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Municipal Geothermal Systems: Evaluation of Three Hungarian Cases

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Abstract. Geothermal energy holds great potential for a sustainable future, as it is a clean and weather-independent form of energy. In addition to energy production, it can also serve the population of a region through direct use. In this paper, three municipal geothermal systems (Szarvas, Nagyszénás, Békéscsaba) in the same Hungarian region which have been recently installed or expanded are presented and analysed. Here, the direct usage of geothermal energy for heating purposes is a very important issue. The three systems show several differences and to some extent face different challenges in the various phases of the projects. Particular attention has been paid to engineering solutions to the problems that arise. The challenges, such as technical difficulties during installation, maintenance difficulties, or problems arising during operation are introduced. The strengths, weaknesses, opportunities, and threats of similar geothermal systems were summarized, based on the relevant literature. These points were evaluated by their appearance and characteristics in the examined systems. This study aims to provide insights, based on recently gained experiences, into geothermal projects, thus providing feedback and practical information for researchers and practitioners.

Keywords: Geothermal System, Geothermal Energy Extraction, Geothermal Well, Engineering Challenges, Case Study, Scaling

1. Introduction

There is a huge amount of geothermal energy potentially available on Earth that could make a significant contribution to mitigating climate change [1]. Geothermal energy is one form of renewable energy with many advantages, such as reliability, huge untapped potential, availability, and a wide range of possible applications [2]. It is independent of the climate, but is strongly dependent on the underlying local, global, and hydrological frameworks [3]. It originates from Earth's heat, which has a temperature of 5,500 °C in its centre, similarly to the Sun's surface temperature level [4].

Geothermal energy is mostly utilized for direct heating/cooling purposes or, occasionally, for electricity generation. According to the International Energy Agency, renewables will overtake coal in early 2025 to become the largest energy source for electricity generation globally [5]. Within electricity production, the share of geothermal energy is still lower than 1% [6]. The developments in the direct use of geothermal heat represent a 6% projected increase in the heat consumption of buildings worldwide [5]. Globally, the efficiency average of electricity generation for geothermal plants is 12% [7], which is lower than that for hydro power plants (up to 90% [8]) and for wind (approximately 40% [9]), but similar to the values for solar power systems (7-25% [10]). Although geothermal power systems are considered to be environmentally friendly and sustainable, various possible environmental impacts are listed in the literature, such as land utilization, geological risks, workers' health and biodiversity impacts, polluted wastewater, solid waste, air pollutant emissions, thermal pollution, noise, and waste heat [11].

Due to technological development in the geothermal sector, reaching deeper subsurface layers and extracting heat with higher temperatures has become possible [12]. The temperature, which typically varies from 20 °C to 180 °C, strongly affects the possible utilization. Lower-temperature working fluid is applied as hot water for low-grade temperature applications such as heat-pump-powered systems, while high temperatures are utilized as saturated steam in binary plants and drying processors [13]. Multi-faceted systems aim to simultaneously utilize deep, medium-deep, and shallow geothermal resources for district heating and cooling, making it a promising future development area [14]. The geothermal form of natural energy has several other possible applications, such as providing warm or cold water for agriculture [15], and balneological usage [12], [16], [17].

There is a lot of potential in geothermal energy, but it also faces technical and economic challenges, which must be handled to increase future utilization. As geothermal systems are mostly exposed to very aggressive media (high temperature, salt-rich fluid, etc.) extensive corrosion of the metallic parts and scaling are typical issues that need to be dealt with [18], [19]. In many cases, increased pressure levels and more expensive maintenance are required [20]. Paints and coatings are also preferred solutions [21], [22], alongside inhibitors [23]–[25], to mitigate such difficulties.

This article focuses on the challenges faced, based on recently gained experiences of installed geothermal systems. All systems are in the southeastern part of Hungary, which has a very good geothermal potential [26]–[29] with high geothermal gradients (approximately 50 °C/km) [30]. Altogether, three municipal geothermal systems are involved in the investigation, each with different characteristics, but to some extent facing similar difficulties. Utilizing this manageable source of energy, the implemented geothermal systems, are analysed in this work, with special emphasis on the engineering challenges. The primary goal of this case study is to share important information and engineering insights gained from the geothermal projects with the members of the scientific community.

