Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal 4.0: Data, Information, Visuals

Gregor Rumberg, Marit Brommer

Charles-de-Gaulles-Str. 5, D-53113 Bonn, Germany

gregor@lovegeothermal.org

Keywords: Geothermal Energy Database, Power Generation, Direct Use

ABSTRACT

Geothermal 4.0 will show the global geothermal community, how data and digital technologies help to push geothermal energy as one of the renewable technologies of choice in the energy mix of the future. Our policy makers need to be fed accurate information coming from global status reports, such as the REN21 published Global Status Report, and it has often been noticed that the global geothermal community is not able to provide the required information on a yearly basis.

The New Global Geothermal Energy Database (Geothermal 4.0) of the International Geothermal Association (IGA) is a web-based database providing data, information and visuals on geothermal power generation and direct use applications worldwide.

Data of geothermal fields and plants can be accessed and aggregated in several ways. The integrated data entry tool helps structuring incoming country updates, for example from the World Geothermal Conferences (WGC), geothermal conferences and workshops and other data collection initiatives on behalf of the IGA and supports to provide an up-to-date data collection. Interfaces to other databases help to connect to geothermal projects and project classifications with several possibilities for a wide information management.

Geothermal 4.0 replaces the Global Geothermal Energy Database. This paper describes the considerations between a recovery of the old database and the chosen implementation of a new database. These experiences can flow into plans for future projects in geothermal information systems. Finally, the paper will describe technical details on Geothermal 4.0, such as set-up and its functionalities for end-users.

1. INTRODUCTION

The International Geothermal Association (IGA) aims “to encourage, facilitate and, when appropriate, promote coordination of activities related to worldwide research, development and application of geothermal resources” (1988). Many of these activities are related to and depend on accurate geothermal data. Hence, the IGA must be able to provide up-to-date data and information about the geothermal status worldwide.

In order to fulfil the role as the data provider in the global geothermal sector, the IGA mainly used the country updates from World Geothermal Congresses (WGC). Limited by the fact, that these WGCs have been held every five years only until the year 2020, collected data mainly mapped these specific points only and hardly considered the developments in the terms between. In addition, and resulting from conference requirements regarding early paper submissions, the presented country reports (for example Bertani et al., 2016) mapped the situation of the previous year, which created a further update gap. Gathering information more frequently and provide them on a yearly and current base lead to framing a project to develop a database with a focus on timeliness.

Obliging to this data update frequency change is the change of the term between the World Geothermal Congresses from five to three years, effective from the WGC 2020, so the following WGC will be held in the year 2023. Nevertheless, this term is too long to provide data on a yearly base. Hence, updates from other sources must be considered. For this purpose, the IGA can take advantage of a worldwide member base with relations to stakeholders in a high number of regions with geothermal activities.

Finally, the IGA noticed a high willingness in the membership to participate in a frequent data collection and update, since this clearly matches with their demand for accurate up-to-date global information on geothermal energy, especially power generation and direct uses worldwide. Since the IGA is a membership focused organization, this gave a clear green light to embark on the development of a fitting database: Geothermal 4.0

2. PROJECT SUMMARY: GEOTHERMAL 4.0

2.1 Concept

With the rapid progress of technical developments and the worldwide availability of information technologies, especially since the establishment of the World Wide Web in the 1990s, many different approaches to digitize and digitalize geothermal information have emerged. In this context, geothermal databases to collect and provide information about geothermal energy production and direct uses have been developed, but many of these databases focus on regional data, do not constitute a complete, coherent and up-to-date set of information or, like a former IGA geothermal energy database, are not available online anymore. But high-quality geothermal data, which means data with a high degree of fulfilment for the attributes availability, correctness, completeness and timeliness, is crucial for stakeholder decisions, the development of geothermal projects, education and classification of geothermal resources or the promotion of geothermal as a rising player in the renewable energy mix.

Moreover, scientists require different information than policy makers or potential investors in geothermal projects. A modern and coherent database should consider different required data aggregations and information extracts for different target groups. Hence, the collection of energy generation data is only one part of a final Geothermal 4.0. Other geothermal or geographical data, but also geothermal meta data, like regulatory, economic and social aspects or classifications tools, like the UNFC classifications for geothermal resources must be included. By combining these information, Geothermal 4.0 can provide new knowledge. This does not necessarily mean, that these databases must be implemented new. Instead, Geothermal 4.0 will act as the platform database and connector hub with interfaces to other existing or upcoming data sources. This requires an agile development of a user interface and flexible database access functions, since storage locations or access methods will change in future releases.

