Interreg Danube Region

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REHEATEAST

Reheateast Pilot 2: District Heating and Cooling System (DHC) in Heat Energy Communities (HEC)

Activity A.2.3

INFOWARE ZRT.
Székhely: Határ út 22, Szigetszentmiklós, 2310 Hungary
Cgj. szám: Cg. 13-10-041366
Adószám: 10900516-2-13
Tel.: +36 24 465 171
Fax: +36 24 442 139
E-mail: office@infoware.hu
Web.: www.infoware.hu

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List of abbreviations

Abbreviation	Report
aFRR	Automatic Frequency Restoration Reserve
ATES	Aquifer Thermal Energy Storage; thermal energy storage in an aquifer
BESS	Battery Energy Storage System; battery energy storage system
BTES	Borehole Thermal Energy Storage; thermal energy storage in boreholes
CAPEX	Capital Expenditure; capital expenditure
CEC	Citizen Energy Community
CEP	Clean Energy Package
CH&C	Community Heating & Cooling; community heating and cooling
CHP	Combined Heat and Power; Combined Heat and Power Generation
CINEA	European Climate, Infrastructure and Environment Executive Agency; EU executive agency
CO_2	Carbon dioxide
COP	Coefficient of Performance; performance efficiency
CSC	Collective Self-Consumption
D2Grids	EU project on 5th-generation district heating and cooling systems
DC	District Cooling; district cooling
DHC	District Heating and Cooling; district heating and cooling
DH	District Heating; district heating
DRP	Danube Region Programme; Danube Region Programme
EED	Energy Efficiency Directive
EBRD	European Bank for Reconstruction and Development; European Bank for Reconstruction and Development
EIB	European Investment Bank

ENABLE-DHC	EU project for the decarbonization of existing DHC systems
EPC	Energy Performance Contracting; performance-based energy contract
ESCO	Energy Service Company; energy service provider
ETS	Emissions Trading System; EU Emissions Trading System
EU	European Union
FCR	Frequency Containment Reserve – primary frequency control
GEG	Gebäudeenergiegesetz; German Building Energy Act
GFO	Economic Department code (tender classification)
GJ	Gigajoule; unit of energy
GW / GWh	Gigawatt / gigawatt-hour
HEC	Heat Energy Community
H2P	Heat-to-Power; conversion of heat to electricity
H2020	Horizon 2020 – EU research program
ICT	Information and Communication Technology
IEA ES TCP	International Energy Agency – Energy Storage Technology Collaboration Programme
InvestEU	EU guarantee program for climate and energy projects
IP	Investment Plan (MUSE-DHC)
KPI	Key Performance Indicator
LT / VLT	Low Temperature / Very Low Temperature – low / very low temperature networks
LTES	Large Thermal Energy Storage; large-scale thermal energy storage
MA	Modernization Fund – ETS-based domestic energy financing fund
mFRR	Manual Frequency Restoration Reserve; manual frequency restoration reserve
MUSE-DHC	LIFE project supporting community-led DHC development (2025–2028)

MW / MWh	Megawatt / megawatt-hour; power / energy
NEKT	National Energy and Climate Plan
NES 2030/2040	National Energy Strategy 2030 / 2040
OPEX	Operational Expenditure; operating costs
PAW	Aardgasvrije Wijken; Dutch “Gas-Free Neighborhoods” program
PCM	Phase Change Material; phase change material
P2H	Power-to-Heat; electricity → heat
PTES	Pit Thermal Energy Storage; pit-type thermal energy storage
REC	Renewable Energy Community; renewable energy community
RED III	Renewable Energy Directive III; EU Renewable Energy Directive (2023/2413)
RES	Renewable Energy Sources; renewable energy sources
SDH	Solar District Heating; solar district heating
TCP	Technology Collaboration Programme (IEA)
TES	Thermal Energy Storage; thermal energy storage technologies
TTES	Tank Thermal Energy Storage; tank-based thermal energy storage
URM	Urban Regeneration Model; urban regeneration model (REMOURBAN)
Wcw	Warmtecollectieve wet; Dutch Collective Heating Act (effective 2026)
WPG	Wärmeplanungsgesetz; German Heat Planning Act

Executive Summary

The Reheateast Pilot 2 study focuses on examining how a modern, community-based heat supply model based on renewable energy sources in the eastern part of the Danube region that simultaneously reduces the demand for fossil fuels, increases local security of supply, and aligns with the decarbonization goals of the EU and Hungary. The document provides a detailed analysis of the domestic and European regulatory environment, presents the full spectrum of thermal storage technologies, explores international operational models, and concludes that Hungary possesses exceptional conditions for establishing a renewable heat energy community (HEC).

The first part of the study analyzes the legal framework of the Hungarian district heating and cooling sector. Legislative changes in recent years have significantly strengthened the potential for integrating renewable and residual heat. At the same time, Hungary has transposed the EU's Energy Efficiency and Renewable Energy Directives (EED, RED III), which are paving the way for a new, digital era in district heating through modern metering, remote reading, and energy efficiency requirements. Although the legal framework for heat energy communities is not yet complete, the regulatory logic of electricity communities already allows for the launch of pilot heat energy community projects, particularly where local renewable or industrial waste heat is available.

The second major section of the document provides a detailed overview of thermal storage technologies, presenting the operation, parameters, and application possibilities of sensible, latent, and thermochemical thermal storage systems. The role of thermal storage in the energy system is no longer limited to balancing heat fluctuations, as thermal storage systems combined with Power-to-Heat and Heat-to-Power technologies are capable of stabilizing the electricity grid, reducing renewable energy curtailment, and efficiently recovering industrial waste heat.

The third part of the study analyzes a wide range of best practices at the EU and Member State levels. Examples from Denmark, the Netherlands, Austria, and Germany show that community-owned or community-managed district heating (DH) systems are the most sustainable models in the long term, as their non-profit operating logic ensures a transparent cost structure and they enjoy strong public support.

Building on this, the Békéscsaba case study highlights that the city's geological conditions and district heating structure make it suitable for establishing one of Hungary's first modular geothermal-based thermal energy communities. The annual heat demand of the three heating zones can be fully met by a system based on a new production well and one or more reinjection wells, while the spa's existing thermal well serves as a redundant heat source, enhancing supply security.

Finally, the study also demonstrates that the Békéscsaba model is highly replicable in other Hungarian cities, particularly where heat consumption is spatially concentrated and usable thermal resources are available. The pilot project is not merely an energy development but a strategic step forward for the Hungarian heating sector.

I. District Heating, District Cooling, and Thermal Energy Communities: An Analysis of the Regulatory Environment and Legal Framework in Hungary

I. Introduction

District heating (DH) and district cooling (DC) systems are key components of Hungary's energy infrastructure, providing heat to hundreds of thousands of households and public institutions. Their operation and development take place within a strict legal and regulatory framework, which has undergone significant changes in recent years as a result of alignment with the European Union's energy efficiency, climate protection, and renewable energy targets. The aim of domestic legislation in this process is to strengthen the sustainability, security of supply, and transparency of heat supply, as well as to reduce consumer costs.

The partial replacement of centralized, fossil-fuel-based heat production is increasingly being supported by the promotion of decentralized local systems based on renewable or residual heat. One new direction in this shift in approach is the concept of heat energy communities (HECs), which is based on community cooperation between local heat producers (e.g., geothermal or industrial waste heat sources) and consumers. Although the legal framework for heat energy communities is still taking shape, the direction of regulatory developments already indicates that community-based, renewable heat generation models will be key areas of domestic development in the coming years[1] .

The legal framework for district heating continues to be based on Act XVIII of 2005, which has been modernized through several comprehensive amendments to promote the utilization of waste heat and the expansion of renewable heat generation[2] . Regulation of district cooling is currently less extensive, but the legislature has already begun harmonizing it based on the model of the district heating system, paving the way for the sector's technological and market development [3] .

II. Key elements of the Hungarian regulatory environment

2.1 The legal framework for district heating

The legal basis for district heating in Hungary is Act XVIII of 2005, which defines the rights and obligations of service providers, the licensing process, and price regulation. The purpose of the law is to ensure safe, affordable, and transparent district heating services[2] . The regulation was significantly amended by Act XLV of 2025, with the main aim of promoting the integration of

renewable and residual heat into the heating market in order to increase energy efficiency and reduce household costs. The legislature has developed regulations that allow for the flexible integration of residual heat and alternative heat sources into the system, as well as the application of guarantees of origin in the heat market [4] .

Key elements of the new regulations:

- *Strengthening the legal framework for waste heat*: The law specifies the conditions under which a waste heat producer (e.g., an industrial facility or data center) may connect to the district heating system.
- *Introduction of a heat origin guarantee system:* This allows for certification that the heat comes from renewable or alternative sources.
- *The possibility of public takeover:* If service security is at risk, the state or local government may take over the operation of a heat-generating facility.

2.2 The role of implementing regulations

The regulatory environment is significantly shaped by Government Decree No. 238/2025 (VII.31.), which contains amendments to the implementing regulations of the Act on District Heating[3] . The decree introduces new rules in several areas that strengthen the long-term planning obligations of local governments and service providers and establish the prerequisites for accessing EU funds.

Key changes:

- *Clarification of residual heat classification:* Clarifies the concept of "residual heat" and its quantitative, qualitative, and temperature requirements. Precisely defines the conditions for authorizing sales.
- *Procedures for public interest redemptions:* Introduces a structured and detailed procedure for public interest redemptions, including the role of experts and the rules for compensation.
- *Requirement for development plans:* District heating providers must prepare a detailed, multi-year development plan that takes into account the criteria for an "efficient district heating system" as defined by the EU.
- *Local heat utilization plans:* Comprehensive strategic planning of the heat supply system is mandatory for municipalities with more than 45,000 inhabitants[3] .

2.3 Transposition of EU Energy Efficiency Directives

EU Directives 2012/27/EU and 2018/2002/EU set out mandatory energy efficiency requirements for Member States. Hungary implemented these in 2023–2024, including in the areas of metering and billing, remote reading, and cost allocation[1] [5] . This transition enhances the transparency of the system and paves the way for a modern, digital metering infrastructure.

Key requirements:

- Starting in 2027, all heat consumption and hot water meters must be remotely readable; where this is not feasible, the use of cost allocators becomes mandatory.
- A uniform cost-effectiveness assessment must be applied to meet energy-saving targets.
- Local governments must adopt their own energy efficiency regulations by 2024 [1][5] .

2.4 Regulation of District Cooling (DC)

District cooling is still not widely used in Hungary, but the EU's climate goals, summer heat waves, and modern building energy efficiency are increasing its importance. Amendments to Government Decree 201/2016. (VII.21.) on district cooling services brought Hungarian regulations into alignment with EU renewable energy directives in 2025–2026, with particular regard to RED III (2023/2413 EU).[5] [6] [7]

The aim of the legislative changes is to:

- to encourage the development of district cooling systems,
- to support cooling systems that utilize renewable or waste heat,
- standardizing the operational framework for service providers,
- encouraging technological innovations and energy efficiency improvements
- more effective integration of renewable energy sources (e.g., geothermal, biomass) into cooling systems.[5] [6] [7]

III. The legal status of heat energy communities (HECs)

Heat energy communities do not yet have a separate, detailed legal framework in Hungary. Current regulations establish the theoretical basis for the operation of heat energy communities primarily by building on the electricity model of energy communities. Support for decentralized heat production, for example through the integration of waste heat and renewable heat producers, clearly favors the future spread of heat energy communities, but several obstacles stand in the way of their practical implementation. Technical limitations, a lack of detailed regulations, and network characteristics linked to utility monopolies all pose obstacles[1] [3] [4] .

However, the current legal environment already allows for the launch of pilot-scale heat energy community projects, particularly in locations where local waste heat or renewable heat sources are available. See Table 1 for a summary of the current state of the legal environment.

1. Table: Current Status of the Legal Framework

Regulatory element	Status	Comment
Definition of the concept of a heat energy community (HEC)	Partially regulated	Frameworks for electricity can be adapted
Operating conditions for a Heat Energy Community (HEC)	Incomplete	No separate heat-specific regulation
Connection to the grid	regulated	Complicated due to limitations of the district heating monopoly
Integration of heat producers (geothermal, waste heat)	Well regulated	Following the 2025 legislative amendment
Community ownership model	No separate regulations	EU guidelines apply

IV. International and EU context

Domestic regulations are closely aligned with key European framework regulations, in particular:

- the RED III Renewable Energy Directive (EU 2023/2413),
- the amended Energy Efficiency Directive (EED) (EU 2023/1791),
- the EU Modernization Fund's development policy, which is already supporting district heating modernization with a 95 billion forint support package.[3] [7]

European Union energy policy priorities clearly emphasize the strengthening of decentralized energy production**,** renewable-based heat generation, and community models based on active consumer participation. These efforts represent not only technological renewal but also a profound transformation of how the heat energy market operates, in which local communities and municipalities can play an increasingly significant role.

Domestic regulatory modernization is therefore not an isolated process, but fits closely into the EU energy policy framework, which has set the goal of a significant, structural transformation of the heating and cooling sector by 2030. These goals include increasing the share of heat production based on renewable sources, the widespread adoption of flexible and smart heat supply systems, and the strengthening of community- and consumer-centered energy solutions. The development of Hungarian regulations can thus be understood as part of a broader European transition, which also strengthens the long-term sustainability of the domestic energy market through the gradual establishment of the frameworks necessary for the introduction of heat energy community models.

II. An overview of concepts and technologies related to thermal storage

I. Basic concepts of thermal energy storage

1.1 Thermal Energy Storage (TES)

Thermal energy storage (TES) is a form of energy storage in which energy is stored in the form of heat and can later be utilized as direct heat or converted into electricity. The goal of TES technologies is to decouple energy production from consumption over time, thereby reducing peak loads, increasing system flexibility, and mitigating the use of fossil fuels. TES systems can be used in industrial, municipal, and district heating systems alike, particularly where heat demand fluctuates significantly or where the integration of large amounts of renewable energy poses grid balancing challenges [8] .

TES technologies can essentially be grouped according to three physical principles:

- *Sensible heat storage:* for example, heating or cooling water or other liquids (e.g., cold-water tanks with stratified layers in TES systems for cooling).
- *Latent heat storage:* using phase-change materials (e.g., ice), where the heat storage potential of melting/freezing is utilized.
- *Thermo-chemical storage:* extremely high energy density can be achieved through reversible chemical reactions [8] .

The Energy Storage team is investigating the development of Large Thermal Energy Storage (LTES) systems within the framework of the IEA (International Energy Agency) Technology Collaboration Programme, particularly in district heating and cooling systems. The latest technological trends include BTES (borehole), ATES (aquifer), PTES (pit storage), and TTES (tank-based) storage systems, which are capable of storing up to several GWh of thermal energy with low losses over long periods, offering significant system management benefits[9] .

1.2 Conversion of electrical energy into thermal energy (P2H)

The goal of power-to-heat (P2H) technologies is to convert electricity directly into heat. Typical examples of such devices include electric boilers and resistance heating elements. P2H plays a particularly important role in electricity systems with a high share of renewables, as it enables the efficient thermal storage of electricity generated during peak production periods that would otherwise be subject to curtailment. P2H+TES ( ) systems can function as a regulatory reserve and a market balancing tool for the power system, while also improving the security of heat supply [10] .

1.3 Heat-to-Power (H2P)

Heat-to-power (H2P) solutions convert heat back into electricity, typically using steam turbines, ORC (Organic Rankine Cycle) systems, or other heat engines. Applications include industrial waste heat recovery, the conversion of heat stored in large-scale storage systems during peak periods, or decentralized energy generation based on steam and heat processes. Although H2P systems generally have lower efficiency, their strategic role is growing in creating energy flexibility across sectors. In large thermal energy storage systems (LTES), heat-to-power conversion can be particularly advantageous when the goal is to coordinate the operation of district heating systems and the electricity grid[8] .

