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Preparing Geothermal Energy Profiles in the Pannonian Basin in Hungary

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1. ABSTRACT

The geothermal potential in the Pannonian Basin in Central and Eastern Europe offers widespread energy production solutions for consumers. Both deep and shallow geothermal energy production have been strongly increasing in this century, and the ambitions for the next decade are even higher.

The large majority of the territory of Hungary provides bright prospects for deep geothermal exploration. Furthermore, Hungary intends to switch from the use of natural gas to renewable energy, and geothermal is the most popular energy source in the country. In the previous decade, the volume of geothermal energy production almost doubled, and in this decade the government wishes to triple it. Therefore, the interest is more and more on new geothermal projects and technologies.

However, the geological background is one of a high temperature basin and not volcanic, so the potential is limited and mainly focuses on heat production. When we discuss with energy consumer clients, we have to describe to them the geothermal opportunities. The GeoInnovator Team has prepared a large number of geothermal project concepts for its clients in recent years. The concept series includes widespread technical solutions for deep, shallow, complex and hybrid geothermal technologies.

The first professional challenge is to prepare a geothermal energy profile for the consumers. In the previous century, one simple technical concept was forced on all geothermal projects. Nowadays, there are numerous technological opportunities to take into consideration. Only the integrated utilization of a realistic geothermal profile and a detailed consumer's profile results in a technically and economically successful geothermal project! They provide essential input for the field management of the targeted reservoirs. The two profiles (geothermal and consumer's) enable us to prepare an accurate list of facilities and precise cost as well as calculations on returns still in the concept phase of the project. The present paper collects the best project type practices and reviews the latest geothermal profile preparation methodology.

Moreover, the GeoInnovator Team has also prepared a projection in order to calculate the details of the national plan to triple the geothermal energy production in ten years. It reviews the general national geothermal potential, the main geological structures, the possible project type models, their opportunities, as well as their aggregate capacities by 2030.

This projection can serve as a geothermal database for the new renewable energy strategies of Hungary and the European Union.

2. INTRODUCTION

Both the European Union and the Hungarian Government wish to triple their geothermal energy production by the end of this decade. It seems to be a realistic plan, but a lot of professional work is required to achieve this ambitious plan.
Hungary's geothermal potential is one of the best in Europe. The geothermal gradient is fairly high (45–65 K/km) across the country, and thermal water can be produced almost everywhere.

Hungary is in the center of the Pannonian Basin, which is a high temperature basin, as shown in the following map.

