ConnectHeat
Community engagement for clean heat

D4.2 IMPLEMENTATION OF PILOT CASE IN CROATIA

NORTH-WEST CROATIA REGIONAL ENERGY AND CLIMATE AGENCY

The LIFE21-CET-ENERCOM-CONNECTHEAT project has received funding from the European Union's LIFE Programme under grant agreement N°101076258

D4.2 IMPLEMENTATION OF PILOT CASES

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DEM	Demonstrator, pilot, prototype, plan designs	☐
DEC	Websites, patents filing, press & media actions	☐
DATA	Datasets, microdata, etc.	☐
DMP	Data management plan	☐
ETHICS	Deliverables related to ethic issues	☐
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OTHER	Software, technical diagram, algorithms, models, etc.	☐

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Summary

The initial scope of this feasibility study encompassed several academic buildings, including the Faculties of Architecture, Civil Engineering, and Geodesy. However, due to ongoing post-earthquake renovations at this complex—situated on cadastral plot no. 2843/4. The New Center—significant constraints emerged. The reconstruction retained the existing steam-based heating system, modernized the high-temperature heating infrastructure, and integrated an air-to-air cooling system. These modifications rendered the complex incompatible with low-temperature heat sources and water-to-air cooling solutions, precluding its inclusion as a potential user in the geothermal system.

An assessment of available documentation, including reports on completed works, identified the potential thermal yield of a borehole heat exchanger at 50 W/m (shallow geothermal energy). Additionally, groundwater potential was evaluated, indicating a feasible pumping capacity of 25 l/s at a temperature of 13.7°C. However, these findings confirmed that the site lacked sufficient soil capacity or groundwater availability to support an energy community with multiple facilities. Consequently, the feasibility study was refined to focus solely on the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) and the Faculty of Food Technology and Biotechnology (PBF).

The study analysed the technical feasibility, investment costs, and potential energy and financial savings associated with implementing heat pump systems. Three key technologies were evaluated:

- **Groundwater geothermal heat pump:** Despite their high efficiency and year-round stable thermal output, space constraints limited installation to 28 boreholes, covering only a fraction of heating and cooling demands (14.44% of existing demand and 27.45% of future demand). The estimated investment cost was €478,000, with minimal annual financial savings of €300 due to the system's limited contribution to overall energy supply.
- **Water-to water geothermal heat pump:** Utilizing an underground water source with a flow rate of 25 l/s, this solution provided significantly greater heating and cooling capacity (48.12% of current needs and 70.00% of future needs). The investment cost was estimated at €332,000, with potential financial savings of up to €52,972 per year in the best-case scenario. However, the extended payback period of 50-60 years rendered a standalone WSHP system financially unviable.
- **Water-to-water heat pump in addition to the water-to-water heat pump:** As a complementary system to WSHP, ASHPs with a total heating capacity of 400 kW and a cooling capacity of 260 kW were proposed to achieve full decarbonization and eliminate the use of natural gas. The combined investment cost for WSHP and ASHP systems was €525,000, with projected annual financial savings of €31,000 and a significantly reduced payback period of 21 years.

The analysis concluded that the optimal solution for complete decarbonization is a hybrid system integrating water-to-water and air-to-water heat pumps. This approach maximizes efficiency, reduces CO_2 emissions, and aligns with spatial and infrastructural constraints.

A critical aspect of this initiative is defining the governance and operational framework for the renewable energy community. Three potential models were identified, varying in faculty involvement, financial responsibility, and the role of external stakeholders, particularly HEP Toplinarstvo, the state-owned district heating company responsible for centralized heating infrastructure in Croatia:

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1. **Independent faculty operation**
    - Faculties fully own, develop, and manage the geothermal energy system.
    - Internal energy-sharing agreements ensure equitable distribution.
    - Faculty members and students can participate as investors.
    - Provides full control but requires significant investment and technical expertise.
2. **Faculty development with HEP Toplinarstvo operations**
    - Faculties develop the system but transfer operational management to HEP Toplinarstvo.
    - Faculties purchase energy under a contractual agreement, maintaining ownership but reducing operational complexity.
    - Integration with the district heating network enhances efficiency and scale.
    - Balances faculty involvement with professional system management but limits pricing control.
3. **Full HEP Toplinarstvo management**
    - Faculties relinquish all operational responsibilities.
    - HEP Toplinarstvo owns, operates, and integrates the geothermal system into the district heating network.
    - Faculties purchase energy at market-driven rates.
    - Eliminates financial and operational risks but reduces institutional control.

The findings of this study highlighted the potential and limitations of establishing an energy community within the selected academic complex. Due to soil capacity and groundwater pumping constraints, a broader energy community encompassing multiple facilities was deemed unfeasible. However, within the RGNF and PBF complex, the concept of an internal renewable energy community remains a viable and strategic approach. By implementing a hybrid WSHP-ASHP system, these faculties could pioneer a localized, sustainable energy model that optimizes resource use, reduces reliance on fossil fuels, and serves as a demonstrative pilot project for future academic energy initiatives.

Model 1 was selected because it enables the RGNF and PBF Faculties to take full responsibility for the development, operation, and maintenance of the geothermal heat pump system, promoting local ownership, technical autonomy, and integration with the academic community. In collaboration with REGEA, a student survey was conducted to assess the readiness for establishing a student-led Renewable Energy Community (REC). A total of 50 completed questionnaires were analyzed, revealing a high level of awareness, interest, and willingness among students to participate in renewable energy initiatives. The survey confirms strong potential for building a participatory energy community model based on student engagement and supported by institutional infrastructure.

The chosen governance model—Independent Faculty Operation—requires a high level of faculty engagement, financial investment, and operational oversight. A clearly defined governance structure will be crucial to ensuring efficient system management, long-term economic sustainability, and compliance with regulatory frameworks. This model supports institutional autonomy and provides a platform for integrating educational, technical, and community-oriented objectives. Moving forward, further dialogue with HEP Toplinarstvo, relevant regulatory agencies, and prospective investors will be important for addressing infrastructural and legal considerations. Although Model 1 places the majority of responsibilities on the faculties, it also offers significant benefits in terms of control, educational value, and long-term cost efficiency. Overall, this initiative marks a meaningful shift toward decentralized, sustainable energy models within academic institutions, reinforcing Croatia's commitment to environmental responsibility and energy independence.

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1. Technical feasibility

As part of global efforts to reduce greenhouse gas emissions and enhance energy efficiency, the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) in Zagreb is actively taking strategic steps towards the decarbonization of its heating and cooling systems, aligning with long-term energy sustainability goals.

RGNF has joined the ConnectHeat project as a pilot project aimed at establishing the first academic energy community for thermal energy**.** The objective is to integrate multiple surrounding academic institutions into a shared, sustainable heating and cooling system based on renewable energy sources**.** As part of this initiative, a comprehensive feasibility study has been conducted to assess the potential implementation of low-carbon heating and cooling solutions**,** specifically a combination of ground-source (ground-to-water), water-source (water-to-water), and air-source (air-to-water) heat pumps**.**

Heat pumps represent a sustainable solution for heating and cooling, significantly reducing CO_2 emissions and contributing to the fight against climate change. By utilizing renewable energy sources**,** they reduce dependence on fossil fuels, minimize the environmental footprint**,** and generate substantial energy and financial savings, which this study aimed to demonstrate. The initial concept of the project envisioned the inclusion of several academic buildings, such as the Faculty of Architecture, Civil Engineering, and Geodesy**.** However, since this faculty is currently undergoing seismic renovation**,** the plan includes retaining the existing heating source while modernizing mechanical installations. Due to technical limitations**,** its system is incompatible with the low-temperature heating sources that are the focus of the ConnectHeat project**.**

As a result, at the outset of the study, it was decided that its scope would be narrowed **to focus exclusively** on the **RGNF complex and the Faculty of Food Technology and Biotechnology (PBF)**. The Faculty of Mining, Geology and Petroleum Engineering and the Faculty of Food Technology and Biotechnology of the University of Zagreb are located in buildings at five locations, and the observed location of this Study is Pierottijeva ulica 4 and 6 (Donji Grad, City of Zagreb) where there are two buildings that are interconnected: building P4 at Pierottijeva ulica 4 and the building at Pierottijeva ulica 6 (composed of the Large and Small buildings). Building P4, at Pierottijeva ulica 4, is located on the cadastral plot number 2858, c.o.

The center has a total gross area of 1,138.00 m2. The building is used for the purpose of the Faculty of Mining, Geology and Petroleum Engineering in Zagreb, five days a week, 8 hours a day. The large and small buildings are located cadastral plot number 2857, c.o. Centre, and are used for the purpose of both faculties – PBF and RGNF. The Small Building has a total gross area of 2,994.00 m2, while the Large Building has a total gross area of 12,736.00 m2. The Small and Large buildings are used five days a week – 8 hours a day by the faculty staff, while the entrance is open for students from 7 am to 9 pm. The Faculty of Mining, Geology, and Petroleum Engineering (RGNF) is one of the leading academic and research institutions within the University of Zagreb, specializing in the fields of mining, geology, and petroleum engineering. It serves as a center for excellence in higher education, scientific research, and innovation, contributing to Croatia's development in natural resource management, sustainable mining, hydrogeology, and energy exploration. RGNF is committed to equipping students and researchers with cutting-edge knowledge and practical skills necessary to address contemporary challenges in energy, geotechnical engineering, and environmental sustainability. The faculty maintains strong collaborations with industry partners, government institutions, and international research bodies, ensuring the alignment of academic programs with global technological advancements and sustainability goals.

The faculty's premises include two interconnected buildings that form part of a larger university complex shared with the Faculty of Food Technology and Biotechnology (PBF). These buildings accommodate modern lecture halls, specialized laboratories, research centers, administrative offices, and student facilities, designed to support both theoretical education and applied scientific research. The campus is well-connected

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to Zagreb's public transportation system, providing easy access for students, faculty, and visiting researchers. Additionally, its proximity to other faculties within the University of Zagreb fosters interdisciplinary collaboration and joint research initiatives.

Figure 1: Complex of buildings of RGNF and PBF at the location Pierottijeva 4 and 6 (source: https://geoportal.zagreb.hr/Karta).

The first phase of the feasibility study involved data collection on the current and future state of the complex, as technical project documentation for its energy renovation was already available, along with data on local geological conditions and available resources. It is important to highlight that the study relied solely on existing technical documentation regarding the potential utilization of ground and groundwater energy—no on-site investigative works were conducted at the specific location.

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To determine the shallow geothermal potential for the implementation of ground-source and water-source heat pumps at the RGNF site, available documentation was reviewed in the form of existing studies, research, university papers, and projects in the Republic of Croatia, the City of Zagreb, and nearby locations to the Faculty of Mining, Geology and Petroleum Engineering (RGNF). For insight into implemented projects with ground-source and water-source heat pumps in the vicinity of the city relative to the RGNF location, the interactive map of the Geographic Information System (GIS) (https://powerlab.fsb.hr/pliges/) was used as a data source. This map was created as part of the project "Mapping Shallow Geothermal Systems in the Republic of Croatia," executed by an interdisciplinary team from two scientific and educational institutions (the Faculty of Mechanical Engineering and Naval Architecture and the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb) and a company specializing in the design and supervision of such systems (TT Inženjering d.o.o.). The project, which ran from February 1, 2023, to April 30, 2024, gathered data on installed geothermal heat pumps and created a publicly available interactive GIS map.

At the Faculty of Mechanical Engineering and Naval Architecture (FSB), as part of a scientific project, a ground-source heat pump system with a borehole heat exchanger (BHE) was installed. The system is located approximately 1.47 km southeast of the RGNF site. This project served as the basis for many final, master's, and doctoral theses that involved testing the ground-source heat pump system. As FSB performed measurements on the first geothermal borehole, 100 meters deep, at their location, data from these measurements were also used.

In addition to the documentation related to the ground-source system at FSB, documentation related to research, measurements, and the use of shallow geothermal energy in the Republic of Croatia and the City of Zagreb was also collected. This includes scientific papers authored by several researchers from the Department of Petroleum Engineering and Energy at the Faculty of Mining, Geology, and Petroleum Engineering [4], and a master's thesis by Kristina Strpić.

Data related to the Zagreb aquifer and the potential for utilizing water resources were obtained from the RGNF documentation concerning sanitary protection zones of the aquifer, the Croatian Geological Institute's documentation regarding groundwater conditions in Pannonian Croatia, a thesis on hydrogeographic features of the Zagreb aquifer [8], a master's thesis on well equipment, and a scientific article on the effect of the Sava River's temperature on groundwater temperature.

The company GEOSERVIS A.S. d.o.o. provided documentation related to exploratory works and the construction of an extraction and infiltration well for the water-source heat pump system at the Palace Hotel, located at Trg J.J. Strossmayera 10 in Zagreb, 1.1 km east of the RGNF location.

A doctoral dissertation on the assessment of shallow geothermal potentials in Croatia by Tomislav Kurevija enabled insight into the analysis of potential and applicability of shallow geothermal energy in the Republic of Croatia.

The legislative standard used for the design and implementation of systems utilizing the ground as a thermal energy source is the German standard VDI 4640, while the conditions for using groundwater are prescribed by the Croatian Waters (Hrvatske vode).

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1.1. Demand side analysis

Overview the existing thermomechanical system – Heating

Heating of the building complex is carried out centrally by means of two gas boilers manufactured by *Viessman Vitorond 200* with a single heat output of 1,080 kW. The permissible working pressure in the boiler is 6 bar, and the maximum temperature of the supply line in the boiler circuit is 110°C. Space heating, i.e. heat transfer to the space, is achieved by means of a radiator and fan coil system. A total of 562 radiators of various types and manufacturers are installed in the complex, with a total installed power of 1304.3 kW. In rooms where radiators do not meet the requirements of thermal comfort, additional electric heaters are used to heat with a total heat output of 99 kW. The total installed heat capacity of all heating elements in the complex is 1,522.6 kW.

Overview the existing thermomechanical system – DHW

Domestic hot water (DHW) was prepared locally at the outlets, using electric hot water heaters (boilers). DHW is used in sanitary facilities, laboratories, kitchens and some offices. The total installed electrical power of the water heater is 252.8 kW, with a total volume of 665 liters.

Overview the existing thermomechanical system – Cooling

The cooling of the complex was achieved through single and multi-split systems for individual rooms, with the exception of the auditorium with lobbies in the Small Building and the large lecture hall in the basement of the Large Building, where centralized systems with water coolers and fan coils were installed that use demineralized water with a starting temperature of 7°C and a return temperature of 12°C as a medium.
A total of 268 air conditioning units with a total cooling capacity of 838.49 kW with an average efficiency of EER=3 were installed in the complex's premises. The total installed cooling capacity of all cooling elements in the complex is 1,038.13 kW.

Electricity bill analysis

The complex of the Faculty of Food Technology and Biotechnology and the Faculty of Mining, Geology and Petroleum Engineering at Pierottijeva ulica 4 and 6 has one billing metering point for the supplied electricity for the entire location (OMM no. 0171020164), and three billing metering points for measuring the amount of natural gas, and the boiler room, more precisely the gas boilers for the central heating system, are connected to one billing metering point no. 028953 (distributor Međimurje-plin d.o.o. The total electricity supplied, for the period from July 2023 to June 2024, according to the invoices of HEP OPSKRBA d.o.o., amounts to 837,933.00 kWh/year. Overview of the electricity supplied to OMM no. 0171020164 of the building complex, provided in the table below.

Month	VT	NT	Total
	kWh	kWh	kWh
July 2023	51.416,00	22.325,00	**73.741,00**
August 2023	38.188,00	19.752,00	**57.940,00**
September 2023	47.394,00	21.087,00	**68.481,00**
October 2023	50.967,00	21.761,00	**72.728,00**
November 2023	53.810,00	20.262,00	**74.072,00**
December 2023	45.895,00	20.100,00	**65.995,00**
January 2024	50.437,00	20.701,00	**71.138,00**
February 2024	47.791,00	19.478,00	**67.269,00**

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March 2024	51.286,00	20.855,00	**72.141,00**
April 2024	46.561,00	21.250,00	**67.811,00**
May 2024	47.944,00	21.944,00	**69.888,00**
June 2024	52.755,00	23.974,00	**76.729,00**
	584.444,00	253.489,00	**837.933,00**

Table 1: Overview of the electricity supplied to OMM no. 0171020164 of the building complexes

To determine the part of the supplied electricity that was used for heating, cooling and DHW systems, the working hours of individual systems were assumed:

- The DHW preparation system has a total installed electrical power of 252.8 kW. If we assume that electric water heaters operate an average of 1 hour a day at full capacity, 20 days a month, all 12 months of the year, we arrive at the data on electricity consumption for the domestic hot water preparation system, which amounts to 60,672.00 kWh/year.
- The cooling system has a total installed cooling capacity of 1,038.13 kW, with an average efficiency of EER=3. By dividing the installed cooling capacity and efficiency, it is possible to obtain information about the electrical power, which is 346.04 kW. If we assume that the cooling system operates on average 8 hours a day, 20 days a month, 3 months a year, with a 50% workload, we arrive at the data on electricity consumption for the operation of the cooling system, which amounts to 83,049.60 kWh/year, while 249,148.80 kWh/year is produced.
- The consumption of the part of the heating system (electric heaters, fan coil system) that needs electricity for operation is also calculated on the basis of estimated working hours (5 months, 20 days a month, 8 hours a day) and amounts to 73,306.67 kWh/year.

The cost of electricity supplied for the RGN and PBF faculties complex, in a period of one year, amounted to EUR 186,435.54/year (Table 2). The stated cost is the cost for all electrical appliances that exist on the site. The estimated electricity consumption only for the heating, cooling and DHW system is given by the previous chapter, and by multiplying the estimated amount of energy by the price of electricity per kWh (for the price of electricity, the price of electricity for the higher tariff of 0.249745 EUR/kWh is taken because the systems in question mostly operate during the higher tariff). The cost of electricity for the operation of the heating, cooling and DHW system is EUR 54,201.73/year. In the following table, the cost of electricity from July 2023 to June 2024 is presented.

Month	VT	Price	Cost	NT	Price	Cost	Total cost
	kWh	€/kWh	€	kWh	€/kWh	€	€
July 2023	51.416,00	0,249745	12.840,89 €	22.325,00	0,159666	3.564,54 €	16.405,43 €
August 2023	38.188,00	0,249745	9.537,26 €	19.752,00	0,159666	3.153,72 €	12.690,98 €
September 2023	47.394,00	0,249745	11.836,41 €	21.087,00	0,159666	3.366,88 €	15.203,29 €
October 2023	50.967,00	0,249745	12.728,75 €	21.761,00	0,159666	3.474,49 €	16.203,25 €
November 2023	53.810,00	0,249745	13.438,78 €	20.262,00	0,159666	3.235,15 €	16.673,93 €
December 2023	45.895,00	0,249745	11.462,05 €	20.100,00	0,159666	3.209,29 €	14.671,33 €
January 2024	50.437,00	0,249745	12.596,39 €	20.701,00	0,159666	3.305,25 €	15.901,63 €
February 2024	47.791,00	0,249745	11.935,56 €	19.478,00	0,159666	3.109,97 €	15.045,54 €
March 2024	51.286,00	0,249745	12.808,42 €	20.855,00	0,159666	3.329,83 €	16.138,26 €
April 2024	46.561,00	0,249745	11.628,38 €	21.250,00	0,159666	3.392,90 €	15.021,28 €
May 2024	47.944,00	0,249745	11.973,77 €	21.944,00	0,159666	3.503,71 €	15.477,48 €
June 2024	52.755,00	0,249745	13.175,30 €	23.974,00	0,159666	3.827,83 €	17.003,13 €
							186.435,54 €

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Table 2: Overview of the cost of electricity from July 2023 to June 2024

The following table presents the cost of electricity from July 2023 to June 2024for heating, cooling, and DHW systems.

	EE	Price	Cost
	kWh/year	**€/kWh**	**€**
HEATING SYSTEM	73.306,67	0,249745	18.307,97
COOLING SYSTEM	83.049,60	0,249745	20.741,22
DHW SYSTEM	60.672,00	0,249745	15.152,53
			54.201,73

Table 3: Overview of the costs of electricity from July 2023 to June 2024for heating, cooling, and DHW systems.

Gas bill analysis

Total delivered thermal energy from gas, for the period from July 2023 to June 2024 according to the invoices of HEP PLIN d.o.o. (from July 2023 to March 2024) and Međimurje-plin d.o.o. (from March 2024 to June 2024). is 1,233,341.00 kWh/year. The specified amount of thermal energy supplied was used exclusively for the heating system.

Month	Quantity
	kWh
July 2023	202,00
August 2023	0,00
September 2023	0,00
October 2023	32.247,00
November 2023	216.604,00
December 2023	253.536,00
January 2024	370.618,00
February 2024	154.022,00
March 2024	138.235,00
April 2024	67.866,00
May 2024	0,00
June 2024	11,00
	1.233.341,00

Table 4: Supplied energy from gas at OMM no. 028953 for the building complex.

The summarized amount of energy consumption (electricity and natural gas) for the operation of heating, cooling and DHW systems is shown in the following table.

