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FOSTERING THE INTEGRATION OF SHALLOW GEOTHERMAL SOLUTIONS FOR COOLING AND HEATING IN BUILDINGS IN THE DANUBE REGION

Abstract

Shallow geothermal energy remains underutilized in the Danube Region despite its potential to reduce fossil fuel dependency and support EU climate goals. The Danube GeoHeCo project addresses this gap by fostering transnational cooperation, aiming to promote hybrid ground-source heat pump (GSHP) solutions. Key outputs include Transnational Action Plan (TAP) focusing on five priorities: regulations, technology, education, financing and awareness, and IT Decision Support Tool for techno-economic optimization of GSHP systems. By mitigating barriers such as data scarcity and high initial costs, two tools align with EU renewable energy directives and provide strategic roadmap for the adoption of geothermal energy and sustainable building practices.

Keywords: heat pumps, hybrid systems, action plan, decision tool, sustainability

ПОДСТИЦАЊЕ ИНТЕГРАЦИЈЕ ПЛИТКИХ ГЕОТЕРМАЛНИХ РЈЕШЕЊА ЗА ГРИЈАЊЕ И ХЛАЂЕЊЕ У ЗГРАДАМА У ДУНАВСКОМ РЕГИОНУ

Сажетак

Плитка геотермална енергија остаје недовољно искоришћена у Дунавском региону упркос свом потенцијалу да смањи зависност од фосилних горива и подржи климатске циљеве ЕУ. Пројекат *Danube GeoHeCo* разматра ове проблеме подстицањем транснационалне сарадње, са циљем да се промовишу хибридна рјешења за геотермалне топлотне пумпе (GSHP). Кључни резултати укључују *Транснационални акциони план (TAP)* који се фокусира на пет приоритета: прописе, технологију, образовање, финансирање и јачање свести, као и припрему *IT* алата подршке за техно-економску оптимизацију *GSHP* система. Ублажавањем препрека као што су недостатак података и високи почетни трошкови, два резултата су усклађена са директивама ЕУ о обновљивим изворима енергије и пружају стратешку мапу пута за усвајање геотермалне енергије и одрживих грађевинских пракси.

Кључне ријечи: топлотне пумпе, хибридни системи, акциони план, IT алат за одлучивање, одрживост.

1. INTRODUCTION

The project titled „*Fostering the implementation of shallow geothermal hybrid heating and cooling systems in the Danube Region (Danube GeoHeCo)*“ is the ongoing international project from the *Interreg Danube Region Programme 2021-2027* and is implemented by 9 countries in the Danube region, including LIR Evolution (Banja Luka, BiH) as project partner. The main objective of Danube GeoHeCo project is to increase the penetration of shallow geothermal energy in the Danube Region through initiating a robust transnational cooperation of promotion and support actions. The purpose of proposed activities is to achieve ambitious EU energy and climate targets by 2030 and consequently 2050. The project fosters the integration of shallow geothermal solutions into existing fossil-fuel based domestic HC systems, raise awareness and enhance capacities.

Project work plan is divided into three individual Work Packages (WPs): WP1 (*Design and technology optimization of shallow geothermal hybrid heating and cooling systems*), WP2 (*Community-led planning for utilization of shallow geothermal heating and cooling potential*) and WP3 (*Digital platform and virtual marketplace for fostering shallow geothermal hybrid heating and cooling*).

The main objective of this article is to present the key outputs of the conducted analysis and research within Danube GeoHeCo project including *Criteria catalogue for optimization of shallow geothermal hybrid systems*, *IT Decision Support Tool* and *Transnational Action Plan* and to promote shallow geothermal use in the Danube Region.

