Geothopica and the interactive analysis and visualization of the updated Italian National Geothermal Database

Eugenio Trumpy[*], Adele Manzella

Institute of Geosciences and Earth Resources, CNR, Via Moruzzi 1, 56124 Pisa, Italy

A B S T R A C T

The Italian National Geothermal Database (BDNG), is the largest collection of Italian Geothermal data and was set up in the 1980s. It has since been updated both in terms of content and management tools: information on deep wells and thermal springs (with temperature > 30 °C) are currently organized and stored in a PostgreSQL relational database management system, which guarantees high performance, data security and easy access through different client applications. The BDNG is the core of the Geothopica web site, whose webGIS tool allows different types of user to access geothermal data, to visualize multiple types of datasets, and to perform integrated analyses. The webGIS tool has been recently improved by two specially designed, programmed and implemented visualization tools to display data on well lithology and underground temperatures.

This paper describes the contents of the database and its software and data update, as well as the webGIS tool including the new tools for data lithology and temperature visualization. The geoinformation organized in the database and accessible through Geothopica is of use not only for geothermal purposes, but also for any kind of georesource and CO_2 storage project requiring the organization of, and access to, deep underground data. Geothopica also supports project developers, researchers, and decision makers in the assessment, management and sustainable deployment of georesources.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Georesource assessment strongly relies on reliable underground data. Direct information on the underground is produced mainly by geothermal, mining and oil and gas companies, which carry out surveys and drilling to improve the knowledge of the resources and increase production. Italian regulation requires that underground information related to explored resources, which are the state's property, is provided to public administrations, but also guarantees that such information remains confidential until the end of the leasing period. Thus, only a small portion of the information from wells is publicly available, and a very minor part is readily accessible.

However, the exploration, as well as the sustainable deployment/use of natural georesources require state-of-the-art data integration and visualization techniques.

The use of subsurface data for problem solving is limited by the freedom users have in their choice of data structures. If users are allowed to work with the data in a way that they are familiar with,

they can spend more time performing data analysis and less time restructuring data, thus increasing productivity and reducing the risks associated with a series of data modification cycles.

The investigation and assessment of geothermal resources rely not only on direct underground geological data, mainly from wells, but also require their integration with indirect sources, from geochemical and geophysical surveys and remote sensing data. The integrated analysis and visualization of multiple types of datasets improve and constrain the exploration. The mechanisms for integrating and displaying information from multiple sources are part of the concept of the Digital Earth. As was clearly mentioned by Gore in his book and speeches (Gore, 1992, 1998 respectively), the Digital Earth is 'A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced information'.

Besides geothermal production data, the geoinformation required by the geothermal sector is specifically intended to assess geological, hydrogeological, geochemical, geophysical and thermal underground conditions. Therefore, geothermal databases of underground information, i.e. those we are dealing with in this paper, typically store lithological and temperature data from wells, and fluid chemistry data from wells and thermal springs.

---

* Corresponding author.
   E-mail address: e.trumpy@igg.cnr.it (E. Trumpy).

Geothermal energy is used to produce electricity in 24 countries around the world, and for direct use of heat in 72 countries (Trumpy et al., 2015). Those countries producing electricity from geothermal resources and some of those direct using geothermal heat store geothermal data in a database, but to the best of our knowledge only a few publish information related to how their geothermal data are organized. This is despite the fact that geothermal databases and the availability of geothermal information can support project developers, researchers, and decision makers in the assessment, management and sustainable deployment of geothermal resources.

Italy is the first country in Europe and the sixth country in the world in terms of electricity generation capacity from geothermal resources, and was the first country in the world to produce electricity from geothermal energy. In 2015, the gross electricity generation reached 5.9 TWh, with an installed capacity of 915.5 MWe (807 MWe efficient capacity). The heat delivered by direct geothermal uses is 10,500 TJ generating 1300 MWth, with about half the installed capacity related to space heating (DHs and individual systems) (Conti et al., 2016). Italy is rich in geothermal resources thanks to its geological setting, and attracts the interest of geothermal project developers, as testified by the over 100 requests of exploration leases. Therefore, data organization and availability are crucial for different stakeholders and the market uptake.

Geothermal data in Italy were systematically collected for the first time at the end of the 1980s, and this led to the Inventory of the Italian National Geothermal Resources (ENEL et al., 1988). The dataset was stored in a stand-alone desktop application and was accessible only onsite for researchers.

This paper describes the Italian Geothermal Database, its functionalities and the data updating. Italian geothermal data are currently stored in a client-server relational database management system, which is the core of a web application hosted in a dedicated website named Geothopica.

2. Background

The relational database management system (RDBMS) provides a practical way to store, access and query any kind of numerical data. RDBMSs are often used in the geothermal sector to manage data by various types of stakeholders. For example, project developers, i.e. ENEL in Italy, archive geothermal exploration and development data in order to share the complete dataset among their offices (Bertani and Magrini, 2000), and the Energy Development Corporation in Philippines (Esberto et al., 2005) uses a RDBMS to fully serve the requirements for a fast and accurate retrieval of information.

In fact, governmental organizations in the Philippines (Fonda, 2005), in Iceland (Hauksdòttir et al., 2005; Gunnarsdottir, 2015), Algeria (Kedaid 2007), and Indonesia (Suharyono, 2013) organize geothermal data in a RDBMS. In the USA, the U.S. department of Energy funded the implementation of a National Geothermal Data System (NGDS), which harvests data from many nodes and acts as gateway for geothermal information (Anderson et al., 2013). Research centres in Switzerland (Sonney and Vuataz, 2008), Mexico (Torres et al., 2005), Java (Setijadji et al., 2005), Nevada (Hanson et al., 2014), Germany (Agemar et al., 2014) make wide use of geothermal databases to collect and maintain information, analyse data and perform models.

Geothermal databases have been developed not only at a national, but also at international levels. European data have been organized within the framework of projects, such as in GEOELEC (Dumas and Angelino 2013a), GEODH (Dumas and Angelino 2013b), and TransEnergy (Nádor et al., 2013). In parts of East Africa geothermal sites were identified, collected and catalogued, thanks to the African Rift Geothermal Development Facility (ARGeo) project,

which was aimed to encourage both private and public developers to accelerate of the development of geothermal resources. World-wide geothermal production data are organized in a database by the International Geothermal Association (IGA) (Trumpy et al., 2015).

