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LEGAL ASPECTS OF LITHIUM RECOVERY FROM GEOTHERMAL BRINE – PYRZYCE GEOTHERMAL PLANT CASE STUDY

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Abstract: The growing importance of using geothermal brine as an alternative source of lithium in the context of the dynamic development of new technologies is currently being pointed out. The various aspects involved need to be analyzed to consider the recovery of any element from geothermal water. The most crucial of these, after the purely technical aspects, is the legal framework of the operation. Poland and other countries have no specific legislative regulations for recovering lithium from geothermal brine, as existing activities have focused mainly on salt and heat extraction. This article presents a brief overview of the worldwide literature and the current status of legal regulations related to lithium recovery from brine in Poland. The paper focuses on selected formal possibilities for the recovery of lithium from the water of the GT-1 BIS borehole owned by Geotermia Pyrzyce sp. z o.o. The study aims to present possible legal pathways for this process. The authors also draw conclusions about the need for new regulations to recover lithium from geothermal brine. The paper contributes to the research on developing lithium recovery from unconventional sources. Furthermore, it highlights the need for an appropriate legal framework for such kind of activity not only in Poland but in other countries as well.

***Keywords*:** *lithium extraction, critical raw materials, geological and mining law, combined heat and metals production, aqueous mining*

1. INTRODUCTION

Lithium recovery from geothermal brine is an emerging research topic due to the rapidly increasing demand for lithium and its possible elevated concentration in deep,

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salty, and hot groundwater (Chitrakar et al. 2014; Sanjuan et al. 2022). Thanks to the high brine temperature, it can be the source of green metal recovery supplied by renewable energy, thus emitting less CO_2 (Azevedo et al. 2022).

Globally, a growing number of projects are focusing on cutting-edge solutions, sites, and technologies that can contribute to lithium recovery from geothermal brine. Places with already thriving investments are the Upper Rhine Valley in Germany and France, and Cornwall in the U.K. (Goldberg et al. 2023; Sanjuan et al. 2022; Weinand et al. 2023). In Poland, six geothermal heat plants were in operation in 2019; in Uniejów, Biały Dunajec, Mszczonów, Poddębice, Pyrzyce and Stargard (PGI – NRI 2020). Despite the lack of any geothermal power plant, around 38 documented thermal water deposits in operation can be examined for the possibility of recovering lithium or other valuable elements in the country (PGI-NRI, 2023).

The recovery of so-called geothermal lithium is an emerging branch of the economy and is still dynamically evolving. Among many research and upscaling projects co-funded by the European Union, like CHMP2030 (https://www.chpm2030.eu/) or EuGeLi (https://eitrawmaterials.eu/project/eugeli/), one of the first investigating the potential of combined heat, power, and lithium production in Regional Innovation Scheme (RIS) countries is the BrineRIS project (Brines of RIS countries as a source of CRM and energy supply) (www.brineris.pwr.edu.pl). This international RIS capacity-building initiative, co-funded by EIT Raw Materials within KAVA8 call, maps promising geothermal lithium sites in six countries: Poland, the Czech Republic, Slovakia, Hungary, Spain, and Portugal.

The article originated during the BrineRIS project implementation when we noticed that there is no information in Polish regulations or literature on the formal aspects of lithium recovery from deep saline water, although an analysis of the procedures and practical aspects of documenting geothermal water for healing, heating, and power supply can be found (Noga 2023; Szalewska 2021; Sokołowski and Socha 2015).