2. TRANSNATIONAL ACTION PLAN (TAP): SCOPE, DEVELOPMENT, STRUCTURE AND IMPLEMENTATION FRAMEWORK

The *Transnational Action Plan* (TAP) to foster shallow geothermal use in the Danube Region, developed under the *Danube GeoHeCo* project, represents a comprehensive, evidence-based strategic document aimed at accelerating the market uptake of shallow geothermal energy (SGE) hybrid heating and cooling systems. The TAP addresses the Danube Region's heavy dependence on fossil fuels for space heating and cooling, limited availability of regionally confined base-load renewables, high capital intensity of deep geothermal energy, and the untapped potential of SGE – a low-CAPEX, geographically widespread resource accessible via ground-source heat pumps (GSHPs or SGHPs). By integrating SGE into existing systems, the plan seeks to achieve significant fossil fuel reduction, lower greenhouse gas emissions, improved energy security, and alignment with EU 2030/2050 climate targets. The TAP is structured around a thorough state-of-play analysis, covering European and national contexts for GSHP deployment, geological suitability, installed capacities, policy frameworks (EU directives, national energy mixes, district heating reliance), regulatory barriers, education gaps, and financing instruments (including ERDF/CF programs and Recovery and Resilience Facility). The different geothermal energy regions in Republika Srpska [1] are shown in Figure 1.

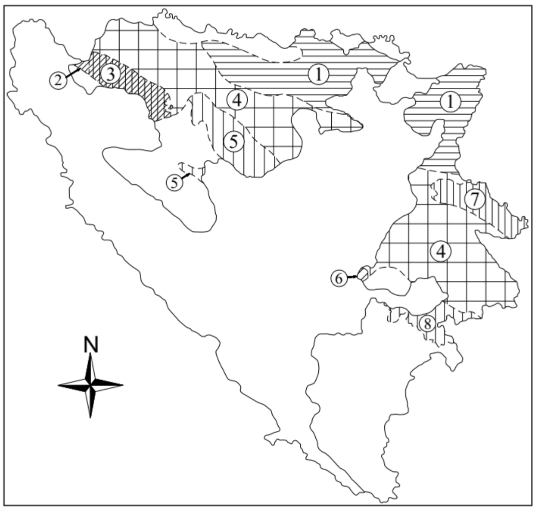

Figure 1. Geothermal energy regions in Republika Srpska [1].

The following geothermal energy regions were identified within the Republika Srpska:

- Artesian basins in the northern part of the Republika Srpska - extending from confluence of the Una River with the Sava to the confluence of the Drina with the Sava. This area encompasses the northern sections of regions 1, 2, 3, and 4, as shown in Figure 1.
- Areas belonging to the Outer Dinarides - characterized by alternating flysch rocks, ophiolites, and contact metamorphic formations of Prosara and Motajica, along with complexes of Cretaceous and Jurassic sediments. These correspond to parts of regions 3, 4, and 5.
- Eastern zones with sedimentary complexes — comprising Cretaceous, Jurassic, and Paleozoic formations. These include portions of regions 4, 6, 7, and 8.

Furthermore, the geothermal gradients, in Republika Srpska, are unevenly covered and have lower values than the average in Europe, which amount to 30°C/km. Areas of the outer Dinarides have lower values, while areas of the inner Dinarides are characterized by a wider range from 21 - 50°C/km. The highest values of the geothermal gradient are in the area of Semberija and Posavina, which range from 45 - 50°C/km. The size of the heat flow, considering the thickness of the Earth's crust of 27 km on the territory of Republika Srpska, ranges from 65 - 100 mW/m^2, north of the line Novi Grad - Banja Luka - Doboj - Zvornik cities [2].

In Bosnia and Herzegovina, the heating with heat exchangers is used mostly in spas (e.g. Ilidža Terme, Ilidža Termalna rivijera, Slatex-Slatina, Slatina and Dvorovi). In a spa Kulaši Prnjavor, the water after balneological use is heated by coal burning and serves for heating closed space of this spa. Closed loop geothermal or ground source heat pumps are proposed for some individual objects [3] while open loop systems with groundwater sources of inlet temperature of 13°C are proposed especially for greenhouses (Klokun – Herzegovina), in line with hydrological parameters. The hydrological structure of BiH [4] is shown in Figure 2.

