

Atlas of Geothermal Resources in Europe

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Abstract

Geothermal resources for most European countries are compiled in the recently published Atlas of Geothermal Resources in Europe, a companion volume to the Atlas of Geothermal Resources in the European Community, Austria and Switzerland. Publication of the atlas comes at a time when the promotion of a sustainable and non-polluting energy supply are high on the agenda of local energy suppliers, municipal administrations and all European governments. The participating countries are: Albania, Austria, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Czech Republic, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom.

A volumetric heat content model for porous reservoirs assuming exploitation of geothermal energy by a doublet is the basis of the resource calculation. Geothermal reservoirs are characterized by a set of 4 maps: depth, thickness, temperature and resources. The assessment methodology is simple and is based on a small number of parameters. In that way, evaluation of regions with very limited data coverage is possible.

An illustrative example in the eastern North German Basin is shown. The maps presented in the atlas permit a first order evaluation of the geothermal potential in terms of technical and economic viability. This uniform procedure applied to all countries and regions allows comparisons and serves as a guide to setting priorities and planning geothermal development. This atlas also aids the search for appropriate objects for international cooperation in geothermal exploration in Europe.

Keywords

Geothermal resources, geothermal energy, Europe, atlas, maps

Introduction

Geothermal energy is worldwide the most extensively used renewable energy besides hydro-power. By the end of 2000, geothermal power plants amounted worldwide to an installed capacity of about 8,000 MW_{el} [1]. They produced electrical energy of roughly 50,000 GWh per year. Besides this about 52,000 GWh of geothermal energy per year [2] were extracted worldwide for direct use for space heating, process heat, thermal spas or greenhouses.

Compared to other renewable energies geothermal heat is advantageous since it is available all day and at all seasons. This and its great resource make geothermal energy an attractive option for a sustainable energy supply in the future.

Geothermal energy can be exploited with various technologies, although it generally, albeit not exclusively, involves drilling and pumping water from depth. It feeds a great diversity of applications, alone or in combination with other sources of energy. Geothermal energy is stored in the subsurface in a certain concentration and fashion. This dictates the kind of application and extraction method. Rigorously, one would need an assessment procedure for each kind of application (direct use, heat pump, electric power generation, etc.) and each type of reservoir (e.g. porous or fractured, water or steam). However, this approach is not very useful to gain an overall view of geothermal resources at a large scale.

An assessment of geothermal energy on a European scale using data from many countries requires a standardized procedure that would allow comparisons between regions and facilitate regional planning of investments in every kind of geothermal application. This was the philosophy of the European project leading to the publication of the Atlas of Geothermal Resources in the European Community, Austria and Switzerland [3] and of the recently completed companion volume: Atlas of Geothermal Resources in Europe [4]. The latter contains updated information on geothermal resources from the participants of the first atlas and includes information of 19 new participating countries. Together these two atlases display information for 32 countries, practically all of the European continent: Albania, Austria, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Czech Republic, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom.

Geothermal resources: definition, assessment and representation

Geothermal resources are defined as that part of the geothermal energy which can be extracted economically and legally in the near future [5]. In order to quantify these resources, the amount of heat available in the rock (geothermal reservoir) and the characteristics of the reservoir with respect to the extraction of that heat need to be determined. There are numerous methods and models for the quantification of geothermal resources. For the two atlases the assessment of geothermal resources is based on a volumetric heat content model for porous reservoirs assuming exploitation of geothermal energy by a doublet [5].

