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Developing Geothermal Projects Using Energy Demand Profiles in the Pannonian Basin

Attila Talamon[1], Attila Kujbus[2]

[1] Dr. Attila Talamon PhD, Ybl Miklós Faculty of Building Science, Óbuda University, H-1146, Budapest, Hungary, Thököly str. 74, e-mail: talamon.attila@ybl.uni-obuda.hu
[2] GeoInnovator Ltd. 100. Becsi str. H-1034 Budapest, Hungary, e-mail: akujbus@geoex.hu

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ABSTRACT

Due to its geography and geology, Hungary is a country rich in geothermal / thermal waters. There are more than 1,300 thermal water wells in Hungary, most of which are used for balneological purposes and form the basis of the spa culture. At the same time, the exploitation of thermal waters has a significant untapped potential in terms of energy: according to a recent strategical proposal, the energy extracted from it should triple by the end of the decade. In 2021, Hungary's total demand for natural gas was 11.2 billion m^3/year. Of this, the direct demand for natural gas for the building sector was 3.9 billion m^3/year. Reducing the use of natural gas is essential for our climate policy objective, as this sector is a major source of greenhouse gases that cause climate change. REPowerEU's plan is to rapidly reduce dependence on fossil fuels and to accelerate the green transition, on the basis of which the demand for renewables is large and widespread. GeoInnovator Kft. has developed and implemented a large number of geothermal projects. The needs of industrial and municipal customers have changed significantly in recent years. The analysis of customer profiles (district heating, town communal heating, industrial, agricultural, space heating, etc.) in the project development phase has become more important. This, together with the emergence of energy communities, has significantly changed the value of mixed business plans. In this paper–as part of field management and one key project strategy component–we present the best practice project developments of the GeoInnovator Team.

1. INTRODUCTION

In the last decade the driving forces in geothermal project development were the EU and the Hungarian Government, which co-financed the EU financial resources, development programs. In December 2022, the Hungarian Parliament adopted the amendment to the Mining Act to unlock the country's vast geothermal potential. According to the government's estimates, communicated by the Ministry of Energy, geothermal energy could substitute up to 1-1.5 billion cubic meters of natural gas by 2030. The Hungarian government also entrusted the licensing and supervision powers of geothermal energy production and utilization to the Supervisory Authority of Regulatory Affairs. The Pannonian Basin in Central Europe is one of the European areas with well-known positive geothermal anomaly, where the rich geothermal resources have been utilized mainly for direct use purposes for a long time. In Hungary the baseline (Nádor et al. 2016) was based on data from 2015 of about 850 active thermal water wells (those having an outflow temperature higher than 30 °C). Despite continuous efforts to merge and harmonize existing databases available at mining authorities, research institutes and water management organizations, the very high number of thermal water wells (around 800-1000), as well as the different registers tailored to their specific needs and purposes of the above organizations, still impede the establishment of a fully harmonized and up-to-date national geothermal database. In this paper we collected, assessed and presented data from 2017 (the latest available at the time of preparing the manuscript). Due to the heterogeneous datasets, some discrepancies (e.g. differences between actual flow rates and reported well data, lack of information on the real temperature gradients, abstracted amount of thermal water and type of utilization, changing data due to seasonal operations of wells, etc.) impede exact calculations. The reported numbers represent the author's own calculations based on data submitted by users and datasets from the various databases, and should be considered as best estimates. The reported numbers show realistic growth compared to the numbers of the previous country update reports (Tóth 2015, Nádor et al. 2016).

Table 1: Summary table of geothermal direct heat uses in Hungary (Tóth 2020)

Use	Installed capacity	Annual energy use
	MW	TJ/year
District heating	223.4	2.288
Individual space heating (communal, other than heat pumps)	77.2	299
Greenhouse heating	358	2.891
Agricultural drying	25	297
Industrial process heat	19	220
Balneology (bathing and swimming)	249	3.684
Geothermal heat pump (residential)	72	1.022
	1.023	10.701

2. BUILDING STOCK AND GENERATIONS OF DISTRICT HEATING SYSTEMS

In Hungary the dwelling stock consisted of 4,586,878 units on 1 January 2023 (HCSO 2024). According to final housing data of the Hungarian Central Statistical Office (HCSO) presented the results of the 2022 census, Hungary's housing stock now stands at 4.6 million dwellings, 21% of which are in Budapest, 52% in other towns, and 27% in villages. Nearly two-thirds of the occupied dwellings are of brick construction, while adobe and prefabricated concrete structures account for 13% each. Thirty-one percent of occupied dwellings have two bedrooms, 32 percent have three bedrooms, and 29 percent have four or more bedrooms. The average floor area of dwellings is 82 square meters, which is 4 square meters more than in 2011. The share of larger residential units continued to rise, with those with a floor area of more than 100 square meters accounting for 28 per cent. There are 237 occupants per 100 dwellings, 11 fewer than in 2011 (HCSO 2023).