II. The Role of Thermal Storage in the Energy System

One of the key challenges of modern energy systems is the fluctuating nature of renewable energy production, as well as the constantly changing dynamics of consumer demand. To manage the time lag between generation and consumption, Thermal Energy Storage (TES) technologies play a key role in increasing the flexibility, stability, and economic efficiency of energy systems. Storing energy in the form of heat allows surplus renewable energy to be utilized during periods when heat or electricity demand is higher, thereby reducing grid and generation burdens resulting from peak loads[10] .

The operation of TES systems directly contributes to the optimization of the electricity grid and heat supply infrastructure. Thermal storage systems are capable of performing the following energy system functions:

- *Relieving the load on the power grid:*
  Storage systems enable excess electricity generated during peak production periods to be converted into heat, which can later be utilized during peak heat consumption periods. This is particularly important for Power-to-Heat (P2H) systems, which, according to the Task 39 report, ensure an efficient sector coupling between the electricity and heat sectors[9] .

- *Reducing the need for balancing energy:*
  Heat storage systems stabilize the output of renewable energy systems, reducing the amount of reserves required by system operators.

- *Reducing renewable energy curtailment:*
  According to a DOE fact sheet and research on LTES systems, thermal storage systems allow excess electricity that cannot be absorbed by the grid to be utilized later in the form of heat, significantly reducing the amount of "wasted" green energy[11] .

- *Reducing natural gas demand in district heating systems:*
  Large-scale thermal energy storage systems, particularly PTES, TTES, BTES, and ATES solutions, enable district heating systems to replace a significant portion of fossil fuel-based generation, even on a seasonal basis. According to IEA ES TCP Task 39 reports, LTES systems with capacities ranging from tens of thousands to hundreds of thousands of cubic meters are capable of radically reducing the carbon intensity of district heating production [9] .

- *Improving the energy efficiency of industrial processes:*
  TES systems contribute to the recovery of waste heat from industrial processes and to more stable process operation, which, according to the findings of the Task 39 Final Report, results in measurable energy and cost savings across numerous industrial sectors[9] .

The energy stored in thermal storage systems can be utilized not only as heat but also converted back into electricity (Heat-to-Power, H2P). Such conversion systems (e.g., steam turbines, ORC cycles) contribute to the provision of balancing and capacity market services, enhancing the controllability of the energy system. The DOE TES review highlights that thermal storage used in combined heat and power (CHP) systems can reduce capital costs, improve equipment utilization, and increase energy supply efficiency[11] .

Based on the findings of the Task 39 Final Report, large-scale LTES systems with capacities of several GWh not only provide operational flexibility but also enable the deep decarbonization of district heating systems, seasonal balancing of grid loads, and integrated stabilization of the power system via P2H systems [9] .

III. Main Types of Thermal Storage Technologies

Heat storage technologies can be classified into three major categories: sensible, latent, and thermochemical heat storage. Each is based on a different physical principle and offers different energy densities, temperature ranges, and application areas. This categorization corresponds to the international technical system used by the DOE and Sandia National Laboratories[12] .

3.1 Sensitive Thermal Energy Storage

Sensitive thermal energy storage is the simplest and most widely used type of TES. In principle, energy is stored or released through changes in the temperature of the storage medium. The amount of stored heat is proportional to the mass of the medium, its specific heat capacity, and the magnitude of the temperature change. According to the DOE and Springer, the advantages of sensible heat storage systems include stable operation, low cost, long service life, and high efficiency, typically around 80–90%[8] [13] .

- *Most common storage media* [12] *:*
  water (e.g., large-volume buffer reservoirs),
  rock and gravel beds (rock-bed storage),
  concrete (massive concrete thermal storage tanks),
  molten salts (high-heat-capacity, high-temperature medium)

- *Typical applications* [9] *:*
  district heating thermal storage systems (e.g., PTES, TTES systems),
  storage of industrial waste heat,
  concentrated solar power (CSP) systems.

Latent heat storage systems also dominate in large-scale (LTES) systems, which IEA Task 39 has identified as a key technology for the decarbonization of district heating [9] .

3.2 Latent heat storage

Latent heat storage (LHS) utilizes the latent heat released or absorbed during a phase change as a source of energy. During a phase change—such as from a solid to a liquid state or vice versa—the material can store large amounts of energy at a nearly constant temperature, which is a major advantage for thermal comfort and industrial control applications. According to the DOE and Sandia, the main advantages of latent heat storage systems are high energy density (greater than that of sensible heat storage systems), a stable temperature profile during phase change, and more compact solutions, which are preferable for building services and industrial applications[12] .

- *Typical PCM (Phase Change Material) materials:*
  ice–water systems,
  paraffin and organic PCMs,
  salt hydrates,
  special industrial melts (e.g., high-temperature salt mixtures).

According to Springer and Sandia, the development of modern PCMs encompasses the reduction of supercooling, corrosion protection solutions, and improvements in thermal conductivity, which enables broader application of the technology[12] [13] .

3.3 Thermochemical Energy Storage

In thermochemical energy storage (TCES), heat is stored through chemical bonds. The process is reversible, as the chemical bond breaks down when heat is applied, or the reaction reverses when heat is removed, at which point the system releases high-density thermal energy. The DOE and Sandia consistently emphasize that thermochemical storage systems have extremely high energy density, are capable of storing energy over the long term with virtually no loss, and are suitable for high-temperature applications (450–750 °C or higher); they are particularly promising for seasonal energy storage and industrial processes [12] .

- *Examples of TCES systems*:
  metal oxide-based systems,
  adsorption/absorption heat storage systems (e.g., silica gel–water systems),
  high-energy-density salt-based systems.

The DOE's TES project list specifically highlights innovations in nanostructured salt-based and solid-state chemical storage materials, which are capable of storing energy for up to months with minimal heat loss [14] .

IV. Technical parameters of thermal storage systems

The performance and applicability of thermal energy storage systems are evaluated based on several interrelated technical parameters. These characteristics determine the extent to which a given technology is suitable for increasing the flexibility of electricity and thermal energy systems, as well as the role it can play in district heating, industrial, or building energy applications.

The following evaluation criteria are also identified as key by the U.S. Department of Energy (DOE) and Sandia National Laboratories in their comparison of TES technologies:[8] [12] .

4.1 Key evaluation parameters

- *Storage capacity (MWh):*
  The amount of thermal energy that can be stored in the system. According to Sandia National Laboratories' TES technology summary, sensible, latent, and thermochemical thermal energy storage systems are suitable for large-scale (LTES) storage in the range of several GWh, particularly for district heating applications.

- *Charging and discharging power (MW):*
  The power level at which the thermal storage system can be charged and discharged. In high-power P2H systems, this enables the rapid conversion of excess electricity into heat.

- *Temperature range (e.g., 55–800 °C):*
  This varies depending on the type of technology. Sensible heat storage typically operates at low to medium temperatures (55–300 °C). Molten salt storage operates at medium to high temperatures (250–600 °C). Thermochemical systems can reach temperatures of 450–750 °C or higher.

- *Response time (ms–min):*
  Charging/discharging speed is a key factor in the flexibility of the power grid. According to the DOE, depending on the application of TES systems, both fast (second-level) and slower (minute-level) response times are achievable.

- *Efficiency (80–98%):*
  Different thermal energy storage technologies have varying thermal storage and recovery efficiencies. According to the DOE TES Fact Sheet, sensible and latent thermal energy storage systems can operate at efficiencies of around 80–90%, while certain industrial systems can achieve even higher cycle efficiencies of nearly 98%.

- *Lifespan (5–60 years):*
  This can vary significantly depending on the storage material and tank technology. According to studies by Sandia National Laboratories, water storage tanks and concrete storage tanks have a service life of several decades, while PCM systems have a shorter lifespan of 5–20 years due to material fatigue. For large-scale PTES/TTES storage systems, a service life of 30–60 years is generally expected with proper maintenance.

- *Cycle Life:*
  The cycle durability of thermal storage systems is particularly important in high-demand applications. The DOE highlights the high cycle life of many TES technologies, which enables the long-term sustainability of daily charge-discharge profiles.

- *Compatibility with heat transfer fluids:*
  TES systems can use different heat transfer fluids, such as steam or water/steam mixed systems, thermal oil, and molten salts. Compatibility determines the system's ability to integrate with industrial thermal processes and district heating networks.

4.2 Comparison of TES technologies with other energy storage methods

The international literature, particularly the DOE's long-term energy storage strategy and the comparative analyses by Sandia National Laboratories[12] [15] , highlights that thermal energy storage (TES) technologies, compared to electrochemical, mechanical, and chemical energy storage solutions, can be applied across a wide range of temperatures and power levels and are cost-effective for large-scale energy storage tasks. Technology comparisons indicate that TES provides an optimal and cost-effective solution, particularly for long-term storage needs (ranging from hours to days), in large-scale grid applications [16] . In many systems, they are capable of providing nearly 100% cycle-to-cycle heat recovery, particularly in sensible heat storage systems where heat transfer fluid losses are minimal. Sandia National Laboratories' overview of TES technology specifically highlights that thermal energy storage, particularly in the case of large-scale sensible heat storage systems, is one of the most reliable and efficient alternatives for long-term energy storage solutions[12] .

V. Applications

Thermal Energy Storage (TES) systems are playing an increasingly critical role in modern energy systems, as they can simultaneously manage fluctuations in renewable energy generation, relieve the load on the power grid, stabilize heat supply systems, and improve the energy efficiency of industrial processes. International research, particularly studies by the U.S. Department of Energy (DOE), Sandia National Laboratories, and the IEA Energy Storage TCP, consistently emphasize that TES systems represent one of the most important energy transition technologies of the coming decade[17] [18] .

5.1 District Heating and Cooling Systems

In district heating and cooling systems, thermal energy storage is primarily intended to balance out temporal discrepancies between production and consumption curves. In this context, TES enables the shaving of peak loads, the replacement of natural gas-fired peak sources, and the storage of surplus electricity—such as during renewable generation peaks—in the form of heat. According to the IEA ES TCP Task 39 report, borehole (BTES), aquifer (ATES), pit (PTES), and large-volume tank (TTES) storage systems are capable of storing up to several gigawatt-hours of thermal energy with low losses, making them particularly valuable in district heating markets where seasonal heat demand fluctuates significantly [9] . These systems can operate across a wide range of temperatures: water-based storage systems at 55–120 °C, while systems based on rock or molten salt can withstand operating temperatures as high as 250–800 °C.

5.2 Industrial Applications

In the industrial sector, which accounts for 30–40% of total final energy consumption globally, thermal energy storage plays a particularly important role. Industrial processes emit significant amounts of waste heat, which, however, does not coincide with heat demand in terms of timing or temperature. Studies by the DOE and Oak Ridge National Laboratory (ORNL) indicate that TES systems enable the delayed, targeted use of this waste heat, thereby reducing industrial energy consumption, improving process control, and mitigating fossil fuel use[19] [20] . TES solutions used in industry, such as Brenmiller Energy's rock-bed storage systems or EnergyNest's concrete accumulator solutions, are all capable of providing a continuous supply of process steam and can also be integrated with steam turbines or ORC systems.

5.3 Electricity Grid and Regulatory Markets

However, thermal energy storage is playing an increasingly important role not only on the heat side but also as a flexibility tool for the electricity system. TES systems integrated with P2H technologies are capable of converting excess or curtailed electricity into heat during peak periods of renewable energy generation, thereby reducing the need for balancing power and grid load. According to the DOE's Long-Duration Storage program, thermal energy storage systems are suitable for playing a role in regulatory markets—such as FCR, aFRR, or mFRR markets—due to their fast response times. Sandia's analyses confirm that several TES technologies—including molten salt, rock, and concrete-based systems—can operate with response times of less than 5 minutes, and in some cases even within seconds, making them suitable for grid regulation tasks. According to NREL's modeling results, TES systems significantly increase the grid integration of renewable energy generation and reduce transmission congestion.[17] [18] [21]

5.4 Building Energy and Comfort Control

Thermal energy storage plays a particularly important role in building energy management and comfort control, where TES systems help reduce heating and cooling peaks, optimize energy consumption, and lower operating costs. According to data from the DOE's building energy program, 45% of the U.S. building stock's electricity consumption is for heating and cooling, a significant portion of which can be offset by the use of TES systems. Architectural applications offer a wide range of options: ice storage systems to reduce peak cooling loads, hot water buffer tanks combined with heat pumps, PCM panels to stabilize thermal comfort, and low-temperature thermal storage systems to optimize electric heating systems. For example, a 2024 GSA technology assessment showed that modular ice storage systems can reduce peak cooling loads by up to 95% and are completely fire-safe because they use a water-based energy storage system. According to NREL's building energy analyses, the use of TES systems also enables the maximum on-site utilization of renewable energy while balancing fluctuations in thermal comfort[22] [21]

Overall, it can be concluded that TES technologies can be flexibly applied to a wide range of applications, from seasonal heat balancing in district heating systems and industrial waste heat utilization to meeting the regulatory requirements of electricity systems and optimizing thermal comfort in building energy systems. Based on international research, thermal storage is one of the key technologies for future energy systems, contributing significantly to decarbonization, reducing operating costs, and radically increasing the integration of renewable energy.

VI. Innovations and Trends

Heat storage technologies have undergone rapid development over the past decade: the rapid advancement of high-temperature energy storage, materials science, electro-thermal integration, and modular systems has all contributed to the industry's growth. The goal of these new technologies is to make renewable energy systems more stable and to enable the replacement of fossil-fuel-based industrial processes.

6.1 General Industry Innovation Trends

- *The spread of high-temperature thermal storage*

International projects clearly demonstrate that the 300–800 °C thermal storage range is becoming increasingly important for industry. Siemens Gamesa ETES, for example, heats volcanic rock in the storage unit to 750 °C, thereby retaining heat for up to a week. Rock, concrete, or molten salt-based systems operating in a similar range offer high energy density, rapid heat release, and industrial steam generation capabilities, making them suitable for the electrification of sectors with high heat demand—such as the steel, chemical, or paper industries.

- *Rapid development of power-to-heat (P2H) integration*

Fluctuations in renewable energy production and frequent periods of overproduction are driving the adoption of Power-to-Heat (P2H) solutions worldwide. The Siemens ETES project is one such system: it converts electricity into heat using resistance heating, which can later be converted back into electricity via a steam turbine. The systems from Azelio and Brenmiller can also be charged via direct electric heating, enabling heat storage systems to become flexibility tools for the electricity market.

- *Growing demand for long-term (seasonal) storage*

Seasonal heat storage requires technologies capable of retaining energy for months. SaltX's thermochemical system uses a reversible reaction between calcium oxide (CaO) and water, enabling nearly loss-free, long-term heat storage—as demonstrated by the 1 MW / 15 MWh pilot being built in the city of Luleå. Thermochemical technologies are therefore particularly promising for the seasonal transfer of industrial waste heat.

- *Modular, transportable, and scalable systems*

Modern TES solutions are increasingly built on a modular basis. Brenmiller's bGen™, for example, uses prefabricated bCube modules that can be quickly installed and scaled from 10 to 500 MWh of capacity. EnergyNest (concrete cells) and Kyoto Heatcube follow a similar modular logic, as they are also assembled from prefabricated components. This trend significantly shortens construction time and reduces investment risks.

- *Hybrid thermal energy systems*

Heat storage systems are increasingly being integrated with other energy technologies. Siemens Gamesa ETES, for example, is capable of feeding electricity back into the grid via a steam turbine (H2P), while the Brenmiller and Kyoto systems can be combined with industrial steam production using P2H charging. Hybridization increases the flexibility of energy systems and reduces consumption peaks.

6.2 Specific innovative technologies

- *EnergyNest – HEATCRETE® concrete heat storage (Norway)*

The development of EnergyNest is based on a special high-thermal-inertia concrete called HEATCRETE®, which stores heat in blocks integrated with steel heat exchanger tubes. The technology enables operation at around 320 °C, a long service life of up to 30–50 years, and low maintenance costs, while being compatible with water/steam or thermal oil media. The system is designed to provide a stable heat supply for industrial processes and is also suitable for energy balancing in combination with renewable energy.

