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ThermoGIS: An Integrated Web-Based Information System for Geothermal Exploration and Governmental Decision Support for Mature Oil and Gas Basins

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ABSTRACT

In the recent years the uptake of geothermal energy through implementation of low enthalpy geothermal production systems for both electricity and heating has been growing rapidly in north-western Europe. Geothermal exploration and production takes largely place in sedimentary basins at depths from 2 to 5 km. Geothermal activities can take considerable advantage from a wealth of existing oil and gas data.

To governmental bodies, such as geological surveys, it is a major challenge to put relevant oil and gas data and derived subsurface structural, temperature, and flow property models available to the geothermal community and to facilitate in quantitative assessment of geothermal potential of targeted areas, for both heat and electricity production (EGS) . In order to face this challenge, TNO has developed a public web-based 3D information system connected to a geothermal performance assessment tool.

The public information system (thermoGIS) includes high resolution 3D geological models covering the complete onshore of the Netherlands, outlining key geothermal reservoirs and allowing users to assess relevant parameters and their underlying uncertainties. State-of-the-art 3D modeling techniques have been used and developed to obtain the reservoir structures, flow properties and temperatures, using constraints from over a thousand deep wells, and detailed subsurface mapping from 3D and 2D seismic. Users can obtain key reservoir parameters, and underlying uncertainties at any location and for any reservoir. In an automated workflow these parameters are fed into the performance assessment tool, in order to assess the probability of success to meet minimum requirements on key performance indicators such as Coefficient of Performance (COP), power produced, and Unit Technical Cost (UTC). The use of the ThermoGIS will aid exploration business decisions and Dutch governmental institutions, law makers and insurance companies.

1. INTRODUCTION

In the recent years the uptake of geothermal energy through implementation of low enthalpy geothermal production systems for both electricity and heating has been growing rapidly in north-western Europe. Geothermal exploration and production takes largely place in sedimentary basins at depths from 2 to 5 km. Geothermal activities can take considerable advantage of a wealth of existing oil and gas data.

To governmental bodies, such as geological surveys, it is a major challenge to make relevant oil and gas data and derived subsurface structural, temperature, and flow property models available to the geothermal community and to facilitate in quantitative assessment of geothermal potential of targeted areas, for both heat and electricity production.

The Netherlands is a relative small country, located in a region of moderately elevated heat flow (Figure 1). However, the Netherlands has a wealth of information of the subsurface worth over 50 billion Euros, which has been collected over the past 30 years by the oil and gas industry. It therefore stands out as an excellent location to use these data for geothermal exploration. In order to face this challenge, TNO has developed a public web-based 3D information system called thermoGIS connected to a geothermal performance assessment tool. It facilitates uptake of geothermal through free accessibility to data, models and performance assessment tools.

This paper describes the key components of the web-based system, the models underlying it and the future outlook for both heat and electricity production

2. 3D MAPPING AND THERMOGIS

In the Netherlands, over the past 30 years over 5,000 wells have been drilled and over 72,000 km of seismic has been collected for oil and gas exploration and production (Figure 2). The subsurface of the Netherlands includes various reservoirs for oil and gas, mostly in Mesozoic sediments penetrating 3-5 km deep (Wong et al., 2007). Most of these wells have been logged and cored promoting assessment of reservoir properties. Over 300,000 core plug measurements of permeability are available. All this data is freely accessible.

In the past decades the data has been used by TNO to develop 3D models of the subsurface structure, allowing insight in geological structures and targeting of exploration and production activities (NITG, 2004). Only recently it has been recognized that the datasets serve as an excellent starting point for geothermal exploration, both for known reservoirs at depth levels of 1500-3500m for heat, as well as targeting deeper (fault) structures for electricity production. However, up till now the mapping did not focus on geothermal reservoir and properties. In response to these needs, TNO has generated a detailed mapping of the onshore Netherlands at a horizontal resolution of 250m, including over 30 different lithostratigraphic formations ranging in age from Carboniferous to Quaternary. It outlines key geothermal reservoirs and allows to asses relevant parameters and underlying uncertainties. State-of-the-art 3D modeling techniques have been used and developed to obtain the reservoir structures, flow properties and temperatures, using constraints from deep wells, and

detailed subsurface mapping from 3D and 2D seismic. Figure 3 gives an example of views on thermoGIS. Its use allows to asses quickly key parameters such as depth, thickness, temperature and flow properties. Novel interactive 3D web-based GIS tools allow users to draw sections highlighting particular reservoirs and navigate simultaneously in geographic contexts tailored to societal needs.