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Consumption of electricity and energy from gas for heating, cooling and DHW system

	EE	PP	TOTAL
	kWh/year	kWh/year	kWh/year
HEATING SYSTEM	73.306,67	1.233.341,00	1.306.647,67
COOLING SYSTEM	83.049,60	0,00	83.049,60
DHW SYSTEM	60.672,00	0,00	60.672,00
	217.028,27	1.233.341,00	**1.450.369,27**

Table 5: Consumption of electricity and energy from gas for heating, cooling and DHW system

Month	**Quantity**	**Procurement and supply price**	**Procurement and supply price**
	kWh	€/kWh	€
July 2023	202,00	0,0572	11,55
August 2023	0,00	0,0572	0,00
September 2023	0,00	0,0572	0,00
October 2023	32.247,00	0,0572	1.844,53
November 2023	216.604,00	0,0572	12.389,75
December 2023	253.536,00	0,0572	14.502,26
January 2024	370.618,00	0,0572	21.199,35
February 2024	154.022,00	0,0572	8.810,06
March 2024	138.235,00	0,0578	7.989,98
April 2024	67.866,00	0,0578	3.922,65
May 2024	0,00	0,0578	0,00
June 2024	11,00	0,0578	0,64
	1.233.341,00		**70.670,77**

Table 6: Overview of gas costs from July 2023 to June 2024 for heating system

The cost of delivered thermal energy from gas for the RGN and PBF faculties complex, in a period of one year, amounted to EUR 70,670.77/year (Table 6). The stated cost refers exclusively to the supplied energy from gas for the heating of the complex. The estimated total costs of energy products for the heating, cooling and DHW preparation system amount to EUR 124,872.50/year.

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1.2. Supply side analysis

This study analyses two scenarios: the initial reference state and the future reference state, providing a thorough evaluation of the energy requirements and the anticipated impacts of the proposed energy renovation project, completed in 2017.

The initial reference state represents the current condition of the RGNF and PBF complexes, which have not yet undergone any renovation. The heating system is based on a high-temperature configuration utilizing gas boilers, operating with a supply water temperature of 90°C and a return water temperature of 70°C. In this state, the estimated heating requirements are 1,800.00 kW, while the cooling needs are assessed at 1,038.13 kW. Additionally, the power required for domestic hot water preparation is estimated at 252.80 kW. These figures indicate the current energy demand of the unrenovated buildings and highlight the necessity for further analysis of thermal losses and gains to ensure accurate data representation.

The future reference state envisions the successful implementation of the proposed energy refurbishment project for the Faculty of Food Technology and Biotechnology and the Faculty of Mining, Geology, and Petroleum Engineering, located at Pierottijeva 4 and 6, Zagreb. This state assumes that the energy renovation has been executed, which includes the installation of low-temperature heating systems and the integration of chilled water distribution for cooling.

In this anticipated future scenario, the maximum allowable annual thermal energy for heating is projected to be 238,184.40 kWh/year, while the maximum for cooling is estimated at 697,450.00 kWh/year, in accordance with relevant technical regulations.

Based on empirical data, it is expected that the energy renovation will lead to a significant reduction in energy requirements, with heating energy needs decreasing by 50% and cooling energy requirements declining by 35% compared to the initial reference state. The projected power requirements after the renovations are estimated to be 1,000 kW for heating and domestic hot water preparation combined, and 675 kW for cooling. These estimates serve as preliminary projections and will require further detailed calculations for confirmation.

In summary, this analysis presents a clear comparison between the initial and future reference states, emphasizing the substantial changes expected in energy demand due to the proposed renovation project.

Initial reference state

The documentation, which was used as a basis for the preparation of this study, does not contain specific and accurate data on the current required power of the device, which is why a design assessment of the initial reference state was made.

- For the initial reference state, it was estimated that the required heat capacity for heating at the source was 1,800.00 kW (the mean value between the currently installed capacity of the heat source and the installed heat capacity of the heating elements inside the premises of the complex).
- For cooling, it is estimated that the currently installed cooling capacity of the device on the building, which is 1,038.13 kW, is required.
- For the purpose of preparing domestic hot water, it is estimated that the currently installed power for DHW heating is required, which is 252.80 kW.

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INITIAL REFERENCE STATE		
Pgr, Init.Ref.	Kw	1.800,00
Phl, Init.Ref.	Kw	1.038,13
PPTV,Init.Ref.	Kw	252,80
Qgr, Init.Ref.	kWh/year	1.306.647,67
Qhl, Init.Ref.	kWh/year	249.148,80
QPTV,Init.Ref.	kWh/year	60.672,00

Table 7: Overview of baseline reference state for RGNF and PBF

Future reference scenario

The future reference state represents the necessary energy for heating, cooling and DHW preparation, provided that the energy renovation of the complex envelope was carried out with the implementation of low-temperature distribution heaters within the complex and devices for the distribution of cooling energy through cooling water that will be able to be connected to the central heating, cooling and DHW preparation system. This intervention is not the subject of the Study, and the future reference state is defined as if the intervention had been carried out.

Based on empirical data, it is estimated that the energy renovation will reduce the required thermal energy by 50% and cooling energy by 35% compared to the values defined by the initial reference state (values based on the invoice) and are taken as the future reference state. The required thermal energy for the preparation of domestic hot water remains the same as in the initial reference state, as no change in the amount of hot water used is expected.

It is estimated that the required thermal capacity for heating and DHW preparation (common system) will be 1 MW, while the required cooling capacity will be 675 kW. The above data is only an estimate, and it is necessary to carry out appropriate calculations for accurate data.

FUTURE REFERENCE SITUATION		
Pgr+PTV, fut.ref.	Kw	1.000,00
Phl, fut.ref.	Kw	675,00
$Qgr_{, fut.ref.}$	kWh/year	653.323,84
$Qhl_{, fut.ref.}$	kWh/year	161.946,72
$QPTV_{, fut.ref.}$	kWh/year	60.672,00

Table 8: Overview of future reference state for RGNF and PBF

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Analysis of the possibilities of using the ground-water geothermal heat pump system

The territory of the Republic of Croatia is predominantly composed of sedimentary rocks, covering over 95% of its surface. These can be classified into two main groups: (a) Clastic rocks – unconsolidated (gravel, sand, silt), partially consolidated (clay), and consolidated (sandstone, siltstone, shale, breccia, marl, conglomerate); (b) Carbonates – limestone and dolomite.

In the northern part of Croatia (north of Karlovac), clastic sedimentary rocks dominate. The term "clastic" refers to rocks or sediments primarily composed of fragmented pre-existing rocks or minerals transported from their original location. In the Pannonian Basin, the most widespread clastic sediments are sandstone and shale. Most unconsolidated clastic sediments are of Holocene and Pleistocene origin, primarily found along the Sava and Drava River basins and throughout eastern Slavonia.

A geological profile of a 90 m deep borehole in Maksimir (Bukovac) was presented in Kurevija's doctoral dissertation. Conducted by GEOSERVIS A.S. d.o.o., the borehole was drilled to explore shallow geothermal energy potential. The aquifer, located at a relatively high elevation compared to the lowland part of Zagreb, exhibits high permeability. Below the surface layer, compact clay extends to a depth of 30 m, followed by an unconsolidated sand and gravel layer (30.0–62.0 m) with high permeability and water saturation. Marl dominates the 62.0–80.0 m interval, followed by a 4.0 m thick gravel aquifer. Compact clay reappears from 80.0 to 90.0 m.

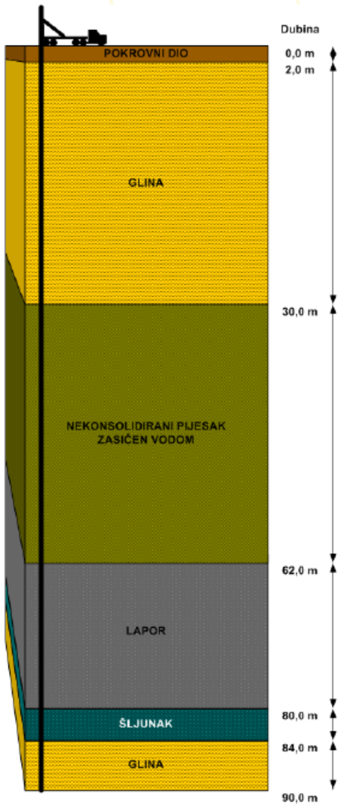

Figure 2: Geological profile of a 90 m deep borehole in the Maksimir – Bukovac area

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Thermal conductivity plays a crucial role in the efficiency of ground-source heat pump systems. Soils with high thermal conductivity adjust quickly to environmental temperature changes, while those with lower conductivity require more time to reach thermal equilibrium. Documentation for a water-to-water heat pump system at the Palace Hotel (1.1 km east of the Faculty of Mining, Geology, and Petroleum Engineering - RGNF) provides insight into soil layers down to 20 m, offering valuable supplementary data.

Thermal conductivity assessment for borehole heat exchangers is conducted through analog methods, laboratory testing, and in-situ measurements. In-situ testing provides the most precise data due to site-specific lithological heterogeneity. Thermal conductivity is the primary parameter for borehole sizing, dependent on volumetric heat capacity and thermal diffusivity.

The undisturbed ground temperature is essential in evaluating shallow geothermal resources. In the absence of direct measurements, it is often approximated using the mean annual air temperature. However, due to soil thermal inertia and the geothermal gradient, actual subsurface temperatures may deviate with depth. Measurements at the Faculty of Mechanical Engineering and Naval Architecture (FSB) recorded temperatures of 13.5°C at 50 m depth and 15.2°C at 100 m.

A 130 m deep geothermal borehole at FSB, equipped with a coaxial heat exchanger and a ground-water heat pump, was used for experimental studies. During the heating season (January 9, 2018), evaporation capacity was measured at 10.8 kW with a flow rate of 0.52 kg/s. The working fluid entered the heat exchanger at 5.49°C and exited at 10.85°C. Simple calculations indicate a borehole heat exchanger yield of 83.08 W/m.

For a master's thesis, innovative thermogeological tests were conducted at nine locations, including RGNF. Test coaxial borehole heat exchangers were installed exclusively for educational purposes in the Applied Thermogeology course, not for faculty heating/cooling.

Thermal response tests (TRT) are standard for assessing soil thermal properties for low-temperature geothermal energy utilization. TRT results provide data on undisturbed ground temperature, effective thermal conductivity, and borehole thermal resistance, crucial for designing efficient geothermal systems.

Defining the optimal ground-to-water heat pump system for the initial reference and future reference state

The required heat output of the source for the current heating needs of the complex [facilities within the RGNF and PBF faculties (Pierottijeva 4 and 6)] is 1,800.00 kW, 252.80 kW for the domestic hot water preparation system, while the required cooling capacity is 1,038.13 kW. The current estimated annual heat energy required for heating is 1,306,647.67 kWh/year (Qgr, starting ref.), while for domestic hot water preparation it is 60,672 kWh/year (QPTV, starting ref.). The current estimated annual cooling energy required for cooling the complex is 249,148.80 kWh/year (Qhl, starting ref.)

The estimated required heat output for the future needs of heating and domestic hot water of the complex (subject to the energy renovation of the buildings, which necessarily includes the installation of thermal insulation of the envelope) is 1,000.00 kW, while the estimated required cooling energy is 675 kW. The future estimated annual heat energy required for heating is 653,323.84 kWh/year ($Q_{gr,\ fut.ref.}$), while for the preparation of domestic hot water it is 60,672.00 kWh/year ($QPTV_{,\ fut.ref.}$). The future estimated annual cooling energy required for cooling the complex is 161,946.72 kWh/year ($Q_{hl,\ fut.ref.}$)

Regardless of whether the initial reference state or the future reference state is considered, the ground-to-water heat pump that can be installed for the site in question (with 28 BIT arrays) has the same capacity (capacity conditioned by borehole heat exchangers and in both cases it is possible to obtain the same

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capacity). Below are the technical characteristics for the field of BITs and ground-to-water heat pumps, i.e. a possible system for the use of shallow geothermal energy at the RGNF location.

FIELD OF BITS		
Number		28
Depth	m	100
Medium flow (glycol-water mixture)	l/s	6,68
Departure temperature	°C	10
Return temperature	°C	5
Heat yield of one BIT	Kw	5
Total heat yield of the field	Kw	140

Table 9: Overview of technical characteristics of the 28-bit array

GROUND-WATER HEAT PUMP		
Heating capacity	kW	186,7
Capacity in Refrigeration	kW	116,67
Flow Medium (Water)	l/s	8,91
Flow temperature - heating	°C	50
Return temperature - heating	°C	45
SCOP		4
Flow Temperature - Cooling	°C	7
Return Temperature - Cooling	°C	12
SEER		5
El. device power	kW	50

Table 10: Technical characteristics of the ground-water heat pump

Impact of selected optimal geothermal heat pump systems (groundwater) – share of meeting the demand for heat and cooling for all buildings

A system with a 28-bit array and a ground-to-water heat pump with the above characteristics can meet only 10% of the currently required heating capacity and 11% of the currently required cooling capacity, while there is no impact on the supplied thermal energy for the preparation of domestic hot water (local preparation). The estimated share of the energy produced by this system in the total required heating and cooling energy of the complex was about 14.44%. More detailed data are given in the following table.

INITIAL REFERENCE STATE		
Pgr, init. Ref.	Kw	1.800,00
Phl, init. Ref.	Kw	1.038,13
PPTV, init. Ref.	Kw	252,8
Qgr, init. ref.	kWh/year	1.306.647,67

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INITIAL REFERENCE STATE		
Qhl, init.ref.	kWh/year	249.148,80
QPTV, init Ref.	kWh/year	60.672,00
GROUND-WATER HEAT PUMP		
HEATING		
Capacity	Kw	186,70
Share in capacity		10%
Share in energy produced		15%
Q	kWh/year	195.997,15
COOLING		
Capacity	Kw	116,67
Share in capacity		11%
Share in energy produced		15%
Q	kWh/year	37.372,32

TOTAL REQUIRED	kWh/year	1.616.468,47
TOTAL PRODUCED	kWh/year	233.369,47
TOTAL SHARE		**14,44%**

Table 11: Usable heat and cooling energy of the new ground-to-water heat pump system for the initial reference state (RGNF and PBF)

A system with a 28-bit array and a ground-to-water heat pump can meet 19 % of the future estimated required capacity for heating and 17 % of the future estimated required capacity for cooling. The estimated share of the energy produced by this system in the total required heat and cooling energy of the complex was about 27.45%. More detailed data are given in the following table.

FUTURE REFERENCE SITUATION		
Pgr+PTV, fut.ref.	Kw	1.000,00
Phl, fut.ref.	Kw	675,00
Qgr, fut.ref.	kWh/year	653.323,84
Qhl, fut.ref.	kWh/year	161.946,72
QPTV, fut.ref.	kWh/year	60.672,00
GROUND-WATER HEAT PUMP		
HEATING		
Capacity	Kw	186,70
Share in capacity		19%
Share in energy produced		28%
Q	kWh/year	199.918,84
COOLING		
Capacity	Kw	116,67
Share in capacity		17%

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Share in energy produced		25%
Q	kWh/year	40.486,68

TOTAL REQUIRED	kWh/year	875.942,56
TOTAL PRODUCED	kWh/year	240.405,52
TOTAL SHARE		**27,45%**

Table 12: Usable heat and cooling energy of the new ground-to-water heat pump system for future reference state (RGNF and PBF)

Analysis of the possibilities of using the water-to-water geothermal heat pump system

One of the primary hydrogeological characteristics of the Pannonian Basin is the presence of shallow groundwater, often at depths of only a few tens of meters or less, depending on the specific location. The Republic of Croatia comprises two distinct hydrogeological regions, with the city of Zagreb situated within the Pannonian Basin. This region predominantly consists of coarse-grained clastic sediments and Quaternary deposits exhibiting primary porosity. In the Drava and Sava River valleys, these formations constitute high-capacity aquifers, with the most productive zones located in the upper reaches of the rivers. Downstream, the aquifers' productivity decreases due to an increasing proportion of fine-grained silt and clay. The interfluve areas are primarily composed of fine-grained deposits, resulting in relatively lower aquifer productivity.

In terms of groundwater quality, the area within the Sava River basin, from the Slovenian border to Sisak, exhibits elevated concentrations of anthropogenic pollutants. This is attributed to both the significant vulnerability of the aquifers to contamination and the presence of numerous pollution sources.

The Zagreb aquifer, delineated in strategic water management documents of Croatia, is a critical groundwater body supplying the city of Zagreb and its surrounding areas. Situated in northwestern central Croatia, it is bordered by the Medvednica Mountain to the north and the Vukomeričke Gorice Hills to the south. The aquifer consists of sand-gravel deposits extending from Podsused to Rugvica. Along with the Samobor-Zaprešić aquifer, it constitutes a strategic water reserve for the Republic of Croatia. The hydrological regime of Zagreb County is governed by the Sava River and its tributaries, with the floodplain serving as a major water storage zone. The Sava, being the only major river in the region, plays an essential role in sustaining the aquifer.

The Zagreb aquifer exhibits varying thicknesses, ranging from approximately 5 meters in the far west to approximately 100 meters in the eastern section. The regional groundwater flow direction is from the west/northwest to the east/southeast, generally following the course of the Sava River. Local groundwater flow patterns are influenced by hydrological conditions and river water levels. Due to the valley characteristics of the Sava River, it does not act as the dominant drainage system for these aquifers.

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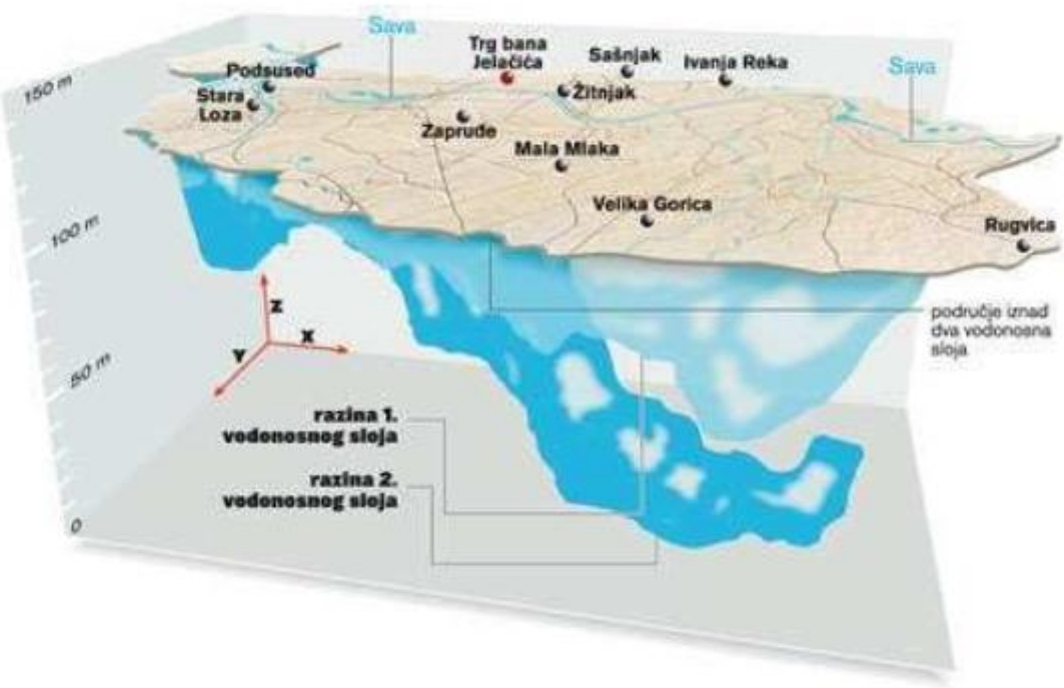

Figure 3: 3D geological model of the Zagreb aquifer

According to publicly available data from Croatian Waters, the lithological composition of the area is predominantly gravel with sand, forming a significant aquifer with an average depth of 10-20 meters, reaching up to 50 meters in a localized depression near Strmec.

The nearest water extraction site to the RGNF location is Sašnjak-Žitnjak, where groundwater temperatures have been recorded between 11.5 and 15.9 °C. The groundwater in this area is slightly alkaline and exhibits moderate to high oxygen saturation.

For the implementation of a ground-water heat pump system at the Palace Hotel (Trg J.J. Strossmayera 10, Zagreb), located 1.1 km east of RGNF, hydrogeological investigations were carried out, followed by the construction of a 20-meter-deep extraction and injection well. The drilling was performed using a rotary drilling method with protective casing and spiral-air removal of drilled material.

To mitigate potential drawdown effects in prolonged exploitation, an optimal extraction rate of 25 l/s was recommended. A subsequent chemical analysis of the groundwater confirmed compliance with the Croatian Drinking Water Regulations.

The findings of this study underscore the considerable potential for harnessing shallow geothermal energy in Zagreb through ground-water heat pump systems, given the favorable aquifer characteristics and stable groundwater temperatures.

