences, PO Box 80021, 3508 TA Utrecht, The Netherlands
[b] TNO, P.O. Box 80015, NL-3508 TA Utrecht, The Netherlands
[c] Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Section 6.2, Telegrafenberg Building A 69, 14473 Potsdam, Germany
[d] TU-Delft, Faculty of Civil Engineering and Geosciences, PO-Box 5048, 2600 GA Delft, The Netherlands
[e] National Research Council of Italy, Institute for Geosciences and Earth Resources, Via Moruzzi 1–56124, Pisa, Italy
[f] Bureau de Recherches Géologiques et Minières (BRGM), Orléans, France

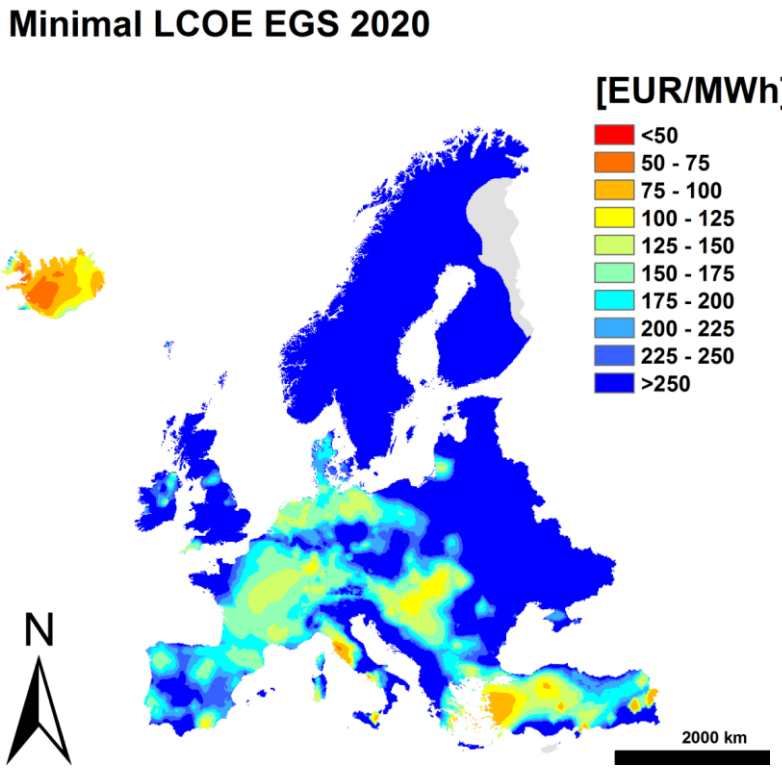
2018

Geometry and property distribution

Boundary conditions

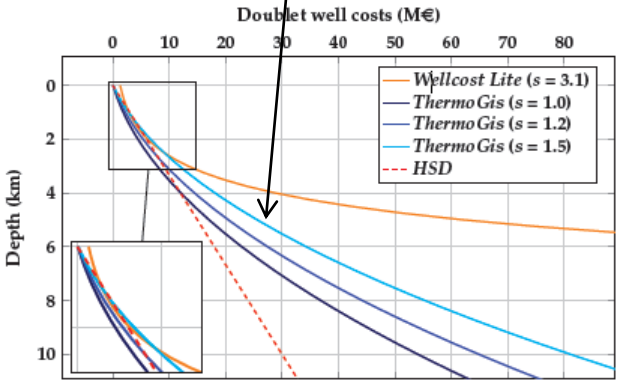


Limberger et al., 2014



Assumptions:

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



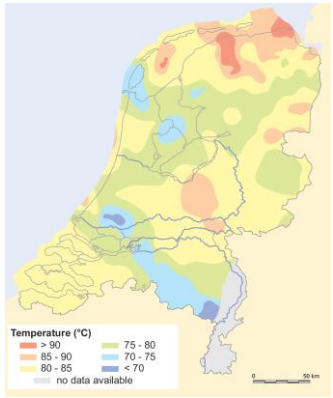
Costs for Enhanced Geothermal Systems in 2020