In order to achieve the goal of a yearly data update, Geothermal 4.0 must also provide applications or interfaces for authorized users to add and update data. Figure 1 shows countries worldwide with geothermal electricity generation or direct uses of geothermal sources a comprehensive database must cover. While light orange colored areas indicate countries with geothermal direct uses, dark orange colored areas indicate countries with geothermal direct uses and power generation. In June 2019, thirty (30) geothermal associations of these countries are affiliated IGA members with many more individual members and experts from countries covering the geothermal world. They are a very good connection to data directly from the source, though country updates from conferences and publications are expected to be an important data source for the next years too.

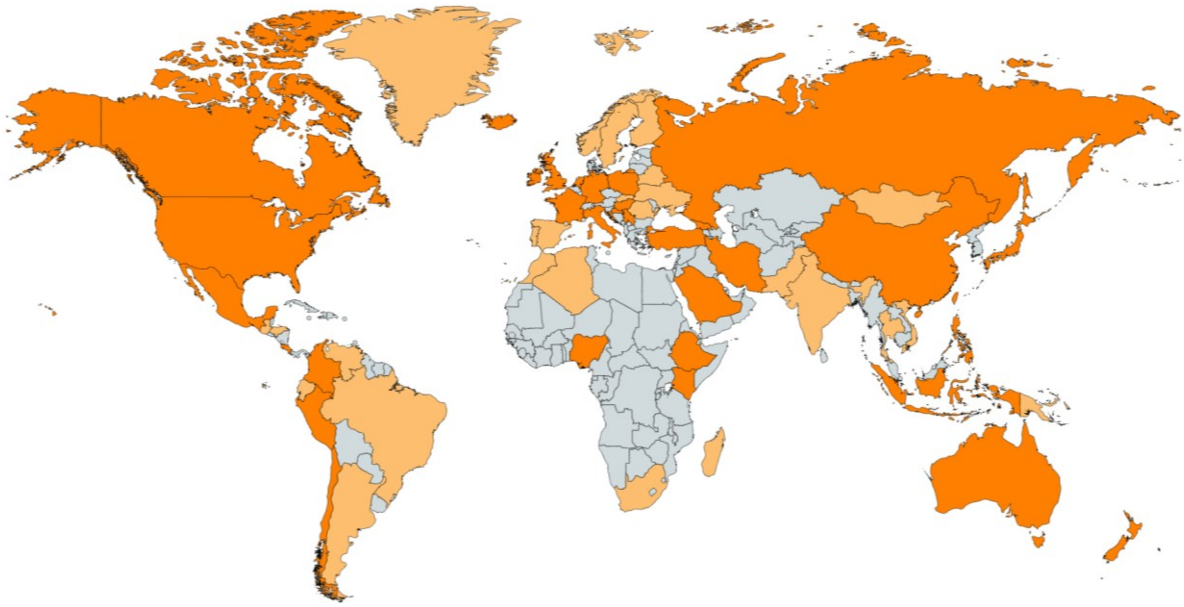

Figure 1: Geothermal usage and installed capacity (Power & Heat) (IGA, 2018)

Finally, users must be able to access information comfortable. This includes comprehensible visual data displays as well as easy access on mobile devices.

In summary, this results into a geothermal database providing the following required main features:

- High (yearly) update frequency
- Precise data
- Coherent data sets and data aggregations for different access groups
- User friendly operation
- Interfaces for external update options or data access

As indicated earlier in this section, the IGA operated a geothermal energy database until the year 2017. Unfortunately, the database does not work properly anymore due to a change in the underlying Business Intelligence (BI) Application. In coordination with the authors of the former database (Trumpy et al., 2015), the option to restore the old database and application has been discarded, since the application has not been designed to support all features as described in this section. Hence, the IGA decided to develop a new scalable database, that has a focus on interfaces from the beginning, in an internal development process. Nevertheless, data from the old database has been migrated to Geothermal 4.0, since this data is a valid base for historic data aggregations and comparisons.

2.2 Development approach and technical requirements

In order to replace the non-operating old database, but since the final requirements of the database and its application are not entirely known yet due to unknown other future data sources, the implementation was performed with an agile development process approach: Extreme Programming (XP). XP is a method, that places the solution of a programming task in the foreground of application development and attaches less importance to a formalized procedure. XP is a process model that is structured by continuous iterations and continuous user feedbacks, that help to improve the next release. Nevertheless, the use of this method is at least bound to a development target, frame conditions and well-defined technical structures, as described in the following sections.