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Defining the reference potential for geothermal energy utilization at the RGNF site

The nearest location to the RGNF site where a groundwater-based heating and cooling system, utilizing groundwater as a heat source/sink for a water-to-water heat pump, is operational, and for which data is available, is the Palace Hotel located at Trg Josipa Jurja Strossmayera 10, Zagreb (1.1 km aerial distance from the RGNF site). As noted in previous sections, the optimal groundwater extraction rate at this location, based on available documentation, is 25 l/s. The documentation related to the aquifer indicates that the nearest groundwater pumping station to the RGNF site is the Sašnjak-Žitnjak pumping station, where the measured groundwater temperature ranges between 11.5°C and 15.9°C. The average temperature of 13.7°C will be assumed for the purposes of this study, with the assumption that this temperature remains constant throughout the year. These parameters will serve as the reference potential for the utilization of groundwater as a heat source/sink for the operation of a water-to-water heat pump at the RGNF site. Based on these values, an analysis will be conducted to evaluate the performance of the system for heating and cooling the RGNF and PBF complexes. The following table presents the reference potential for groundwater utilization as a heat source/sink at the RGNF location**.**

REFERENCE POTENTIAL FOR WATER-TO-WATER HEAT PUMP	
Groundwater extraction rate (q)	25 l/s
Groundwater Temperature (T)	13,7 °C

Table 13: Reference potential for groundwater utilization as a heat Source/sink at the RGNF location

At the RGNF site, test coaxial borehole heat exchangers have been installed, which are exclusively used for educational purposes and are not utilized for the heating or cooling of the faculty buildings. According to the available documentation, the specific thermal output of the respective coaxial borehole heat exchanger is 54 W/m. For the purposes of this study, it is assumed that the specific thermal output of the borehole heat exchanger is 50 W/m, with a borehole length of 100 meters. The assumed ground temperature at a depth of 50 meters is 13.5°C, and at a depth of 100 meters, it is 15.2°C, based on measurements conducted at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb. This assumption will serve as the basis for the subsequent analysis of the implementation of a heating and cooling system utilizing a heat pump, which uses the ground as a heat source/sink for the RGNF and PBF complexes.

Defining the optimal water-to-water geothermal heat pump system for the initial reference and future reference state

The available documentation of nearby groundwater interventions indicates the potential of pumping groundwater in the amount of 25 l/s at one exploitation (pumping) well, with a groundwater temperature of 13.7 °C. Further analysis is based on the above data, i.e. that the possibility of pumping groundwater of 25 l/s from one exploitation well for the operation of the water-to-water heat pump and the return of groundwater to one absorption well can be expected.

Respecting the basic rules when positioning wells, the graphic representation of Annex IV gives the location of the exploitation and absorption well. The exploitation well is positioned on cadastral plot no. 2856, while the absorbent well is positioned on cadastral plot no. 2859. Regardless of whether the initial reference condition or the future reference state is considered, the water-to-water heat pump that can be installed for

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the site in question has the same capacity (capacity conditioned with groundwater pumping of 25 l/s and in both cases it is possible to obtain the same capacity). Below are the technical data for the wells and the achievable capacity of the water-to-water heat pump according to the available groundwater flow.

WELLS		
The number of exploits		1
Number of absorbent		1
Depth	m	20
Flow Medium (Groundwater)	l/s	25
Departure temperature	°C	13,7
Return temperature	°C	9

Table 14: Technical data – exploitation and absorption well

WATER-TO-WATER HEAT PUMP		
Heating capacity	kW	615,13
Capacity in Refrigeration	kW	421,80
Flow Medium (Water)	l/s	29
Flow temperature - heating	°C	50
Return temperature - heating	°C	45
SCOP		5
Flow Temperature - Cooling	°C	7
Return Temperature - Cooling	°C	12
SEER		6
EL. Device power	kW	160

Table 15: Technical data – Water-to-water heat pump

Impact of selected optimal geothermal heat pump systems (water-to-water)- share of meeting the demand for heating and cooling energy for all buildings

A geothermal system with a water-to-water heat pump of the above characteristics can meet only 34% of the currently required heating capacity and 41% of the currently required cooling capacity, while there is no impact on the supplied thermal energy for the preparation of domestic hot water (local preparation). The estimated share of the energy produced by this system in the total required heating and cooling energy of the complex was about 48.12%. More detailed data are given in the following table.

INITIAL REFERENCE STATE		
Pgr, init.Ref.	Kw	1.800,00
Phl, init.Ref.	Kw	1.038,13
PPTV, init.Ref.	Kw	252,8
Qgr, init.ref.	kWh/year	1.306.647,67
Qhl, init.ref.	kWh/year	249.148,80

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QPTV, Ref.	kWh/year	60.672,00
WATER-TO-WATER HEAT PUMP		
HEATING		
Capacity	Kw	615,13
Share in capacity		34%
Share in energy produced		50%
Q	kWh/year	653.323,84
COOLING		
Capacity	Kw	421,80
Share in capacity		41%
Share in energy produced		50%
Q	kWh/year	124.574,40

TOTAL REQUIRED	kWh/year	1.616.468,47
TOTAL PRODUCED	kWh/year	777.898,24
TOTAL SHARE		**48,12%**

Table 16: Usable heat and cooling energy of the new water-to-water heat pump system for the initial reference state (RGNF and PBF)

A geothermal system with a water-to-water heat pump can meet 62% of the future estimated heating capacity required and 62% of the future estimated cooling capacity required. The estimated share of the energy produced by this system in the total required heating and cooling energy of the complex was about 70%. More detailed data are given in the following table.

FUTURE REFERENCE STATE		
Pgr+PTV, fut.ref.	Kw	1.000,00
Phl, fut.ref.	Kw	675,00
Qgr, fut.ref.	kWh/year	653.323,84
Qhl, fut.ref.	kWh/year	161.946,72
QPTV, fut.ref.	kWh/year	60.672,00
WATER-TO-WATER HEAT PUMP		
HEATING		
Capacity	Kw	615,13
Share in capacity		62%
Share in energy produced		70%
Q	kWh/year	499.797,09
COOLING		
Capacity	Kw	421,80
Share in capacity		62%
Share in energy produced		70%
Q	kWh/year	113.362,70

TOTAL REQUIRED	kWh/year	875.942,56

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TOTAL PRODUCED	kWh/year	613.159,79
TOTAL SHARE		**70,00%**

Table 17: Usable heat and cooling energy of the new water-to-water heat pump system for the future reference state (RGNF and PBF)

If groundwater investigations confirm sufficient potential, it is planned to utilize groundwater as a renewable energy source for heating and cooling. For existing needs, a groundwater flow of 75 l/s, equivalent to 1.8 MW of thermal power, will be required, while future needs will demand an additional 41 l/s, providing 1 MW of thermal power. To ensure optimal operation of the system, multiple water-to-water heat pumps should be installed to operate in parallel rather than relying on a single large unit. This configuration allows for flexible operation based on seasonal demand, with individual units operating as needed, and also simplifies maintenance by enabling partial system shutdowns during servicing or repairs.

For the current facility, three heat pumps are recommended, all of which will be required during the winter months, while only two will likely be necessary to meet summer cooling demands. For future needs, two additional heat pumps, each with a 500 kW heating capacity, are proposed. It is important to note that water-to-water heat pumps operate with a significantly lower heating medium temperature (around 50°C) compared to traditional high-temperature systems.

To accommodate the new centralized heating and cooling system, modifications will be necessary within the buildings. These include the replacement of the existing pipe distribution network and the installation of fan coil units to effectively distribute thermal energy via forced convection.

Proposal for the installation of an additional air-to-water heat pump in addition to the water-to-water heat pump

As the system with a water-to-water heat pump represents the greatest potential for the use of a stable renewable source/heat sink, it is proposed, in case of inability to pump enough groundwater to cover the necessary heat and cooling energy for the future needs of the complex, the installation of an additional air-to-water heat pump. This recommendation is only related to the future situation because the current needs of the building and the high-temperature heating system are not satisfied using a low-temperature heat source. An air-to-water heat pump uses air as a renewable energy source, and most often a compression heat pump is also used, which, to increase the energy level of the refrigerant, uses the mechanical operation of the compressor. The basic parts of such a heat pump are an evaporator, a compressor, a condenser and an expansion valve. The compressor pressurizes the refrigerant in a gaseous state. At the outlet of the compressor, the refrigerant is under high pressure and temperature and as such enters the heat exchanger (condenser), and there it condenses into a liquid that is still under high pressure. Such high pressure is lowered to the initial pressure value before entering the compressor by means of an expansion valve or capillary. The refrigerant then enters another heat exchanger (evaporator) where it absorbs heat from the environment, for example, and re-enters the compressor.

Ambient air is the largest and most affordable heat tank. Its use does not require large connection costs, but only an accessible and safe space in which an outdoor unit can be installed. The outdoor unit can be a source of noise due to built-in fans and compressors, which must be considered when choosing an installation location. The biggest disadvantage of air, which greatly affects the efficiency of the system, is that the air has a large fluctuation in temperature throughout the year.
In addition, in the winter months, the appearance of frost and ice on the evaporator pipes is possible due to moisture in the air, which further impairs the efficiency of the device.

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The average seasonal heating efficiency (SCOP) for an air-to-water heat pump is 3.2 kWh/kWh, while the average seasonal cooling efficiency (SEER) is 4 kWh/kWh. In addition to a water-to-water heat pump with a capacity of 615.13 kW in heating and 421.80 kW in cooling (groundwater flow 25 l/s), it is recommended to install an air-to-water heat pump with a minimum heating capacity of 400 kW (at an outdoor air temperature of -10 °C) and a minimum cooling capacity of 260 kW (35 °C outdoor air temperature). If, in addition to the water-to-water heat pump, the air-to-water heat pump is included in the calculation, it is possible to produce the total required amount of heat and cooling energy from renewable energy sources.

FUTURE REFERENCE SITUATION		
Pgr+PTV, fut.ref.	Kw	1.000,00
Phl, fut.ref.	Kw	675,00
Qgr, fut.ref.	kWh/year	653.323,84
Qhl, fut.ref.	kWh/year	161.946,72
QPTV, fut.ref.	kWh/year	60.672,00
WATER-TO-WATER HEAT PUMP		
HEATING		
Capacity	Kw	615,13
Share in capacity		62%
Share in energy produced		70%
Q	kWh/year	499.797,09
COOLING		
Capacity	Kw	421,80
Share in capacity		62%
Share in energy produced		70%
Q	kWh/year	113.362,70
AIR-TO-WATER HEAT PUMP		
HEATING		
Capacity	Kw	400,00
Share in capacity		40%
Share in energy produced		30%
Q	kWh/year	214.198,75
COOLING		
Capacity	Kw	260,00
Share in capacity		39%
Share in energy produced		30%
Q	kWh/year	48.584,02
TOTAL REQUIRED	kWh/year	875.942,56
TOTAL PRODUCED	kWh/year	875.942,56
TOTAL SHARE		**100,00%**

Table 18: Usable heat and cooling energy of the new system with water-to-water heat pump and air-to-water heat pump for future reference condition (RGNF and PBF)

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2. Costs and benefits

The cost-benefit analysis (CBA) plays a crucial role in project development, strengthening the economic rationale for project approval. It benefits both project promoters and evaluators by supplying valuable insights to decision-makers at critical stages of the project development cycle by identifying and narrowing down strategic and technical options during the initial programming and project development phases. The CBA will also help to prioritize and rank project solutions to achieve intended objectives within limited (public funding) resources and promote transparency and accountability in project selection through a standardized approach that enables testing of assumptions. This simplified CBA will consist of financial and economic analysis to evaluate different investment solutions' environmental and socioeconomic benefits.

2.1. Financial analysis

A financial analysis is an integral part of the socioeconomic analysis and the overall CBA methodology. It assesses a project's financial feasibility, profitability, and risks before making investment decisions. Evaluating costs, revenues, and financial returns helps determine whether a project is worth pursuing from a monetary standpoint. Financial and economic analyses, although both parts of the CBA differ in scope, are the basis for the valuation of the costs and benefits (e.g. financial analysis does not consider non-cash flow items such as externalities) and the discount rates used.

Methodology

Key components of a financial analysis include:

- Initial Investment (Capital Expenditure - CAPEX) includes costs for preparation activities, equipment, infrastructure, technology, and other required assets (e.g., licenses, fees).
- Operating Costs (OPEX) include recurring expenses such as energy, utilities, maintenance, salaries, insurance, etc.
- Revenues which can result from financial savings (e.g. lower energy consumption and maintenance and operation costs) or revenues generated from the production of energy or other services provided on the market
- Cash flow analysis, which evaluates inflows (revenues) and outflows (expenses) to ensure liquidity

When conducting a financial analysis, several key assumptions must be made to ensure accurate and meaningful projections. These assumptions provide the foundation for forecasting future financial performance and evaluating investment decisions. Here are the most important ones:

- Reference period (time horizon) - Defines the period the financial analysis will cover (e.g., 5, 10, 20 years). It should align with the project's economic life, investment horizon, or expected repayment period. Therefore, the chosen reference period for evaluating all investment solutions within this study was set at 20 years.
- Financial discount rate (FDR) - Represents the required rate of return, often based on the Weighted Average Cost of Capital. A higher discount rate reflects greater risk and can vary depending on the specific sector, market conditions, risk premiums, and cost of financing. The WACC values should be those officially set at the national level by the regulating authority for those (sub)sectors where this is available. A 4% financial discount rate, which was used as a standard in the CBA 2014-2020 period, will also be used to evaluate investment solutions in this study, although a different rate can also be applied if needed.
- Residual Value - is the estimated value of an asset, project, or investment at the end of its useful life or reference period. It represents the remaining worth after depreciation or after a project has been completed. Different reference periods were set for each piece of equipment, depending on their expected economic life.

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- Value-Added Tax (VAT) - The treatment of VAT in financial analysis depends on the context and purpose of the analysis. Whether VAT is eligible depends on whether it is recoverable/refundable. In this particular case, the faculty can recover VAT, meaning that all investments and energy costs in this study do not include VAT.

Key performance indicators

The key performance indicators or profitability metrics of the financial analysis within this study are:

- Financial Net Present Value (FNPV) is a financial metric that calculates the present value of future cash flows, discounted at a required rate of return, and subtracts the initial investment. It helps determine whether a project or investment is financially viable.
- Financial Internal Rate of Return (FRR) represents the discount rate that makes the Financial Net Present Value (FNPV) of a project equal to zero. It represents the expected annual rate of return on an investment or project. In simpler terms, FIRR is the rate at which the present value of cash inflows equals the present value of cash outflows. It helps investors and businesses determine whether a project is financially worthwhile.
- Simple Payback Period (SPP) represents the time it takes for an investment to be fully recovered from its cash inflows without considering the time value of money. It is a quick way to evaluate how long a project takes to break even.
- Discounted Payback Period (DPP) is the time required to recover an investment, considering the time value of money. Unlike the regular payback period, DPP discounts future cash flows to their present value before summing them up.
- The financial sustainability analysis at the project level aims to assess whether the project can balance out its positive and negative cash flows during the reference period.

Specification of investment costs for a groundwater geothermal heat pump system and its financial impact

Investment costs for the heating/cooling system with a ground-to-water heat pump, consist of costs for exploration works (exploration well and test measurements), preparation of project and technical documentation, implementation of equipment procurement and installation, and operating costs (heat pump service). The table below provides a more detailed description of the investment and the cost of each item. The operating cost is shown on an annual basis.

INVESTMENT COSTS - GROUND-WATER HEAT PUMP SYSTEM	
RESEARCH WORKS	
Drilling of an exploration well with a depth of 100 m (drilling, installation of an exchanger and filling of the well)	8.000,00 €
Test measurements and preparation of a study on effective thermal properties of soil based on soil thermal response	4.000,00 €
Σ	**12.000,00 €**
PROJECT AND TECHNICAL DOCUMENTATION	
Preparation of a preliminary design	5.000,00 €
Preparation of the main project	30.000,00 €
Preparation of the detailed design (optional)	22.000,00 €
Σ	**57.000,00 €**
PROCUREMENT AND INSTALLATION OF EQUIPMENT	

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Field with 28 borehole heat exchangers, colquetor pipes, connecting pipeline to the engine room, manifold/collector and manhole (procurement and installation)	250.000,00 €
Ground-to-water heat pump (186.70 kW heating and 116.67 kW cooling)	80.000,00 €
Equipment in the engine room (accumulation tank 1000 l, circulation pumps, expansion vessel, pipe distribution, shut-off and measuring-regulation fittings, ethylene glycol, small consumables)	35.000,00 €
Installation of equipment in the engine room	40.000,00 €
Adaptation of the boiler room space to accommodate the heat pump (ventilation)	4.000,00 €
Σ	**409.000,00 €**
TOTAL	**478.000,00 €**
OPERATING COSTS	
Service once a year (cost on an annual basis)	2.000,00 €

Table 19: Investment costs for a system with a ground-to-water heat pump

The investment in the system with a ground-to-water heat pump, with a heating capacity of 186.7 kW and 116.67 kW in cooling, amounts to EUR 478,000.00 (the same amount for both the initial and future condition). An additional cost on an annual basis is the cost of service, which amounts to 2,000.00 EUR/year.

The investment in question will have an impact on energy and financial savings. Using the data obtained on the energy supplied by the ground-to-water heat pump, which uses soil (renewable energy source) and electricity as energy sources, the energy consumption of the new system was calculated, and comparing it with the existing system, the energy savings on an annual basis were calculated for the initial and future reference state.

CURRENT STATE		
INITIAL REFERENCE STATE		
Qgr, init.ref.	kWh/year	1.306.647,67
Qhl, init.ref.	kWh/year	249.148,80
QPTV, init Ref.	kWh/year	60.672,00
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	1.233.341,00
El. Energy for the heating system	kWh/year	73.306,67
El. Energy - cooling system	kWh/year	83.049,60
El. energy - DHW system	kWh/year	60.672,00
		1.450.369,27
NEW SYSTEM		
DT SOIL WATER		
Qgr	kWh/year	195.997,15
SCOP		4
Eel.en.	**kWh/year**	**48.999,29**
Qhl	kWh/year	37.372,32

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SEER		5
Eel.en.	**kWh/year**	**7.474,46**
EXISTING SYSTEM		
Natural gas (heating)	**kWh/year**	**1.037.343,85**
Eel.en. (heating)	**kWh/year**	**73.306,67**
Qhl	kWh/year	211.776,48
Eel.en. (cooling)	**kWh/year**	**70.592,16**
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	1.037.343,85
El. energy for the heating system	kWh/year	122.305,96
El. energy - cooling system	kWh/year	78.066,62
El. energy - DHW system	kWh/year	60.672,00
		1.298.388,43
ENERGY SAVING [kWh/year]		**151.980,84**

Table 20: Energy savings with a ground-to-water heat pump system — Initial reference state

The table above shows the calculation of the energy savings for the initial reference state. For energy not supplied by the ground-to-water heat pump, it was stated that this amount of energy is supplied by the existing heating, cooling and DHW system.

Investment costs in the geothermal system for the initial reference state will result in a reduction in energy consumption by 151,980.84 kWh/year.The reduction in energy supplied will result in a reduction in annual costs of EUR 238,12/year (Table 21).

CURRENT STATE						
	EE	Price	Cost	PP	Cost	TOTAL
	kWh/year	€/kWh	€	kWh/year	€	€
HEATING SYSTEM	73.306,67	0,249745	18.307,97	1.233.341,00	70.670,77	88.978,74
COOLING SYSTEM	83.049,60	0,249745	20.741,22	0,00	0,00	20.741,22
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			54.201,73		0,00	**124.872,50**
NEW SYSTEM						
HEATING SYSTEM	122.305,96	0,249745	30.545,30	1.037.343,85	59.439,80	89.985,10
COOLING SYSTEM	78.066,62	0,249745	19.496,75	0,00	0,00	19.496,75
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			65.194,58		59.439,80	**124.634,38**
FINANCIAL SAVINGS (EUR/year)						**238,12**

Table 21: Financial savings with a ground-to-water heat pump system – Initial reference condition

The financial savings are negligible because the capacity of the ground-water heat pump, which can be installed on site, contributes a small share to the total energy supplied, which is extremely large compared to today's construction standards for the needs of the existing state of the buildings.

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Energy savings for the future reference state are calculated based on the estimated energy needs of the buildings after the implementation of the energy envelope of the building. Initially, energy consumption for future needs was calculated, using the existing heating, cooling and DHW system (necessary for using comparable data). After that, the energy consumption was calculated for the future situation in which the ground-water heat pump system is partially used, and the existing system is partially used. The data is displayed **Error! Reference source not found.** where it is evident that the said investment would result in energy savings in the amount of 155,337.35 kWh/year.