Limberger et al., 2014

+20mln stimulation

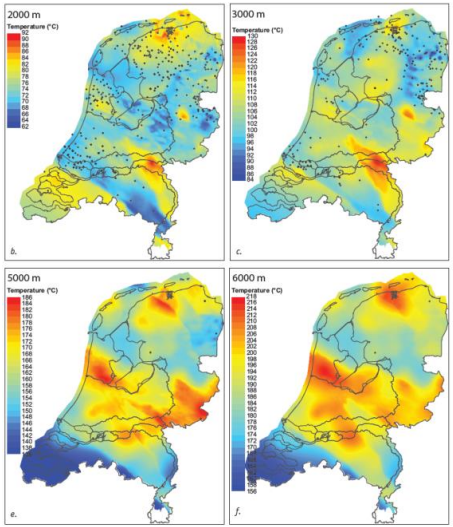
3D REGIONAL TEMPERATURE MODELLING - NETHERLANDS

Interpolating temperatures without geology



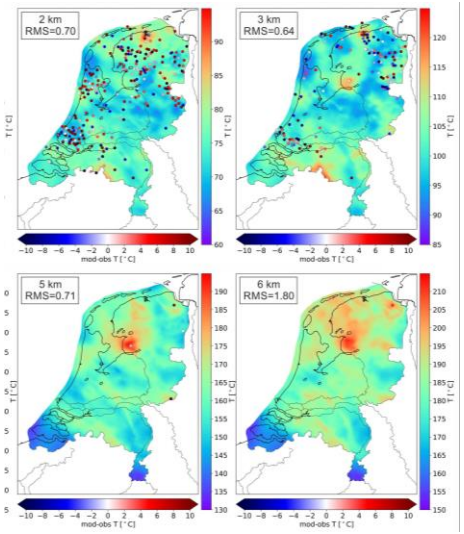
Lokhorst & Wong, 2007

Physics-based 3D temperature modeling



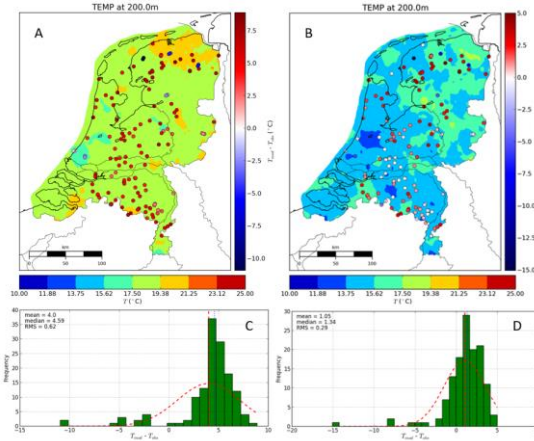
Bonté et al., 2012

Updated 3D temperature modeling - deep



Békési et al., 2020

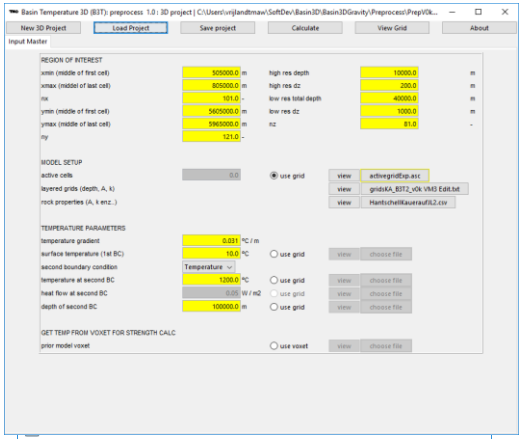
Updated 3D temperature modeling - shallow