The resource H_1 (in J), is given by

$$H_1 = H_0 \cdot R_0 \quad (1)$$

H_0 represents the heat in place (in J) contained of the reservoir under a surface area A . The fraction of this heat that can be extracted is R_0 , a recovery factor that depends on the extraction technology used. H_0 comprises the heat stored in the rock matrix (index m) and in the water filling the pores (index w):

$$H_0 = [(1-P) \cdot \rho_m \cdot c_m + P \cdot \rho_w \cdot c_w] \cdot [T_1 - T_0] \cdot A \cdot \Delta z \quad (2)$$

where:

ρ_m, ρ_w density of the rock matrix and water, respectively, kg/m^3 ,
 c_m, c_w specific heat capacity of the rock matrix and water, respectively, $\text{J}/(\text{kg K})$,
 P effective porosity, dimensionless,
 T_t temperature at the top of the aquifer, $^\circ\text{C}$,
 T_0 temperature at the surface, $^\circ\text{C}$,
 A surface area under consideration, m^2 ,
 Δz net aquifer thickness, m.

For a doublet system, i.e. with a production borehole and an injection borehole used to re-inject the fluid after use, it can be shown that [6]:

$$R_0 = 0.33 \frac{(T_t - T_r)}{(T_t - T_0)} \quad (3)$$

where T_r is the re-injection temperature. An expert group of the European Commission (EC) recommended a value of $T_r = 25$ $^\circ\text{C}$. Re-injection avoids a pressure decline in the aquifer during exploitation or prevents environmental degradation of superficial water and soil due to the disposal of highly saline geothermal water.

In order to display the geothermal resources of a region, a set of four maps was recommended:

1. The map of the depth of the top of the aquifer shows the range of depth variation of the reservoir. Depth is a critical parameter for evaluating the order of magnitude of the investment needed to develop the available geothermal resource, as drilling costs still make up the major part of this investment.
2. The map of the aquifer thickness is a measure of the magnitude of the resource. Experience in geothermal energy applications in northern Germany indicates that aquifers of net thickness less than 20 m are rarely capable of supporting the required production rates.
3. The temperature at the top of the aquifer provides a lower bound on the range of temperature in the aquifer, indicating what type of application may be installed. The Lindal diagram in Figure 1 [7] shows typical applications of geothermal energy.
4. The distribution of the resources over a region is shown in a map of isolines representing the resources per unit area (H_1/A , in GJ/m^2). Here the effects of all parameters in equations 2 and 3 are lumped together. It is possible to display resources information that includes confidential data (e.g. porosity of certain aquifers) without explicitly revealing this data.

The data needed for this assessment consist of borehole information (stratigraphy, porosity from cores or geophysical logging, temperature measurements) and geophysical and geological surveys to determine structures (faults) and the spatial distribution of reservoir formations. The classification of an aquifer as a geothermal resource is based mainly on the effective porosity of the aquifer. Generally, fluid extraction is governed by hydraulic conductivity or transmissivity. Data on porosity is generally much easier to access (from cores or geophysical logs) and gives at least some hints on the transport properties of the formation. However, the knowledge of these parameters requires expensive pumping tests, an investment more often undertaken in studies for a specific location rather than for the overall characterisation of an aquifer. Information on the chemistry (salinity) of the geothermal fluid

is important for evaluating the extraction technology. The need to re-inject the produced fluid can be evaluated and measures planned for preventing scaling or corrosion can be taken. Wherever available, these data have been included in the set of four maps in the atlas. Unfortunately these important data are often not available.