Regarding online publications of geothermal underground information (e.g. temperature and geochemical sampling data), besides Italy only five countries (USA, Iceland, Germany, Kenya and Ethiopia) publish geothermal data through web applications or portals. Iceland publishes national geothermal maps (temperature at depth and heat flux) and general information about wells. Germany presents geothermal potential maps as well as metadata for 2D and 3D seismic data and eventually borehole information in tables; however, when temperature data are recorded, numerical data are not provided but only indicated as being present. For Kenya and Ethiopia, the ARGeo project developed a portal, which is currently mainly related to production information. For the USA, the NGDS portal provides different types of information: datasets, documents, maps and application & tools (GIS resources and Geothermal Analysis Resources). The complete datasets including lithology and temperature of wells are available for download and data location is provided in a webGIS map together with a summary of the related information. None of the five portals listed allow online data visualization.

Geological surveys or other governmental organizations often collect and organize underground information for general geological purposes. Some of them organize underground data that are useful for geothermal assessments, but the available datasets are not complete. The Netherlands, for example, with its large geological database and advanced tools for online data visualization and analysis, provides a subset of useful information: litho-stratigraphic piles, well-log reports and well deviation data, temperature distribution maps at various depths, and geothermal potential maps.

In Italy a Geothermal Database (BNDG, Banca Nazionale Dati Geotermici) was implemented in 1988 by the International Institute for Geothermal Research (IIRG, now become as the Institute of Geosciences and Earth Resources IGG) of the National Research Council (CNR) of Italy, as the completion of the inventory of deep geothermal resources by CNR, ENEA (Agenzia Nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile – Italian National Agency for new Technologies, Energy and Sustainable Economic Development), ENEL (Ente Nazionale per l'Energia Elettrica – National Agency for Electricity) and ENI (Ente Nazionale Idrocarburi – National Body for Hydrocarbons), under Law No 896 of 1986. Data were continuously updated until 2001 (Barbier et al., 2000 and reference therein).

The original database was used as a back-end of a desktop application. Through a user interface it was possible to browse geothermal wells or springs to obtain the location and relevant data. A toolbar also enabled users to further explore specific thematic data reports (e.g., temperature data, litho-stratigraphic data, technical data, reservoir characters, . . .). The application had the option to use a geographical data viewer to search through geothermal data.

In 2008, a software improvement and data update was performed with the Institute of Geosciences and Earth Resources, the coordination of Saipem, the financial support of ENI Refining & Marketing, R & S management, and in collaboration with UNMIG (Ufficio Nazionale Minerario per gli Idrocarburi e le Georisorse – National Office for Mining Hydrocarbons and Earth Resources), a department of the National Ministry of Economic Development, who guaranteed the access to a new dataset.

This led to an upgrade with the resulting BDNG (the acronym was slightly changed) to become the most complete and organized underground (wells and thermal springs) data repository at

a national level. The BDNG was also made accessible by a dedicated web-site named Geothopica.

3. Geothermal data description

Geothermal technologies use the renewable thermal energy stored in rocks and in fluids circulating in the underground to generate electricity and/or the direct use of heat. To extract energy from the underground, water is mostly used as a carrier of heat. As the crust is highly fractured and thus permeable to fluids, surface water, essentially rainwater, penetrates at depth and exchanges heat with the rocks. A geothermal reservoir is formed where underground conditions allow the storage of hydrothermal fluids in permeable rocks, which can be exploited by drilling wells and discharging the hot fluids to the surface. Sometimes hydrothermal fluids can naturally reach the surface through fractures and faults, resulting in natural geothermal manifestation such as hot springs, geysers, and fumaroles (Di Pippo, 2008).

The use of geothermal energy, both for power production and for direct uses of the heat (e.g. district heating, greenhouses, industrial process), relies on the discovery and exploitation of geothermal reservoirs, the hydrothermal resources, which are accessible at competitive costs. Finding a productive reservoir, known as geothermal exploration, is a complex task. First, the geothermal resource is assessed through exploration in order to identify the amount of heat and physical-chemical characteristics of the underground, which is required for the correct planning of the later activities. In parallel, especially for heat use, the amount and rate of required thermal energy needs to established. After the assessment stage, the wells are drilled and the resource is accessed and verified. The technology to use in the plant is defined on the basis of the information retrieved during the assessment and then refined in the drilling stages.

Identifying geothermal resources involves the acquisition, processing and analysis of a large quantity of data from different kinds of surveys performed during the exploration phase. Any kind of earth observation, with both traditional surface methods (e.g., Di Pippo and references therein) and remote sensing methods (e.g., Qin et al., 2011; Van der Meer et al., 2014 and references therein), is crucial to understanding the natural underground systems and their time domain.

In addition to the general geological exploration data, geothermal assessment requires specific information, such as temperature and related parameters for correction calculation, specific geochemical data, adsorption and other specific hydraulic information. These latter underground data are not usually recorded in general geological databases, and only a few countries organize them into national geothermal databases or as part of the geothermal section of more general geological data collections. The underground geothermal databases discussed in this article are intended to support geothermal exploration, research and future development plans.

In the late 1980s, the Italian National Inventory of Geothermal Resources, provided the first occasion to collect and organize information regarding deep geothermal resources for power production, and to build the Italian geothermal database, the BDNG.

3.1. Data content, classification, terminology

The database contains geothermal data for the whole of Italy, such as deep and shallow geothermal exploration and production wells, as well as thermal springs and surface manifestation (with temperatures >30 °C). Useful underground information is also retrieved from hydrocarbon wells, both onshore and offshore, which provide information on the underground 'state'. Of a total

Table 1
Types of information related to geothermal and hydrocarbon wells.

Information	Description
General information	Geographical coordinates, name, depth, owner, administrative issues, status, scope, use, outcome, date of completion
Thermal state	Temperature at depth, corrected temperature, method of correction, heat flux, thermal conductivity, geothermal gradient, stop and circulation time
Litho-stratigraphic	Bottom & top of lithology, formations, mineralization, age
Chemistry fluid	Water, steam and gas analysis
Technical issues	Well deviation, casing structure, casing anomaly, circulation loss
Reservoir/fracture character	Pressure, water level, type of fluid, permeability, flow rate (NB: there is only limited information on reservoirs)

Table 2
Types of information related to thermal springs.

Information	Description
General information	Geographical coordinates, name, administrative issues, status, type of spring, regime, use, typology, flow rate
Thermal state	Temperature computed with geothermometers, type of geothermometer used
Chemistry fluid	Water, steam and gas analysis

number of 3434 wells, 1041 are geothermal, 2349 are hydrocarbon, and 43 are very shallow wells drilled for civil use.