Structured Query Language (SQL)

The Structured Query Language (SQL) is a very powerful - and at the same time easy to learn - database language designed for relational databases. This leads to the fact, that SQL has prevailed since its introduction in 1970 and is still number one for relational database systems in the year 2019. The relational data model is used for logical data organization and divides the viewed excerpt from the real world into a model, that defines and describes the database to be created. The data in the relational data model is structured in tables. Data in one table can relate to data in another table, if both tables have a common data element. A row in this table is an entity, representing a real-world object. This can be for example an object or a person. Attributes describe an entity in more detail. They are thus the properties of the entities. For example, the entity country could have the attributes name, continent, area size or abbreviation.

A clearly structured data organization is an important prerequisite for an efficient database. Hence, the modelling of the database is a crucial but also a complex task. On the one hand it is a challenge to logically form the real-world section into a data structure, on the other hand it is required to unite different user groups with different requirements and heterogeneous application systems. In order to reduce complexity, the database design is divided into four phases: requirements analysis, conceptual modelling, logical design and the implementation phase. As described above, Geothermal 4.0 follows an Extreme Programming approach. Hence, the phases have been passed in a shortened procedure and are repeated in many iterations.

MySQL

MySQL is a SQL-based relational Database Management System (DBMS), which means that data is stored in separate tables. This makes it more flexible and faster than other database management systems. MySQL is open source, so the source code can be displayed and adapted to the user needs.

MySQL is not only a DBMS, which is excellently suited to create and manage large databases. Due to its ease of use, it is just as well suited for smaller databases that are connected via web application. Therefore, though other Database Management Systems like NoSQL or PostgreSQL gain an increasing importance, MySQL is still the most used system. A successful overall system is usually created in cooperation with the script language PHP.

PHP Hypertext Preprocessor (PHP)

PHP is short for PHP Hypertext Preprocessor and is a scripting language for server-side programming. This means that the PHP code is executed on the server and not on the client in the browser. PHP can be used to create dynamic pages. These are pages that are generated each time after the call from the server anew and are filled with current data and sent to the client. Thus, for example, the search pages of a database are created. With the help of PHP, a database query is started for the searched term. Then, according to the rules of the PHP script, an individual page is created by the server, which is exactly tailored to the search term. This is then sent to the client as an HTML file and displayed by the browser.

PHP makes it possible to work with databases and provides many useful functions. This makes PHP an extremely powerful scripting language.

Application Programming Interface (API)

Provides also an Application Programming Interface (API). The programming interface serves to exchange information between Geothermal 4.0 and individual programs in a standardized way. The transfer of data and commands is structured according to a previously defined syntax.

Model View Controller (MVC)

The MVC paradigm is an architectural pattern. An architectural pattern differs of a design pattern with regard to its tasks. A design pattern represents a proven generic solution for a recurring problem in software architecture or software development. Design samples therefore deal with the concrete solution of a problem. An architectural pattern determines the organization and cooperation of software components. The MVC concept serves for the construction of user interfaces and is realized by three classes:

- Model Class
- View Class
- Controller class

The model classes are used to enter application data and are stored in the Business layer (application layer). The view class defines the layout of a screen presentation and is placed in the presentation layer. The controller classes are used for communication between the model classes and the view classes. In this way, the user interface can respond to user input react. The controller classes are also in the presentation layer. In Geothermal 4.0, a user requests to view a page by entering a URL and the Controller receives that request. It uses the Models to retrieve all required data, organizes it, and sends it off to the View, which then uses that data to render the final webpage presented to the user in their browser.

The MVC paradigm decouples the three classes mentioned. This provides the flexibility and reusability of the components, which is especially important due to the described development method of Extreme Programming.

