GeotIS: Free Access to Maps and 3D Models for Geothermal Project Planning in Germany

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ABSTRACT

The internet-based geothermal information system GeotIS (https://www.geotis.de) developed at the Leibniz Institute for Applied Geophysics provides data and information about the geothermally usable medium deep and deep subsurface. It provides access to critical parameters for planning and thus contributes to an improvement in the quality of project planning for geothermal installations and reduces the exploration risk. Information about existing geothermal installations are also included in the system. GeotIS includes the following contents and features:

- 3D models of geothermal relevant horizons and a 3D model of subsurface temperature
- Interface for interactive cross sections
- Distribution, temperature, and depth of relevant geological horizons
- Formation hydraulic conductivity in selected areas;
- Sandstone facies and salt structures in North Germany
- Information about deep reaching faults
- Location and metadata of wells and 2D/3D seismic surveys
- Statistical data about geothermal electricity generation and direct heat use in Germany
- Selected operational data on geothermal installations in Germany and adjacent areas

1. INTRODUCTION

In Germany, industrial oil and gas exploration unveiled a lot of the geology of deep sedimentary systems. Although the first drilling for oil began as early as in 1858, most deep boreholes were drilled in the 50s and 60s of the last century. Borehole data, core samples, as well as data from seismic surveys of the hydrocarbon industry help to understand the geologic setting and the tectonic development of the Upper Rhine Graben, the North Alpine Foreland Basin in southern Germany, the North German Basin, and other basins. In recent years, these data have proven to be useful for many geothermal projects. Unfortunately, in Germany, the bulk of relevant data has never been published. Due to German judiciary, companies are only obliged to deliver exploration results to the competent authorities (geological survey or mining agency), which are bound to secrecy. In other countries (e.g. Spain, Netherlands, and the UK), these proprietary rights are limited in time and expire after a period of 3 to 10 years. In Germany, project planners must contact owners of the data rights on any account to get permission for use. This places obstacles in the path of municipalities who want to figure out if geothermal energy could be a climate and environmentally friendly alternative for heat supply in their region.

However, the situation has changed since the Leibniz Institute for Applied Geophysics (LIAG) has set up the geothermal information system GeotIS with generalized geological information derived from raw data. To do so, LIAG has made agreements with the German association for natural oil, gas and geoenergy (BVEG) to use industry data, which is compiled in the Hydrocarbons Information System (https://www.lbeg.niedersachsen.de/energie_rohstoffe/erdoel_und_erdgas/fachinformationssystem/kohlenwasserstoff-fachinformationssystem-kw-fis-670.html), for research and for GeotIS.

The first maps and 3D models relevant for geothermal project planning were published in 2009. Since then, further research and development has expanded the content of the digital web atlas GeotIS. This happened in several projects, funded by BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) and BMWi (Federal Ministry for Economic Affairs and Energy).

This paper describes the underlying data, the models generated from them, and finally the software and hardware architecture of the overall system. It also briefly describes the tools used for application lifecycle management (ALM, Hüttermann 2012) and knowledge transfer within the projects.

2. DATA

For the geothermal information system, numerous data and information on the geothermally usable subsurface and about geothermal installations have been compiled mainly from Germany. They should contribute to quality improvement for planning geothermal installations and should reduce the exploration risk. The data and their formats differ from each other, originally analogue and digital data had to be integrated. Various workflows have been defined for data processing. Important commercial tools for processing were the GIS software ArcGIS™ and the geological 3D modelling software SKUA-GOCAD™. Further conversions and in particular, imports from databases were carried out by Java programs developed by the project team.