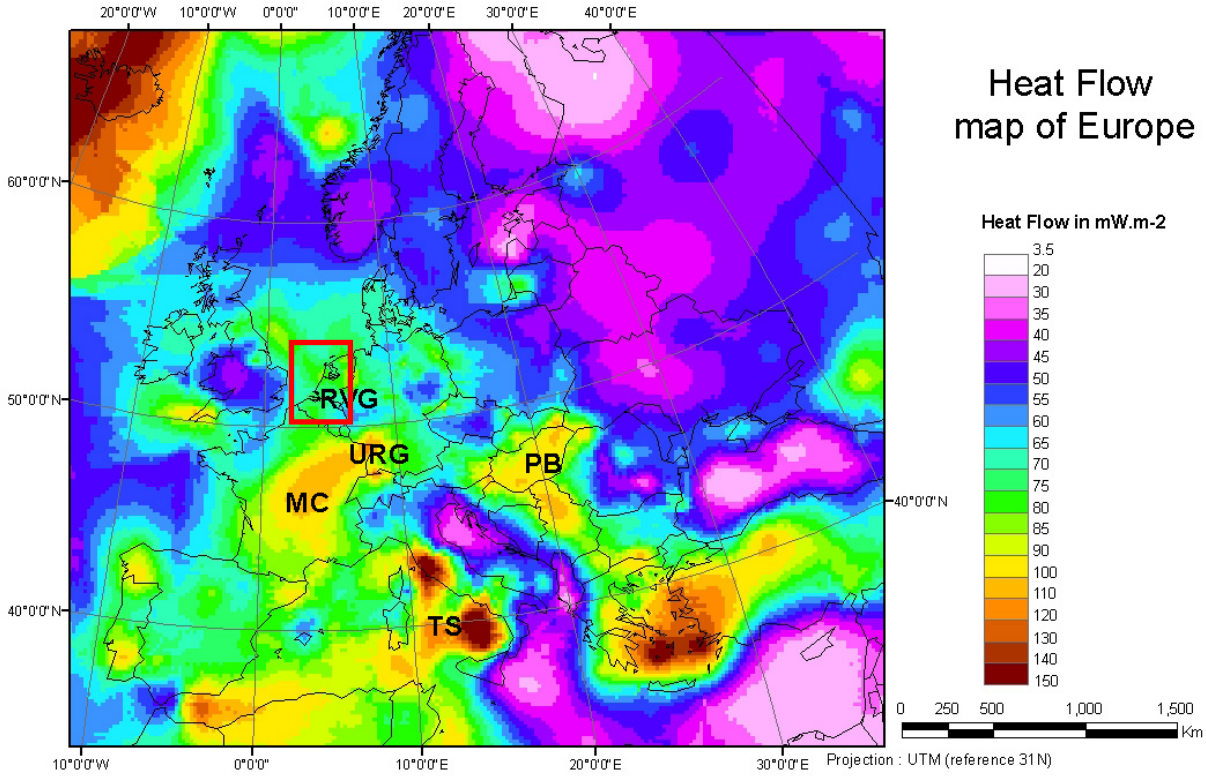


Figure 1: Surface heat flow and tectonic provinces in Europe. URG: upper rhine graben, PB: pannonian basin; RVG: roer valley graben; MC: Massif Central. TS: Tyrenean Sea. Geothermal. The Netherlands are located in the red box.

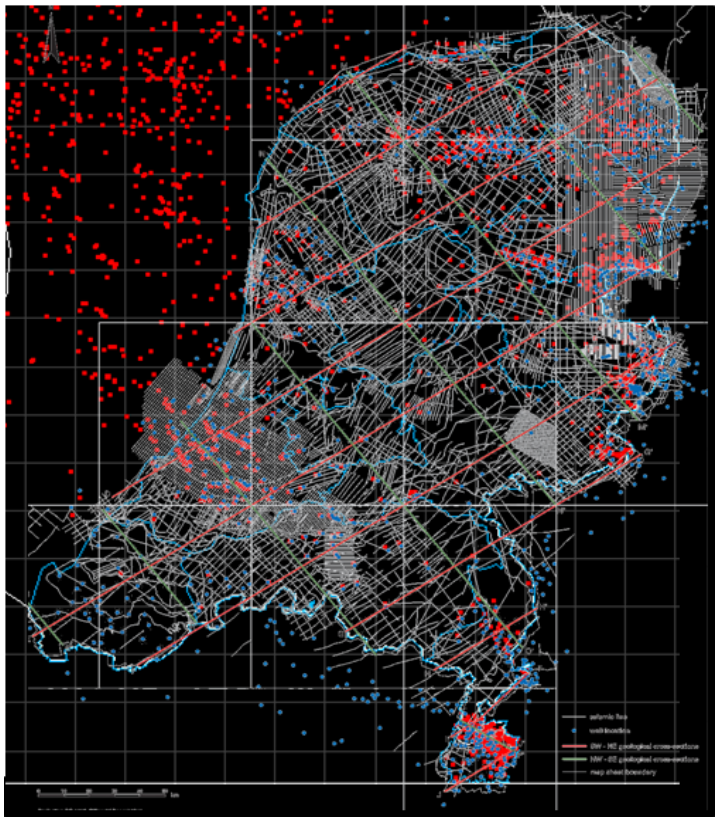


Figure 2: Wells (5872) and seismic coverage (over 70.000 km) in the Netherlands.

