Risk analysis in the geothermal potential assessment - Case study Croatia

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Keywords: *geothermal projects, risk assessment.*

ABSTRACT

The purpose of the techno-economic assessment of geothermal potential is to determine the possibility of exploiting geothermal energy. All geothermal exploration areas in the Republic of Croatia are located in the hydrocarbon exploration areas. The knowledge about the existence of geothermal water is mostly related to exploratory drilling for oil and gas and related infrastructure. This paper considers one geothermal exploration area in the northwestern part of Croatia with old oil and gas well data. These data were analyzed to obtain a clear picture of geological structures, distribution and thickness of the formations, water saturation and to determine geothermal characteristics at the potential location. A preliminary assessment of the exploitation of geothermal water for thermal purposes, geothermal plant installed power, as well as an economic analysis of the project have been analyzed. For more precise analyses, hydrodynamic test data were missing which would give a better assessment of the geothermal potential and the project's implementation. The costs of work and equipment were also missing due to large price fluctuations in the global market. The project is also accompanied by environmental restrictions. The qualitative risk analysis is the research goal of this paper according to the aforementioned project prerequisites, within which potential risks were identified. The risk analysis took into account the main techno-economic, environmental, and institutional obstacles and their possible impact on the implementation of the project itself or its results. During the risk analysis, it was necessary to define critical variables and their probability, impact, and overall level of risk. As part of the research results, measures were proposed to prevent the occurrence of risks and mitigate the consequences in the event of their occurrence. The main aim of the proposed measures was to reduce the uncertainty of the geothermal project's critical variables assessment.

1. INTRODUCTION

Last decade there is a rising interest for the utilization of oilfield bottom aquifers, water-flooded wells in mature oilfields, or to reutilise abandoned wells via deep bore-hole heat exchangers in order to exploit geothermal reservoirs and utilise its renewable energy. With this reuse, the fossil fuel infrastructure can be used to increase renewable energy production (Kurevija et al., 2022). The benefits of infrastructure reutilisation, especially for dry and/or abandoned exploratory hydrocarbon wells have been investigated previously (Morita et al. 1985, Kujawa et al. 2006, Nian and Cheng, 2018).

Exploiting geothermal reservoirs with temperature up to 150°C degrees is usually used for central heating but it can be used for electricity production also (Lund 1996; Oldmeadow et al. 2011; Rezaie and Rosen 2012; Urbancl et al. 2016; Østergaard and Lund 2015; Weinand et al. 2011). Due to necessity of reducing the high investment costs of geothermal heating systems, new systems have been investigated (Carotenuto et al. 2017; Moya et al. 2018; Ziabakhsh-Ganji et al. 2018; Tian and You 2019, Sanmamed et al. 2020). The literature review showed that there is limited data on experience with exploiting geothermal energy from a mature oil field in urban areas for example (Nordquist and Johnson 2012; Wang et al. 2016; Weydt et al. 2018; Xin et al. 2012; Wang et al. 2018). Xin et al. (2012) investigated exploitation of geothermal energy with geothermal brine co-production. In addition to power generation, medium temperature geothermal reservoirs can be used for central heating. Junrong et al. (2015) researched geothermal production for central heating a, greenhouse heating, and balneology with other ways of utilisation. Weydt et al. (2018) emphasised that that cooperation is needed in unlocking geothermal potential. Wang et al. (2018) provided a comprehensive review of geothermal projects within previous or existing oil fields or using abandoned exploratory oil and gas wells. The most important part of assessment is the location of fields. For electricity generation close connection to power grid is essential, and for district heating close vicinity of consumers are, it is advantageous if potential users are in relative proximity to avoid heat to decrease risks and costs of investment. Reutilisation of the existing oil or gas wells into geothermal wells decrease the high investment costs of well decommissioning and extended the use of the infrastructure (Macenić, 2020) and the risk assessment should be the part of each assessment (Karasalihović Sedlar et.al., 2023).

The purpose of the techno-economic assessment of geothermal potential is to determine the possibility of exploiting geothermal energy. All geothermal exploration areas in the Republic of Croatia are in the hydrocarbon exploration areas. The knowledge about the existence of geothermal water is mostly related to exploratory drilling for oil and gas and related infrastructure. This paper considers one geothermal exploration area in the northwestern part of Croatia with old oil and gas well data. These data were analysed to obtain a clear picture of geological structures, distribution and thickness of the formations, water saturation and to determine geothermal characteristics at the potential location. A preliminary assessment of the exploitation of geothermal water for thermal purposes, the exergy power of a potential geothermal power plant, as well as an economic analysis of the project have been conducted. Risk defining during geothermal potential assessment will be analysed further.