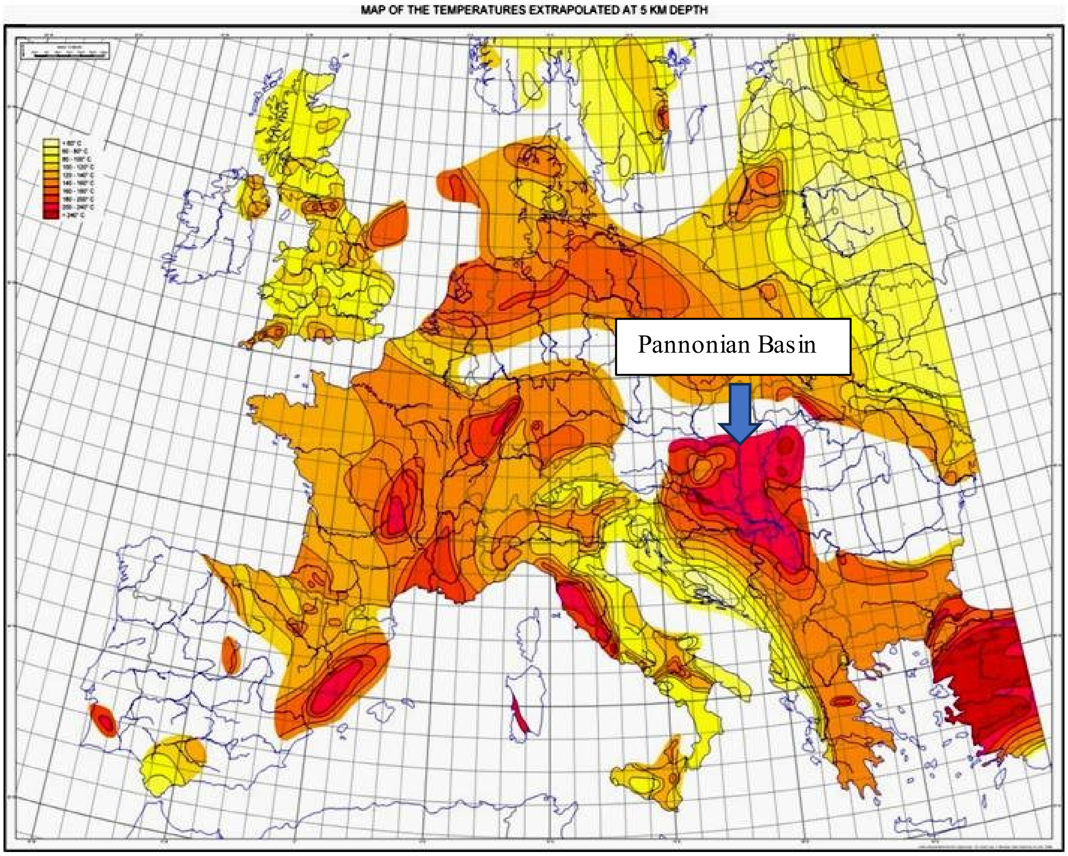

Figure 1: Temperature in 5 km depth in the Pannonian Basin (based on EGEC)

During the planning of a new deep geothermal site, we have to prepare a geothermal profile related to this site including the following data:

- Thermal water capacity, (kg/s)
- Thermal water temperature on the well-head, (ºC)
- Maximum heat capacity, (MW_{th})
- Coefficient of the performance, (kW/kW)
- Lifetime of the reservoir, (years)

The excellent geothermal potential provides an opportunity to create complex deep-shallow and also hybrid systems with other renewable units. Therefore, we can add further shallow geothermal and solar, bioenergy parameters to the abovementioned data.

These technical parameters describe the geothermal energy production opportunities well. Having informed about this geothermal profile, the potential consumers can make decisions related to investing in a geothermal project.

A feasibility study with this approach can help not only the investor to make an optimal decision related to their planned geothermal project, but this approach can also help the national and EU regulators to set up more integrated subsidies on renewable energy resources.

3. TWO MAIN GEOLOGICAL STRUCTURES IN HUNGARY AND THEIR POTENTIAL

The main direction of the enlargement of geothermal energy production is to find new reservoirs and determining thermal water bodies. There are two main types of prospective geological structures in the Pannonian Basin in Central Eastern Europe: sandstone reservoirs and fractured carbonate reservoirs.

3.1. Sandstone reservoirs in the Hungarian plain

The Pannonian Basin is one of the most prospective regions in Europe for producing geothermal energy. Hungary is just in the middle of this basin. Over the past one hundred years, intensive hydrocarbon exploration has taken place in the country. There are over 8,000 hydrocarbon wells drilled in this small country of a little over 93,000 square kilometers. There are a lot of geological data in the well files; the area of the country is well explored.

The following figure illustrates that thermal water wells (>1400) cover almost the whole area of Hungary.