2. Materials and Methods

2.1. Study Area

Recently, three municipalities in Békés County (Hungary) have made significant progress in using renewable energy sources to replace natural gas-based heating systems. Thus, municipal facilities and companies have been given the opportunity to switch to alternative geothermal heating systems. Compared to other parts of the country, Békés county has particularly good geothermal potential, based on the temperature of the extractable thermal water [26]. All the investigated cases are open-loop systems, as thermal groundwater is pumped to heat exchangers and then the used water is discharged into injection wells or surface water bodies.

- Szarvas (approximately 14,000 inhabitants):

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Two production wells were established by the municipality of Szarvas in 1986. The geothermal heating system of the town was built on these thermal wells in several steps. The used and cooled thermal water is discharged into a surface watercourse; no injection wells were installed. For further cooling of the thermal water used, an open-surface reservoir is used before discharging to the watercourse. Environmental requirements are met by ensuring a favourable dilution rate.

- Nagyszénás (approx. 5,000 inhabitants):

In 2017, the municipality of Nagyszénás completed the rehabilitation of an existing production well and the installation of one injection well to recirculate the used water. The secondary use of the cooled water (waste heat) returned after the heating system is to ensure the operation of the public bath in the centre of the municipality with a highly economical technical solution.

- Békéscsaba (approx. 55,000 inhabitants):

In Békéscsaba, a completely new greenfield investment project started in 2021 to build a geothermal heating system. The project included the construction of one geothermal production well and two geothermal injection wells in the city centre, capable of handling the entire volume of extracted thermal water. Furthermore, an insulated geothermal heat pipeline was laid in the ground connecting the wells.SWOT analysis of geothermal systems

SWOT analysis is a widely used technique to evaluate geothermal systems [31]–[34]. It highlights their strengths, weaknesses, opportunities, and threats. The typical aspects of the SWOT analysis result for geothermal systems are summarized in Figure 1. The elements of the general SWOT analysis that appeared in the examined cases and newly identified components are presented in the results section.

S	Non-intermittent resource, no weather dependency Lower maintenance cost compared to conventional systems Long service life Small land usage Minor environmental issues	INTERNAL
W	High initial investment cost Requires professional knowledge for installation, maintenance, and production Lower level of technological maturity Inadequate economic assessments	
O	Diversification of the energy mix Direct uses are possible Funding supports Exploitation of geothermal potential in volcanic areas	EXTERNAL
T	Imprudence in energy policy Commercial competition with other renewable resources Incorrect dimensioning of the systems	

Figure 1. SWOT analysis of geothermal systems [15], [31]–[34]

3. Results

3.1. The geothermal system of Szarvas

In the settlement of Szarvas, which also has very attractive geothermal potential within the region, two thermal wells were established in 1986 with state support, originally for extraction and injection. When the geothermal energy supply was started in 1987, only a few heat consumers located close to the wells were served. This resulted in the utilization of just a small fraction (approx. 20%) of the available capacity. It further deteriorated when the largest consumer campsite disconnected from the system. The injection was not built because of technical difficulties, and the system operated for years under these circumstances. Then the local authority decided to install and operate a geothermal heating system in the town. After obtaining the necessary water rights and environmental permits, the system was designed and built. The project was financed by a World Bank loan and the operation was started in 1994. Since 2004 the system has been operated by the municipality's own company. Further modernization and expansion were carried out in 2014-15, based on an EU Operational Programme, connecting new consumers to the geothermal system.

In 2017, the owner municipality won another tender for non-refundable, 100% subsidies under the Széchenyi 2020 program. Within the framework of the project, two buildings of the Mayor's Office, the building of the general practitioner's office, the Public Employment Centre and the Public Safety Centre were connected to the existing thermal system. Furthermore, in the second phase of the geothermal system development, the commissioning of the second production well was completed. For the buildings connected to the system, the construction of underground disconnection manholes and lines established in public areas, and the placement of the shut-off fittings necessary for sectioning, were realized. The pipes are made of special corrosion-resistant materials and are insulated. Wall penetrations and mechanical control and sectioning facilities were also provided in the existing heat centre. As part of the investment, after the construction of the system connection-pipeline system, the mechanical design of the institutional substations was also carried out so that they could receive the thermal water. The primary goal of the project was to ensure that the thermal energy from the renewable energy source is used to heat the buildings managed by the municipality connected to the system, reducing, or completely replacing gas consumption in favourable weather conditions. Institutions equipped with additional solar capacity can also provide hot water for domestic use outside the heating season without the use of piped natural gas.

