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A tool for planing geothermal development: Atlas of geothermal resources in Europe

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ABSTRACT

Geothermal resources for most European countries are assembled in the recently completed Atlas of Geothermal Resources in Europe, a companion volume to the Atlas of Geothermal Resources in the European Community, Austria and Switzerland. The participating countries are: Albania, Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom. A volumetric heat content model for porous reservoirs assuming exploitation of geothermal energy by a doublet or a singlet system is the basis of the resource calculation. Maps of depth, thickness, temperature and resources characterize the geothermal reservoir. The assessment methodology is simple and relies 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 permits comparisons and serves as a guide to setting priorities and planing geothermal development. This atlas also aids the search for appropriate objects for international cooperations in geothermal exploration in Europe.

KEYWORDS

Geothermal resources, Europe, atlas, maps.

1. Introduction

Geothermal energy can be extracted with a variety **of** technologies, although it generally, albeit not exclusively, involves drilling and pumping water from depth. This energy feeds a great diversity of applications, alone or in combination with other sources of energy.

Geothermal energy is stored 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 (doublet, heat pump, electric power generation, etc.) and each type of reservoir (e.g. porous or fractured, fluid or steam). However this approach is not very useful to gain an overview of geothermal resources at a large scale.

Therefore, it is necessary to quantify resources in such a way as not to constrain perspectives on new applications or technologies. Many new, mostly low enthalpy, applications have been developed that can be installed in regions considered earlier to not have enough resource concentration to be of interest. It would be ideal to have a single procedure for assessing geothermal resources that would allow comparisons between regions and facilitate regional planing 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 (Haenel and Staroste, 1986) and of the recently completed companion volume: Atlas of Geothermal Resources in Europe. It contains updated information on geothermal resources from the participants of the first atlas and includes information of 14 new participating countries. Together these two atlases display information for 25 countries, practically all of the European continent: Albania, Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

2. Geothermal resources: definition, assessment and representation

Geothermal resources are that part of the geothermal energy which can be extracted economically and legally in the near future (Muffler and Cataldi, 1978). 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 these resources, however, they will not be discussed here. The work of Muffler and Cataldi (1978) is a useful starting point.

The resource H_1 (in J), is given by

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

H_0 represents the heat in place (in J) contained by the reservoir assuming a volume model of heat extraction (Muffler and Cataldi, 1978). It takes into account the heat stored in the rock matrix (m) and in the water occupying the pores (w):

$$H_0 = \left[(1-P)\cdot\rho_m\cdot c_m + P\cdot\rho_w\cdot c_w\right]\cdot\left[T_t - T_0\right]\cdot A\cdot\Delta z \qquad (2)$$

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, J/(kg K),

P effective porosity, without unit,

T_t temperature at the top of the aquifer, °C,

T_0 temperature at the surface, °C,

A surface area under consideration, m^2,

Δz net aquifer thickness, m.

The fraction of this heat capable of being extracted is R_0, a recovery factor that depends on the extraction technology used. If exploitation is made with 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 (Lavigne, 1978):

$$R_0 = 0.33\frac{(T_t - T_r)}{(T_t - To)} \qquad (3a)$$

where T, is the re-injection temperature. 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. The expert group **of** the European Commission (EC) recommends a value of $T_r = 25$ °C. This restriction cannot be applied to countries in which the mean annual temperature is low (e.g. Sweden). The same temperature difference (T_t-T_r), albeit with much lower reservoir and re-injection temperature may produce comparable resource and exploitation possibilities **as** in countries of wanner climate and higher reservoir temperatures.

If the extraction of geothermal energy is planned with one production borehole only, a singlet, then the recovery factor reduces to (Gringarten, 1979):

$$R_0 \approx 0.1 \qquad (3b)$$

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

1. The map of the depth to 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 potential, 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 temperatures in the aquifer, indicating what type of application may be installed.
4. The distribution of the resources over a region is shown with a map of isolines representing the resources per unit area (H_l/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 fiom cores or geophysical logging, temperature measurements) and geophysical and geological surveys to determine structures (faults) and the spatial distribution of reservoir formations. In the procedure presented above, the resources are based on the effective porosity of the aquifer. Generally, fluid extraction is governed by hydraulic conductivity or transmissivity. 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 spent 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. Although these additional data are important, they are often not available. On the other hand, porosity determinations (on cores in the laboratory or during geophysical logging) seem to be easier to secure.

3. Contents of the atlas

This atlas follows closely the structure of the previous one. The general information supplied by the project partners was supplemented by partial contributions of Belarus, Croatia and the Ukraine that were incorporated into these European overviews. Heat-flow density, temperature at depths **of** 1000 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, 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 map containing the major geological and tectonic features in the background. Geological cross-sections supplement this information. A map of temperature at a depth of 500 m reveals the shallow thermal regime. Maps characterising the geothermal potential and resources of selected aquifers form the body of this atlas. These maps depict depth, thickness, temperature and geothermal resource of the aquifer. 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.

4. 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 map can be looked at against the distribution of potential consumers (cities in the background) and an area selected 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 the selected area, if the hydraulic properties are found to be favourable in some future local study. The depth to which one has to drill in order to reach the reservoir (depth map) allows a first order estimate to the financial means 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 a partners from another European countries with a similar geological setting to pool resources for a joint venture. Government authorities may use the atlas as an aid to ranking different regions for planing 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.

5. Discussion and outlook

The resources evaluation procedure used for compiling the present atlas is simple and requires generally available information. It does, however, not consider the critical conditions needed for successful extraction of the resources. Exploitation of geothermal resources is practically determined by the permeability of the aquifer, which constrains production rates. Permeability data and pumping test results are **only** available for specific areas. It would not be possible to obtain assessments for most of Europe based only 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.

Both atlases contain a selection of material. Format constraints of the hardware (paper with a determined page size) and fmancial 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 geothermally 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 fiom 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 optimisation of exploitation technology. Hopefully, some of the geological constraints to the use of geothermal energy will be overcome, so that applications **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 (hydrofiacs) may open needed pathways. Another important consideration is the optimisation 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 fiom the same resource (Demange et al., 1995). The usable quantity of geothermal energy was increased without any investment in new boreholes.

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