Table 1: Data sources of the Geothermal Information System GeotIS

Data source	Origin / References	Contents
Catalog of geothermal installations in Germany	"Deep Geothermal Energy" working group of the national panel of state geological surveys. Since 2011 compiled by LIAG; Agemar et al. (2014b).	Geothermal installation data
Hydrocarbons Information System	Brauner (2003)	Well data, porosity and permeability data, 2D seismic lines, 3D seismic survey areas
Geophysics Information System	Kühne et al. (2003)	Temperature data
Data collected by project partners		Hydraulic tests, well data, facies, horizon thickness, geological sections
Atlas to visualize potential conflicts between CO_2 storage (CCS) and deep geothermal energy	Suchi et al. (2014), Schulz et al. (2013b)	Areas of conflicting use and potential geothermal utilization (maps)
Static vertical sections Baden-Wuerttemberg	Regierungspräsidium Freiburg; Jodocy, M. and Stober, I.	Vertical sections with geothermal horizons and projected temperature
Static vertical sections Hesse	TU Darmstadt; Arndt, D. and Bär, K.	Vertical sections with geothermal horizons and projected temperature
Fault zones	Schulz et al. (2013b), Suchi et al. (2014), Agemar et al. (2016)	Map
Salt structures in North Germany	Reinhold et al. (2008)	Map
Seismics in Baden-Wuerttemberg	Regierungspräsidium Freiburg	2D seismic lines
Formation hydraulic conductivity (T/H) Northeast germany	Kuder (2012)	Map
Formation hydraulic conductivity (T/H) Molasse basin	Birner (2013), modified by Kuder, J.	Map
Sandstone facies	Franz et al. (2015), Franz et al. (2018a), Franz et al. (2018b), Zimmermann et al. (2018)	Maps: thickness, facies, reservoir quality, survey points. Upper Bajocian, Upper Aalenian, Upper Toarcian, Lower Toarcian, Upper Exter formation, Lower Exter formation Upper Schilfsandstein, Lower Schilfsandstein in North East Germany
Concession areas	in Baden-Wuerttemberg: Regierungspräsidium Freiburg in Lower Saxony: State Office for Mining, Energy and Geology	Map
Statistical data of energy consumption	Statistical offices of the German states in cooperation with the Federal Statistical Office	Map
Statistical data of population density	Federal statistical Office of Germany	Map

2.1 3D Temperature Model

The subsurface temperature plays a central role in geothermal energy production. The output of a geothermal system increases proportionally to the product of the flow rate and the temperature. A higher formation temperature at the same flow rate increases the exploitable heat quantity. The most important data source for calculating the 3D temperature model is LIAG's Geophysics Information System (https://www.fis-geophysik.de/). Since the available temperature measurements are of different quality (see Table 2), spatially redundant measurements of low or moderate quality are not used. At the surface, soil temperatures supplement the data stock.

On this basis, a geostatistical model of the subsurface temperature field was calculated using 3D universal kriging (Agemar et al. 2012). No modelled temperatures or temperatures calculated from heat flux density values were used. By projection from the 3D temperature model, the temperature can be specified for any geological surface. A major advantage of the Kriging method compared to other interpolation methods is the possibility to also determine the uncertainty of the prediction.

Table 2: Temperature records and quality (BHT = bottom hole temperature).

Description	Quality
Equilibrium log, precise measurements in reservoirs, pits and tunnels	1 (high)
Production tests	2
BHT, >2 shut-in times Cylinder Source Model	3
BHT, 2 shut-in times, Instantaneous Line Source Model	
BHT, 2 shut-in times, Continuous Line Source Model	
disturbed log (corrections applied for NE-Germany)	
BHT, 1 shut-in time and known radius, Cylinder Source Model	
BHT known radius, guessed shut-in time, Cylinder Source Model	4 (low)
BHT guessed shut-in time and radius, Cylinder Source Model	