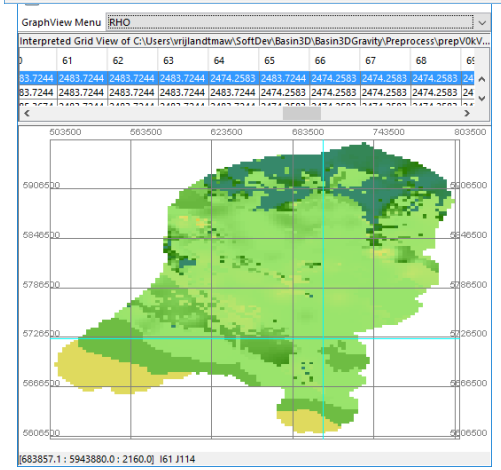


Gies et al., under review

IMAGE DATA –ASSIMILATION WORKFLOW

TNO innovation for life





Step 0
Multi-1-D model

Boundary conditions:
- Surface temperature
- Heat flow at 10 km depth

Step 1
Prior 3-D model

Boundary conditions:
- Surface temperature
- Heat flow at the LAB

Initial thermal properties

misfit

obs mod

Step 2
Update the basal boundary condition (heat flow at the LAB)

Step 3
Update the radiogenic heat production of the upper crust

Step 4
Update the vertical thermal conductivity of sediments

Step 5
Posterior 3-D model

Updated thermal properties

misfit

obs mod

- ES-MDA
- 5000 runs
- User friendly
- steady state
- Runs on PC

Bekesi et al., 2017, for Hungary, GPC
Limberger et al., 2018, for Europe, 2018, GPC

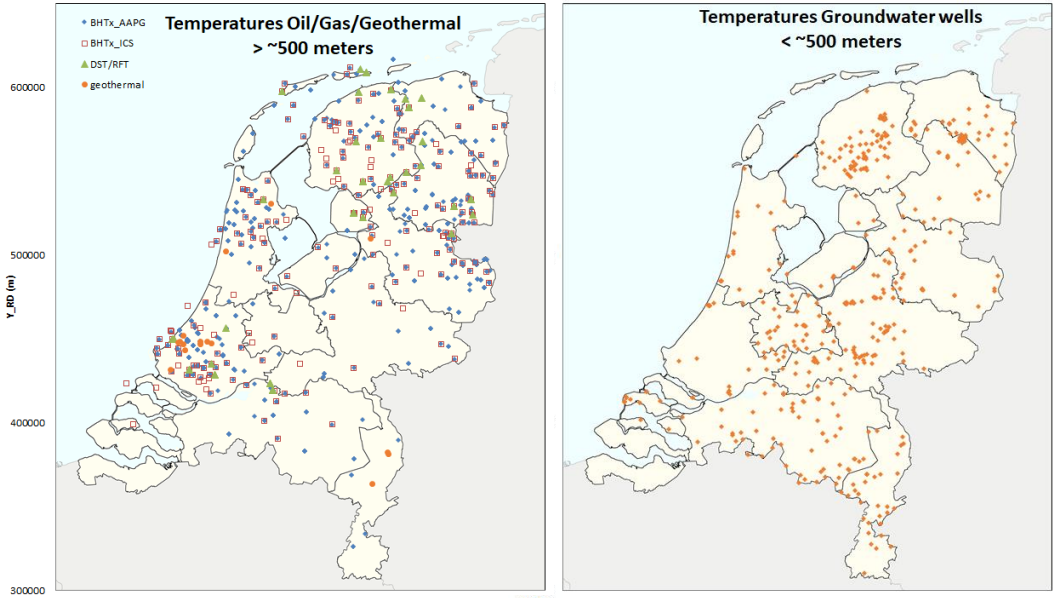
TEMPERATURE DATA

“Deep” temperature database

- Raw data freely available after 5 years (http://www.nlog.nl) (~4100)
- Selection of:
    1. Bottom Hole Temperatures (BHT)
    2. Drill Stem Tests & Repeat Formation Tests (DST & RFT)
    3. Production temperatures from geothermal wells
    4. Fibre optics (FO) no data available yet
- Correction needed

“Shallow” temperature database

- Shallower then 500 meters
- ~400 wells with temperature profile
- No correction needed



Bekesi et al., geothermics (2020)