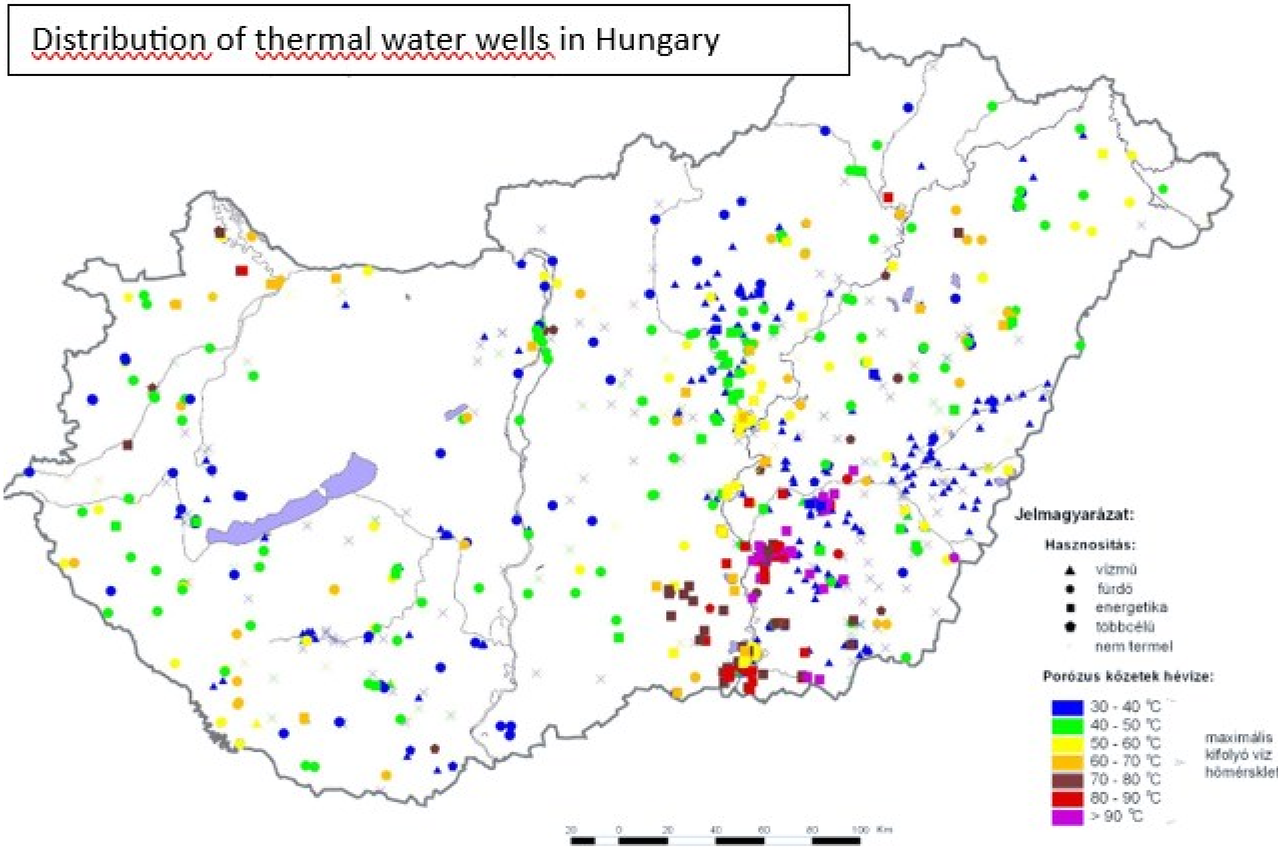

Figure 2: Distribution of thermal water wells in Hungary (based on the Hungarian Geological Survey)

The most widespread deep geothermal technology in Hungary is the thermal water production from porous sandstone sediment reservoirs, and there is a huge further potential in the Pannonian Basin. Based on the geological knowledge of the hydrocarbon exploration activity, there are a lot of well-known reservoirs and finding thermal water is the less risky. Unfortunately, 100% reinjection is a controversial technology.

The following figure presents the main Upper-Pannonian sedimentary formations in Southeastern Hungary.