- *Kyoto Group – Heatcube™ (Norway)*

The Kyoto Heatcube™ is a modular, molten salt-based thermal storage system developed specifically for industrial power-to-heat solutions. The technology can be charged using P2H resistance heating and delivers heat in the 150–450 °C range via a steam generator. Depending on the installation, the system can scale up to tens of MWh in capacity and is capable of up to ~10

MW of charging power. Its advantages include high energy density and easy integration into industrial processes.

- *Brenmiller Energy – bGen™ (Israel)*

Brenmiller bGen™ is a crushed rock-based, sensible heat storage system optimized for industrial heat and steam production. The technology is available with capacities ranging from 100 to 500 MWh and heat outputs of 1–80 MWth; charging can be performed either electrically or thermally. The system enables storage temperatures of up to 650 °C and supports industrial electrification with its fast response time. Due to the storage unit's compact design, it is also suitable for brownfield industrial sites.

- *SaltX – EnerStore / Luleå Pilot (Sweden)*

SaltX's nano-coated calcium oxide-based thermochemical energy storage technology uses the $CaO + H_2O \leftrightarrow Ca(OH)_2$ reaction to store and recover heat. The 1 MW / 15 MWh pilot developed in Luleå is designed for the large-scale reuse of industrial waste heat, and its unique feature is that heat can be stored for up to months without loss. The technology is thus suitable for seasonal energy storage and industrial emission reduction.

VII. International Examples

Industrial and commercial applications of thermal storage technologies are undergoing spectacular development worldwide. The following international examples are not merely experimental solutions, but operational, full-scale systems that concretely demonstrate the technical feasibility, industrial applicability, and economic potential of sensible, latent, and thermochemical heat storage. See Table 2 for a comparison of the international examples presented below.

7.1 Siemens Gamesa ETES – Hamburg, Germany

The ETES (Electric Thermal Energy Storage) system developed by Siemens Gamesa is one of the world's largest operational sensible heat storage facilities. According to the official project description, the facility built in the Hamburg-Altenwerder area uses 1,000 tons of volcanic rock as a storage medium, which is heated to up to 750 °C using electric heating. The system has a charging capacity of 5.4 MW and a thermal storage capacity of 130 MWh, which it can retain for up to a week and then convert back into electricity via a steam turbine as needed. This project demonstrates that thermal storage is suitable for high-temperature energy storage lasting up to several days and for integration into metropolitan industrial systems[23] .

7.2 Azelio TES.POD – Sweden / MBR Dubai

The Azelio TES.POD system uses recycled aluminum phase-change material (PCM) that stores heat at approximately 600 °C. The TES.POD is a hybrid, latent-sensing thermal storage system

that converts stored heat into electricity via a Stirling engine, while also providing low-temperature (55–65 °C) heat supply . The system is capable of 13 hours of continuous discharge time and has an estimated lifespan of 30 years. This is an excellent example of how latent storage and decentralized power generation can be combined [24] .

7.3 1414 Degrees – SiBox (Australia)

The SiBox, developed by 1414 Degrees, is one of the world's most advanced high-temperature latent heat storage systems, using silicon as the energy storage medium. Silicon's extremely high latent heat of fusion (1414 °C) enables the SiBox to provide air at temperatures ranging from 700–850 °C, and even above 900 °C in certain tests, for industrial applications. The demonstration module, supported by the company and the Australian government, was commissioned with a capacity of 1 MWh and demonstrated stable operation over dozens of cycles [25] .

7.4 Brenmiller Energy – bGen (Israel / Italy / EU)

Brenmiller's bGen and "bCube" systems are solid-state, rock-based thermal energy storage units that can be heated to temperatures of up to 650 °C. bGen technology has been installed in several countries, including Italy as a partner of Enel, as well as at multiple industrial sites worldwide. The system is capable of converting electrical energy into heat, and then into steam or hot air, which can be directly integrated into industrial processes [26] .

7.5 SaltX EnerStore – Luleå, Sweden

SaltX EnerStore is one of the world's first large-scale thermochemical energy storage systems, utilizing nano-coated salt in reversible thermochemical reactions. The 1 MW / 15 MWh demonstration system being built in Luleå aims to enable long-term, loss-free (seasonal) storage of industrial waste heat. According to the official project announcement, the system is being implemented in collaboration with local steel industry and district heating network operators [27] .

2. Table: Comparison of international examples

Parameter	Siemens Gamesa ETES (DE)	Azelio TES.POD (SE/UAE)	1414 Degrees SiBox (AU)	Brenmiller bGen (IL/EU)	SaltX EnerStore (SE)
Type of storage principle	Sensitive (rock)	Latent technology and Stirling engine CHP	Latent (silicon)	Sensitive (rock)	Thermochemical (nano-coated salt)
Storage medium	Volcanic rock (1,000 t)	Recycled aluminum PCM (600 °C)	Silicon and SiBrick (1414 °C melting point)	Rock (up to 650 °C)	Nanocoated salt (thermochemical cycles)
Energy capacity	130 MWh	13-hour discharge time (~13 kWh/kW)	1 MWh demonstrator (75 MWh planned)	10–500 MWh scalable	15 MWh
Charging power	5.4 MW (electric)	5–6 hours charging time (approx. 13 kW per unit)	Grid-connected electric heating (MW level)	2–100 MW electric charging	Industrial waste heat and electric charging
Operating temperature	750 °C rock heating; 480 °C steam	600 °C PCM; 55–65 °C heat supply	700–850 °C (demo), up to 900 °C	100–530 °C (steam/heat)	300–450 °C typical reaction range (industrial waste heat)
H2P mode	Backflow power generation from a steam turbine	Stirling engine electricity generation	Heat only; no H2P	Steam turbine optional	Suitable for steam generation, primarily heat
Discharge time	up to 1 week of heat retention	13 hours of electricity + heat	6–12 hours of continuous heat output	Continuous 24/7 steam/heat supply	Multiple days–weeks (thermochemical)
Application area	Grid-connected LDES; Re-electrification	Decentralized CHP; off-grid	Industrial high-temperature processes	Industrial steam/heat; P2H	Industrial waste heat, district heating

VIII. Applicability of thermal storage systems in Hungary

Hungary's energy system—including district heating, industrial heat consumption, and the electricity grid—possesses structural characteristics that make it particularly conducive to the widespread application of thermal energy storage (TES) technologies. According to the international literature, TES systems can be utilized most efficiently where there are significant fluctuations in heat demand over time, a high share of renewable energy, and substantial waste heat generation; in Hungary, all three conditions are clearly met.

In district heating systems, which provide heat to more than 650,000 households in Hungary, thermal energy storage can create particularly high added value. Based on international examples and DOE publications, TES systems significantly reduce the need for natural gas-based peak heat generation and enable the more efficient integration of renewable heat sources (solar collectors, heat pumps, biomass) into the network[17] [19] . Large-scale solutions providing seasonal storage, such as PTES, BTES, or TTES, are capable of handling energy quantities in the order of several GWh[9] .

The domestic industrial sector generates significant amounts of waste heat, the temperature, volume, and temporal profile of which often do not align with production needs. According to data from the DOE Industrial Waste Heat Recovery program and the ORNL waste heat utilization study, TES systems are particularly suitable for this type of waste heat recovery, as they enable delayed heat utilization, improve process stability, and reduce primary energy consumption[28] [20] . Modern industrial TES solutions, such as rock-bed or concrete-based high-temperature storage systems, are all capable of producing process steam and can also be integrated with ORC or steam turbine systems, which increase the flexibility of electricity generation.

From the perspective of the electricity system, thermal energy storage systems offer additional strategic advantages. In Hungary, due to the rapid growth of solar power capacity, renewable energy overproduction is becoming increasingly common, which can lead to curtailment. Based on grid flexibility research by the DOE and NREL, TES systems combined with P2H technologies are capable of converting excess electricity into heat, thereby reducing curtailment rates and relieving the transmission and distribution grid[15] [21] . According to numerous analyses, several thermal storage technologies are suitable for providing balancing services (such as FRR or mFRR), as their response times can be as short as a few minutes, and in some cases even on the order of seconds[18] .

Among the various technologies, sensible heat storage (water, rock, concrete, molten salt) currently offers the widest range of applications and the greatest cost-effectiveness in Hungary. According to comparative studies by the DOE and Sandia, these systems offer low specific costs, high cycle stability, and heat storage and recovery efficiencies of up to 80–95% in particularly low temperature ranges[12] [15] . Thermochemical heat storage, on the other hand, offers extremely high energy density and loss-free long-term storage, making it an excellent pilot technology for Hungary, particularly for seasonal storage needs or industrial high-temperature processes [18]

III. Operational examples and best practices from EU member states

This chapter of the study reviews how district heating and cooling (DHC) systems relate to energy and heat energy communities (CEC/HEC) in the European Union. We systematize cooperation patterns, governance, and financing models. We then illustrate existing practices using country examples (Denmark, the Netherlands, Austria, Germany), with a particular focus on community-owned or community-managed district heating and cooling solutions and 4th–5th generation low-/very low-temperature networks. We examine the question of whether there are heat energy communities in the EU and discuss the situation in Hungary.

I. Cooperation models for district heating, district cooling systems, and heat energy communities

Cooperation between district heating and cooling (DHC) systems and energy communities—specifically, community-owned or community-managed heat energy communities (HECs) focused exclusively on heat energy—has gradually emerged in the EU. The two key concepts of the Clean Energy for All Europeans package (CEP)—renewable energy communities (REC) and civic energy communities (CEC)—now clearly extend to the heating and cooling sector as well. This framework enables local communities—residents, municipalities, and small businesses—to generate, share, sell, or store energy, including heat, under joint ownership and open, democratic governance[29] [30] .

One of the main advantages of linking district heating and cooling systems with thermal energy communities is that, due to the nature of the heating market, a large portion of the investments consists of infrastructure that functions as a natural monopoly (pipeline networks, heating plants, storage facilities). Community ownership or, at the very least, community control is particularly well-suited to the cost-effective operation of this infrastructure, as it reduces end-user costs, ensures stability in long-term planning, and minimizes the risk of excessive profit extraction. This is reinforced by the fact that REScoop.eu explicitly recommends the use of non-profit accounting and pricing models in community heating systems, as this ensures the affordability of heat services and transparent operation[31] [32] .

Typical models of cooperation include:

- a *fully community-owned district heating and cooling cooperative (such as several Danish heat suppliers),*
- *a mixed-ownership structure (municipality + community + ESCo),*
- *as well as decentralized, low-temperature systems in which residents themselves own and operate heat pumps and micro-scale heat generation units.*

Systematic case studies from the MUSE-DHC and ENABLE-DHC projects show that community participation in the planning and investment phases significantly improves the soundness of technological decisions, social acceptance, and long-term sustainability[33][34] .

II. Presentation of use cases and technological models

The technical framework for cooperation between district heating and cooling systems and thermal energy communities can be extremely diverse, but based on European trends, three main technical approaches can be distinguished.

First, waste heat-based integration stands out, which involves the use of heat released from industrial processes, data centers, wastewater treatment plants, or thermal water. According to the 2024 European report, many major cities, such as Paris, Geneva, Copenhagen, and Tampere, are integrating natural cooling or various waste heat sources for cooling and heating purposes. This relieves the burden on the electrical grid, reduces the demand for fossil fuels, and is particularly suitable for community-owned district heating systems, as locally available waste heat creates local value [35] .

The second key trend is the integration of renewable heat sources—biomass, geothermal energy, large heat pumps, and solar collectors. In Austria, for example, the installation of large-scale solar district heating has been successful in several regions (Graz Andritz, Mürzzuschlag), and heat storage systems connected to SDH systems enable a high share of renewables. Denmark is similarly advanced in this regard: the combination of heat pump, biomass-based, and solar collector systems strengthens local energy security[36] [37] .

The third trend is the spread of 4th- and 5th-generation district heating and cooling systems (4GDHC/5GDHC), which operate at low temperatures (30–55 °C or below), often with bidirectional heat flow, and combine heat generation with decentralized heat pumps. These are particularly suitable for energy communities because they allow individual consumers—such as residential complexes and apartment buildings—to even export heat to the network or reduce peak loads through local heat storage. The concepts of collective self-consumption (CSC) and energy sharing fit seamlessly into the operation of 4GDHC systems, as renewable electricity generated collectively on the electrical side can be converted into community heat via heat pumps[38] [39] .

III. Best practices in EU member states

3.1 Denmark – the strongest European example of community heat supply

Over several decades, Denmark has developed a district heating and cooling system that operates on a non-profit basis and is almost entirely built on community and municipal ownership. Nearly two-thirds of heat suppliers are consumer-owned cooperatives, and the majority of the rest are municipal companies, meaning the public directly shapes the heat supply strategy. The Heat Supply Act, in effect since the 1970s, grants municipalities full authority over heat planning and allows them to designate which city districts must connect to the district heating system. This model has been proven to promote long-term, stable investments and a public service approach[40] [41] .

Among the Danish examples**,** the Avedøre Energy Community stands out, where residents of social housing, the municipality, and the local district heating company jointly established an energy community that combines solar energy, heat production, and community decision-making. Thanks to its transparent, democratic governance and the active participation of residents, the project is an excellent example of how district heating and cooling systems can be strengthened through social innovation. A similar model is the community district heating system in the village of Føns: here, a self-organized group of residents launched the network, which today supplies the majority of the village's households, primarily using renewable energy sources[42] [43] .

3.2 Netherlands – a new generation of low-temperature community district heating and cooling systems

In recent years, the Netherlands has become the European laboratory for 4GDHC and 5GDHC systems. The ThermoBello energy community in Culemborg operates a system utilizing aquathermal heat at 30–50 °C derived from a drinking water source; it is owned and managed by the residents themselves, who also play a significant role in development decisions. The system operates with a COP of 5, efficiently manages local heat, and supplies hundreds of homes, schools, and offices. The project is a frequently cited benchmark for the "community-led heating" model [44] .

Dozens of pilot projects under the national "Aardgasvrije Wijken" (Gas-Free Neighborhoods) program also demonstrate that low-temperature systems, equipped with decentralized heat pumps and smart controls, are better suited to local energy potentials than traditional high-temperature systems. The pilots often combine heating and cooling, representing a new direction in community energy sharing. This is reinforced by an expected shift in national regulations: Starting in 2026, the Collective Heating Act (Wcw) will require that new district heating companies be at least 50% community- or municipally-owned, and that tariffs be based on actual costs—this creates an extremely favorable environment for community models[45] [46] .

3.3 Austria – solar energy + thermal storage + large-scale urban heat pumps

Austria offers numerous successful examples of Solar District Heating (SDH) systems. In various districts of Graz, Mürzzuschlag, and Salzburg, large solar collector fields are in operation; when combined with seasonal or multi-day thermal storage, they are capable of covering a significant proportion of the heat demand. These models often operate on an ESCO basis or in cooperation with local governments and fit well with the model of community-owned heat supply[47] [37]

The capital city, Vienna, has launched a particularly intensive heat pump reform. Large-scale heat pumps utilizing heat from the wastewater treatment plant and relying on local thermal sources will be operational as early as 2022, and the municipal utility has allocated more than 1 billion euros for the complete decarbonization of the district heating system. The goal of these developments is to increase renewable-based production, utilize waste heat, and stabilize consumer rates [48] .

3.4 Germany – Heat Planning Act, Comprehensive Transition, and Community District Heating

In 2024, Germany entered a new era of energy policy: the Gebäudeenergiegesetz (GEG) and the Wärmeplanungsgesetz (WPG) are radically reshaping the path to decarbonizing heating. Under the new rules, new heating systems must use at least 65% renewable energy or waste heat, and every municipality must develop a comprehensive heat plan. This heat planning obligation opens up new opportunities for cooperation between energy communities and municipal district heating companies: community-owned systems align more easily with the new criteria and offer advantages for long-term investments[49] .

