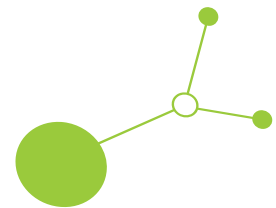


Feasibility study for the pilot region Pomurje (Pannonian Basin)

TRANS GEO Deliverable 2.3.6



Version 1
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D.2.3.9. Feasibility study for the pilot region Pomurje (Pannonian Basin)

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Executive Summary

The feasibility study evaluates the potential for reusing the abandoned hydrocarbon exploration well RAK-1/86, located in Rakičan, Municipality of Murska Sobota, as a deep borehole heat exchanger (DBHE) system for local geothermal heat production. The study forms part of the TRANSGEO project, which aims to develop strategies for repurposing abandoned oil and gas infrastructure across Central Europe for geothermal energy use.

Abandoned wells in Slovenia are mostly represent by originally drilled wells for hydrocarbon exploration. Repurposing these assets for geothermal applications can help reduce dependence on fossil fuels, decarbonize local heating systems, and contribute to regional energy security. The RAK-1/86 site was selected as a pilot due to favourable geological conditions, accessible location, and proximity to potential users such as greenhouses, aquaponic systems, the Rakičan Castle complex, and nearby residential areas. The RAK-1/86 well was drilled in 1986 to a depth of 1,280 m. It penetrates Pliocene and Miocene sedimentary formations overlaying a Paleozoic gneiss basement. The geothermal gradient is estimated at 53.8 °C/km, with temperatures around 60 - 70 °C at 1.000 m reservoir depth.

The feasibility study evaluates the DBHE system. Assumption is that the system will work between 4.000 and 6.000 hours annually and the expected heat output is between 720 - 1.620 MWh. Yearly revenue is expected to be in the range of 35.000 to 190.000 EUR and the simple payback indicates the period of investment return from 5 to 14 years.

The feasibility study confirms that the reuse of the RAK-1/86 well for geothermal energy production is technically viable and environmentally acceptable. The DBHE configuration offers a low-risk, low-maintenance renewable heating solution for agricultural or community applications. The pilot project could serve as a replicable model for transforming other abandoned wells in Slovenia and the wider Pannonian Basin into sustainable geothermal assets.

The TRANSGEO project (<https://www.interreg-central.eu/projects/transgeo/>) is co-funded by the European Regional Development Fund through the Interreg Central Europe program. The overall objective of TRANSGEO is to investigate the potential to transform abandoned hydrocarbon wells into new sources of green geothermal energy. To reach this goal, the TRANSGEO team is providing new tools and knowledge to support communities and industries in the energy transition and to break down economic and technical barriers to well reuse. This deliverable report reflects the views of the authors.

1. Introduction

This feasibility study investigates the potential for reusing an abandoned hydrocarbon exploration well as a Deep Borehole Heat Exchanger (DBHE) system at the Rakičan pilot site in the Municipality of Murska Sobota, northeastern Slovenia. The study is conducted within the framework of the TRANSGEO project, which aims to develop transnational strategies and practical solutions for the conversion of abandoned oil and gas wells into sustainable geothermal energy sources.

The purpose of this study is to assess the technical, environmental, spatial, and economic feasibility of revitalizing the existing RAK-1/86 well, originally drilled in 1986 for hydrocarbon exploration, for geothermal energy utilization. The analysis evaluates closed-loop DBHE system configurations, comparing the expected heat output, investment costs, operational efficiency, and environmental performance.

The Rakičan site was selected due to several favourable characteristics:

- Proven thermal gradient of approximately 53.8 °C/km.
- The existing well infrastructure, including production casing, suitable for installation of DBHE technologies.
- Proximity to potential users, such as agricultural facilities, greenhouses, aquaponic systems, residential zones, and the Rakičan Castle complex.
- State-owned land, with clear administrative conditions and no major environmental or spatial restrictions for intervention.

The study integrates data from previous geological and geothermal investigations, regional seismic surveys, and spatial planning documentation, as well as legal frameworks governing geothermal energy use in Slovenia. The document provides an overview of:

- Geological, hydrogeological, and structural-tectonic conditions of the Rakičan area.
- The well's construction parameters and status.
- Environmental impact considerations in line with national and EU legislation.
- A techno-economic evaluation of investment scenarios, including capital and operating expenditures, energy yields, cost savings, and payback periods.

The ultimate objective of the study is to support the proof-of-concept for transforming disused wells into productive geothermal assets, contributing to Slovenia's renewable energy transition, reducing CO₂ emissions, and promoting local energy self-sufficiency in the Pomurje Region.

2. Geographic Location and Analysis of Spatial Planning Documentation

2.1. Location

The location of the well is in the middle of an agricultural field. In the immediate vicinity of the village of Rakičan. In the wider area, there are a few wells that were in the works and today do not have permits (Murska Sobota) and a few wells that are in production and have permits for exploitation (Moravske Toplice).



Figure 1: Location of existing wells (red dots) in the surrounding area of the well RAK-1. Source: Atlas okolja.

Well Rak-1 coordinates E: 593 205, N: 169 038, altitude 185,40 m

The potential location is in municipality Murska Sobota, near the village Rakičan. The potential influence area is inside the cadastral unit Rakičan.

The selected area located in the **Municipality of Murska Sobota** is one of the 12 municipalities in the Republic of Slovenia with its seat in Murska Sobota. It is the smallest urban municipality in Slovenia in terms of area, and the second to last in terms of population (almost 19,000 people). In addition to Murska Sobota, the largest and most important town is Rakičan with more than 1,500 inhabitants, where the Pomurje regional General Hospital Murska Sobota is located. Bakovci,

Černelavci and Krog are almost as numerous, and Pušča, which is the largest Slovenian Roma settlement.

Overall, there are 11 local communities in the Municipality of Murska Sobota. As follows Rakičan, Bakovci, Krog, Satahovci, Pušča, Černelavci, Veščica, Kupšinci, Polana, Markišavci and Nemčavci.

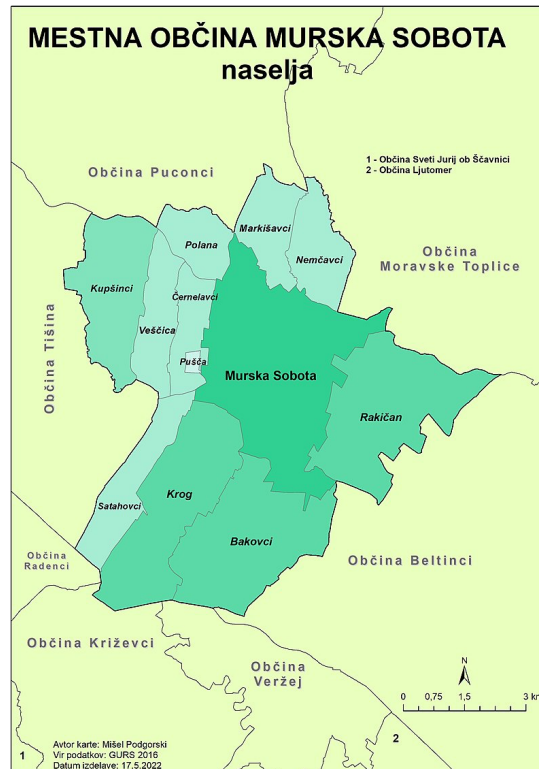


Figure 2: Municipality Murska Sobota and local communities. Source: GURS, 2016.

Given the location of the well and the proximity of infrastructure such as the MS General Hospital, Rakičan Castle, Rekičan Urban Settlement and agricultural land, there would be several opportunities for the revitalization of the well and the exploitation of its energy potential. Below is a marked area that could potentially be served by the selected well.

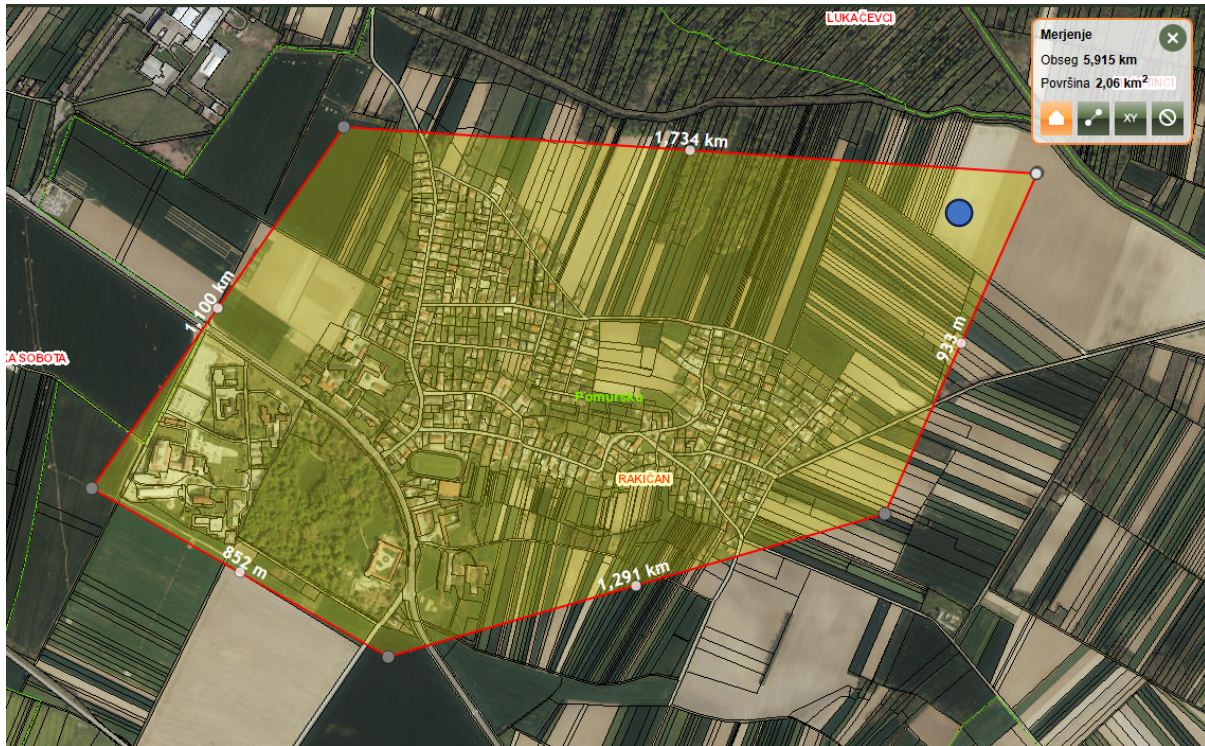


Figure 3: Location of the existing well Rak-1 (blue dot) and potential heat supply area (yellow polygon).

The site covers an area of approximately 2 km² and could function as an independent energy unit, achieving a level of self-sufficiency based on the geothermal capacity of the selected well. In terms of utilization, we have two options for the exploitation of geothermal potential:

- Hydrothermal Energy (HE) system
- Deep Borehole Heat Exchanger (DBHE) system

According to the current legislative framework in Slovenia, the exploitation of a hydrothermal (HE) system without reinjection is not permitted. Therefore, implementing an open loop HE system for heat utilization would require drilling a second reinjection well, which substantially increases the investment cost. In contrast, the Deep Borehole Heat Exchanger (DBHE) system operates as a closed-loop configuration and does not require any additional wells, making it significantly more cost-effective and practical to implement. All key design parameters and performance characteristics of the DBHE system are described and evaluated in the following sections.