98 percent of occupied dwellings have piped water. The public sewerage network has expanded significantly, while the proportion of households using domestic sewerage (septic tanks) has fallen to less than half. The number of households that also use electricity for heating has increased more than fivefold since the last census, to 357 thousand. The increasing importance of sustainability is reflected in the spread of modern energy solutions. There are 165 thousand dwellings in buildings with solar panels, 68 thousand dwellings use heat pumps for heating, and 28 thousand dwellings have solar collectors for hot water. In addition to the approximately 622,460 district-heated dwellings in Hungary, of the remaining 3.96 million dwellings, about 209,357 have building central heating, the rest have individual apartment or room heating.

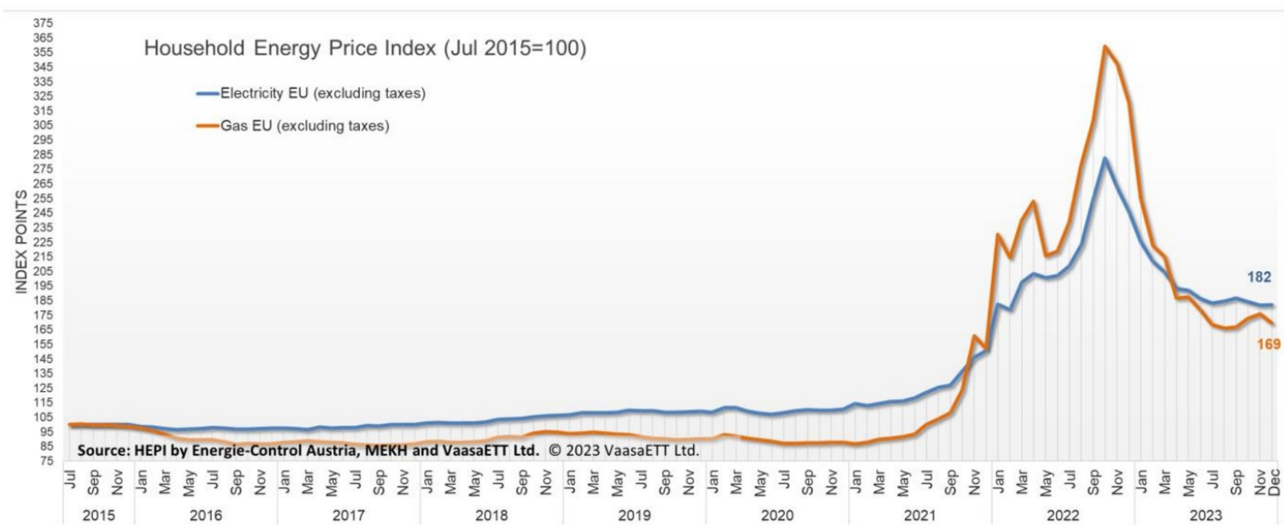

Figure 1: Evolution of residential energy and distribution prices excluding taxes in the EU, EU-28 values were used between July 2015 and January 2024 (MEKH et al. 2024)