According to research, the future market share of district heating and cooling (DHC) systems in Germany could grow by as much as 2–5 times by 2050, provided that network expansion focuses on densely built-up urban areas. A recent report by Agora Energiewende highlights that the current annual rate of 25,000–35,000 new connections falls short of the target of 100,000 buildings per year, making urgent infrastructure developments necessary. The advantage of community- and municipality-owned networks is that they can lead to greater public support and faster implementation, which is why they are receiving increasing attention in the German context as well[50] [51] .

IV. Presentation of EU-level projects and knowledge base

The EU, particularly through the LIFE, H2020, and CINEA programs, has launched several large-scale projects to integrate district heating and cooling models into the European energy market. The project is developing detailed investment and management plans for nine new community-led district heating and cooling (DHC) systems at the European level, using “Living Lab” local workshops where residents, experts, and municipal stakeholders jointly evaluate technical and financial options. One of the project’s most important outcomes is the Blueprint for Action, which provides practical guidance to energy communities on preparing heating projects [52] .

ENABLE-DHC examines decarbonization pathways for existing district heating systems and, through case studies, supports operators in integrating renewables, waste heat, or digital control.

In addition, it produces detailed risk assessments, sector coupling models, and financial roadmaps that can serve as a reference for any heat community launching a new district heating and cooling system project. projects are closely linked to the ManagEnergy and Euroheat & Power knowledge platforms, which publish a wide range of materials on the latest trends in European district heating and cooling systems[34] .

4.1 MUSE-DHC: Development and Testing of Community-Driven District Heating and Cooling Systems

The MUSE-DHC project (LIFE24-CET-MUSE-DHC/101215495) is a multi-country EU initiative running from 2025 to 2028, aimed at designing community-led district heating and cooling systems, developing operational models, and examining their local integration. The project comprehensively investigates the conditions under which energy communities can generate, share, distribute**,** and finance heat**,** as well as how community governance can be integrated into heat supply systems [52] .

- *The project's research focus:*

The project analyzes three major themes [52] :

1. *Establishment of new, community-led district heating and cooling networks:*

   MUSE-DHC is developing detailed investment plans (IPs) for nine new heating networks currently under development. The aim is to establish decentralized heating systems based on renewable energy sources such as biomass, geothermal energy, solar energy, aquathermal energy, and local waste heat. The project examines how to establish democratic governance, a community-owned structure, and a sustainable financial framework for these systems.

2. *Mechanisms for community participation and social innovation:*

   At each location, local working groups called "Living Labs" have been established, where residents, local governments, heat producers and waste heat suppliers, energy experts, and local businesses participate together in the planning process. The project examines how community participation can be integrated into district heating and cooling (DHC) system developments in a structured, decision-supporting manner.

3. *Hybrid ownership and financing models:*

   One of the project's most innovative investigations focuses on how municipal ownership, community ownership (energy communities, cooperatives), and the private sector (e.g., ESCO companies) can be combined into a stable, transparent, and long-term sustainable structure. As a result, the project's "Blueprint for Action" document will develop guidelines for launching heat energy communities across Europe.

- *Geographical locations of the studies:*

MUSE-DHC is conducting nine case studies in five European countries: Spain, France, Ireland, Italy, and the Netherlands. Each location represents a different type of area. These include densely built-up urban districts, smaller rural settlements, and mixed-use (residential-industrial-public) neighborhoods. This ensures that the study covers a large part of the potential application spectrum of district heating and cooling systems[52] .

- *Organizations and stakeholders participating in the project:*

The project is coordinated by the Italian organization Ambiente Italia and operated by a consortium of 10 other partners. The consortium participants include, among others [52] :

- REScoop.eu – *the umbrella organization for European energy communities*
- Energie Samen (NL) – *a community energy developer with extensive experience*
- OSONA Energia (ES) – *a local energy cooperative*
- SUNO Enginyeria (ES) – *technical energy developer*
- Energy Cities / Energie-Cités – *European network of cities*
- Bois Énergie Renouvelable (FR) – *local forestry and biomass technical partner*
- Claremorris Energy Coop (IE) – *Irish energy community*
- EnGreen Srl (IT) – *technical and economic analysis firm*

- *Results achieved by the project so far*

Within the framework of the project, investment plans were developed for nine new district heating and cooling networks. Detailed technical, business, and community models were created for each case study. Community governance models were developed to conduct a comparative analysis of decision-making and ownership structures. A key achievement is the "Blueprint for Action," a European-level guide designed to facilitate the creation of future thermal energy communities. In addition, strategic guidelines and position papers were formulated regarding energy transition legislation [52] . The results show that community heat supply, particularly low-temperature, renewable-based systems, is technically and economically viable and enjoys high social acceptance.

4.2 ENABLE-DHC: Exploring Decarbonization Opportunities for Existing District Heating Systems

The ENABLE-DHC project (2024–2027) is one of the EU's most comprehensive initiatives, specifically focused on how existing district heating and cooling networks can become more efficient, renewable-friendly, and low-emission. The project examines 9 different district heating and cooling systems in 7 countries (Austria, Croatia, Ireland, Italy, Latvia, Slovenia, Ukraine) [34] .

- *The project's specific areas of investigation:*

The research focus of ENABLE-DHC can be divided into three main areas of investigation [34] :

1. *Detailed assessment of the technical condition of existing district heating and cooling networks*:

   The project conducts detailed data collection at each site regarding the heat generation mix (gas, biomass, waste heat, geothermal energy), the condition of the network, and heat losses. It also examines system failures that impair energy efficiency. The aim of the study is to determine which technologies can reduce CO_2 emissions most quickly and cost-effectively.

2. *Development of decarbonization roadmaps and investment strategies:*

   The project will prepare separate medium- and long-term investment plans for each district heating and cooling system, which will include, among other things, the costs of integrating renewable energy sources, the installation of digital control systems (sensors, optimization algorithms), the role of thermal storage and heat pumps, and network retrofitting options (toward 4GDHC). The plans also include specific risk analyses and sector-linking studies.

3. *International knowledge sharing and replication:*

   The goal is for the studies to be utilized not only at the local level but also as a model for Europe. To this end, the project organizes national workshops and pan-European webinars. It also operates a joint "Case Study Assembly" forum. As part of the study, 18 "follower cities" are also involved so that the lessons learned can be applied in other cities.

- *Study locations and country coverage*

ENABLE-DHC operates in 7 different countries, with 9 case studies. The 7 countries are Austria, Croatia, Ireland, Italy, Latvia, Slovenia, and Ukraine. Due to the varying climatic, infrastructural, and economic conditions at the sites, the project is able to compare the differences, typical obstacles, and potential solutions for district heating and cooling systems in Eastern, Central, and Western Europe[34] .

- *Institutions and professional partners participating in the project*

The project was organized within the framework of the DHC+ Platform and the Euroheat & Power professional network, with the active participation of energy authorities and heat suppliers from several countries. These include national/municipal heat suppliers, technical research institutes, heat supply engineering firms, and energy policy organizations. The project's technical

coordination is of an exceptionally high standard, covering the entire heat market value chain [34] .

- *Results and conclusions of the project to date*

The results of ENABLE-DHC to date include, among other things, 9 comprehensive decarbonization plans, each containing hundreds of pages of technical, financial, and regulatory analysis. The most significant efficiency issues (obsolete heat generators, high heat losses, limited waste heat integration) were successfully identified through multiple technical diagnoses. A common European guide was developed that provides district heating and cooling providers with a step-by-step description of the options for transitioning their heating networks. Thanks to the project, a broad professional collaboration has emerged involving more than 50 supporting partners and 18 follower cities [34] . One of the project's most important findings is that the technical modernization of most district heating and cooling networks does not require a complete infrastructure overhaul**;** rather, targeted renewable integration and digitalization can achieve a 20–40% increase in efficiency.

V. The existence of EU thermal energy communities

Based on available European examples, it can be clearly stated that EU thermal energy communities exist, even if the concept is not a legally distinct category but appears as part of energy communities (REC/CEC). ThermoBello (NL), the Avedøre Energy Community (DK), the Føns (DK) community district heating system, and the new district heating and cooling networks examined within the framework of several LIFE projects all demonstrate this practice. A common feature of these is community-based decision-making, democratic oversight, and the fact that the heat supply infrastructure is owned by the community or at least partially by the community[44] [42] [43] [52] .

The REScoop.eu Guidelines on Community-Led Heating and Cooling also contain specific recommendations on how these practices can be adapted in other regions. This also means that community-led district heating is not a marginal phenomenon in the EU, but an increasingly important model, particularly in municipalities affected by heat decarbonization[32] .

IV. Potential Pilot Sites in Hungary

I. Introduction

1.1 Connection to the overall objectives of the REHEATEAST project

The main objective of the REHEATEAST project is to reduce the fossil fuel consumption of district heating systems in the eastern parts of the Danube region and to promote the integration of renewable energy sources, including geothermal energy, into local energy communities.

This study presents Békéscsaba as a potential pilot project site in Hungary that directly supports this objective, as:

- It relies on 100% renewable geothermal heat production for a group of sports, recreational, and public facilities.
- A modular, expandable district heating (DH) system can be developed, which increases the share of renewables through the gradual integration of local heating zones (A, B, C).
- Geothermal conditions allow for the replacement of fossil gas, which is one of REHEATEAST's most important outcomes.

Furthermore, the pilot:

- demonstrates the practical application of the HEC (Heat Energy Community) concept by connecting multiple heat sources and multiple consumer zones,
- increases local supply security,
- reduces the carbon intensity of the district heating system.

The identified heat market is divided into three main heat zones (A, B, C), which include municipally owned, community, and sports facilities, see Table 3.

3. Table: Heating zones of the identified heating market

Heating Zone	Major consumers	Estimated heat demand (GJ/year)
A	Sports hall, fencing hall, sports fields, swimming pool	19,248
B	Children's dining hall, event halls	23,602
C	Árpád Medical and Beach Baths (with its own thermal spring)	as an integrable source

The city's heat demand is concentrated in a densely built-up, utility-connected area, which favors the development of a short heat pipeline network.
The combined heat demand of the "A+B" districts is 2.6–3.0 MW, which can be fully met by a newly constructed geothermal production well and two reinjection wells.

1.2 Link to Specific Objective 2.1

The aim of Specific Objective 2.1 of the Interreg Danube Region Programme is the decarbonization of the energy and transport sectors by strengthening the integration of renewable energy sources, with a particular focus on the transformation of local and regional energy systems. This objective specifically encourages investments and pilot projects that serve to replace fossil fuels, increase the share of renewable energy, and improve local energy independence. [53]
The Békéscsaba pilot is closely linked to the objectives of Specific Objective 2.1:

1. *Integration of renewable energy into the heating sector*
   The pilot project will establish a new geothermal production well with a flow rate of 25 l/s and an outlet temperature of ~100 °C, along with one or more reinjection wells. This fully supports the Danube Region Program's goal of increasing the share of renewables in district heating systems.

2. *Replacing fossil fuels*
   Heating for local sports facilities, event halls, and public institutions currently relies predominantly on natural gas. Geothermal supply can replace gas sources in thermal zones A and B and provide a redundant solution for the spa facility in thermal zone C.

3. *Energy efficiency and network modernization*
   The project includes the construction of a new heating plant, new primary and secondary transmission lines, the integration of heating zones, and the development of a reinjection system, which strengthens the decarbonization of the district heating sector.

4. *Regional pilot project*
   The pilot effectively demonstrates how a renewable district heating system based on a heat energy community can be gradually established in a medium-sized city—serving as a model for the entire Danube Region.

1.3 Link to Activity 2.3

Activity 2.3 of the REHEATEAST project focuses specifically on the preparation and testing of pilot projects, with particular emphasis on the integration of renewable heat generation technologies into district heating systems. The aim of the activity is to develop well-founded pilot projects that are technically and legally sound, which can later be transformed into actual

investments or replicable demonstration projects.[54] [55] The Békéscsaba pilot project fits this activity perfectly, as:

1. *Detailed technological preparation has been carried out:*
   – geothermal potential assessment (45.1 °C/km gradient, 110 °C formation temperature),
   – technical plans for thermal well construction,
   – heat zone consumption data, with a maximum demand of 2.1–2.65 MW.
2. *Testing of three DH configurations (A / A+B / A+B+C).*

3. *Development of a renewable heat integration model with multiple heat sources and modular scalability.*
4. *Risk analysis, exploration of regulatory frameworks, with reinjection and surface disposal options.*
   – Permits: preliminary review, water rights permit, MEKH district heating producer permit, etc.
5. *Comprehensive pilot preparation that meets the requirements of Activity 2.3 "Preliminary technical and legal preparation."*

1.4 The Békéscsaba pilot's contribution to the objectives of the Danube Region Programme

In line with the DRP's "green" priority, member states must focus on projects that:

- reduce CO_2 emissions,
- improve local energy independence,
- increase the integration of renewables,
- support sustainable urban development. [53]

Accordingly, the pilot:

- *reduces CO_2 emissions*
  Replacing gas heating with geothermal energy enables a reduction of several thousand tons of CO_2 annually.
- *Increases energy independence*
  Békéscsaba is not dependent on the volatility of the natural gas market; it covers a large portion of its heating needs with local resources.
- *Integrates renewable energy*
  100% geothermal supply + integration of existing thermal wells.
- *Demonstrates DH + RES integration as a pilot*
  The three possible configurations clearly illustrate scalable development.

1.5 Alignment with national, regional, and EU energy strategies

The Békéscsaba pilot is closely aligned with the energy policy documents of the European Union and Hungary.

- *EU-level strategies:*
  - EU Energy Efficiency Directive (EED) and RED III
    The project is in line with the requirements of the Energy Efficiency and Renewable Energy Directives (RED III – 2023/2413 EU), particularly regarding the decarbonization of district heating systems and increasing the share of renewables.[56] [57]
  - EU 2030 Climate and Energy Framework
    The geothermal system contributes to meeting the 2030 targets, which include a minimum 32% share of renewables and a 55% reduction in GHG emissions. [58]
- *National Energy Strategies*
  - Hungary's National Energy and Climate Plan (NEKT)
    Key objectives of the NEKT include increasing the share of renewable energy, reducing dependence on energy imports, and greening district heating systems. [59] The Békéscsaba pilot meets these objectives by integrating renewable heat into an urban district heating network.
  - National Energy Strategy 2030 (with a view to 2040)
    The strategy highlights the need to harness geothermal potential, particularly in rural towns[60] . The pilot provides a concrete example of the strategy's practical application.

- *DH-specific policy documents*
  - District Heating Development Action Plan / District Heating Programs of the Modernization Fund:
    Both major domestic funding programs (MEGÚJULÓ + INFRA) support heat storage, renewable heat generation, geothermal systems, and the modernization of heating plants and networks[61][62] . The specific technical scope of the Békéscsaba pilot corresponds to these eligible activities.

II. Pilot Description

2.1 Problem Definition and Context

- *The pilot's objective and relevance*

Békéscsaba is a major regional center in the Danube Region, where heat supply to public institutions relies predominantly on natural gas. Consumer areas outside the existing district heating network (sports facilities, event halls, community buildings) do not have a heat supply solution based on renewable energy sources, even though the city's region has one of the country's best geothermal potentials.

These geothermal potentials are as follows:

- Geothermal gradient: 45.1 °C/km (one and a half times the global average)
- Accessible depth: 2,200–2,500 m
- Expected formation temperature: 100–110 °C
- Expected flow rate: 20–25 l/s (sustainably maintainable in pumped mode)
- Chemical composition: medium–high hardness water, moderate methane content (CH_4 ≈ 30–50%)

Previous studies (e.g., wells with cadastral numbers 3-102, 3-137, and 3-4) confirm that the Upper Pannonian aquifers possess excellent heat supply capacity. Based on this, Békéscsaba is an excellent pilot site for geothermal district heating from a geological perspective.