EXISTING		
FUTURE REFERENCE SITUATION		
Qgr, fut.ref.	kWh/year	653.323,84
Qhl, fut.ref.	kWh/year	161.946,72
QPTV, fut.ref.	kWh/year	60.672,00
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	580.017,17
El. Energy for the heating system	kWh/year	73.306,67
El. Energy - cooling system	kWh/year	53.982,24
El. energy - DHW system	kWh/year	60.672,00
		767.978,08
NEW		
DT SOIL WATER		
Qgr	kWh/year	199.918,84
SCOP		4
El.en.	**kWh/year**	**49.979,71**
Qhl	kWh/year	40.486,68
SEER		5
El.en.	**kWh/year**	**8.097,34**
EXISTING SYSTEM		
Natural gas (heating)	**kWh/year**	**380.098,33**
Eel.en. (heating)	**kWh/year**	**73.306,67**
Qhl	kWh/year	121.460,04
Eel.en. (cooling)	**kWh/year**	**40.486,68**
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	380.098,33
El. Energy for the heating system	kWh/year	123.286,38
El. Energy - cooling system	kWh/year	48.584,02
El. energy - DHW system	kWh/year	60.672,00
		612.640,73
ENERGY SAVING [kWh/year]		**155.337,35**

Table 22: Energy savings with a ground-to-water heat pump system – Future reference state

From a financial point of view, the savings are again negligible (321.35 EUR/year) in terms of the future reference situation with the existing or new system installed, and the reason for this is also the insufficiently optimal capacity of the ground-water heat pump and the existing gas price, which is significantly lower than

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the price of electricity recorded according to the invoices. Compared to the existing energy costs for the facility, the financial savings are EUR 44,930.91/year, but these savings are exclusively the result of the renovation of the building envelope, which has significantly reduced the required heat and cooling energy, and thus the consumption of energy products.

CURRENT STATE						
	EE	Price	Cost	PP	Cost	TOTAL
	kWh/year	€/kWh	€	kWh/year	€	€
HEATING SYSTEM	73.306,67	0,249745	18.307,97	580.017,17	33.234,98	51.542,96
COOLING SYSTEM	53.982,24	0,249745	13.481,79	0,00	0,00	13.481,79
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			46.942,30		33.234,98	**80.177,28**
NEW SITUATION						
HEATING SYSTEM	123.286,38	0,249745	30.790,16	380.098,33	21.779,63	52.569,79
COOLING SYSTEM	48.584,02	0,249745	12.133,62	0,00	0,00	12.133,62
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			58.076,30		21.779,63	**79.855,93**
FINANCIAL SAVINGS (EUR/year)						**321,35**

Table 23: Financial savings with a ground-to-water heat pump system – Future reference state

The return on investment in the case of installing a system with a ground-water heat pump does not need to be calculated because it is evident that the investment is significantly higher than the financial savings on energy products on an annual basis, and the result is that the investment is unprofitable.

Specification of investment costs for a geothermal heat pump system (water-to-water) and its financial impact

Investment costs for the heating/cooling system with a water-to-water heat pump consist of costs for water investigation works (exploration well), preparation of project and technical documentation, implementation of equipment procurement and installation, and operating costs (heat pump service and cost of groundwater interventions for the initial and future reference state). The table below provides a more detailed description of the investment and the cost of each item. Operating expenses are presented on an annual basis.

INVESTMENT COSTS - WATER-TO-WATER HEAT PUMP SYSTEM	
WATER INVESTIGATION WORKS	
Preparation of a program of water exploration works by an authorized person, execution of an investigation-piezometer well 20 m deep with experimental pumping and Final Report on the performed exploration wells with all technical data on the execution and testing of the well	13.000,00 €
Σ	**13.000,00 €**
PROJECT AND TECHNICAL DOCUMENTATION	
Preparation of a preliminary design	5.000,00 €
Preparation of the main project	25.000,00 €
Preparation of the detailed design (optional)	15.000,00 €
Σ	**45.000,00 €**

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INVESTMENT COSTS - WATER-TO-WATER HEAT PUMP SYSTEM	
PROCUREMENT AND INSTALLATION OF EQUIPMENT	
Construction of an exploitation and absorption well 20 m deep with trial pumping, testing and quality control of samples, and preparation of a report on the performed exploitation and absorption well, as well as the procurement and installation of an underground pipeline to the facility.	50.000,00 €
Water-to-water heat pump (615.13 kW heating and 421.80 kW cooling)	130.000,00 €
Equipment in the engine room (3000 l storage tank, circulation pumps, intermediate heat exchanger, expansion vessel, piping, shut-off and measuring-regulation fittings, ethylene glycol, small consumables)	50.000,00 €
Installation of equipment in the engine room	40.000,00 €
Adaptation of the boiler room space to accommodate the heat pump (ventilation)	4.000,00 €
Σ	**274.000,00 €**
TOTAL	**332.000,00 €**
OPERATING COSTS	
Service once a year (cost on an annual basis)	2.000,00 €
GROUNDWATER ABSTRACTION - INITIAL REF. STATE	
Groundwater abstraction (0.013 EUR/m3) - 122,169.00 m3/year of groundwater (annual cost)	1.588,20 €
GROUNDWATER ABSTRACTION - FUTURE REF. STATE	
Groundwater abstraction (0.013 EUR/m3) - 97,314.00 m3/year of groundwater (annual cost)	1.265,08 €

Table 24: Investment costs for a water-to-water heat pump system

The investment in the system with a water-to-water heat pump, with a heating capacity of 615.13 kW and 421.80 kW in cooling, amounts to EUR 332,000.00/year (the same amount for both the initial and future condition). An additional cost on an annual basis is the cost of service, which amounts to 2,000.00 EUR/year. An additional cost on an annual basis is groundwater intervention, which represents a cost of EUR 0.013 per cubic meter of pumped and returned groundwater. For the initial reference state, the amount of pumped groundwater is 122,169.00 m3/year and represents a cost of EUR 1,588.20 per year. For the future reference situation, the amount of pumped groundwater is 97,314.00 m3/year and represents a cost of EUR 1,265.08 per year.The investment in question will have an impact on energy and financial savings. Using the data obtained on the energy supplied by the water-to-water heat pump, which uses groundwater (renewable energy source) and electricity as energy sources, the energy consumption of the new system was calculated, and comparing it with the existing system, the energy savings were calculated on an annual basis for the initial and future reference state.

CURRENT STATE		
INITIAL REFERENCE STATE		
Qgr, init.ref.	kWh/year	1.306.647,67
Qhl, init.ref.	kWh/year	249.148,80
QPTV, init.Ref.	kWh/year	60.672,00
ENERGY CONSUMPTION		

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Thermal energy from gas	kWh/year	1.233.341,00
El. Energy for the heating system	kWh/year	73.306,67
El. Energy - cooling system	kWh/year	83.049,60
El. energy - DHW system	kWh/year	60.672,00
		1.450.369,27
NEW SYSTEM		
DT WATER WATER		
Qgr	kWh/year	653.323,84
SCOP		5
Eel.en.	**kWh/year**	**130.664,77**
Qhl	kWh/year	124.574,40
SEER		6
Eel.en.	**kWh/year**	**20.762,40**
EXISTING SYSTEM		
Natural gas (heating)	**kWh/year**	**580.017,17**
Eel.en. (heating)	**kWh/year**	**73.306,67**
Qhl	kWh/year	124.574,40
Eel.en. (heating)	**kWh/year**	**41.524,80**
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	580.017,17
El. Energy for the heating system	kWh/year	203.971,44
El. Energy - cooling system	kWh/year	62.287,20
El. energy - DHW system	kWh/year	60.672,00
		906.947,80
ENERGY SAVING [kWh/year]		**543.421,47**
ENERGY SAVINGS [%]		**37,47%**

Table 25: Energy savings with a water-to-water heat pump system — Initial reference state

The table above shows the calculation of the energy savings for the initial reference state. For the energy not supplied by the water-to-water heat pump, it was stated that this amount of energy is supplied by the existing heating, cooling and DHW system. Investment costs in the water-to-water geothermal system for the initial reference state will result in a reduction in energy consumption by 543,421.47 kWh/year (a decrease of 37.47%). The reduction of energy supplied from energy products will result in a reduction in annual costs by EUR 9,988.22/year (**Error! Reference source not found.**).

CURRENT STATE						
	EE	Price	Cost	PP	Cost	TOTAL
	kWh/year	€/kWh	€	kWh/year	€	€
HEATING SYSTEM	73.306,67	0,249745	18.307,97	1.233.341,00	70.670,77	88.978,74
COOLING SYSTEM	83.049,60	0,249745	20.741,22	0,00	0,00	20.741,22
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			54.201,73		70.670,77	**124.872,50**
NEW SYSTEM						

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HEATING SYSTEM	203.971,44	0,249745	50.940,85	580.017,17	33.234,98	84.175,83
COOLING SYSTEM	62.287,20	0,249745	15.555,92	0,00	0,00	15.555,92
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			81.649,29		33.234,98	**114.884,28**
FINANCIAL SAVINGS (EUR/year)						**9.988,22**

Table 26: Financial savings with a water-to-water heat pump system — Initial reference condition

Financial savings are significantly higher compared to a system with a ground-to-water heat pump with a capacity that can be installed on site, but the percentage of savings compared to the current situation is still not significantly high (about 8%), and the reason for this is the insufficient capacity of the water-to-water heat pump and a significantly lower price of natural gas than the price of electricity used by the heat pump for the operation of the compressor. Energy savings for the future reference state are calculated based on the estimated energy needs of the buildings after the implementation of the energy envelope of the building. Initially, the consumption of energy products for future needs was calculated, using the existing heating, cooling and DHW system (necessary for the purpose of using comparable data). After that, the energy consumption was calculated for the future state in which the water-to-water heat pump system is partially used, and the existing system is partially used. The data is displayed **Error! Reference source not found.** where it is evident that this investment would result in energy savings in the amount of 418,731.45 kWh/year (a decrease of 54.52%).

EXISTING		
FUTURE REFERENCE SITUATION		
Qgr, fut.ref.	kWh/year	653.323,84
Qhl, fut.ref.	kWh/year	161.946,72
QPTV, fut.ref.	kWh/year	60.672,00
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	580.017,17
El. Energy for the heating system	kWh/year	73.306,67
El. Energy - cooling system	kWh/year	53.982,24
El. energy - DHW system	kWh/year	60.672,00
		767.978,08
NEW		
DT WATER-TO-WATER		
Qgr	kWh/year	499.797,09
SCOP		5
Eel.en.	**kWh/year**	**99.959,42**
Qhl	kWh/year	113.362,70
SEER		6
Eel.en.	**kWh/year**	**18.893,78**
EXISTING SYSTEM		
Natural gas (heating)	**kWh/year**	**80.220,08**
Eel.en. (heating)	**kWh/year**	**73.306,67**
Qhl	kWh/year	48.584,02

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Eel.en. (cooling)	**kWh/year**	**16.194,67**
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	80.220,08
El. Energy for the heating system	kWh/year	173.266,09
El. Energy - cooling system	kWh/year	35.088,46
El. energy - DHW system	kWh/year	60.672,00
		349.246,63
ENERGY SAVING [kWh/year]		**418.731,45**
ENERGY SAVINGS [%]		**54,52%**

Table 27: Energy savings with a water-to-water heat pump system – Future reference state

From a financial point of view, (**Error! Reference source not found.**), the savings are higher compared to the system with a ground-to-water heat pump and amount to EUR 8,392.64/year (a decrease of 10%). The reason for the low percentage of savings compared to the current situation is the significantly lower existing gas price compared to the price of electricity per kilowatt hour. Compared to the existing energy costs for the building, the financial savings are EUR 52,972.21/year, but these savings are mostly the result of the renovation of the building envelope, which significantly reduced the required heat and cooling energy, and thus the consumption of energy products.

CURRENT STATE						
	EE	Price	Cost	PP	Cost	TOTAL
	kWh/year	€/kWh	€	kWh/year	€	€
HEATING SYSTEM	73.306,67	0,249745	18.307,97	580.017,17	33.234,98	51.542,96
COOLING SYSTEM	53.982,24	0,249745	13.481,79	0,00	0,00	13.481,79
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			46.942,30		33.234,98	**80.177,28**
NEW SITUATION						
HEATING SYSTEM	173.266,09	0,249745	43.272,34	80.220,08	4.596,61	47.868,95
COOLING SYSTEM	35.088,46	0,249745	8.763,17	0,00	0,00	8.763,17
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			67.188,03		4.596,61	**71.784,64**
FINANCIAL SAVINGS (EUR/year)						**8.392,64**

Table 28: Financial savings with a water-to-water heat pump system – Future benchmark

The return on investment is in the range of 50-60 years in both cases and does not represent a financially profitable investment.

Specification of the investments costs in the system of the geothermal heat pump (water-to-water) and air-to-water heat pump for the future reference state of the complex and its financial impact

Throughout the chapters of the study, it is stated that the installation of an additional air-to-water heat pump is proposed alongside the existing water-to-water heat pump, given its higher utilization potential compared to the ground-to-water heat pump. This system would ensure the full capacity required for heating and

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cooling the complex after renovation, aligning with future energy requirements. The investment cost is detailed in the table below, totalling €525,000.00, with annual operational expenses amounting to €5,265.08.

INVESTMENT COSTS - WATER-TO-WATER AND AIR-TO-WATER HEAT PUMP SYSTEM	
WATER INVESTIGATION WORKS	
Preparation of a program of water exploration works by an authorized person, execution of an investigation-piezometer well 20 m deep with experimental pumping and Final Report on the performed exploration wells with all technical data on the execution and testing of the well	13.000,00 €
Σ	**13.000,00 €**
PROJECT AND TECHNICAL DOCUMENTATION	
Preparation of a preliminary design	7.000,00 €
Preparation of the main project	35.000,00 €
Preparation of the detailed design (optional)	20.000,00 €
Σ	**62.000,00 €**
PROCUREMENT AND INSTALLATION OF EQUIPMENT	
Construction of an exploitation and absorption well 20 m deep with trial pumping, testing and quality control of samples and Preparation of a report on the performed exploitation and absorption well	50.000,00 €
Underground pipe distribution to the building	6.000,00 €
Water-to-water heat pump (615.13 kW heating and 421.80 kW cooling)	130.000,00 €
Air-to-water heat pump (400 kW heating and 260 kW cooling)	100.000,00 €
Equipment in the engine room (4000 l storage tank, circulation pumps, intermediate heat exchanger, expansion vessel, piping, shut-off and metering and regulation fittings, ethylene glycol, small consumables)	70.000,00 €
Installation of equipment in the engine room	90.000,00 €
Adaptation of the boiler room space to accommodate the heat pump (ventilation)	4.000,00 €
Σ	**450.000,00 €**
TOTAL	**525.000,00 €**
OPERATING COSTS	
Service once a year (cost on an annual basis)	4.000,00 €
GROUNDWATER ABSTRACTION - FUTURE REF. STATE	
Groundwater abstraction (0.013 EUR/m3) - 97,314.00 m3/year of groundwater	1.265,08 €

Table 29: Investment costs for a system with a water-to-water heat pump and an air-to-water heat pump

These investments would enable the abolition of the existing thermomechanical system completely (abolition of gas as an energy source, centralization of heating, cooling and domestic hot water systems), and at the same time the energy savings would be significant – reduction of energy consumption by 570,041.76 kWh/year (reduction of 74.23% compared to the energy consumed by the existing system in a complex with an energy-renovated envelope).

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EXISTING		
FUTURE REFERENCE SITUATION		
Qgr, fut.ref.	kWh/year	653.323,84
Qhl, fut.ref.	kWh/year	161.946,72
QPTV, fut.ref.	kWh/year	60.672,00
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	580.017,17
El. Energy for the heating system	kWh/year	73.306,67
El. Energy - cooling system	kWh/year	53.982,24
El. energy - DHW system	kWh/year	60.672,00
		767.978,08
NEW		
DT WATER WATER		
Qgr	kWh/year	499.797,09
SCOP		5
Eel.en.	**kWh/year**	**99.959,42**
Qhl	kWh/year	113.362,70
SEER		6
Eel.en.	**kWh/year**	**18.893,78**
DT AIR WATER		
Qgr	kWh/year	214.198,75
SCOP		3,2
Eel.en.	**kWh/year**	**66.937,11**
Qhl	kWh/year	48.584,02
SEER		4
Eel.en.	**kWh/year**	**12.146,00**
ENERGY CONSUMPTION		
Thermal energy from gas	kWh/year	0,00
El. energy for heating and DHW system	kWh/year	166.896,53
El. Energy - cooling system	kWh/year	31.039,79
		197.936,32
ENERGY SAVING [kWh/year]		**570.041,76**
ENERGY SAVINGS [%]		**74,23%**

Table 30: Energy savings by water-to-water heat pump system and air-to-water heat pump system — Future reference state

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In addition to energy, investing in such a system would also result in significant financial savings due to the reduction of energy consumption, and on an annual basis, the achievable savings are EUR 30,743.68 / year.

CURRENT STATE						
	EE	Price	Cost	PP	Cost	TOTAL
	kWh/year	€/kWh	€	kWh/year	€	€
HEATING SYSTEM	73.306,67	0,249745	18.307,97	580.017,17	33.234,98	51.542,96
COOLING SYSTEM	53.982,24	0,249745	13.481,79	0,00	0,00	13.481,79
DHW SYSTEM	60.672,00	0,249745	15.152,53	0,00	0,00	15.152,53
			46.942,30		33.234,98	**80.177,28**
NEW SITUATION						
HEATING AND VENTILATION SYSTEM	166.896,53	0,249745	41.681,57	0,00	0,00	41.681,57
COOLING SYSTEM	31.039,79	0,249745	7.752,03	0,00	0,00	7.752,03
			49.433,61		0,00	**49.433,61**
FINANCIAL SAVINGS (EUR/year)						**30.743,68**

Table 31: Financial savings by water-to-water heat pump system and air-to-water heat pump system — Future reference state

By implementing a system with a water-to-water and air-to-water heat pump for the future reference state, both energy and financial profitability of the investment would be achieved, as the return on investment would be about 21 years, which is significantly less than a system that uses a ground-to-water and water-to-water heat pump

RETURN ON INVESTMENT		
SAVINGS ON ENERGY PRODUCTION	€/year	30.743,68
OPERATING COSTS	€/year	5.265,08
INVESTMENT COST	€	525.000,00
RETURN ON INVESTMENT (year)		21

Table 32: Return on investment of water-to-water and air-to-water heat pump systems – Future benchmark

2.2. Economic evaluation

An economic assessment of a project evaluates its overall impact on society by analyzing economic efficiency, social benefits, and costs beyond direct financial returns. Unlike financial analysis, which focuses on profitability for investors, economic assessment considers broader societal impacts, including environmental, social, and long-term economic effects. The key concept of the economic analysis is the use of shadow prices to reflect the social opportunity cost of goods and services, instead of prices observed in the market, which may be distorted due to fiscal requirements, subsidies and non-monetized externalities.

Methodology

To properly assess the true impact of renewable energy and energy efficiency projects on society, a move from the financial to economic analysis has to be made by:

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- Making fiscal corrections by removing VAT, other taxes and subsidies from all prices used in the analysis (even if taxes are not recoverable)
- Converting market to shadow prices by using conversion factors for non-tradable goods or border prices for imported goods (prices excluding domestic taxes and subsidies but including international transportation costs and trade tariffs)
- Assessing non-market impacts and correcting for externalities

Future costs and benefits must be discounted once market prices are adjusted and non-market impacts are estimated. In investment project evaluations, the Social Discount Rate (SDR) reflects how society values future costs and benefits against present ones. However, since a simplified CBA analysis was chosen for this evaluation, only fiscal corrections and the assessment of non-market impacts and externalities will be conducted.

While financial analysis primarily considers the project owner's perspective, the economic cost-benefit analysis (CBA) assesses the broader socioeconomic impact of energy investments on society as a whole. In the scope of the economic assessment, with a simplified CBA methodology, the following key parameters and assumptions will be used:

- Social Discount Rate – The EU Member States can use their country-specific SDRs, although, in the absence of specified national values, 3% SDR will be taken as a reference point for EU-funded projects in the 2021-2027 period
- Direct project benefits:
    - Extension of the economic life of the building (elements) or equipment - represents a deferred cost benefit, i.e. the financial advantage gained by postponing significant capital expenditure, such as replacing or rebuilding a building, infrastructure, or equipment. By extending the economic life of an asset, the need for costly replacements or significant renovations is delayed, leading to savings in present value terms. The related annual value is estimated as the constant annuity over the operational phase of the reference period whose NPV equals the NPV of the project investment cost net of the residual value of the equipment replaced by the project
    - Reduction in building or heat system maintenance costs - The possible reduction in costs relates to both preventive maintenance activities and estimated corrective maintenance
- Environmental and energy-related externalities:
    - Avoided energy (heat/electricity/cooling) generation, operating, and fuel costs. Data on local energy production should be used in the analysis where it is available. Fuel costs should ideally be expressed at border price plus transportation cost, net of taxation.
    - Avoided emissions or sequestered CO_2 - The shadow price used for the monetisation of the estimated reduction in CO_2 emissions have been taken from the values published in Economic Appraisal Vademecum 2021-2027 - General Principles and Sector Applications by the EIB and DG CLIMA for each year until 2050
    - Sequestered or avoided emissions of air pollutants – According to the methodologies for monetization of key air pollutants developed within the NEEDS[1] and ExternEE[2] projects the following values per air pollutant (damage values) that will be used in the economic analysis:
        - Particulate matter - PM2.5:
            - Dense urban areas: EUR 24,261 per ton

[1] Valuation of Weighting Methods for Measuring the EU-27 Overall Environmental Impact, 2011, European Commission Joint Research Centre Institute for Environment and Sustainability

[2] Externalities of Energy. Volume 2, Methodology, 1995, DG Research and Innovation

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- Particulate matter - PM10:
  - Dense urban areas: EUR 1,383 per ton
- Sulphur oxides (SOx):
  - Dense urban areas: EUR 7,079 per ton
- Nitric oxides (NOx):
  - Dense urban areas: EUR 8,223 per ton
- Enhanced security of supply - in cases where the primary energy saved comes from imported fossil fuels, a standardized (EIB) value of EUR 10/MWh will be used for the calculation of this benefit

Key performance indicators

The economic analysis' key performance indicators or metrics which will be used in study are:

- Economic Net Present Value (ENPV) - an indicator used to evaluate the economic feasibility of a project, policy, or investment by considering both financial and socio-economic costs and benefits over time. It is a variation of the Net Present Value (NPV) approach but includes broader economic and social impacts beyond direct financial returns. If ENPV > 0, the project creates net economic value and is economically viable. In cases where ENPV < 0 the society is better off without the project.
- Economic Rate of Return (ERR) - a measure used in the economic analysis of projects to evaluate their overall benefit to society. It is the discount rate at which the Economic Net Present Value (ENPV) becomes zero. ERR differs from the FRR because it includes non-market benefits and costs (e.g., environmental and social factors).
- The Benefit-Cost (B/C) Ratio is an economic indicator used in cost-benefit analysis (CBA) to assess the feasibility of a project or investment. It compares the total economic benefits of a project to its total economic costs. If the B/C Ratio > 1, the project is economically viable (Benefits exceed Costs), and if the B/C Ratio < 1, the project is not viable (Costs exceed Benefits), and society is better off without the project.