In 2023, another expansion of the geothermal system was carried out by the town. The Hungarian Evangelical Church launched a tender among its institutions to counter the drastic increase in energy prices and its consequences. The Old Church Charity Service in Szarvas was one of the winners; therefore several modernization works were carried out, including a connection to the local geothermal system. The location of the energy investment series for geothermal energy was the central building, which is partly protected as a historical monument. The investment demonstrates that economic operators can also benefit from the advantages of the urban system where appropriate. The social institution's outdated, high-capacity gas boilers were fully replaced by thermal heating, and the system was successfully commissioned for the start of the 2023 autumn heating season. The parallel installation

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of a 50kW solar photovoltaic system was also completed to provide hot water for domestic use outside the heating season when the geothermal energy supply is suspended. The project was finished in November 2023, without affecting the institution's operations more than necessary.

A major advantage of the system in Szarvas is that the temperature of the water flowing through the entire city system is high, with temperatures of 78-85 °C measured at the institutional sub-centres. If the heat dissipation inside the buildings is also done with modern controls and devices, the system can work with very good efficiency.

3.2. The geothermal system of Nagyszénás

The thermal water of Nagyszénás is 95 °C at the surface outlet, which was used by the local spa until it was closed in 1999. After its closure, the thermal water flowed without utilization for 15 years. In 2014, a project to exploit thermal water was started, resulting in the installation of a system that uses the extracted thermal energy to serve the heating needs of municipal buildings through heat exchangers [35].

One recent development belongs to the previously mentioned Old Church Charity Service in Szarvas, as it has a local institution in Nagyszénás. The institution had already signed a letter of intent for the connection to the local geothermal system in 2015. In 2022, due to the Russian-Ukraine war electricity prices went up very rapidly. A project aiming to reduce energy costs was completed in 2022, involving the installation of geothermal heating connections and mechanical parts. By January 2023, the replacement of gas heating with geothermal heating was completed. The system supplies water at a temperature of 75-80 °C to the 350kW liquid-liquid heat exchanger installed in the heat centre of the institution. The previously operated 300kW gas boiler capacity was replaced. Further heating system upgrades followed to optimize heat dissipation.

There is still a lot of potential in the geothermal system of Nagyszénás [35]:

- Further thermal water utilization by adding new circuits in the centre of the municipality to connect more institutions and multi-apartment residential buildings to the system.
- Another new thermal circuit to connect horticultural and other companies (potential 5,000 m^2 greenhouse area).
- Improvement of the public bath, based on the therapeutic thermal water. Construction of an indoor 25-meter swimming pool.
- Construction of a medical centre based on thermal water, and development of a campsite in the public bath area.
- Except for the heating season, the gas content of the extracted thermal water could be used to generate electricity using gas engines. There are currently two 80kW gas boilers in operation to burn the captured gas, which is trapped by the gas extraction system and stored in a 20 m^3 storage tank. During the heating season, 100% of the gas can be used for heating.

3.3. The geothermal system of Békéscsaba

In 2021, the municipality of Békéscsaba started a project to build a geothermal district heating system supported within the framework of the Modern Cities Program. The aim was to replace the natural gas heating systems of public institutions and sports facilities (municipal sports hall, volleyball hall, gymnastics club, and local football stadium) with a modern 5.3 MW geothermal district heating system.

The utilization of the thermal water located under the city of Békéscsaba had been planned for a long time, but it was only in 2021 that the appropriate financial resources became available thanks to the Modern Cities Program. The geothermal system helps to heat a total of 16 properties, so very significant savings can be achieved in the operation of these public buildings.

The system consists of one production well and two injection wells, which are connected by the geothermal pipeline system. According to the plans, the wells were established with a base depth of 2,500 meters. The two injection wells are capable of dealing with the total volume of extracted thermal water. The heat is extracted from the thermal water in the thermal centre next to the sports hall, where the cooled water is returned to the aquifers via two injection wells. The extracted heat from the heat centre is piped through separate district heating pipes to several municipal institutions. It is interesting to note that the connection for the heating of the grass surface of the centre field of the football stadium was also built. The first stage of the construction was started in May 2021, with the handover of the site, and it was completed in autumn 2023. The project aimed to promote sustainability and energy efficiency in the city of Békéscsaba through the implementation of a geothermal heat recovery system. By using geothermal energy, the city's heat-intensive and energy-demanding facilities can be heated with environmentally friendly, green energy, avoiding the burning of significant amounts of hydrocarbon fuels and greenhouse gas emissions, thus protecting both the local and global environment.