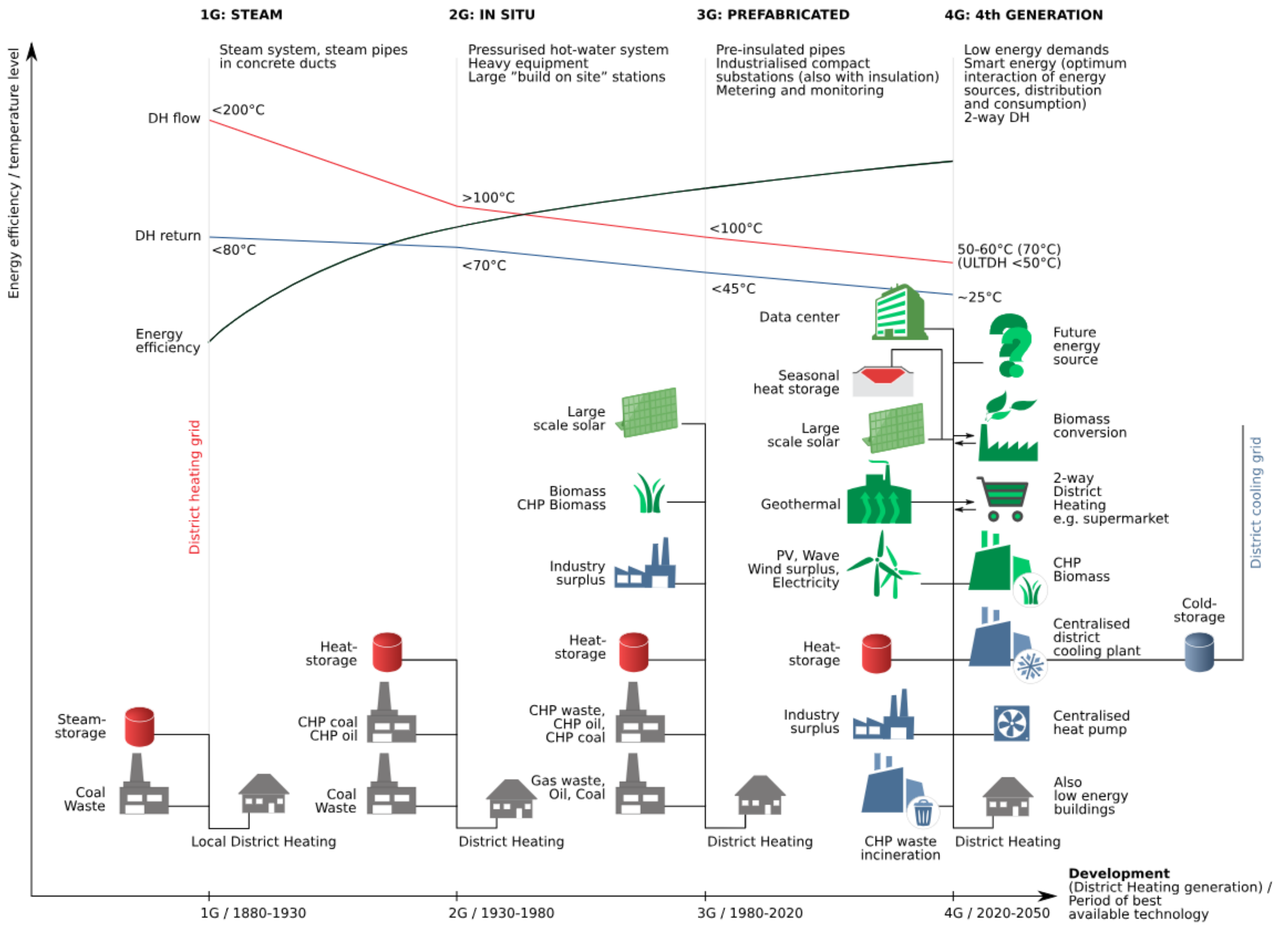

Figure 2: The development of DH networks throughout the years first presented in 2014 in Lund et al., 2014 but later updated in 2018 in Lund et al. 2018.

A joint data publication of the Hungarian Energy and Public Utility Regulatory Authority (MEKH) and the Professional Association of Hungarian District Heating Suppliers (MaTáSzSz) has been published, summarizing the operational data of the Hungarian district heating sector in 2021. The publication presents, among other things, the operating model of Hungarian district heating and the most important national district heating data. In Hungary, there are about 650 thousand apartments in 95 towns supplied by district heat. Approximately 80% of the thermal energy sold by district heating suppliers is consumed by households (for heating and hot water). District heating services are local public utility services. The participants of the sector are district heat suppliers, district heat generators (generally acting as traders) and district heat traders (those who do not generate heat, but purchase it and sell it to suppliers). In general, one district heat supplier operates in each town. There are, however, several towns with more than one district heat supplier holding an operating license, and there are companies that provide district heating service in more than one town. Those suppliers engaging in district heat generation as well (either via cogeneration and/or using furnaces) hold a generating license in the town supplied by the service. The majority of district heat suppliers owned by municipalities–in some cases, the district heat generator (a heating power plant holding an electricity generation license) have acquired shares in the respective service provider company. The operation of the district heat supplier is also facilitated for private companies through concession agreements in a few towns. A regulated price is applicable to the supply of households and public institutions, while the price for the rest of the consumers is dependent on bilateral agreements.

On 1 October 2022, Hungary had a population of 9.6 million and 4.6 million dwellings. The former is 3.4% less and the latter 4.3% more than in the previous census. By 2022, housing density has been further reduced. The average floor area of occupied dwellings continued to increase, a higher proportion of them had all modern conveniences compared to the 2011 census, and nearly three-quarters had wired internet in 2022.

Table 2: Occupied dwellings by heating fuels, 2022, in Hungary (HCSO 2023)

Area	One type of heating fuel				Multiple fuels			With district heating (district heating from a heating center)	Total
	Mains (piped) gas	Mains electricity	Firewood	Other heating fuel	Mains (piped) gas and mains electricity	Mains (piped) gas and firewood	Other heating fuels		
Country total	1,763,249	127,445	617,175	20,816	163,684	542,925	123,761	622,460	3,981,515

Table 3: Occupied dwellings by type of heating, 2022 in Hungary (HCSO 2023)

Territorial unit	Central heating				By room with convection gas heater, stove or other means	Total
	One dwelling heated by boiler	More dwellings heated by boiler	District heating (from a heat center)	Together		
Country total	1,997,100	209,357	622,460	2,828,917	1,152,598	3,981,515

Table 4: Dwellings and their occupants, density standard in Hungary (HCSO 2023)

Year	Dwelling			Occupants in dwellings	Occupants per 100 occupied dwellings
	occupied	unoccupied	total		
1949	2,424,892	41,622	2,466,514	9,021,346	372
1960	2,710,826	46,799	2,757,625	9,456,327	349
1970	3,034,383	83,713	3,118,096	9,925,115	327
1980	3,371,417	171,001	3,542,418	10,348,847	307
1990	3,607,688	245,600	3,853,288	10,119,256	280
2001	3,690,773	373,880	4,064,653	9,933,033	269
2011	3,912,429	477,873	4,390,302	9,687,682	248
2022	3,981,515	599,023	4,580,538	9,418,760	237