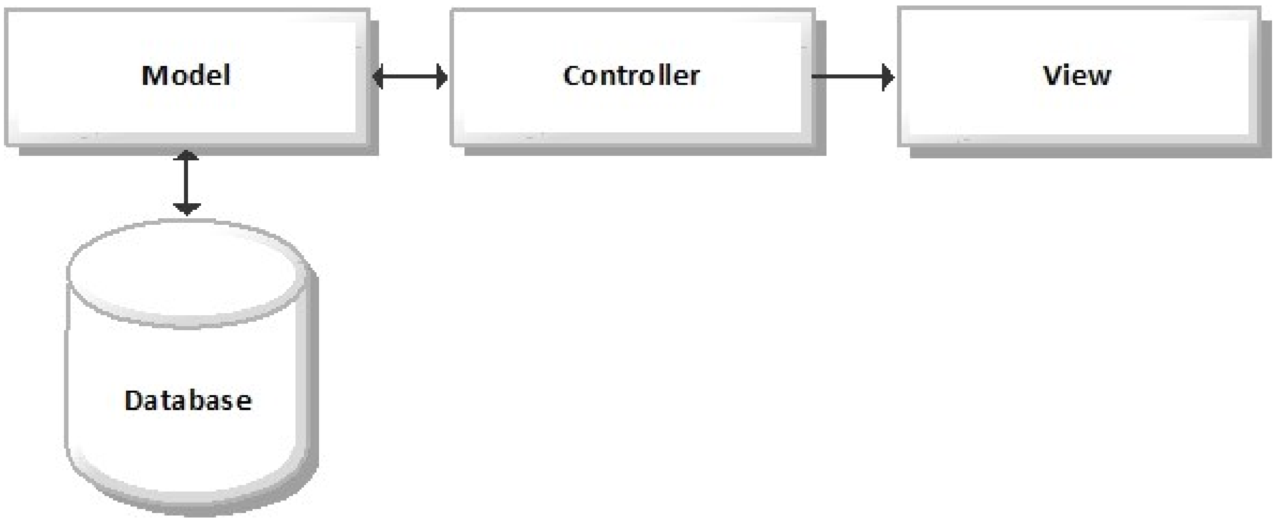

Figure 2: Model View Controller (MVC)

3. DATABASE

The database contains five tables in total, excluding additional master data tables for country information or data type definitions. The five main tables contain:

- Field
- Plant
- Unit
- Direct use
- Company

Field Data

Dickson and Fanelli define a Geothermal Field as a geographical area indicating an area of geothermal activity at the earth's surface. In cases without surface activity this term may be used to indicate the area at the surface corresponding to the geothermal reservoir below (2004). These areas are usually characterized by a relatively high heat flux and occupied by the installation of a geothermal system.

A geothermal field is usually located in one country and owned or operated by a company. Field entities contain the number of wells drilled, the depth of the deepest well and the average temperature of the field. Since the average temperature is in a range, it is divided into min and max values. Table 1 shows a list of the attributes indicating primary keys in bold and foreign keys in italic.

Attribute name	**Attribute description**	**Data type**
fieldID	Unique ID of field	INT
fieldName	Name of field	VARCHAR
fieldCountry	Country short code	VARCHAR(2)
fieldOwnerFID	ID of field owner	INT
fieldWellsDrilled	Number of wells drilled	INT
fieldAvgTempMin	Average temperature of field (minimum)	INT
fieldAvgTempMax	Average temperature of field (maximum)	INT
fieldDeepestWell	Depth of deepest well	INT

Table 1: Field attributes

Plant Data

A geothermal plant is a geothermal system used in order to generate electricity using geothermal energy. A plant is assigned to a geothermal field and an owner.

Attribute name	**Attribute description**	**Data type**
plantID	Unique ID of plant	INT
plantName	Name of plant	VARCHAR
plantOwnerFID	ID of field owner	INT
plantFieldFID	ID of geothermal field	INT

Table 2: Plant attributes

Unit Data

A unit is usually one specific turbine in a plant. A unit dataset contains information about the type of the unit, the status and year of commission as well as the installed and running capacity, wellhead temperature and average flow rate.

The capacity of a unit is the capacity is separated in two values. While the installed capacity indicates the maximum capacity as stated by the manufacturer, the running capacity is the effective capacity, that can be produced in this special environment and resource characteristics like temperature, flow rate or pressure.

Attribute name	**Attribute description**	**Data type**
unitID	Unique ID of field	INT
unitName	Name of field	VARCHAR
unitManufacturerFID	ID of field owner	INT
unitPlantFID	ID of plant	INT
unitType	Unit typologie	INT
unitYearCommissioned	Year commissioned (optional)	INT
unitStatus	Status of unit	INT
unitCapacityInstalled	Installed capacity in MW	DECIMAL
unitCapacityRunning	Running capacity in MW	DECIMAL
unitEnergyProduced	Produced energy per year in MWh	DECIMAL
unitMaxWellheadTempExpl	Wellhead temperature in exploration in °C	DECIMAL
unitMaxWellheadTempProd	Wellhead temperature in production in °C	DECIMAL
unitWellheadTempInj	Wellhead temperature in injection in °C	DECIMAL
unitAvgFlowRate	Average flow rate in Kg per second	DECIMAL

Table 3: Unit attributes

The unit type separates the different play-types of geothermal energy production, like flash, binary, dry steam or hybrid. As many other repetitive appearing data like countries, the unit type is only stored with an according identification number, that refers to information from a separate table. This table contains further information about these types, that can be easily accessed by the user of the front-end-application.