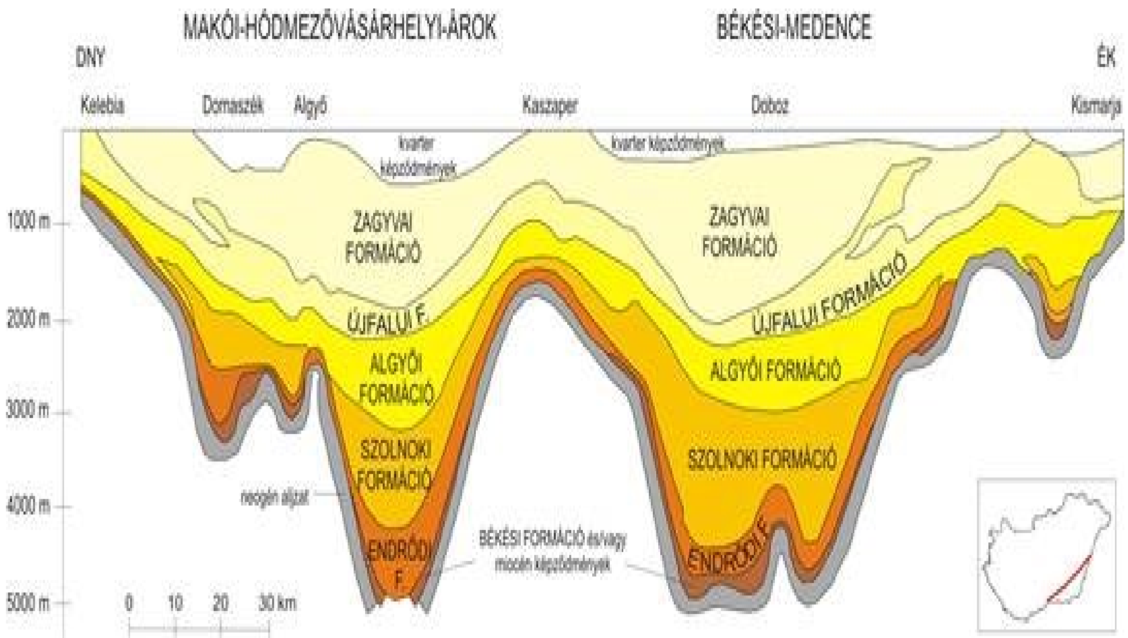

Figure 3: Cross section of the Pannonian Basin, in order to determine the appropriate formation

According to the long thermal water production experience, the Újfalui and Szolnoki formations are the two most prospective opportunities to explore new reservoirs. This concept makes the geological risk low. Naturally, during the exploration process we need a cautious evaluation process. The analysis after the drilling exploration is presented in the next figure.

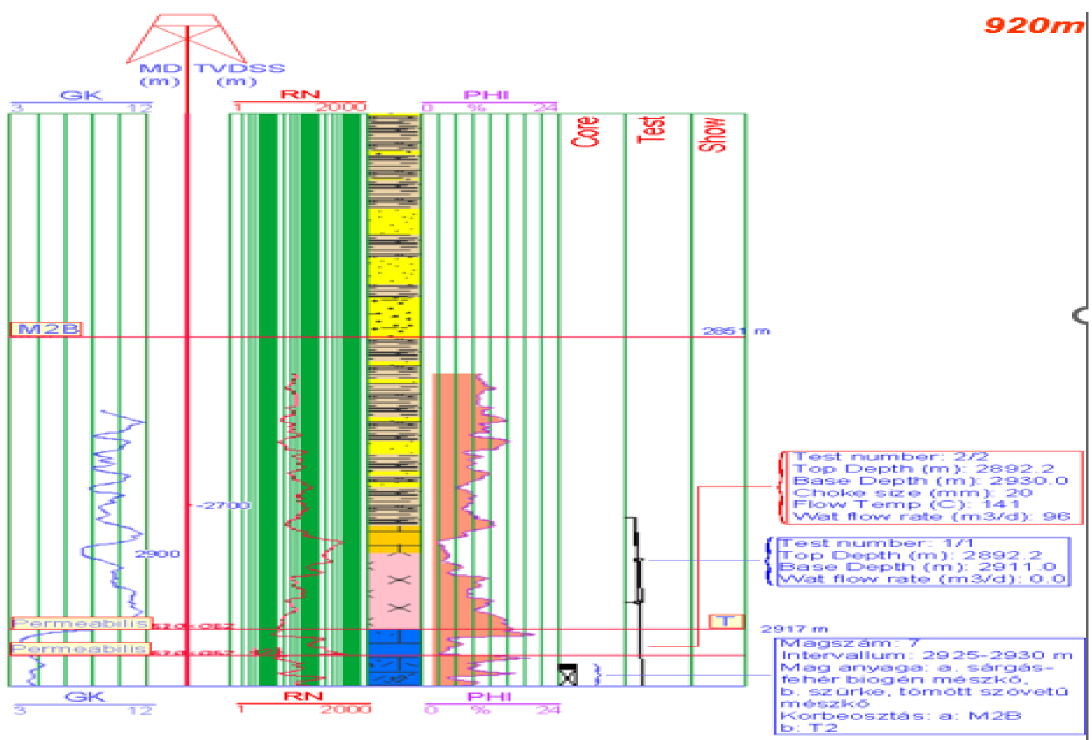

Figure 4: Determination of reservoir parameters

In Hungary, the majority of the thermal water bodies are in sandstone sediment areas in upper Pannonian formations. The main advantages of these formations are the low-level risk of the flow rate and the large water body. However, there are also disadvantages such as limited yield (max. 40 kg/s), the technical difficulties in reinjection, and water chemistry issues in deeper (>2 km) zones.