2.3. Evaluation results

Solution 1 - Groundwater geothermal heat pump system

This investment foresees the installation of a groundwater geothermal heat pump for heating and cooling purposes in two different scenarios: initial reference state and future reference state (after the energy renovation of buildings). Capital and operational expenditures, which also include the current and future costs of energy, have been presented in detail in Chapter 2.1.2.1.

The key financial performance indicators for this technical solution and this specific scenario (initial reference state with no energy renovation of the building) can be seen below.

The results of the financial analysis for the initial reference state (Table 33) indicate that the investment is not profitable. The reason is the low financial savings, which are insufficient to cover the initial investment. As a result, all financial indicators are unfavourable, and this technical option is not recommended from the standpoint of financial viability and sustainability.

Key performance indicator	Result
Financial net present value (FNPV)	EUR -455,750
Financial rate of return (FRR)	Negative
Simple financial payback time	Payback not achieved
Discounted financial payback time	Payback not achieved

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Table 33: Key financial indicators - Groundwater geothermal heat pump system – initial reference state

The economic analysis (Table 34), as opposed to the financial analysis, shows favourable results due to significant positive environmental impacts and the extension of the heating equipment's economic lifetime. The ENPV is marginally positive, and the ERR is above the SDR. From a societal perspective, the investment has positive effects.

Key performance indicator	Result
Economic net present value (ENPV)	EUR 30,162
Economic rate of return (ERR)	3.72%
Benefit/Cost ratio (B/C)	1.07

Table 34: Key economic indicators - Groundwater geothermal heat pump system – initial reference state

Even with the higher financial savings achieved, the results of the financial analysis for the future reference state (Table 35) indicate that the investment is still not profitable. The reason is the low financial savings, which are insufficient to cover the initial investment. As a result, all financial indicators are unfavorable, and this technical option is not recommended from the standpoint of financial viability and sustainability.

Key performance indicator	Result
Financial net present value (FNPV)	EUR -454,426
Financial rate of return (FRR)	Negative
Simple financial payback time	Payback not achieved
Discounted financial payback time	Payback not achieved

Table 35: Key financial indicators - Groundwater geothermal heat pump system – future reference state

Again, the economic analysis (Table 36) shows favourable results due to significant positive environmental impacts and the extension of the heating equipment's economic lifetime. The ENPV is positive, albeit marginally higher than for the initial reference state, and the ERR is above the SDR. From a societal perspective, the investment has positive effects.

Key performance indicator	Result
Economic net present value (ENPV)	EUR 31,329
Economic rate of return (ERR)	3.75%
Benefit/Cost ratio (B/C)	1.07

Table 36: Key economic indicators - Groundwater geothermal heat pump system – future reference state

Solution 2 - Water-to-water geothermal heat pump system

The results of the financial analysis for the initial reference state (Table37) indicate that the investment is not profitable. The reason is the low financial savings, which are insufficient to cover the initial investment. As a result, all financial indicators are unfavourable, and this technical option is not recommended from the financial viability and sustainability standpoint.

Key performance indicator	Result
Financial net present value (FNPV)	EUR -161,445
Financial rate of return (FRR)	Negative (-3.1%)
Simple financial payback time	Payback not achieved

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Discounted financial payback time	Payback not achieved

Table 37: Key financial indicators - Water-to-water geothermal heat pump system – initial reference state

The economic analysis (Table 38) shows favourable results due to significant positive environmental impacts and the heating equipment's economic lifetime extension. The ENPV is positive and high, while the ERR is much bigger than the SDR. From a societal perspective, the investment has positive effects.

Key performance indicator	Result
Economic net present value (ENPV)	EUR 788.416
Economic rate of return (ERR)	19.9%
Benefit/Cost ratio (B/C)	5.30

Table 38: Key economic indicators - Water-to-water geothermal heat pump system – initial reference state

The results of the financial analysis for the future reference state (Table 39) indicate that the investment is less profitable than compared to the initial reference state. The reason is the insufficient financial savings, which cannot cover the initial investment. As a result, all financial indicators are unfavorable, and this technical option is not recommended from the standpoint of financial viability and sustainability.

Key performance indicator	Result
Financial net present value (FNPV)	EUR -186,629
Financial rate of return (FRR)	Negative (-4.6%)
Simple financial payback time	Payback not achieved
Discounted financial payback time	Payback not achieved

Table 39: Key financial indicators - Water-to-water geothermal heat pump system – future reference state

The economic analysis (Table 40) shows favourable results due to significant positive environmental impacts and the heating equipment's economic lifetime extension. The ENPV is positive and high, while the ERR is much bigger than the SDR. From a societal perspective, the investment has positive effects.

Key performance indicator	Result
Economic net present value (ENPV)	EUR 766,230
Economic rate of return (ERR)	19.5%
Benefit/Cost ratio (B/C)	4.73

Table 40: Key economic indicators - Water-to-water geothermal heat pump system – future reference state

Solution 3 - Air-to-water heat pump in addition to the water-to-water heat pump

The results of the financial analysis for the air-to-water heat pump and the water-to-water heat pump (Table 41) indicate that the investment is borderline acceptable from the financial standpoint. Although the financial savings are still insufficient to cover the initial investment, the payback period is shorter than the economic lifetime of the equipment. This technical option can, therefore, be conditionally recommended.

Key performance indicator	Result
Financial net present value (FNPV)	EUR -19,486
Financial rate of return (FRR)	-3.5%
Simple financial payback time	13.7
Discounted financial payback time	Payback not achieved

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Table 41: Key financial indicators – air-to-water heat pump in addition to the water-to-water heat pump – future reference state

The economic analysis (Table 42) shows very favourable results due to high positive environmental impacts and the heating equipment's economic lifetime extension. The ENPV is positive and high, while the ERR is much bigger than the SDR. From a societal perspective, the investment has positive effects and can be recommended for realization.

Key performance indicator	Result
Economic net present value (ENPV)	EUR 1,087,264
Economic rate of return (ERR)	19.0%
Benefit/Cost ratio (B/C)	14.23

Table 42: Key economic indicators – air-to-water heat pump in addition to the water-to-water heat pump – initial reference state– future reference state

2.4. Available funding sources

The analysed investment solutions can be financed through a mix of national, EU, and private funding sources. Considering their limited financial cost-effectiveness, grant funding would be needed to make the investment payback more appealing to the project developer. The following chapters provide an overview of current financing sources for this type of investment.

European Structural and Investment Funds (ESIF)

The European Structural and Investment Funds (ESIF) provide significant funding in Croatia for the modernization of heating systems in public buildings, especially when those upgrades contribute to energy efficiency, decarbonization, and the use of renewable energy sources. The focus is not just on switching the heating source but on the comprehensive energy efficiency of the building. The goal is to reduce energy consumption by at least 30–50% per EU directives and Croatia's energy renovation strategy. Funding is typically awarded through public calls under Operational Programmes — mainly the Operational Programme "Competitiveness and Cohesion" (OPKK) for the 2021–2027 period. Eligible projects receive non-refundable grants, covering 60–85% of the total investment cost, depending on the project's location, type of institution, and whether it's located in a less-developed region.

Recovery and Resilience Facility (RRF)

The National Recovery and Resilience Plan (NPOO), funded through the EU's Recovery and Resilience Facility (RRF), plays a significant role in financing the modernization of heating systems in public buildings in Croatia, especially as part of the green transition and climate objectives. Croatia's NPOO has six main components. Component C6 – Energy efficiency, renewable energy sources and green transition in buildings – is directly relevant to modernising heating systems, including introducing renewable energy technologies like geothermal heat pumps in public and residential buildings. NPOO provides non-refundable grants — typically covering 60% to 100% of eligible project costs for public buildings, depending on the type of project and entity. There's often a minimum percentage reduction in energy consumption required — for instance, 30%–50%, depending on the building's current classification. Grants are accessed via public calls published by various ministries or implementing bodies. Some NPOO components are also available through financial instruments (e.g. soft loans from HBOR) but heating modernization in public buildings is typically grant-based.

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Environmental Protection and Energy Efficiency Fund (FZOEU)

The Environmental Protection and Energy Efficiency Fund, known in Croatia as FZOEU, is the central institution responsible for financing environmental and energy-efficiency projects in the country. It operates under the Ministry of Economy and Sustainable Development and is funded primarily through environmental levies collected from various sources such as polluters, vehicles, and packaging. These funds are then reinvested into projects that aim to protect the environment and improve energy efficiency.

FZOEU plays a key role in supporting Croatia's transition to renewable energy. One of its main focus areas is the co-financing of renewable energy installations, including geothermal heat pumps, especially in modernizing heating systems in residential, commercial, and public buildings. The fund regularly announces public calls through which citizens, legal entities, housing associations, and public institutions can apply for financial support. Depending on the applicant's location and the region's socio-economic classification, FZOEU may cover between 40 and 80 per cent of the eligible costs. To apply, applicants must wait for a public call to open, then prepare documentation such as ownership proof, an energy certificate or audit, the main design for reconstruction and other supporting materials.

Croatian Bank for Reconstruction and Development (HBOR)

The Croatian Bank for Reconstruction and Development is Croatia's national development bank. It is central in financing projects that support economic growth, regional development, environmental protection, and the green transition. Established as a state-owned institution, HBOR is not a commercial bank but rather a development bank that provides favorable financing conditions for public and private sector investments that align with national and EU priorities.

One of HBOR's key focus areas is support for renewable energy and energy efficiency. This includes financing projects that incorporate technologies like geothermal heat pumps, especially when they are part of broader investments in sustainable energy or building renovation. HBOR offers loan programs designed to support investments in technologies that reduce energy consumption and environmental impact. These programs often come with highly favorable terms, such as low interest rates (between 2-4%), long repayment periods (sometimes up to 14 or 17 years), and grace periods of a few years before repayment begins. Loan amounts vary depending on the project's scope and the type of borrower, ranging from smaller investments to large-scale infrastructure projects.

HBOR financing can cover the purchase and installation of the heat pump itself, as well as associated construction work, technical documentation, energy audits, and project management. Eligibility typically requires a well-defined investment plan, supporting technical documentation, and, in some cases, an energy audit or feasibility study to demonstrate energy savings or environmental benefits.

HBOR also often partners with EU funding mechanisms such as the European Structural and Investment Funds (ESIF) and Croatia's National Recovery and Resilience Plan (NPOO). These collaborations allow HBOR to offer financial instruments that combine grants with low-interest loans, which can be particularly attractive for energy-related investments. Businesses or institutions pursuing geothermal systems may therefore be eligible for both financing and partial grant support, provided the project meets certain criteria tied to climate objectives

Commercial green loans

Several commercial banks in Croatia offer "green loans" or "eco loans" that can be used to finance renewable energy projects. These loan products are designed to support energy efficiency and the transition to clean energy in homes, buildings, and small businesses, with more favourable borrowing conditions (interests, repayment periods) than regular loans.

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Zagrebačka banka (ZABA) offers various personal and housing loans that can be used for energy renovations, including modernization of heating and cooling systems. They have promoted "green" or "eco" loans with reduced interest rates for customers investing in renewable energy systems. ZABA has also participated in EU co-financed schemes (such as ESIF energy efficiency loans) where geothermal systems are eligible.

Privredna banka Zagreb (PBZ) provides green loans specifically tailored for environmental and energy-saving home improvements. These include the installation of solar panels, thermal insulation, and renewable energy heating systems like heat pumps. PBZ has also partnered with HBOR on subsidized lending schemes that are ideal for larger or more comprehensive energy renovation projects.

Erste banka has actively promoted sustainability-focused financial products, including "green" consumer and housing loans. Their green loans cover investments in geothermal, solar, and other renewable heating systems. Erste's green loan offerings may include both fixed and variable interest rate options and are often paired with flexible repayment terms. For business clients, Erste also offers financing for renewable energy investments as part of their broader ESG and climate finance strategy.

Raiffeisenbank (RBA) offers eco-friendly loans to customers who want to improve their energy footprint. These loans support the installation of renewable systems like geothermal heat pumps, especially when part of a larger home renovation. RBA also participates in joint financing programs in cooperation with HBOR and EU development instruments, which allows it to offer favorable conditions for environmentally responsible projects.

Hrvatska poštanska banka (HPB) has green credit lines for energy efficiency improvements in homes and commercial spaces. Their green loans are often available with no administrative fees and can finance projects like heat pump installation, insulation, and other energy-saving upgrades. HPB may also collaborate with public programs like FZOEU or HBOR, enabling borrowers to combine grants and loans in a single project.

Generally, most of these commercial banks require basic documentation including an investment plan with cost estimates, invoices or offers from certified installers, and in some cases proof of ownership or energy audit results.

Energy Supply Contracting (ESCO)

Energy Supply Contracting (often just called Energy Contracting or the ESCO model) is a financing model in which an Energy Service Company (ESCO) takes on the responsibility of modernizing and operating an energy system, such as heating or cooling, in a building or facility. It is especially useful when the building owner does not want to, or cannot invest upfront in things like a geothermal heat pump or energy efficiency upgrades.

Instead of the building owner paying to install a new heating and cooling system, an ESCO finances, installs, operates, and maintains the system. The building owner pays the ESCO through regular energy bills, which are usually lower than what they paid before because of improved efficiency. The ESCO earns back its investment from the energy cost savings over a long-term contract—usually 5 to 15 years. The key feature of this model is that the investment risk shifts from the building owner to the ESCO. If the system doesn't perform and energy savings aren't achieved, the ESCO absorbs the loss.

In Croatia, energy contracting is supported by both national policy and EU directives. It is mainly used in public buildings like schools, hospitals, and municipal buildings, but the model is increasingly being adapted for more significant residential buildings, housing associations, and private businesses. The Energy Performance Contracting (EPC) variant is a more advanced form, in which the ESCO guarantees a certain level of energy savings. If those savings aren't met, the ESCO covers the difference.

Croatia's Agency for Legal Transactions and Real Estate Brokerage (APN) has established a national programme to enable energy renovation and modernization of public buildings through ESCOs using a Public-Private Partnership (PPP) approach. APN standardized and managed the model, which provides a legal and

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procedural framework for the entire process. It includes contract templates, energy performance guarantees, and guidance to protect the interests of the building users (e.g., public institutions).

Crowdfunding and crowdinvesting

Crowdfunding models in Croatia are still relatively new, but they're slowly gaining traction, including in the energy sector. While not as widely used as in some Western European countries, crowdfunding is becoming a potential alternative financing method for renewable energy projects, especially community-based initiatives, cooperatives, or small-scale installations.

Croatia has a stagnating ecosystem of platforms, legal frameworks, and pilot projects supporting crowdfunding. The most common forms used in the country are:

- Donation-based crowdfunding
- Reward-based crowdfunding
- Equity crowdfunding – where investors receive shares in a company or project.
- Lending-based crowdfunding (peer-to-peer lending) – individuals lend money to a project with agreed interest rates

While donation and reward models are most common for renewable energy, equity and lending models are increasingly being explored.

Since 2021, Croatia has aligned its regulations with the EU Crowdfunding Regulation (Regulation (EU) 2020/1503), which makes it easier to launch equity and lending-based crowdfunding platforms under a single EU-wide license. However, the local market is still developing, and there's a lack of established local platforms explicitly focused on energy. Currently, only one crowdinvestment platform, run by the Green Energy Cooperative has been able to set up a citizen-financed platform and implement several RES projects.

2.5. Environmental impact and CO_2 emissions

The biggest advantage of heat pumps, i.e. the benefit for the environment, is the reduction of CO2 emissions, which reduces the harmful impact on the environment because it uses renewable energy sources that do not have carbon dioxide emissions, and a smaller part of the electricity it uses for operation can be produced from renewable energy sources. Carbon dioxide is one of the main gases that causes the greenhouse effect and compared to the other main gases that participate in this effect, it stays in the atmosphere the longest. After CO_2 emissions into the atmosphere, 40% will remain in the atmosphere for 100 years, 20% will remain in the atmosphere for 1000 years, and 10% will remain in the atmosphere for 10,000 years. This literally means that the emissions of harmful gases that we release today will affect the climate in the distant future.

The investments covered by the Study contribute to the reduction of CO_2 emissions compared to the existing thermomechanical system in the RGNF and PBF complex using renewable energy sources.

By using emission factors for energy products prescribed by the Ordinance on the System for Monitoring, Measuring and Verification of Energy Savings (Official Gazette No. 98/21, 30/22 and 96/23), CO2 emissions were calculated for all processed systems (Table 49, Table 50, Table 51).

By installing a ground-to-water heat pump of potential capacity, the reduction in CO_2emissions is 11.34 tons per year (a reduction of 11.71% compared to the existing system) for the initial baseline and 35.69 tCO2 per year (a decrease of 23.18%) for the future baseline.

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By installing a water-to-water heat pump of potential capacity, the reduction in CO_2 emissions is 122.34 tons per year (a reduction of 40.99% compared to the existing system) for the initial baseline and 94.07 t CO_2 per year (a reduction of 61.08% compared to the existing system) for the future baseline.

By installing a water-to-water heat pump and an air-to-water heat pump, the reduction in CO_2 emissions amounts to 122.54 tonnes per year (a reduction of 79.56% compared to the existing system) for the future baseline.

GROUND-WATER HEAT PUMP

INITIAL REFERENCE STATE			
	Amount of energy	Emission factor	CO_2 emissions
	kWh/year	kg CO_2 /kWh	kgCO2/year
EXISTING SYSTEM			
Natural gas	1.233.341,00	0,214	263.934,97
Electrical energy	217.028,27	0,159	34.507,49
			298.442,47
NEW SYSTEM			
Natural gas	1.037.343,85	0,214	221.991,58
Electrical energy	261.044,58	0,159	41.506,09
			263.497,67
REDUCING CO_2 EMISSIONS			**34.944,80**
CO_2 EMISSION REDUCTION [%]			**11,71%**

FUTURE REFERENCE SITUATION			
	Amount of energy	Emission factor	CO_2 emissions
	kWh/year	kg CO_2 /kWh	kgCO2/year
EXISTING SYSTEM			
Natural gas	580.017,17	0,214	124.123,67
Electrical energy	187.960,91	0,159	29.885,78
			154.009,46
NEW SYSTEM			
Natural gas	380.098,33	0,214	81.341,04
Electrical energy	232.542,39	0,159	36.974,24
			118.315,28
REDUCING CO_2 EMISSIONS			**35.694,17**
CO_2 EMISSION REDUCTION [%]			**23,18%**

Table 43: Reducing CO_2 emissions by installing a ground-to-water heat pump — Initial and future reference status

WATER-TO-WATER HEAT PUMP

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INITIAL REFERENCE STATE			
	Amount of energy	Emission factor	CO_2 emissions
	kWh/year	kg CO_2 /kWh	kg CO_2 /year
EXISTING SYSTEM			
Natural gas	1.233.341,00	0,214	263.934,97
Electrical energy	217.028,27	0,159	34.507,49
			298.442,47
NEW SYSTEM			
Natural gas	580.017,17	0,214	124.123,67
Electrical energy	326.930,64	0,159	51.981,97
			176.105,64
REDUCING CO_2 EMISSIONS			**122.336,82**
CO_2 EMISSION REDUCTION [%]			**40,99%**

FUTURE REFERENCE SITUATION			
	Amount of energy	Emission factor	CO_2 emissions
	kWh/year	kgCO2/kWh	kgCO2/year
EXISTING SYSTEM			
Natural gas	580.017,17	0,214	124.123,67
Electrical energy	187.960,91	0,159	29.885,78
			154.009,46
NEW SYSTEM			
Natural gas	80.220,08	0,214	17.167,10
Electrical energy	269.026,54	0,159	42.775,22
			59.942,32
REDUCING CO_2 EMISSIONS			**94.067,14**
CO_2 EMISSION REDUCTION [%]			**61,08%**

Table 44: Reducing CO_2 emissions by installing a water-to-water heat pump — Initial and future reference status

WATER-TO-WATER AND AIR-TO-WATER HEAT PUMP

FUTURE REFERENCE SITUATION			
	Amount of energy	Emission factor	CO_2 emissions
	kWh/year	kg CO_2 /kWh	kg CO_2 /year
EXISTING SYSTEM			
Natural gas	580.017,17	0,214	124.123,67
Electrical energy	187.960,91	0,159	29.885,78
			154.009,46
NEW SYSTEM			

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Natural gas	0,00	0,214	0,00
Electrical energy	197.936,32	0,159	31.471,87
			31.471,87
REDUCING CO2 EMISSIONS			**122.537,58**
CO_2 EMISSION REDUCTION [%]			**79,56%**

Table 45: Reducing CO_2 emissions by installing a water-to-water heat pump and an air-to-water heat pump — Future reference status

Using systems with geothermal heat pumps brings with it several potential negative impacts:

- Permanent change in soil temperature (ground-water heat pump),
- Soil and groundwater pollution,
- High noise level of the heat pump.