Geothermal system	Depth of the wells [m]	Well-head temperature [^{o}C]
Szarvas	2,200	97
Nagyszénás	3,027*	95
Békéscsaba	2,500	92

Table 1. Well-head temperature and depth of the wells

**The depth of the hydrocarbon exploration well was 3,027 meters; it is operating with a subsequent collapse-type filter system between 1,800 and 2,200 meters*

3.4. Operational challenges and solutions

3.4.1. Szarvas

The injection well designed for the system failed because it could not pump the extracted water back into the aquifer; therefore it was converted into a production well. The heating system is circulated with thermal water; thus, the feed water is high temperature, which is good for heating efficiency, but chemical agents are necessary due to scaling. Scaling can cause operation problems such as huge loss in power consumption, high consumption of chemical additives, and damage to the heat exchange pipes [36]. The cooled thermal water is discharged into a surface watercourse, which provides adequate dilution but is also an environmental burden.

3.4.2. Nagyszénás

It is not possible to inject 100% of the extracted thermal water back with the one injection well due to seasonal differences. The hourly peak demand during the heating season can be seen in Table 2. During the heating season, the average daily thermal water demand is 512 m^3/day, while outside the season it is just 10 m^3/day. As the injection well's daily capacity is 288 m^3/day, the remaining 224 m^3/day volume (annually around 40,768 m^3/year, calculating for 182 heating days) cannot be injected during the heating season. Such considerations have led to two injection wells being planned for the geothermal system of Békéscsaba.

Institution	**Heating** [m^3/h]	**Domestic hot water** [m^3/h]	**Ventilation** [m^3/h]	**Total** [m^3/h]
Mayor's Office	1.2	-	-	1.2
Primary School (1st-4th classes)	3.0	-	-	3.0
Primary School (5th-8th classes)	5.7	-	-	5.7
House of Culture and Library	2.5	-	2.1	4.6
Kindergarten	1.1	0.4	-	1.5
Medical Office	1.1	0.4	-	1.5
Public Bath	10.5	-	1.0	11.5
Social Care Home (planned)	*5.2*	*0.6*	-	*5.8*
80-unit apartment building (planned)	*5.2*	-	-	-
Total	**35.5**	**1.4**	**3.1**	**40**

Table 2. Hourly peak water demand of the geothermal system of Nagyszénás during the heating season (values from the implementation documentation)

During operation, the 170 m deep thermal water pump often ran dry with increased gas production. It became necessary to extend the production pipe and install the pump at a depth of 250 m. The existing well casing had to be replaced for the intervention, which solved the problem with the new pump. However, because of improper installation, the electrical cable to the pump suffered insulation damage, as can be seen in Figure 2.

Figure 2. Insulation damage to the thermal water pump's electrical cable (Nagyszénás)

Due to scaling, maintenance was required approximately every 3 months, at a significant cost. For protection against scaling an electromagnetic system and chemical agent dosing were installed down to the production depth. The wellhead also had to be modified to accommodate the chemical dosing pipeline. To increase the efficiency of scaling inhibition the previous chemical agent was replaced by a new one (CAS (Chemical Abstracts Service) no.: 55965-84-9, reaction mass of 5-chloro-2-methyl-4-

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isothiazolin-3-one and 2-methyl-2H -isothiazol-3-one). Thanks to these interventions the scaling intensity decreased significantly, resulting in approximately 50% less deposition within one maintenance cycle.

Figure 3. Scaling in the geothermal system (Nagyszénás)

Due to the high volume of gas production, the degasification system must be regularly maintained. Complete dismantling of the internal mechanical equipment of the degasification tower and the removal of deposits by acidification of the separator must be carried out every year before the heating season. The frequency range of the electromagnetic system protecting the stainless-steel pipeline section leading to the degasifier had to be accurately calibrated, which required a longer period. With a well-adjusted frequency, the amount of scale that appeared in the gas separator was significantly reduced. Increased gas production would justify the installation of a gas engine for electricity generation, to make efficient use of the neutralized gas outside the heating season.