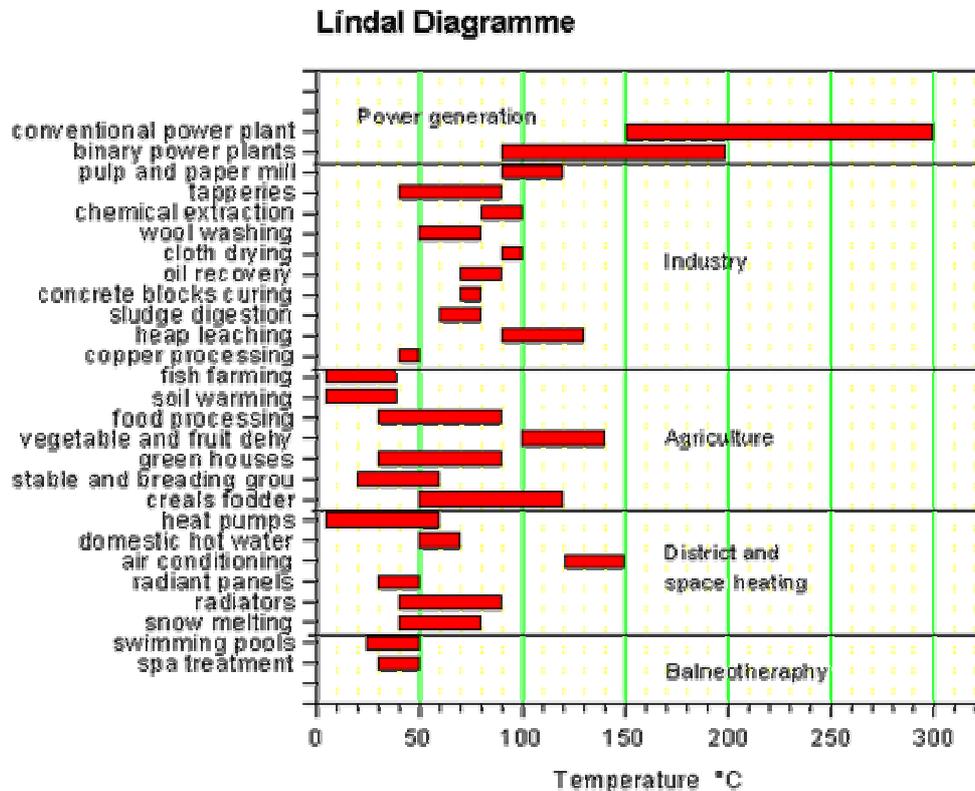


Figure 1. Application fields for geothermal energy depending on the water temperature

Contents of the atlas

The present atlas follows closely the structure of its predecessor. The general information supplied by the project partners (individual country contributions) was supplemented by partial contributions of Belarus, Bosnia-Herzegovina, Croatia, Iceland and the Ukraine that were incorporated into these European overviews. Heat-flow density, temperature at depths of 1000 m (Figure 2 [4]) and 2000 m provide a large scale view of the thermal field, while maps depicting the locations of presently operating geothermal installations and the areas for which more detailed resources assessment can be found in specific national contributions complete this general section.

It is followed by more than 500 maps at a national and regional scale. Contributions for individual countries include: Albania, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom. Geothermal springs and installations currently operating or under construction are presented on the geothermal thematic maps containing the major geological and tectonic features in the background. Geological cross-sections supplement this

information. Temperature maps at a depth of 500 m reveal the shallow thermal regime. Maps characterizing the geothermal resources of selected aquifers form the body of this atlas. These maps depict depth, thickness, temperature and geothermal resource of the aquifers. As an example the maps of the Buntsandstein aquifer in the North-East German basin are shown in Figure 3a-3d [4]. Because of the salt tectonics, great variations of depth (Figure 3a) and thickness (figure 3b), exceeding locally 1000 m, occur within short distances. This is reflected also in the temperature (Figure 3c) and resource (Figure 3d) maps. The porosity of the aquifer ranges from 10 – 35%, with a mean of 22%. Where available, transmissivity, piezometric head and salinity are also shown on the maps. The explanatory text and tables include information that cannot be adequately displayed on maps.