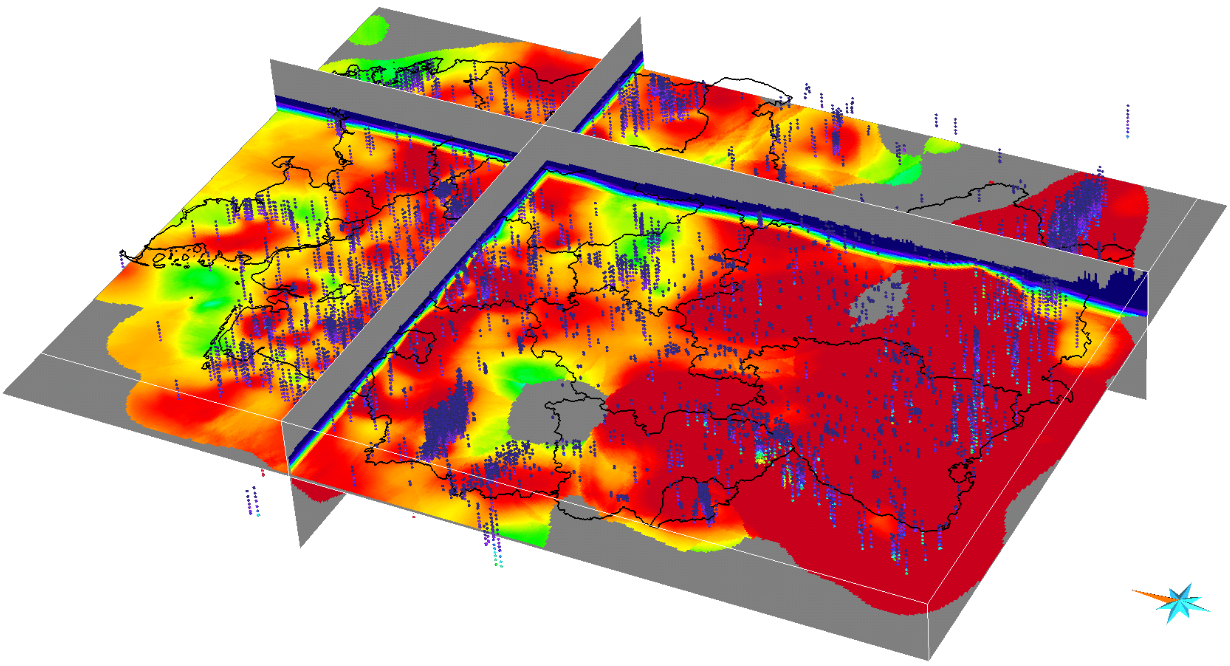

Figure 1: Visualization of the 3D-temperature model with three sections perpendicular to each other in SKUA-GOCAD™.

This 3D temperature model is until today an important part of GeotIS and has been updated every 2 to 3 years. In addition, it was used for many other scientific studies and maps – e.g. for the Bavarian Geothermal Atlas (Fritzer et al. 2014) or the "Geothermal Atlas for the Representation of Possible Competitive Uses between CCS and Deep Geothermal Energy" (Schulz et al. 2013, Suchi et al. 2014).

2.2 3D Structure Models

Whether a geothermal project is successful depends greatly on subsurface geological conditions. These are crucial for the locations of new facilities. Therefore, the 3D structural models implemented in GeotIS represent an important information base for new projects.

Based on geological maps, drilling logs and seismic data, triangulated surfaces of geological units with geothermal aquifers were modelled with the SKUA-GOCAD™ 3D software. Some newer models were created as hexahedral grids (SGrids). The surfaces were attributed with the subsurface temperature, gridded (100 m grid) and stored as binary data in the GeotIS database. GeotIS users can interactively generate cross sections from 5 to 300 km length with any vertical exaggeration or create map extracts of the top or base view from stratigraphic units suitable for geothermal exploitation. Most of the 3D models were developed in the four GeotIS projects, partly with partners from the state geological surveys of Germany; some were made available to the project by third parties.

Table 3: 3D structural models used in the Geothermal Information System GeotIS.