Each geothermal well stored in the database is described both general information and, based on data existence or availability, by different types of information (Table 1). Thermal springs are described in Table 2.

3.2. Geothermal thematic maps

Besides the underground data, the BDNG has five thematic maps: three temperature maps at different depths from ground level (i.e., 1, 2, 3 km) and two different versions of the surface heat flux density. These maps were computed and published by Cataldi et al. (1995) and Della Vedova et al. (2001) on the basis of the underground data stored in the BDNG. To insert them into the BDNG, the maps were digitized using Quantum GIS Open Source software (Quantum GIS Development Team, 2012). The digitalization was carried out in three steps: i) georeferenciation the original maps, by taking 30 control points; ii) implementation of geodatabase including points, lines and polygon layers to store centroids, temperature or heat flux isolines and temperature or heat flux areas; and, where necessary, iii) digitalization of the features.

At the end of the digitalization, a topological check was performed in order to guarantee a high coherence among the digitized items.

3.3. Data updating

Starting in 2008, stored data have been reviewed and controlled, and new data have been added. The data review was aimed at discovering possible errors, duplications or incongruences occurring during data entry operations. All original hard copy documents (ENEL et al., 1988; AGIP, 1977, 1986, 1994; ENI, 1972) were checked.

New well data were then added, drawing from the VIDEPI project, which collects a wide dataset of hydrocarbon well-logs in pdf format (UNMIG, 2012). Data retrieved from well-logs were digi-
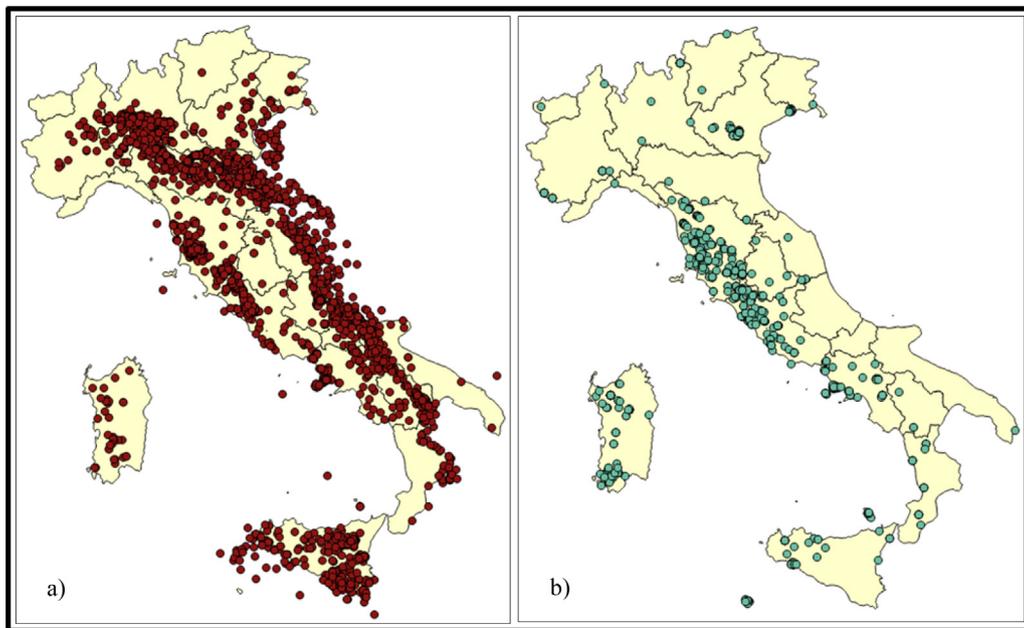
Fig. 1. a) well distribution, b) thermal spring distribution. (For interpretation of the references to color in this text, the reader is referred to the web version of this article.)

Table 3
Information related to wells and number of records.

Information	Number of records
General information	3434
Thermal state	2712
Litho-stratigraphic	3404
Chemistry fluid	101
Technical issues	961
Reservoir/fracture characters	427

Table 4
Information related to thermal springs and number of records.

Information	Number of records
General information	586
Geothermometers	153
Chemistry fluid	513

tized and archived in the database. Spring data were retrieved from scientific literature and reports.

After this data update, the archived data increased from 2649 to 3434 wells, and from 460 to 586 thermal springs, Fig. 1. Not all of them contained all data types, as reported in Table 3 (wells) and Table 4 (spring).

4. Database structure

The geothermal data collected in BDNG and referring to the terms described above are stored in the PostgreSQL database (PostgreSQL, 2010; PostgreSQL, 2012), the world's most advanced open-source RDBMS, running on a GNU-Linux server. The database software (on the server-side) guarantees (i) integration (maintains data referential integrity), (ii) speed (highly performing queries), (iii) data management (data can be inserted, deleted and updated), (iv) concurrent access (multi-user data connection without interference), (v) information confidentiality (limited access), and (vi) data recovery (by means of a database dump).

The benefit of using a RDBMS comes is that it stores data in a "normalized" format. This is a concept originally presented in Codd 1970; who mathematically developed the relational model and improved the database structures. Data normalization is a simple way of organizing data and allows increased efficiency of data storage and retrieval.

Spatial features are important for BDNG data, since wells and thermal springs refer to specific geographical locations. The geospatial data management was provided by PostGIS (PostGIS, 2010; PostGIS, 2012), a PostgreSQL extension, that stores and queries spatial data inside the database, and handles data coordinates and their reference systems.

Fig. 1 shows the entity relations. The database spatial entities are the wells and thermal springs, outlined in red in Fig. 2. Entities including well information are outlined in blue, those related to thermal spring in green. Entities outlined in yellow refer to geochemical fluid analysis from wells and thermal springs. The vocabularies used are shown in violet.

The relation between the entities is maintained by a specific field called "key". This key in the well and spring entities acts as a Primary Key, whereas in the other entities, the "key" field is the Foreign Key.

Within the database there are some controlled vocabularies, such as: type (well typology), scope (well purpose), outcome (well outcomes), uses (well uses), status (well condition), methods (well temperature extrapolation method) and Italian administrative entities (municipalities, provinces, regions).

The BDNG database can be accessed, from the client-side, with some of the most popular open source database client software such as PgAdminIII (pgAdminIII, 2012) or phpPgAdmin (Phppgadmin, 2012) or simply by the command line, using PostgreSQL SQL (Structured Query Language) language. Access is allowed to users that have been granted permission by the database administrator.