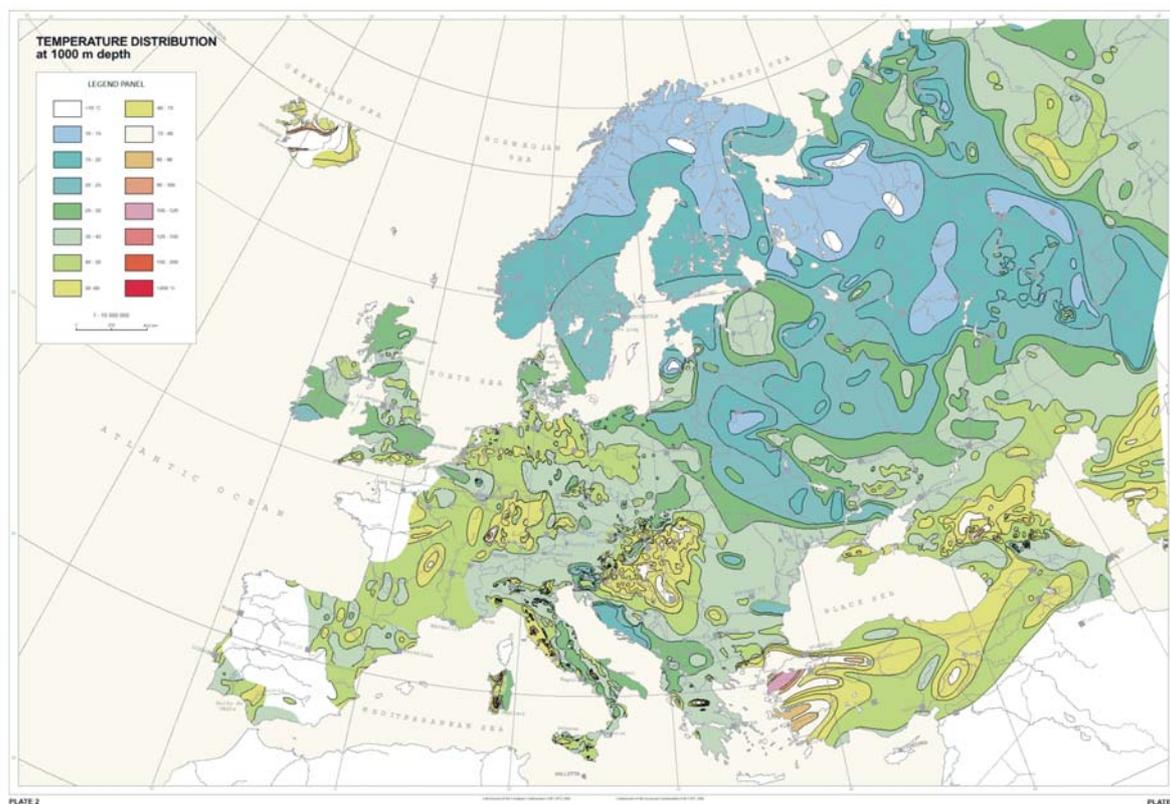


Figure 2. Temperature distribution at 1000 m depth in Europe

How can the information in the atlas be used?

The atlas is not a tool to determine drilling sites for geothermal installations. Rather, it should be employed in activities preceding the targeting of drilling for geothermal purposes. It serves as a guide to set priorities for future investments in local studies and auxiliaries in delineating target areas for these investments. The atlas does not explicitly account for the availability of consumers for the resources presented. However, background information on the maps, such as cities, provides an indication of potential consumers.

The resources maps allow a rough estimate on the total heat that can be produced during the life time of a doublet (that generally exploits an area of 1-2 km²) and to select areas for further investigation. The temperature map indicates what kind of application could be of interest and the thickness map gives a first indication of whether such an application can be supported in

