ГЛАСНИК Српског географског друштва 105(2) 645-658
BULLETIN OF THE SERBIAN GEOGRAPHICAL SOCIETY 2025

Original scientific paper UDC 351.834.11:662.997(497.11)
https://doi.org/10.2298/GSGD2502645J

Received: October 15, 2025
Corrected: November 21, 2025
Accepted: December 1, 2025

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UTILIZATION OF VERY SHALLOW GEOTHERMAL ENERGY IN TOURIST, URBAN, AND RURAL AREAS OF SERBIA: POTENTIALS, BENEFITS, AND CHALLENGES

Abstract: The Serbian heating sector remains heavily reliant on fossil fuels, leading to persistent exceedances of particulate matter and gaseous pollutants during winter and placing significant burdens on public health. This paper synthesizes evidence on air quality, health impacts, and the technical and spatial characteristics of geothermal resources, with particular emphasis on very shallow geothermal potentials (vSGP; ≤10 m). vSGP systems, typically implemented as horizontal closed-loop collectors, can eliminate on-site combustion and associated local emissions while providing efficient heating and cooling year-round. Their performance depends on near-surface soil conditions (soil composition, grain size, moisture, insolation) and the integration of the system with heat pumps and low-temperature distribution. Distinct application pathways are emerging as rural and peri-urban areas favor horizontal collectors and dual land use, while compact urban zones require hybrid solutions, vertical drilling, or integration with modern low-temperature district heating. Despite clear environmental and social benefits, expansion is constrained by high initial costs, limited regulatory incentives, data gaps (0-10 m soil properties), and modest public awareness. The paper concludes that targeted pilot projects in health-relevant hotspots, stable financing mechanisms, simplified permitting and standards, and an open cadaster of shallow geothermal resources could enable scalable adoption, improve air quality, and advance Serbia's climate and energy goals.

Keywords: very shallow geothermal potentials (vSGP), renewable energy, heating and cooling, Serbia

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Introduction

Rapid industrialization and economic growth have been accompanied by excessive energy consumption, leading to various environmental problems such as high greenhouse gas (GHG) emissions, climate change, biodiversity loss, rising sea levels, extreme weather events, and negative impacts on human health and well-being. The demand for fossil fuels from non-renewable energy sources has prompted countries worldwide to develop short-, medium-, and long-term plans to assess the potential for transitioning to renewable energy sources (Akbi et al., 2017; Pušić et al., 2024). The Paris Agreement on Climate Change (2015) commits signatory countries to limit the rise in global average temperature to no more than 1.5°C above pre-industrial levels. Achieving this target, however, remains highly challenging due to ongoing urbanization, industrialization, and technological development, all of which contribute to increasing energy demand and, consequently, to excessive GHG emissions. The heating and cooling sectors in both residential and industrial contexts are among the primary sources of these emissions. In 2019, approximately 63% of heating and cooling energy in Europe was derived from fossil fuels, including natural gas (38%), coal (22%), and oil (3%), while only 30% originated from renewable energy sources. To address this imbalance, the European Commission has set ambitious targets to reduce GHG emissions by 55% by 2030, alongside increasing the share of renewable energy to at least 32%. Within Europe, the use of coal as a primary fuel remains concentrated mainly in Germany, Poland, and Sweden, which together account for 57% of total coal consumption (Ahmed et al., 2022; European Union, 2016; Osička et al., 2020).

The Republic of Serbia is one of five Western Balkan countries whose 18 coal-fired power plants emitted twice as much SO_2 in 2019 as all 221 such facilities in the EU combined. Therefore, a key solution is the energy transition towards renewable energy sources (CREA & CEE Bankwatch Network, 2021). The National Emission Reduction Plan of the Republic of Serbia ("*Sl. glasnik RS*", No. 10/2020) defines measures to reduce emissions of major pollutants from large combustion plants with capacities greater than 50 MW, with the main goal of reducing SO_2, nitrogen oxides, and particulate matter (PM) to the limit values defined by the Plan. Thermal power plants using lignite as their main fuel account for 95% of the total installed heat capacity in Serbia (Josimović et al., 2023). Individual heating units are present in both rural and urban areas and are characterized by the combustion of fuels with low energy potential or poor ecological quality (wood, lignite, municipal waste), along with a lack of control and penalty mechanisms.