The BDNG database consists of sixty-three tables in total. Twenty-one of them are simple vocabulary tables, thirty tables contain alphanumeric information on wells, ten tables describe thermal spring features, and two tables (wells and thermal springs) include general information and have spatial characteristics. The whole database size is about 231 Mbytes when exported into a textual intelligible format, the dump file.
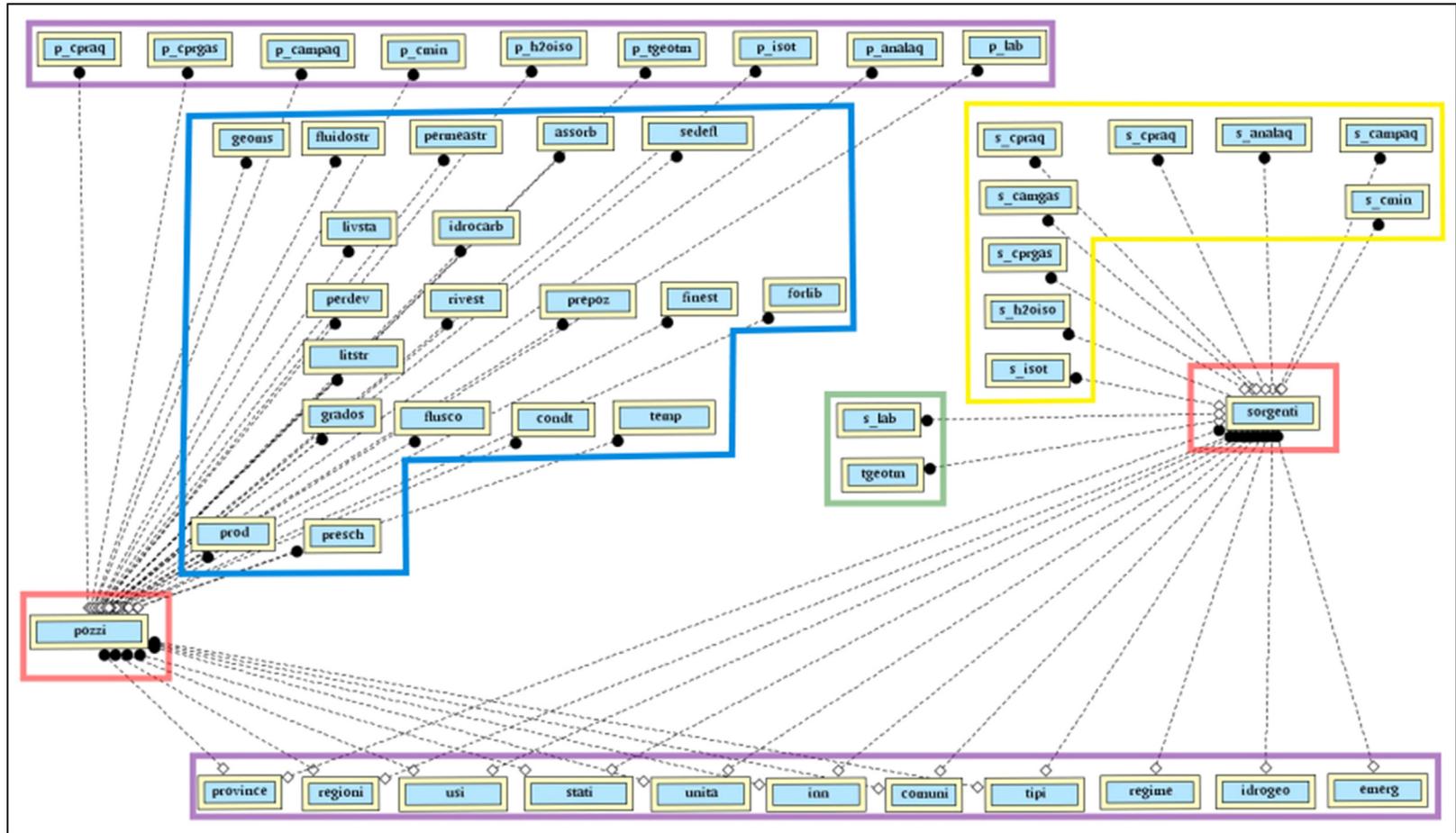
Fig. 2. BDNG design and table relationship. Boxes define the entities, and their relations are shown as dotted lines with their cardinality: the white diamond refers to zero or one, and the black bullet refers to 'more' in the IDEF1X data modelling technique. (For interpretation of the references to color in this text, the reader is referred to the web version of this article.)
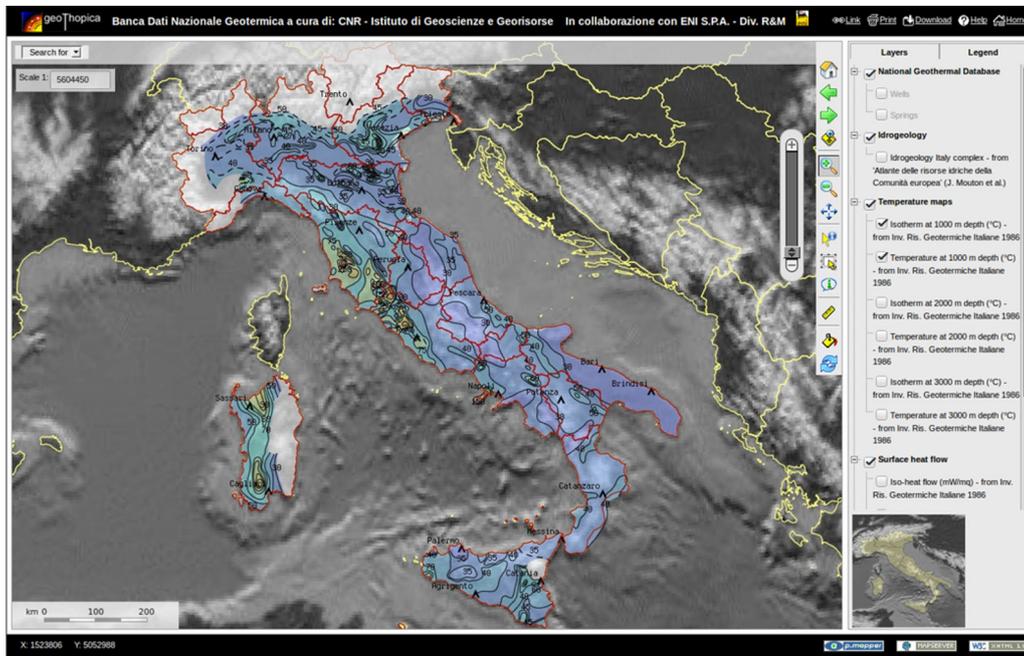
Fig. 3. Geothopica webGIS user interface. The temperature map at 1000 m depth is represented by a red to blue colour scale, black lines show the temperature isolines at a 1000 m depth. Areas within the borders of Italy with no colour are 'No data' areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5. Geothopica website

Geothopica is the name of the BDNG website (CNR-IGG, 2012). The name is inspired by the Greek words: Geo – γεω indicating the Earth, Th suggesting heat (thalpos – θάλπ○z), and topos – τόπ○ζ which marks the place.