The objective of the pilot project:

- to investigate the development of a small-scale, modularly expandable, geothermal-based district heating system;
- to integrate the heating zones in phases A → A+B → A+B+C;
- the partial or complete replacement of fossil natural gas;
- practical demonstration of the thermal energy community concept within the REHEATEAST framework.

This represents a new approach that replaces the existing fragmented institutional heat supply with a unified system based on renewable energy.

- *Added value*

The Békéscsaba pilot is the first to explore the creation of a thermal energy community system comprising multiple heating zones and thermal wells**,** which also integrates the energy from the existing spa well and presents a modular DH model that can be replicated in any Hungarian city of similar size. It increases supply security (by connecting the spa well to the public sector district) and generates surplus heat suitable for later industrial or agricultural use (greenhouses, fish farming, snow melting).

- *Needs and challenges addressed by the pilot*

The study identified the following issues:

- the heat supply for public institutions is heavily dependent on natural gas;
- consumers are scattered, forming small, isolated groups with heat demand, which hinders grid integration;
- existing geothermal potential remains untapped, despite the availability of a decades-old network of thermal wells;
- the thermal well serving the spa's heating zone is not connected to other institutional heat consumers, so supply security is not optimal.

Its significance is also outstanding at the national level, as Hungary's geothermal potential is of strategic importance, yet most rural towns have not yet exploited it.

2.2 Analysis of the current situation

- *Data collection and information used*

  The preparation of the pilot project was based on the following data:

  - Archival thermal well databases (depth, temperature, yield) – analysis of wells drilled between 1959 and 1982 at depths of 800–2,500 m.
  - Heat consumption data provided by the municipality of Békéscsaba (heating zones A, B, C).
  - Defined heat demand profiles (2.1 MW; 2.65 MW peak load).
  - Planned new well yield of 25 l/s based on free-flow yields of 6–22 l/s.
  - Annual temperature curves and heating capacity distribution (365-day meteorological statistics).

- *Assumptions and limitations*

Limitations of the study:

- no detailed geological model was prepared (preliminary-level assessment);
- heating demands are partly estimates, as detailed energy audits were not available for all buildings;
- the network design was prepared only with high-level geometry (A, A+B, A+B+C variations).

- *Identified shortcomings*

  The pilot demonstrates that:

  - no renewable energy is currently integrated into these institutions;
  - the spa's own well does not supply the city's public institutions, even though it has the capacity to do so;
  - there is no interconnected, redundant geothermal network, so there is no heat energy community model;
  - there are no thermal storage facilities or P2H solutions in the area;
  - the current low utilization of geothermal energy does not meet the requirements of either EU RED III or NEKT.
  - the district heating licensing and network model does not automatically support new connections.

  These shortcomings underscore that the modernization of the system is not only an energy issue but also a structural and institutional one.

2.3 Optimization objectives

The Békéscsaba pilot serves the optimization goals summarized in Table 4.

4. Table: Optimization objectives for Békéscsaba

Optimization goal	Specific objective	Key Performance Indicators (KPIs)
1. Optimization of heat production	Full replacement of consumer heat demand (19,248–23,602 GJ/year) with geothermal energy	Share of renewable energy (%) Reduction in gas consumption (m^3/year)
2. Optimization of heat distribution (heat district integration)	Gradual interconnection of heating districts A → A+B → A+B+C	Supplied heat capacity (MW) Network loss (%)
3. Increasing supply security	Integration of multiple thermal wells (new well + Árpád Baths well)	Number of redundant heat sources Number of avoided outages
4. Secondary utilization	Use of cooled thermal water for agricultural / industrial / snow melting purposes	Secondarily utilized thermal energy (GJ/year)

2.4 Cooperation objectives

The pilot is based on cooperation among multiple stakeholders; see Table 5. The goal of the cooperation is to develop a broad-based, shared-responsibility energy community model.

5. Table: Pilot participants

Stakeholder	Role	Objective
MJV Municipality of Békéscsaba	Consumer data, site provision	Involvement of institutional heating districts
Local district heating provider / municipal utility	Operation	DH integration
Spa operator	Transfer of existing thermal well	Improving supply security

Geothermal engineering organization	Technical preparation	Determination of well parameters
REHEATEAST partners	methodological and thermal energy community model support	International knowledge sharing

2.5 Implemented solutions and pilot implementation steps

The pilot implements the technical and organizational solutions presented in Table 6.

6. Table: Technical and organizational solutions of the pilot

Pilot solution	Specific activities
1. Testing the integration of geothermal sources	• Drilling of a new production well at the Sports Hall • Construction of reinjection wells (1–2 wells) • Construction of a primary geothermal loop (~1,500–4,100 m)
2. Interconnection of heating zones	• Connecting heating zones A (sports facilities) → B (public institutions) → C (spa) • Construction of a 920 m long connecting pipeline
3. Construction of a new heating plant	• Installation of heat exchangers • Pumps • Design of control systems
4. Assessment of secondary heat recovery	• Greenhouse heating options • Fish farming applications • Heat utilization for snow melting

2.6 Main steps and milestones of the pilot implementation

The steps and milestones to be implemented during the pilot are distributed as listed below, and the Gantt chart for the project is illustrated in Figure 1.

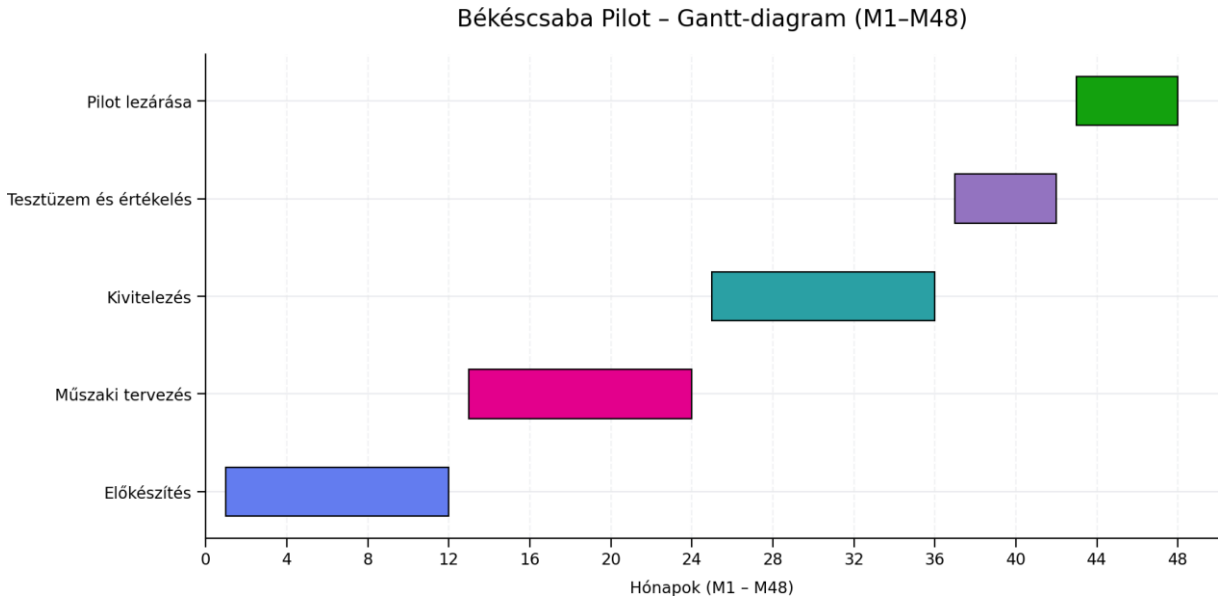
- *Preparation phase (0–12 months)*
  - Preliminary geological assessment, well parameter estimation;
  - determination of heat demand for heating zones;
  - development of 3 system layout models;
  - initiation of the permitting process (preliminary review).

- *Technical design (12–24 months)*
  - water rights construction permitting;
  - design of geothermal and consumer networks;
  - Finalizing the locations of production wells and reinjection wells.

- *Construction (24–36 months)*
  - Well drilling and testing;
  - construction of heat pipelines;
  - construction of a heat distribution center;
  - Network construction from Zone A to Zones A+B and C.

- *Test operation and evaluation (36–42 months)*
  - system trial operation,
  - collection of heat production data,
  - optimization recommendations.

- *Pilot project closure (42–48 months)*
  - transfer of the operating model;
  - Heat Energy Community (HEC) proposal package;
  - international dissemination.



1. Image: Pilot Gantt chart

III. Analysis and results

3.1 Methods and tools used

The Békéscsaba pilot employed a methodological framework suitable for the preparation and evaluation of a DH system based on renewable energy sources. The main tools and methods used in the pilot:

- *Geothermal potential assessment:*
  Processing of archived thermal well databases (wells drilled between 1959 and 1982 at depths of 800–2,500 m) and analysis of actual bottomhole temperature measurements (values between 110–134 °C). Determination of the area's characteristic geothermal gradient of 45.1 °C/km, which is above the Hungarian average.

- *Heat Zone Segmentation*
  Based on an analysis of the heat demand of municipal public institutions and sports facilities, three heating zones (A, B, C) were defined, which can be examined separately and then integrated into a multi-source system.

- *Heat demand and consumption profile analysis*
  Detailed building list and heat output estimates (max. demand: Zone A: 2.1 MW, A+B: 2.65 MW). The annual heat demand range is 19,248–23,602 GJ/year.

- *Development of technical system models*
  Three system configurations are tested (A, A+B, A+B+C) and various well and pipeline geometries are examined. Re-injection alternatives are determined.

- *Analysis of the permitting process*
  A detailed regulatory permitting structure was identified in the pilot (water rights permit, MEKH permits, preliminary review, etc.).

3.2 Impact assessment

The aim of the pilot is to demonstrate the technical and economic feasibility of a geothermal-based, modular DH system. Table 7 lists the project results and quantitative performance metrics.

The project achieved the following impacts:

- *Qualitative impacts*
  - Energy and environmental results
    The gas consumption of the entire group of institutions (sports and public facilities) can be significantly replaced by geothermal energy. The integration of the spa's

existing thermal well results in further CO_2 reductions. Exposure to external fossil fuel markets is minimized.

- Operational impacts
  Security of supply is increased through redundant heat sources (new well + well in Zone C). Scalable system—suitable for the future integration of industrial consumers (e.g., greenhouses, process heat applications).

- *Impacts on target groups*
  - Municipality: reduced utility costs, security of supply.
  - Sports and public facilities: stable heat supply, lower operational risk.
  - Residents: cleaner air, environmentally friendly infrastructure.
  - Danube Region: replicable project with demonstration value.

7. Table: Quantitative KPIs

KPI category	Indicator	Value	Comment
Energy production	Geothermal yield	25 l/s	based on model
	Outlet water temperature	~100 °C	estimate
Share of renewable energy	Increase in RES share	0% → 80–100%	A+B can be fully supplied
CO_2 reduction	Annual emissions avoided	600–800 t/year	Heat demand × 56 kg/GJ
Heat loss	Reduction in network losses	10–15%	due to short route
Economic benefit	Gas substitution	600,000–900,000 m³/year	Heat demand × Specific emissions
	Reduction in institutional utility costs	20–35%	Lower geothermal OPEX
Security of supply	Number of redundant heat sources	2	New well + spa well
Secondary heat utilization	Utilizable low-temperature heat	20–40%	greenhouse, snow melting, H2P

3.3 Stakeholder engagement

Several stakeholders are involved in the implementation of the pilot project, all playing a key role; see Table 8.

8. Table: Stakeholders involved in the pilot implementation

Stakeholder	Role	Method of involvement
MJV Local Government of Békéscsaba	Heat demand data, securing the site	workshops, data requests
Sports centers, institutions	Heat consumption data	interviews, site visits
Spa operator	technical data of existing well	technical consultations
Mannvit Kft. (geothermal engineer)	preparation of a preliminary technical study	Engineering consultations
REHEATEAST project partners	methodological support	regional meetings

3.4 Transferability – Transferability and replicability

The Békéscsaba model is exceptionally well-suited for adaptation to other municipalities because:

1. *Modular heating district logic:*
    - Geothermal supply to small local heat demand nodes → integration of multiple districts.

2. *Repurposing existing thermal wells:*
    - There are more than 900 thermal wells in Hungary – typically underutilized.

3. *Low network construction requirements:*
    - not a full-scale urban district heating system, but targeted “micro-DH.”

4. *Easily adaptable decision-making and permitting model:*
    - REHEATEAST methodology → preparation guide for other cities.

3.5 Sustainability

Long-term sustainability benefits of the pilot:

- Geothermal energy as a continuous, weather-independent renewable source
- Reinjection ensures the regeneration of the aquifer
- The system can flexibly serve different consumer zones
- Operating costs are predictable (low dependence on primary energy prices)

3.6 Potential integration into policy recommendations

The pilot's results are directly linked to:

- The Hungarian NEKT – increasing the share of renewable heat
- National Energy Strategy 2030 – the strategic role of geothermal energy
- RED III (2023/2413 EU) – increasing the share of renewables in the heating and cooling sector
- Domestic district heating programs under the Modernization Fund

The results of the pilot could contribute to the development of a "Hungarian Geothermal Micro-DH Guide" that could be applied nationwide.

3.7 Budget and costs

Table 9 illustrates the estimated investment costs of the three alternatives based on the study.

9. Table: Investment Costs

Option	2.0 billion HUF
Option A+B	3.0 billion HUF
Variant A+B+C	3.1 billion HUF

Potential financing instruments:

- Modernization Fund (MA/TÁVHŐ/01 and 02)
- EU "Greening the heating sector" funds
- Municipal co-financing
- ESCO or concession model (involving a geothermal service provider)

IV. Conclusions

4.1 Key lessons

The most important lesson from the Békéscsaba pilot is that the local integration of geothermal energy works effectively when the heat consumer structure is spatially concentrated and the system can be expanded modularly. The consumer structure divided into three heating zones (A–B–C) provides an ideal environment for a DH system that can be developed gradually, step by step.

The pilot project confirmed that:

- the area's outstanding geothermal conditions (45.1 °C/km gradient, >100 °C bottom temperature) represent a genuine strategic advantage;
- a production well with a flow rate of around 25 l/s is capable of covering the entire heat demand of heating zones A and B on its own;
- the existing thermal well (Zone C – Árpád Bath) can be integrated, thereby increasing supply security and reducing technical risk;
- connecting the heating zones creates a new type of multi-source thermal energy community.

This experience is also important for other municipalities: geothermal systems work best when multiple heat sources and multiple consumer units form a network, rather than when isolated, small-capacity systems operate in parallel.

4.2 Summary of Key Findings

1. Full suitability for renewable heat supply
    - Based on the technical models examined, public institutions in Békéscsaba can be supplied with geothermal energy either partially or entirely. The heat demand (19,248–23,602 GJ/year) is consistent with the heat capacity of the production well.
2. Significant CO_2 and natural gas reduction potential
    - Replacing natural gas with geothermal energy would result in annual CO_2 savings of several hundred tons.
3. Technical simplicity + scalability
    - The logic of one central heating plant + two pipeline branches + a reinjection well can be easily expanded to additional districts.
4. Security of supply benefits
    - Connecting the existing spa well provides redundancy—a rare advantage in Hungarian cities.
5. High transferability

- The model can be easily adapted to groups of institutions with a similar structure in other Hungarian cities (Gyula, Kecskemét, Szolnok).

4.3

1. *The heat district-based planning logic*

A heating district consisting of small, densely located institutions is best suited for geothermal supply. This reduces network losses and results in a more financially sustainable investment.

2. *Integration of existing thermal wells*

Many towns in Hungary have underutilized thermal wells.

The example of Békéscsaba shows that it is not necessary to build entirely new infrastructure: the existing well is a very valuable element of supply security.

3. *Modular development phases (A → A+B → A+B+C)*

Phased development allows for the minimization of investment costs and risks.