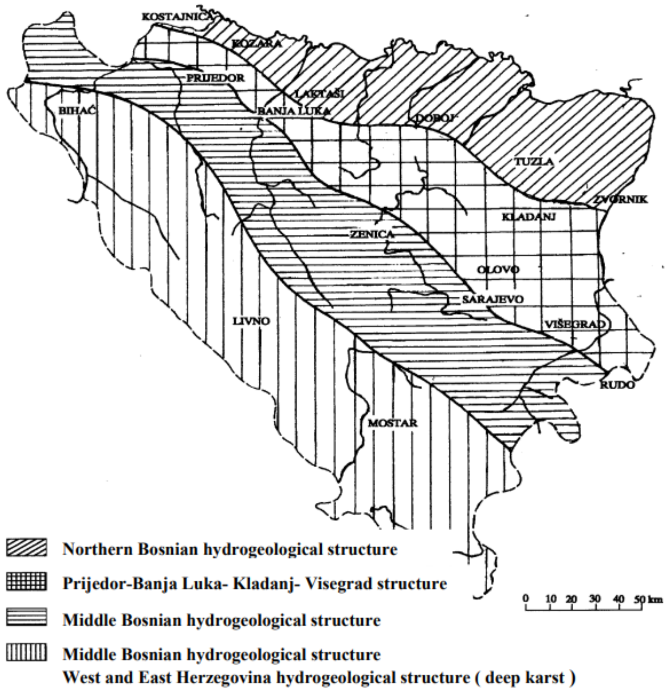

Figure 1. Hydrological structure of BiH, Source: [4]

The core of the TAP lies in five interconnected priorities and their specific areas of intervention, each with concrete, actionable recommendations divided into national-level adaptations and transnational cooperation measures. These were elaborated through transnational working groups involving project partners from Austria, Bosnia and Herzegovina, Croatia, Hungary, Romania, Serbia, Slovakia, and Slovenia, incorporating stakeholder inputs from deployment desks and questionnaires. TAP is structured around five individual **Priorities** with specific areas.

Priority 1 – Resources and Regulations (foundational enablers)

It focuses on overcoming data scarcity and regulatory fragmentation.

Area 1.1: Resource mapping and standardized data collection.

Develop harmonized geological databases and open-access subsurface platforms across partner countries. Standardize SGE potential assessment methodologies, promote data sharing among authorities and drillers, and create unified mapping tools to reduce exploration risks and support informed planning for borehole heat exchangers and ground-source heat pumps. This transnational action lowers uncertainties and enables better site selection.

Area 1.2: Harmonizing regulatory framework of SGE.

Simplify permitting for drilling and installations by establishing unified depth thresholds, clear water well usage rules, and streamlined environmental impact procedures. Align national regulations with EU directives, reduce administrative delays, and create transparent guidelines for approvals. Transnational harmonization minimizes cross-border inconsistencies and encourages investment in hybrid SGE systems.

Priority 2 – Technology and Design (closing performance and innovation gaps)

It targets the technological lag in the Danube Region compared to Western Europe.

Area 2.1: Filling the technological gap in the Danube Region.

Promote technology transfer through joint Research & Development (R&D) projects, pilot demonstrations of advanced GSHP components, and knowledge exchange platforms. Encourage partnerships between leading and lagging countries to adopt high-efficiency heat pumps and hybrid integrations, closing the performance gap compared to Western Europe.

Area 2.2: Optimization of drilling in order to cope with limited geological data.

Develop low-cost, low-impact drilling techniques with risk-based protocols adapted to sparse data. Provide training for drillers, introduce standardized equipment guidelines, and promote innovative methods (e.g., directional drilling) to reduce costs and environmental footprint while maintaining system reliability.

Area 2.3: Borehole heat exchanger field modelling for improving system performance.

Implement advanced simulation software for borehole heat exchangers (BHE) field design to optimize spacing, prevent thermal interference, and ensure long-term efficiency. Transnational guidelines and training will enable accurate modeling, improving payback times and system durability in varying geological conditions.

Area 2.4: Application of smart control system for better integration with existing heating systems.

Integrate IoT (Internet of Things) - based smart controls in hybrid SGE-conventional setups for dynamic load balancing, demand-response, and energy cost optimization. Develop common protocols and pilot applications to demonstrate real-time performance gains and user comfort improvements.

Area 2.5: Application of GHPs in geothermal district heating.

Promote GSHPs as temperature boosters in low-enthalpy district heating networks, including retrofits and new installations. Share best practices for integration, economic modelling, and case studies to scale district-level SGE solutions across the region.

Area 2.6: Setting up energy cost monitoring system for demonstrating performance characteristics of SGE solutions.

Establish standardized monitoring protocols, public dashboards, and data collection frameworks to track real-world energy costs, savings, and CO_2 reductions. Transnational benchmarks and case studies will prove viability and support evidence-based advocacy.