Serbia is a candidate for EU membership and has committed to following EU policies and programmes related to the use of renewable energy sources by 2030 (UN General Assembly, 2015). However, low public awareness of the advantages of renewable energy, insufficient investment, a poorly defined legal framework, and inadequate infrastructure hinder the achievement of these prescribed goals (Vukelić et al., 2023). Regulatory policies should include measures to limit fuel use in individual heating systems, supported by subsidies, tax incentives, and the wider promotion of renewable energy sources. The *Law on Air Protection* (*"Sl. glasnik RS"*, No. 51/2025) defines provisions for the control, protection, and reduction of air pollution. The *Air Quality Programme of the Republic of Serbia for the period 2022–2030*, together with the *Action Plan* (2022), is aligned with EU air quality regulations and relevant international agreements and conventions. One of the key objectives of the National Programme is to achieve a 58.2% reduction in $PM_{2.5}$ emissions by 2030 compared to 2015 levels, across the energy, transport, and individual heating sectors. In Serbia, however, the air quality monitoring network remains insufficiently developed, limiting the ability to conduct effective monitoring and to provide a realistic assessment of air quality. The network lacks a sufficient number of measuring stations, and many existing stations either do not measure all required parameters or experience frequent interruptions in operation. Weekly, monthly, and annual air quality reports are available on the website of the Environmental Protection Agency (SEPA).

Air Quality in Serbia during Winter

The type of equipment and heating systems in use has a direct impact on pollution levels. Individual heating units emit high concentrations of NO_2 and CO, posing significant health risks even in rural areas, where household heating can increase PM concentrations by up to 30% (Braniš et al., 2007; Salva et al., 2023; Stanojević et al., 2024). In a study by Đurić and Vujović (2020), air pollution levels were measured at four locations in Belgrade during 2011, accompanied by analyses of wind speed and air temperature data. The results were later confirmed in the winters of 2012 and 2013. At three of the observed sites, concentrations of SO_2, NO_2, PM_{10}, O_3, and CO indicated poor air quality on more than 78% of the monitored days. The heating season in Belgrade typically extends from mid-October to mid-April, when temperature inversions and anticyclonic weather conditions prevent the dispersion of pollutants, leading to their maximum accumulation. As a result of widespread individual heating, SO_2 emissions are considerably higher during winter compared to the summer period, when heating is not required. In contrast, NO_2 emissions, primarily originating from vehicle exhaust, exhibit no significant seasonal variation. For instance, at the "Mostar" monitoring station, located in a high-traffic area, the lowest SO_2 values and the highest NO_2 concentrations were recorded. Additionally, individual heating systems are a major source of PM_{10} emissions in the city (Đurić & Vujović, 2020).

Findings from the European Environment Agency indicate that PM concentrations in Serbia are among the highest recorded in Europe. The majority of PM_{10} emissions originate from heat generation facilities with capacities below 50 MW and from individual household heating, together accounting for approximately 64% of total national emissions. On average, an estimated 13,522 premature deaths occur annually in Serbia as a consequence of air pollution (European Environment Agency, 2022).

In the study by Stanojević et al. (2024), supported by data from SEPA's *Air Quality Reports for Serbia* (Agencija za zaštitu životne sredine, 2024), daily PM concentration series were analyzed for both heating and non-heating seasons over the period 2011–2022. Extreme pollution events were classified according to their intensity and duration, and the types of heating equipment and fuels used across Serbia were examined. The results show that central heating systems are most common in larger urban areas. Gas installations prevail mainly in the northeastern part of the country, whereas the majority of households rely on individual heating systems that use low-quality fuels.