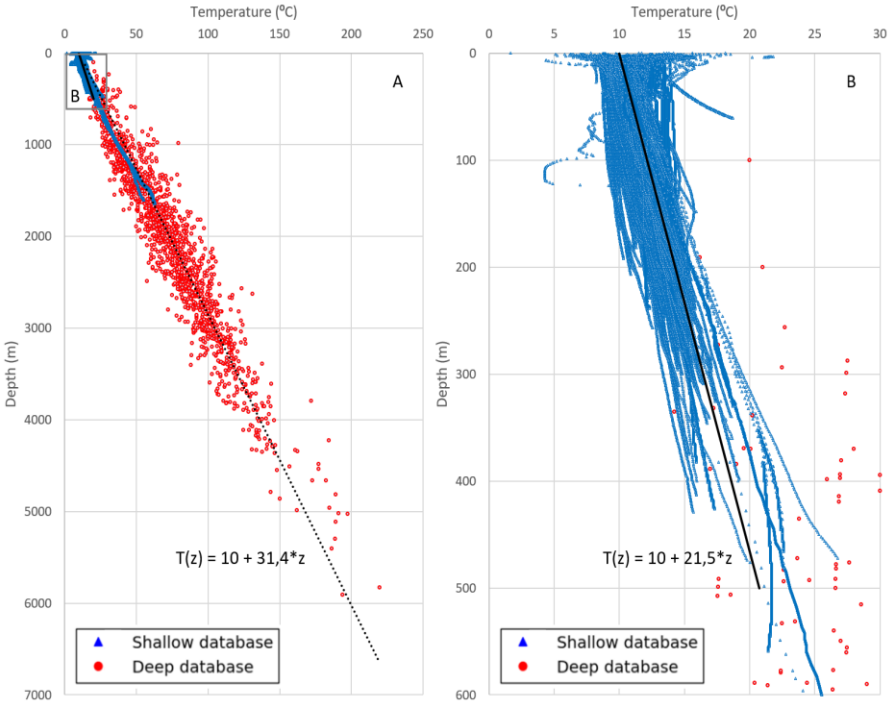
TEMPERATURE DATA AND ANALYSIS

“Deep” temperature database

- Average gradient of 31°C/km
- ~1500 corrected measurements

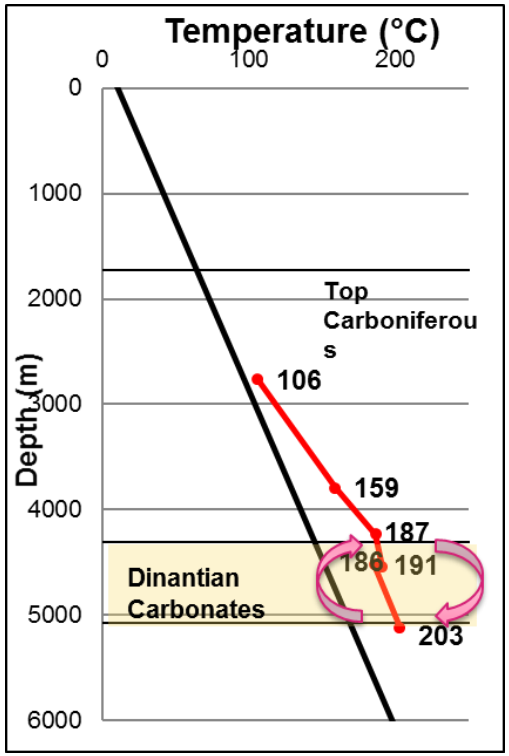
“Shallow” temperature database

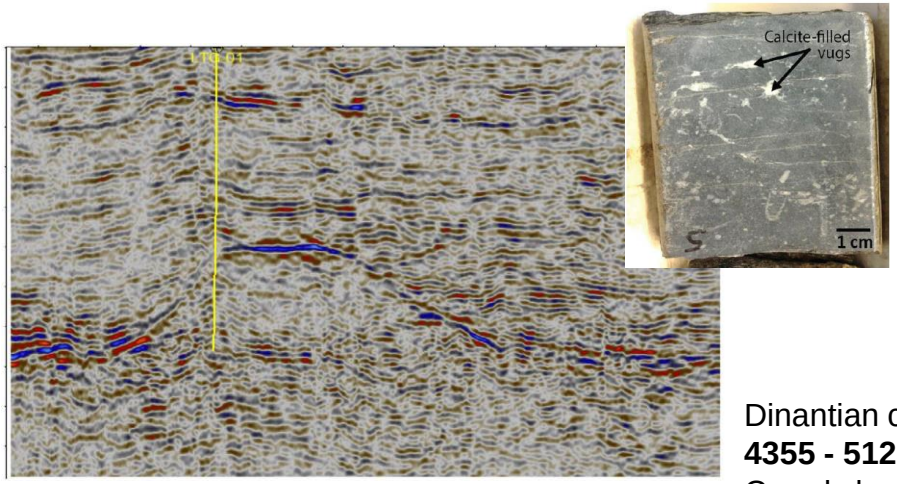
- Average gradient of 21°C/km
- ~400 wells

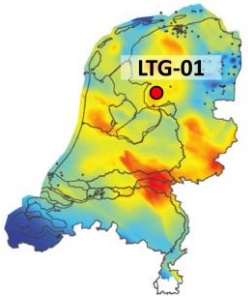


Gies et al., under review

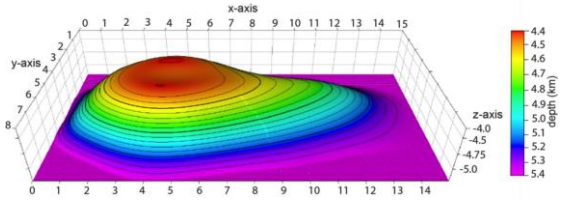
INVESTIGATION OF THE LTG-01 THERMAL ANOMALY







Dinantian carbonates platform **4355 - 5123 m** (768 m thick).