Unit Type		
1F (single flash)	Binary (ORC)	Hybrid
2F (double flash)	Binary (Kalina)	Back pressure
3F (triple flash)	Dry Steam	Other

Table 4: Unit types

Direct Use

Direct use is an important use of geothermal energy resources since it is a relatively unique feature in the renewable energy mix.

Attribute name	Attribute description	Data type
duseID	Uniques ID of direct use	VARCHAR
duseName	Name of direct use	VARCHAR
duseCompanyFID	ID of owner	INT
duseCountry	Country short code	VARCHAR(2)
duseType	Type of direct use	INT
duseCapacityInstalled	Installed capacity in MW	DECIMAL
duseAnnualUse	Annual use in MW	DECIMAL

Table 5: Direct use attributes

The direct use type separates the different types of direct uses, like heating or cooling.

Direct Use type		
Individual space heating	Fish farming	Snow melting
District heating	Animal farming	Bathing and Swimming
Air conditioning (cooling)	Agricoltural drying	Geothermal heat pumps
Greenhouse	Industrial process heat	Other

Table 6: Direct use types

Company

A company can be engaged as a manufacturer, operator or owner. Some companies even operate in multiple roles. Hence, these organizations are stored in one table to avoid data redundancy.

Since no personal data is stored in this table respectively the entire database, special data protection considerations like the General Data Protection Regulation (GDPR) do not apply.

Attribute name	Attribute description	Data type
companyID	Unique ID of company	INT
companyName	Name of company	VARCHAR

Table 7: Company attributes

Figure 3 shows a simplified data model and the relation between the tables. As an example, one Field can contain unlimited Plants, while one specific Plant is assigned to exactly one Field (1-n relation).