2.2 Transport Connectivity

The potential area is located beside the motorway A5 from Maribor to Lendava, and close to the local road 232 connecting Murska Sobota and Beltinci. Close by is also the railway connection No#41 connecting Hodoš and Ormož. The international airport in Zagreb is 153 km away and the

international airport in Slovenia is 182 km away. In the local community of Rakičan there is also a national sport airport.

2.3 Power Grid

The municipality of Murska Sobota has a good energy infrastructure and connection to the electricity distribution network. The medium-voltage distribution network is managed by the company Elektro Maribor. The distribution network is connected to the transmission network via RTP (distribution-transformation stations). The Pomurska region has four stations: RTP Murska Sobota, RTP Lendava, RTP Dobrovnik and RTP Mačkovci. It consists of transformation stations (TPs) and power lines of various voltage levels (110 kV, 1-35 kV and 0.4 kV), which are intended for the distribution of electricity to end consumers. Smaller electricity producers are also connected to the distribution network.

Several power lines run in the wider area of consideration:

- DV 400 kV, connection Lendava - Ljutomer
- 2 x DV 110 kV, connection Mačkovci - Murska Sobota
- DV 110 kV, connection Murska Sobota - Ljutomer
- 20 kV, connection approx. 500 m from the location

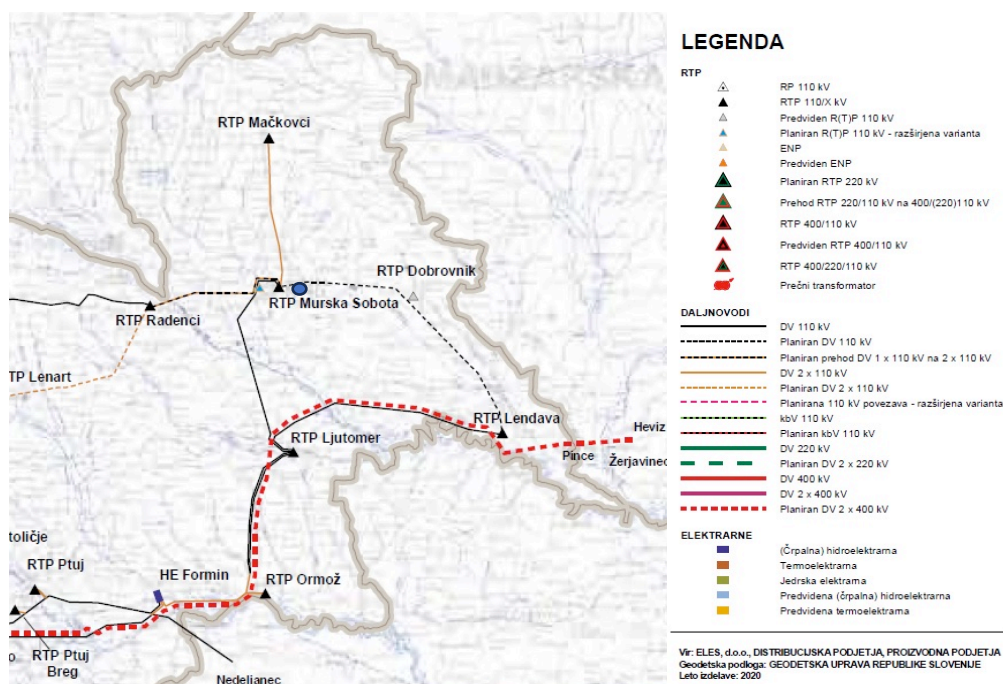


Figure 4: 400 kV and 110 kV power grid lines.



Figure 5: 20V power grid lines (green lines) and well Rak-1 (blue dot).

The Murska Sobota regional unit represents the largest geographic coverage area of the electricity provider Elektro Maribor. It encompasses 19 municipalities and supplies electricity to approximately 36,500 customers, accounting for about 17% of Elektro Maribor's total customer base.

2.4 Demographic Aspects

The local community Rakičan is part of municipality Murska Sobota, which belongs to the Pomurje statistical region. It measures 64 km². It ranks 106th among 212 Slovenian municipalities in terms of area.

Statistical data for 2023 (Statistični urad Republike Slovenije, eSTAT, 2025) show the following picture of this municipality:

In mid-2023, the municipality had approximately 18,640 inhabitants (approximately 9,030 men and 9,610 women). It ranked 22nd among Slovenian municipalities in terms of population. On average, 290 inhabitants lived per square kilometre of the municipality's area; therefore, the population density here was higher than in the entire country (105 inhabitants per km²).

The number of live births was lower than the number of deaths. The natural increase per 1,000 inhabitants in the municipality was therefore negative in that year, amounting to -6.5 (in Slovenia - 2.1). The number of those who moved out of this municipality was lower than the number of those who immigrated to it. The migration increase per 1,000 inhabitants in the municipality was therefore

positive, amounting to 2.8. The sum of the natural and migration increase per 1,000 inhabitants in the municipality was negative, amounting to -3.8 (in Slovenia 3.3).

The average age of the citizens was 47.6 years and thus higher than the average age of the inhabitants of Slovenia (44.1 years).

Among the inhabitants of this municipality, the number of the oldest was - as in most Slovenian municipalities - greater than the number of the youngest: for every 100 persons aged 0-14, there were 222 persons aged 65 or over. This ratio indicates that the value of the ageing index for this municipality was higher than the value of this index for the whole of Slovenia (which was 145). It also indicates that the average age of the inhabitants of this municipality is rising on average faster than in the whole of Slovenia. The data, presented by gender, show that the value of the ageing index for women in all Slovenian municipalities, except for six (Črna na Koroškem, Dobrovnik/Dobronak, Grad, Hodoš/Hodos, Jezersko and Mislinja), was higher than the ageing index for men. In the municipality, as in most Slovenian municipalities, there were more women aged 65 or over than those under 15; the picture was the same for men.

There were 10 kindergartens in the municipality, attended by 649 children. Of all children in the municipality aged 1-5, 86% were enrolled in kindergarten, which is more than in all kindergartens in Slovenia combined (83%). Approximately 1,720 students were educated in the local primary schools in the 2023/2024 school year. Around 640 students attended various secondary schools. There were 33 students and 7 graduates per 1,000 inhabitants in the municipality; in Slovenia there were 38 students and 8 graduates per 1,000 inhabitants.

Among people aged 15-64 (i.e. the working-age population), approximately 63% were employed or self-employed (i.e. in the labour force), which is lower than the Slovenian average (69%).

2.5 Compliance of Interventions with Current Spatial Planning

Documentation

For the whole municipality Murska Sobota the following spatial planning documents are currently valid:

- Ordinance on the Municipal Spatial Plan of the City Municipality of Murska Sobota (SD OPN 1), Official Gazette of Republic Slovenia 64/14
- Ordinance on the Municipal Spatial Plan of the City Municipality of Murska Sobota (SD OPN 1), Official Gazette of Republic Slovenia 54/16
- Ordinance on amendments and supplements to the Ordinance on the Municipal Spatial Plan of the City Municipality of Murska Sobota (SD OPN 1), Official Gazette of Republic Slovenia 67/16

2.5.1. Exploitation of underground waters, mineral resources and geothermal energetic sources

Spatial implementation conditions in landscape areas Article 83 (landscape areas), Planning Units BA 2, VE 4, MS 1, MS 2, MS 3, MS 4, MS 5, MS 7, MS 8, MS 9, MS 10, MS 12, MS 13, MS 14, MS 15, MS 16, MS 17, MS 18, MS 19, MS 20, MS 21, MS 22/1, MS 22/2, MS 23, MS 24, MS 25, MS 26, MS 27, MS 30, MS 31, MS 32, MS 33, MS 34, MS 35, MS 38, MS 45 and MS 46

- exploration of groundwater, mineral resources and geothermal energy sources;

Article 84 (landscape areas in nature protection areas) a) Conditions regarding the intended use and type of spatial interventions (1) Management units MS 36, MS 37, MS 39, MS 40, MS 41, MS 42, MS 43 and MS 44

- exploration of groundwater, mineral resources and geothermal energy sources;

(forest areas near the city) a) Conditions regarding the intended use of the area and conditions for implementation: (1) In management units MS 6 and MS 11, around forest land, with a more detailed designated use designation G,

- exploration of groundwater, mineral resources and geothermal energy sources;

2.5.2. Measures for protection of the geological network areas

Special areas are areas of regimes that are protected by sectoral regulations. These are nature protection areas, cultural heritage areas, water catchment protection areas, and floodplain areas along watercourses.

All nature protection areas have been registered around the Municipality of Murska Sobota. They are all located in the southern part of the municipality along the Mura River. Nature conservation areas are areas proposed for protection (Mura Regional Park), natural values, ecologically important areas (EPO Mura), special protection areas (Natura 2000 areas), habitat areas (flowing water vegetation, annual communities of muddy river banks, lowland tall grasses, wet mesotrophic and eutrophic meadows and pastures, oligotrophic wet meadows with blue cone and related communities, nitrophilous forest edges and moist riparian tall grasses, mesotrophic to eutrophic cultivated grasslands, oak-hornbeam forests, Illyrian oak-hornbeam forests, riparian willow forests) and areas with landscape elements important for the conservation of biodiversity (borders, isolated bushes and trees, depressions with tall grasses).

2.5.3. Infrastructure

The energy potentials in the municipality are represented by geothermal energy, biomass energy and the Mura River (hydropower). For the generation of electricity, priority is given to the renovation, modernization, ecological rehabilitation or replacement of existing production units with newer and more efficient production facilities. In the further development of electricity, the municipality will consider all possibilities for the use of renewable energy sources, such as geothermal energy, biomass energy, solar energy and other sources in spatial planning, considering the efficiency of the selected system and spatial, environmental and social acceptability. Biomass energy is based primarily on the use of waste from agriculture and agricultural products and not on the processing of agricultural products.

The Mura River has great energy potential, but it is also an important nature conservation area, which is why hydroelectric power plants are planned in the upper reaches of the river and are still in the study phase.

Rich deposits of geothermal energy resources (thermal waters) have been identified around the municipality, which are already being used in tourism (swimming pools in the Diana Hotel), for heating (apartment blocks in Murska Sobota) and for heating water in the city swimming pool. Further exploitation of geothermal energy resources and exploitation of groundwater as a heat source for smaller consumers, in combination with other energy sources, are encouraged.

Due to increased electricity needs, a connection of Murska Sobota and Lendava and Murska Sobota and Mačkovci with 110 kV transmission lines is planned. Both transmission lines are state projects and will be built in the coming years.

The city municipality is well covered by the gas pipeline network. The P 152 transmission pipeline (diameter 150, pressure 50 bar) runs to the MRP Murska Sobota gas station. Other gas transmission pipelines represent the city network of Murska Sobota, which supplies larger consumers and is part of the natural gas transmission system.