A permanent change in soil temperature in borehole heat exchangers may be caused by unfavourable thermal energy ratios for heating and cooling, deviations in performance compared to design, heat pump performance characteristics that are different from those intended, thermal interference with other installations, or unfavourable orientation and field geometry of the BITs with respect to the direction of groundwater. In order to avoid this, it is necessary to correctly size the system (determining the exact needs of the building and determining the properties of the soil), plan the heat exchangers in the ground (increasing the spacing, separating the fields into several smaller ones, additional heat sources/sinks), correctly perform the works (control of the performance of BITs and heat pump systems) and properly use the system with monitoring the temperature of the medium in the exchangers.

Contamination of soil and groundwater is a possible occurrence if a system with a ground-to-water or water-to-water heat pump is not carried out or used in a proper way. If the manholes on the wells are not properly executed, there is a possibility of oil leaking from the surfaces, which can pollute groundwater, and to avoid

this, the manhole must be made waterproof and in an airtight design. The glycol mixture and the water circulating through the borehole heat exchangers pose a potential problem if glycol leaks into the soil and groundwater. Elimination of such a potential hazard is done by selecting the appropriate pipe material and regular inspections of the system and service by an authorized person. During the execution of works, various construction machinery is used that can have a negative impact on the environment (noise, dust and pollutants), and to reduce negative impacts, it is recommended that:

- *Perform works with small-scale machines, devices and means of work and transport*
- *Organize noisy works in such a way that they are performed during the day, and only in exceptional cases, when technology requires it, during the night*
- *Switch off the drive motors of construction machinery and transport vehicles used during construction, when not in use*
- *When using construction machinery and vehicles on the construction site, prevent the leakage or release of liquids into the environment by applying good practice procedures in the handling of fuels and lubricants*
- *When building in case of leakage of fuel or lubricant from machinery or vehicles, provide intervention quantities of dry soil cleaning agents at the site.*
- *In the event of a spill of petroleum products from the tanks of machinery, immediately take measures to prevent further spillage, collect the contaminated soil and spilled contents, place them in special barrels and hand them over to an authorized person.*

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- *During construction in dry weather, spray water on roads where dust has sedimented in order to prevent dust from being lifted from the roads due to traffic.*
- *During the works, all waste will be sorted and properly disposed of*
- *After the completion of all works, noise measurements will be carried out on devices that are a significant source of noise. If the measured noise values at the reference points show that the permitted values are exceeded, additional noise reduction measures should be taken in order to reduce the cumulative impact of noise spreading into the environment from the location in question to an acceptable level. The authorized person who carries out the measurements will select the measuring points depending on the situation in the field*

Negative noise impacts caused by the noise produced by the operation of a geothermal heat pump. The maximum volume values of a heat pump for an urban area are 63 db(A) during the day and 45 db(A) at night. It is necessary to ensure sufficient distance between the heat pump and adjacent buildings. To reduce vibration, it is recommended to install the heat pump on rubber anti-vibration pads. Acoustic insulation is achieved by cladding the enclosure with soundproofing materials and additionally acoustic panels to absorb or redirect noise.

2.6. SWOT analysis

The installation of a geothermal heat pump system at the RGNF and PBF complex is a key initiative aimed at advancing sustainable heating and cooling solutions. This project seeks to leverage renewable energy sources to reduce carbon emissions, enhance energy efficiency, and serve as a model for academic energy communities. Additionally, it will establish a shared energy community, promoting collaborative energy management and resource optimization. The following SWOT analysis provides a comprehensive evaluation of the project's strengths, weaknesses, opportunities, and threats.

Strengths:

- **Environmental sustainability**: The installation of geothermal heat pumps significantly reduces CO_2 emissions, aligning with EU climate action goals and the Green Deal objectives.
- **Energy efficiency**: The proposed system utilizes renewable energy sources (ground and water heat), ensuring a stable and sustainable heating and cooling solution with reduced reliance on fossil fuels.
- **Decarbonization potential**: The combination of water-to-water and air-to-water heat pumps enables a nearly complete transition away from natural gas, contributing to long-term carbon neutrality.
- **Operational stability**: The technology ensures a stable and efficient heating and cooling system with predictable performance throughout the year.
- **Academic and research value**: As an integral part of an academic energy community, the system provides a real-world demonstration project for research, education, and technological innovation in the field of renewable energy.
- **Energy community formation**: The project fosters a collaborative energy-sharing model among academic institutions, enhancing overall energy efficiency and sustainability.
- **Community participation**: The model of community involvement would include active participation from university staff and students, not only as consumers but also as investors in the project. Through collective financing, the academic community—staff and students alike—would have the opportunity to invest in the energy system and participate in its decision-making. This approach promotes local ownership and empowerment, aligning with the European Commission's objective to encourage citizen involvement in energy transition projects.

Weaknesses:

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- **High initial investment**: The upfront capital cost for system installation, including drilling, technical documentation, and equipment procurement, is significant (estimated at €525,000).
- **Long payback period**: While financially viable in the long run, the return on investment spans approximately 21 years, which may present a challenge for immediate financial justification.
- **Limited spatial capacity**: The available urban space restricts the number of boreholes and heat exchange capacity, limiting the scalability of the ground-source heat pump system.
- **Dependence on technical feasibility**: The project relies on available geological and hydrological conditions, which could present challenges in terms of long-term groundwater sustainability and regulatory compliance.

Opportunities:

- **EU and national funding**: Potential for securing additional grants, subsidies, or low-interest loans from EU and national funding programs aimed at promoting renewable energy solutions.
- **Replicability and expansion**: The success of this project could serve as a model for wider implementation in other academic and public institutions, further promoting the use of renewable heating solutions.
- **Technological advancements**: Ongoing improvements in heat pump efficiency and storage solutions could enhance the system's overall performance and cost-effectiveness.
- **Policy and regulatory support**: The European Green Deal and national climate policies encourage investment in renewable energy projects, facilitating regulatory approval and financial incentives.
- **Energy independence**: Reducing reliance on imported fossil fuels enhances energy security for the academic complex and aligns with broader EU energy transition strategies.
- **Community-based energy sharing**: The formation of an academic energy-sharing community enables optimized resource utilization and collective cost savings, reinforcing the project's long-term sustainability.

Threats:

1. **Regulatory barriers**: Potential administrative and legal constraints related to groundwater extraction and land use planning could delay or complicate project implementation.
2. **Uncertain geological conditions**: The final efficiency and feasibility of the geothermal system depend on subsurface thermal properties and water availability, which may require further site-specific investigations.
3. **Market fluctuations**: Variability in equipment and installation costs due to supply chain disruptions or inflation could impact project budget estimates.
4. **Operational maintenance costs**: Although annual maintenance costs are estimated at €1,300, unforeseen technical issues or system inefficiencies could lead to additional long-term expenditures.
5. **Regulatory barriers to energy community formation**: The establishment of a renewable energy community may face challenges due to regulatory constraints, including issues related to energy distribution, grid access, and legal frameworks governing collective energy projects.

The installation of a geothermal heat pump system for the RGNF and PBF complex represents a highly strategic investment in sustainable energy, aligning with EU climate objectives and demonstrating leadership in academic energy solutions. While financial and spatial constraints pose challenges, the long-term environmental, economic, and educational benefits make this a model project for future energy transitions. The combination of water-to-water and air-to-water heat pumps is identified as the optimal solution, ensuring high efficiency, significant emissions reductions, and a feasible pathway towards full decarbonization of the complex. Furthermore, the establishment of an academic energy-sharing community

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strengthens the project's impact by fostering cooperative energy management and maximizing renewable energy utilization.

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3. Community model

The decarbonization of urban energy systems, particularly heating and cooling, is one of the central pillars of the European Union's energy transition strategy. The integration of renewable energy sources (RES) into distributed and centralized systems is essential to achieving climate neutrality targets, enhancing energy security, and reducing dependence on fossil fuels. Within this context, energy communities—defined under EU legislation as legal entities based on voluntary and open participation, governed democratically, and aimed at providing environmental, economic, or social benefits to their members or the local area—emerge as a transformative model for citizen engagement and decentralization of the energy sector.

Croatia, while having taken legislative steps to implement the key types of EU-recognized energy communities—Citizen Energy Communities (CECs) and Renewable Energy Communities (RECs)—still faces significant regulatory and practical obstacles that hinder their widespread adoption and integration into national energy systems. This is particularly evident in the heating sector, where the current penetration of RES remains exceptionally low, despite the country's significant geothermal and solar potential. The rigid structure of the thermal energy distribution framework, coupled with complex licensing and concession procedures, continues to limit innovation, private sector participation, and the expansion of low-carbon heating solutions.

In this context, the proposed project at the University of Zagreb represents a pioneering effort to operationalize a Renewable Energy Community (REC) that unites two faculties—the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) and the Faculty of Food Technology and Biotechnology (PBF)—into a shared, decentralized thermal energy system based on geothermal heat pump technology. Both faculties, located at Pierottijeva 4 and 6 in Zagreb, currently rely on conventional, carbon-intensive systems powered by natural gas and electricity. The transition to a renewable heating and cooling model not only supports institutional decarbonization goals but also lays the groundwork for scaling the system to serve surrounding public buildings, thus forming the nucleus of a broader urban renewable energy community.

At its core, the project demonstrates how energy communities can act as catalysts for the integration of distributed renewable technologies into existing urban infrastructure. However, for such a community-based model to function effectively within a broader centralized heating framework, it must overcome several systemic challenges. Chief among them is the lack of regulatory recognition for energy communities as eligible actors within the thermal distribution sector. While the Thermal Energy Market Act identifies centralized heating systems as a matter of strategic national interest, it fails to create a viable regulatory pathway for RECs to access existing distribution infrastructure or develop new branches connected to the centralized network. This legal omission forces energy communities to either remain isolated or to establish closed distribution systems—models that, while functional, restrict scalability and cross-sectoral integration.

The proposed REC at the University of Zagreb will thus serve as both a technological and institutional pilot, testing the feasibility of integrating small-scale RES production into urban energy networks and navigating the complex governance structures that currently define Croatia's energy regulatory landscape. The project will be managed through a dedicated governance framework that ensures transparency, legal compliance, stakeholder participation, and financial accountability. This includes full alignment with EU principles regarding voluntary participation, democratic decision-making, and prioritization of local benefit over profit.

Furthermore, the initiative addresses the broader issue of spatial planning, which remains a critical bottleneck in the deployment of renewable-based heating systems in urban areas. Current land-use regulations in Croatia often prohibit the construction of renewable heat production facilities in residential or mixed-use zones, regardless of their minimal environmental footprint. To support the implementation of decentralized and modular systems like heat pumps, legislative amendments are needed to explicitly allow

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such infrastructure to operate within or adjacent to the existing distribution network, particularly in urban areas with identified geothermal potential.

To ensure long-term viability and replicability of such projects, the establishment of supportive financial mechanisms is essential. Given the high upfront investment costs associated with renewable heating technologies and the relatively low return due to regulated energy prices, projects like this require co-financing schemes that reduce the capital burden and de-risk investment. Without dedicated national and EU-level funding streams, Croatia's ability to meet the renewable integration targets prescribed by EU directives remains in question.

In conclusion, the University of Zagreb geothermal energy-sharing project is not merely a technical upgrade—it represents a model of systemic transformation. By leveraging the principles of renewable energy communities, integrating RES technologies into institutional infrastructure, and challenging the current constraints of thermal energy regulation, it provides a replicable framework for sustainable urban heating. It also highlights the urgent need for regulatory reform to enable the participation of energy communities in the centralized heating sector and to facilitate the development of decentralized distribution models that are compatible with Croatia’s climate goals and EU obligations.

3.1. Energy communities in Croatia

The primary focus of energy communities is on energy production, with Citizen Energy Communities (CECs) specifically concentrating on electricity. The national definitions of CECs and Renewable Energy Communities (RECs) align with EU directives concerning renewable energy and electricity market design transposed to the Law on the electricity market and Renewable energy law. Similar to energy cooperatives, they are strong proponents of refurbishment, healthy living environments, and energy efficiency measures.

Energy communities are open and voluntary, and they combine non-commercial aims with environmental and social community objectives. There are different forms and definitions of energy communities. Regarding their basic goal and mode of operation and according to European law framework they can be divided into two basic groups: citizens energy communities (EZG) and communities of renewable energy sources (ZOIE)[3] They both (EZG and ZOIE) offer the possibility of joint investment for citizens, entrepreneurs and public sector in various energy projects.

The aim of energy communities and renewable energy communities is basically the same- to ensure that the citizens and other partners become active participants in energy transition and to give them access to direct benefits such as reducing their energy costs, enhancing energy efficiency and using renewable energy sources. This approach also involves vulnerable groups and directly contributes to the alleviation of energy poverty, which is one of the biggest problems today. Energy communities anticipate the involvement of a wide spectrum of participants - local and regional government, private citizens as well as micro, small and medium-sized companies. They all get involved in various energy projects which will directly benefit the local community.

- EU solar energy strategy[4] anticipates that the EU member countries will cooperate in:
  - establishing at least one energy community based on renewable energy sources per each local public authority with more than 10.000 inhabitants by 2025

[3] In Croatia these two forms of civil energy are defined by the Law on electrical energy market (OG 111/21, 83/2023) and the Law on renewable energy sources and highly efficient cogeneration (OG 138/21, 83/2023)

[4] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13338-EU-solar-energy-strategy_en

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    - ensuring that energy poor and vulnerable consumers have access to solar energy (for example - through installations in state-provided accommodation, energy communities or financial support for individual installations)

- Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity defines the citizens energy community (EZG) as a legal subject that:[5]
    - has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits.
    - may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;
    - is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises.

- The Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources defines the communities of renewable energy (ZOIE) also as a legal entity that:[6]
    - has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits. The community of renewable energy (ZOIE) sources is established in accordance with applicable national law and it is based on open and voluntary participation. It is independent and actually supervised by the shareholders or members located in the vicinity of renewable energy projects owned or developed by the legal entity in question. Its shareholders or members are natural persons, small or medium- sized companies or local government bodies.

- In Croatian legislature these two forms of civil energy are defined by the Electricity Market Act (OG 111/2021, 83/2023)
    - which regulates the field of citizens power communities (EZG) as well as

- The law on renewable energy sources and highly efficient cogeneration (OG 138/21, 83/2023)
    - which defines the communities of renewable energy sources (ZOIE)
- Regulation on the general conditions for electricity supply (OG 100/2022)
- Rulebook on Linces on the carrying out energy activities and certification (OG 44/2022)
- The decision regarding the compensation for the performance of energy activities regulation (OG, 38/22)
- The law on financial operations and accountancy of non-profit organizations (OG 121/2014, 114/22)
- The law on associations (OG 74/14, 70/17, 98/19)
- The law on cooperatives (OG 34/11, 125/13, 76/14, 114/18, 98/19).

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944
[6] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

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In the Republic of Croatia, no entities have been formally registered as Renewable Energy Communities (RECs), but as of 16 September 2024, three Citizen Energy Communities (CECs)[7] have been officially established. While this marks a positive development toward citizen participation in the energy transition, these communities currently exist only formally, as the technical prerequisites for active electricity sharing among members have not yet been met. This situation underscores the necessity for continued efforts in developing the regulatory framework, establishing clear procedures, and implementing the required technical infrastructure. Without these foundational elements, the full potential of energy communities to contribute to a decentralised, democratic, and sustainable energy system in Croatia cannot be realised.

Amendments to the existing energy legislation and its associated regulatory frameworks are currently in progress. Currently, there is a notable interest from more than ten energy initiatives in initiating their respective energy projects, and over one hundred multi-apartment buildings are actively exploring the establishment of their individual solar photovoltaic (PV) systems and exploiting energy sharing and collective self-consumption schemes.

Energy cooperatives can engage in energy markets if they obtain the necessary license. Under Croatian electricity market regulations, any producer with an installed capacity exceeding 1 MW must acquire an energy activity license from the Croatian Energy Regulatory Agency (HERA). For producers with an installed capacity below 1 MW, such a license is not mandatory. Nevertheless, other requirements involving the transmission system operator (TSO), distribution system operator (DSO), and the Croatian energy market operator (HROTE) still apply. Although energy communities are not formally recognized in Croatia at this time, industrial and commercial entities are allowed to carry out energy sharing within closed distribution systems, as outlined in the Electricity Market Act. A closed distribution system (CDS) is defined as a network that distributes electricity within a geographically confined industrial or commercial area.

At present, there are no specific government-backed support programs dedicated to energy communities. The advancement and strengthening of these communities, particularly in terms of access to information and advisory services, are mainly driven by projects funded by the European Union and various international funding sources. There are ongoing, informal talks about setting up financial mechanisms for community energy and establishing comprehensive national support centres. Some of these discussions are leaning towards the idea of implementing national quotas. Local municipalities are engaged in research and development projects focused on renewable energy sources (RES), which could form the basis for energy efficiency (EE) projects linked with energy communities. Additionally, the revenue generated from RES projects could potentially be allocated for EE initiatives benefiting the community members.

The Croatian Energy Communities Forum was officially established in April 2024 as a collaborative platform aimed at supporting the development of energy communities across Croatia. The Forum currently brings together 17 member organizations, including local and regional authorities, energy cooperatives, NGOs, development agencies, and academic institutions. Its core mission is to facilitate dialogue, identify legislative and administrative barriers, and propose actionable solutions for the promotion of both Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) in line with the EU's Clean Energy Package and national climate goals. The Forum operates as an open, cross-sectoral initiative committed to advancing citizen participation and decentralization in the energy sector.

[7] HERA - Registar energetskih zajednica građana

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REGEA (North-West Croatia Regional Energy and Climate Agency) is an active founding member of the Forum, contributing its technical expertise and on-the-ground experience in community-based renewable energy

projects. To ensure the successful implementation of our pilot energy community within the ConnectHeat project, continuous institutional support, targeted regulatory improvements, and dedicated financial instruments are essential. Sustained efforts in this area will be key to enabling this and similar initiatives to take root and scale up in the coming years, making a tangible contribution to a just and inclusive energy transition in Croatia.

3.2. Identified models for developing the energy community at faculties

Given the complex nature of energy transition projects, a key aspect of this initiative is determining the most appropriate governance and operational model for the energy-sharing system. Three distinct models were identified during the planning phase, each offering varying levels of involvement and responsibility for the faculties, external stakeholders, and the management of the geothermal energy system. These models were developed based on considerations such as financial feasibility, operational capacity, regulatory compliance, and the degree of involvement from the academic community, specifically faculty staff and students.

The identified models represent different paths for the establishment and operation of the Renewable Energy Community (REC). They vary in terms of the faculties' direct involvement in the development and operation of the geothermal system, as well as the role of external entities such as HEP Toplinarstvo, the state-owned district heating company. Each model has been designed to ensure that the energy-sharing system can be scaled up over time, supporting both the immediate needs of the faculties and the broader objectives of the energy transition in Croatia.

Below, we outline the three models in detail, along with their potential implications for governance, energy distribution, stakeholder engagement, and financial sustainability.

- **Option 1: Faculties independently develop and operate the system**

In this first model, the faculties would take on full responsibility for developing, operating, and maintaining the geothermal energy system. This approach emphasizes self-sufficiency and full control over the energy-sharing process. The two faculties would own and manage the geothermal infrastructure, share the energy produced between them, and bear the operational and financial responsibilities themselves.

The faculties would also manage the technical aspects of the geothermal system, such as installation, monitoring, and maintenance, as well as the financial management of the energy system. An internal energy-sharing agreement would be established to ensure equitable distribution of energy, based on consumption patterns and predefined quotas. The energy would be tracked using a digital monitoring platform to ensure transparency in consumption.

This model would also include the active participation of university staff and students, who would not only be consumers but could also become investors in the project. Through collective financing, the academic community—staff and students alike—would have the opportunity to invest in the energy system and participate in its decision-making. This model would promote a sense of local ownership and empowerment,

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aligning with the European Commission's objective to encourage citizen involvement in energy transition projects.

Governance and engagement: The faculties would establish a community governance structure, where staff and students would actively participate in decision-making processes related to energy distribution, pricing, and system expansion. Additionally, faculty members could serve as energy managers, overseeing the operational aspects of the system.