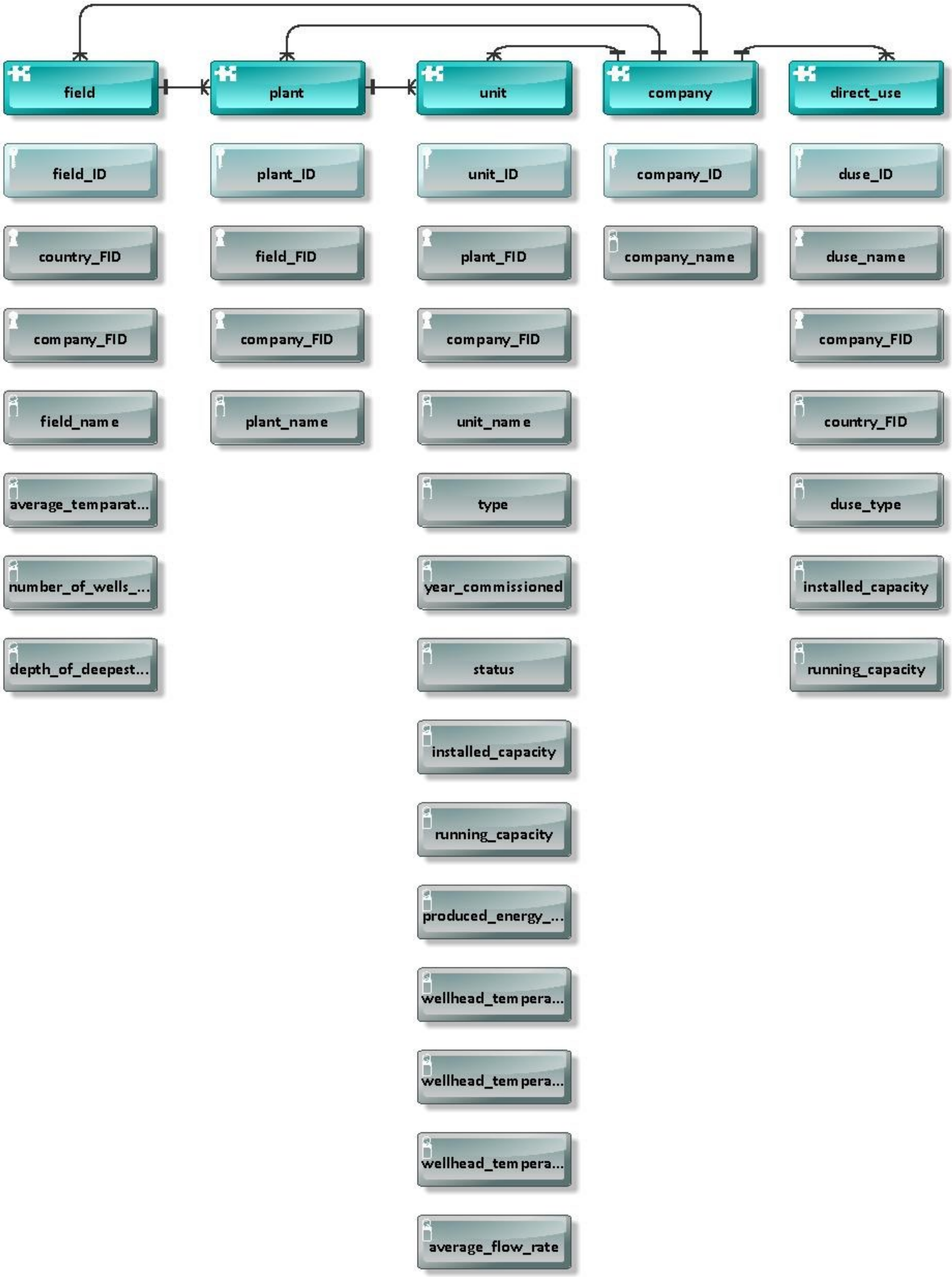

Figure 3: Simplified data model

Data statistics

Table 8 shows the number of entities per table. The status (operating, planned or decommissioned) is only set for geothermal units. A Plant without an operating plant is evaluated as temporary not operating.

Table	Total Count	operating	planned	decommissioned
Geothermal Field	282			
Plant	552			
Unit	1127	613	274	160
Direct Use	281			

Table 8: Row count statistics

4. USER APPLICATION

The user interface has been implemented in PHP version 7, while the PDO extension of PHP is used to access the MySQL database. PDO supports prepared statements and can handle multiple database types compared to the MySQLI interface. This brings a considerable advantage to the possibility of further use of the data model, especially when changing or connecting to another database. Reusable classes support the four fundamental data operations Create, Read, Update and Delete (CRUD).

The implementation follows the MVC scheme, where the view class is connected to and supported by the Bootstrap framework. Bootstrap is an open-source frontend CSS framework containing HTML5 and CSS based design templates for grid systems, typography, form elements, tables, navigation and other interface elements as well as additional JavaScript extensions. The framework also supports a responsive web design. This means, that the graphical structure of web pages is dynamic and adapts the properties of the used browser - like Chrome, Firefox, Edge, Internet Explorer, Opera or Safari - or device - such as PC, Tablet or Smartphone. Therefore, arranged elements automatically adjust to the screen resolution, screen orientation or window size.

Data can be aggregated for example by Plant, Geothermal Field, Country or Continent. Among others, the following data queries can be processed:

- Fields by Country or Continent
- Fields by Owner
- Plants by Country or Continent
- Plants per Field
- Plants per Owner
- Units by Plant

Figure 4 shows a sample query result for all geothermal fields filtered by country (Italy) and company (EGP).