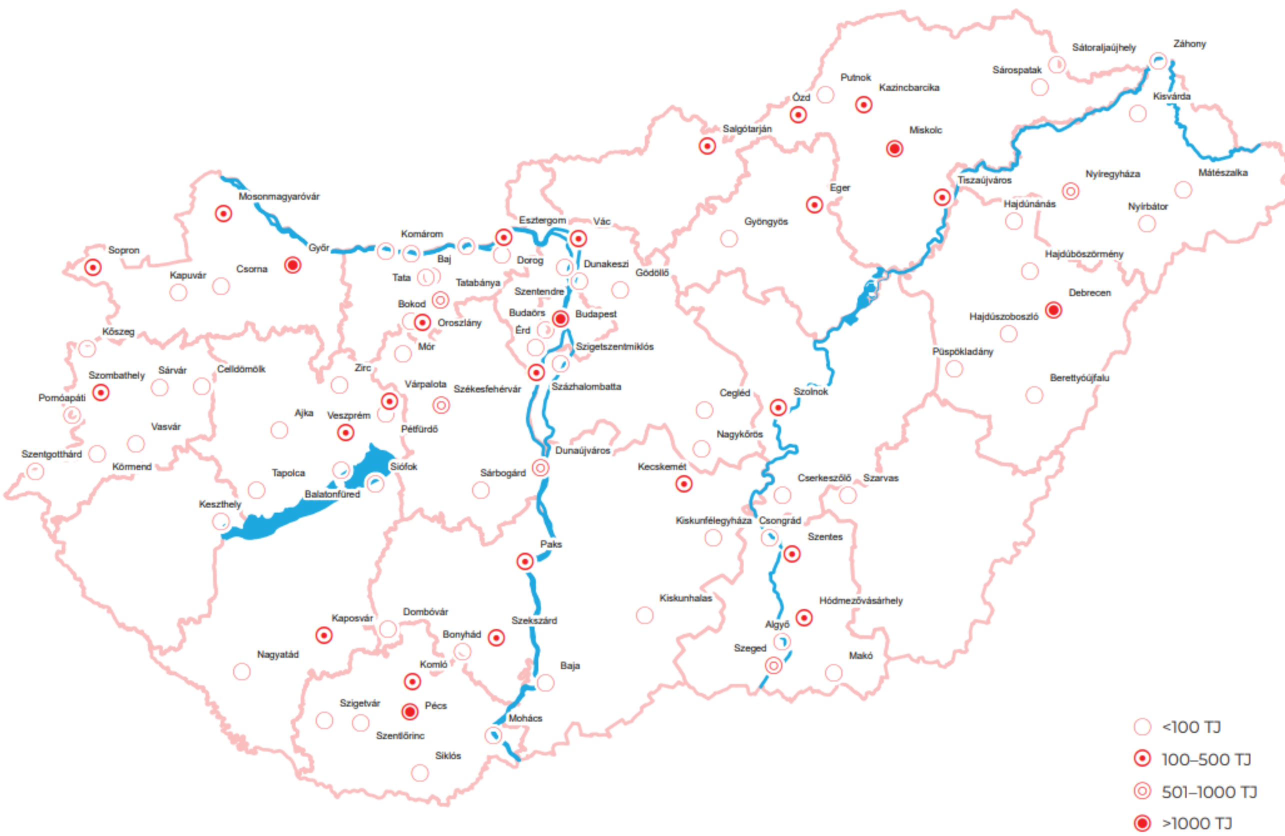

Figure 3: Settlements supplied with district heating in Hungary (MEKH et al. 2021)

In Hungary, more than one and a half million people live in around 650,000 district-heated homes, and the number of settlements with district heating will be nearly 100 in 2021. District heating is now the dominant energy source worldwide, not only because it is convenient, safe and competitively priced, but also because it is an increasingly important key factor for a sustainable environment. District heating plays a key role in the expansion of renewable energies, because district heating systems can accommodate almost any kind of energy carrier – making them, among other things, an almost indispensable player in the protection of air quality in large cities.

Data from a statistical publication just published by MEKH and MaTáSzSz show that the number of residential tariff payers continues to rise steadily and heat sales have also increased compared to 2020. A comparison of the energy sources used shows that natural gas accounts for almost 69% of the district heat produced, or 29,841 TJ, but biomass, geothermal energy and waste-to-energy are also important.

In 2021, 27,765 TJ of heat was sold by district heating companies, of which 20,835 TJ was for residential use and 6,929 TJ for other users (MEKH et al. 2021).