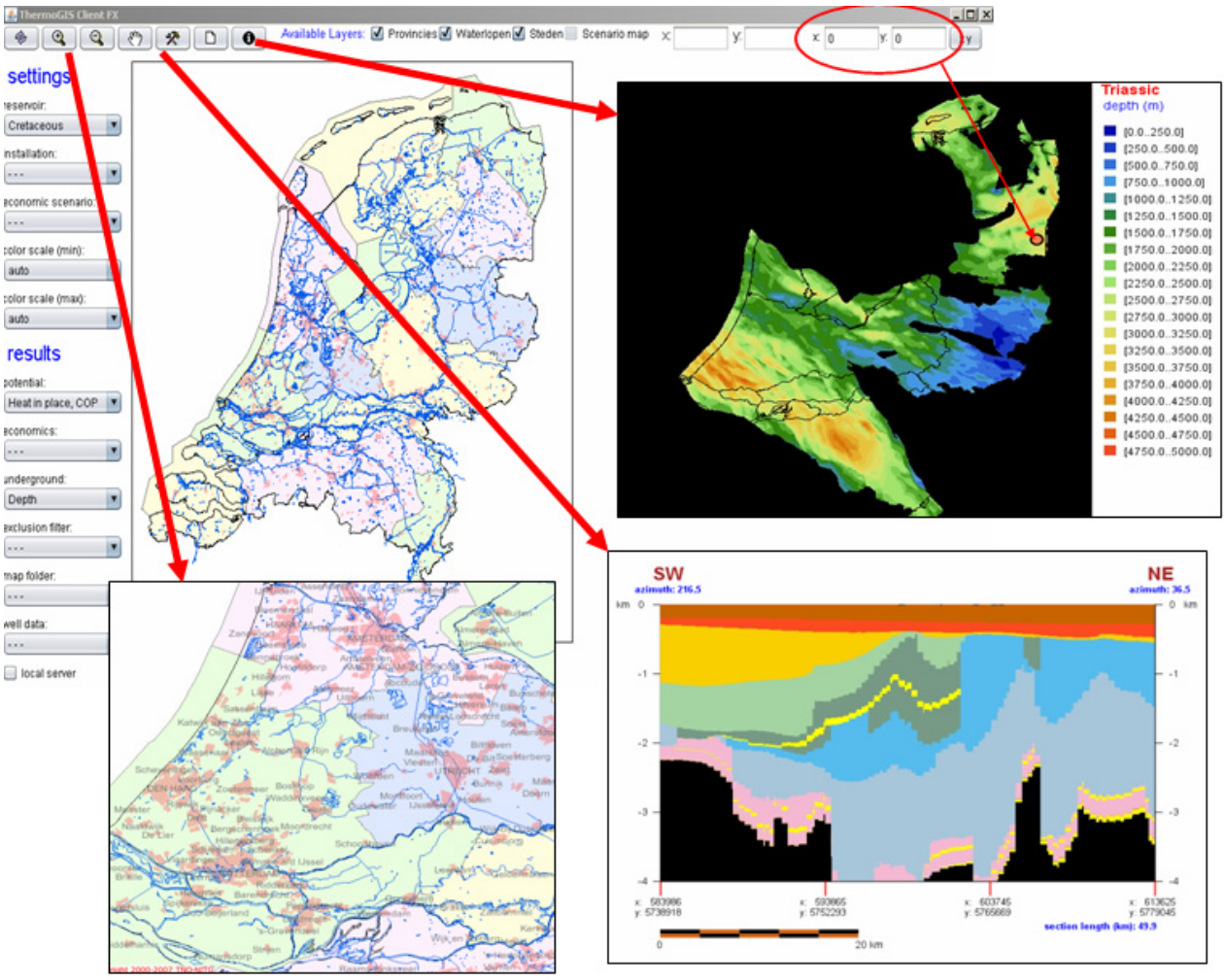


Figure 3: Overview of some of the functionalities in ThermoGIS. (lower left) zoom in to regional or local view of a preferred location. (lower right) a cross section of the subsurface, showing the continuity of potential reservoirs (in yellow) and major faults (faults with an offset of at least 100 m). (upper right) Temperature, thickness and depth maps of potential aquifers can be retrieved.

3. THERMAL STRUCTURE

Thermal properties of the 3D model have been based on detailed mapping of the subsurface as described in the previous section. For each formation thermal properties, such as heat conductivity and radiogenic heat production, have been determined using generalized relationships of properties based on rock type, temperature and depth dependent porosity. Alternatively thermal properties have been derived directly from well log information. An example of thermal conductivities in the model at 2000m depth is given in Figure 4 (left).