4. *Secondary heat utilization*

The use of the cooled fluid in additional applications (e.g., greenhouses, fish farming, snow melting) provides a separate revenue stream or supply security benefit.

4.4 Long-term expected impacts

The geothermal pilot project in Békéscsaba will significantly reduce the share of fossil fuels in the city's heat supply over the long term, as the current natural gas-based system will be replaced by a stable, local, and weather-independent renewable source. The use of geothermal energy also contributes to making heating prices more predictable and stable in the long term, as geothermal energy is not subject to fluctuations in the prices of international energy sources. The pilot creates an opportunity for the gradual expansion of the DH system, potentially including residential connections, which would significantly support the greening of the city's energy mix and the decentralization of heat supply. The implementation of the project also has local economic and labor market impacts: it increases employment, strengthens knowledge and competencies related to geothermal technologies, and may open up new service sectors for the city in the long term. As a result of all this, Békéscsaba could, in the long term, become one of the Danube Region's leading "geothermal model cities," demonstrating in an exemplary manner the operation and benefits of renewable-based community heating systems.

4.5 Recommendations and suggestions for further development

1. *From pilot to demonstration project*

It is recommended to implement the system up to Zones A and B, followed by the integration of the spa. This ensures the best cost-benefit ratio.

2. *Detailed geological and well-site modeling*

Next steps: aquifer modeling, pumping tests, and design of a new well.

3. *Integration of thermal storage (PTES / TTES)*

Heat storage between the summer and winter seasons improves system efficiency and increases the share of renewable energy.

4. *Gradual integration of institutional and industrial consumers*

The system's excess capacity provides an opportunity to connect industrial heat users, agricultural producers, and new urban facilities.

5. *Preparation of the HEC (Heat Energy Community) model*

Development of a proposed legal-business model: community ownership, municipal participation, service provider partnership.

V. Financial resources for the investment (mixed financing options)

I. Hungarian grant funds

The modernization of domestic district heating in the 2025–2026 period is supported by two key grant schemes financed by the Modernization Fund. These utilize funds from the European Union's Emissions Trading System (ETS) to achieve Hungary's climate goals, particularly the 30% renewable energy share [54].

1.1 Development of renewable-based heat generation

This program, with a budget of 51 billion forints, aims to replace fossil fuels by integrating renewable energy sources and innovative technologies [55].

The main objectives of the call for proposals:

- Technological transition: Installation of geothermal, biomass-based, and high-performance heat pump systems.
- Circular energy: Utilization of industrial and municipal waste heat, as well as the construction of thermal storage units to ensure system flexibility.
- Reducing import dependency: Directly replacing natural gas consumption with local, green sources.

Application criteria and framework:

- Eligibility: Business entities and budgetary agencies holding a district heating producer license (or obtaining one by the end of the project).

- Requirements: A 5-year, irrevocable commitment statement from the heat recipient is mandatory.
- Funding: The amount of the non-repayable grant may range from 200 million to 3.5 billion HUF.
- Grant intensity: Typically 45–65%, but up to 100% of costs may be claimed if a funding shortfall is demonstrated [55].

1.2 Modernization of district heating infrastructure (INFRA program)

The second budget of 45 billion HUF focuses on reducing network losses and improving the technical standards of existing systems [56].

Eligible activities:

- Modernization of heating centers: Separation of provider and user heating centers, installation of new control and measurement technologies, and digital telemechanics systems.
- Network reconstruction: Replacement and insulation of primary district heating pipelines, and installation of modern operational components to minimize heat loss.
- Future-proof solutions: Preparation for low-temperature (4GDHC/5GDHC) systems and integration of heat storage.

Important restrictions:

- Target group: Only district heating providers may apply (consortia are not eligible).
- Excluded activities: The development of secondary (in-building) heating circuits, the purchase of real estate, or investments facilitating disconnection from district heating are not eligible for support.
- Funding: The amount available ranges from 20 to 1,500 million HUF, also available at 100% intensity upon proof of a natural monopoly or a financing gap [56].

II. International financing opportunities

Domestic sources are increasingly being supplemented by international financial instruments that support large-scale energy investments through blended finance models. The essence of blended finance arrangements is that public subsidies and guarantees attract private capital by reducing investor risk and improving the bankability of projects.

The European Commission's 2026 Energy Efficiency Financing Report emphasizes that, in addition to pure grant-based schemes, financial instruments and blended finance systems provide significantly higher leverage, with a multiplier of up to 14 times, while program development tools, such as ELENA[63] and LIFE CET [64] , can achieve a leverage effect of up to thirty times.[65]

International institutions, primarily the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD), play a key role in financing large-scale thermal storage and district heating projects.[66] The EIB has supported the development of high-temperature storage facilities or energy-efficient networks in several European projects through preferential loans, while the EBRD's Green Cities program has facilitated the modernization of district heating systems in numerous Central and Eastern European cities using blended finance structures.[67] . Between 2021 and 2024, the EIB provided preferential loans for high-temperature TES solutions in several projects in Scandinavia and Germany[68] . According to international analyses, it is a key player in blended finance across the entire EU energy sector, particularly in promoting energy efficiency investments[69] .

2.1 Application of ESCO models in heat storage and district heating system investments

ESCO-based (Energy Service Company) investment models play an important role among financing options, offering a solution particularly when the project owner lacks sufficient own funds. In ESCO arrangements, the investment is financed by an energy service company, and the return on investment comes from the energy or cost savings generated later. This can be particularly advantageous for thermal storage systems, where high investment costs are accompanied by a longer payback period.

There are various forms of ESCO models, such as energy performance contracts (EPCs), BOO/BOOT solutions based on long-term ownership structures, or the "Heat-as-a-Service" model, in which the investor remains the owner of the asset and the service provider simply purchases heat from them. European practice—particularly in the Scandinavian countries—shows that ESCO-based investments can increase the financial stability of projects while significantly reducing risks for end-users. [70]

According to the 2024 summary of the PROSPECT+ program, which presents EU city-level project financing practices, ESCO models based on energy performance contracts (EPCs) successfully secure financing for municipal or utility investments where there is insufficient equity, and the project's payback period would also be long [71] .

International ESCO professional forums highlight that the sector's main financing challenges include small project size, high transaction costs, and a lack of expertise among investors and banks. [70] The 2025 International ESCO Symposium concluded that project aggregation, the capitalization of future savings, and guarantee systems (white certificates, government guarantees) significantly increase the attractiveness of ESCO financing [72]

The following ESCO models are particularly relevant for thermal storage investments:

- EPC (Energy Performance Contracting): performance-based savings guarantee,
- BOO/BOOT: the ESCO owns the thermal storage facility and transfers it to the service provider after a fixed period,

- Heat-as-a-Service: the service provider does not invest, but only purchases heat from the ESCO.

These business models have already proven themselves in major international projects. In Denmark, for example, several seasonal thermal energy storage systems (PTES) were built under a structure where district heating providers and private actors ensured a return on investment through long-term capacity purchase agreements in a joint ownership model[66][73] .

III. Financing models for large-scale thermal storage systems in Europe

The decarbonization of district heating systems and the increase in the share of renewable energy sources are now inconceivable without the use of large-scale thermal storage technologies. Seasonal thermal storage systems (PTES – Pit Thermal Energy Storage) are particularly important in countries where renewable-based heat production varies significantly over time, and there is a need to decouple production and consumption in terms of timing. Denmark has one of the world's most advanced thermal storage infrastructures, and its experience spanning more than a decade now serves as a model for other countries, including Hungary.

3.1 The Significance of the Vojens, Dronninglund, and Høje Taastrup Projects

Danish PTES systems are among the world's largest and most extensively studied thermal storage facilities. The Marstal and Dronninglund (60,000–75,000 m³) storage facilities are early examples of how seasonal thermal storage can improve the integration of renewable heat into district heating networks. Detailed monitoring data demonstrate that these systems significantly reduce the use of fossil peak sources, improve system efficiency, and provide predictable operating costs for utilities. [73]

The 70,000 m³ thermal storage facility in Høje Taastrup represents a new generation: it enables dynamic, short-cycle (1–2 week) charge-discharge operation, with up to 25–30 full cycles per year—a rarity among seasonal storage systems. This flexibility is particularly valuable in countries where the heat generation mix is changing rapidly. [16]

Financing for Danish projects typically consists of a combination of several sources:

- government subsidies (energy transition and renewable energy programs),
- subsidized EIB or state-backed loans,
- equity contributions from municipal or regional energy companies,
- long-term heat purchase agreements (capacity off-take).

The Høje Taastrup storage facility is unique in that it is jointly owned 50–50% by two district heating companies, and the return on investment is guaranteed by a 20-year capacity purchase agreement, which provides a predictable revenue structure for the heat storage facility. [74] [66]

Such a model allows for the sharing of investment risks, increases the project's bankability, and reduces financing costs, thereby contributing to making large-scale thermal storage a sustainable business model in the long term.

3.2 Multi-source financing in European urban policy projects: lessons from REMOURBAN

Another example is the REMOURBAN project (REgeneration MOdel for accelerating the smart URBAN transformation), one of the European Union's flagship urban development projects, which aimed to develop a holistic, energy-, mobility-, and digital-focused urban regeneration model and validate it in a metropolitan setting. The program was launched in three "lighthouse cities" (Valladolid, Spain; Nottingham, United Kingdom; Tepebaşı/Eskisehir, Turkey), but two "follower cities" were also part of the European-level replication process: Seraing (Belgium) and Miskolc (Hungary). The task of the follower cities was not to fully replicate the " " but to examine the model's adaptability, design it to suit local conditions, and prepare potential investment packages[75] .

The energy retrofit carried out in the district of Valladolid (Spain), for example, uniquely combined:

- EU grants,
- municipal contributions,
- subsidized loans,
- an EPC (Energy Performance Contracting)-based ESCO model.

These were integrated into a comprehensive urban regeneration program. In the project, energy efficiency measures (building renovations, modernization of a biomass-based district heating system, and installation of solar panels) were implemented using a combination of various financial instruments, ensuring their long-term sustainability.[65] [76]

One of the most important lessons from REMOURBAN is not merely the accumulation of financial instruments, but rather the flexible design of the financing mix, which allows other instruments (e.g., EPC or preferential loans) to assume part of the investment risks in the event that a particular component (e.g., a grant) is reduced. [76]

3.3 Miskolc's Role in the REMOURBAN Project

Miskolc, as a major city with a significant industrial history and an extensive district heating system, played a key role in the EU-funded REMOURBAN project. The program's goal was to

test and adapt an integrated urban development model (Urban Regeneration Model – URM) that builds on the synergy between energy, mobility, and digital systems.

- *Strategic Tasks and Objectives*

During the project, Miskolc's task was to analyze the development potential of complex urban systems and assess replicable business models. The activity focused on the following areas:

- System-level approach: Joint examination of interconnected urban systems (district heating, transportation, ICT) rather than separate sectoral policies [69].
- Removing barriers: Identifying technical, legal, and social barriers that stand in the way of investments.
- Capacity building: Developing decision-support mechanisms and monitoring systems that lay the groundwork for future large-scale energy efficiency projects [71].

- *Innovative financing and technological solutions*

One of REMOURBAN's most significant outcomes was introducing EPC (Energy Performance Contracting) and ESCO-type business models to municipal decision-makers. This approach is particularly relevant for Miskolc because:

- Modernizing the aging building stock and the district heating sector requires massive capital investment, which can only be effectively achieved through hybrid financing (EU funding + low-interest loans + private capital) [71].
- The use of ESCO models reduces the municipality's investment risks and relieves the burden on the city budget.
- The ICT platforms used help develop realistic investment scenarios and actively involve the public in the developments [73].

- *Key lessons and vision*

The Miskolc assessment highlighted that the city's structural conditions are excellent for the coordinated development of energy and mobility systems. The most important conclusions are as follows:

- Integrated decarbonization: District heating and building energy efficiency improvements are most effective when combined with energy storage and renewable sources.
- Data-driven planning: The digital platforms introduced in the project can support the city's energy strategy and the integration of heat storage technologies in the long term.
- Development roadmap: REMOURBAN is not merely a theoretical framework but a practical guide that aligns with Hungary's climate goals through 2030 and can be directly applied to the preparation of future large-scale energy investments.

IV. Conclusions: The Future of Thermal Storage Investments in Hungary

Based on the above, it is clear that the future of financing heat storage investments lies largely in a combination of grant funding, preferential development loans, guarantee schemes, and ESCO models. Future heat storage investments will be based on a hybrid financing model in which the following elements play a decisive role:

4.1 Grant funding

The Hungarian Modernization Fund offers particularly favorable terms for energy and district heating development projects, thus providing a stable foundation for financing heat storage systems.

Since 2021, the Modernization Fund has awarded more than 20.7 billion euros in grants to 12 member states, including Hungary, which received 279 million euros in 2025 for various energy projects (e.g., district heating system development, energy efficiency, energy storage, and renewable-based heat generation). [77] A December 2025 announcement from the Modernization Fund confirms that the investments supported by include energy storage and district heating development projects, which are directly relevant to the greening of heat storage and heat supply [78] . In 2024, the Commission specifically supported three Hungarian energy programs through the Modernization Fund—two of which were aimed at greening and modernizing district heating systems. [79]

4.2 Concessional development loans

Loans from the EIB and other development banks are particularly suitable for supporting large-scale projects with long payback periods.[68] The EIB's Energy Lending Policy prioritizes low-carbon investments aligned with climate goals and provides favorable loan terms for energy efficiency, grid development, and energy storage projects.[80] The Commission's report on energy efficiency financing (COM/2026/118) also highlights that financial instruments—such as EIB loans—provide significantly higher leverage than grants alone. [65] Such arrangements played a key role in the financing of Danish PTES projects. [73]

4.3 Guarantee schemes (e.g., InvestEU)

Risk-mitigating guarantees significantly improve the bankability of projects, particularly when new technologies or large-scale investments are involved. The InvestEU program supports the climate and energy transition with an EU guarantee worth €26–28 billion and has already mobilized nearly €100 billion in projects by 2025 (including energy efficiency, renewables, and infrastructure) [81] . According to an analysis by Net Zero Investor, the InvestEU guarantee

“represents the risk-sharing mechanism behind the loans, which makes green infrastructure projects attractive to private investors as well.”[82]

4.4 ESCO models and EPC contracts

The EPC-based ESCO model is particularly relevant in municipalities where the investor (local government or district heating provider) lacks sufficient capital, or where the project risks would be too high if financed with their own funds. The REMOURBAN example demonstrated that, when properly combined, this model can even enable the financing of complex heat and energy efficiency investments. [65]

According to the Smart Cities Marketplace summary, REMOURBAN (H2020 SCC1) demonstrated in several European cities, including Miskolc, that an EPC-based, ESCO-centered financing structure can be effectively combined with:

- EU funding,
- municipal contributions,
- subsidized loans,
- integrated energy efficiency and renewable energy developments. [83]

VI. Aligning pilot projects with national and EU strategies

The geothermal pilot project in Békéscsaba is being implemented within an energy policy environment in which both the European Union and Hungary have set the goals of rapidly decarbonizing the heating and cooling sector, increasing the share of renewable energy, and strengthening energy independence. The pilot is thus not an isolated local initiative, but a concrete manifestation of a broader, coordinated strategic effort.

The project's alignment can be interpreted on multiple levels: it is consistent with the EU's climate and energy framework, domestic energy strategies, and the Danube Region Programme's goals prioritizing the integration of renewable energy.