2. RISK DEFINING

Defining project risks involves the following necessary activities: identifying risks, conducting qualitative risk analysis, monitoring, and conducting quantitative risk analysis. As part of this research, potential risks will be identified, and a qualitative risk analysis will be conducted. In the continuation of the research, when all critical variables and their impact on the financial and economic results of the project are known, it will be essential to conduct a sensitivity analysis of the project in relation to the movement of individual critical variables and to carry out a quantitative risk analysis. Below is a qualitative risk analysis considering the main technical-technological, economic, ecological, and institutional barriers that may realistically arise during the development of the geothermal project and affect, to a greater or lesser extent, the realization of the project itself or its results. In the risk analysis, it was essential to define critical variables and the probability for those critical variables, their impact, and the overall level of risk (probability × impact), while proposing measures to prevent the occurrence of risks and to mitigate the consequences in case they arise. The risk analysis methodology was conducted according to the risk gradation based on probability (Guide to Cost-Benefit Analysis of Investment Projects 2014-2020, European Commission, 2014) and is presented in Table 1. The probability of risk has been assessed on a scale from 0-100% through five different probabilities (0-10% very unlikely, 10-33% unlikely, 33-66% neither likely nor unlikely, 66-90% likely, 90-100% very likely).

The impact has been assessed through five categories (1 - not relevant, 2 - minor impact, 3 - moderate impact, 4 - critical impact, 5 - catastrophic impact). The overall level of risk has been assessed as low, moderate, high, or very high.

Table 1: Risk gradation according to probability and impact (Guide to Cost –Benefit Analysis of Investment Projects 2014-2020, European Commission, 2014).

		Impact				
		1-not relevant	2 – minor impact	3 – moderate impact	4 – critical impact	5 – catastrophic impact
Probability	Highly improbable (0-10 % probability)	Low	Low	Low	Low	Moderate
	Improbable (10-33 % probability)	Low	Low	Moderate	Moderate	High
	Not probable, nor improbable (33-66 % probability)	Low	Moderate	Moderate	High	Very high
	Probable (66-90 % probability)	Low	Moderate	High	Very high	Very high
	Highly probable (90-100 % probability)	Moderate	High	Very high	Very high	Very high

Proceedings 47th New Zealand Geothermal Workshop
11 -13 November 2025
Rotorua, New Zealand
ISSN 2703-4275

For each identified risk, it is essential to describe the cause of the risk, the consequences, and the impact on costs, benefits, project implementation time, and financial sustainability (Table 1).

It is essential to specify the risk owner and how the risk can be influenced, as well as the phase of the project in which the risk occurs (preparatory phase, implementation phase, or operational period). All impacts on financial indicators will need to be examined in the continuation of the research during the preparation of the sensitivity analysis. The potential risks of the exploitation project are presented in Table 2, along with the qualitative analysis during the project's implementation.

Table 2: Qualitative risk analysis during project implementation.

RISK GROUP	RISK	Proba-bility (P)	Impact (I)	P×I	DESCRIPTION AND MITIGATION MEASURES
1. Technical and technological risks	The risk of the inability to implement the proposed technological option at the location.	70%	3	High	Risks are present due to geological (geological structures, changes in petrophysical properties) and technological risks (design of technological equipment). The risk of the inability to achieve technological realization at the site is possible due to the availability of free space as well as the location is in an area restricted by spatial planning documentation, as well as the conditions arising from the deviation from the Ecological Network Natura 2000. The technological risks of implementation will only be reduced after the hydrodynamic tests are conducted in the well that will be the first to be drilled.
	Risk of change in the expected energy obtained	90%	5	Very high	The risk of changes in the expected energy yield is possible and very high, with the consequences of this risk potentially having a significant impact on the project's implementation and on the project's outcomes. The mentioned risk will be reduced after hydrodynamic tests are conducted prior to further investment in the construction of the power plant, which is certainly important for assessing energy consumption for the operation of the pumps.
	Change in the duration of isothermal production	75%	1	Low	The change in the time of isothermal production is also possible since the behaviour of the aquifer is not defined, but the expected time of isothermal production is longer than the analysed time of the considered technological variant, and it is anticipated that this will be more than sufficient for the realization of the project being considered at a level of 25 years, as is the case with most energy investment projects. It is also necessary, in the development phase, to analyse the possibilities of exploitation and to optimize the extraction process considering the isothermal extraction time.