The model has been calibrated to high quality temperature measurements in wells based on Drill String Tests (DST), and, if not available, on corrected Bottom Hole Temperatures (BHT). The well data are marked by a considerable variation in temperature gradient (Figure 4, right), which can be related, among others, to spatial variations in thermal properties and basal heat flow (cf. Van Wees et al., 2009).

Temperature measurements and thermal properties are marked by considerable uncertainty, which will have a strong influence on the temperature predictions. In addition various tectonic and surface temperature evolution scenarios are possible.

In this paper one particular model realization is shown. Temperature predictions at 2000m and 5000m depth presented in Figure 5 show a considerable spatial variation, indicating excellent geothermal potential at ca 2000 m depth for district heating, and electricity production at deeper levels using binary plants. However note that the models are subject to major uncertainties, at 2000 m estimated at ca 15°C and at 5000m up to 40°C.

The model is based on heat conduction only. Some thermal anomalies may be related to thermal advection through faults and aquifers. This is topic of future research.

4. PERFORMANCE ASSESSMENT

In building thermoGIS it has been recognized that many stake-holders including governmental bodies, green house developers, building developers, investors and insurance companies have a need for quick scan facilities for geothermal potential.

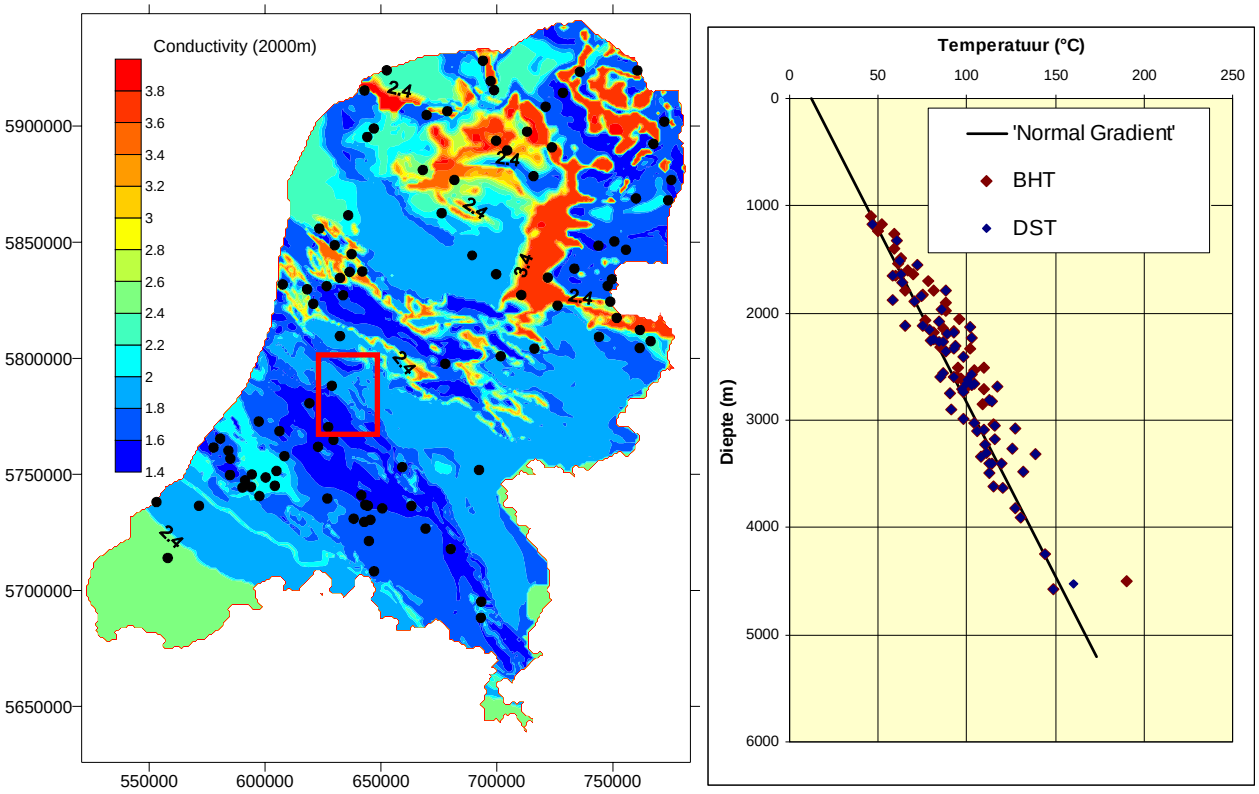


Figure 4: (left) Thermal conductivities at 2000 m depth and well locations for model calibration (black dots). (right) well temperatures at well locations.