Figure 4. Electromagnetic system protecting the stainless-steel pipeline section leading to the degasifier (Nagyszénás)

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3.4.3. Békéscsaba

The system, with the newly drilled production and two injection wells, was completed in autumn 2023. The project was significantly delayed due to technical problems during the construction phase. The entire drilling operation, including testing, was expected to take two to three months for each well. While drilling one of the wells, some of the stored pipes fell back into the well, almost ruining it. Due to the recent installation operational experiences are still missing in this case.

3.5. Evaluation of the systems

In the evaluated cases some elements of the SWOT analysis (Figure 1) were much more significant than others. Among the strengths, the continuous operation independent of weather conditions has been confirmed so far. The claim of only minor environmental impacts was found to be true in two cases (Nagyszénás and Békéscsaba). These sites have injection wells, but in the case of the Szarvas system, the used water is discharged to a surface water reservoir. Here, the only way to stay within the required legal limits was achieved through proper dilution. Maintenance became another important issue, especially in the case of Nagyszénás, where due to very intensive scaling the maintenance cycles had to be shorter. The situation improved a lot after replacing the scaling inhibitor with a new chemical agent, and by using an electromagnetic system the gas separator is better protected. Additionally, deep-seated thermal water pumps increased the cost of maintenance.

Due to the high initial investment costs, external funding was needed to install and/or upgrade the systems. Lack of professional knowledge during the installation, maintenance, and production also resulted in challenges. As was mentioned earlier, in the case of Békéscsaba, technical problems resulting from unprofessional operations led to very significant delays during installation. In Nagyszénás, the transmission line of the pumps suffered insulation damage due to improper installation, resulting in malfunctions and outages. The maintenance and operation also require a high level of knowledge, which has been already proven in the case of the systems evaluated. From this, it can be highlighted that the significant methane emissions must be treated by a gas separation system.

Diversification of the energy mix and exploiting the possibility of direct use have also been realized. External funding support could be obtained for the systems at different stages. However, economic evaluations were cited as a weakness if they were inadequate, although it has recently been shown that unexpected events (such as the war in Ukraine) have led to a significant increase in energy prices. This has changed the payback period of the systems, reducing them significantly.

Among the threats, all geothermal systems must deal with competition from other renewable sources, although such sources can be a good complement to the systems, as the example of Szarvas illustrates. Significant problems have emerged relating to injection wells. In the case of Szarvas, the well was converted to a producer well because it could not pump the extracted water back into the aquifer. In the case of Nagyszénás, due to seasonal variations, one well was insufficient to fully return the extracted water. Taking this into account, the Békéscsaba system was dimensioned with two injection wells. Figure 5 summarizes the findings based on the experiences.

S	Non-intermittent resource, no weather dependency Minor environmental issues *(with injection wells, with dissolved gas treatment)*	INTERNAL
W	High initial investment cost Requires professional knowledge for installation *(delay due to technical problems)* , maintenance *(scaling, high chemical usage)* , and production *(dissolved gas treatment)* Higher maintenance cost than expected *(scaling, target instruments)* Environmental issues *(without injection wells, without dissolved gas treatment)*	INTERNAL
O	Diversification of the energy mix Direct uses are possible Funding supports Shorter payback periods due to unexpected events	EXTERNAL
T	Commercial competition with other renewable resources Incorrect dimensioning of the systems *(insufficient injection capacity)*	EXTERNAL

Figure 5. SWOT analysis based on the three investigated systems – Elements experienced from the general SWOT (Figure 1) extended with new or modified elements (highlighted in red) and with additional comments (italics in brackets)

4. Conclusions

Three recently installed or expanded municipal geothermal systems were introduced here. All systems originate from the same region of Hungary but have different characteristics. Each case has been evaluated with special emphasis on the engineering challenges that appeared during the installation, maintenance, and operation. In this article, whenever possible, the solutions for the actual challenges have also been presented. The strengths, weaknesses, opportunities, and threats faced by similar geothermal systems have been examined, and their emergence and significance for the systems under investigation assessed.

Of course, such studies have their limitations, as many of the issues presented and discussed here are site-specific. At the same time, they provide valuable insights into similar situations. It is hoped that this work can also provide useful information for the investigation, evaluation, or even practical implementation of similar geothermal systems.

References

[1] G. Axelsson, "Sustainable geothermal energy utilization," *Int. Rev. Appl. Sci. Eng. IRASE*, vol. 1, no. 1–2, pp. 21–30, 2010, doi: 10.1556/irase.1.2010.1-2.4.