2. Economic risks	Change in the amount of investment as well as the change in annual operating costs.	90%	5	Very high	The change in the amount of investment as well as the change in the annual operating costs is very likely; it's just a matter of the extent of that change. At this stage, without knowing the final capacity of the deposit, the final selection of the technological solution for the project, and understanding how the facility operates, it is impossible to assess all the financial inputs that should affect the financial structure of investment and operational costs. For example, the contractors for certain works are not known, and therefore the cost of carrying them out is also unknown in the event that a specific participant in the project undertakes them. Namely, the mentioned costs have been estimated based on the services provided by service companies in this area, but in this market, there are service companies that have the logistics and infrastructure to carry out a significant portion of the aforementioned technical and technological work for the drilling and well completion along with the construction of other infrastructure. On the other hand, the investor can present themselves as a qualified entity to apply for various projects within the EU for the withdrawal of funds aimed at increasing the share of renewable energy sources and energy transition. Certain investment costs related to the drilling and completion of new geothermal wells will be able to be assessed more accurately after binding offers for the aforementioned arrive. Specifically, for a detailed analysis of the investment, it is necessary to request offers from equipment manufacturers and service providers primarily for the costs of drilling and completion of wells and the costs of building the geothermal power plant. Similarly, operational costs will be estimated after the precise micro-location for the construction of the geothermal power plant is selected, although they will still be highly sensitive to changes in energy prices as well as the project's revenues.
	Risk of energy price changes.	90%	5	Very high	The economic risks of the project include the risk of changes in energy prices. Currently, the maximum reference values for the market premium for new geothermal power plants with an installed capacity greater than 500 kW are not known. The calculation was made based on the premium prices from the 2023 Program year. Also, after the subsidized period expires, the question arises regarding the movement of long-term market prices, which at the time of the economic analysis were at levels that are twice as low as the premium prices. The change in energy prices needs to be considered, even though it is currently impossible to predict future price movements; therefore, a sensitivity analysis on changes in electricity prices has been conducted. Based on historical trends in energy prices as well as geopolitical developments in the upcoming period, it is possible to expect that prices will remain at similar levels for gas, oil, and electricity. Changes in energy prices can affect both the revenue and expenditure sides of the project. Revenues are calculated based on the projected prices of electricity and thermal energy, while expenses are calculated based on the annual operating costs for the energy needs of the geothermal power plant, as well as the energy required for the operation of pumps in the wells. Now when tenders for new subsidised models of co-financing production from renewable energy sources are announced, or when other models are offered, it will be possible to calculate the revenue side of the project more accurately.

ISSN 2703-4275

3. Ecological risks	Construction restrictions due to the limitations of the Natura 2000 ecological network conditions.	90%	5	Very high	The analysed exploratory geothermal area is partially located within the Natura 2000 ecological network, for which special construction conditions and environmental protection measures will certainly be prescribed for the drilling and completion of wells and the construction of power plant. Given the location of the well site in the area, it will be necessary to exclude the site marked as the economically managed forest for the placement of mining facilities and the geothermal power plant from economic use. Risks can be reduced by locating the geothermal power plant and wells at the same micro location of the BRP.
	Risk of accidental situations and ecological disasters	25%	2	Low	If an accidental situation occurs during the execution of the observed operation (the release of produced geothermal water into the environment), there will be a heat exchange with the external atmosphere and the release of gases present in the geothermal water. In that case, it is necessary to carry out technical interventions to address the problem and prevent the leakage of water into the environment. However, it is necessary to analyse the adverse effects on the environment, taking into account the composition and quality of the water. It is necessary to analyse the infiltration of water into the soil and/or onto the surface due to the corrosion of transport pipelines, taking into account the mineral composition in order to define the level of risk, that is, whether the water poses a danger to any component of the environment. Since the exploitation of geothermal water involves the production of a non-flammable fluid, no fire or explosion hazard zones have been designated for the wells at the observed geothermal well locations, whereas it is common practice to establish fire and explosion hazard zones for gas and oil wells. Additionally, in the process of producing and using geothermal water, substances that could potentially cause fire or explosion will not be used. Since accidents are a rare occurrence and have not been recorded during the past years of geothermal water exploitation at existing locations in Croatia, it is not expected that an increase in geothermal water exploitation would significantly disrupt the condition of environmental components in the observed area. With regular monitoring and maintenance of the geothermal water extraction and injection systems, there is no risk of an ecological disaster occurring.
	The risk of pollution after the cessation of exploitation.	10%	2	Low	In the event of ceasing the use of geothermal water, there is no danger of harmful effects on the environment. Wells must be equipped or abandoned to ensure the system's airtightness. In the event of the cessation of geothermal water use, the surface infrastructure will be removed. During the execution of these works, there may be an increase in noise levels and the generation of dust. The mentioned impacts will be temporally and spatially limited and will not have lasting consequences for the environment. The process of well abandonment will be carried out according to the standard procedures outlined in the professional literature. A decision to terminate production must be made for the decommissioning of the wells. Based on the existing technical documentation for the wells and the condition of the equipment in the wells and at the surface of the wellheads, it is necessary to develop a program for the technology of well decommissioning. In order to restore the sites to their original condition, the wells must be decommissioned safely, that is, install cement barriers for layer separation at appropriate depths, dismantle the wellheads, cut the protective pipes at least 1.5 meters below the level of the surrounding land, and weld a cover flange onto that. After that, it is necessary to restore the land to its original condition using agronomic measures.