Priority 3 – Education and Training (human capacity building)

It addresses skills shortages and knowledge fragmentation.

Area 3.1: Harmonized higher educational programmes on SGE.

Develop joint university curricula/modules on SGE, promote student mobility, and integrate topics into construction/engineering/geology programs. Transnational cooperation ensures consistent knowledge transfer and skilled workforce development.

Area 3.2: Standardized vocational and training programmes for installers and performance monitoring.

Create certified training programs for installers (installation, operation, maintenance), with common standards, accreditation, and performance certification. Include ongoing monitoring training to ensure quality installations and system longevity.

Area 3.3: Stronger academia-industry partnerships for education and training in the Danube Region.

Foster collaborative R&D, internships, joint projects, and knowledge platforms between universities and companies to bridge theory and practice in SGE deployment.

Area 3.4: Establishment of open access knowledge source and information base to eliminate language barrier in knowledge transfer.
Build a multilingual online repository, offering free access to technical resources, best practices, case studies, and guidelines to overcome language barriers and accelerate knowledge dissemination.

Priority 4 – Financing (economic viability)
Tackles high upfront costs and limited support schemes.
Area 4.1: Tailored financial support schemes for shallow geothermal investments.
Recommend dedicated grants, soft loans, tax rebates, green bonds, and risk-sharing for SGE projects, aligned with EU funds and national schemes to reduce upfront costs and improve economic feasibility.
Area 4.2: Setting up energy price schemes for the promotion of wider use of SGE solutions.
Advocate for carbon pricing, dynamic tariffs, feed-in premiums for excess heat, and fossil fuel phase-out incentives to favor renewables like SGE, creating market signals for wider adoption.

Priority 5 – Awareness Raising (demand creation and acceptance)
Emphasizes communication to change perceptions.
Area 5.1: Awareness raising for the general public about SGE solutions.
Launch campaigns, success stories, public demonstrations, and educational materials highlighting comfort, savings, dual heating/cooling, and environmental benefits to increase public acceptance and demand.
Area 5.2: Capacity building for decision-makers and institutional stakeholders on SGE solutions.
Organize workshops, policy briefs, study tours, and training for authorities, planners, and financiers to build institutional support, integrate SGE into planning, and facilitate policy uptake.

TAP Implementation Framework

The TAP adopts a quadruple-helix model of stakeholders (academia, industry, government and civil society) for the achievement of goals. Actions are split into national (country-specific adaptations, e.g., Bosnia and Herzegovina's focus on incentives and training) and transnational ones (joint standards, shared platforms, cross-border pilots). Monitoring includes annual progress reviews, stakeholder forums, integration into national energy/climate plans, and alignment with EU funding cycles. Stakeholder roles are clearly assigned (e.g., public authorities for regulations, industry for pilots, academia for education). The TAP emphasizes replication of project pilots, capitalization of the digital platform/IT tool, and long-term policy uptake to ensure lasting impact.
The TAP provides a balanced, pragmatic pathway to mainstream SGE in the Danube Region, combining technical, regulatory, educational, financial, and awareness measures. It leverages the project's transnational cooperation to overcome common barriers, promote scalable solutions, and contribute to a low-carbon, resilient energy future.

3. THE DEVELOPMENT OF IT DECISION-MAKING TOOL

The Criteria Catalogue for Optimization of Shallow Geothermal Hybrid Systems serves as a foundational resource for identifying and prioritizing key areas in shallow geothermal energy utilization across the Danube Region. Priority areas are defined through a systematic analysis of country-specific status reports, encompassing technical, economic, environmental, regulatory, and geological factors. These areas emerge from aggregated data on installed systems, energy balances, geology and hydrogeology, cost comparisons and restrictions, as detailed in sections for each involved country. Definition of priority areas begins with categorizing criteria into core domains:

- *Technical Priorities*: Focus on system design, including borehole heat exchangers (BHE), heat pump efficiency (coefficient of performance - COP), and hybrid integration with secondary sources like biomass boilers. Defined via thermogeological parameters (e.g., ground conductivity, porosity) and load profiles.
- *Economic Priorities*: Emphasize capital costs (drilling, equipment), operational expenses (OPEX), and levelized cost of heat (LCOH), derived from energy price comparisons and incentives.
- *Environmental Priorities*: Address sustainability, such as groundwater protection, thermal plume impacts, and restrictions on drilling depths or antifreeze use.