3D Model	Horizons	States	Institutions involved	References
NOD model	Lower Cretaceous Dogger Lias Upper Keuper Middle Keuper Middle Buntsandstein	Mecklenburg-Vorpommern, Saxony-Anhalt, Berlin, Brandenburg	LIAG, LUNG	Agemar et al. (2018) Schulz et al. (2009) Schulz et al. (2013a)
NWD model	Lower Cretaceous Upper Keuper Middle Buntsandstein	Lower Saxony	LIAG	Schulz et al. (2013a) Kuder et al. (2014) Baldschuhn et al. (2001) Dornbal and Stevenson (2010)
GG model*	Dogger Upper Keuper Middle Buntsandstein	Schleswig-Holstein	LLUR	Hese et al. (2017)
SH model	Dogger Upper Keuper Middle Buntsandstein	Schleswig-Holstein, Sydjütland (Denmark)	LLUR, GEUS, University Kiel	Kirsch et al. (2015)
MB model	Upper Jurassic (top surface only) Upper Muschelkalk	Baden-Württemberg, Bavaria, Upper Austria	LfU, GBA, RPF, LIAG	Schulz et al. (2009) Schulz et al. (2013a) Agemar and Tribbensee (2018) Diepolder et al. (2016)
NRW model	Upper Cretaceous	North Rhine-Westphalia	LIAG, GD-NRW	Baldschuhn et al. (2001) Dölling and Juch (2009) Doornenbal and Stevenson (2010)
HES model	Bunter Rotliegend	Hesse	TU Darmstadt, HLNUG	Arndt (2012) Bär (2012)
FB model*	Keuper Buntsandstein	Bavaria	LIAG, LfU	Kunkel et al. (in review)

LIAG = Leibniz Institute for Applied Geophysics; LUNG = State Office for the Environment, Natural Conservation and Geology (Mecklenburg-Vorpommern); LLUR = State Office for Agriculture, Environment and Rural Areas (Schleswig-Holstein); GEUS = Geological Survey of Denmark and Greenland; LfU = Bavarian State Office for the Environment; GBA = Geological Survey of Austria; RPF = Regierungspräsidium Freiburg; GD NRW = Geological Survey North Rhine-Westphalia; HLNUG = Hessian Agency for Nature Conservation, Environment and Geology
* Work in progress

3. ARCHITECTURE

3.1 Application Architecture

The application is designed as a web based client/server system. A fundamental feature of the architecture is the strict separation of work and presentational data for data security reasons, since the former are usually confidential. The presentational data are generated by generalization, aggregation and filtering. Only these data are publicly accessible via the internet application. The application is a mix of Java, PHP and JavaScript technologies including numerous OpenSource libraries (for JavaScript e.g. Dojo and OpenLayers). PHP was chosen because of its better integration with MapScript, Java because of its higher execution speed and better suitability for more complex programming tasks.