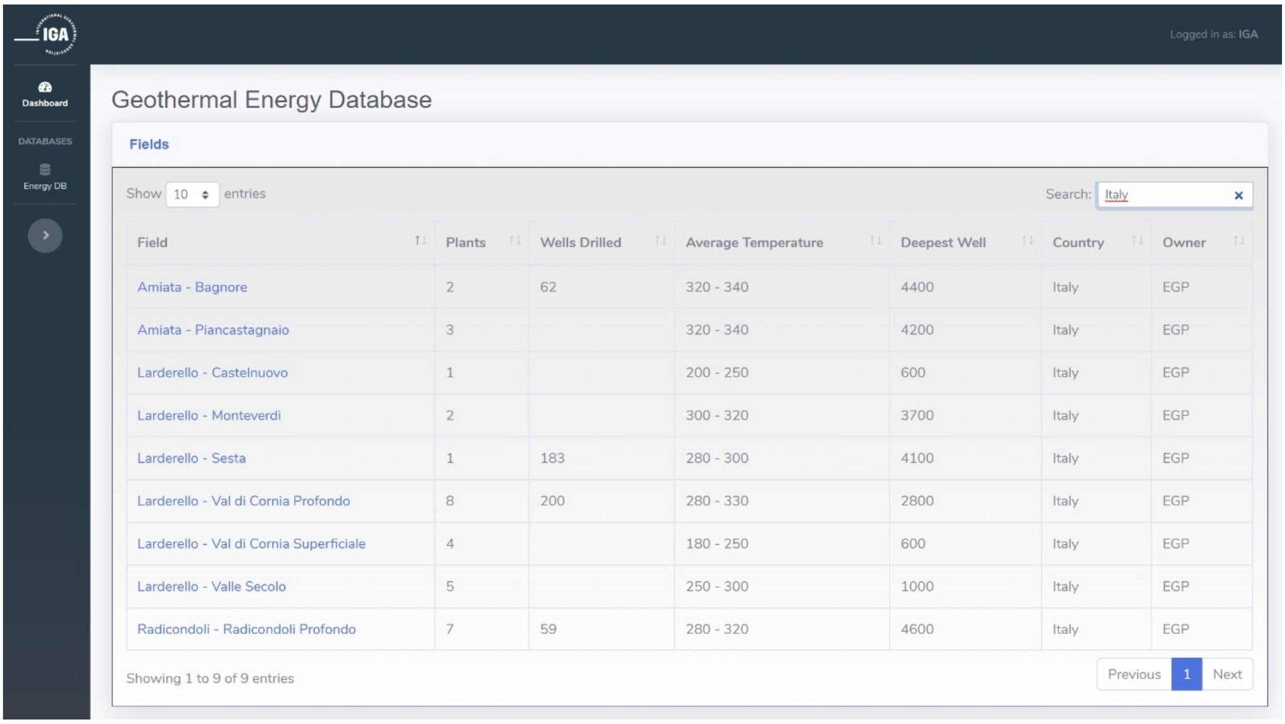

Figure 4: Listing of geothermal fields, filtered by country (Italy) and owner (EGP)

Dynamically generated pages for each field or plant show summarized information, like geographical information, all plants on the field respectively all units in a plant. Data can be downloaded for further processing as Comma Separated Values (csv) file.

The presentation is visually supported by an interactive map, which allows a comfortable navigation (Figure 5).