Proceedings 47th New Zealand Geothermal Workshop
11 -13 November 2025
Rotorua, New Zealand
ISSN 2703-4275

4. Institutional risks	Inability to ensure conditions for construction in the area.	90%	4	Very high	Considering that this is land in the area of economically managed forests, it will be necessary to exclude the location for the placement of mining facilities and the geothermal power plant from land use. Risks can be reduced by locating the geothermal power plant and the well site at the same micro location.
	Risks in obtaining documentation	90%	4	Very high	The lengthy process of obtaining approval for the exploitation of geothermal potential is a real risk due to the need for land acquisition. Due to the complexity of obtaining legal documents related to the exploitation of geothermal water, which already requires lengthy procedures to secure all necessary documentation (exploitation decision, mining projects, environmental impact study, location and construction permits, as well as operational permits for wells and facilities), there is a risk of extending the project's duration. This needs to be minimized through clear project management, collaboration with the relevant Ministry, the Hydrocarbon Agency, and local government units. The risk of such influences on the project's realization needs to be minimized through a clear definition of the methods and forms of collaboration, as well as through the definition of the goals of individual participants in the project, along with the establishment of mandatory steps and the consequences of failing to take them by the investors in the project.
	Changes in subsidized purchase prices of electricity	100%	5	Very high	The change in the premium price of electricity has a very high impact and a 100% probability, which means that it is likely that a change will occur considering that in 2024 nor in 2025 it was not defined in the program for promoting production from geothermal power plants, but the entire project is based on previously available prices from 2023. year. There is also a risk of lowering the subsidized purchase prices, which would significantly negatively impact the implementation of geothermal projects in general in Croatia.
5. Global risks	The risk of supply chain disruptions and the inability to procure equipment, materials, and raw materials due to geopolitical impacts in the world.	85%	3	Very high	The risk of disruption in supply chains and the inability to procure equipment, materials, and raw materials due to geopolitical events in the world is high at the time of preparing the study, as there are currently rising disturbances in the supply chains of raw materials and energy. The mentioned influences can occur and affect all segments of procurement, but it is assumed that a relatively stable situation could be maintained during the project's implementation, provided there are no significant geopolitical changes in the global or regional market. One of the risks is the availability of drilling and repair service and well completion, considering the increased demand for service recently due to the issuance of a larger number of exploration permits on one hand and the small number of certified drilling and repair facilities on the other. To reduce the risk, it is necessary to immediately initiate negotiations for contracting the well drilling.
	Extreme fluctuations in energy and raw material prices due to geopolitical events in the world.	90%	4	Very high	Extreme changes in energy and raw material prices due to geopolitical events in the world are likely at the time of preparing the study, considering the geopolitical developments in the global market, although there are currently no significant disruptions in the energy markets, but Middle East crisis could change that instantly. The mentioned influences are present and can be extreme, having a critical impact, and should not be overlooked. Given that extreme price movements in energy have been recorded over the past couple of years, it is necessary to continuously monitor the circumstances in energy markets and to attempt to respond promptly to potential disruptions.

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11 -13 November 2025
Rotorua, New Zealand
ISSN 2703-4275

3. CONCLUSION

For more precise reservoir and physical parameter analyses and capital cost evaluation, hydrodynamic test data were missing which would give a better assessment of the geothermal potential and the project's implementation. The costs of work and equipment were also missing due to large price fluctuations in the global market. The project is also accompanied by environmental restrictions. The qualitative risk analysis is the research goal of this paper according to the aforementioned project prerequisites, within which potential risks were identified. The risk analysis considered the main techno-economic, environmental, and institutional obstacles and their possible impact on the implementation of the project itself or its results. During the risk analysis, it was necessary to define critical variables and their probability, impact, and overall level of risk. As part of the research results, measures were proposed for each risk to prevent the occurrence of risks and mitigate the consequences in the event of their occurrence. The main aim of the proposed measures was to reduce the uncertainty of the geothermal project's critical variables assessment.

ACKNOWLEDGEMENTS

This research was conducted according to the EU funded project objectives of the: Adaptation Model of Oil and Gas Infrastructure in line with Low-Carbon Development of the Energy Sector project, University of Zagreb, Faculty of Mining geology and Petroleum Engineering (2025).

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