Table 5: Share of heat production technologies in district heat generation (MEKH et al. 2021)

PRODUCTION TECHNOLOGY	HEAT PRODUCTION (GJ)				
	2017	2018	2019	2020	2021
Gas engine	3,381,620	3,562,561	3,040,059	3,026,482	3,010,894
Other CHP technology	9,471,264	10,037,679	10,155,552	11,065,296	11,906,908
Direct heat technology	14,596,342	13,333,063	12,401,328	12,522,385	12,516,297
Geothermal	2,880,765	2,324,248	2,878,099	2,688,599	2,888,062
Other non-CHP technology	95,369	40,937	131,638	165,157	45,016

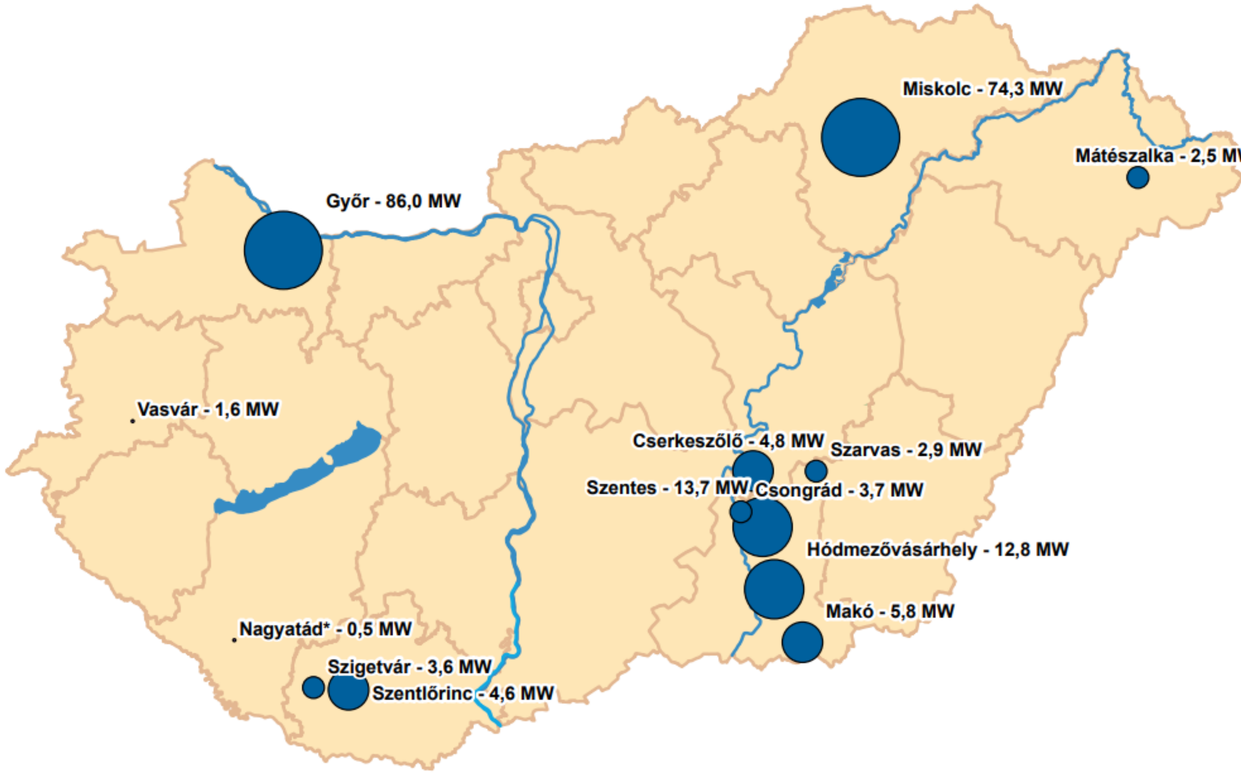

Figure 4: Available heating capacity of geothermal heat producers by settlement (MEKH et al. 2021)

In Hungary geothermal district-heating and thermal water heating cascade systems represent a major part of direct use available in 23 towns representing about 223.36 MW_{th} installed capacity and 635.66 GWh_{th}/year annual production. Major new projects have been established in Győr and Szeged. Individual space heating (mostly associated with spas) is available at nearly 40 locations representing an estimated installed capacity of about 77.2 MW_{th} and 83.1 GWh_{th}/year production. The agricultural sector is still a key player in direct use, especially in the southern part of Hungary, where heating of greenhouses and plastic tents have long traditions. These account for about of ~ 358 MWth installed capacity and ~ 803 GWh_{th}/year production. Balneology has historical traditions in Hungary, more than 250 wells yield thermal water, sometimes medicinal waters which represent a total installed capacity of 249.5 MW_{th} with an annual use of about 745.5 GWh_{th}/yr. The first Hungarian geothermal power plant project has been implemented in Tura, with a 3 MW_e capacity. The shallow geothermal sector unfortunately does not show real development and due to the lack of registers it is hard to assess the real number of ground source heat pumps (GSHPs). In the family house market and in other official and industrial applications the air-based heat pumps became dominant. The majority of the new applications are installed in new office buildings (Nádor et al. 2019, Tóth 2020).