Cored show dark-grey limestones



Carbonate structure from seismic

DEEP DUTCH TEMPERATURE MODEL

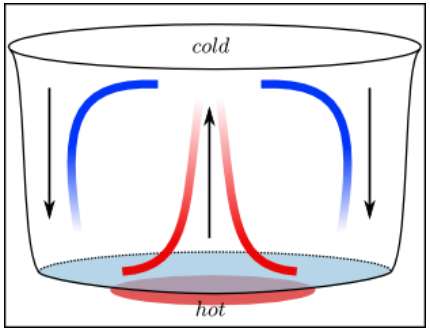
2012 – Old temperature model (Bonté et al., 2012)
Could not fit higher temperatures at larger depth in the dinantian carbonates (LTG-01)

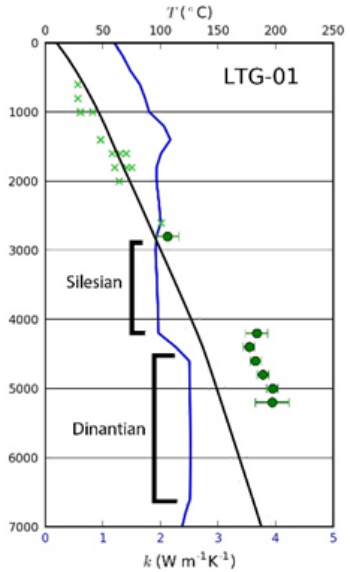
Hydrothemal convection in dinantian carbonates in the Luttelgeest well?

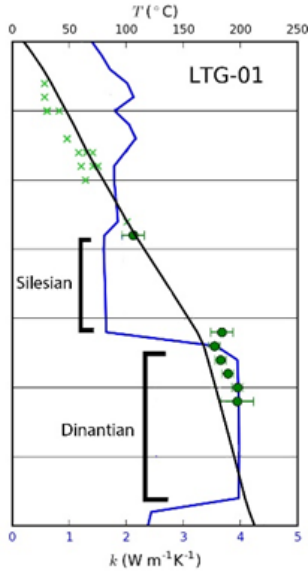
- Studies (Lipsay et al., 2016) show convection could occur