3.2 Fractured carbonate reservoirs

Geothermal energy production is a very traditional activity in Hungary. In the 20th century the geothermal energy sector was "the poor little brother" of the hydrocarbon industry. Simple water management concepts for well-known water bodies were enough to launch a deep geothermal project, and local geothermal exploration was not implemented. The hydrocarbon explorations proved a sufficient number of thermal water bodies. Often abandoned hydrocarbon wells were tested and set into operation to produce thermal water.

However, the easily achievable water bodies are already under exploitation and 100% reinjection is required; therefore, the same level of effort as in the hydrocarbon industry exploration is necessary in the case of geothermal projects.

Two decades ago, geophysical exploration was not used, but already it is an important part of the projects. In case of fractured carbonate reservoirs, it is a must. We often need three-dimensional models as well.

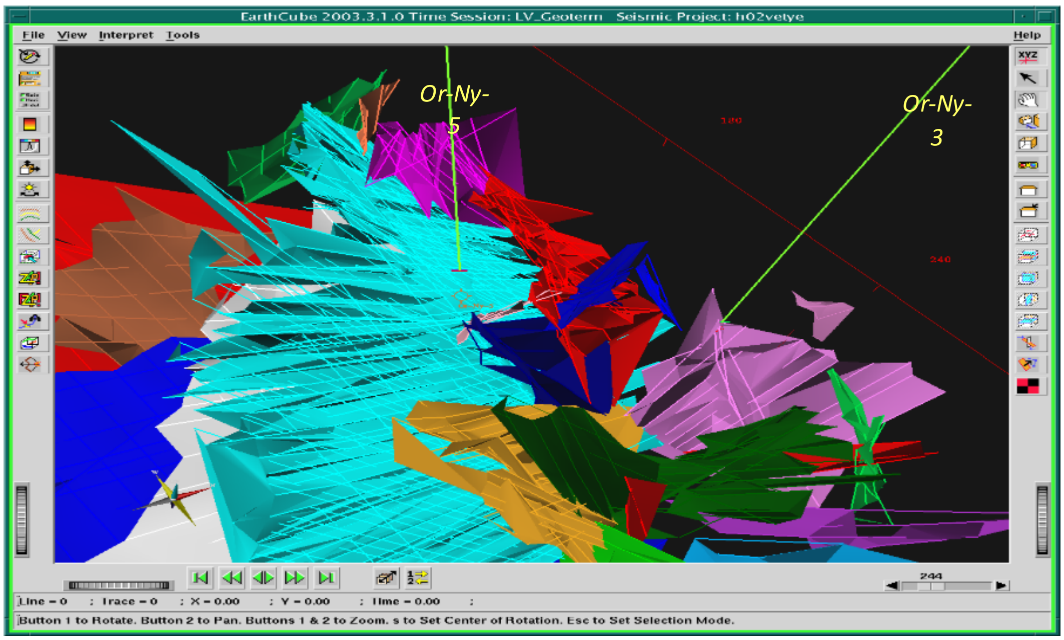

Figure 5: Three-dimensional model in fractured reservoirs

In case of fractured reservoirs, we are seeking fractures and it is necessary to use the most feasible methods, such as the analysis of cores or seismic section analysis as shown in the next figure.