The arrangement of the distribution gas pipeline network and gas pipeline connections for the needs of technological processes and household needs is encouraged throughout the entire area of the city municipality.

2.5.4. Cultural heritage

Cultural heritage objects and areas are cultural monuments, influential areas of cultural monuments, heritage protection areas, registered cultural heritage and influential areas of heritage, which are protected under regulations in the field of cultural heritage protection and are an integral part of

the OPN. Objects and areas are protected by the Decree on the Declaration of Immovable Cultural and Historical Monuments in the Area of the Municipality of Murska Sobota (Official Gazette, No. 8/91). In the area of the Municipality of Murska Sobota there are 4 archaeological areas, 1 settlement area (the town of Murska Sobota), 4 archaeological monuments, 2 castles, 25 buildings of bourgeois and market architecture (all in the town of Murska Sobota), 2 sacral monuments, 19 ethnological monuments and 4 historical monuments. (4) The protection zones of the water catchments in Krog, Črnske meje and Fazanerija, which are the central water catchments in the municipality, are protected by the municipal Ordinance on the protection of water resources of Črnske meje, Krog and Fazanerija (Official Gazette of the Republic of Slovenia, No. 34/00). With the adoption of the ordinance, the Rules for the management of agricultural land, farms and estates in the water protection area of Črnske meje, Krog and Fazanerija were also adopted. In addition to the protection zones of the central water catchments, the protection zone of the Lukavci water source is also located in the area of the municipality, which is protected by the municipal ordinance of the Municipality of Križevci, the Ordinance on the protection of the Lukavci water source (Official Gazette of the Republic of Slovenia, No. 56/00 and 110/00).

2.6. Spatial Plan of micro location of the pilot site Rakičan

The micro-location spatial arrangement belongs to the MS 22 area, representing the intended use of the best agricultural land. The identification number of the intended use is 2010, which is regulated as a spatial act area with ID 666, Procedure ID 255008 (light green colour).

The target area of use would be greenhouses that could be heated using energy produced from an existing well or an urban area within a radius of 1 km from the well location.

The micro-location spatial arrangement belongs to the RA 1 area, representing the intended use of residential areas. The identification number of the intended use is 1011, which is regulated as a spatial act area with ID 666, Procedure ID 255008 (yellow colour).

The micro-location spatial arrangement belongs to the RA 3 area, representing the intended use of a rural settlement. The identification number of the intended use is 1013, which is regulated as a spatial act area with ID 666, Procedure ID 255008 (yellow colour).

The target area of use could also be an industrial zone or a general hospital area, both locations are approximately 1.5 - 1.9 km from the well location.

The micro-location spatial arrangement belongs to the RA 4 area, representing the intended use of the economic zone. The identification number of the intended use is 1032, which is regulated as a spatial act area with ID 666, Procedure ID 255008 (purple colour).

3. Research Area Rakičan

3.1. General information

The Murska Sobota area is located between two zones of the thrust or horst structure of the Mursko-Sobočki massif, which is also the main source of the thermal flow. The influence of this thermal flow is also visible in the strong carbonization of plant remains in the Lendava Formation (Lipa - Beltinci area).

The deeper lying Miocene layers are mainly silty in development, but due to the magmatic choke at depths above 1000 m they are also slightly to strongly metamorphosed, which with increasing depth already pass into paragneiss. In general, the Murskosoboška Formation is in a fine-grained clastic development of claystones and marls with individual thinner layers of slightly metamorphosed compact sandstone.

The metamorphic rocks of the basic mountain range are strongly tectonically destroyed in the contact zone, together with the younger Miocene layers, and therefore also with greater secondary porosity, which means the possibility that the cracks can be filled with fluids that have a higher temperature.

3.2 Rakičan pilot site area

The location of the Rakičan research area is northeast of the Rakičan settlement. It is located on agricultural land and is accessible via a field path. The well is 700 m from the settlement, 1500 m from the economic zone and 1900 m from the MS General Hospital. To the north of the well is the bed of the Ledava River, which is approximately 330 m from the well location. To the southwest of the location is the main road connecting Muska Sobota and Beltinci.

The approximate coordinates of the well are:

Y = 593 205

X = 169 038

Elevation (h) = 185,40 m

3.2.1. Stratigraphic-lithological conditions

The oldest metamorphic rocks of the migmatite Pohorje series, Gbm (gneiss series in amphibolite facies) are of Riphean-Cambrian age (Cm), which were formed in a eugeosynclinal environment (pelites and psammites), and they build the bottom of the basic basin of Miocene rocks. In contact with younger Miocene layers are metamorphic rocks that are strongly tectonically destroyed.

The bottom of the basin is built by rocks of Upper Badenian age (M43) in the facies of rapidly changing regression-emersion processes with strongly destroyed lithic to brecciated sandstones, silty marl and clay-marly siltstones to siltstones. Sarmatian ages (M5) are developed in a brackish facies with lithic sandstones and marls.

The Pannonian rocks (M6), which lie unconformably on the Sarmatian strata, are developed in the Caspibrachic and oligohaline facies of quartz sandstones with marl to marly claystones and siltstones to silty sandstones.

The Lower Pontic rocks (M71) are developed in the lacustrine-fluviatile to marshy facies of organogenic clays with plant remains and traces of coal with silty sands to poorly bound sandstones and siltstones.

The Upper Pontic rocks (M72) are developed in the fluviatile and marshy facies of organogenic clays with plant remains, sandy gravels, sands and silts.

The Miocene strata overlie the Pleistocene-age strata (Q1) in the fluvioglacial sandy gravel facies with intercalations of silty-sandy clays.

3.2.2. Structural-tectonic conditions

Based on regional geological mapping (INA-Geological Consulting, 1990-91), geophysical (Geofizika, 1985 and 1990) and mining research (Nafta Lendava, 2001), a detailed division of geotectonic units into the Murska Sobota Ridge, the Martjanci Ridge and the Martjanci Bay has been determined in the Murska Sobota area. In the narrowest area of Murska Sobota, near the proposed location of the Sob-3 well (Černelavci), only the basic structural-tectonic unit of the Murska Sobota Ridge (petroleum-geological classification) or the umbrella system of the Drava Range and the Krka or the Grač Paleozoic (geothermal classification, Transthermal Slovenia-Austria, 2000-2006) can be distinguished.

Based on detailed petrographic studies of the oldest metamorphic rocks of the Middle Austroalpine (Riphean-Cambrian, Cm), their formation has been established. Tectonically, this zone is classified as the eastern extension of the Eastern Alps. Pelitic-psamitic deposits, which formed in a eugeosynclinal environment with initial volcanism, were migmatized during the subduction of the oceanic crust in the Taconian phase of the Caledonian orogeny (Upper Ordovician, O3) and in this way a gneiss series in amphibolite facies was formed.

From the end of the Mesozoic to the beginning of the Miocene, the collision of the Adriatic microplate, the Eurasian continental plate and the African continental plate lasted, which resulted in the tectonic "escape" of the Eastern Alps towards the east and thus a more active restructuring of the basic geological structure began within the emerging Paratethys Pannonian Basin. This divergent contact

between the plates resulted in strong neotectonic and relaxational failures of the basic geological structure with the movement of blocks in the NW-SE direction, namely along the Ledava and from Pušča towards the Bakovska gravel pit, which conditioned the formation of coastal lagoons and shallow seas (L. Placer, GeoZS, 2008).

3.2.3. Well status

The RAK-1 well is currently abandoned, and its technical condition within the wellbore is not fully known nor publicly available. Therefore, additional investigation and diagnostic measurements would be required to accurately assess its current technical state and structural integrity.

The well is located within a concrete-lined shaft and is covered with a concrete slab for protection. According to the available information, the well is equipped with a wellhead assembly and is properly sealed and secured, preventing any environmental or safety risks at the surface.

3.3. Geological Research at pilot site Rakičan

The hydraulic field of the Miocene stack in the Murska Sobota area is, due to the strongly dissected layers, slightly horizontal (the top part of the horst structure in the central part of the city of Murska Sobota) to strongly inclined (along the Ledava fault and the Pušča-Bakovska gravel fault). In the deeper part, especially in the contact zone, where the rocks of the Miocene stack are already metamorphically altered (paragnais), the hydraulic field is oriented only to horizontally to subhorizontally broken and crushed rocks. The next and deepest part of the hydraulic field is in the strongly broken metamorphic stack (orthogneiss) of Paleozoic age (Pohorje gneiss series in amphibolite facies).

Based on all known geological (GeoZS, 1990), geophysical (Geofizika, 1985 and 1990) and geothermal (Transthermal Slovenia-Austria, 2000-2006) data, the potential of geothermal aquifers is predicted according to the Hochstein classification (Hochstein, 1988).

In Slovenia, the most common hot springs are of the mixed type, where water circulates through fracture zones that are covered or closed by rocks with lower thermal conductivity.

Based on all known data, we conclude that around the Rak-1 well, we expect the following types of geothermal reservoirs:

- from 500-1160 m low-temperature aquifers with a lower to good recharge, with a temperature of 44-85°C. Given that the porous aquifers of the Lower Pontic age (M71) have a very low permeability (GeoZS, 1988), we predict the yield of these aquifers with thermal

water of all captured aquifers in the interval from 500-565 m between 2.9 and 4.5 l/s and with a water temperature at the well mouth of 39-44 °C.

- In the deeper aquifers of Pannonian (M6), Sarmatian (M5) and Badenian (M4) age up to the contact with the metamorphic bedrock, we assume medium-quality porous aquifers with a low permeability and a yield of all captured aquifers in the interval from 605-1141 m between 1.3 and 3.2 l/s and with a water temperature at the wellhead of 53-58 °C.

3.4. Geological-Geophysical Features and Lithological profile at site Rakičan

The lithological column of the Rak-1 well is based on regional geological mapping (Geological Institute of Ljubljana, INA-Geological Consulting, Zagreb; 1990-91), seismic surveys (Geofizika, Zagreb, 1985-86), gravimetric surveys (Geofizika, Zagreb, 1985), magnetometric surveys (Geofizika, Zagreb, 1985) and data from the following wells: Sob-1/87, Sob-2/88, Sob-3/12 and Sob-4/13. The following chronostratigraphic and lithostratigraphic units are represented in the Rak-1 well:

Table 1: Chronostratigraphic and Lithostratigraphic units of reh area of interest.

Chronostratigraphic units		Lithostratigraphic unit	Interval
KVARTAR, Q 1	Pleistocen Q1	MURA FORMACIJA	0 - 30 m
PLIOCEN	PLIOCEN, P1/2		30 - 680 m
PLIOCEN	PLIOCEN, P1/1	LENDAVSKA FORMACIJA	680 - 910 m
MIOCEN	MIOCEN M7/1	MURSKO SOBOŠKA FORMACIJA	910 - 1160 m
PALEOZOIK	KAMBRIJ CM	OSNOSVNO GORSTVO	1160 m -

The Mura Formation is built by layers of Upper Pontian age (M72) in the facies of sandy gravels, sands, silty clays, sandy silt with plant remains and organogenic clay.