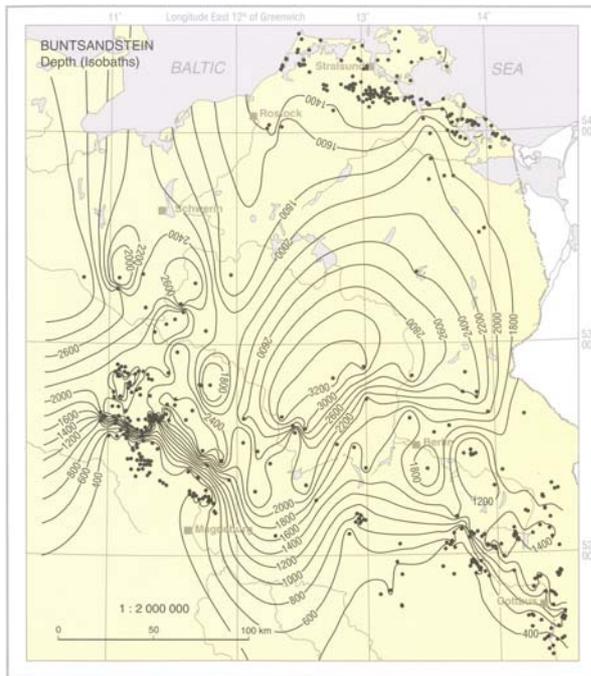


Figure 3a. The depth to the top of the Buntsandstein aquifer in the North-East German basin varies from 400 to 3200 m.

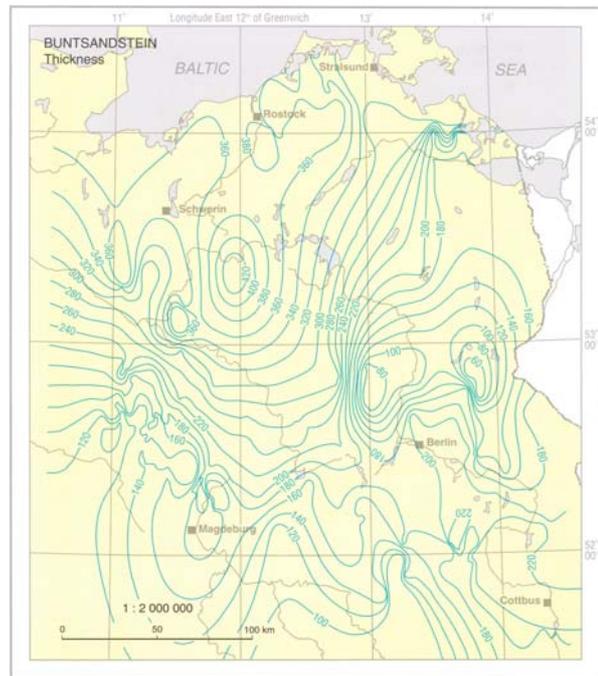


Figure 3b. The Buntsandstein aquifer thickness in the North-East German basin changes from 100 to 420 m.

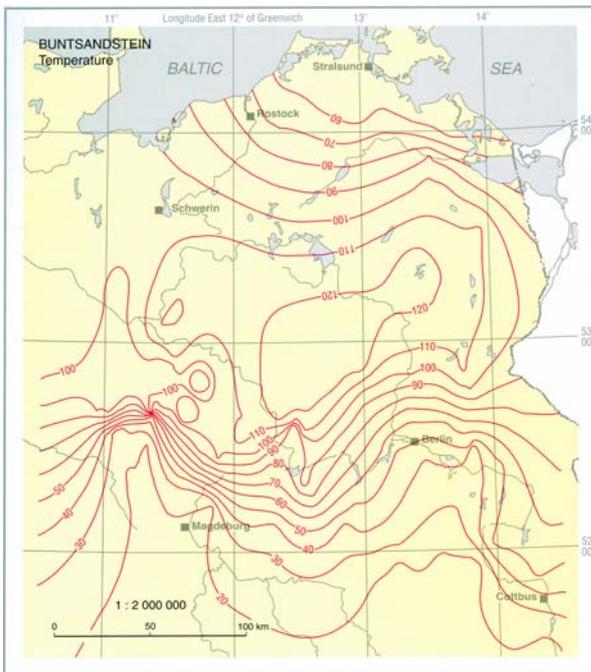


Figure 3c. The temperature at the top of the Buntsandstein aquifer in the North-East German basin amounts 20 to 120 °C.