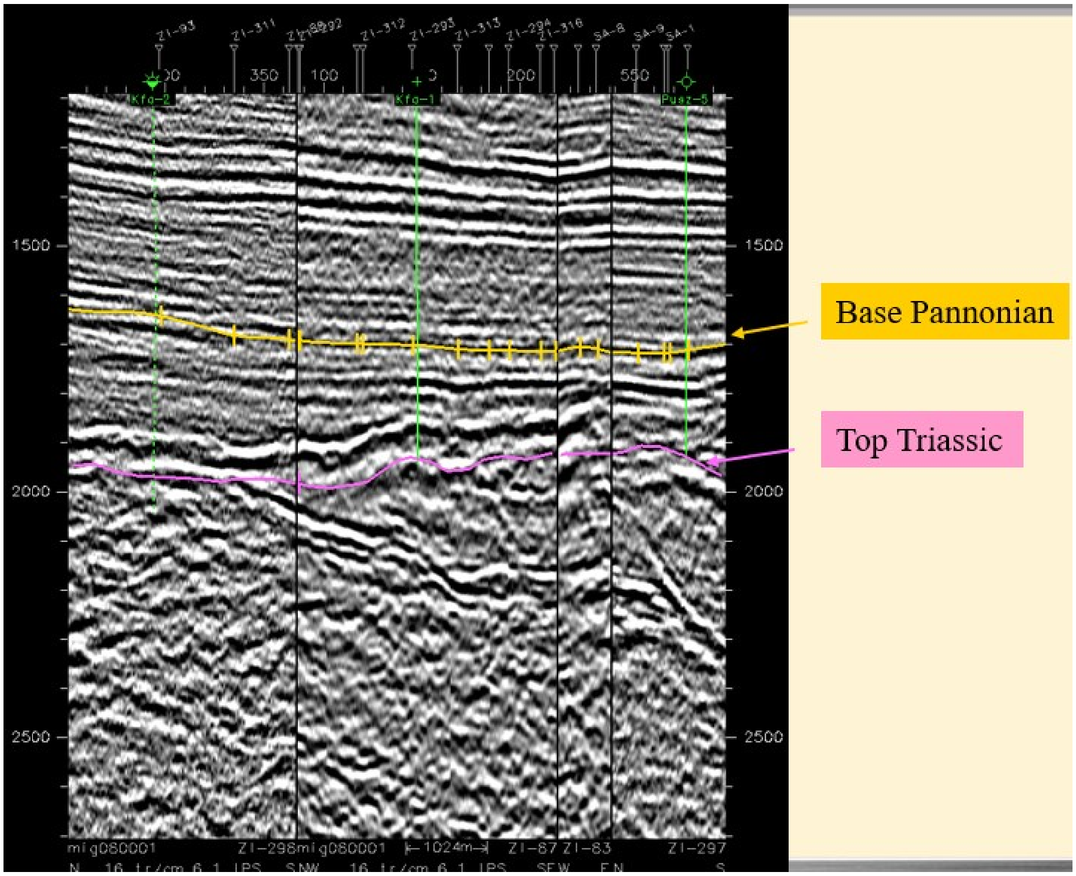

Figure 6: Seismic section analysis

Using whole exploration methods, we are able to create fracture maps and identify the thermal water holding structures. An important advantage of the fractured carbonate reservoirs is the highest achievable flow rate (>100 kg/s/well). A disadvantage is the higher geological risk on the yield.

3.3 Generating deep geothermal profile parameters in different geological structures

In order to achieve the ambitious objectives in the geothermal sector, we all have to leave behind the earlier comfortable approach and we need to improve all exploration techniques. In this case we can exploit the optimal quantity of geothermal and ambient (shallow) energy.

The following table provides a summary of the key technical parameters of the two main geothermal heat structures.

Main thermal water reservoirs	**Fractured carbonates**	**Porous sandstone sediments**
Area in Hungary	10,000 km^2	40,000 km^2
Thickness	80–100 m	200–300 m
Depth	> 2,500 m	800–2500 m
Porosity	< 5%	20 - 30%
Permeability	500–1,500 mD	500–1,500 mD
Project capacity	2 - 20 MW_{th}/doublet	1 - 6 MW_{th}/doublet

Table 1: Hungarian geothermal potential (on the basis of the Hungarian Geological Survey)

We can see from the table that while sandstone reservoirs ensure a large number of smaller projects, the fractured carbonate reservoirs ensure fewer, but larger geothermal units.

The most important part of the preparation of the geothermal profile is the hydrogeological calculation. It requires a lot of inputs but provides the key parameters that the next figure provides.