The website provides general information on the Geothopica project, database, data sources and includes the disclaimer on the BDNG, the link to the dataset metadata, and the instructions on how to request data of interest. The core of the Geothopica website is the webGIS application which provides access to BDNG data, browses the geothermal thematic maps, and performs simple data analysis.

5.1. WebGIS

The webGIS application was created by exploiting the open source map engine Mapserver (Mapserver, 2015) together with the pMapper front-end framework (Pmapper, 2015).

Two types of access to the webGIS application are possible: i) public access for all users, which provides public information, and ii) customized access with credentials for private use, which provides additional thematic maps and data provided by the client (e.g. ENI in 2008 who supported the database update).

The webGIS interface (Fig. 3) contains widgets such as search and scale (top left), scale bar as well as X and Y coordinates (bottom left), create a link to the map, download and print the visualized map (top right).

The main framework of the webGIS interface is the map area in the centre, while on the right of the map there is a table of contents, the legends and the main toolbar.

The main toolbar offers common tools for browsing the map, i.e., zoom in/out, pan and for inspecting the represented features, i.e., identify (to get feature info in a popup box), select (to select features in a specific layer chosen from a combo box that appears on the top right of the map area) and tooltip (to get feature info in a box on the bottom right). The toolbar has a ruler to measure segments and/or

areas on the map and a tool to arrange the transparency of each layer.

The webGIS application provides five geothermal thematic maps (see Section 3.2), and four spatial dataset layers from BDNG: i) well location including general info, ii) thermal springs including general info, iii) well litho-stratigraphic description, and iv) well temperature data. Upon completion some layers were included as cartographic references concerning Italian boundary regions, European country boundaries, principle Italian cities, and two different base maps served as map tiles, from Open Street Map [OSM] and Natural Earth [NaturalEarthData].

5.2. Tools for data analysis

To facilitate the BDNG data analysis, two different tools were developed: i) litho-stratigraphic well representation, and ii) well temperature vs depth chart.

The tools codes were developed in PHP (PHP, 2015) and use Highchart (Highcharts, 2015) javascript library to render data from BDNG graphically. Once the user performs a feature selection (see Section 5.1), the webGIS shows an attribute table. The content of the first column allows, on clicking, to run the data analysis tool.

Both codes use the PHP GET variable to store the 'key' values of the well selected with the identify webGIS tool. Afterwards the code executes a query on the BDNG which takes into account the key stored in the PHP GET variable to access litho-stratigraphic or temperature data. The values from the rows retrieved are then arranged in a multi-stack bar chart or in a scatter plot for litho-stratigraphic data and temperature data respectively by Highchart javascript library.

The litho-stratigraphic well representation shows the various lithologies drilled in the available wells in the form of a column. The well name and the maximum depth are indicated at the top of the column. By pointing on the column, a tooltip reveals the lithology and its thickness, as shown in Fig. 4.

The well temperature chart tool displays the measured or extrapolated temperature versus depth, of the selected well. The
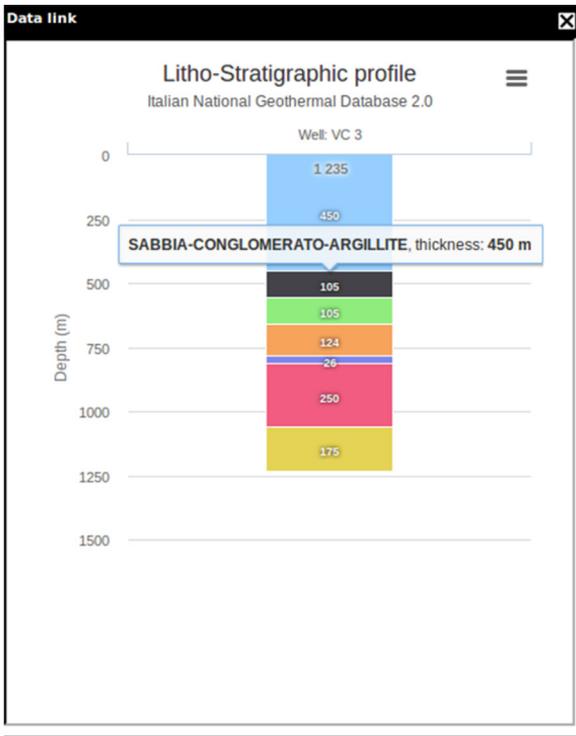
Fig. 4. Litho-stratigraphic tool. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
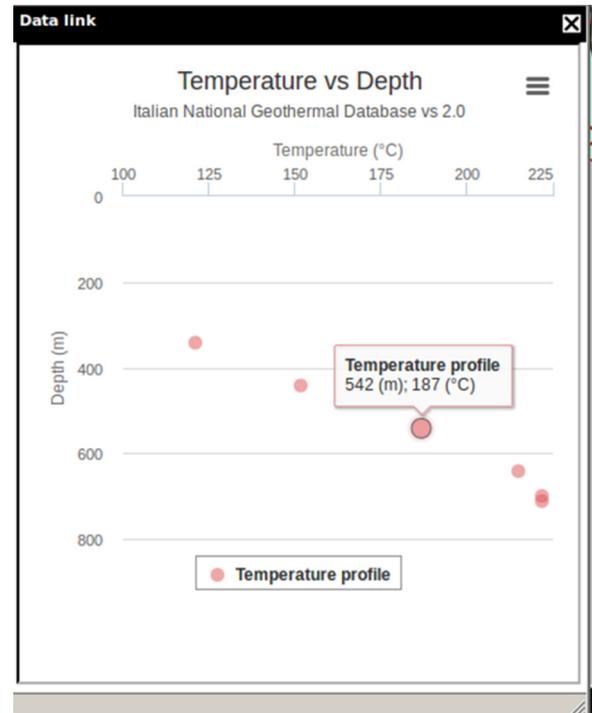

Fig. 5. Well temperature chart. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tooltip reports the temperature and depth by passing over any point in the chart, as in Fig. 5.