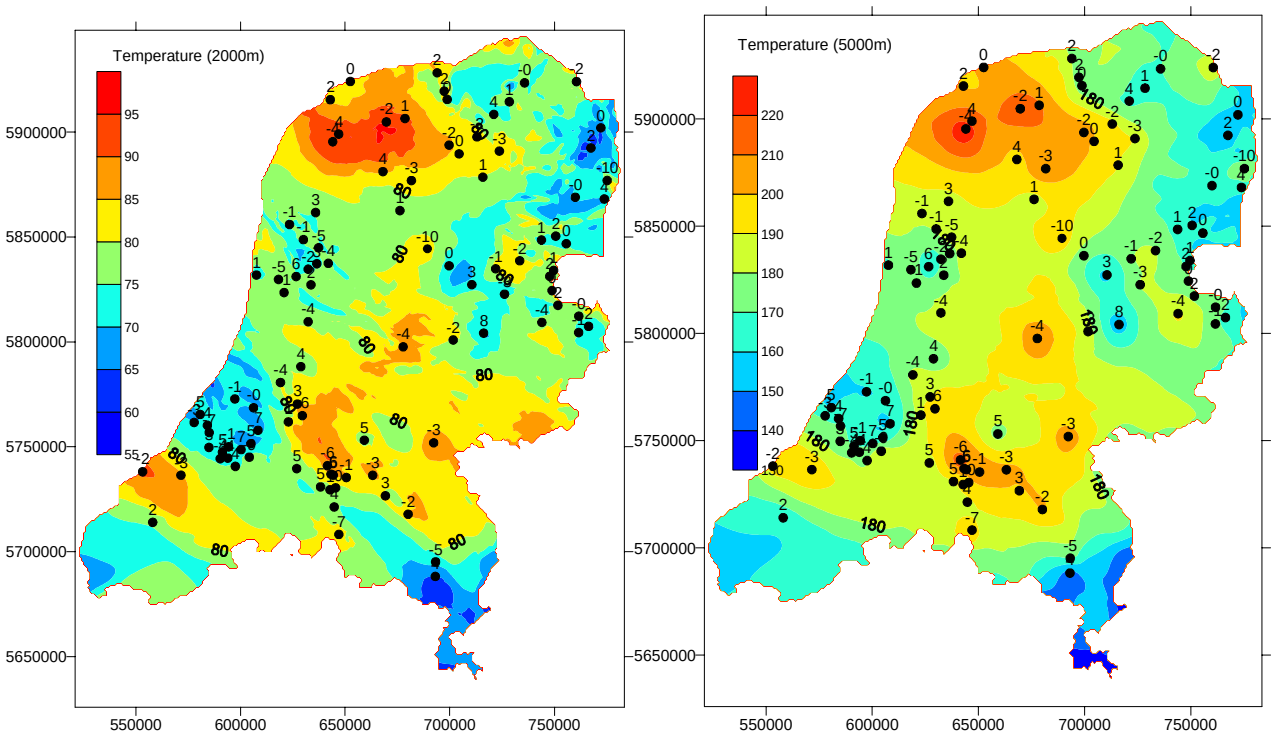


Figure 5: Temperature at 2 km (left) and 5 km (right) depth. Numbers denote difference between model temperatures and measured well temperatures.

For the broad variety of stakeholders dedicated maps are presented in a filtering approach (Figure 6) from a theoretical capacity of heat in place (HIP), to delineating potential assets through techno-economic performance assessment outlining economically feasible recoverable heat (RH) and RH matched to heat demand. The definition of the filtering is outlined further below.

Heat in Place (HIP)

This is the heat capacity of the reservoir (cf. Muffler and Cataldi, 1978). It is the product of weighted volumetric heat capacity of rock and pore fluid times the volume of the rock times the temperature difference of reservoir and average surface temperature.

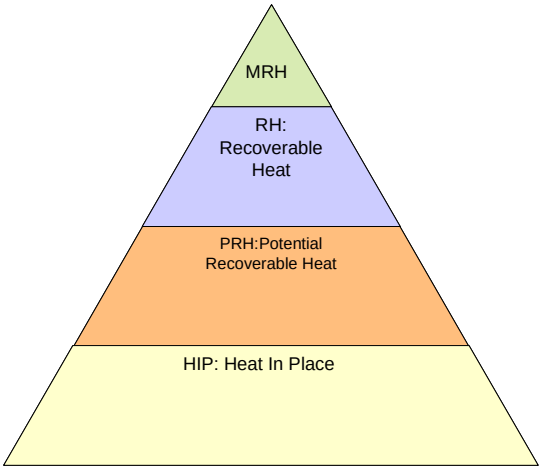


Figure 6: Progressive filtering of theoretical capacity (HIP) to recoverable heat, matched to heat demand (MRH).