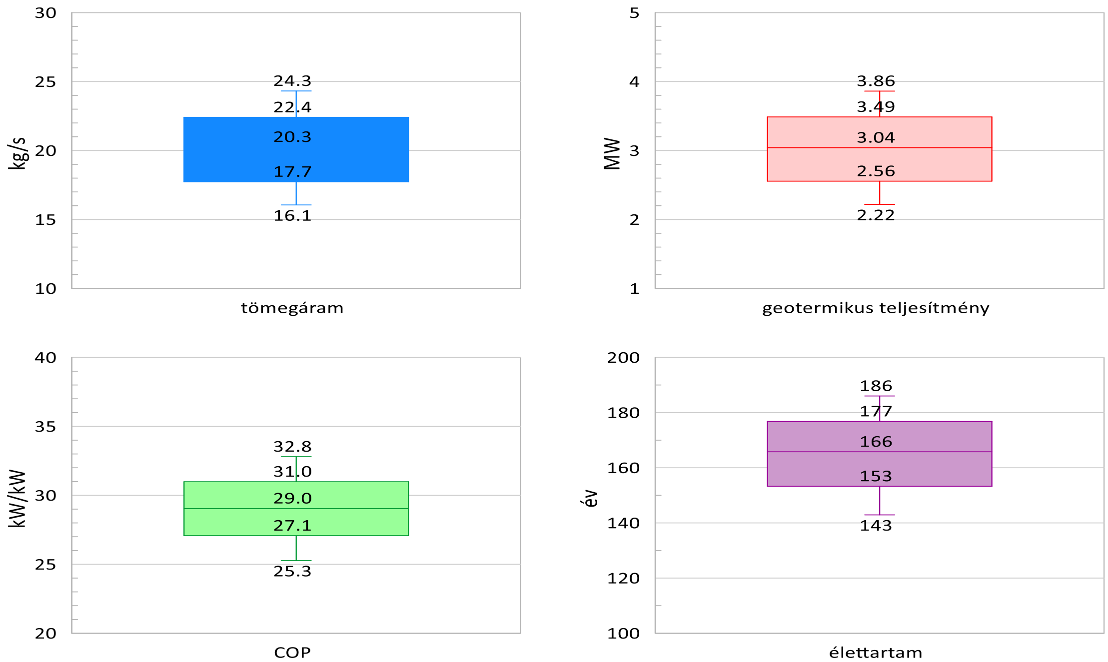

Figure 7: Key parameters of the geothermal profile of a Hungarian site after hydrogeological calculation

This calculation relates to one well-doublet. The left upper data is the flow rate on the well-head. The left lower parameter is the COP for deep geothermal, the produced heat per necessary electricity for pumping the thermal water. It doesn't include the electricity need of the complete surface facilities. The right upper data is the calculated heat power of the doublet. The right lower parameter is the calculated lifetime of the reservoir for heat supplying. Naturally, the lifetime of the wells is generally shorter.

4. GEOTHERMAL PROFILES IN THE PANNONIAN BASIN

The GeoInnovator Team prepared dozens of feasibility studies in Hungary in recent years. The key chapter of these studies was the geothermal profiles.

Based on the experience of the Team, the next table presents the main parameters and their ranges in Hungarian deep geothermal sites.

Parameter	Dimension	Quantity range in Hungary	Remark
Thermal water capacity	kg/s	5–120	In sandstones max. 40 kg/s
Thermal water temperature on well-head	°C	60–160	Flowing speed in production well influences it
Maximum heat capacity	MW_{th}	0.5–60	In sandstones max. 12 MW_{th} per doublet
Coefficient of performance	kW/kW	12–100	Depends on the electricity demand of surface facilities and reinjection
Lifetime of the reservoir	years	40-160	Depends on reinjection

Table 2: Main parameters and their ranges in Hungarian deep geothermal sites

These main parameters describe the geothermal profile of the site. On the basis of this deep geothermal profile, we can create also an integrated technology for this site, depending on the consumers' profile:

- Deep geothermal;
- Shallow geothermal;
- Deep + shallow (shallow suffices specific demand of the consumers);
- Geothermal + other renewable (solar, bio, etc.).

5. NEW TECHNICAL CHALLENGES IN DEVELOPING GEOTHERMAL PROJECTS IN HUNGARY

5.1 Tripling production by 2030

Geothermal energy production has long traditions in Hungary. The first geothermal energy focused direct heat production launched in the 19th century. Since then, all the easily achievable reservoirs have been explored and their majority has been under exploitation, many of them for a long time.

Therefore, we have to review all possible geothermal technologies and we have to seek new areas, new geological structures when we want to improve the geothermal energy production. We need to widen our geothermal scopes.

Hungarian geothermal energy production	Capacity, MW_{th}	Production TJ/y
2010	635	6,800
2020	1,024	10,700
2030 (est.)	3,000	33,000
New project capacities, 2020-30	1,976	22,300

Table 3: National ambition 2030 (based on Country Updates)

The planned almost 2 GW_{th} new capacity is rather large in this small country. However, the geothermal potential exists, so

- realistic projection and complex renewable energy strategy,
- intellectual and planning capacities,
- updated technologies and implementing human and technical capacities, as well as
- financing capacities are needed.