6. Discussion

The main aim of integrated analyses by accessing, mapping and visualizing a vast amount of underground data, is to locate and assess georesources and in particular geothermal reservoirs, as well as to generate decision Supporting information. In fact, the stakeholder distribution of data requests for BDNG is 65% from research bodies, 15% from project developers, 15% from freelance geologists, and 5% from public authorities.

The overlay of multiple layers of data and maps also assists in understanding the spatial correlations between the various datasets, so that geoscientists can integrate the data, define what data are missing and where, and develop interpretation and plan new surveys.

The webGIS is a highly dynamic visualization system in which the individual layers can be switched on or off. The legends for each layer explain the data content, quality and/or quantity. Many data interactions can be made via the toolbar.

Fig. 6 shows an example of the efficacy of spatial visualization, interpretation and interactive survey planning. It shows the underground temperature distribution at a 2 km depth, where the warm colours indicate the highest temperatures. Each area is edged by
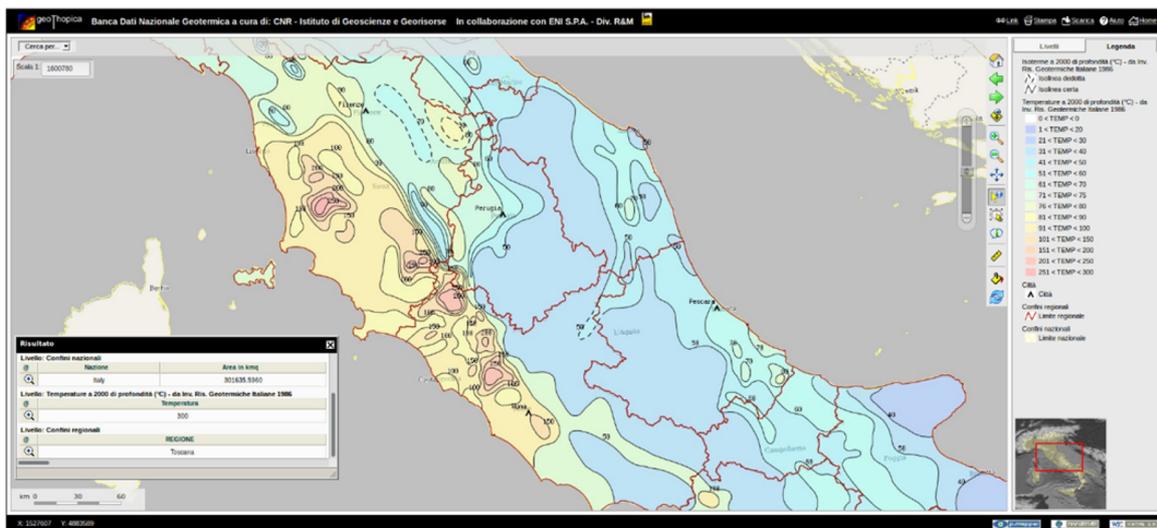

Fig. 6. Temperature distribution at 2 km below ground level. Area temperature value is shown as tabular data. On the right, the legend of the visualized layer and window frame location with respect to Italian boundaries. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
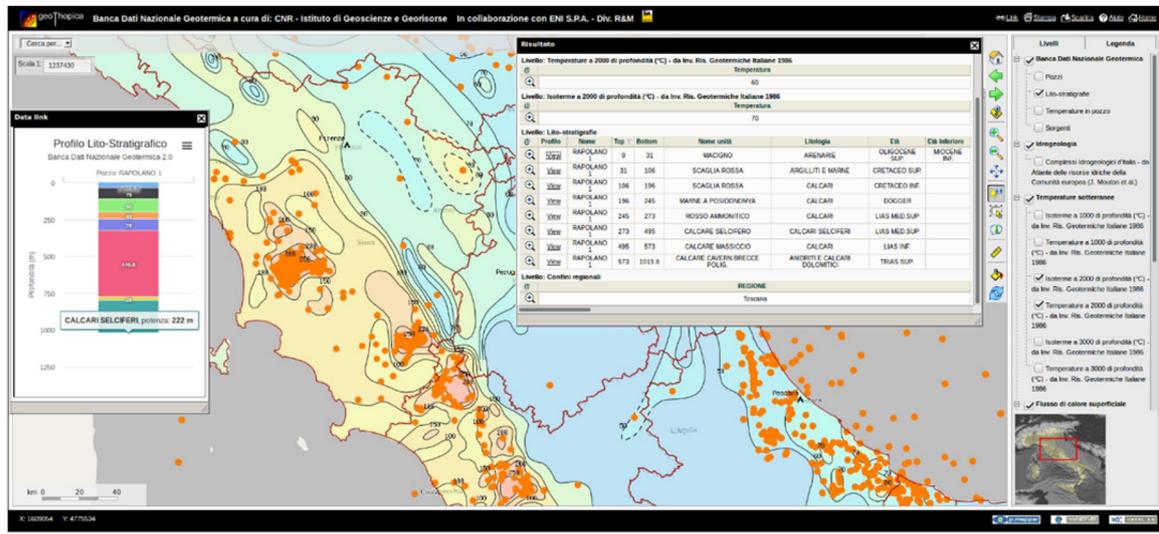
Fig. 7. Well litho-stratigraphic tabular and plot output. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 8. Well temperature tabular and plot output. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
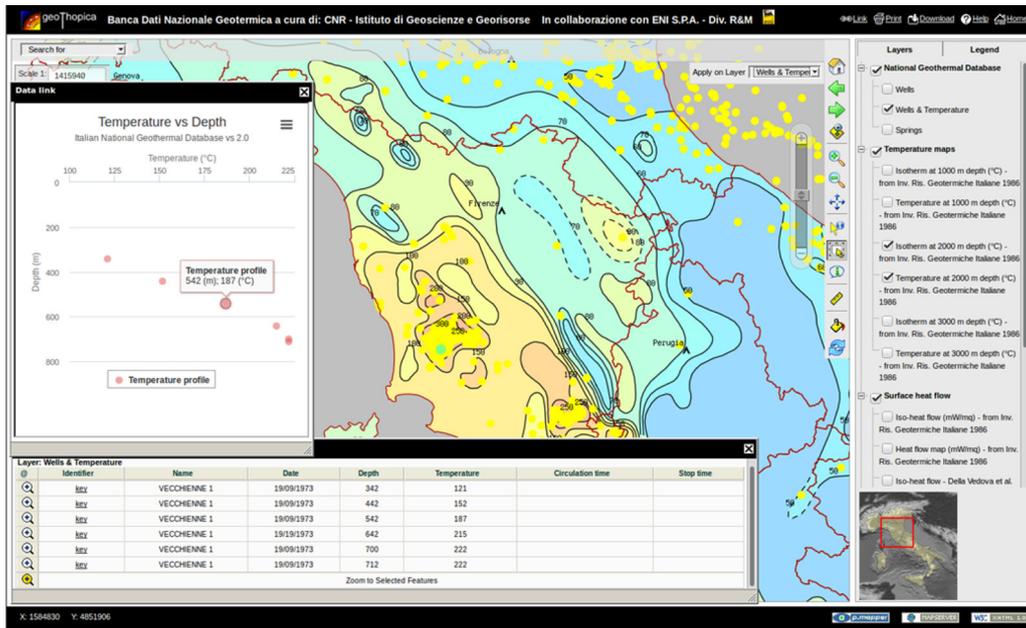
temperature isolines represented as black continuous or dashed lines, in case of certain or uncertain lines, respectively. The user can recognize the temperature both by comparing the colour of the area of interest with the legend, and querying the point of interest using the tools for dataset analysis (e.g., identification, selection).