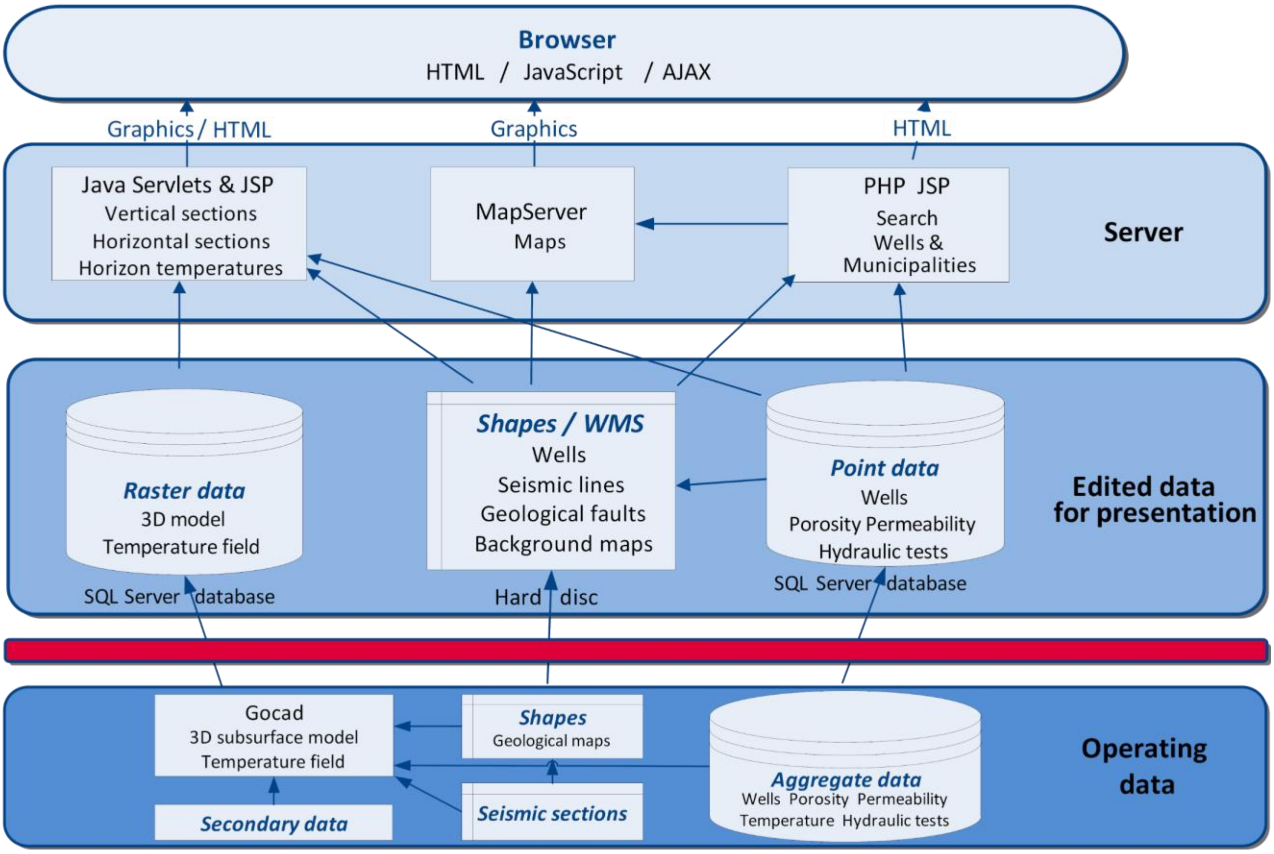

Figure 2: Application architecture with data flows and server components.

3.2 Technical Architecture

The system is redundantly designed and consists of two server nodes. Firewalls and Web Application Firewalls (WAFs) protect these from unauthorized access in a DMZ from the Internet. Two load balancers distribute the load between the two servers. The database server is virtualized; in case of an error, simply a new database server instance is started.