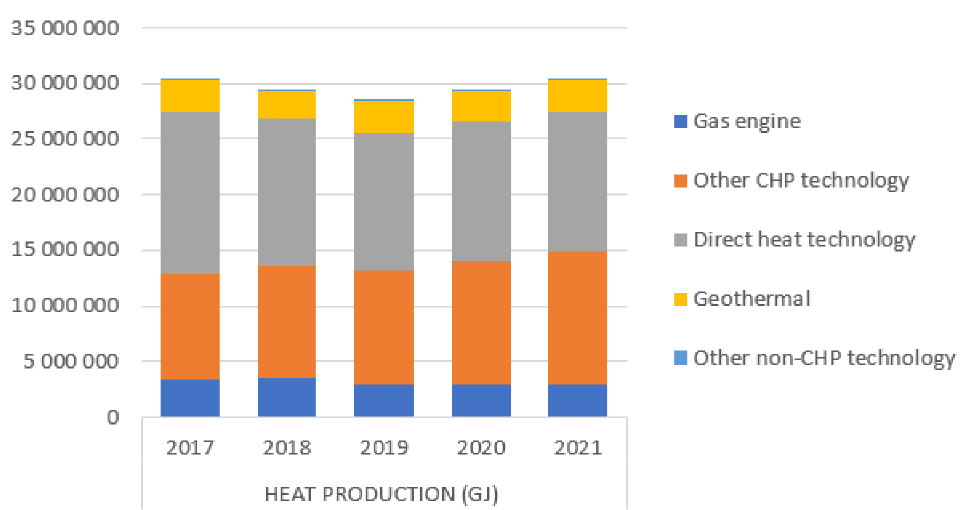

Figure 5: Share of heat production technologies in district heat generation (MEKH et al. 2021)

Table 6: Technical data of the facilities of district heat producing licensees (MEKH et al. 2021)

District heating project model types	Settlement	Production technologies	Installed thermal capacity [MW]
Big-scale porous sandstone sediments	Hódmezővásárhely	natural gas + geothermal	37.7
	Szentes	natural gas + geothermal	30.7
	Cserkeszőlő	geothermal	15.2
	Makó	geothermal	5.8
	Csongrád	geothermal	4.2
Small-scale porous sandstone sediments	Szarvas	geothermal	2.9
	Mátészalka	geothermal	2.5
Big-scale fractured carbonates	Győr	geothermal	51.4
	Miskolc	geothermal	48.2
	Győr	geothermal	30.0
	Miskolc	geothermal	30.0
Small-scale fractured carbonates	Szentlőrinc	natural gas + geothermal	4.6
	Szigetvár	geothermal	4.6
	Budapest	natural gas + solar collector + geothermal heat pump	2.8
	Nagyatád	natural gas + geothermal	2.5
	Vasvár	geothermal	1.6
			274.7

3. CREATING A PROJECT AND OPTIMALIZATION OF RENEWABLE ENERGY-BASED DISTRICT HEATING SYSTEMS

1. Preparation of the related geothermal energy profile
- Deep geothermal
- Shallow geothermal
- Deep + shallow (shallow suffices some specific demand of the consumers)
2. Preparation of the related consumers' profile
- District heating for the population
- Town heating for communal buildings
- Industrial for communal and industrial processes
3. Integrated utilization of the two profiles
- Project is created when the two profiles meet each other
- Not only the annual capacities are taken into consideration. but peak powers as well as seasonal and weekly changes
- Then we can prepare List of Facilities, calculate Cost of Investment and also Return on Investment.

Residential shallow technologies, as family houses' heat pump systems using underground heat of shallow reservoirs seem to be the most dynamically developing sector of geothermal energy utilization (Lund et al., 2010). In contrast with most geothermal energy utilization types, heat pump systems do not require absolutely good geothermal conditions, their installation and operation can be executed almost anywhere. The number of these systems shows exponential growth in many countries where encouraging factors such as proper national income, environmental awareness and availability of technological and economical tools exist. The projections till 2030 show Hungary's residential shallow systems as outstanding at more than 350 MW.

For optimized renewable geothermal technologies, an important economic aspect is to minimize the capex value of the equipment and, at the same time, to consider redundant operation. This is best optimized by examining monovalent and bivalent systems. A monovalent system is one where the heat pump is able to cover the whole heating load of the property throughout the year without the support of any other heat source, such as a boiler. A bivalent system is one where the heat pump is combined with an additional or existing heat source, such as a boiler. This would be the case where during colder spells of weather, when the property's heat loss would be greater, the heat pump would not be able to match the whole heating load of the property due to its lower flow temperature, as could be the case with a lot of older properties, and therefore require the additional input of the boiler to increase the flow temperature to match the heating load of that property.