The table of contents enables the layers available to be switched on/off, and to explore the underground temperature distribution up to 3 km. The temperature information can be also coupled with two different versions of the Italian heat flux map in order to assess the thermal state of the subsurface. In particular, the heat flux map from Della Vedova et al., 2001; also reports the most important factors influencing surface heat flux distribution such as deep meteoric water infiltration areas, recent sediment basins, high temperature convective systems, low temperature convective and/or advective systems, upflow of thermal fluids through fractures and no-anomaly or undefined areas.

The layers from the BDNG help to focus on the geothermal character related to a specific location. Well data queries on the litho-stratigraphic layer, in the form of a tabular or plot output (Fig. 7), represent the rock typologies encountered during drilling and provide crucial information on the geothermal underground framework, the geometries (top and bottom depths) of the potential geothermal reservoir, and the petro-physical and thermal character of a drilled area.

Underground temperature data are one of the most important parameters for geothermal exploration and for indicating the presence of a potential geothermal reservoir. The well temperature data access (as tabular data or plots, Fig. 8) shows the temperature values recorded by the well log at various depths. Times of stop or circulation of the drilling mud are also archived. This further information needs to be taken into account to perform temperature corrections since measured temperatures are affected by the cooling effect of

the circulating drilling mud. Thus, an adequate estimation of the real formation temperature can be computed.

By integrating information from litho-stratigraphic and temperature layers, important underground features can be identified and integrated with other data to facilitate geothermal resources and, in general, underground assessments. Temperature in the formations can guide users/researchers in characterizing the subsurface thermal gradients and the main heat and mass transport mechanisms acting in the subsurface.

Integrated methodologies for underground assessment are among the research frontiers for exploring geothermal and other georesources, and structured databases such as BDNG and its Geothopica website, should be designed to follow and support this trend in order to fully exploit geothermal exploration.

7. Conclusions

The Italian National Geothermal Database was revised and updated by means of a client-server architecture technology, built completely with open sources software, thus enabling users to access and manage the geothermal datasets.

The Geothopica website provides a platform for interactive and efficient queries, retrieval, processing, analysis, and visualization of geothermal datasets. A webGIS interface was set up to display five geothermal maps and four datasets from the BDNG. The webGIS interface is equipped with analytical tools to interact with the information shown. In addition, two new analytic tools were specially developed to allow further data visualization and integration. This approach helps geoscientists and users in the integrated analysis and interpretation of these datasets.

Geothopica, with BDNG at its core, is a useful tool in all projects that require underground information at a depth of 0–7.8 km (the depth of the deepest archived well), such as geothermal energy and CO_2 storage.

The information provided can also be useful for i) project developers, to be more (cost and time) effective in exploration and project development, ii) researchers, to study and/or assess the potential of georesources, iii) decision makers, to establish new policies aimed at fostering geothermal energy or to manage georesources in general, and iv) anybody interested in increasing awareness of geothermal energy.

The approach proposed is a brick in the wide concept related to the Digital Earth using geospatial data visualization and integration to better understand the processes and changes taking place on earth.

Acknowledgements

References

Agemar, T., Alten, J., Ganz, B., Kuder, J., Kuehne, K., Schumacher, S., Schulz, R., 2014. The geothermal information system for Germany. GeotIS ZDGG 165 (2), 129–144.

AGIP, 1977. Temperature Sotterranee (Subterranean Temperatures)—Inventario Dei Dati Raccolti Dall'AGIP Durante La Ricerca Di Idrocarburi in Italia. AGIP, Milan (1390 pp).

AGIP, 1986. Aggiornamenti temperature sotterranee–Pozzi a terra–Esplorazione Geotermica.

AGIP, 1994. Acque dolci sotterranee—Inventario dei dati raccolti dall'AGIP durante la ricerca di idrocarburi in Italia (dal 1971 al 1990), 515 pp.

Anderson, A., Blackwell, D., Chickering, C., Boyd, T., Horne, R., MacKenzie, M., Moore, J., Nickull, D., Richard, S.A., Shevenell, L., 2013. National geothermal data system (ngds) geothermal data domain: assessment of geothermal community data needs. In: Proceedings, Thirty-Eighth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11–13, 2013 SGP-TR-198.

Barbier, E., Bellani, S., Musmeci, F., 2000. The italian geothermal database. Proceedings World Geothermal Congress 2000.

Bertani, R., Magrini, M., 2000. ENEL geothermal database. Proceedings World Geothermal Congress 2000.

Cataldi, R., Mongelli, F., Squarci, P., Taffi, L., Zito, G., Calore, C., 1995. Geothermal ranking of italian territory. Geothermics 24 (1), 115–129.

CNR-IGG, 2012. Geothopica web site. Italian national geothermal database. Available online at: http://geothopica.igg.cnr.it/ [last access 01.01.12.].

Codd, E.F., 1970. A relational model of data for large shared data banks. Commun Assoc Comput Mach 13 (6), 377–387.

Conti, P., Cei, M., Razzano, F., 2016. Geothermal energy use, country update for Italy (2010–2015). In: Proceedings of the European Geothermal Congress 2016, Strasbourg, France, 19–24 September 2016.

Della Vedova, B., Bellani, S., Pellis, G., Squarci, P., 2001. Deep temperatures and surface heat flow distribution. In: In Anatomy of an Orogeny: the Apennines and Adjacent Mediterranean Basins. Springer, Netherlands, pp. 65–76, http://dx.doi.org/10.1007/978-94-015-9829-3_7.