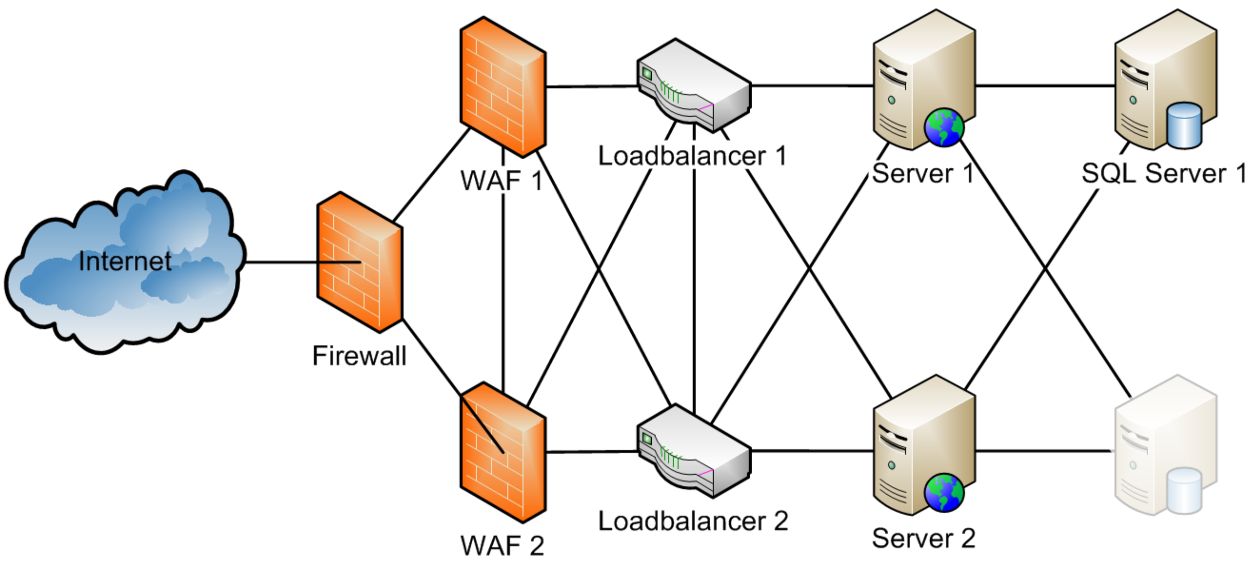

Figure 3: Illustration of the GeotIS system hardware architecture with firewall, web application firewalls, server nodes, and database servers (faded: stand-by database server).

4. APPLICATION LIFECYCLE MANAGEMENT (ALM) AND KNOWLEDGE TRANSFER

Over a period of 13 years, 13 developers have written more than 122,000 lines of code for the GeotIS. In addition, there exists approx. 14 GB 2D and 3D data, as well as 5.8 million database records.

In order to make this code and data basis manageable, an infrastructure is required that automatically manages and versions data, performs tests, monitors interfaces, generates documentation and makes it searchable, documents errors and the progress made in eliminating them, and offers numerous feedback options. This infrastructure for GeotIS consists of seven server components that can exchange data with each other and with different client components:

- **Version control system** (Subversion® Edge) – records all version statuses in a central archive. Changes can be traced back and, if necessary, reversed.
- **Continuous Integration** (Jenkins®) – enables application building and testing, creating documentation, applying metrics, and notifying developers of the success or failure of a build.
- **Bugtracker** (JIRA®) – using so-called “tickets”, program errors and suggestions for improvement can be recorded, and the progress of work and decisions on a ticket can be documented.
- **Instant Messaging** (Openfire) – is used for communication between team members, and the continuous integration server sends messages with it.
- **Static program analysis** (Sonarqube™) – examines the technical quality of the program code with respect to various features, such as test coverage, potential errors, etc. (see Campbell and Papapetrou 2013).
- **Repository manager** (Artifactory®) – serves for the central storage of binary program files and for their download optimization.
- **Enterprise wiki** (Confluence®) – provides an interface for accessing the individual ALM components and provides options for collaboration, documentation, versioned document storage, and full-text search.

With the last-mentioned and temporally last introduced enterprise wiki component a system is available, which is used as knowledge base and central source of information in the GeotIS project. The technical and non-technical project documentation is thereby easily searchable and versionable. Documents can also be created collaboratively. The bottom-up approach of a wiki encourages the self-organization of the team.

5. RESULTS

The Geothermal Information system for Germany (GeotIS) has been set up as an online geothermal atlas that provides data and information for reducing exploration risk (Agemar et al. 2014a). The front end of the application conforms to the widely distributed web GIS applications and is therefore easy to use. Its data basis of approximately 30,000 wells, including 11,000 with temperature data, is unique for Germany. The temperature data was regionalized with universal kriging. Procedures that are not offered by commercially available geographic information systems were developed on the basis of 3D sections for data presentation. Changes in the data can be modelled easily − as is not the case with a printed atlas − and the system can also be extended for new requirements. It would not have been possible to build this system in time and budget without the ALM tools. Work and communication in the project was greatly supported by the enterprise wiki.