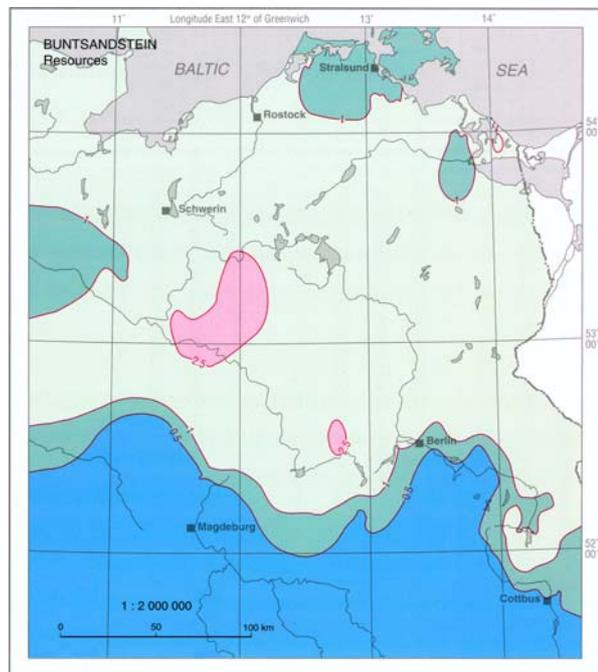


Figure 3d. The resources distribution of the Buntsandstein aquifer in the North-East German basin averages from 0.5 to 2.5 GJ/m².

the selected area, since the transmissivity of an aquifer is proportional to the thickness. The depth to which one has to drill in order to reach the reservoir (depth map) allows a first order estimate of the investment needed to exploit the resource. This information is assembled quickly and provides an aid for selecting areas worth a more detailed survey.

The information in this atlas is displayed in such a form, that decision makers at all levels can understand and use it. For instance, mayors, together with local companies may search for partners from other European countries with a similar geological setting to share their knowledge and experiences and to form a joint venture. Government authorities may use the atlas as an aid to ranking different regions for planning geothermal development. We stress again, that no decision on building a geothermal installation can be made on the basis of this atlas without a thorough local study.

Discussion and outlook

The resources evaluation procedure used for compiling the present atlas is simple and is based on generally available information. It does, however, not consider the critical conditions needed for successful economic extraction of the resources. Exploitation of geothermal resources is critically determined by the transmissivity of the aquifer, which constrains production rates. Transmissivity data and pumping test results are only available for specific areas. It would not be possible to obtain assessments for most of Europe based on such data. Furthermore, permeability may vary over several orders of magnitude within short distances with almost unpredictable consequences for the exploitation. Even if our resources assessment were to include permeability and more sophisticated models, it would still not allow predictions about the system at specific locations.

Both atlases contain a selection of the material provided by the participating countries. Format constraints of the hardware (paper with a determined page size) and financial limitations mandated a certain choice, which is, in some cases, not the choice of preference of the editors nor participating countries. The material included there does not exhaust all knowledge on geothermal potential areas. The electronic media of representing such endeavours in the future will do much to lift some of these limitations.

The geothermal resources assessment procedure adopted for the Atlas of Geothermal Resources in Europe does not invalidate nor substitute other methods of resource evaluation and may even be considered inferior to some other methods. However, at present, it is still the only manner to display resources from Portugal across to Russia on a comparable basis. The current trend to a global economic system will reinforce the need to carry out further comparative resource assessments.

No matter which method is used to quantify resources, the energy that can be gained ultimately is related to the development and optimization of exploitation technology. Hopefully, some of the geological constraints to the use of geothermal energy will be overcome, so that geothermal systems may be placed closer to the consumer. The first glimpse of such a development is seen in the present Hot-Dry-Rock technology of enhancing permeability with hydraulic stimulation. Where previously there was only a marginal possibility to install a geothermal application because of low hydraulic conductivity, hydraulic stimulation (hydrofracs) may open the needed pathways. Another important consideration is the optimization of exploitation. Careful monitoring and research to gain

detailed understanding of the geothermal reservoir in the Paris Basin has led to more geothermal energy being exploited from the same resource [8]. The usable quantity of geothermal energy was increased without any investment in new boreholes.

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