Potential Recoverable Heat (PRH)

This is the heat which can be recovered from the reservoir, unconstrained by techno-economic limitations, irrespective of flow properties. It is assumed that due to legal reasons doublets are oriented in rectangles, enclosed by circles which are centered at the injector and producer well and which touch each other at half way (Figure 7). In a doublet system of an aquifer about 50% of heat can be technically recovered, before thermal breakthrough (cf Gringarten, 1978). Further the layout of multiple doublets will not be ideal, due to geological and economic reasons, leaving unrecovered heat in the space which can not be filled in further (Figure 8). Taking into account these effects it is assumed that the recoverable heat is about 33% of the HIP. However 3D heat diffusion effects can delay thermal breakthrough up to 50% and heat extraction can be 50% increased (e.g. Ungemach et al., 2005), depending on local reservoir conditions.

Further the PRH is calculated replacing surface Temperature with injection temperature for a specific application, and putting an associated lower limit to production temperature. Consequently, compared to HIP, less heat can be recovered and particular areas will not be available for heat production, depending on the minimum required production temperature. Therefore the volume of rock in PRH is a subset of HIP.

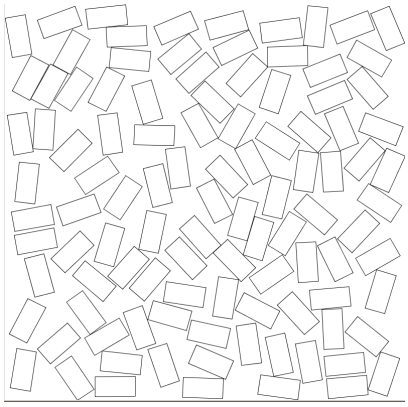


Figure 7: Complete random orientation of doublet rectangles, covering ca 50% of surface area compared to structured orientation.

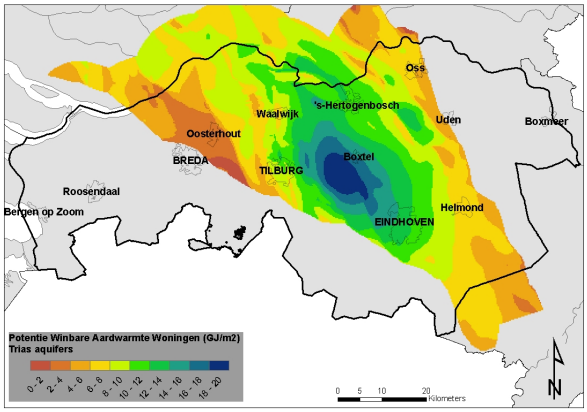


Figure 8: Example of Potential recoverable heat for space heating - minimum production temperature 75C, return temperature 40C .

Recoverable Heat (RH)

Techno-economically Recoverable Heat, assuming local heat demand. This is evaluated from PRH taking into account flow properties, production , depth and thickness of the reservoir. Its Key performance indicator is Unit Technical Cost(UTC) through a NPV calculation for a specific application and using an asset calculation. The volume of rock in RH is a subset of PRH. In order to allow users to execute performance assessments detailed subsurface information of thermoGIS can be easily fed into dedicated performance assessment tools, such as developed for heat production for Dutch government (Figure 9) and performance assessment tools for electricity production (ENGINE, 2009).

Further taking uncertainty on thickness, production temperature, flow rate, probabilistic calculations allows to asses the probability of success to meet minimum requirements on heat demand and COP.

Matched Recoverable Heat (MRH)

This is Recoverable heat matched to heat demand at surface and corrected UTC for different energy usages and associated surface installation costs.

5. GEOTHERMAL PROSPECTIVITY AND CONCLUSIONS

A wealth of information from oil and gas exploration and production activities provides an excellent stepping stone for geothermal development in the Netherlands. Recent detailed mapping of geothermal reservoirs, properties and thermal structure allows to asses key technical parameters to unlock the geothermal energy potential. The developed information system thermoGIS demonstrates over eight geothermal reservoirs levels with excellent potential for heat production. It is estimated that geothermal potential for heat production can deliver heating for an equivalent of ca 1 million houses over the next 100 years.

Mapping also contains excellent insights in active fault systems (Figure 10). Electricity production by low-bin systems is most likely possible in the SE Netherlands in the Roer Valley Graben in geothermal play settings, similar to the Upper Rhine Graben in Germany. Once proven successful through pilot projects it may well provide up to hundreds of MWe.