Challenges and considerations: While this model promotes independence and local ownership, it would require significant investment from the faculties, both for the initial infrastructure and for ongoing operations. The financial burden could be alleviated by applying for EU grants and national funding programs, but the faculties would need to manage all aspects of the energy system, which could require substantial technical expertise.

- **Option 2: Faculties develop the system, but operations are taken over by HEP Toplinarstvo**

In this second model, the faculties would remain the developers of the geothermal system, handling the construction and initial setup. However, once the system is operational, the responsibility for its management and ongoing operations would be transferred to HEP Toplinarstvo, a state-owned company that specializes in district heating. This would mean that while the faculties maintain ownership of the energy system, they would no longer be directly involved in its day-to-day management.

Under this model, the faculties would still benefit from the geothermal energy generated but would enter a contractual arrangement with HEP Toplinarstvo, which would integrate the geothermal system into the broader district heating network. The faculties would purchase the energy they consume from HEP Toplinarstvo, based on agreed pricing structures that consider production, maintenance, and operational costs.

Governance and engagement: While the operational responsibilities would shift to HEP Toplinarstvo, the faculties would still play an active role in governance by establishing an energy-sharing agreement that defines energy pricing, consumption quotas, and the roles of each party. Faculty staff and students would continue to be involved in monitoring the system's performance, but their involvement in decision-making would be more advisory in nature.

Challenges and considerations: While this model alleviates the operational burden on the faculties, it could limit their control over energy prices and decision-making related to system maintenance. However, by integrating with the district heating network, the geothermal system would be able to reach a larger network of consumers, potentially creating efficiencies of scale.

- **Option 3: Faculties transfer full control to HEP Toplinarstvo**

The third model involves the faculties relinquishing all control over the development, operation, and management of the geothermal energy system. In this case, HEP Toplinarstvo would take on the full responsibility of integrating the geothermal system into the district heating network and would sell heat to the faculties under a Heat Purchase Agreement (HPA). The faculties would remain consumers of energy, purchasing the geothermal heat from HEP Toplinarstvo based on market-driven prices.

HEP Toplinarstvo would manage all aspects of the system, from installation to maintenance, and would ensure that the surplus energy generated by the geothermal system is fed back into the district heating

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network. This would allow the faculties to benefit from a reliable, renewable energy source without needing to manage the operational complexities of running the system.

Governance and engagement: In this model, the faculties would have less direct control over the energy system but could still engage with HEP Toplinarstvo through an advisory committee that includes faculty staff and student representatives. These stakeholders would have a role in monitoring the system's performance and ensuring that it meets their energy needs.

Challenges and considerations: The main advantage of this model is that it shifts all operational and financial risks to HEP Toplinarstvo, ensuring that the faculties do not bear the burden of system management. However, the faculties would have less flexibility in terms of pricing and energy distribution, as these would be governed by the terms of the Heat Purchase Agreement.

Each of these three models provides a different path toward establishing a sustainable and efficient renewable energy community at the University of Zagreb. The decision on which model to pursue will depend on various factors, including the level of control the faculties wish to retain, the financial and technical capacity to manage the system, and the degree of involvement they want from external stakeholders such as HEP Toplinarstvo.

In the next phase of the project, further consultations with stakeholders, including HEP Toplinarstvo, regulatory bodies, and potential investors, will be necessary to assess the feasibility of each model and to select the one that aligns best with the university's long-term energy strategy. Regardless of the model chosen, the project will contribute to the broader goal of transitioning to a more sustainable, decentralized energy system in Croatia and will engage the academic community in the energy transition process, ensuring that the initiative remains inclusive and transparent.

All three proposed models have been developed in close collaboration with the project's Advisory Group and the Community Energy Board (CEB), whose principal representative is Mr. Vladislav Brkić, Dean of the Faculty of Mining, Geology and Petroleum Engineering. This joint development process ensured that each model reflects both the technical and institutional capacities of the University, as well as the long-term strategic goals of the energy transition.

It is important to emphasize that, to date, no community energy model has been implemented in Croatia in the heating and cooling sector. This initiative therefore represents a pioneering approach—introducing a new governance and operational framework that could serve as a national reference point for future Renewable Energy Communities (RECs).

From the outset of the project, all stakeholders—including faculty leadership, researchers, technical experts, and administrative staff—have been actively engaged in shaping the models. This inclusive process extended to the academic community, particularly students, whose voices were intentionally incorporated through a structured questionnaire. The survey aimed to assess students' interest in active participation and co-ownership of the energy community and has directly informed the design of engagement mechanisms within

Model 1, which has emerged as the most promising and well-aligned approach. Based on its strong potential for implementation, stakeholder involvement, and long-term sustainability, **Model 1 has been selected as the preferred model** and will be further developed and described in detail in the following sections.

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3.3. Chosen model: Independent development and operation by faculties

Model 1 proposes that the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) and the Faculty of Food Technology and Biotechnology (PBF) at the University of Zagreb take full responsibility for the development, operation, and maintenance of a geothermal heat pump system. This decentralized model emphasizes local ownership, technical autonomy, and close integration with the academic community, particularly students. The model is aligned with EU policies promoting energy democracy, education in sustainability, and citizen involvement in energy transition processes.

To assess the feasibility and readiness for establishing a student-led Renewable Energy Community (REC), a collaborative initiative was undertaken faculties together with REGEA – North-west croatia Regional Energy and Climate Agency. Recognizing the critical role that young people and academic institutions play in accelerating the energy transition, a targeted student survey was designed and distributed to gather data on awareness, interest, and willingness to engage in community-based renewable energy initiatives.

A total of 50 completed surveys were collected and analysed. The questionnaire format is provided in the annex, along with 50 completed survey responses submitted as an appendix to this study. The survey serves as a foundational step for developing an inclusive and participatory energy community model, built on student engagement and supported by educational and institutional infrastructure. Below is a comprehensive overview of the survey results, accompanied by strategic insights and initial implementation steps aimed at turning student interest into concrete action.

1. Awareness of the energy community concept

The first objective was to understand the baseline level of awareness among students regarding energy communities. Results indicate:

- 20% (10 students) were fully familiar with the concept of energy communities.
- 60% (30 students) reported partial understanding.
- 20% (10 students) were unfamiliar with the concept altogether.

While most students (80%) possess at least some level of familiarity with the concept, the relatively low percentage of full awareness points to a clear opportunity for educational enhancement. The existence of a 20% knowledge gap is particularly relevant, as awareness is a prerequisite for informed participation. It is critical to ensure all students—not only those studying energy or environmental sciences—are equipped with a basic understanding of what energy communities are, how they function, and what roles individuals can play within them.

2. Interest in participating in the renewable energy community

Students were asked to indicate their level of interest in joining the energy community. Results show:

- 70% (35 students) are very interested.
- 24% (12 students) are moderately interested.
- 4% (2 students) are not interested.
- 2% (1 student) is uncertain.

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These figures reflect an exceptional level of enthusiasm. With 94% expressing either strong or moderate interest, it is evident that the idea of a community-led renewable energy initiative resonates strongly among students. This offers a solid social foundation for launching the REC and justifies immediate planning and engagement activities. The low disinterest rate further supports the conclusion that students see added value—educational, environmental, and personal—in participating in this initiative.

3. Willingness to contribute financially (up to €50)

The question on financial contribution aimed to assess students' willingness to support the REC with a personal monetary input. Responses indicate:

- 68% (34 students) are willing to contribute up to €50.
- 18% (9 students) might be willing depending on circumstances.
- 14% (7 students) are unwilling to contribute.

These results highlight a high level of ownership and seriousness among students regarding the REC. Financial contributions, although modest, suggest that students are prepared to support the project materially, not just in spirit. This is particularly noteworthy given the typically limited financial resources of students. The 18% expressing conditional willingness signal the importance of transparent communication about how contributions will be used and what benefits will result. If these conditions are met, even greater participation can be expected.

4. Integration into academic studies and research

The academic dimension of the REC was evaluated through a question on whether students would like to connect the project with their studies. The results are:

- 82% (41 students) want to incorporate the REC into coursework, projects, or theses.
- 10% (5 students) are open to it, depending on availability.
- 8% (4 students) are not interested.

This is one of the most promising outcomes of the survey. A project that aligns with academic development is likely to attract consistent interest and support, particularly if credit-bearing activities or thesis topics are made available. This strong academic alignment also provides a strategic advantage in securing institutional backing, faculty mentorship, and potential EU funding under programs that support education, research, and youth participation in climate action.

5. Willingness to volunteer

Volunteering as a form of active, non-financial engagement was also measured:

- 62% (31 students) are willing to volunteer.
- 28% (14 students) may volunteer depending on obligations.
- 10% (5 students) are not willing to volunteer.

Most students are willing to contribute time and effort, a critical resource for the long-term sustainability of any community-led initiative. However, the relatively high portion of students who are hesitant underscores

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the need for flexibility and clarity in role expectations. Offering task-based volunteering and acknowledging contributions (certificates, credits) will help turn passive interest into sustained participation.

6. Student role in management and oversight

Lastly, students were asked about their preferences regarding governance:

- 88% (44 students) support student involvement in managing the REC.
- 10% (5 students) are uncertain.
- 2% (1 student) opposes student involvement in management.

This overwhelming support for student governance demonstrates that students are not merely interested in joining an existing initiative but want to shape and lead it. This democratic approach reflects a strong desire for empowerment and aligns well with EU principles on youth participation and community engagement. It also offers long-term benefits for students' leadership and organizational development.

The survey reveals a high level of awareness, interest, and readiness among students to engage in and co-create a Renewable Energy Community. From academic integration and financial commitment to voluntary participation and governance, the findings point to a well-informed, enthusiastic student base ready to take collective action toward sustainability.

To translate this momentum into structured action, the following strategic steps are recommended as the first phase of the REC development:

- **Establish a student-led founding group** - Form a working group composed of students from different academic backgrounds, supported by faculty mentors. This team will co-develop the REC's mission, values, and basic organizational structure.
- **Launch an awareness and engagement campaign** - Target students with limited understanding of RECs through information sessions, visual content, and interactive workshops. This campaign will ensure inclusiveness and improve general literacy around renewable energy topics.
- **Connect with academic structures** - Collaborate with faculty departments to create opportunities for REC involvement within study programs. This includes elective courses, seminar topics, and research projects related to energy, governance, or sustainability.
- **Design a financial participation model -** Create a transparent, voluntary contribution model with low-entry thresholds (e.g., €10, €25, €50 tiers), allowing students to financially support the REC based on their means. Communicate clearly how funds will be used.
- **Develop a volunteer program -** Structure a volunteering framework with flexible roles and time commitments. Provide skill-building opportunities and formal recognition (e.g., certificates, co-curricular records) to encourage participation.
- **Formalize governance and oversight structures -** Create an internal constitution and governance model with democratic elections for roles (Chairperson, Treasurer, etc.). Involve REGEA and university staff in advisory roles to ensure compliance and guidance.

This initiative presents a remarkable opportunity to place students at the forefront of the green transition. The survey results clearly demonstrate a strong foundation of interest, commitment, and enthusiasm among

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the student body, confirming the readiness to establish a student-led Renewable Energy Community (REC). With the coordinated support of university faculties, expert mentorship from REGEA, and a clear implementation strategy, this REC has the potential to become a beacon of youth-led climate action, academic innovation, and civic engagement.

The high levels of interest in active participation—whether through financial contributions, volunteering, or integration into academic research—underscore the capacity of this initiative to foster deep and sustained student involvement. Notably, students have expressed a strong desire to assume leadership roles in shaping the REC's direction, revealing a robust potential for democratic governance and long-term project ownership.

To fully unlock this potential, targeted actions will be necessary to bridge existing knowledge gaps, particularly around the concept of energy communities. Increasing awareness through educational outreach and ensuring flexible, accessible volunteering options will help engage a broader spectrum of students. At the same time, aligning the project with curricular and research activities will enhance both its academic value and practical impact.

In essence, the findings illustrate not only a willingness—but a clear eagerness—among students to contribute to and co-create a sustainable energy future. With the appropriate institutional structures, educational integration, and inclusive engagement strategies, this initiative can evolve into a replicable model that advances both EU energy goals and the educational mission of higher education institutions.

3.4. Organizational and management structure of the community energy project

Following a comparative evaluation of three proposed governance and operational models for the development of a renewable-based heating and cooling system within the ConnectHeat initiative, Model 1 has been selected as the most optimal and strategically aligned. This model places full responsibility for the development, operation, and maintenance of a geothermal heat pump system under the joint leadership of the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) and the Faculty of Food Technology and Biotechnology (PBF) at the University of Zagreb.

This decentralized model is designed to promote institutional autonomy, local ownership, and deep integration with academic and student communities, while remaining fully aligned with EU policies focused on sustainability, energy democracy, and educational inclusion in the green transition.

RGNF has long-standing expertise in geothermal systems, hydrogeology, and sub-surface energy engineering, while PBF contributes knowledge in environmental systems, biotechnology, and sustainable process optimization. Together, they provide a robust interdisciplinary foundation necessary for the successful deployment and long-term management of a ground-source heating and cooling system. Their ability to independently plan, implement, and operate this system significantly reduces reliance on third-party contractors or commercial developers.

Model 1 ensures full control remains with the faculties themselves. This decentralized governance model resonates strongly with EU values of energy democracy, enabling public institutions to lead the shift to renewable energy through community-driven efforts. It provides a meaningful response to the EU's call for local actors to take ownership of clean energy solutions in the spirit of the Green Deal and REPowerEU.

A defining strength of Model 1 is its integration into the academic mission of both faculties. Students will be involved in real-world applications of renewable energy through:

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- Feasibility assessments
- Technical simulations
- Environmental performance monitoring
- Data analysis and reporting
- Policy evaluation and communication
- Volunteering and leadership within the Renewable Energy Community

This hands-on experience reinforces academic learning with applied research, skill development, and climate literacy, thus creating a new generation of professionals equipped to lead Europe's energy transition.

Model 1 operationalizes key EU energy and climate policies:

- Encourages renewable heating and cooling technologies, such as geothermal energy, in line with Fit for 55 and REPowerEU objectives
- Facilitates citizen-led (student-led) community energy projects
- Strengthens links between academic institutions and climate action
- Supports just and inclusive energy transitions through public sector engagement

This governance model is easily adaptable to other universities and public institutions across Europe, making it a scalable prototype. The University of Zagreb can position itself as a model for how higher education institutions can become operational leaders in climate action—not just through research and education, but by managing real, functioning infrastructure based on renewable sources.

Unlike externally managed models, Model 1 allows for internal reinvestment of operational savings. These resources can support:

- Further system expansion
- Student innovation projects
- Faculty-led research
- Training and capacity-building for technical staff and students

This self-sustaining cycle reinforces the long-term viability of the system and aligns with the EU's goal of building resilient, community-powered infrastructure.

Model 1 represents the optimal path forward for the University of Zagreb and its Renewable Energy Community. It reflects a shared commitment between faculties, students, and the broader community to develop a technically sound, socially inclusive, and environmentally sustainable energy system.

By selecting this decentralized model, the project builds a foundation for long-term engagement, educational excellence, and practical climate leadership. Moreover, it enhances the EU-wide relevance of the initiative by offering a replicable, student-powered model that connects learning with tangible environmental impact. This approach not only meets the technical and academic needs of the university but also responds directly to EU policy priorities—demonstrating how universities can lead the energy transition from within.

The proposed Renewable Energy Community (REC) which aims to produce and share renewable energy for heating and cooling at the University of Zagreb represents a pioneering initiative in Croatia's energy sector. This project is designed in alignment with the Croatian Law on Renewable Energy Sources and Highly Efficient

Cogeneration which defines Renewable Energy Communities (hrv. Zajednice obnovljive energije - RECs) and aims to create an innovative, sustainable, and cooperative approach to energy production and consumption.

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At its core, this initiative is a collaborative effort between two faculties: the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) and the Faculty of Food Technology and Biotechnology (PBF). By integrating locally produced renewable energy and engaging the academic community in investment, this project aligns with EU energy directives and supports Croatia's transition to decentralized, sustainable energy solutions.

The energy community will be established as the aforementioned Renewable Energy Community (REC) in accordance with Croatian legislation. To ensure long-term sustainability and compliance with both national and EU regulations, the governance and management structure will be built on democratic governance principles. This will involve the faculties, in partnership with other stakeholders, entering into a legally binding agreement to form an energy-sharing community.

The energy-sharing model will ensure that both faculties have access to energy based on their respective consumption needs, with a transparent allocation system that promotes fairness and efficiency.

- Energy distribution:
  - The geothermal energy generated will be allocated between the two faculties based on predefined consumption quotas. Each faculty's energy usage will be monitored and calculated using a digital monitoring platform to track real-time consumption.
  - An Internal Energy Service Agreement (IESA) will be established to define energy pricing, usage quotas, and responsibilities for maintenance and operation between the two faculties.
- Excess energy distribution:
  - In the event of surplus energy (i.e., energy produced in excess of the faculties' consumption), the excess will be redirected into the district heating network managed by HEP Toplinarstvo, facilitating the sale of surplus energy into the larger energy market. This will allow the University to generate revenue and contribute to the broader goal of increasing the share of renewable energy in the energy mix.
- Energy pricing:
  - The price for the energy consumed by each faculty will be determined based on the cost of production, maintenance, and operational expenses, as well as the market value of the surplus energy sold. The pricing model will ensure transparency and fairness, with periodic reviews to adjust for market fluctuations.

A key feature of this REC model is the active involvement of the academic community—comprising faculty staff and students—in the investment and decision-making process. In this case, the term "citizens" refers specifically to the students and staff of the university, who act as the core stakeholders in the community. Through collective financing, these stakeholders will be able to become active participants in the energy community. This model not only ensures the financial viability of the project but also fosters a sense of local ownership, making the energy transition process inclusive.

Faculty staff and students will have the opportunity to co-invest, share profits from energy sales or cost savings, and participate in the democratic governance of energy management. This engagement aligns with the European Commission's support for citizen involvement in energy initiatives, as students and faculty embody the concept of citizens in this example.

The initial phase of the geothermal energy project is designed to serve the energy needs of the two faculties. However, the long-term vision includes the potential scaling up of this energy-sharing model to include additional university buildings, neighboring institutions, or other local stakeholders. This scaling-up process will enable the system to contribute to a larger, more integrated renewable energy network, fostering a more sustainable and efficient energy system for the wider community.

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- Scalability of the energy system:
  - The geothermal system will be designed with scalability in mind. The infrastructure will allow for future expansion to additional buildings within the nearby institutions. This will be achieved by increasing the capacity of the geothermal plant and expanding the distribution network to include additional users.
  - Future users may include other faculties or local public institutions, all benefiting from the geothermal energy produced.
- Integration with the district heating network:
  - As the project scales, surplus energy generated by the expanded geothermal system could be increasingly integrated into the city's district heating network. This would enhance the use of renewable energy in the broader urban area, further reducing the dependency on fossil fuels and contributing to Croatia's climate goals.
- Financial implications and incentives:
  - The scaling-up process will be supported by ongoing EU funding, as well as potential investments from the City of Zagreb, local energy providers, and private investors interested in renewable energy. Financial mechanisms will be explored to ensure that the costs of expansion are covered while maintaining the financial sustainability of the project.
  - Additionally, the EU's Horizon Europe funding program and other energy transition grants could play a crucial role in supporting the scaling-up efforts.
- Stakeholder engagement:

A clear strategy for stakeholder engagement will be crucial for the scaling-up process. As new users are added to the energy community, it will be important to ensure their participation in decision-making processes and to maintain transparency about energy allocation, pricing, and governance. This may involve the creation of new agreements and the development of further collaborative partnerships with local authorities, energy providers, and potentially other universities or educational institutions. The development of the energy community and its operational model will be carried out in consultation with the following stakeholders, ensuring full compliance with the obligations and rights that the Renewable Energy Community (REC) must fulfill under the applicable regulatory framework:

- **Faculty of Mining, Geology, and Petroleum Engineering (RGNF) and Faculty of Food Technology and Biotechnology (PBF):** Act as prosumers (producers and consumers) of energy.
- **City of Zagreb:** Provides regulatory facilitation and supports funding applications.
- **REGEA (North-west Croatia Regional Energy and Climate Agency):** Offers technical and administrative oversight.
- **Croatian Energy Regulatory Agency (HERA):** Ensures compliance with national energy regulations.
- **Croatian Water Ltd:** Manages water resource permits and ensures compliance with environmental regulations.
- **HEP Toplinarstvo** will act as an external operator, responsible for integrating the geothermal energy system into the wider district heating network, managing the distribution of excess energy, and overseeing its maintenance and operation.
- **National funding bodies:** Provide financial support for project development and expansion.

Renewable energy communities represent a vital step toward a decentralized, fair, and sustainable energy system in Croatia. With the support of appropriate legislation and pilot projects such as ConnectHeat, there is significant potential for their expansion—especially in specialized environments like higher education institutions and the public sector.