5.2 Heat and electricity market segmentation

The following sector development modelling is focusing on heat supply. Electricity production exists (one site of 3,35 MW_e) and there are technical plans to establish further sites, with a total 40–60 MW_e power in the long term. However, presently the plans are mainly connected to heat producing projects, when the well-head temperature is much over 100°C.

5.3 Integration of the shallow and deep geothermal heat production (complex field management)

The geothermal sector is already able to satisfy the complex demand of the consumers. The consumers often need more temperature level heat with different capacity and the demand is significantly changing in every season because of the continental climate.

This complex heat supply needs complex exploration of

- shallow (<500 m),
- deep (500–3,000 m) and
- ultra-deep (3,000–7,000 m.) geothermal ranges.

Taking into consideration that sandstone reservoirs sometimes have 5–15 water production layers and we can add 100, 200 and 400 m deep shallow heat production, we often face to very exciting challenges of a complex field management.

Nowadays an increasing number of deep geothermal projects have shallow geothermal facilities. And also, the deepest project under development includes the reutilization of a 7,000 m deep abandoned hydrocarbon well.

6. MODELLING THE GEOTHERMAL SECTOR DEVELOPMENT TO ACHIEVE THE HUNGARIAN NATIONAL OBJECTIVES (PROJECT TYPE MODELS)

Based on the approach above, we are already able to set up geothermal project types and a projection by 2030.

Project model types	Temperature °C	Average capacity, MW_{th}	New projects by 2030	Projection by 2030, MW_{th}
Small deep in sandstones	60	2 /doublet	70 doublets	140
Large deep in sandstones	110	6 /doublet	46 doublets	276
Small deep in fractures	80	5 /doublet	40 doublets	200
Large deep in fractures	120	20 /doublet	20 doublets	400
Residential shallow	60	12 kW	30,000	360
Small shallow	60	3	40	120
Large shallow	60	15	14	210
Small deep+large temp heat pumps	130	6	20	120
Large deep+large temp heat pumps	185	15	10	150
Total			316 + resindential	1976

Table 4: Project types and projection 2030

The interest is so large in the latest few years, that the GeoInnovator Team prepared feasibility study of every model type shown in the first column of Table 4.

In order to achieve this projection, the project generation, development and implementation processes are to be accelerated. According to the economy policy, in the European Union and also in Hungary as a member state, this decade the geothermal energy sector can receive subsidies. The permitting process is already updated; the time required to receive an implementation permit is reduced from 5–13 months to 2–3 months.

Deep geothermal:

- Larger drilling capacity is needed (the large majority can come from the hydrocarbon industry).
- Financial resources (more investors) are needed for the existing technical and financial models of municipalities, industrial and agricultural heat consumers. European Union estimations calculate with 50% private investment.

Shallow geothermal:

- Deeper wells are needed. So far, in Hungary the depth of the probes was max. 120 m. We need the higher capacity of 200–400 m deep well/probe planning and implementation.
- High temperature heat pumps are needed up to 130–185°C, with wide capacity range.

7. SUMMARY

The leaders of the European Union and Hungary have set an ambitious objective to triple the geothermal energy production between 2020 and 2030. It was mainly a top-down planning method.

This paper includes a bottom-up professional approach to verify this objective in Hungary, one of the leading deep geothermal energy production countries.

Firstly, the geothermal potential was presented. Both the geothermal gradient and existence of water is one of the best in Europe and appropriate to settle further deep and shallow geothermal sites. The two main geological formations are appropriate to supply the improved heat energy demand.

The used technologies were also addressed. It is important to develop technologies, mainly reinjection into sandstones and a structured technology utilization required. The preparation of geothermal profiles at a site strongly supports the optimization of the technologies used. This profile includes all necessary technical parameters of supplying the demand of consumers and also for financial and return calculations.

In this case, by evaluating the geothermal energy profiles of the potential new projects, to establish further 2 GW_{th} is realistic. However, the existence of financial resources and also the planning, implementing capacities strongly influence the deadline. We are now in 2024 and the year of 2030 is appallingly near to achieve our ambitious objectives.

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