The European Union's Renewable Energy Directive (RED III) mandates that member states continuously increase the share of renewables in the heating and cooling sector, placing particular emphasis on the role of local, decentralized energy sources and the integration of waste heat. The Békéscsaba pilot is fully in line with this, as a significant portion of the city's heating demand can be met by connecting a new, locally available geothermal production well with an existing spa well, which enables a significant reduction in natural gas-based heat production and a radical increase in the share of renewables in the connected heating districts. The project thus directly contributes to the European recommendations and commitments set out in RED III for 2030, which prioritize the modernization and decarbonization of district heating systems. [84]

The pilot also complies with the requirements of the Energy Efficiency Directive (EED), which aims to reduce final energy consumption, increase the efficiency of heating networks, and modernize consumption metering and data collection. The new heating plant created as part of the project, the integrated control technology, and the optimized network configuration all contribute to meeting energy efficiency goals, as they reduce network losses, stabilize supply, and enable local renewable heat production to play a dominant role. All of this aligns well with the EU's efforts to digitize and modernize district heating systems in the long term. [85]

Hungary's energy policy documents reflect a similar direction. The National Energy and Climate Plan (NEKT) prioritizes increasing the share of renewable energy, reducing energy import dependency, and greening the district heating sector. The Békéscsaba project directly supports these efforts, as it enables the complete or partial replacement of natural gas for an entire district heating group (sports, community, and public buildings). The renewable-based, redundant heat generation structure and the modular interconnection of heating districts are both in line with the NEKT's objective of increasing the share of renewable heat and reducing the dominance of fossil fuel combustion in Hungary's district heating networks.[86] [87]

The National Energy Strategy 2030 (with a outlook to 2040) places special emphasis on Hungary integrating its significant, currently underutilized geothermal potential much more effectively into

its thermal energy systems in the future. The geological conditions in Békéscsaba—a geothermal gradient of 45.1 °C/km, the 2,200–2,500-meter-deep aquifers, and water at a temperature of 100–110 °C—exactly match the parameters identified by the strategy document as an extremely favorable starting point for development. The pilot also demonstrates how multiple geothermal sources can be interconnected within an urban district heating network, thereby creating a new, decentralized model for supply security. [88]

The project also addresses another key aspect: it is closely linked to the "Green" priority of the Danube Region Programme and Specific Objective 2.1, which supports the countries of the region by integrating renewable energy and reducing dependence on fossil fuels. The pilot project in Békéscsaba is one of the most tangible examples of this, as it demonstrates, at the level of a medium-sized city, how an entire district heating system can be transitioned to renewable energy sources, while the project's methodological framework—such as the energy community model that combines multiple heat sources—can be easily replicated in other municipalities across the Danube region. The project is therefore not only an energy modernization initiative but also a regional pilot project that aligns well with the program's decarbonization goals. [89]

The pilot is also aligned with several EU research and innovation initiatives—such as the MUSE-DHC and ENABLE-DHC projects—which examine the creation of community-based district heating systems, the integration of renewables, and the decarbonization of existing district heating networks[90] [91] [92] . Similar to these projects, a decentralized system connecting multiple heat sources and consumer groups is being established in Békéscsaba, which is technically efficient, economically viable, and socially acceptable. The pilot thus represents the local application of a broader EU knowledge base, building on system developments and energy community models.

Overall, the Békéscsaba project aligns with the objectives of both European and national energy strategies. The implementation of a modular district heating, district cooling, and thermal energy community system based on geothermal heat generation simultaneously supports climate policy goals, the reduction of fossil fuel dependency, the spread of thermal energy communities, and regional development priorities. The project presents solutions that ensure a long-term stable, sustainable, and scalable energy infrastructure, while also charting the future direction of the modernization of Hungary's thermal energy systems.

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REHEATEAST

Establishment of a Geothermal Heating Community in Békéscsaba – Pilot

Activity A.2.3

Authors

INFOWARE ZRT.
Székhely: Határ út 22, Szigetszentmiklós, 2310 Hungary
Cgj. szám: Cg. 13-10-041366
Adószám: 10900516-2-13
Tel.: +36 24 465 171
Fax: +36 24 442 139
E-mail: office@infoware.hu
Web.: www.infoware.hu

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Project partners

Lead partner: Pannon European Grouping of Territorial Cooperation (PANNON), HU

PP2: NFFKÜ International Fund Development and Coordination Agency (IDEFA), HU

PP3: Energy Institute Hrvoje Požar (EIHP), HR

PP4: Technical University of Cluj-Napoca (UTCLUJ), RO

PP5: Local Energy Agency Pomurje (LEAPOM), SLO

PP6: European Grouping of Territorial Cooperation Via Carpatia (VIACARP), SK

PP7: Standing Conference of Towns and Municipalities (SCTM), SRB

PP8: Jožef Stefan Institute (JSI), SLO

PP9: Resource Aarhus Center in Bosnia and Herzegovina (AC-BIH), BiH

PP10: Center for Energy Efficiency Eneffect (ENEFFECT), BG

PP11: ABE Renewable (ABE), SRB

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Abbreviations

Abbreviation	Full name
HEC	Heat Energy Community
DH	District Heating; district heating system
DRP	Danube Region Programme
RES	Renewable Energy Source
EED	EU Energy Efficiency Directive
NEKT	Hungarian National Energy and Climate Plan
P2H	Power to Heat; converting electrical energy into thermal energy
MJV	City with County Rights
KPI	Key Performance Indicator
OPEX	Operational Expenditure
H2P	Heat to Power; conversion of thermal energy into electrical energy
PTES	Pit Thermal Energy Storage; Pit-type thermal energy storage
TTES	Tank Thermal Energy Storage; Tank-based thermal energy storage

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Executive Summary

This study presents the Békéscsaba pilot project developed within the framework of the REHEATEAST project, which examines the feasibility of establishing an innovative, geothermal-based, modularly expandable district heating and cooling (DHC) system. The project aims to reduce the use of fossil fuels—particularly natural gas—in the heating of municipal public institutions, while increasing the share of renewable energy sources and strengthening security of supply.

The pilot is based on three spatially distinct heating zones (A, B, C), which include sports facilities, public institutions, and the local spa. Based on the analyses, the heat demand of these zones (approximately 19,000–23,600 GJ per year) can be fully met by a new geothermal well with a flow rate of approx. 25 l/s and a temperature of ~100 °C, particularly in zones A and B. The system can be expanded gradually and modularly (A → A+B → A+B+C), which allows for the optimization of investment risks and costs.

One of the project's greatest added values is the practical application of the Heat Energy Community (HEC) concept, which enables the integrated operation of multiple heat sources and multiple consumer groups. The inclusion of the existing thermal well (Zone C) as a redundant heat source further increases the system's operational reliability. The use of geothermal energy can prevent up to 600–800 tons of CO_2 emissions annually and achieve significant natural gas substitution.

The pilot aligns closely with European and domestic energy policy goals, particularly efforts to increase energy efficiency, integrate renewable energy sources, and decarbonize district heating systems (e.g., EED, RED III, NEKT). In addition, it offers a model solution for other cities with similar characteristics, particularly those with significant but untapped geothermal potential.

Overall, the Békéscsaba pilot demonstrates that a sustainable, economical, and secure renewable-based heat supply system can be implemented even in a medium-sized city, contributing in the long term to energy independence, cost stabilization, and reduced environmental impact.

1. Introduction

1.1 Connection to the overall objectives of the REHEATEAST project

The main objective of the REHEATEAST project is to reduce the fossil fuel consumption of district heating systems in the eastern parts of the Danube region and to promote the integration of renewable energy sources, including geothermal energy, into local energy communities.

This study presents Békéscsaba as a potential pilot project site in Hungary that directly supports this objective, as:

- It relies on 100% renewable geothermal heat production for a group of sports, recreational, and public facilities.
- A modular, expandable district heating (DH) system can be developed, which increases the share of renewables through the gradual integration of local heating zones (A, B, C).
- Geothermal conditions allow for the replacement of fossil gas, which is one of REHEATEAST's most important outcomes.

Furthermore, the pilot:

- demonstrates the practical application of the HEC (Heat Energy Community) concept by connecting multiple heat sources and multiple consumer zones,
- increases local supply security,
- reduces the carbon intensity of the district heating system.

The identified heat market is divided into three main heat zones (A, B, C), which include municipally owned, community, and sports facilities, see Table 1.

Table 1: Heating zones of the identified heating market

Heating Zone	Main consumers	Estimated heat demand (GJ/year)
A	Sports hall, fencing hall, sports fields, swimming pool	19,248
B	Children's dining hall, event halls	23,602
C	Árpád Medical and Beach Baths (with its own thermal spring)	as an integrable source

The city's heating demand is concentrated in a densely built-up, utility-connected area, which favors the development of a short heat pipeline network.
The combined heat demand of the "A+B" districts is 2.6–3.0 MW, which can be fully met by a newly constructed geothermal production well and two reinjection wells.

1.2 Link to Specific Objective 2.1

Specific Objective 2.1 of the Interreg Danube Region Programme aims to decarbonize the energy and transport sectors by strengthening the integration of renewable energy sources, with a particular focus on the transformation of local and regional energy systems. This objective specifically encourages investments and pilot projects that serve to replace fossil fuels, increase the share of renewable energy, and improve local energy independence. The Békéscsaba pilot is closely aligned with the objectives of Specific Objective 2.1:

1. *Integration of renewable energy into the heating sector*
   The pilot project will establish a new geothermal production well with a flow rate of 25 l/s and an outlet temperature of ~100 °C, along with one or more reinjection wells. This fully supports the Danube Region Program's goal of increasing the share of renewables in district heating systems.

2. *Replacing fossil fuels*
   Heating for local sports facilities, event halls, and public institutions currently relies predominantly on natural gas. Geothermal supply can replace gas sources in thermal zones A and B and provide a redundant solution for the spa facility in thermal zone C.

3. *Energy efficiency and network modernization*
   The project includes the construction of a new heating plant, new primary and secondary transmission lines, the integration of heating zones, and the development of a reinjection system, which strengthens the decarbonization of the district heating sector.

4. *Regional pilot project*
   The pilot project effectively demonstrates how a renewable district heating system based on a thermal energy community can be gradually established in a medium-sized city—serving as a model for the entire Danube Region.

1.3 Link to Activity 2.3

Activity 2.3 of the REHEATEAST project focuses specifically on the preparation and testing of pilot projects, with particular emphasis on the integration of renewable heat generation technologies into district heating systems. The aim of the activity is to develop well-founded, technically and legally sound pilot projects that can later become actual investments or replicable model projects. The Békéscsaba pilot fits this activity perfectly, as:

1. *Detailed technological preparation has been carried out:*
   - geothermal potential assessment (45.1 °C/km gradient, 110 °C formation temperature),
   - technical plans for thermal well construction,
   - heat zone consumption data, with a maximum demand of 2.1–2.65 MW.
2. *Testing of three DH configurations (A / A+B / A+B+C).*
3. *Development of a renewable heat integration model with multiple heat sources and modular scalability.*
4. *Risk analysis, exploration of regulatory frameworks, with reinjection and surface disposal options.*
   – Permits: preliminary review, water rights permit, MEKH district heating producer permit, etc.
5. *Comprehensive pilot preparation that meets the requirements of Activity 2.3 "Preliminary technical and legal preparation."*

1.4 The Békéscsaba pilot's contribution to the objectives of the Danube Region Programme

In accordance with the DRP's "green" priority, Member States must focus on projects that:

- reduce CO_2 emissions,
- improve local energy independence,
- increase the integration of renewables,
- support sustainable urban development.

Accordingly, the pilot:

- *reduces CO_2 emissions*
  Replacing gas heating with geothermal energy enables a reduction of several thousand tons of CO_2 annually.
- *Increases energy independence*
  Békéscsaba is not dependent on the volatility of the natural gas market; it covers a large portion of its heating needs with local resources.
- *Integrates renewable energy*
  100% geothermal supply + integration of existing thermal wells.
- *Demonstrates DH + RES integration as a pilot*
  The three possible configurations clearly illustrate scalable development.

1.5 Alignment with national, regional, and EU energy strategies

The Békéscsaba pilot is closely aligned with the energy policy documents of the European Union and Hungary.

- *EU-level strategies:*
  - EU Energy Efficiency Directive (EED) and RED III[1]

1 European Commission. (2023). Directive (EU) 2023/2413 of the European Parliament and of the Council on the promotion of the

The project is in line with the requirements of the Energy Efficiency and Renewable Energy Directives (RED III – 2023/2413 EU), particularly regarding the decarbonization of district heating systems and increasing the share of renewables.

- EU 2030 Climate and Energy Framework[2]
  The geothermal system contributes to meeting the 2030 targets, which include a minimum 32% share of renewables and a 55% reduction in GHG emissions.

- *National Energy Strategies*
  - Hungary's National Energy and Climate Plan (NEKT)[3]
    Key objectives of the NEKT include increasing the share of renewable energy, reducing dependence on energy imports, and greening district heating systems. The Békéscsaba pilot meets these objectives by integrating renewable heat into an urban district heating network.
  - National Energy Strategy 2030 (with a view to 2040)[4]
    The strategy highlights the need to harness geothermal potential, particularly in rural towns. The pilot provides a concrete example of the strategy's practical application.

- *DH-specific policy documents*
  - District Heating Development Action Plan / District Heating Programs of the Modernization Fund[5] :
    Both major domestic funding programs (MEGÚJULÓ + INFRA) support heat storage, renewable heat generation, geothermal systems, and the modernization of heating plants and networks. The specific technical scope of the Békéscsaba pilot aligns with these eligible activities.

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2. Pilot Description

2.1 Problem Definition and Context

- *Purpose and Relevance of the Pilot*

Békéscsaba is a major regional center in the Danube Region, where heat supply to public institutions relies predominantly on natural gas. Consumer areas outside the existing district heating network (sports facilities, event halls, community buildings) do not have a heat supply solution based on renewable energy sources, even though the city's region has one of the country's best geothermal potentials.

These geothermal potentials are as follows:

- Geothermal gradient: 45.1 °C/km (one and a half times the global average)
- Accessible depth: 2,200–2,500 m
- Expected formation temperature: 100–110 °C
- Expected flow rate: 20–25 l/s (sustainably maintainable in pumped mode)
- Chemical composition: medium–high hardness water, moderate methane content (CH_4 ≈ 30–50%)

Previous studies (e.g., wells with cadastral numbers 3-102, 3-137, and 3-4) confirm that the Upper Pannonian aquifers possess excellent heat supply capacity. Based on this, Békéscsaba is an excellent pilot site for geothermal district heating from a geological perspective.

The objective of the pilot project:

- to investigate the development of a small-scale, modularly expandable, geothermal-based district heating system;
- to integrate the heating zones in phases A → A+B → A+B+C;
- the partial or complete replacement of fossil natural gas;
- practical demonstration of the thermal energy community concept within the REHEATEAST framework.

This represents a new approach that replaces the existing fragmented institutional heat supply with a unified system based on renewable energy.

- *Added value*

The Békéscsaba pilot is the first to explore the creation of a thermal energy community comprising multiple heating zones and thermal wells**,** which also integrates the energy from the existing spa well and presents a modular DH model that can be replicated in any Hungarian city of similar size. It increases supply security (by connecting the spa well to the public sector

district) and generates surplus heat, which is suitable for subsequent industrial or agricultural use (greenhouses, fish farming, snow melting).

- *Needs and challenges addressed by the pilot*

The study identified the following issues:

- the heat supply of public institutions is heavily dependent on natural gas;
- consumers are scattered, forming small, isolated groups with heat demand, which hinders grid integration;
- existing geothermal potential remains untapped, despite the availability of a decades-old network of thermal wells;
- the thermal well serving the spa's heating zone is not connected to other institutional heat consumers, so supply security is not optimal.

Its significance is also outstanding at the national level, as Hungary's geothermal potential is of strategic importance, yet most rural towns have not yet exploited it.

2.2 Analysis of the current situation

- *Data collection and information used*

The preparation of the pilot project was based on the following data:

- Archival thermal well databases (depth, temperature, yield) – analysis of wells drilled between 1959 and 1982 at depths of 800–2,500 m.
- Heat consumption data provided by the municipality of Békéscsaba (heating zones A, B, C).
- Defined heat demand profiles (2.1 MW; 2.65 MW peak load).
- Planned new well yield of 25 l/s based on free-flow yields of 6–22 l/s.
- Annual temperature curves and heating capacity distribution (365-day meteorological statistics).