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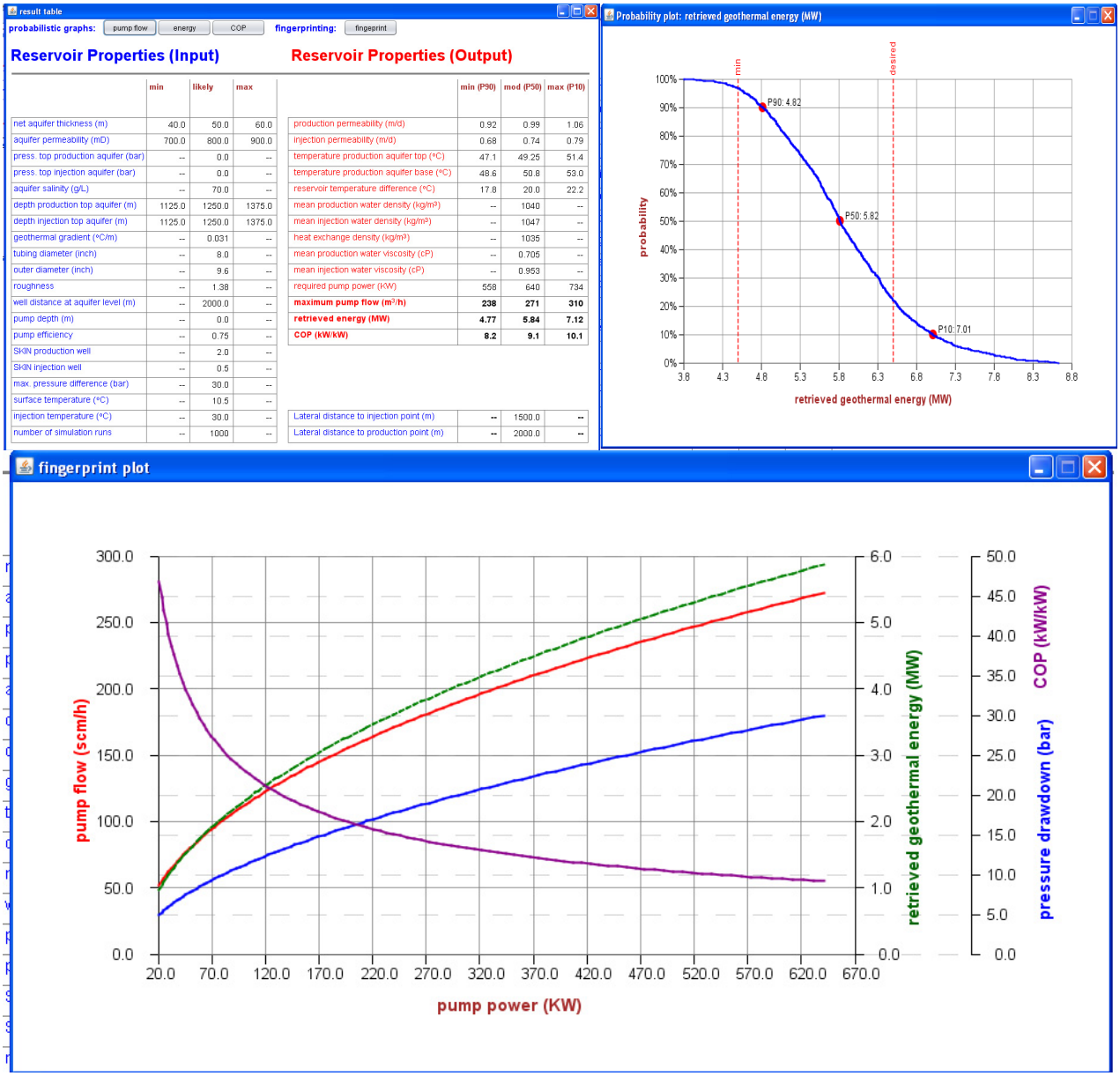
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	min	likely	max
net aquifer thickness (m)	40.0	50.0	60.0
aquifer permeability (mD)	700.0	800.0	900.0
press. top production aquifer (bar)	--	0.0	--
press. top injection aquifer (bar)	--	0.0	--
aquifer salinity (g/L)	--	70.0	--
depth production top aquifer (m)	1125.0	1250.0	1375.0
depth injection top aquifer (m)	1125.0	1250.0	1375.0
geothermal gradient (°C/m)	--	0.031	--
tubing diameter (inch)	--	8.0	--
outer diameter (inch)	--	9.6	--
roughness	--	1.38	--
well distance at aquifer level (m)	--	2000.0	--
pump depth (m)	--	0.0	--
pump efficiency	--	0.75	--
SKIN production well	--	2.0	--
SKIN injection well	--	0.5	--
max. pressure difference (bar)	--	30.0	--
surface temperature (°C)	--	10.5	--
injection temperature (°C)	--	30.0	--
number of simulation runs	--	1000	--

	min (P90)	mod (P50)	max (P10)
production permeability (m/d)	0.92	0.99	1.06
injection permeability (m/d)	0.68	0.74	0.79
temperature production aquifer top (°C)	47.1	49.25	51.4
temperature production aquifer base (°C)	48.6	50.8	53.0
reservoir temperature difference (°C)	17.8	20.0	22.2
mean production water density (kg/m³)	--	1040	--
mean injection water density (kg/m³)	--	1047	--
heat exchange density (kg/m³)	--	1035	--
mean production water viscosity (cP)	--	0.705	--
mean injection water viscosity (cP)	--	0.953	--
required pump power (kW)	558	640	734
maximum pump flow (m³/h)	**238**	**271**	**310**
retrieved energy (MW)	**4.77**	**5.84**	**7.12**
COP (kW/kW)	**8.2**	**9.1**	**10.1**
Lateral distance to injection point (m)	--	1500.0	--
Lateral distance to production point (m)	--	2000.0	--