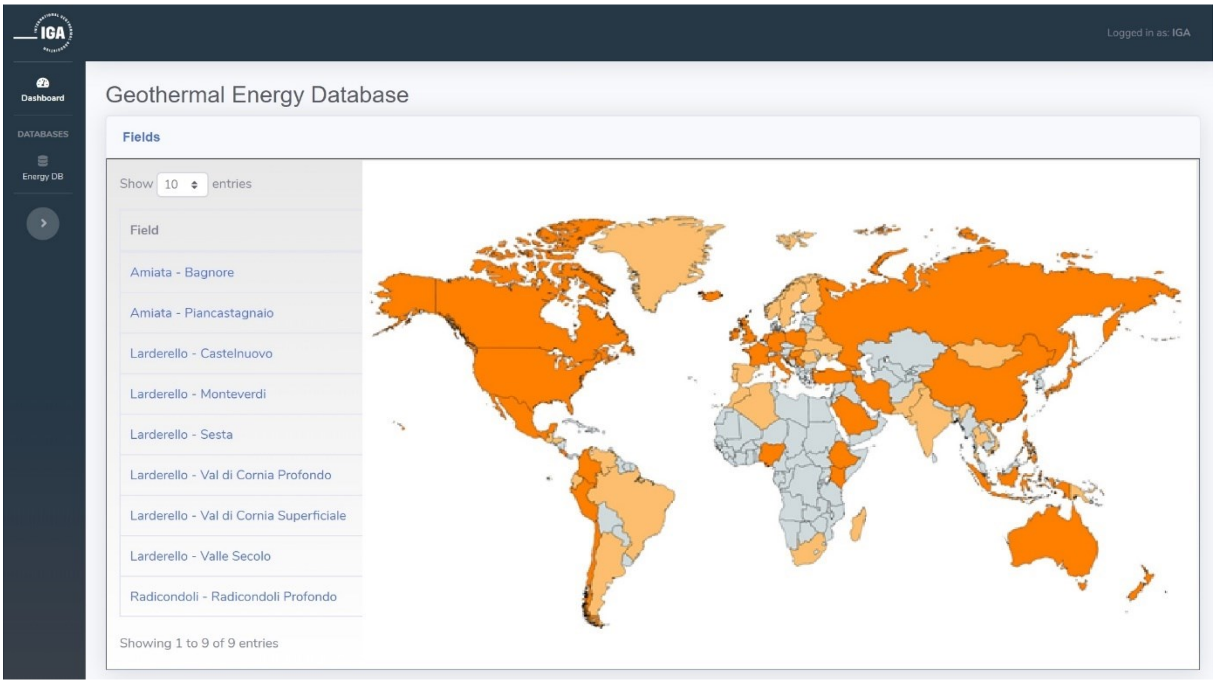

Figure 5: Interactive map of countries with geothermal energy data

The user interface is multilanguage ready. The current release is in English language, other languages can be added easily. All language definitions and translations are stored separate in external Extendable Mark-up Language (xml) files and can be processed, edited and updated with many other software applications as well as in a simple text editor. Figure 6 shows an example for a xml language file.

```
<?xml version='1.0' standalone='yes'?>
<languages>
  <english>
    <iMenu>
      <field>Field</field>
      <plant>Plant</plant>
      <unit>Unit</unit>
      <duse>Direct Use</duse>
    </iMenu>
  </english>
  <german>
    <iMenu>
      <field>Feld</field>
      <plant>Kraftwerk</plant>
      <unit>Einheit</unit>
      <duse>Direktnutzung</duse>
    </iMenu>
  </german>
</languages>
```

Figure 6: Sample for language file

Access to Geothermal 4.0 is restricted with three type of access: free access with limited data access, member access with full data access and special access for authorized user with edit and update privileges.

Since the IGA uses an external Membership Management System (MMS) with separate accounts to manage its memberships, users can use the account from the MMS to login at Geothermal 4.0 too. These user accounts have been connected via the API of the MMS, which confirms the advantage of a modular design with interfaces to other sources.

Users logged in with an account having the required privileges can access the data entry tool and API. The data entry tool supports to add new data to the database as well as updating existing data. Access to the API will requires also an additional individual key, given out to authorized persons by the IGA. Figure 7 shows a sample PHP script to access the API. The user can write own scripts and use several functions to receive or submit data. A full documentation of all API functions and options is available online as a help page within the user interface.

```php
<?php
function GPDBconnect() {
    $ch = curl_init("https://database.geothermal-energy.org/api/post");
    $data = http_build_query([
        "token" => "[PERSONAL_USER_TOKEN]",
    ]);
    curl_setopt($ch, CURLOPT_CUSTOMREQUEST, 'POST');
    curl_setopt($ch, CURLOPT_POSTFIELDS, $data);
    curl_setopt($ch, CURLOPT_RETURNTRANSFER, true);
    curl_setopt($ch, CURLOPT_SSL_VERIFYPEER, false);
    $result = curl_exec($ch);
    curl_close($ch);
    return $result;
}
?>
```

Figure 7: Sample PHP script for API access

5. CONCLUSION

Geothermal 4.0 helps the IGA to provide up-to-date data and information about the geothermal status worldwide. The system is developed considering latest technical developments and provides a state-of-the-art sample for current database and application development. Data can be easily accessed and aggregated in various ways, considering the different user types and information demands.

The current database and dataset provide a very good and scalable base for future data updates. The API supports these data updates in an aimed yearly frequency. Incoming country updates from the WGCs every three years will help to synchronize with interim updates within a reasonable timeframe. Involving the IGA membership and relationships to stakeholders in the regions and in the fields helps gathering and providing up-to-date geothermal information.

However, managing geothermal energy data is not limited to details about geothermal conditions and applications, but also understanding regulatory, economic and social (including environmental) aspects or capacity building and training. Required data is often available, but spread over different locations, databases or platforms. A rising number of international organizations promotes standardization processes and frameworks for geothermal resources and projects to manage and include these “meta-data”. Hence, future data collections must take this heterogeneity of information into account. Geothermal 4.0 is ready for this.

REFERENCES

Bertani, R.: Geothermal Power Generation in the World 2010-2014 Update Report, *Geothermics*, 60, (2016), 31-43

Dickson, M.H. and Fanelli, M.: What is geothermal energy, *Internal report*, (2004)

International Geothermal Association: IGA Charter, (1988), online: https://www.geothermal-energy.org/download/1445/, (accessed: 26.07.2019)

REN21: Global Status Report, Report, (2019), online: https://www.ren21.net/reports/global-status-report/, (accessed: 26.07.2019)

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