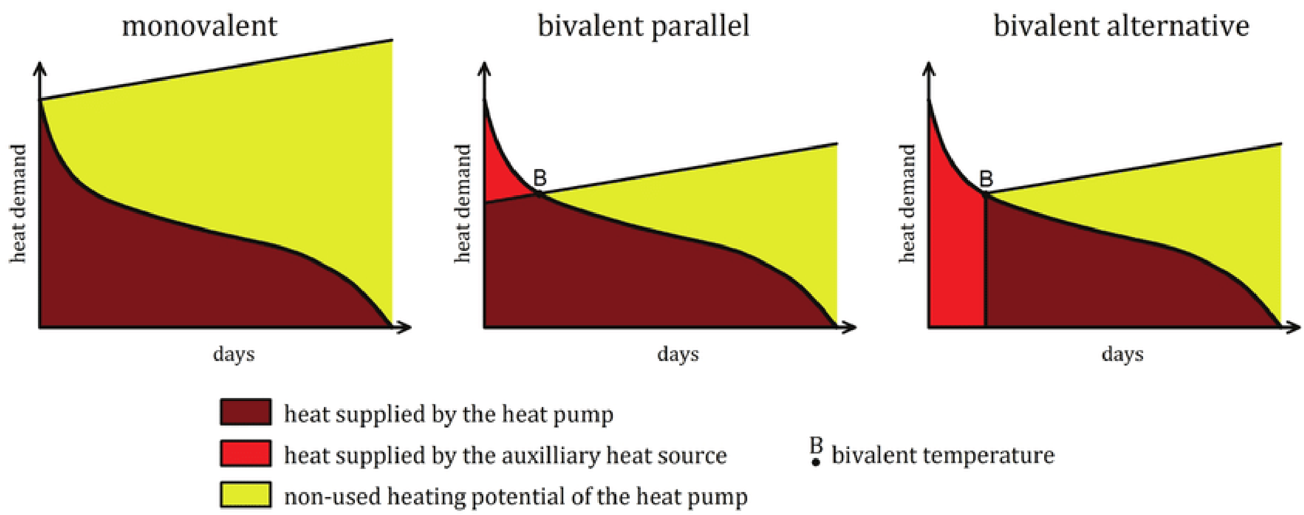

Figure 6: optimization of the consumer profile and the primary heating energy generation (Buday 2014)

5. GEOTHEMAL PROFILE VS. CONSUMERS' PROFILE IN THE PANNONIAN BASIN

The average geothermal gradient in Hungary is 5 °C/100 m, which is about one and a half times the world average. The measured heat flux values are also high: 2001 drillings deeper than 1 km have been measurements taken at depths of more than 90 mW/m^2, with maximum values (120-140 mW/m^2) in the southern part of the country and minimum values (20-40 mW/m^2) in karst water seepage areas (Lenkey et al. 2021), while the European continent, the average value is 60 mW/m^2 (Dövényi et al. 1988). At the surface, the mean temperature is about 10 °C, and with the geothermal gradient mentioned above, the average temperature at 1 km depth is 60 °C, and at 2 km depth 110 °C in rocks and the water stored in their pores. It is also because good aquifers have a maximum depth of 2.5 km. Here temperatures can reach 130-150 °C (Szanyi et al. 2009, Lenkey et al. 2021).

Water moving upward in thermal water wells cools down during this time, so the water temperature at the surface rarely exceeds 100 °C. This temperature and potential is also suitable for large-scale district heating systems (Szanyi et al. 2021).

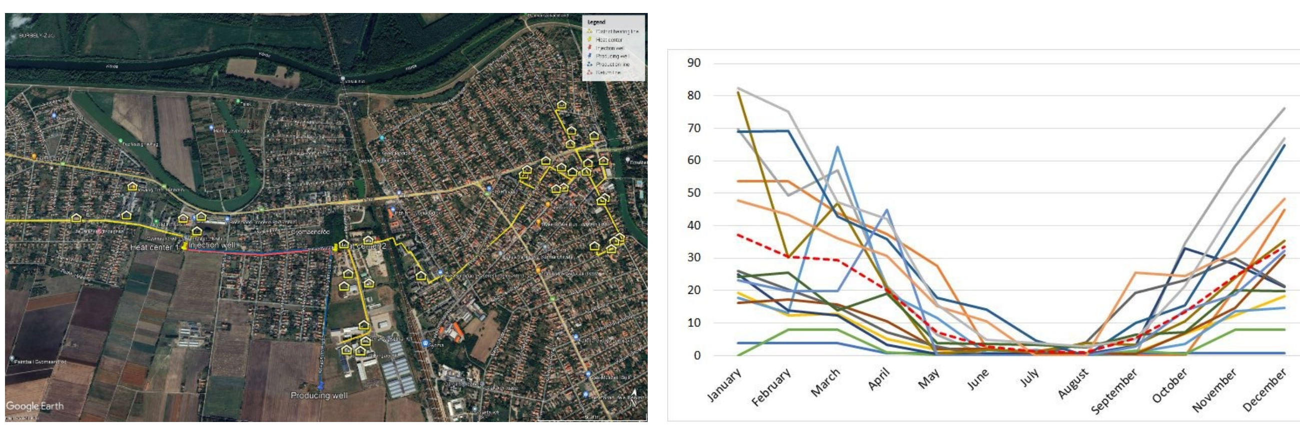

Figure 7: Consumers' profile and heat supply in a municipality in Hungary

6. NEW CHALLENGES IN DEVELOPING GEOTHERMAL DISTRICT HEATING PROJECTS IN HUNGARY

New winds are blowing in EU energy policy. While the energy supply system and infrastructure used to be one-way, unidirectional, today it has become multi-directional, creating new opportunities but also challenges. On the one hand, consumers have become producers, and among these producer-consumers there is a need to share the energy they produce but do not consume. This type of cooperation has given rise to the energy community.

One of the goals of the EU's Energy Strategy is to achieve an extraordinary expansion of energy communities, which could also benefit geothermal project development. The Hungarian Energy Strategy aims to have at least one energy community in each of Hungary's 197 districts by 2030. In reality, an even bigger breakthrough is expected, with energy communities in the thousands depending on the regulation. The increase in energy costs will further encourage the creation of energy communities at the user level, as members will face lower electricity costs where appropriate. In the future, the European Union will support these objectives through grants and soft loan products.