The Lendava Formation is built by layers of Lower Pontian age (M71) in the facies of silty marls, organogenic clays with traces of coal, gravels, sands and silts.

The Murskosoboška Formation or Petišovci Series is built by layers of Pannonian age (Pannonian sensu stricto, M6) in the facies of quartz sandstones, marls, claystones and silts and Sarmatian layers (Sarmatian sensu stricto, M5) in the facies of strongly organogenic clayey-marlstone mudstones, siltstones, lithic sandstones and breccia sandstones.

The basic mountain range is built of metamorphic rocks of Riphean-Cambrian age (Cm) of the Pohorje gneiss series in amphibolite facies as muscovite-biotite gneisses.

3.5. Well Construction at site Rakičan

The well schematic is as follows:

- Total depth of the well is 1280 m
- Casing installed:
 - o Surface casing installed and cemented to surface.
 - o I installed intermediate casing and cemented to surface.
 - o II intermediate casing installed and cemented to surface.
- The well was perforated, no gravel pack nor filters were installed,
- The actual depth of intervals is not clear, more investigation would be needed
- The well is vertical.

3.6. Conclusion of Drilling and Testing the Well Pilot Site

Rakičan

After drilling the well, well test data were not obtained. The goal of the well was to find hydrocarbons, but this did not happen. The well was closed and out of use after drilling. In a later period around the year 2000, the well was reactivated, and it was found that the well produces thermal water. During well testing, it was found that the production was 5 l/s at a temperature of 45°C.

3.7. Exploration Concession Area Pilot Site Rakičan

There are no concessions in the area under consideration, therefore there are no restrictions for starting the concession application process. The only limiting factor is that in case of water exploitation, a reinjection well must be provided. If the well is used as a closed energy system, this is not necessary.

3.8. Locations of All Wells

In the wider area there are several wells as shown on the picture below.

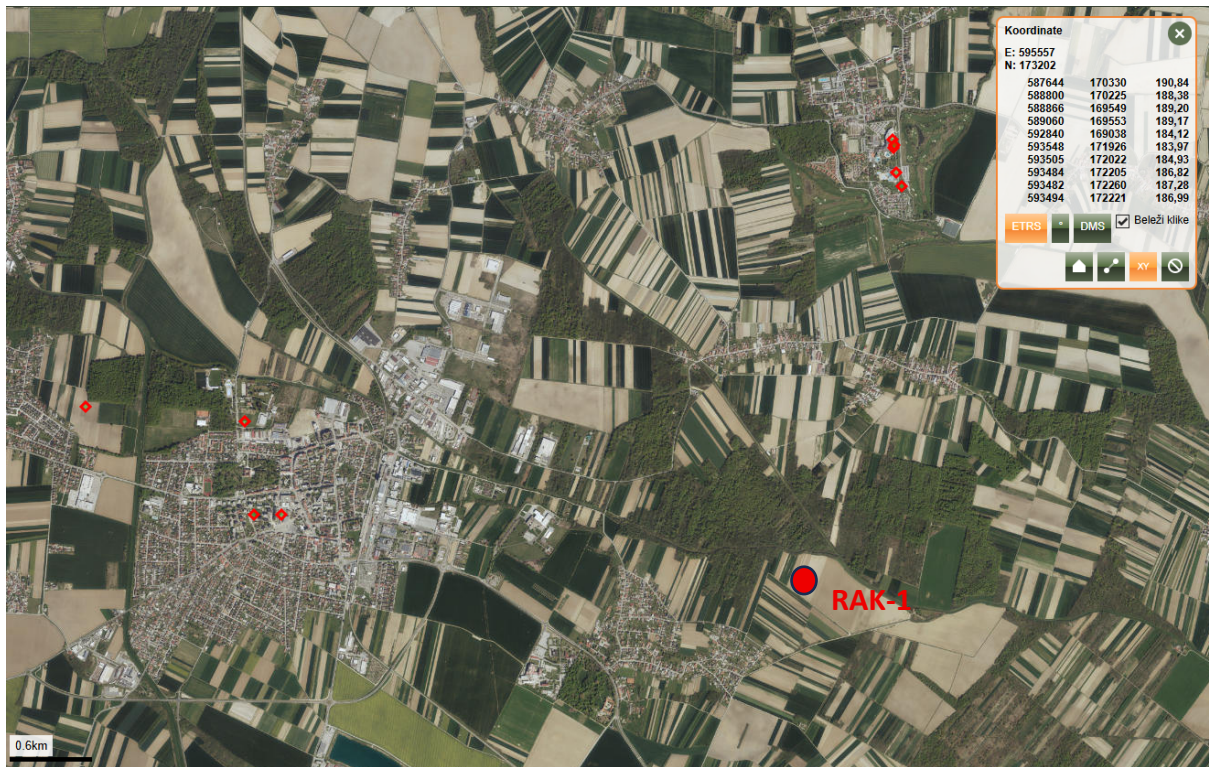


Figure 7: Location of existing wells (red dots) in the surrounding area of the well RAK-1. Source: Atlas okolja.

4. Geological Structure of the Geothermal Reservoir at the Potential Location and Broader Locations from Available Data

4.1 Geological Description

The wider area of interest is in the Mura Depression or in the northeastern part of the Mursko-Soboški massif. This area is covered by a relatively dense network of seismic profiles (seismic measurements) that were carried out during the exploration of oil and gas deposits. Based on the obtained seismic data and data obtained during the drilling of exploratory wells for hydrocarbons, GeoZS produced maps according to the characteristic markers b and Pt.

The Martjanci, Rakičan and Noršinci structures lie in the wider area of the northeastern part of the Mursko-Soboški massif. The structural map shows that the base of the Tertiary is located at depths of 1300 to 1500 m throughout the area. The Martjanci anticline (Moravske Toplice) is separated from the Rakičan anticline by a shallow Martjanski trench. The base of the Tertiary rises slightly towards the southwest, so that in this area it is located at depths of 1000 to 1100 m.

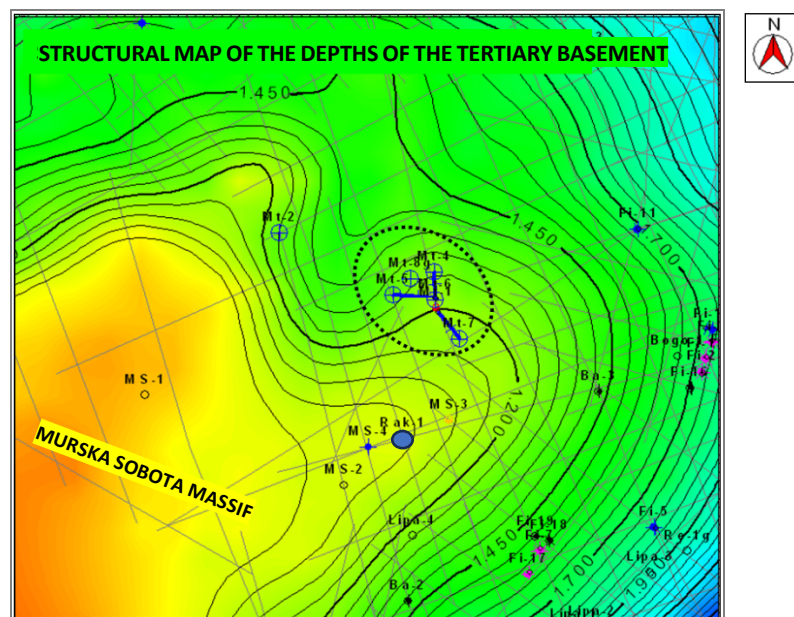


Figure 8: Structural map of the subsurface with location of RAK-1 (blue dot). GeoZS, 2016.

In the Rakičan area Quaternary sediments are represented by sandy clay, Mura gravel, sandy (puffy) clay and alluvial deposits. This is followed by sediments and sedimentary rocks of Pontian and Pannonian age. Sediments of the Upper Pannonian (Mura Formation) are represented by gravel, sand and sandy clay with coal inclusions. This is followed by sedimentary rocks of the Lower Pontian and

Pannonian (Lendava and Murskosoboška Formations), which are clay marls and mica-quartz sandstones. The base of the Tertiary in this area is represented by the basic uplands - gneiss of Paleozoic age.

The boundary between the Mura and Lendava Formations drops steeply and unevenly to the east. In the Murska Sobota area, it is located at a depth of 776 - 787 m, in Rakičan at a depth of 850 - 900 m, and in Moravci at a depth of 940 m.

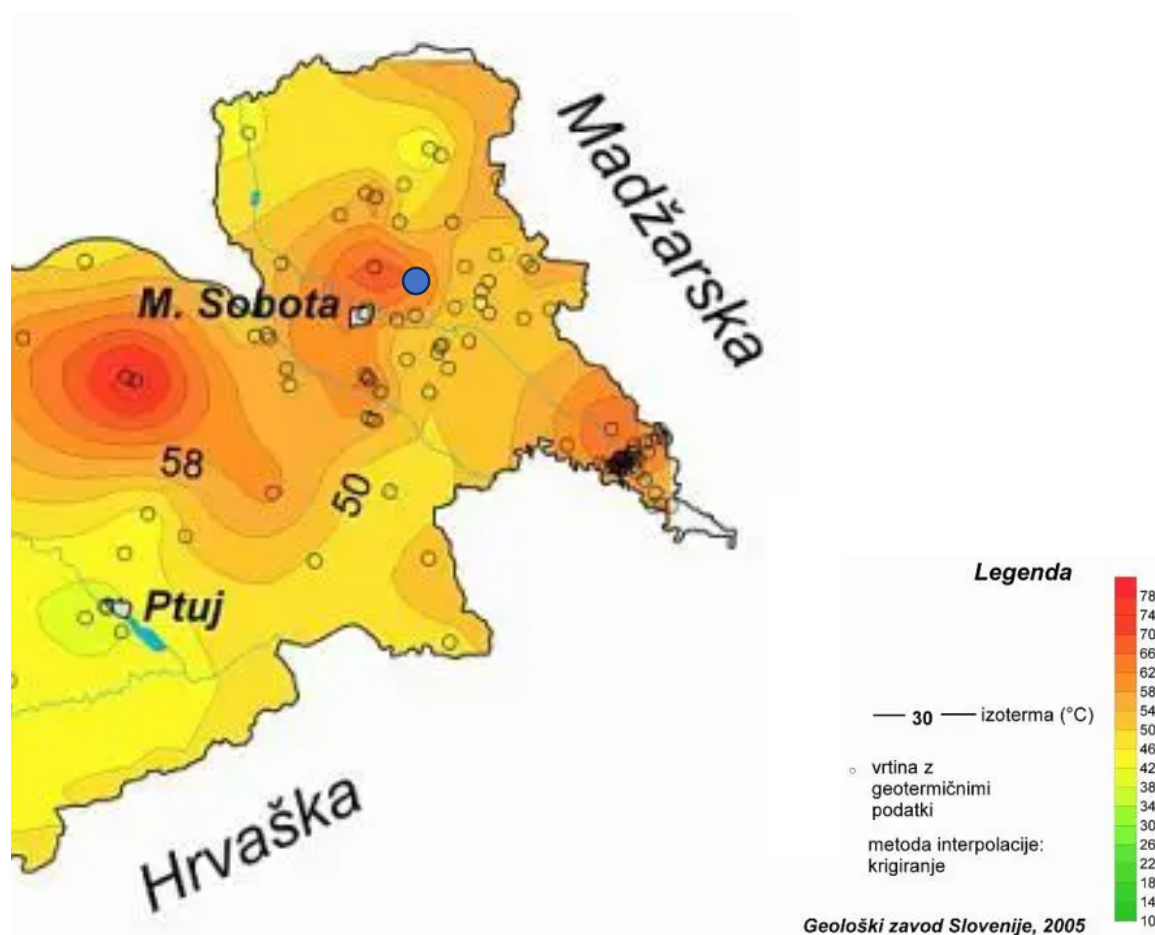


Figure 9: Map of temperatures at 1000 m below surface. Source, GeoZS 2005.