Figure 9: With the performance assessment tool the user can determine the probability of success to meet minimum requirements on key performance indicators such as Coefficient of Performance (COP), power produced and pressure drawdown. Through clicking the map (cf Figure 3) all relevant data will be inserted automatically.

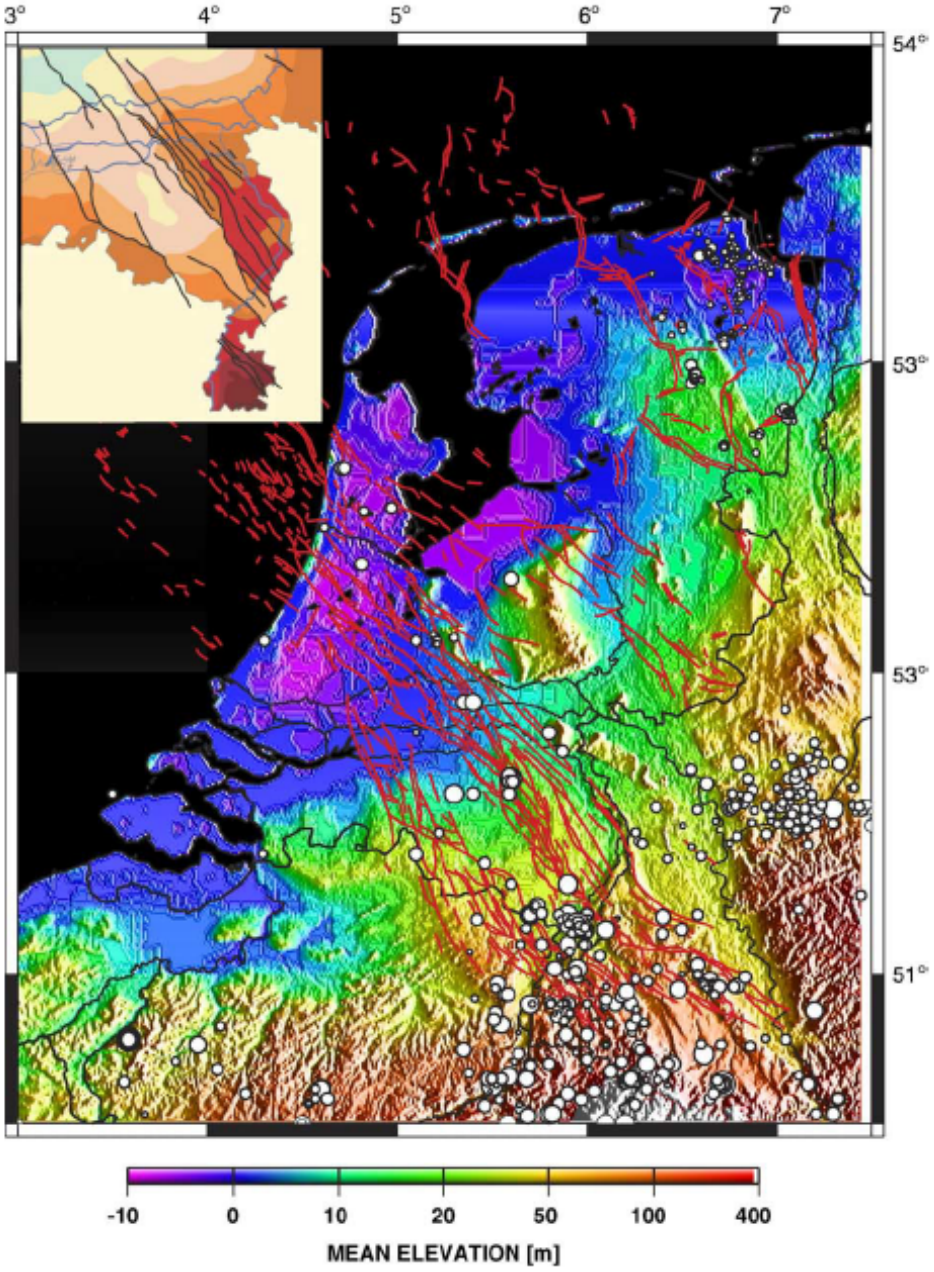


Figure 10: Base Tertiary faults and seismicity. Inset base Quaternary map and active faults.