2018 – New temperature model - deep
Take into account possible convection →

Pseudo-convective approach

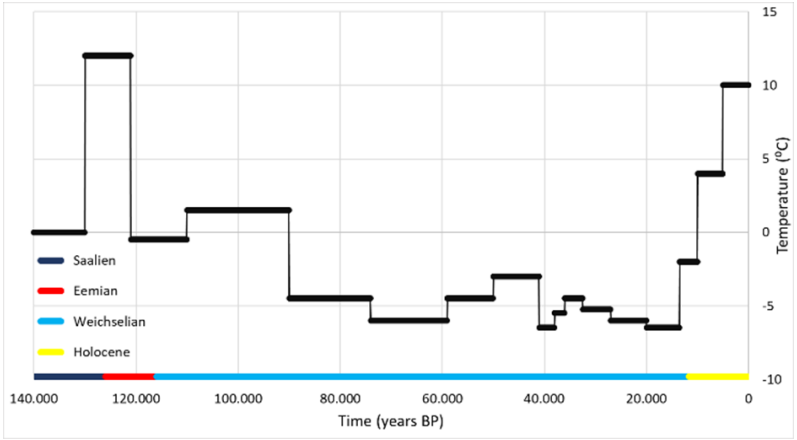


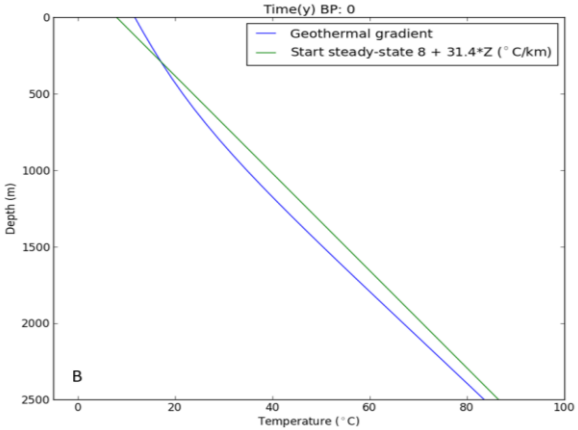


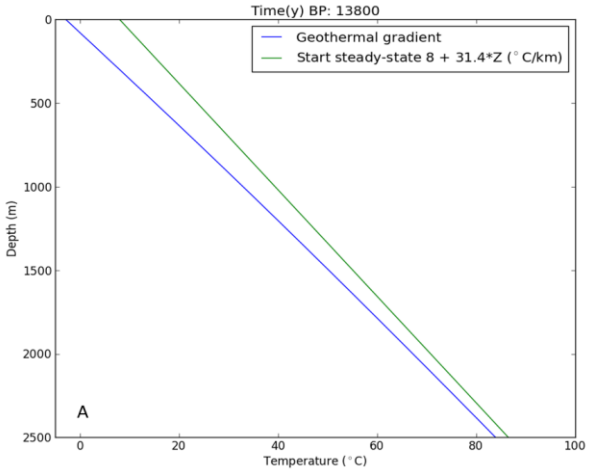


PALEO-SURFACE EFFECT

- Based on climate proxy data
- Weichselen → T_0 <= 0 °C and Holocene 10.000 year
- Influence on todays temperature profile