4.2. Lithological Description for each Well at the Pilot Site

The description of well Rak-1 is as follows (Table 2):

Table 2: Geological features for the well Rak-1.

Chronostratigraphic units		Lithostratigraphic unit	Interval
KVARTAR, Q 1	Pleistocen Q1	MURA FORMACIJA	0 – 30 m
PLIOCEN	PLIOCEN, P1/2		30 – 680 m
PLIOCEN	PLIOCEN, P1/1	LENDAVSKA FORMACIJA	680 – 910 m
MIOCEN	MIOCEN M7/1	MURSKO SOBOŠKA FORMACIJA	910 – 1160 m
PALEOZOIK	KAMBRIJ CM	OSNOSVNO GORSTVO	1160 m -

Lithological column	Geological Sediments descriptions	Interval
Pleistocen Q1	Gravel	0 – 30 m
PLIOCEN, P1/2	Sandy clay, gray to gray green	30 – 70 m
	Sandy clay, gray green, with grains of quartz sand	70 – 120 m
	Sand, gray medium-grained, with gray-green hard sandy clay	120 – 190 m
	Sandy clay gray to gray-blue, soft	190 – 680 m
PLIOCEN, P1/1	Coal, Sandy clay gray	680 – 810 m
	Sandstone	810 -830 m
	Clay marl	830 – 870 m
	Sandstone	870 – 880 m
	Clay marl	880 – 910 m
	Clay marl	910 – 1000 m
MIOCEN M7/1	Sandstone	1000 – 1030 m
	Clay marl	1030 – 1150 m
	Sandstone	1150 – 1160 m
KAMBRIJ CM	Gneiss	1160 m -

4.3. Drill Stem Tests/Flow Tests/Pressure Buildup Tests/Interference Tests

A flow test was performed around the year 2000. There were some measurements of flow, temperature and pressure characteristics of the reservoir. The well information available point out the following:

- Flow rate between 5 - 10 l/s
- Temperature outlet from 40 - 45°C
- Estimated Reservoir pressure 112 bar at 1050 m depth

5. Geothermal Features of Potential Location with Quantification of Possible Brine Production from the Current Well Assets and any New Drilling

5.1 Pilot Site Location

5.1.1 Size of the Geothermal Reservoir at the Pilot Site

In Slovenia, thermal waters are extracted from low-temperature geothermal systems, also called hydrothermal systems or geothermal aquifers. In the northeast of Slovenia, intergranular regional high-yielding sandy aquifers in the Pannonian sedimentary basin dominate. In them, the temperature, content of dissolved minerals and gases in the water increase continuously with depth. In the Pannonian basin, the most widespread and abundant intergranular aquifers in sedimentary basins are mostly cross-border. They are tapped by 87% of all wells, which together provide approximately 70% of all extracted thermal water. This includes the cross-border aquifer in the Pontic and Upper Pannonian poorly cohesive sandstones of the Mura Formation in the Mura-Zala basin, which Slovenia shares with Hungary and Croatia. In Slovenia 21 wells extract thermal water from this aquifer at 13 locations.

According to experience, the area of influence is usually 1 - 2 km radius from the well location. Based on the above, we can assume that the area of influence will be at most 12.5 km². If we consider the potential intervals for exploitation, which are 70 m thick, we have a volume of stored geothermal energy of 0.875 million m³.

5.1.2. Reservoir Pressure and Reservoir Temperature at pilot site

The assumed reservoir pressure can be assumed to be roughly 112 bar and reservoir temperature 70°C. This can be different. Accordingly, it would be necessary to check the current conditions on the well.

5.1.3 Characteristics of the Reservoir Fluid

The characteristics of the reservoir fluid are as follows:

- Water salinity 4000 mg/l
- pH = 7,4
- CO₂ content 1000 mg/l

Other parameters are not available and would need to be measured. Accordingly, it is recommended to check the current conditions of the well.

5.1.4 Physical Properties of Rocks

No physical properties of rocks for the pilot site are available. Therefore, it would be necessary to make an investigation with logging equipment to check those features and collect the data from analogue sites and rocks.

6. Environmental Assessment of the Project

6.1. Mitigation of environmental impact

All research activities, equipment and devices are designed and technologically advanced in such a way that they are safe for the environment and use. During the implementation of seismic and drilling activities, the following environmental impacts are expected:

6.1.1. Emission to air

During the implementation of workover activities pollutant emissions into the air are not expected, because the power will come from the electricity line.

From a safety point of view, during workover operation, emissions into air are measured at several locations at the site.

6.1.2. Emission of substances into water

During the implementation of research activities there are not expected any emissions into water. Storm water from the site will be collected in the peripheral shaft of the worksite and will evaporate into the atmosphere or leaked into the ground in accordance with environmental protection regulations. Water pumped during the activation of the well will be collected in the collection lagoon and chemically analysed before handing over to an authorized waste collector. If possible, the produced water will be dispersed along the existing drainage trenches by obtaining the appropriate permit determined by regulations in the field of environmental protection. At the time of discharge, water quantities, temperature and chemical analyses and the gas content of the water will be monitored.

During the execution of well workover, the works will be carried out in accordance with the Decree on the emission of substances and heat during wastewater discharge into waters and public sewage system (Official Gazette of the Republic of Slovenia, No. 64/12, 64/14 and 98/15), in accordance with the Decree on the discharge and treatment of urban waste water (Official Gazette of the Republic of Slovenia, No. 98/2015 and 76/17) and with all applicable legislation and regulations for water protection.

6.1.3. Disposal/release of substances into soil

During operation, no release into soil is expected. When conducting workover at a mobile worksite, non-hazardous chemicals will be stored for the purpose of preparing working fluid for workover and fuel, as well as lubricants for the drive and maintenance of machines and devices. The storage sites

of these substances will be determined by the design for the installation of the drilling set and shall be arranged in such a way as to avoid any emission of the substance into the soil. Where necessary, standard oil traps will be manufactured in accordance with the SIST EN 858 standard (wherever oil catcher is prescribed).

For temporary storage of chemicals that will be used during mining work, a prescribed covered landfill with an impermeable base and controlled drainage of water will be prepared. During operation, it is not planned to deposit substances at the site of the well.

6.1.4. Generation of waste

During the implementation of workover works, waste material will be generated, which will be managed in accordance with the Waste Regulation (Official Gazette of the Republic of Slovenia, No. 37/15 and 69/15).

During the implementation of research activities, a waste collection point will be organized, where separation and collection will take place. Occasional waste collection will be organised with local authorised collectors to prevent them from accumulating on mobile worksites.

6.1.5. Noise

During operation, noise is kept within the legally permissible limits. During measurements and workover, the noise level at the workplace and the environment will be measured. If certain activities are found to exceed noise limits, this is reduced by appropriate safety fences and screens.

6.1.6. Radioactive radiation

During the implementation of research activities and after the completion of the works, there will be no radioactive radiation into the environment.

6.1.7. Electromagnetic radiation

During the implementation of research activities and after the completion of the works, there will be no electromagnetic radiation into the environment.

6.1.8. Ambient light radiation

During the implementation of the research activities of seismic measurements and after the completion of the works, there will be no radiation of light into the environment. During the exploratory workover, the work will take place 12/7 and lighting of the work site will not be required to ensure proper visibility at night.

6.1.9. Air/water warming

During the implementation of research activities and after the completion of the works, there will be no warming of the atmosphere and water.

6.1.10. Smell

During the implementation of research activities and after the completion of the works, no stench will be caused.

6.1.11. Visible exposure

During the implementation of research activities, a workover tower will be visible and a safety fence of the worksite will be placed. The site and tower will be temporary facilities that will be removed at the end of the workover, so the short-term visible exposure is negligible.

6.1.11. Vibrations

During the implementation of research activities, no vibration is expected to be created.

6.1.12. Land use change

During the implementation of research activities, no land use change is expected to be needed.

6.1.13. Change of vegetation

During the implementation of research activities, they will not affect the vegetation in the environment.

6.1.14. Explosion

During the implementation of research activities, flammable and explosive substances that would affect the soil or the surrounding area are not expected. No explosions are expected during research activities.

6.1.15. Physical change/surface transformation

During and after the implementation of the research activities, no significant physical changes or surface transformations are expected to occur at the site. Upon completion of all activities, site rehabilitation will be carried out, ensuring that the area is restored to its original condition. The final installation will not cause any long-term alteration of the terrain or land use.

6.1.15. Water usage

During the implementation of research activities, water use is foreseen during workover to prepare work fluid, for which water approval will be obtained. The consent will also include the research activity of well activation and the initial pumping test.

6.1.16. Protection of cultural and historical buildings

Before starting research activities, it is necessary to obtain consent from the competent institutions that there are no such facilities in the planned space or that they will not be endangered by the intended work. If the contractor encounters archaeological traces during the execution of works, he is obliged to inform the competent authorities of the Ministry of Culture. All interventions in the vicinity of known or unknown archaeological sites shall be protected.

6.1.17. Agriculture

When designing alignments for the implementation of research activities, permanent crops and larger cultivated areas should be avoided where possible.

6.1.18. Forestry

No forestry area is near by the intervention location, therefore no impact to forestry is expected.

6.1.19. Hunting and fishing

During the implementation of research activities would be foreseen to establish an agreement with competent hunting families on the method of game protection and the transfer of feed and stands to other places. This includes identification of paths within the hunting grounds along which workers can move.