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3.5. Project roadmap

The feasibility study for the decarbonization of heating and cooling systems at the Faculty of Mining, Geology, and Petroleum Engineering (RGNF) has been successfully completed, marking the conclusion of the project's initial phase. Conducted by a team of external experts, the study demonstrates both the technical and economic viability of implementing a heating and cooling system utilizing a combination of water-to-water and air-to-water heat pumps. This solution has been identified as the most optimal approach to achieving full decarbonization while addressing the existing spatial and infrastructural limitations within the faculty complex.

Due to certain regulatory barriers at the national level, the implementation of the proposed model is currently facing challenges. The key national regulation—the Renewable Energy Sources and High-Efficiency Cogeneration Act (ZOIEVK)—is currently open for public consultation until the end of March 2025. This legislation introduces essential amendments to align with European Union regulations and to promote the use of renewable energy in Croatia. Some of the anticipated changes include:

- Increasing the national renewable energy target to 42.5% of final energy consumption by 2030.
- Starting January 1, 2026, self-consumers will no longer be exempt from grid fees and other charges when drawing electricity from the grid.
- Introducing new rules and incentives for self-consumption, as well as encouraging the development of renewable energy communities.
- Establishing provisions for community registration, a plan for the development of the electricity grid, and energy storage solutions to support the integration of renewable energy.
- More clearly defining the role of active consumers, enabling energy exchanges between locations, subject to network usage fees.

Currently, however, there is a lack of clear legal definitions or regulatory guidance on energy sharing, including key aspects such as energy exchange, internal sales within communities, and the associated costs. These uncertainties present significant technical, legal, and financial barriers to the practical implementation of energy-sharing models in Croatia. It is expected that once the amendments are adopted, a new law will be enacted within six months, providing clearer guidelines and facilitating the progress of the project.

To progress towards implementation, several critical steps must be completed, including securing necessary approvals, permits, and investment funding.

At this stage, only the feasibility study has been completed. No formal approvals, permits, or construction works have commenced. For the project to transition into the execution phase, the following approvals and documentation must be obtained:

- **Property rights and land-use approvals:** If the land required for system installation is not owned by the faculty, formal agreements must be secured from the relevant landowners. The building permit process is directly influenced by land ownership, and delays may occur if approvals are not granted promptly.
- **Construction and environmental permits:** Several regulatory approvals are required to begin installation, including a building permit (due to modifications of the existing heating and cooling system), a water management permit (since groundwater will be used as a renewable energy source), and an environmental impact assessment (if required by regulatory authorities).
- **Technical and project documentation:** The project must undergo a three-stage design process, including:
    1. Conceptual design

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2. Main project design
3. Execution project design (optional, depending on regulatory requirements)

- **Procurement and equipment installation:** Once permits and approvals are secured, procurement of the geothermal and air-to-water heat pumps and supporting infrastructure must take place. This phase will also include adaptations to the existing boiler room to accommodate the new system.
- **Regulatory compliance and energy system integration:** Approvals from energy and utility providers must be secured to ensure seamless integration into the existing energy infrastructure. Additionally, public procurement procedures must be followed to ensure compliance with EU funding regulations and to maintain transparency and fair competition.

The activity timelines for the implementation of the project involving ground-source and water-to-water geothermal heat pumps, as well as the project execution itself. A key factor affecting the project timeline is the ownership of the parcel where the intervention is taking place – it is essential to obtain a construction permit from the landowner, and the time required to acquire this permit is impossible to predict due to the influence of numerous factors. The expected project duration is largely dependent on the approval timelines for permits and land-use rights. The feasibility study highlights that delays in administrative approvals and land ownership issues could impact the project timeline.

Despite these potential challenges, the combination of water-to-water and air-to-water heat pumps presents an innovative, cost-effective, and energy-efficient solution. This system not only ensures financial savings and carbon footprint reduction but also serves as a model for sustainable energy transition within academic institutions.

3.6. Risks

Several **critical risks** could affect the implementation of the project. These risks arise from **regulatory, financial, technical, and market-related uncertainties**.

The project is subject to **national and EU regulatory frameworks** governing renewable energy systems, water resource management, and construction. Potential changes in:

- Energy and environmental regulations may require additional modifications to the planned system.
- Permit approval processes could lead to unexpected delays.
- Legislative changes or new government policies may alter funding mechanisms or compliance requirements.

The project's economic viability depends on **investment costs, energy prices, and financial savings**. Key financial risks include:

- Budget overruns due to unforeseen infrastructure costs.
- Changes in energy pricing policies that could impact cost savings.
- Delays in securing EU or national funding, which may affect cash flow for project execution.

Given the complexity of the project, **delays in obtaining property rights and permits** are a major risk factor. If **land-use approvals are not secured**, the project may face substantial delays or require **alternative site selection**, increasing costs and timelines.

The existing **spatial and infrastructural limitations** at the faculty present challenges for system installation. The feasibility study identified key technical risks:

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- Adaptation of the existing boiler room may require additional modifications.
- Ensuring compatibility with existing heating and cooling distribution systems could present design and engineering challenges.

The successful deployment of the project requires **access to qualified experts, suppliers, and contractors**. Risks include:

- Limited availability of specialized expertise for designing and installing advanced heat pump systems.
- Potential supply chain disruptions for procuring heat pumps and related equipment.
- Fluctuations in market demand for renewable energy solutions, which may affect procurement costs and technology selection.

The financial and energy performance of the system depends on **future energy demand and pricing trends**. Potential risks include:

- Variations in electricity prices affecting operating costs.
- Changes in policy incentives for renewable energy, which could impact the project's return on investment.

Despite these risks, the feasibility study clearly demonstrates that the proposed system configuration—combining water-to-water and air-to-water heat pumps—is the most viable and efficient solution for achieving full decarbonization of the faculty's heating and cooling systems.

The implementation of this system represents a significant step towards sustainable energy transition and serves as a scalable model for other academic institutions. With appropriate risk mitigation strategies, timely regulatory approvals, and strong project management, this project has the potential to become a flagship example of decarbonization within the education sector.

The long-term goal is to create a model that can be replicated in other academic and municipal institutions across Croatia and the EU, setting a precedent for the establishment of Renewable Energy Communities in the heating and cooling sector.

This initiative represents a transformative step toward energy independence and sustainability at the University of Zagreb. By creating Croatia’s first Renewable Energy Community for heating and cooling, the project serves as a blueprint for future energy-sharing networks. Through collective investment, active participation by the academic community, and adherence to EU and Croatian energy policies, this model not only ensures financial sustainability but also sets the stage for a broader transition to decentralized, renewable energy production.

The successful implementation of this project will establish a resilient and scalable energy-sharing framework, contributing to Croatia’s climate goals and demonstrating how academic institutions can drive the energy transition. By overcoming regulatory, financial, and technical challenges, this project is poised to become a pioneering example of how Renewable Energy Communities can be effectively established and expanded in Croatia and beyond.

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Annex

Recap of geothermal potential for baseline reference state (RGNF and PBF)

INITIAL REFERENCE STATE								
Pgr, Ref.	Phl, Ref.	PPTV, Ref.	Qgr, po.ref.	Qhl, dec.ref.	QPTV, Ref.	Energy consumption	Cost	CO_2 emissions
Kw	Kw	Kw	kWh/year	kWh/year	kWh/year	kWh/year	EUR/year	t/ CO_2year
1.800,00	1.038,13	252,80	1.306.647,67	249.148,80	60.672,00	1.450.369,27	124.872,50	298,44

SYSTEM	Pgr	Phl	SCOP/SEER	Qgr	Qhl	Share in the total need	Energy consumption (DT + existing system)	Cost	Cost of investment	Operating cost	**Energy savings**	**Financial savings**	Reducing CO_2emissions	Reducing CO_2 emissions
	Kw	Kw		kWh/year	kWh/year	%	kWh/year	EUR/year	EUR	EUR/year	**EUR/year**	**EUR/year**	tCO2/year	%
SOIL-WATER	186,70	116,67	4/5	195.997,15	37.372,32	14,44%	1.298.388,43	124.634,38	478.000,00	2.000,00	**151.980,84**	**238,12**	34,94	11,71%
WATER-WATER	615,13	421,80	5/6	653.323,84	124.574,40	48,12%	906.947,80	114.884,28	332.000,00	3.588,20	**543.421,47**	**9.988,22**	**122,34**	**40,99%**

Recapitulation of geothermal potential for future reference state (RGNF and PBF)

FUTURE REFERENCE SITUATION								
Pgr, bud.ref.	Phl, bud.ref.	PPTV, bud.. ref.	Qgr, bud.ref.	Qhl, bud.ref.	QPTV, bud.ref.	Energy consumption	Cost	CO_2 emissions
Kw	Kw	Kw	kWh/year	kWh/year	kWh/year	kWh/year	EUR/year	t CO_2/year
1.000,00	675,00	0,00	653.323,84	161.946,72	60.672,00	767.978,08	80.177,28	154,01

SYSTEM	Pgr	Phl	SCOP/SEER	Qgr	Qhl	Share in the total need	Energy consumption (DT + existing system)	Cost	Cost of investment	Operating cost	Energy savings	Financial savings	Reducing CO_2emissions	Reducing CO_2 emissions
	Kw	Kw		kWh/year	kWh/year	%	kWh/year	EUR/year	EUR	EUR/year	EUR/year	EUR/year	tCO2/year	%
SOIL-WATER	186,70	116,67	4/5	199.918,84	40.486,68	27,45%	612.640,73	79.855,93	478.000,00	2.000,00	155.337,35	321,35	35,69	23,18%
WATER-WATER	615,13	421,80	5/6	499.797,09	113.362,70	70,00%	349.246,63	71.784,64	332.000,00	3.588,20	418.731,45	8.392,64	94,07	61,08%
WATER-WATER AND AIR-WATER	1.015,13	681,80	5/6 (water-to-water)3.2/4 (air-to-water)	713.995,84	161.946,72	100,00%	197.936,32	49.433,61	525.000,00	5.265,08	570.041,76	30.743,68	122,54	79,56%

Form of survey for students

ConnectHeat
Community engagement for clean heat

May 2025

Questionnaire on participation in an academic energy community for thermal energy
RGNF and PBF as pilot faculties within the ConnectHeat project (EU LIFE Programme)

Dear Sir/Madam,

The Faculty of Mining, Geology and Petroleum Engineering (RGNF) and the Faculty of Food Technology and Biotechnology (PBF) of the University of Zagreb are participating as pilot faculties in the European project *ConnectHeat*, funded by the LIFE Programme of the European Union. The aim of the project is to establish the first academic energy community for thermal energy, enabling the connection of multiple higher education institutions into a shared, sustainable heating and cooling system based on renewable energy sources. This initiative seeks to develop a business model and framework for establishing the first renewable energy community in the heating and cooling sector within the academic environment. To assess the level of interest and potential involvement of students and staff, we kindly ask you to complete this short questionnaire. Your responses will help shape further project activities in line with the needs of the community.

1. **Are you familiar with the concept of an energy community or renewable energy community?**
   o Yes, I am well informed
   o I am somewhat familiar
   o No, I am not familiar
2. **How interested are you in participating in an energy community at your faculty?**
   o Very interested
   o Moderately interested
   o Not interested
   o Not sure
3. **Would you consider making a symbolic financial contribution (up to €50) to support the development of a sustainable heating and cooling system?**
   o Yes
   o Maybe
   o No
4. **Would you like to see the project integrated into your study programme or research activities (e.g., courses, final/master's theses, projects)?**
   o Yes, very much
   o Maybe, depending on the possibilities
   o No
5. **Would you be willing to volunteer within the project (e.g., as an energy ambassador: educating peers, communicating about the project, collecting opinions and needs)?**
   o Yes, I am interested in such involvement
   o Maybe, if my obligations allow
   o No
6. **Do you believe that students should have a role in the management and oversight of the energy community?**
   o Yes, definitely
   o Maybe
   o No
   o Not sure

Thank you for your time and contribution to this important step toward a sustainable energy future within the academic community.

Sincerely,
The ConnectHeat Project Team – REGEA, RGNF and PBF

The LIFE21-CET-ENERCOM-CONNECTHEAT project has received funding from the European Union's LIFE Programme under grant agreement N°101076258

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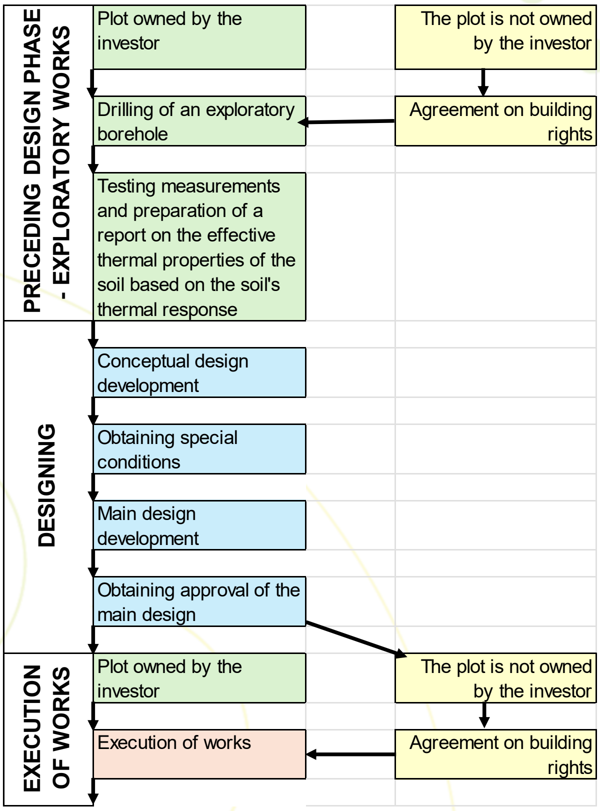
Activity timeline – Right of use, concessions, and permits for groundwater geothermal heat pump



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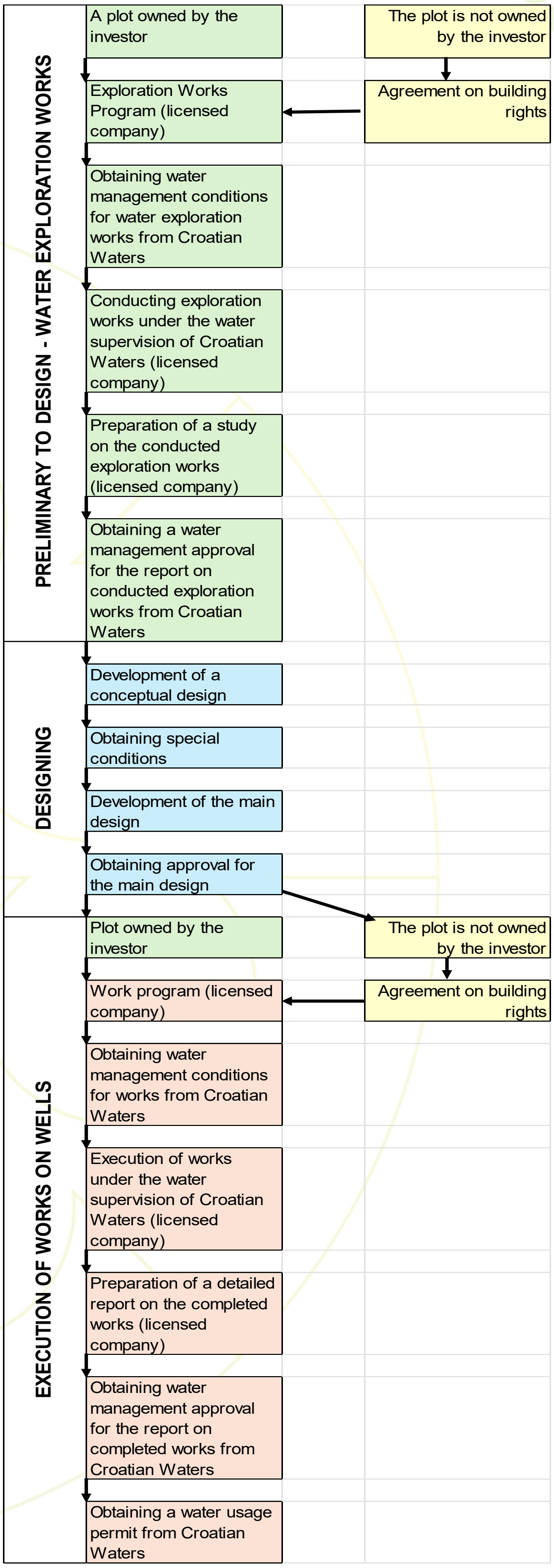
Activity timeline – Right of use, concessions, and permits for water-to-water geothermal heat pump system



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Activity timeline with deadlines – Groundwater geothermal pump (Investor-owned plot)

	Activity	Expected duration		
PRECEDING DESIGN PHASE - EXPLORATORY WORKS	Plot owned by the investor	3 weeks	Total: 3 weeks	The plot is not owned by the investor
	Drilling of an exploratory borehole			Agreement on building rights
	Testing measurements and preparation of a report on the effective thermal properties of the soil based on the thermal response of the soil			
DESIGNING	Conceptual design development	2 weeks	Total: 12 weeks	
	Obtaining special conditions	3 weeks		
	Main design development	4 weeks		
	Obtaining approval of the main design	3 weeks		
EXECUTION OF WORKS	Plot owned by the investor			The plot is not owned by the investor
	Execution of works	6 weeks	6	Agreement on building rights
TOTAL DURATION (WEEKS)			21	

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Activity timeline with deadlines – Groundwater geothermal pump (the plot is not owned by the investor)

	Activity	Expected duration	
PRECEDING DESIGN PHASE - EXPLORATORY WORKS	The plot is not owned by the investor	3 weeks	Total: 3 weeks
	Agreement on building rights		
	Drilling of an exploratory borehole		
	Testing measurements and preparation of a report on the effective thermal properties of the soil based on its thermal response.		
DESIGNING	Conceptual design development	2 weeks	Total: 12 weeks
	Obtaining special conditions	3 weeks	
	Main design development	4 weeks	
	Obtaining approval of the main design	3 weeks	
EXECUTION OF WORKS	The plot is not owned by the investor	4 weeks or more (impossible to estimate exactly)	4 weeks
	Agreement on building rights		
	Execution of works	6 weeks	6
	TOTAL DURATION (WEEKS)		**25**

Activity timeline with deadlines – Groundwater geothermal pump (the plot is not owned by the investor))

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Activity timeline with deadlines – Water-to-water geothermal pump (plot not owned by the investor)

	Activity	Expected duration		
PRELIMINARY TO DESIGN - WATER EXPLORATION WORKS	Plot owned by the investor	4 weeks	Total: 8 weeks	The plot is not owned by the investor → Agreement on building rights
	Exploration Works Program (licensed company)			
	Obtaining water management conditions for water exploration works from Croatian Waters			
	Conducting exploration works under the water supervision of Croatian Waters (licensed company)			
	Preparation of a report on the conducted exploration works (licensed company)	4 weeks		
	Obtaining a water management approval for the report on conducted exploration works from Croatian Waters			
DESIGNING	Conceptual design development	2 weeks	Total: 12 weeks	
	Obtaining special conditions	3 weeks		
	Main design development	4 weeks		
	Obtaining approval of the main design	3 weeks		
EXECUTION OF WORKS	The plot is owned by the investor			The plot is not owned by the investor
	Work program (licensed company)	4 weeks	Total: 8 weeks (including the execution of connection works with the heat pump and other equipment)	Agreement on building rights
	Obtaining water management conditions for works from Croatian Waters			
	Execution of works under the water supervision of Croatian Waters (licensed company)			
	Preparation of a detailed report on the completed works (licensed company)	4 weeks		
	Obtaining water management approval for the report on completed works from Croatian Waters			
	Obtaining a water usage permit from Croatian Waters			
TOTAL DURATION (WEEKS)			28	

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Activity timeline with deadlines – Water-to-water geothermal pump (plot not owned by the investor)

	Activity	Expected duration	
PRELIMINARY TO DESIGN - WATER EXPLORATION WORKS	The plot is not owned by the investor	4 weeks or more (it is impossible to estimate exactly)	Total: 12 weeks
	Agreement on building rights		
	Exploration Works Program (licensed company)	4 weeks	
	Obtaining water management conditions for water exploration works from Croatian Waters		
	Conducting exploration works under the water supervision of Croatian Waters (licensed company)		
	Preparation of a report on the conducted exploration works (licensed company)	4 weeks	
	Obtaining a water management approval for the report on conducted exploration works from Croatian Waters		
DESIGNING	Conceptual design development	2 weeks	Ukupno: 12 tjedana
	Obtaining special conditions	3 weeks	
	Main design development	4 weeks	
	Obtaining approval of the main design	3 weeks	
EXECUTION OF WORKS	The plot is not owned by the investor	4 weeks or more (it is impossible to estimate exactly)	4 weeks
	Agreement on building rights		
	Work program (licensed company)	4 weeks	Ukupno: 8 tjedana (u tom vremenu je i izvođenje radova na spajanju s dizalicom topline i ostalom opremom)
	Obtaining water management conditions for works from Croatian Waters		
	Execution of works under the water supervision of Croatian Waters (licensed company)		
	Preparation of a detailed report on the completed works (licensed company)	4 weeks	
	Obtaining water management approval for the report on completed works from Croatian Waters		
	Obtaining a water usage permit from Croatian Waters		
TOTAL DURATION (WEEKS)			**36**

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