- *Regulatory Priorities*: Cover permitting, incentives, and policies, highlighting harmonization needs across countries.
- *Geological Priorities*: Based on site-specific data like undisturbed ground temperature and Darcy velocity, influencing feasibility.

Importance weighting is achieved through a multi-criteria evaluation framework implicit in the catalogue. Weights are assigned qualitatively based on impact metrics: high weight (e.g., 30-40%) to technical and economic factors for direct influence on system performance and viability; medium (20-25%) to environmental and geological for sustainability and risk mitigation; lower (10-15%) to regulatory for enabling deployment.

Table 1. Pairwise comparison of categories of criteria with respect to the overall goal of Hybrid geo system optimization and project design [11]

Parameters	Technical and Technological	Geological, Thermogeological, Hydrogeological	Socioeconomic	Environmental policy and Climate
Technical and Technological	1,000	0,647	1,019	1,318
Geological, Thermogeological, Hydrogeological	1,545	1,000	0,789	1,232
Socioeconomic	0,981	1,267	1,000	1,141
Environmental policy and Climate	0,759	0,812	0,876	1,000

This weighting draws from cross-country comparisons, where barriers like high drilling costs in low-permeability soils (e.g., BiH) elevate economic priorities, while aquifer protection in Hungary boosts environmental ones. Quantitative scoring, inferred from statistics (e.g., installed capacity vs. potential), prioritizes areas with the greatest gaps, such as underutilized hybrid systems in non-residential sectors.

Incorporation of Criteria Catalogue into the *IT Decision-Making Tool* integrates these priorities via modular inputs and simulations. The tool, developed in *Python* programming language with a web interface, uses weighted criteria for optimization: users input data from priority areas (e.g., BHE setup weighted by geological parameters, HP performance by technical COP tables, costs by economic LCOH formulas). Simulations compute long-term outcomes like capacity factors, energy coverage, and borehole temperatures, applying weights to balance trade-offs (e.g., minimizing LCOH while respecting environmental min. inlet temps). Sensitivity analysis allows iterative weighting, e.g., adjusting bivalent temperatures to prioritize economic over technical efficiency. This ensures holistic decision-making, aligning with catalogue-derived priorities to foster shallow geothermal adoption.

The GeoHeCo *IT Decision Support Tool* is a software designed to aid engineers and designers in optimizing shallow geothermal energy (SGE) systems, particularly hybrid ground-source heat pump (GSHP) setups for heating and cooling (HC). It promotes SGE penetration in the Danube Region by integrating fossil-fuel systems with renewables, enhancing efficiency, awareness, and capacities. The tool simulates long-term GSHP operations, testing configurations with secondary heaters (e.g., gas boilers or electric) in parallel mode below a bivalent temperature threshold.

It addresses design challenges in hybrid SGE systems by providing techno-economic optimizations. Users input site-specific data to estimate performance, costs, and feasibility, supporting pilot site selections and investments. By modelling demand-supply dynamics, it minimizes energy use, reduces costs, and ensures sustainability, aligning with EU goals for renewable HC integration.

This tool fosters informed decisions, reducing risks in SGE adoption across diverse geologies, as per criteria catalogues.

4. DISCUSSION

The main findings of this study, centred on the *Transnational Action Plan (TAP)* and the *IT Decision Support Tool* developed under the *Danube GeoHeCo project*, underscore the transformative potential of shallow geothermal energy (SGE) in the Danube Region. The TAP's five priorities provide a structured framework to address systemic barriers, such as regulatory fragmentation and technological gaps, enabling a shift from fossil-fuel dominance to hybrid GSHP systems [7]. For instance, this can be achieved by harmonizing resource mapping (Priority 1) and promoting smart controls (Priority 2). The IT tool simulations are incorporating criteria from the catalogue—like borehole heat exchanger (BHE) modelling and cost sensitivities-facilitates informed design, minimizing risks in diverse geologies and optimizing efficiency [8].

These outputs have profound impacts: economically, they lower CAPEX through standardized drilling optimizations; environmentally, they mitigate thermal plumes via groundwater flow considerations; and socially, they enhance energy security in fossil-dependent areas like Bosnia and Herzegovina (BiH), where coal accounts for 50-60% of energy mix [5].