Wood is the dominant fuel used for household heating in Serbia, accounting for approximately 60% of total consumption, while coal contributes around 30%, primarily in areas near mining basins. Natural gas is more commonly used in the northern regions of the country, and electric heating is prevalent in certain parts of Belgrade. Thermal power plants rely largely on oil and coal for heat production, further contributing to PM emissions. There are pronounced regional differences in Serbia's heating network, determined by proximity to mining basins, gas infrastructure, and the rural or urban character of settlements. At more than half of the analyzed monitoring stations, average daily PM_{10} concentrations exceeded the maximum allowable values, while nearly all stations recorded $PM_{2.5}$ levels above the legal limits. During the heating season, pollutant concentrations were several times higher than in the non-heating period, clearly indicating that elevated air pollution levels are a direct consequence of heating activities. The primary sources of emissions are individual heating, followed by energy production and transport. Individual heating contributes to air pollution on local, national, and even global scales, including indoor environments. Transitioning to renewable energy sources would significantly reduce air pollution and promote a more rational and sustainable use of natural resources (Mahmoud et al., 2021; Stanojević et al., 2024).

Public Health Consequences

Air pollution is associated with a wide range of adverse health outcomes, including cardiovascular diseases, lung cancer, acute respiratory infections, immune system disorders, asthma, chronic bronchitis, and increased susceptibility to viral infections. Both short-term and long-term exposure to air pollutants can lead to serious health effects (Kampa & Castanas, 2008; Todorović et al., 2019). According to Yu et al. (2024), approximately one million deaths worldwide between 2000 and 2019 were attributed to short-term exposure to $PM_{2.5}$, with urban populations being particularly affected. In Europe, an estimated 450,000 premature deaths in 2015 were linked to $PM_{2.5}$ exposure, with residential emissions identified as a major source of particulate pollution (Gu et al., 2023).

Todorović et al. (2019) conducted a mid-term assessment of cardiovascular, respiratory, and overall mortality associated with exposure to PM_{10}, O_3, NO_2, and SO_2 in Belgrade, Novi Sad, and Niš. The analysis covered approximately 25% of Serbia's total population during the period 2011-2015 and employed AirQ+ modeling based on baseline mortality rates and daily pollutant concentration data. The study found that cardiovascular mortality attributable to air pollution was higher than respiratory mortality. On average, exposure to pollutants accounted for an estimated 2,013 premature deaths due to PM, 831 deaths related to NO_2, and 443 deaths linked to SO_2.

Geothermal Potentials

The accelerating pace of climate change, driven primarily by human activities and the extensive use of fossil fuels, underscores the urgent need to transition toward renewable energy sources. These include solar, wind, hydropower, biomass, geothermal, and emerging forms of marine energy. Renewable energy can solve numerous environmental problems, but various financial obstacles and investment risks of potential investors impede its rapid growth (Panaitescu et al., 2020). According to global energy projections, renewable sources are expected to surpass fossil fuels as the dominant contributors to total energy production by 2050, accounting for approximately 63% of global generation (Ramachandran et al., 2024).

Geothermal energy originates from the natural heat of the Earth's interior and can be utilized either for electricity generation or for direct heating applications. Unlike solar and wind energy, geothermal systems provide a stable and continuous source of power, as their operation is independent of weather conditions and daily or seasonal variability (Şimşek & Gungor Celik, 2025). It is recognized as one of the most reliable and clean sources of energy. The integration of heat pumps with geothermal energy significantly contributes to decarbonization efforts (Ahmed et al., 2022).

A specific segment of geothermal energy resources is represented by very shallow geothermal potentials (vSGP). Unlike deep geothermal resources, typically located at depths greater than 400 m, and shallow ones found up to 400 m below the surface, vSGP occur close to the Earth's surface, generally at depths not exceeding 10 m (Zeh et al., 2021). Their proximity to the surface makes them particularly suitable for heating and cooling applications, as they offer lower utilization costs and simpler engineering solutions compared to deeper geothermal systems. However, these systems generally require a larger land area for installation (Shi et al., 2022).