6.2. Legal obligations during the execution of work related to environmental protection

When conducting research activities for the protection of the environment, nature and water, the following regulations shall be considered and applied mutatis mutandis when carrying out research works:

6.2.1. European directives

- Directive 91/271/EEC concerning urban wastewater treatment
- Directive 2001/81/EC on national emission ceilings for certain atmospheric pollutants
- Directive 2002/49/EC relating to the assessment and management of environmental noise
- Directive 2006/118/EC on the protection of groundwater against pollution and deterioration
- Directive 2008/50/EC on ambient air quality and cleaner air for Europe
- Directive 2008/98/EC on waste management
- Directive 2000/60/EC on water
- Directive 2010/75/EC on industrial emissions (integrated pollution prevention and control)
- Decision 406/2009/EC on the effort of Member States to reduce their greenhouse gas emissions
- European Union Strategy on adaptation to climate change (COM (2013))

6.2.2. Rules governing general requirements

- Act on the introduction of devices to produce electricity from renewable energy sources (Official Gazette of the Republic of Slovenia, No. 78/23)
- Environmental Protection Act (Official Gazette of the Republic of Slovenia No. 39/06 - official consolidated version, No. 49/06 - ZMetD, No. 66/06 - para. US, No 33/07 – ZPNačrt, No 57/08 – ZFO-1A, No 70/08, No 108/09, No 108/09 – ZPNačrt-A, No 48/12, No 57/12, No 92/13, No 56/15, No 102/15, No 30/16, No 61/17 – GZ, No 21/18 – ZNOrg and No 84/18 – ZIURKOE, 158/20)
- Water Act (Official Gazette of the Republic of Slovenia No. 67/02, No. 2/04 - ZZdri-A, No. 41/04 - ZVO-1, No. 57/08, No. 57/12, No 100/13, No. 40/14, No 56/15 and No 65/20)
- Spatial Planning Act (Official Gazette of the Republic of Slovenia No. 61/17)
- Spatial Planning Act (Official Gazette of the Republic of Slovenia, No. 33/07, 70/08 - ZVO-1B, 108/09, 80/10 - ZUPUDPP, 43/11 - ZKZ-C, 57/12, 57/12 - ZUPUDPP-A, 109/12, 76/14 - para. US, 14/15 - ZUUJFO and 61/17 - ZUreP-2)
- Decree on environmental interventions subject to an environmental impact assessment (Official Gazette of the Republic of Slovenia, No. 51/14, 57/15, 26/17, 105/20)
- Decree on the content of the report on the effects of the intended intervention on the environment and how it is prepared (Official Gazette of the Republic of Slovenia, No. 36/09, 40/17)

- Mining Act (Official Gazette of the Republic of Slovenia, No. 14/14 - official consolidated text and 61/17 - GZ)
- Building Act (Official Gazette of the Republic of Slovenia No. 61/17, No. 72/17 - pr. and Nos 65/20, 15/21 - ZDUOP)

6.2.3. Regulations governing requirements in the field of mining

- Decree on the management of waste from extractive and other activities of extracting mineral resources (Official Gazette of the Republic of Slovenia, No., 30/11, 64/21)
- Rules on the content and method of drafting a general act on safety and health at work, which shall be prepared by the mining contractor before the start of work (Official Gazette of the Republic of Slovenia, No. 68/01 and 61/10 - ZRud-1)
- Rules on requirements for ensuring safety and health at work and on technical measures for blasting work for exploration and exploitation of mineral resources, carrying out other mining works and carrying out explosive work in other activities (2003). Official Gazette of the Republic of Slovenia, No. 111/03 and 61/10-Zrud-1 (4.3.2021).

6.2.4. Rules governing requirements for groundwater

- Rules on the methodology for determining groundwater bodies (Official Gazette of the Republic of Slovenia No. 65/03)
- Rules on the designation of groundwater bodies (Official Gazette of the Republic of Slovenia No. 63/05 and No. 8/18)
- Rules on operational monitoring of groundwater status (Official Gazette of the Republic of Slovenia, No. 13/21)
- Rules on groundwater monitoring (Official Gazette of the Republic of Slovenia No. 31/09)
- Rules on drinking water (Official Gazette of the Republic of Slovenia, Nos. 19/04, No. 35/04, No. 26/06, No. 92/06, No. 25/09, No. 74/15 and No. 51/17)
- Decree on the status of groundwater (Official Gazette of the Republic of Slovenia No. 25/09, No. 68/12 and No. 66/16)
- Rules on the criteria for determining the water protection area (Official Gazette of the Republic of Slovenia, Nos. 64/04, No. 5/06, No. 58/11 and No. 15/16)

6.2.5. Regulations governing working with dangerous substances

- Decree on the storage of dangerous liquids in stationary storage containers (Official Gazette of the Republic of Slovenia, No. 104/09, 29/10 and 105/10)
- Rules on technical and organizational measures for the storage of hazardous chemicals (Official Gazette of the Republic of Slovenia, No. 23/18)

6.2.6. Rules governing requirements for surface waters

- Rules on operational monitoring of surface water status (Official Gazette of the Republic of Slovenia No. 91/13)
- Decree on the status of surface waters (Official Gazette of the Republic of Slovenia No. 14/09, No. 98/10, No. 96/13 and No. 24/16)

6.2.7. Regulations governing wastewater requirements

- Rules on the first measurements and operational monitoring of wastewater (Official Gazette of the Republic of Slovenia, Nos. 94/14 and 98/15) Decree on the emission of substances and heat from the discharge of wastewater into waters and public sewage (Official Gazette of the Republic of Slovenia No. 64/12, No. 64/14 and No. 98/15)
- Decree on the discharge and treatment of urban wastewater (Official Gazette of the Republic of Slovenia No. 98/15, No. 76/17 and No. 81/19)

6.2.8. Air

- Decree on ambient air quality (Official Gazette of the Republic of Slovenia, No. 9/11, 8/15, 66/18)
- Decree on arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (Official Gazette of the Republic of Slovenia, No. 56/06)
- Decree on national emission ceilings for ambient air pollutants (Official Gazette of the Republic of Slovenia, No. 48/18) Decree on the emission of substances into the air from stationary sources of pollution (Official Gazette of the Republic of Slovenia, No. 31/07, 70/08, 61/09, 50/13)
- Decree on the prevention and reduction of particulate matter emissions from construction sites (Official Gazette of the Republic of Slovenia, No. 21/11)
- Decree on the emission of substances into the air from medium combustion plants, gas turbines and stationary engines (Official Gazette of the Republic of Slovenia, Nos. 17/18 and 59/18)
- Decree on the emission of substances into the air from small combustion plants (Official Gazette of the Republic of Slovenia, No. 46/19)
- Ordinance on the classification of areas, agglomerations and subareas according to ambient air pollution (Official Gazette of the Republic of Slovenia, No. 38/17, 3/20 and 152/20)
- Rules on the first measurements and operational monitoring of emissions of substances into the air from stationary sources of pollution and on the conditions for its implementation (Official Gazette of the Republic of Slovenia, No. 105/08)

6.2.9. Regulations governing soil requirements

- Rules on operational monitoring of soil condition (Official Gazette of the Republic of Slovenia, No. 66/17 and 4/18) Decree on burdening soil with waste input (Official Gazette of the Republic of Slovenia, Nos. 34/08 and No. 61/11)

6.2.10. Regulations governing nature protection requirements

- Nature Conservation Act (Official Gazette of the Republic of Slovenia, Nos. 56/99, No. 119/02, No. 22/03, No. 41/04, No. 96/04, No. 61/06 - ZDru-1, No. 8/10 - ZSKZ-B, No. 46/14, No. 21/18 - ZNOrg, No. 31/18 and No. 82/20)
- Rules on the definition and protection of natural values (Official Gazette of the Republic of Slovenia, Nos. 111/04, No. 70/06, No. 58/09, No. 93/10, No. 23/15 and No. 7/19)
- Decree on Genres of Natural Values (Official Gazette of the Republic of Slovenia, Nos. 52/02 and No. 67/03)
- Decree on protected wild plant species (Official Gazette of the Republic of Slovenia, Nos. 46/04, Nos. 110/04, Nos 115/07, Nos 36/09 and Nos 15/14)
- Decree on special protection areas (Natura 2000 areas) (Official Gazette of the Republic of Slovenia No. 49/04, No. 110/04, No 59/07, No 43/08, No 8/12, No 33/13, No 35/13 - Avg., No. 39/13 - para. US, No 3/14, No 21/16 and No 47/18)
- Decree on ecologically important areas (Official Gazette of the Republic of Slovenia No. 48/04, No. 33/13, No. 99/13 and No. 47/18)
- Decree on habitat types (Official Gazette of the Republic of Slovenia, Nos. 112/03, Nos 36/09 and No. 33/13)

6.2.11. Noise pollution

- Decree on the assessment and regulation of environmental noise (Official Gazette of the Republic of Slovenia, Nos. 121/04 and No. 59/19)
- Decree on limit values for environmental noise indicators (Official Gazette of the Republic of Slovenia, Nos. 43/18 and No. 59/19)
- Rules on noise emission of machines used outdoors (Official Gazette of the Republic of Slovenia, Nos. 106/02, 50/05, 49/06, 17/11-ZTZPUS-1)
- Rules on the first measurements and operational noise monitoring for noise sources and on the conditions for its implementation (Official Gazette of the Republic of Slovenia, No. 105/08)

6.2.12. Light pollution

- Decree on limit values for light pollution of the environment (Official Gazette of the Republic of Slovenia, No. 81/07, 109/07, 62/10, 46/13)

6.2.13. Electromagnetic radiation

- Decree on electromagnetic fields in the natural and living environment (Official Gazette of the Republic of Slovenia, No. 70/96, 41/04-ZVO-1)

6.2.14. Cultural heritage and landscape

- Protection of Cultural Heritage Act (Official Gazette of the Republic of Slovenia, Nos. 16/08, 123/08, 8/11 - ORZVKD39, 90/12, 111/13, 32/16, 21/18-ZNOrg)

6.2.15. Waste management regulations

- Decree on waste (Official Gazette of the Republic of Slovenia, Nos. 37/15, No. 69/15 and No. 129/20)
- Decree on the management of waste generated during construction work (Official Gazette of the Republic of Slovenia, No. 34/08)
- Decree on waste oils (Official Gazette of the Republic of Slovenia, No. 24/12)
- Decree on soil burdening by introducing waste (Official Gazette of the Republic of Slovenia, No. 34/08, No. 6/11)

6.2.16. Local government regulations

- Ordinance on the Municipal Spatial Plan of the City Municipality of Murska Sobota (SD OPN 1), Official Gazette of Republic Slovenia 64/14
- Ordinance on the Municipal Spatial Plan of the City Municipality of Murska Sobota (SD OPN 1), Official Gazette of Republic Slovenia 54/16
- Ordinance on amendments and supplements to the Ordinance on the Municipal Spatial Plan of the City Municipality of Murska Sobota (SD OPN 1), Official Gazette of Republic Slovenia 67/16

7. Techno-Economic Analysis of the Feasibility of Investing in a Geothermal Field at the Potential Location with the Aim of Producing Electrical and Thermal Energy

7.1 Introduction to Techno-Economic Analysis

Energy prices are important for ensuring an affordable and efficient supply of the population and the economy of local communities and the state. According to available statistical data on energy in Slovenia, we have 47.5% energy import dependence. The share of energy obtained from renewable sources is 25.07%. The average price of electricity for households is 0.19 EUR/kWh (P. Bahun, 2025), while the average price of natural gas is 0.09 EUR/kWh (Lider, 2025). The average price of electricity for non-households is 0.18 EUR/kWh, while the average price of natural gas for non-households is 0.06 EUR/kWh.