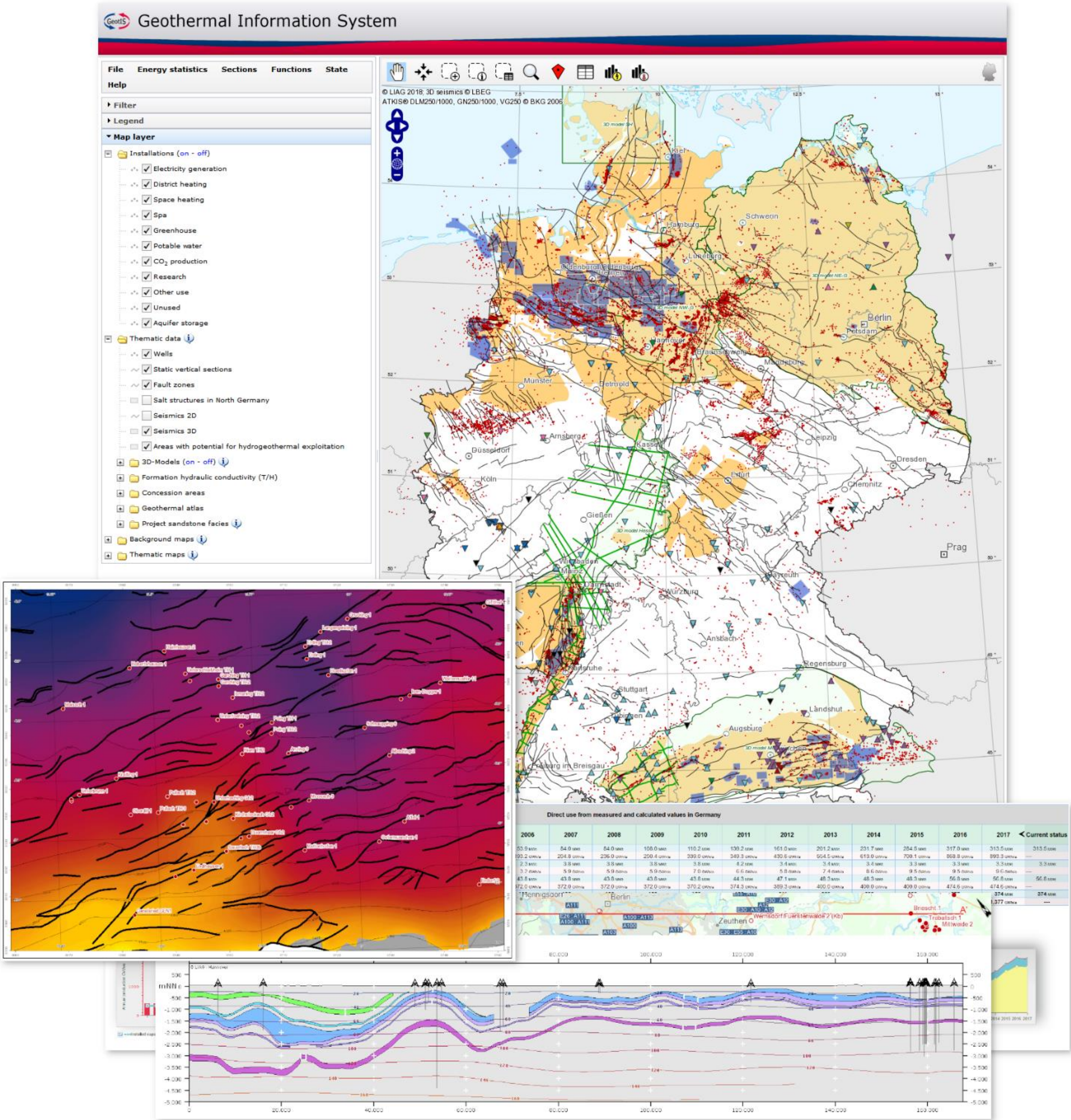

Figure 4: Compilation of some GeotIS screenshots.

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