At these depths, closed-loop systems are most commonly used to harness ground energy for thermal applications. The petrophysical characteristics of the soil are a key factor determining the feasibility of utilization, while insolation, air temperature, and precipitation also play important roles. Solar radiation supports the regeneration of the upper soil layers; however, areas with prolonged sub-zero temperatures are less favorable for system performance. Similarly, extremely arid regions can reduce the soil's thermal conductivity. Among the physical constraints, the slope of the terrain is also significant: although a steep slope does not inherently diminish the geothermal potential of the soil, it can complicate installation due to limited accessibility for construction equipment (Bertermann et al., 2024).

The upper 10 m of the soil profile is generally divided into three sublayers: 0-3 m, 3-6 m, and 6-10 m, each characterized by distinct thermal properties (Bertermann et al., 2014). Soil composition and grain size exert the greatest influence on thermal conductivity, with the dominant soil type playing a decisive role. Thermal conductivity can be estimated using various empirical and semi-empirical models (Bertermann et al., 2018; Schwarz et al., 2022). One of the advantages of utilizing vSGP lies in the fact that almost any soil type can be used for such applications. The overall potential of very shallow geothermal energy depends primarily on the thermal conductivity of the soil (λ) (Bertermann et al., 2014), which is defined by physical soil parameters such as moisture content, bulk density, and grain size distribution (Abu-Hamdeh, 2003; Abu-Hamdeh & Reeder, 2000; Bertermann et al., 2014; Farouki, 1981; Ma et al., 2009; Rammler et al., 2023; Schwarz et al., 2022).

Rammler et al. (2023) investigated the influence of spatial and seasonal variations in groundwater conditions on soil moisture and demonstrated that these variations significantly affect the thermal conductivity of very shallow geothermal systems. Their study employed simulation-based modeling to estimate moisture content at different locations around collector systems, accounting for local weather conditions and groundwater levels. The results revealed that seasonal differences in thermal conductivity lead to measurable changes in system performance. Specifically, spatial and seasonal variations in groundwater-related thermal conductivity can cause fluctuations in heat extraction of approximately 7-9%, while differences in soil texture and associated thermal properties can result in variations of 13-14%. These findings highlight the importance of conducting detailed subsurface investigations and developing site-specific system designs to fully utilize the potential of shallow geothermal wells. Furthermore, climatic changes and lowering groundwater levels may reduce soil thermal conductivity, thereby influencing long-term system efficiency (Rammler et al., 2023).

Systems designed to utilize vSGP are typically configured in horizontal arrangements, such as horizontal collectors, trench collectors, and heat baskets. A variety of collector designs are available on the market, developed to maximize heat extraction efficiency and adapt to different soil and site conditions. In addition to the collector itself, the heat pump and the building's internal heating and cooling system, whether residential or commercial, constitute essential components of the overall geothermal installation.

Horizontal collectors, most commonly installed at depths ranging from 1.5 m to 3 m, do not interfere with agricultural land use. This allows the same surface area to serve multiple functions, combining energy generation with agricultural production (Jocić et al., 2020).

Possibilities of Application in Serbia

Many regions of Serbia exhibit significant potential for the utilization of geothermal energy, from the northern province of Vojvodina to various parts of Central Serbia (Doljak & Jojic-Glavonjic, 2016; Nakomcic-Smaragdakis et al., 2012). Numerous studies have addressed alternative energy sources in Serbia and explored strategies to reduce the country's pronounced dependence on traditional fossil fuels. While considerable research has focused on geothermal resources, most of it examines thermomineral waters and hydrogeothermal sources intended for direct exploitation. In contrast, the use and assessment of vSGP remain insufficiently represented in national research and development efforts.