Taking into consideration the number of ground source heat pumps (GHP) units per land area Switzerland is the most densely equipped country followed by the Netherlands and Sweden, countries of the Danube region are lagging behind. Per capita figures show even more extreme differences among European countries: Sweden and Finland are in favourable position with 30-60 pcs of installed GHP units per 1000 inhabitants, while the same figure for Austria is 13, for Slovenia 8, for Hungary only around 0.5 [6] and for Croatia, Serbia and BiH even less. The top 20 countries of GSHP per country area and population [6] are shown in Figures 13a and 3b.

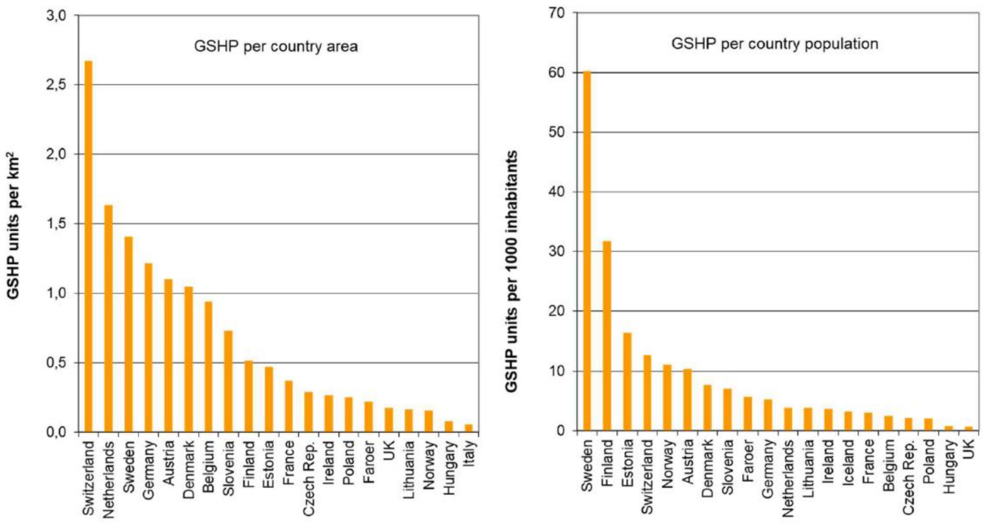

Figure 2. a) Top 20 countries of GSHP per country area in 2020/2021, b) Top 20 countries of GSHP per country population in 2020/2021 [6].

On an EU scale, the Danube GeoHeCo outputs resonate with broader research showing SGE's role in decarbonization [9]. Unlike LEGEND's Adriatic project focus on market strategies, Danube GeoHeCo emphasizes transnational education, fostering academia-industry ties to overcome language barriers. Critically, the IT Tool provides practical optimization, weighting priorities to balance trade-offs, potentially accelerating adoption in underutilized regions like BiH.

The EU's Joint Research Centre (JRC) report [10] explicitly outlines the "*Vision for 2050*," stating that geothermal heat should supply more than 25% of Europe's demand for space heating and cooling by that year. Overall, our project findings amplify EU-wide calls for scaling geothermal, with impacts including 25% heating/cooling coverage by 2050 but highlight the need for BiH-specific adaptations to match advanced EU deployments.

5. CONCLUSIONS

The Danube GeoHeCo project demonstrates that shallow geothermal energy, through hybrid GSHP integrations, offers a viable pathway to meet EU 2030/2050 climate targets in the Danube Region.

The *Transnational Action Plan* provides a comprehensive strategy across five priorities, emphasizing resource harmonization, technological advancements, capacity building, tailored financing, and awareness campaigns to overcome barriers like data scarcity and high upfront costs.

The *IT Decision Support Tool* complements this by enabling precise simulations for optimal system design, reducing risks and enhancing efficiency in diverse geological contexts.

Key to success is transnational cooperation, as seen in BiH's potential for expanding from spa-based uses to broader hybrid applications, aligning with regional disparities. By implementing these outputs, the region can achieve significant fossil fuel reductions, energy security and sustainability, urging stakeholders to adopt the plan for a low-carbon future.

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