- *Assumptions and limitations*

Limitations of the study:

- no detailed geological model was created (preliminary-level assessment);
- heating demands are partly estimates, as detailed energy audits were not available for all buildings;
- the network design was prepared only with high-level geometry (A, A+B, A+B+C variations).

- *Identified shortcomings*

The pilot establishes that:

- renewable energy is not currently integrated into these institutions;
- the spa's own well does not support municipal public institutions, even though it has the capacity to do so;

- there is no interconnected, redundant geothermal network, so there is no heat energy community model;
- there are no heat storage facilities or P2H solutions in the area;
- the current low utilization of geothermal energy does not meet the requirements of either EU RED III or NEKT.
- the district heating licensing and network model does not automatically support new connections.

These shortcomings underscore that the modernization of the system is not only an energy issue but also a structural and institutional one.

2.3 Optimization objectives

The Békéscsaba pilot serves the optimization objectives summarized in Table 2.

Table 2: Optimization objectives for Békéscsaba

Optimization goal	Specific objective	Key Performance Indicators (KPIs)
1. Optimization of heat production	Full replacement of consumer heat demand (19,248–23,602 GJ/year) with geothermal energy	Share of renewables (%) Reduction in gas consumption (m^3/year)
2. Optimization of heat distribution (heating district integration)	Gradual interconnection of heating districts A → A+B → A+B+C	Supplied heat capacity (MW) Network loss (%)
3. Increasing supply security	Integration of multiple thermal wells (new well + Árpád Baths well**)**	Number of redundant heat sources Number of avoided outages
4. Secondary utilization	Use of cooled thermal water for agricultural / industrial / snow melting purposes	Secondarily utilized thermal energy (GJ/year)

2.4 Cooperation objectives

The pilot is based on the cooperation of multiple stakeholders; see Table 3. The goal of the cooperation is to develop a broad-based, shared-responsibility energy community model.

Table 3: Pilot participants

Stakeholder	Role	Objective
MJV Municipality of Békéscsaba	Consumer data, securing locations	Involvement of institutional heating districts
Local district heating provider / municipal utility	Operation	DH integration
Spa operator	transfer of existing thermal well	Improving supply security
Geothermal engineering organization	technical preparation	Determination of well parameters
REHEATEAST partners	methodological and thermal energy community model support	International knowledge sharing

2.5 Implemented solutions and pilot implementation steps

The pilot implements the technical and organizational solutions presented in Table 4.

Table 4: Technical and organizational solutions of the pilot

Pilot solution	Specific activities
1. Testing the integration of geothermal sources	• Drilling of a new production well at the Sports Hall • Construction of reinjection wells (1–2 wells) • Construction of a primary geothermal loop (~1,500–4,100 m)
2. Interconnection of heating zones	• Connecting heating zones A (sports facilities) → B (public institutions) → C (spa) • Construction of a 920 m long connecting pipeline
3. Construction of a new heating plant	• Installation of heat exchangers • Pumps • Design of a control system
4. Investigation of secondary heat utilization	• Greenhouse heating options • Fish farming applications • Heat utilization for snow melting

2.6 Main steps and milestones of the pilot implementation

The steps and milestones to be implemented during the pilot are distributed as listed below, and the Gantt chart for the project is illustrated in Figure 1.

- *Preparation phase (0–12 months)*
  - Preliminary geological assessment, well parameter estimation;
  - determination of heat demand for heating zones;
  - development of 3 system layout models;
  - Initiation of the permitting process (preliminary review).

- *Technical design (12–24 months)*
  - Water rights permit;
  - geothermal and consumer network design;
  - Finalizing the locations of production wells and reinjection wells.

- *Construction (24–36 months)*
  - Well drilling and testing;
  - construction of heat pipelines;
  - construction of a heat distribution center;
  - Network construction from Zone A to Zones A+B and C.

- *Test operation and evaluation (36–42 months)*
  - system trial operation,
  - collection of heat production data,
  - optimization recommendations.

- *Pilot project closure (42–48 months)*
  - transfer of the operating model;
  - proposal package for a thermal energy community;
  - international dissemination.

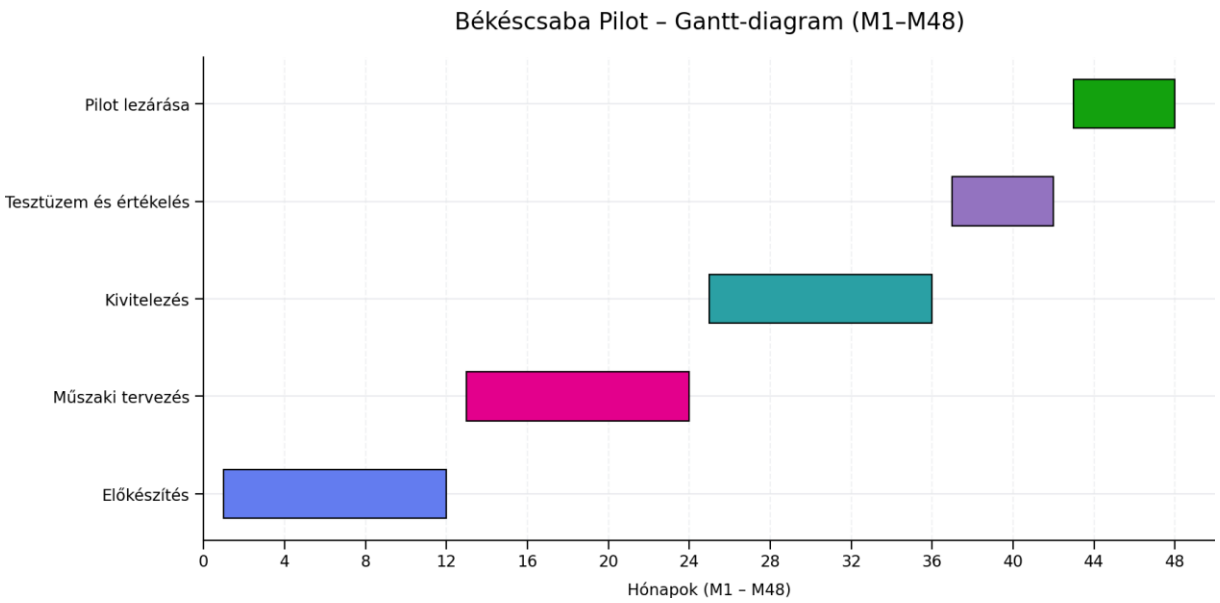

Figure 1: Pilot Gantt chart

3. Analysis and results

3.1 Methods and tools used

The Békéscsaba pilot project employed a methodological framework suitable for the preparation and evaluation of a district heating system based on renewable energy sources. The main tools and methods used in the pilot project were:

- *Geothermal potential assessment:*
  Processing of archival thermal well databases (wells drilled between 1959 and 1982 at depths of 800–2,500 m) and analysis of actual bottomhole temperature measurements (values ranging from 110–134 °C). Determination of the area's characteristic geothermal gradient of 45.1 °C/km, which is above the Hungarian average.

- *Heat Zone Segmentation*
  Based on an analysis of the heat demand of municipal public institutions and sports facilities, three heating zones (A, B, C) were defined, which can be examined separately and then integrated into a multi-source system.

- *Heat demand and consumption profile analysis*
  Detailed building list and heat output estimates (max. demand: Zone A: 2.1 MW, A+B: 2.65 MW). The annual heat demand range is 19,248–23,602 GJ/year.

- *Development of technical system models*
  Three system configurations are tested (A, A+B, A+B+C) and various well and pipeline geometries are examined. Re-injection alternatives are determined.

- *Analysis of the permitting process*
  A detailed regulatory permitting structure was identified in the pilot (water rights permit, MEKH permits, preliminary review, etc.).

3.2 Impact assessment

The aim of the pilot is to demonstrate the technical and economic feasibility of a geothermal-based, modular DH system. The project results and quantified impacts are listed below. Table 5 lists the project results and quantitative performance indicators.

The project achieved the following impacts:

- *Qualitative impacts*
  - Energy and environmental outcomes
    Geothermal energy can significantly replace the gas consumption of the entire group of institutions (sports and public facilities). Incorporating the spa's existing thermal

well will result in further CO_2 reductions. Exposure to external fossil fuel markets will be minimized.

- Operational impacts
  Security of supply is increased through redundant heat sources (new well + well in Zone C). Scalable system—suitable for the future integration of industrial consumers (e.g., greenhouses, process heat applications).

- *Impacts on target groups*
  - Municipality: reduced utility costs, security of supply.
  - Sports and public institutions: stable heat supply, lower operational risk.
  - Residents: cleaner air, environmentally friendly infrastructure.
  - Danube Region: replicable project with demonstration value.

Table 5: Quantitative KPIs

KPI category	Indicator	Value	Note
Energy production	Geothermal yield	25 l/s	based on model
	Outlet water temperature	~100 °C	estimate
Share of renewable energy	Increase in RES share	0% → 80–100%	A+B can be fully supplied
CO_2 reduction	Annual emissions avoided	600–800 t/year	Heat demand × 56 kg/GJ
Heat loss	Reduction in network losses	10–15%	due to short route
Economic benefit	Gas substitution	600,000–900,000 m^3/year	Heat demand × specific emissions
	Reduction in institutional utility costs	20–35%	Lower geothermal OPEX
Security of supply	Number of redundant heat sources	2	New well + spa well
Secondary heat utilization	Utilizable low-temperature heat	20–40%	greenhouse, snow melting, H2P

3.3 Stakeholder engagement

Several stakeholders are involved in the implementation of the pilot project, all playing a key role; see Table 6.

Table 6: Stakeholders involved in the pilot implementation

Stakeholder	Role	Method of involvement
MJV Local Government of Békéscsaba	Heat demand data, securing the site	workshops, data requests
Sports centers, institutions	Heat consumption data	interviews, site visits
Spa operator	technical data of existing well	technical consultations
Mannvit Kft. (geothermal engineer)	preparation of a preliminary technical study	Engineering consultations
REHEATEAST project partners	methodological support	regional meetings

3.4 Transferability – Transferability and replicability

The Békéscsaba model is exceptionally well-suited for adaptation to other municipalities because:

1. *Modular heating district logic:*
    - Geothermal supply to small local heat demand nodes → integration of multiple districts.

2. *Repurposing existing thermal wells:*
    - There are more than 900 thermal wells in Hungary – typically underutilized.

3. *Low network construction requirements:*
    - not a full-scale urban district heating system, but targeted “micro-DH.”

4. *Easily adaptable decision-making and permitting model:*
    - REHEATEAST methodology → preparation guide for other cities.

3.5 Sustainability

Long-term sustainability benefits of the pilot:

- Geothermal energy as a continuous, weather-independent renewable source
- Reinjection ensures the regeneration of the aquifer
- The system is capable of flexibly serving different consumer zones
- Operating costs are predictable (low dependence on primary energy prices)

3.6 Potential integration into policy recommendations

The pilot's results are directly linked to:

- The Hungarian NEKT – increasing the share of renewable heat
- National Energy Strategy 2030 – the strategic role of geothermal energy
- RED III (2023/2413 EU) – increasing the share of renewables in the heating and cooling sector
- Domestic district heating programs under the Modernization Fund

The results of the pilot could contribute to the development of a "Hungarian Geothermal Micro-DH Guide" that could be applied nationwide.

3.7 Budget and costs

Table 7 illustrates the estimated investment costs of the three alternatives based on the study.

Table 7: Investment Costs

Option	2.0 billion HUF
Option A+B	3.0 billion HUF
Variant A+B+C	3.1 billion HUF

Potential financing instruments:

- Modernization Fund (MA/TÁVHŐ/01 and 02)
- EU "Greening the heating sector" funds
- Municipal co-financing
- ESCO or concession model (involving a geothermal service provider)

4. Conclusions

4.1 Key lessons learned

The most important lesson from the Békéscsaba pilot is that the local integration of geothermal energy works effectively when the heat consumer structure is spatially concentrated and the system can be expanded modularly. The consumer structure divided into three heating zones (A–B–C) provides an ideal environment for a DH system that can be developed gradually, step by step.

The pilot project confirmed that:

- the area's outstanding geothermal conditions (45.1 °C/km gradient, >100 °C bottom temperature) represent a genuine strategic advantage;
- a production well with a flow rate of around 25 l/s is capable of meeting the entire heat demand of heating zones A and B on its own;
- The existing thermal well (Zone C – Árpád Baths) can be integrated, thereby increasing supply security and reducing technical risk;
- Connecting the heating zones creates a new type of multi-source thermal energy community.

This experience is also important for other municipalities: geothermal systems work best when multiple heat sources and multiple consumer units form a network, rather than when isolated, small-capacity systems operate in parallel.

4.2 Summary of Key Findings

1. Full suitability for renewable heat supply
    - Based on the technical models examined, public institutions in Békéscsaba can be supplied with geothermal energy either partially or entirely. The heat demand (19,248–23,602 GJ/year) is consistent with the heat capacity of the production well.
2. Significant CO_2 and natural gas reduction potential
    - Replacing natural gas with geothermal energy would result in annual CO_2 savings of several hundred tons.
3. Technical simplicity + scalability
    - The logic of one central heating plant + two pipeline branches + a reinjection well can be easily expanded to additional districts.
4. Security of supply benefits
    - Connecting the existing spa well provides redundancy—a rare advantage in Hungarian cities.
5. High transferability
    - The model can be easily adapted to groups of institutions with a similar structure in other Hungarian cities (Gyula, Kecskemét, Szolnok).

4.3

1. *The heat district-based planning logic*

A heating district consisting of small, densely located institutions is best suited for geothermal supply. This reduces network losses and results in a more financially sustainable investment.

2. *Integration of existing thermal wells*

Many towns in Hungary have underutilized thermal wells.

The example of Békéscsaba shows that it is not necessary to build entirely new infrastructure: the existing well is a very valuable element of supply security.

3. *Modular development phases (A → A+B → A+B+C)*

Phased development allows for the minimization of investment costs and risks.

4. *Secondary heat utilization*

The use of the cooled fluid in additional applications (e.g., greenhouses, fish farming, snow melting) provides a separate revenue stream or supply security benefit.

4.4 Long-term expected impacts

The Békéscsaba geothermal pilot project will significantly reduce the share of fossil fuels in the city's heat supply in the long term, as the current natural gas-based system is replaced by a stable, local, and weather-independent renewable source. The use of geothermal energy also contributes to making heat prices more predictable and stable in the long term, as geothermal energy is not subject to fluctuations in the prices of international energy sources. The pilot creates an opportunity for the gradual expansion of the DH system, potentially including residential connections, which would significantly support the greening of the city's energy mix and the decentralization of heat supply. The implementation of the project also has local economic and labor market impacts: it increases employment, strengthens knowledge and competencies related to geothermal technologies, and may open up new service sectors for the city in the long term. As a result of all this, Békéscsaba could, in the long term, become one of the Danube Region's leading "geothermal model cities," demonstrating in an exemplary manner the operation and benefits of renewable-based community heating systems.

4.5 Recommendations and suggestions for further development

1. *From pilot to demonstration project*

It is recommended to implement the system up to Zones A and B, followed by the integration of the spa. This ensures the best cost-benefit ratio.

2. *Detailed geological and well-site modeling*

Next steps: aquifer modeling, pumping tests, and design of a new well.

3. *Integration of thermal storage (PTES / TTES)*

Heat storage between the summer and winter seasons improves system efficiency and increases the share of renewable energy.

4. *Gradual integration of institutional and industrial consumers*

The system's excess capacity provides an opportunity to connect industrial heat users, agricultural producers, and new urban facilities.

5. *Preparation of a HEC (Heat Energy Community) model*

Development of a proposed legal-business model: community ownership, municipal participation, service provider partnerships