Examples of good practice can be found in spa towns and settlements rich in thermomineral springs, such as Vranjska Banja, Gornja Trepča, and Bogatić, where geothermal energy is also used for heating purposes (Milanović Pešić et al., 2022). These locations have leveraged their geothermal resources not only for heating but also for tourism development, including spa and recreational facilities that support local economies.

Studies have also examined the use of geothermal energy for heating buildings in urban environments. For instance, research conducted in residential blocks in Kragujevac explored the application of vertically installed geothermal pipes (Macut et al., 2018). Urban settings, however, face physical limitations due to high building density and scarce available land, which restricts the installation of horizontal systems. Consequently, geothermal applications in cities are more feasible through vertical installations. In contrast, rural areas possess greater potential for implementing horizontal systems and integrated renewable energy networks. Comprehensive urban-rural energy planning that combines geothermal resources with other locally available renewable sources (such as solar, biomass, and wind) is therefore essential. In this process, the mitigation of urban sprawl should also be considered, while successful international examples, such as Reykjavík, can serve as valuable references (Jovanovic & Cekic, 2017).

Estimates suggest that, alongside the direct use of hydrogeothermal energy, the utilization of ground heat through heat pumps could replace nearly two-thirds of the total energy currently required for heating in Serbia, which is predominantly produced from fossil fuels (Dragovic et al., 2019).

Regarding district heating systems, data show that slightly more than 43% of apartments in urban areas, or about 25% of all households in Serbia, are connected to district heating networks. The majority of these systems rely on fossil energy sources, including natural gas, oil derivatives, and coal, while renewable sources, mainly wood biomass, account for only a small fraction (Živković et al., 2025). Such reliance on fossil fuels is inconsistent with current European trends in modern district heating, which increasingly employ low-temperature and fourth-generation systems designed for higher efficiency and integration with renewable energy (Zeh et al., 2021).

Therefore, the modernization of Serbia's district heating infrastructure represents a national priority. This transition should aim for a direct leap toward advanced, low-temperature systems rather than gradual, incremental upgrades. At the same time, geothermal systems combined with heat pumps offer a promising solution for individual households, particularly in areas where fossil fuels remain the dominant heating source.

Ecological, Social and Economic Benefits

The utilization of vSGP and the implementation of systems based on it offer a range of environmental, social, and economic benefits. Heating systems powered by heat pumps generate zero harmful emissions at the point of consumption and, compared to fossil fuel-based systems, can reduce GHG emissions by up to 90%, depending on the energy sources used for electricity generation (Casasso & Sethi, 2017). Other studies indicate that heat pumps are approximately 75% more efficient than gas-fired water heaters (Dong et al., 2023). The contribution of heat pumps to reducing GHG emissions is well established (Bayer et al., 2012), and continuous technological advancements further enhance their efficiency. The use of renewable electricity in combination with geothermal heating can further minimize emissions, achieving near-zero GHG output. Importantly, by eliminating direct fuel combustion, vSGP systems also completely eliminate local emissions of PM, SO_2, NO_x, and CO_2.

The absence of local emissions brings notable public health benefits. Transitioning households to low-emission heating technologies such as vSGP represents one of the most effective community-level health interventions. For example, exposure to $PM_{2.5}$ particles increases the risk of overall mortality by approximately 6% per 10 $\mu g/m^3$, regardless of age, gender, or residence. The risk of death from lung cancer rises by 15-21%, and from cardiovascular diseases by 12-14% for the same increase in $PM_{2.5}$ concentration (Chen et al., 2008).

In addition to heating, such systems can also be used for cooling during the summer months, providing dual functionality (Walch et al., 2022). Although the initial investment in these systems is relatively high, long-term operation leads to significant financial savings (f.e. Marcic, 2004). Moreover, maintenance costs are lower compared to many conventional heating systems, and government subsidies and incentive programs are often available to support installation. Finally, these systems offer resilience to fluctuations in global energy prices, making them an economically and environmentally sustainable option for both residential and commercial use.