[2] M. Soltani *et al.*, "A comprehensive review of geothermal energy evolution and development," *Int. J. Green Energy*, vol. 16, no. 13, pp. 971–1009, 2019, doi: 10.1080/15435075.2019.1650047.

[3] N. Arbad, H. Emadi, and M. Watson, "A comprehensive review of geothermal cementing from well integrity perspective," *J. Pet. Sci. Eng.*, vol. 217, 2022, doi: 10.1016/j.petrol.2022.110869.

[4] D. Borzuei, S. F. Moosavian, A. Ahmadi, R. Ahmadi, and K. Bagherzadeh, "An Experimental and Analytical Study of Influential Parameters of Parabolic trough Solar Collector," *J. Renew. Energy Environ.*, vol. 8, no. 4, pp. 52–66, 2021, doi: 10.30501/jree.2021.261647.1172.

[5] IEA, "Renewables 2023 Analysis and forecast to 2028," 2024. [Online]. Available: www.iea.org.

[6] IEA, "World Energy Outlook 2023," 2023. [Online]. Available: www,iea.org.

[7] S. J. Zarrouk and H. Moon, "Efficiency of geothermal power plants: A worldwide review," *Geothermics*, vol. 51, pp. 142–153, Jul. 2014, doi: 10.1016/J.GEOTHERMICS.2013.11.001.

[8] V. K. Singh and S. K. Singal, "Operation of hydro power plants-a review," *Renew. Sustain. Energy Rev.*, vol. 69, pp. 610–619, Mar. 2017, doi: 10.1016/J.RSER.2016.11.169.

[9] F. Dincer, "The analysis on wind energy electricity generation status, potential and policies in the world," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 5135–5142, Dec. 2011, doi: 10.1016/J.RSER.2011.07.042.

[10] J. Khan and M. H. Arsalan, "Solar power technologies for sustainable electricity generation – A review," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 414–425, Mar. 2016, doi: 10.1016/J.RSER.2015.10.135.

[11] A. Q. Al-Shetwi, "Sustainable development of renewable energy integrated power sector: Trends, environmental impacts, and recent challenges," *Sci. Total Environ.*, vol. 822, 2022, doi: 10.1016/j.scitotenv.2022.153645.

[12] A. Wachowicz-Pyzik, A. Sowiżdżał, and L. Pająk, "Environmental benefits from geothermal energy use with a well doublet located in the Szczecin Trough (NW Poland)," *Environ. Geochem. Health*, vol. 44, no. 7, pp. 2325–2339, 2022, doi: 10.1007/s10653-022-01220-0.

[13] N. Azizi *et al.*, "Critical review of multigeneration system powered by geothermal energy resource from the energy, exergy, and economic point of views," *Energy Sci. Eng.*, vol. 10, no. 12, pp. 4859–4889, 2022, doi: 10.1002/ese3.1296.

[14] D. Romanov and B. Leiss, "Geothermal energy at different depths for district heating and cooling of existing and future building stock," *Renew. Sustain. Energy Rev.*, vol. 167, p. 112727, Oct. 2022, doi: 10.1016/J.RSER.2022.112727.

[15] C. Kinney, A. Dehghani-Sanij, S. B. Mahbaz, M. B. Dusseault, J. S. Nathwani, and R. A. Fraser, "Geothermal energy for sustainable food production in Canada's remote northern communities," *Energies*, vol. 12, no. 21, 2019, doi: 10.3390/en12214058.

[16] M. Soltani *et al.*, "A comprehensive study of geothermal heating and cooling systems," *Sustain. Cities Soc.*, vol. 44, pp. 793–818, 2019, doi: 10.1016/j.scs.2018.09.036.

[17] J. W. Lund, G. W. Huttrer, and A. N. Toth, "Characteristics and trends in geothermal development and use, 1995 to 2020," *Geothermics*, vol. 105, 2022, doi: 10.1016/j.geothermics.2022.102522.

DOI: 10.21791/IJEMS.2024.018

[18] T. Schott and F. Liautaud, "Monitoring and mitigating corrosion in geothermal systems," *Mater. Corros.*, vol. 73, no. 12, pp. 1916–1942, 2022, doi: 10.1002/maco.202213359.

[19] K. A. Lichti, S. Ghaziof, R. Julian, and B. W. Mountain, "Geochemical modelling of heavy metal deposition in a geothermal heat exchanger," *Geothermics*, vol. 118, 2024, doi: 10.1016/j.geothermics.2023.102884.