Project generation, development and implementation are to be accelerated. In the previous decade, the utilization of geothermal energy doubled in Hungary, and in this decade the utilization has to be at least tripled. The interest is so large in the latest few years, that GeoInnovator Team prepared feasibility studies of every model type shown**.**

In order to achieve this projection, the project generation, development and implementation processes are to be accelerated. According to the economic 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; to receiving time of an implementation permit is reduced from 5–13 months to 2–3 months.

Deep geothermal:

- Larger drilling capacity is needed (the large majority can arrive 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.

Table 7: Projection of installed thermal capacity 2030 in Hungary (MEKH et al. 2021)

District heating project model types	Present pieces	Present installed thermal capacity [MW]
Big-scale porous sandstone sediments	5	93.53
Small-scale porous sandstone sediments	2	5.445
Big-scale fractured carbonates	4	159.64
Small-scale fractured carbonates	5	16.1
	16	274.7 MW

District heating project model types	Projection pieces 2030	Projection of installed thermal capacity 2030 [MW]	Newly installed thermal capacity present - 2030 [MW]
Big-scale porous sandstone sediments	20	360.53	267
Small-scale porous sandstone sediments	8	20.445	15
Big-scale fractured carbonates	16	599.64	440
Small-scale fractured carbonates	20	59.1	43
	64	1,039.7 MW	765 MW

7. CONCLUSION

Achieving the EU's 2030 targets will require a large amount of new geothermal capacity to be integrated into the system in Hungary. Around 2000 MW of new capacity will need to be built, the expected composition of which is shown in Table 8. In balneology, several major existing spa developments have been launched in Hungary, involving the renewal of existing spas or the redevelopment of a long-closed but soon to be renovated facility. No major new-build spa developments are expected to appear in the coming years. The 40% of new geothermal capacity is expected in the district heating sector. About 30% of new geothermal capacity is expected in greenhouse heating, agricultural drying, balneology and industrial process heat sector. Around 30% of new geothermal capacity is expected in heap pumps and individual space heating sector.

Although Hungary has favorable natural conditions for geothermal energy production, production and utilization have lagged behind expectations. Nevertheless, there are promising signs. For the Hungarian geothermal industry to progress, it requires a well-considered energy policy together with a framework of supportive legal and financial conditions. REPowerEU’s plan is to rapidly reduce dependence on fossil fuels and to accelerate the green transition, on the basis of which the demand for renewables is large and widespread. GeoInnovator Kft. has developed and implemented a large number of geothermal projects. The needs of industrial and municipal customers have changed significantly in recent years. The analysis of customer profiles (district heating, town communal heating, industrial, agricultural, space heating, etc.) in the project development phase has become more important. This, together with the emergence of energy communities, has significantly changed the value of mixed business plans.

Table 8: Summary table of geothermal direct heat uses in Hungary (Tóth 2020)

<table>
<tr><th rowspan="2">Use</th><th>Present installed capacity</th><th>Projected capacity 2030</th></tr>
<tr><th>MW</th><th>MW</th></tr>
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<tr><td></td><td>1.023</td><td>3.000</td></tr>
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Figure 9: District heating sector data of certain European countries - Data collected by the Association of Hungarian District Heating Enterprises from the countries below.

Values in 2021			Austria	Czech Republic	Estonia	Finland	Lithuania	Hungary	Serbia	Slovenia
Share of energy sources used to generate district heating	Natural gas	%	34.9	21.3	20.2	10.0	23.5	68.9	79.6	31.5
	Crude oil and crude oil products	%	2.8	0.2	1.9	3.0	1.6	0.1	5.1	0.6
	Coal	%	5.3	46.5	0.0	12.0	0.1	0.1	13.8	46.9
	Biomass	%	47.9	14.7	55.3	36.0	66.7	12.7	1.5	17.3
	Geothermal energy	%	0.0	0.1	0.0	0.0	0.0	**10.9**	0.0	0.1
	Other renewable energy sources	%	1.1	2.7	0.2	24.0	0.7	0.1	0.0	0.0
	Waste	%	7.3	5.2	8.2	5.0	6.3	5.4	0.0	2.6
	Other	%	0.9	9.3	14.5	10.0	1.1	1.8	0.0	1.0
Network loss		%	n.a.	8.0	13.1	9.0	13.6	11.4	12.0	14.0
Network loss		TJ	n.a.	12.784	2.414	13.881	4.666	3.676	2.884	1.321
Total installed district heating capacity		MW_{th}	n.a.	39.043	n.a.	23.677	7.800	7.905	n.a.	2.155
Trench length of district heating pipeline system		km	n.a.	n.a.	1.600	16.051	2.980	1.964	n.a.	924
District heat sales in residential sector		TJ	n.a.	36.758	n.a.	60.961	21.060	20.836	17.155	3.427
Total district heat sales		TJ	n.a.	84.171	16.059	126.718	29.340	27.765	21.179	7.492
Number of dwellings connected to district heating		thous-and	n.a.	1.700	14.39	1.227	n.a.	663	651	100