Barriers and Challenges

Despite the clear environmental and social benefits of very shallow geothermal systems, several obstacles still hinder their wider application in Serbia. Restrictions can be seen in the framework of economic, political and social frameworks (Jocić et al., 2020).

High initial investment costs remain one of the main obstacles. Although operation and maintenance costs are relatively low, the initial financial outlay for installing heat pumps and horizontal collector systems discourages many households and investors, especially in the absence of targeted subsidies or low-interest financing instruments.

In addition, the lack of regulatory incentives and strategic guidelines limits the development of the geothermal sector. The current legal framework does not sufficiently recognize very shallow geothermal systems as part of the national strategy for renewable energy sources, nor does it provide clear procedures for their installation, certification or integration into district heating systems.

Public awareness of the benefits of geothermal energy is also limited. Many citizens remain unfamiliar with the technology, its long-term savings and its environmental benefits. Wider educational and promotional campaigns, together with pilot projects, could help overcome this obstacle.

Finally, stronger institutional support and improved access to European funding mechanisms, such as Horizon Europe, LIFE and cohesion policy instruments, would significantly contribute to research, demonstration projects and large-scale deployment of very shallow geothermal systems in Serbia.

Conclusion and Recommendations

The analysis presented in this paper highlights the significant potential of vSGP for improving air quality and reducing GHG emissions in Serbia. Considering the country's long-term dependence on fossil fuels for the production of heat and the pronounced seasonal deterioration of air quality, especially during the winter months, the use of renewable and locally available energy sources such as geothermal energy is becoming an essential part of the national energy transition. The introduction of a vSGP system could contribute to a significant reduction of particulate and gaseous pollutants by eliminating on-site fuel combustion, thereby improving environmental quality and public health.

The current structure of heating in Serbia, which relies heavily on individual fossil fuel systems and outdated heating plants, represents both a challenge and an opportunity. Diversification of energy sources by integrating geothermal energy and heat pumps can provide stable, low-emission and cost-effective solutions. The application of the vSGP system is particularly suitable for rural areas, where land availability enables horizontal collectors and combined agricultural use, but it can also play an important role in urban areas through hybrid approaches and connection with modern low-temperature central heating systems.

However, several obstacles hinder the wider application of these technologies. High initial investment costs, insufficient regulatory incentives and limited public awareness remain major obstacles. Furthermore, the lack of an updated geothermal cadaster, limited access to geological and soil-forming data, and insufficient institutional coordination limit the development of local projects. Establishing clearer legal procedures for installation, certification and integration into the network, as well as ensuring stronger support from national and local institutions, would significantly improve the feasibility and attractiveness of the vSGP system. Access to European funding instruments such as Horizon Europe and LIFE could further encourage pilot projects and research activities, encouraging wider adoption of these technologies.

In addition to their environmental and economic advantages, very shallow geothermal systems can bring important social benefits. Their implementation reduces air pollution and associated health risks, while long-term operating costs remain lower than those of fossil fuel systems. In combination with electricity produced from renewable sources, these systems can achieve heating and cooling with almost zero emissions, directly contributing to Serbia's obligations under the climate and energy policies of the EU.

Very shallow geothermal potentials represent an underutilized but promising renewable energy source in Serbia. Their wider implementation requires coordinated action - technical, regulatory and educational. The integration of vSGP technologies into national energy and spatial planning strategies could significantly improve air quality, reduce GHG emissions and contribute to sustainable regional development. Strengthening institutional support, improving access to financing and raising public awareness are key steps to enable a fair and efficient transition to clean and resilient heating systems based on local geothermal resources.

Acknowledgments: This paper is part of the project Mapping of Very Shallow Geothermal Potentials in Serbia (Contract No. 001545243 2025 13440 003 000 000 001 03 009). The research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-137/2025-03/200091). During the preparation of this manuscript, the authors used ChatGPT5 and InstaText to improve grammar, readability, and clarity of expression. After using these tools, the authors carefully reviewed and edited the content, and take responsibility for the final version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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