Di Pippo, R., 2008. Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact, 2nd ed. Butterworth-Heinemann (Elsevier), Oxford, U.K, pp. 2008 (ISBN 978-0-7506-8620-4, 2008).

Dumas, P., Angelino, L., 2013a. GEOELEC project: develop geothermal electricity in europe to have a renewable energy mix. In: Proceedings of the European Geothermal Congress, Pisa, June 3–6.

Dumas, P., Angelino, L., 2013b. GEODH project: promote geothermal district heating system in europe. In: Proceedings of the European Geothermal Congress, Pisa, June 3–6.

ENEL, ENI-AGIP, CNR, ENEA, 1988. Inventario Delle Risorse Geotermiche Nazionali E Indagine d'insieme Sul Territorio Nazionale. Ministero dell'industria, del commercio e dell'artigianato (attualmente Ministero dello sviluppo economico) (p. 75).

ENI, 1972. Acque dolci sotterranee—Inventario dei dati raccolti dall'AGIP durante la ricerca di idrocarburi in Italia. 914 pp. ISBN-10: A000097736.

Esberto, M.B., Austria, J.J.C., Sarmiento, Z.F., 2005. WellTaPPS, a web-Based oracle database wellbore temperature and pressure plotting software. Proceedings World Geothermal Congress 2005.

Fonda, A.D., 2005. Application of database in monitoring the Performance of Geothermal Steam Fields and Power Plants in the Philippines. Proceedings World Geothermal Congress 2005.

Gore, A., 1992. Earth in the Balance: Ecology and the Human Spirit. Houghton Miffin, Boston.

Gore, A., 1998. The Digital Earth—Al Gore. digitalearth-isde.org. 1998-01-31. [Retrieved 2015-10-13].

Gunnarsdottir, S., 2015. Design and use of relational databases in the geothermal sector. In: Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19–25 April 2015.

Hanson, H., Wood, R., Augustine, C., Mines, G., Lopez, A., Hettinger, D., 2014. Development of a geothermal well database for estimating In-Field EGS potential in the state of nevada. GRC Trans. 38, 2014.

Hauksdòttir, S., Tulinius, H., Kristjànsson, B.R., 2005. Iceland geothermal database; an online interactive map interface. Proceedings World Geothermal Congress 2005.

Highchart, 2015. Highchart Interactive JavaScript charts for your webpages. Available online at: www.highcharts.com/ [last accessed 20.12.15.].

Kedaid, F.Z., 2007. Database on the geothermal resources of Algeria. Geothermics 36, 265–275, http://dx.doi.org/10.1016/j.geothermics.2007.02.002.

Mapserver, 2015. Mapserver website. An open source web mapping, available online at: http://mapserver.org/, [last accessed 01.03.15.].

Nádor, A., Rotár Szalkai, A., Prestor, J., Tóth, G., Goetzl, G., Lapanje, A., Rman, N., et al., 2013. Transboundary geothermal energy resources of Slovenia, austria, hungary and slovakia (TRANSENERGY)—contributions to integrated resource management policies and regional development transboundary geothermal energy resources of Slovenia, Austria, Hungary and Slovakia. In: Proceedings of the European Geothermal Congress, Pisa, June 3–6.

pgAdminIII, 2012. pgAdminIII website, Available online at: https://www.pgadmin.org/ [last accessed 01.02.12.].

PHP, 2015. PHP Hypertext pre-processor website, available online at: http://php.net [last accessed 01.02.12.].

Phppgadmin, 2012. phppgAdmin, website, available online at: http://phppgadmin.sourceforge.net/doku.php [last accessed 01.02.12].

Pmapper, 2015. A MapServer PHP/MapScript Framework website, available online: http://www.pmapper.net/, [last accessed 01/03/2015].

PostGIS, 2012. PostGIS reference, available on line at: http://postgis.refractions.net/documentation/manual-1.5/ [last accessed 01.02.12].

PostGIS, 2010. PostGIS web-site, available online at: http://postgis.refractions.net/, [last accessed 01.02.10].

PostgreSQL, 2012. PostgreSQL references, available on line at: http://www.postgresql.org/docs/8.3/interactive/index.html, [last accessed 01.02.12].

PostgreSQL, 2010. PostgreSQL web-site, available on line at: http://www.postgresql.org/, [last accessed 01.02.10].

Qin, Q., Zhang, N., Nan, P., Chai, L., 2011. Geothermal area detection using Landsat ETM+ thermal infrared data and its mechanistic analysis—a case study in Tengchong China. Int. J. Appl. Earth Obs. Geoinf. 13 (4), 552–559.

Quantum GIS. Development Team, 2012. Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project. Retrieved from http://qgis.osgeo.org [last access 01.12.12].

Setijadji, L.D., Watanabe, K., Wahyuningsih, R., Wintolo, D., 2005. Towards the digital data model for geothermal databases: technology trends, fundamental concepts, case study of Java Island, and preliminary data model. In: Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24–29 April 2005.

Sonney, R., Vuataz, F.D., 2008. Properties of geothermal fluids in Switzerland: a new interactive database. Geothermics 37, 469–509, http://dx.doi.org/10.1016/j.geothermics.2008.07.001.

Suharyono, A.P., 2013. Model website database for production and potential inventory geothermal Indonesia. In: Proceedengs Indonesia Geothermal Convention & Exhibition 2013, 13th Annual Meeting Indonesia Geothermal Association, June 12–14, 2013.

Torres, R.J., Martìnez-Estrella, J.I., Iglesias, E.R., 2005. Database of mexican medium to low temperature geothermal resources. In: Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24–29 April 2005.

Trumpy, E., Bertani, R., Manzella, A., Sander, M., 2015. The web-oriented framework of the world geothermal production database: a business intelligence platform for wide data distribution and analysis. Renew. Energy 74, 379–389.

UNMIG, 2012. VIDEPI project: Visibilità dei dati afferenti all'attività di esplorazione petrolifera in Italia (Visibility of the data from hydrocarbon exploration activity in Italy), Ufficio nazionale minerario per gli idrocarburi e le georisorse del Ministero dello Sviluppo Economico (National Mining Office for hydrocarbon and geothermal energy of the Ministry for Economic Development). Available online at: http://unmig.sviluppoeconomico.gov.it/videpi/ [last access 01.12.12.].

Van der Meer, F., Hecker, C., Van Ruitenbeek, F., Van der Werff, H., De Wijkerslooth, C., Wechsler, C., 2014. Geologic remote sensing for geothermal exploration: a review. Int. J. Appl. Earth Obs. Geoinf. 33, 255–269.