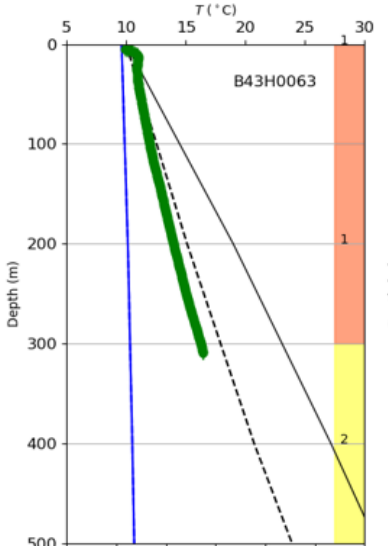




Gies et al., under review

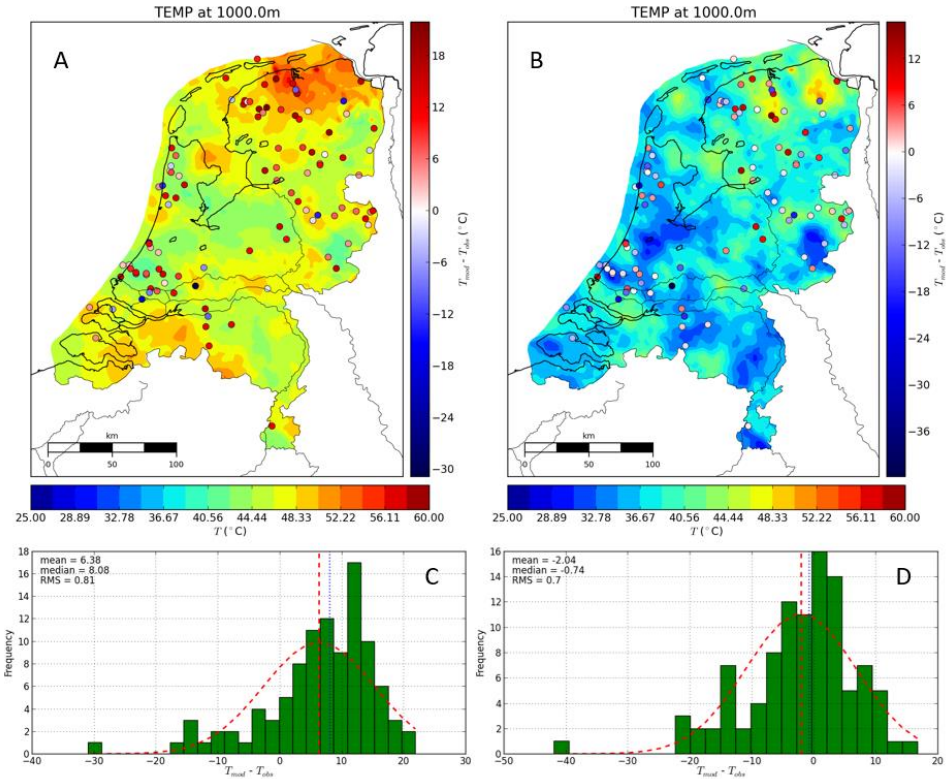
INCLUDED IN MODEL

- Add paleo-surface effect in 3D temperature modelli
- Significant improvements



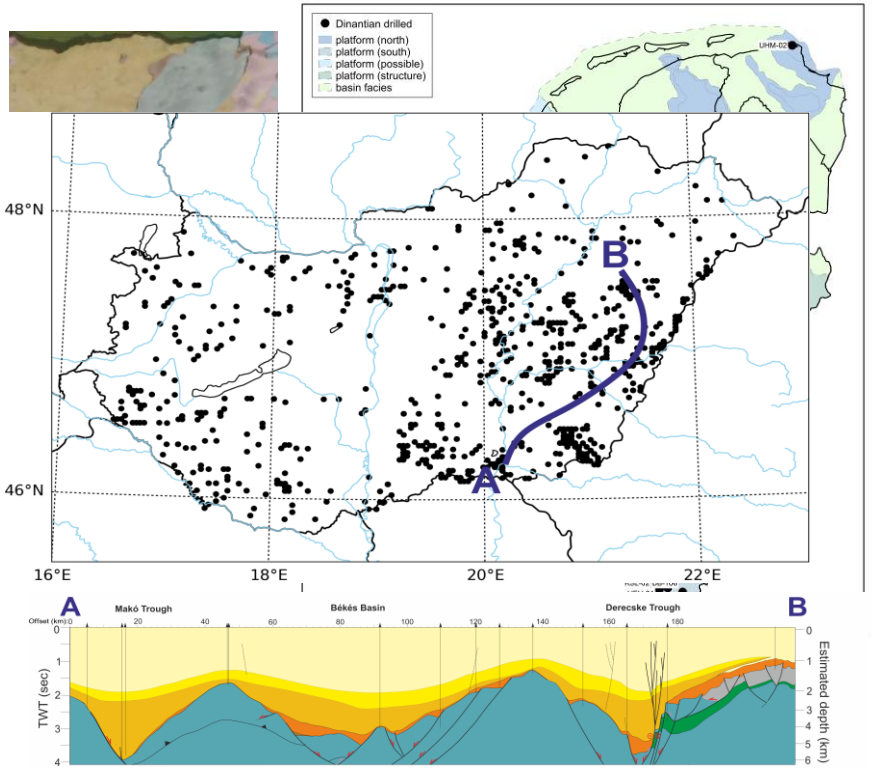
“deep” model

“shallow” model



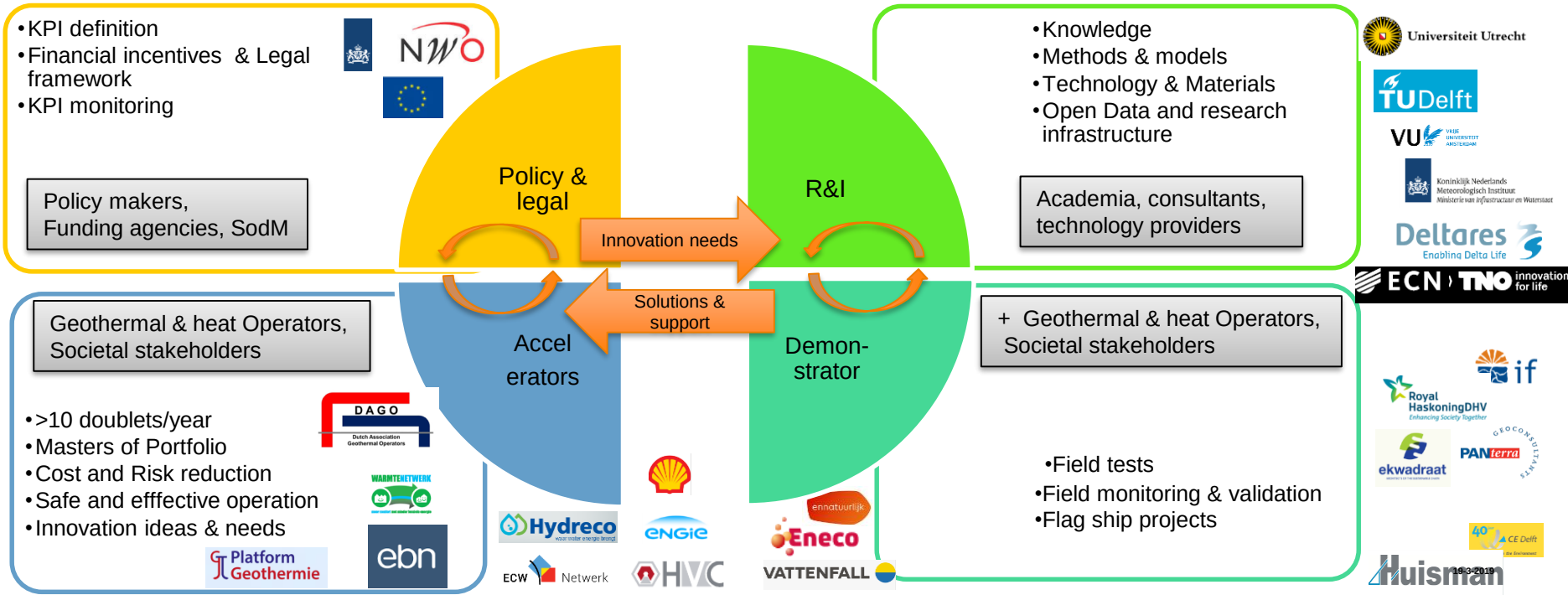
CONCLUSIONS

- ES-MDA powerful data assimilation for temperature and densiity models, supports high res external constrains
- Temperature anomalies in NL strongly dependent on conceptual constraints (deep convection – paleo surface temp. effects)
- Easy to use, applied in various settings



- Calibrated with >3500 temperature measurements
- Bekesi et al., 2017, Global and Planetary Change

Mission Driven Approach Needed

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