[20] L. Zacherl and T. Baumann, "Quantification of the effect of gas–water–equilibria on carbonate precipitation," *Geotherm. Energy*, vol. 11, no. 1, 2023, doi: 10.1186/s40517-023-00256-4.

[21] F. Fanicchia and S. N. Karlsdottir, "Research and Development on Coatings and Paints for Geothermal Environments: A Review," *Adv. Mater. Technol.*, vol. 8, no. 18, 2023, doi: 10.1002/admt.202202031.

[22] S. N. Karlsdóttir, *Corrosion, scaling and material selection in geothermal power production*, vol. 7. 2012.

[23] Y. Li *et al.*, "An efficient silica scale inhibiting strategy for geothermal systems: Combination of cationic and anionic polymers," *J. Appl. Polym. Sci.*, vol. 140, no. 32, 2023, doi: 10.1002/app.54245.

[24] J. Yan, X. Tan, and S. Qi, "High-Temperature-Resistant Scale Inhibitor Polyaspartic Acid-Prolineamide for Inhibiting CaCO<inf>3</inf> Scale in Geothermal Water and Speculation of Scale Inhibition Mechanism," *Water (Switzerland)*, vol. 15, no. 8, 2023, doi: 10.3390/w15081457.

[25] S. Qiao *et al.*, "A novel and efficient CaCO<inf>3</inf> scale inhibitor in high-temperature and high-salinity geothermal systems: A deprotonated quadripolymer," *J. Appl. Polym. Sci.*, vol. 140, no. 10, 2023, doi: 10.1002/app.53581.

[26] L. Lenkey, J. Mihályka, and P. Paróczi, "Review of geothermal conditions of Hungary | Magyarország geotermikus viszonyainak áttekintése," *Foldt. Kozlony*, vol. 151, no. 1, pp. 65–78, 2021, doi: 10.23928/foldt.kozl.2021.151.1.65.

[27] B. Kulcsár, "Combined energy production in the North Great Plain Region," *Int. Rev. Appl. Sci. Eng. IRASE*, vol. 2, no. 1, pp. 63–67, 2011, doi: 10.1556/irase.2.2011.1.10.

[28] A. Nádor, A. Kujbus, and A. Toth, *Geothermal Energy Use, Country Update for Hungary*. 2016.

[29] A. Toth, *Country Update for Hungary*. 2020.

[30] J. Szanyi and B. Kovács, "Utilization of geothermal systems in South-East Hungary," *Geothermics*, vol. 39, no. 4, pp. 357–364, Dec. 2010, doi: 10.1016/J.GEOTHERMICS.2010.09.004.

[31] D. Romanov and B. Leiss, "Geothermal energy at different depths for district heating and cooling of existing and future building stock," *Renew. Sustain. Energy Rev.*, vol. 167, 2022, doi: 10.1016/j.rser.2022.112727.

[32] G. Herrera-Franco *et al.*, "Bibliometric Analysis and Review of Low and Medium Enthalpy Geothermal Energy: Environmental, Economic, and Strategic Insights," *Int. J. Energy Prod. Manag.*, vol. 8, no. 3, pp. 187–199, 2023, doi: 10.18280/ijepm.080307.

[33] A. Ramos-Escudero and M. S. García-Cascales, "Barriers behind the Retarded Shallow Geothermal Deployment in Specific Areas: A Comparative Case Study between Southern Spain and Germany," *Energies*, vol. 15, no. 13, 2022, doi: 10.3390/en15134596.

[34] S. Widi Hastuti, A. N. M. Anugrah, K. Nafista, and A. Kahfi Ilham, *SWOT Analysis for Geothermal Enhanced System (EGS) As New Technology for Development Geothermal in Indonesia*. 2021.

[35] K. Szolga and D. Kocsis, "Modern use of geothermal energy in Nagyszénás (Case Study)," *Int. J. Eng. Manag. Sci.*, vol. 7, no. 3 SE-Environmental Engineering, pp. 106–115, Dec. 2022, doi: 10.21791/IJEMS.2022.3.10.

[36] Q. Khan, M. A. Maraqa, and A. M. O. Mohamed, "Inland desalination," *Pollut. Assess. Sustain. Pract. Appl. Sci. Eng.*, pp. 871–918, Jan. 2020, doi: 10.1016/B978-0-12-809582-9.00017-7.