Electricity production in Slovenia is divided into 4 sources. Most electricity is produced from nuclear power plants, followed by thermal power plants and hydroelectric power plants. However, electricity production systems from renewable sources such as solar and wind are on the rise.

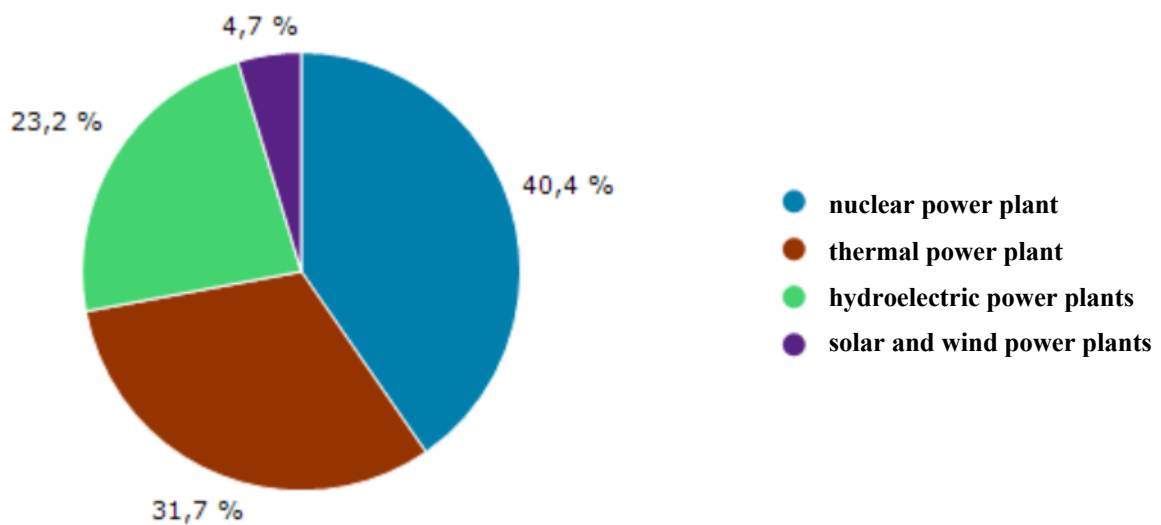


Figure 10: Diagram of electricity production in Slovenia, February 2025. Source: e-stat.

In 2023, the Government of the Republic of Slovenia adopted the Regulation on the formation of the price of heat from district heating (Official Gazette of the Republic of Slovenia No. 9/2023 - hereinafter referred to as the Regulation) and set the variable part of the price for heat for household consumers at 98.70 EUR/MWh. The average price of district heating for household consumption in

Murska Sobota is 139.82 EUR/MWh. The price of heat for business consumers is not capped; therefore the market price applies, which is 187.84 EUR/MWh.

The Energy Agency uses the term typical consumer for an average apartment, with 7 KW of thermal connected power and heat consumption of 6.21 MWh per year, from this data, two contributions (OVE (renewable energy sources) and SPTE (Combined heat and power generation) and VAT, the average price for heat is calculated, which allows for price comparison between distributors in the Republic of Slovenia.

The primary source of heating in Murska Sobota is natural gas, the price of which has increased significantly. In Ljubljana, coal, wood biomass and fuel oil are used as primary energy sources, while natural gas is used only in a small proportion. In Celje, the primary source of heat production is a municipal waste energy recovery facility with an incinerator. Another affordable heating price is in Velenje, where they are heated with heat from the Šoštanj Thermal Power Plant. All the above are not comparable to systems that use natural gas as the main energy source and at the same time achieve a high degree of independence from unstable natural gas and electricity prices on the energy market.

In the structure of the variable part of the heat price in Murska Sobota, in 2023, the shares are as follows:

natural gas: 94.10%,

electricity: 6.90%.

7.1.1 Plan of Engineering Works for the Revitalization of the Existing Well

The intervention for revitalization of the well Rak-1 will include following:

- Documentation
 - Preparation of the work program for the intervention
 - Obtaining a permit for the intervention
 - Arrangement of land registry conditions, obtaining an easement
- Construction work
 - Preparation of the work site 30 x 30 m
 - Construction of an access road to the well 30 m
- Mining work
 - Mobilization of the workover rig
 - Installation of the workover rig and preparation for the intervention on the well
 - Arrangement of the wellhead before the start of work
 - Hermeticity control
 - Replacement of valves

- Replacement of sealing elements
- Installation of well cleaning equipment
 - Preparation of well cleaning fluid
 - Installation of a chisel and well cleaning tools
- Carrying out logging measurements
 - Multi finger caliper,
 - CBL (cement bound log)
 - Acoustic measurement
- Installation of production equipment for establishing a DBHE
 - Installation of insulated pipes for production
 - Hermeticity testing
- Assembly of the wellhead
- Documentation
 - Obtaining a construction permit
- Mechanical work
 - Assembly of surface equipment for heat production
 - Surface installations and fittings
 - Installation of heat exchanger
 - Construction of pipeline connections to consumers 1000 m
 - Installation of pumps to establish circulation of heat transfer medium (e.g., water)
 - Valves, pressure gauges and thermometers for monitoring
- Electrical works
 - Installation of electrical equipment and control system
 - Construction of connecting power cable approx. 500 m
 - Wiring of surface heat production system
 - Wiring of equipment for monitoring and management of the system
- Documentation
 - Obtaining a usage permit

Economical evaluation of the intervention is given in Table 3, which includes description and the estimated value of each step from documentation preparation, mining works, mechanical works and electrical works to establish a functional system for heat production and distribution to end users.

Table 3: Economic evaluation of the intervention on the existing well Rak-1.

Documentation		
- Preparation of the work program for the intervention	25.000 €	
- Obtaining a permit for the intervention		
- Arrangement of land registry conditions, obtaining an easement		
Construction work		
- Preparation of the work site 30 x 30 m	65.000 €	
- Construction of an access road to the well 30 m		
Mining work		
- Mobilization of the workover rig	125.000 €	
- Installation of the workover rig and preparation for the intervention on the well		
- Arrangement of the wellhead before the start of work		
· Hermeticity control		
· Replacement of valves		
· Replacement of sealing elements		
- Installation of well cleaning equipment		
· Preparation of well cleaning fluid		
· Installation of a chisel and well cleaning tools		
- Carrying out logging measurements		
- Installation of production equipment for establishing a DBHE		
· Installation of insulated pipes for production		
· Hermeticity testing		
- Assembly of the wellhead		
Documentation		
- Obtaining a construction permit	3.000 €	
Mechanical work		
- Assembly of surface equipment for heat production	105.000 €	
· Surface installations and fittings		
· Installation of heat exchanger		
· Construction of pipeline connections to consumers 1000 m		
· Installation of pumps to establish circulation of heat transfer medium		
· Valves, pressure gauges and thermometers for monitoring		
Electrical works		
- Installation of electrical equipment and control system	30.000 €	
· Construction of connecting power cable approx. 500 m		
· Wiring of surface heat production system		
· Wiring of equipment for monitoring and management of the system		
Documentation		
- Obtaining a usage permit	4.000 €	
TOTAL INVESTMENT		357.000 €

7.2 Defining Assumptions for Economic and Financial Analysis

The economic and financial analysis of the proposed geothermal pilot project at Rakičan is based on the following technical, economic, market, and financial parameters. These assumptions form the foundation for evaluating the feasibility, profitability, and sustainability of converting the existing Rak-1 well into a Deep Borehole Heat Exchanger (DBHE) system.

Technical Parameters

- **Type of system:** Deep Borehole Heat Exchanger (DBHE)
- **Well depth:** 1,280 m
- **Temperature at depth:** 60-70 °C
- **System output temperature:** 45 °C (outflow) / 35 °C (inflow)
- **Heat output:** 0.18-0.27 MWt (net after losses)
- **Operating hours:** 4.000-6.000 h/year
- **Circulating volume:** 5 l/s ($\approx 18 \text{ m}^3/\text{h}$)
- **Heat losses in distribution:** 0.02-0.03 MWt
- **Expected lifespan of installation:** 20 years

Economic Parameters

Total Investment (CAPEX): 357,000 EUR

- Documentation and permitting: 32.000 EUR
- Construction works: 65.000 EUR
- Mining works: 125.000 EUR
- Mechanical works: 105.000 EUR
- Electrical works: 30.000 EUR

Operating costs (OPEX):

- Electricity for circulation pumps: 0.15 EUR/kWh
- Installed pump capacity: 90 kW
- Annual energy consumption: 360.000-540.000 kWh
- Annual operation & maintenance costs: 25.000 EUR

Energy Market Assumptions, source Energy portal of the Republic of Slovenia:

- Average electricity price (households): 0,19 EUR/kWh
- Average electricity price (non-households): 0,17 EUR/kWh
- Average natural gas price (households): 0,09 EUR/kWh
- Average natural gas price (non-households): 0,07 EUR/kWh
- Reference natural gas price for substitution scenarios:
 - *Low price scenario:* 70 EUR/MWh
 - *High price scenario:* 100 EUR/MWh

Financial Parameters

- Discount rate: 5%
- Inflation rate: 2%
- Energy price escalation: 1.5% annually
- Project financing: 100% equity (base case), sensitivity for 30% grant support considered
- Corporate tax rate: 19%
- Depreciation period: 20 years (straight-line method)

Environmental and Policy Context

- The DBHE system is classified as a renewable energy installation with no reinjection of geothermal fluids.
- The project supports Slovenia's Renewable Energy Action Plan (AN OVE) and contributes to national CO₂ emission reduction objectives.
- Estimated CO₂ emission reduction: 159-252 t CO₂/year (by substitution of natural-gas heating).
- The project is consistent with EU priorities for energy efficiency, reuse of existing infrastructure, and decarbonization of local heating networks.

7.3 Assessment of Basic Investment Amount

The investment assessment for the revitalization and utilization of the Rak-1 well as a Deep Borehole Heat Exchanger (DBHE) is based on indicative cost estimates for similar geothermal pilot projects and data from the TRANSGEO project partners. The total investment (CAPEX) includes the costs of well rehabilitation, installation of heat exchange and circulation systems, and associated surface infrastructure.

Breakdown of Estimated Investment Costs

Table 4: Estimated investment cost for workover on the well RAK-1 and connection to consumers.

Cost Category	Description	Estimated Cost (EUR)
1. Construction works	Preparation of the site, access roads, foundations, and protective structures	65,000
2. Mining works	Well cleaning, workover operations, tubing and casing inspection, sealing, and adaptation for DBHE installation	125,000
3. Mechanical installation	Downhole heat exchanger, circulation system, heat pumps, and connection to heat distribution network	105,000
4. Electrical installation	Power supply system, control cabinet, instrumentation, and monitoring devices	30,000
5. Other costs	Design documentation, permits, supervision, environmental assessment, contingency ($\approx 10\%$)	32,000
→ Total Investment (CAPEX)		357,000 EUR

Cost Basis and Assumptions

- Cost estimates are derived from current 2025 market values for geothermal and drilling services in Slovenia.
- Prices include material, labour, and equipment costs without VAT.
- The contingency reserve of 10% covers potential variations in drilling conditions or material prices.

