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

Jan-Diederik van Wees
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

~35km ~27km

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

3 PJ installed (2019)
Overlay with data density

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
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

IMPACT: urban heating demonstrators

Enhancing REServoirs in Urban deVelopment: smart wells and reservoir development
Rijswijk Center for Sustainable Geo-energy
GEOTHERMAL HEAT FOR THERMAL GRIDS: SYSTEM INTEGRATION

- Production
- Heat pump technology
- Thermal energy storage
- Optimization of KPIs:
  - costs
  - sustainability
  - flexibility
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?
A CENTURY OF DEDICATION TO GEOTHERMAL ENERGY

Kawah Kamojang: 1926 - First Indonesian geothermal test well, now largest geothermal field in Indonesia.

EERA: World Aquifer Viewer

GEOTHERMAL ATLAS (EUROPE)

1988-2003: Inventory and mapping of geothermal potential.

IEA Technology Roadmap Geothermal Energy 2011-2050

GEOLATT: European Geothermal Resource Assessment

2012: Resource assessment of Europe. Prospection study on the geothermal energy potential in the EU.

Image: Integrated methods for advanced geothermal exploration

Develop reliable exploration and assessment methods.

Geocap: Geothermal Capacity Building

Expedition and research.

Geothermic!

- CAGE: (composite setting)
-uge: Perform (reservoir performance), Indexing (PHE)
- GeoPipes (right-facing connections)

Geothermic India

- CAGE: (composite setting)
- Perform (reservoir performance), Indexing (PHE)
- GeoPipes (right-facing connections)

A CENTURY OF DEDICATION TO GEOTHERMAL ENERGY


Thermogis/Dutch Geothermal Aquifer Information Systems

2010: Public tool for pre-drill geothermal capacity estimations.

Doublet Calc 2D

1D and 2D performance assessment tool.

HiPE

Development: Ultradeep geothermal play in the Netherlands.

SUE:

- Radial jet drilling
- DESS: Reservoir stimulation
- GEOWELL: High temperature wells
- GEMEX: Cooperation Mexico

1926-2012

Resource Mapping for Geothermal in the Netherlands

Surface heat flow as indicator for deep temperature

\[ q = -k \frac{dT}{dz} \]
SEDIMENTARY BASINS - GLOBAL POTENTIAL INDICATORS

Figure 3: World map of deep aquifer systems

Note: World map of deep aquifer systems modified from (Penwell, 1984). Ovals are expected average production temperatures for a depth interval starting at excess temperatures of 60°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 Masters (1997). Local performance strongly depends on natural heat flow conditions and surface temperature. Sources: TNO, www.bthermegis.it/worldaqua.png.

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


* Utrecht University, Department of Earth Sciences, PO Box 80022, 3508 TA Utrecht, The Netherlands
† TNO, PO Box 80025, NL-2500 AA UTRECHT, THE NETHERLANDS
‡ HZDR, Helmholtz Centre Dresden-Rossendorf, GFZ German Research Centre for Geosciences, Section 6.2, Integrationsbuilding A 09, 14478 Potsdam, Germany

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


* Utrecht University, Department of Earth Sciences, PO Box 80022, 3508 TA Utrecht, The Netherlands
† TNO, PO Box 80025, NL-2500 AA UTRECHT, THE NETHERLANDS
‡ HZDR, Helmholtz Centre Dresden-Rossendorf, GFZ German Research Centre for Geosciences, Section 6.2, Integrationsbuilding A 09, 14478 Potsdam, Germany

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


* Utrecht University, Department of Earth Sciences, PO Box 80022, 3508 TA Utrecht, The Netherlands
† TNO, PO Box 80025, NL-2500 AA UTRECHT, THE NETHERLANDS
‡ HZDR, Helmholtz Centre Dresden-Rossendorf, GFZ German Research Centre for Geosciences, Section 6.2, Integrationsbuilding A 09, 14478 Potsdam, Germany

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


* Utrecht University, Department of Earth Sciences, PO Box 80022, 3508 TA Utrecht, The Netherlands
† TNO, PO Box 80025, NL-2500 AA UTRECHT, THE NETHERLANDS
‡ HZDR, Helmholtz Centre Dresden-Rossendorf, GFZ German Research Centre for Geosciences, Section 6.2, Integrationsbuilding A 09, 14478 Potsdam, Germany

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


* Utrecht University, Department of Earth Sciences, PO Box 80022, 3508 TA Utrecht, The Netherlands
† TNO, PO Box 80025, NL-2500 AA UTRECHT, THE NETHERLANDS
‡ HZDR, Helmholtz Centre Dresden-Rossendorf, GFZ German Research Centre for Geosciences, Section 6.2, Integrationsbuilding A 09, 14478 Potsdam, Germany
Geometry and property distribution

Boundary conditions

Limberger et al., 2014
Assumptions:
- Doublet
- COP = 50
- $T_{\text{min}} = 100^\circ\text{C}$
- Flow rate = 70 l/s
- Welcost scaling = 1.5
- $Z_{\text{max}} = 7\text{km}$
- Stimulation costs = 20M euro

Costs for Enhanced Geothermal Systems in 2020
Limberger et al., 2014
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
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

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

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

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

Hydrothermal 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 $\rightarrow$ $T_0 \leq 0$ °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 density 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

- KPI definition
- Financial incentives & Legal framework
- KPI monitoring

Policy & legal

- Innovation needs
- Solutions & support

R&I

- Knowledge
- Methods & models
- Technology & Materials
- Open Data and research infrastructure

Academia, consultants, technology providers

- Geothermal & heat Operators, Societal stakeholders

Innovation needs

Accelerators

- >10 doublets/year
- Masters of Portfolio
- Cost and Risk reduction
- Safe and effective operation
- Innovation ideas & needs

Demonstrator

+ Geothermal & heat Operators, Societal stakeholders

- Field tests
- Field monitoring & validation
- Flag ship projects

Policy makers, Funding agencies, SodM
THANKS FOR YOUR ATTENTION

For more inspiration
TIME.TNO.NL