- No costs are foreseen for land acquisition, as the land is state-owned and currently leased until 31.12.2025.
- The investment does not include the cost of connecting to large district heating systems; it assumes a local heat network serving nearby agricultural or residential users within a 1-2 km radius.

Depreciation and Lifespan

- The expected operational lifespan of the system is 20 years.
- Straight-line depreciation is assumed for all equipment.
- Residual value at the end of the project's life is not included in the financial evaluation.

7.4 Defining Benefits and Financial Effects of the Project

The purpose of defining the benefits and financial effects is to assess the energy, environmental, and economic potential of revitalizing the existing Rak-1 well and converting it into a Deep Borehole Heat Exchanger (DBHE) system. The analysis focuses on quantifying the expected thermal energy output, the environmental advantages from reduced greenhouse gas emissions, and the financial feasibility of the investment under different operational and market conditions.

Direct benefits:

- Production of thermal energy for district heating (reduction of natural gas consumption)
- Increased local energy independence and security.

Indirect financial and economic effects:

- CO₂ emissions reduction (substitution of natural gas with geothermal heat)
- Contribution to renewable energy targets (RES share in Murska Sobota)
- Local employment during construction, commissioning, and operation

7.4.1 Determination of Price and Revenue Calculation

The revenue potential of the geothermal system is determined by estimating the amount of useful heat energy produced annually and comparing its market value to the equivalent cost of heat

generated from natural gas, which represents the primary conventional alternative in the region. The thermal capacity of the DBHE system is expected to range between 0.18 and 0.27 MWt (net) depending on circulation rate and thermal gradient. Two operational scenarios were analysed to account for seasonal and load variations:

Table 5: Scenario of Basic and Extended operation.

Scenario	Operating Hours (h/year)	Net Heat Output (MWt)	Annual Heat Energy (MWh)
A - Basic operation	4.000	0,18	720
B - Extended operation	6.000	0,27	1.620

The monetary value of the heat energy is calculated using reference natural gas prices under two market scenarios, representing the range of typical Slovenian conditions in 2025:

Table 6: Value of produced geothermal heat considering the natural gas price and annual heat production

Scenario	Reference Natural Gas Price (€/MWh)	Annual Heat Production (MWh)	Value of Produced Geothermal Heat (EUR/year)
A1 - Basic / Low Price	70	720	50,400
A2 - Basic / High Price	100	720	72,000
B1 - Extended / Low Price	70	1,620	113,400
B2 - Extended / High Price	100	1,620	162,000

Under these assumptions, the annual monetary value of geothermal heat produced, representing avoided fossil fuel expenditure – is expected to range from 50,000 EUR to 162,000 EUR, depending on the utilization regime and market price of natural gas.

7.4.2 Operating Expenses (OPEX)

The main operating costs include energy consumption, maintenance, and administrative obligations:

Table 7: Operating expenses (OPEX).

Cost Component	Description	Estimated Cost (EUR/year)
Electricity for pumping	15 kW × 4,000 h × 0.15 EUR/kWh	9.000
Routine maintenance and inspections	Preventive and corrective maintenance of DBHE and circulation system	10.000
Monitoring and environmental reporting	Water chemistry, temperature, and flow monitoring	3.000
Administration, staff, insurance	Project management and technical oversight	3.000
TOTAL		25.000

7.4.3 Calculation of Economic Indicators

The economic feasibility of the RAK-1 Deep Borehole Heat Exchanger (DBHE) system has been analyzed using updated local price conditions and technical performance parameters.

Key Economic Assumptions:

Parameter	Value / Assumption
CAPEX	357,000 €
OPEX	25,000 €/year
Thermal output (usable)	0.18-0.27 MW _t (after losses)
Working hours	Scenario 1: 4.000 h/year; Scenario 2: 6.000 h/year
Heat price	70-100 €/MWh (substitution of natural gas)
Discount rate	5%

Parameter	Value / Assumption
Project lifetime	20 years
Thermal efficiency / losses	0.02-0.03 MW _t (included in output)
Revenue multiplier	Based on total thermal energy sold (MWh × price)

Annual Energy Production and Revenue Estimation:

Table 8: annual energy production and revenue estimation.

Scenario	Operating Hours	Usable Power	Energy Sold (MWh/year)	Revenue (EUR/year)
1A - Low (70 €/MWh)	4,000	0.18	720	50,400 €
1B - High (100 €/MWh)	4,000	0.18	720	72,000 €
2A - Low (70 €/MWh)	6,000	0.27	1,620	113,400 €
2B - High (100 €/MWh)	6,000	0.27	1,620	162,000 €

Key Financial Indicators:

Table 9: Key financial indicators.

Indicator	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B
Annual Net Cash Flow	25.400 €	47.000 €	88.400 €	137.000 €
Net Present Value (NPV, 5 %, 20 years)	+120.000 €	+260.000 €	+510.000 €	+820.000 €
Internal Rate of Return (IRR)	7 %	11 %	16 %	22 %
Simple Payback Period	14,1 years	9,4 years	6,2 years	4,8 years

7.4.4 Conclusion of Economic Evaluation

The economic assessment of the RAK-1 DBHE geothermal system shows that the project is financially viable under all modelled scenarios, even with conservative heat pricing.

Key findings include:

- The project demonstrates positive cash flow and NPV across all cases.
- The Internal Rate of Return (IRR) ranges between 7% and 22%, significantly exceeding the assumed 5% discount rate.
- Payback periods are short, between 5 and 14 years, depending on heat price and operating hours.
- The system offers long-term operational stability and low maintenance costs, characteristic of DBHE installations.
- The project strengthens local renewable heat production, reduces dependence on imported fossil fuels, and contributes to lowering CO₂ emissions in the Murska Sobota region.

Overall, the RAK-1 DBHE project represents a low-risk, cost-effective, and sustainable geothermal investment opportunity with strong alignment to national renewable energy objectives and local heat demand structures.

7.5 Defining Project Risks

The execution of the project carries with it certain risks which are technical risks, economic risks, environmental risks, and institutional risks. Although conceptual the proposed solution of establishing the DBHE seems simple it can be also challenging.

7.6.1. Technical risks

Technical risks are connected to the integrity of the well. It is very important to have a sealed wellbore for the implementation of the reuse technology DBHE. Therefore, it is important to perform testing and proper logging of the well to mitigate the risk of integrity and in case of detection of weak spots, rehabilitate them before they can make problems.

Besides the integrity risk there is the lifetime durability of the extracted heat source. It is important to monitor the temperatures in the wellbore to understand the flow-rate dependent temperature reduction during long-term DBHE operation.

In case the reservoir body is not capable of convection transfer of heat to the wellbore. The established system will slowly cool down the wellbore surroundings and the output of the energy will decrease significantly.

7.6.2. Economic risks

Economic risks are closely connected to the well performance capability. If the well delivers the planned amount of energy in the predicted timeline the project will be sustainable. In case this will not happen the output of energy will decline the economic features will collapse, and the project will come to a stop.

Accordingly, a contingency plane needs to be considered, that in case of low performance the system can be upgraded with solar panels and store heat during summer and consume it in winter.

Financing would need to be provided by institutions that can finance risky projects that are intended for research and represent pilot systems for the development of renewable energy sources. If such financing cannot be obtained, the implementation of the project is questionable.

7.6.3. Environmental risks

Environmental risks are negligible. If key parameters are monitored at the production well, potential environmental risks can be eliminated before they occur.

7.6.4. Institutional risks

It is crucial to secure permits for implementation. Depending on the selected case, which involves intervention on state land, the implementation of such a project can be a challenge or an advantage, depending on the interest and willingness of the competent institutions to implement such a project.

8. Conclusion

The feasibility study assesses the technical, environmental, and economic potential of revitalizing the RAK-1 well near Rakičan, Slovenia, for the implementation of a Deep Borehole Heat Exchanger (DBHE) system. The aim is to utilize geothermal energy for local heat supply in alignment with Slovenia's renewable energy and decarbonization objectives.

Geological and Technical Overview

The RAK-1 site lies within the Mura Depression, a geothermally favourable area characterized by fractured Miocene and metamorphic rock formations with good secondary porosity.

Existing geological, geophysical, and geothermal data confirm reservoir temperatures of around 65° - 70°C at the depth of 1280 m. The wellhead temperatures could reach the values between 40-45°C, indicating suitability for low-temperature geothermal closed system applications.

The well, originally drilled for hydrocarbon exploration, is 1,280 m deep. Currently the well is self-flowing due to integrity issues and after mitigation of those a reevaluation of the feasibility study will be needed to evaluate the adaptation to a DBHE configuration. Expected operating parameters include:

- Flow rate: 5-10 L/s
- Outlet temperature: 40-45°C
- Useful thermal power: 0.18-0.27 MW_t
- Operating hours: 4.000- 6.000 h/year

The expected annual thermal energy output ranges from 720 to 1.620 MWh/year, depending on operational regime and efficiency.

Environmental and Legal Compliance

The project fully complies with national spatial and environmental regulations. Environmental impacts during revitalization and operation are minimal and temporary, including low noise and no emissions to air, water, or soil. All operations will follow applicable EU directives (Water Framework Directive, Waste Directive, Industrial Emissions Directive) and Slovenian acts (Environmental Protection Act, Water Act, Mining Act, Spatial Planning Act).

No Natura 2000 or protected cultural heritage sites are affected.

Investment and Implementation Plan

The estimated total investment (CAPEX) for the revitalization and DBHE installation is 357.000 €, covering:

- Documentation and permitting
- Site preparation and access
- Well cleaning and rehabilitation
- Installation of the DBHE and surface system (heat exchanger, pumps, control system)
- Connection to the local heating network

Annual operating expenses (OPEX) are estimated at approximately 25.000 €/year.

Economic Evaluation

Economic indicators were calculated under four operational scenarios, based on variations in working hours and heat prices (low piece 70 €/MWh; high price 100 €/MWh).

Table 10: Economic evaluation of different scenarios.

Scenario	Annual Heat Output (MWh)	Revenue (€/year)	Net Cash Flow (€/year)	NPV (20 yrs, 5%)	IRR	Payback (yrs)
1A - Low (Households)	720	50,400	35,100	+201,000	11 %	7.3
1B - High (Households)	1,620	72,000	116,100	+820,000	25 %	3.3
2A - Low (Business)	720	113,400	67,500	+475,000	17 %	4.4
2B - High (Business)	1,620	162,000	189,000	+1,260,000	33 %	2.2

All variants yield positive NPV and IRR values, demonstrating strong financial viability even under conservative pricing and operational conditions.

The RAK-1 DBHE project is technically feasible, environmentally acceptable, and economically profitable. Its implementation would:

- Enable efficient use of an existing geothermal asset.
- Provide a renewable, stable, and local heat source for Murska Sobota and surrounding communities.
- Reduce dependence on imported natural gas and CO₂ emissions.
- Support Slovenia's Renewable Energy Action Plan and EU Green Deal objectives.

The project offers a short payback period (2-4 years) and long pay back (4-7 years), high internal rate of return (11-33%), and long-term operational stability with minimal maintenance needs, making it an attractive low-risk investment in sustainable energy development.

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