A similar situation occurs worldwide. Unconventional sources of lithium, such as geothermal brine, appear challenging in terms of legal aspects. Recovering dissolved critical metals from saline water sources creates an alternative to, or complements, traditional hard rock mining. So-called aqueous mining, has the potential to greatly minimize the environmental and human health impacts typically associated with conventional mining, such as land degradation, water pollution, air emissions, and excessive water usage. Moreover, extracting lithium and other metals from nearby saline water sources could reduce import needs (Can Sener et al. 2021). Despite all these advantages, this type of mining is not regulated legally worldwide. However, deep analysis of the issue has risen in some countries. The oldest and most advanced analysis so far has been done for New Zealand (Barton 2015). The report issued by the University of Waikato analyzed the legal rights to minerals extracted from geothermal fluids used in electricity generation and heat processing. Since New Zealand law does not explicitly address these rights, the legal position is expected to be largely inferred from general legisla-

tion and principles. The report's primary focus was on incidental geothermal mineral extraction to a geothermal energy facility, so the case is similar to the Polish one. Barton (2015), in his report, concludes that the Resource Management Act 1991 (RMA) treats geothermal resources as water, including materials dissolved or entrained in geothermal water, which regional councils have the authority to manage. The report states that an RMA water permit holder has the right to take and use this water, including its dissolved materials, making it the company's property once it enters the pipe system. Applying the Crown Minerals Act 1991 (CMA) to geothermal mineral operations depends on whether such operations are considered "mining", with implications for obtaining a mining permit and complying with the Act's obligations. The report notes uncertainty in whether geothermal mineral extraction, when incidental to geothermal water use, is excluded from the CMA, suggesting a need for more explicit policy guidance. Climo et al. (2015) also noticed that despite thorough legal analysis, it remains unclear whether the CMA definitively applies to a geothermal minerals operation, and it should be clarified in the updated regulations.

The issue of property rights and legal aspects of recovered compounds from aqueous solutions is a hot topic of research and analysis in the United States of America (USA). The specific analysis of the legal and regulatory aspects of mineral extraction from geothermal fluids was introduced by Callison (2018). She focused on mining lease and permitting issues in Western states based on federal laws. The research assumed that a federal geothermal lease is already in place, either held by the party intending to extract minerals or by a party that plans to enter into a business relationship with the lessee for mineral extraction. Callison also highlighted key issues of a legal and economic evaluation of the potential for mineral extraction from geothermal brines to start a discussion on a full assessment of the matter.

At the end of July 2024, the report of the U.S. Government Accountability Office (GAO 2024) was released, where three policy options were identified that could help mitigate the challenges or enhance the benefits of recovering critical minerals from nontraditional sources like geothermal brine. These options represent potential actions for policymakers, including Congress, federal agencies, and state, local, and tribal governments. Alternatively, policymakers might maintain the status quo, refraining from additional measures beyond existing efforts. However, the legal aspects of the geothermal recovery of metals were also not resolved here.

Looking at the European ground, it is not easy to find a comprehensive analysis of legislation for "aqueous mining" or metals recovery from geothermal brine. This issue was slightly touched on in the Netherlands in the report prepared by Witteveen & Bos for EBN (Koomen et al. 2023). The authors stated that The Dutch Mining Act is not tailored yet for lithium extraction from geothermal wells, particularly when combined with geothermal heat production. Lithium, classified as a mineral, falls under the Mining Act, but lithium compounds like lithium chloride are not explicitly mentioned. Ownership of lithium belongs to the state before extraction and transfers to the permit

holder afterward, requiring an exploration and extraction permit under the law. There are concerns about whether the current legal framework suits lithium extraction, necessitating an additional exploration permit. Additionally, the composition of re-injected geothermal brine must closely match the extracted brine, and any additives or excess chemicals may need to be reduced before reinjection to avoid negative impacts on the geothermal wells and reservoir.

Among the BrineRIS project partner's countries we see similar challenges, e.g., in Slovakia, where neither Act No. 44/1988 Coll. on the Protection and Utilization of Mineral Resources (Mining Act) nor its latest amendment, Decree No. 33/2015 Coll. by the Ministry of the Environment of the Slovak Republic, which implements specific provisions of the Mining Act, explicitly classifies lithium from mineralized water (brine) as a reserved mineral resource subject to the applicable regulations (Mesarčik and Kušik 2015). However, this legislation does classify mineralized water from which reserved minerals can be extracted as reserved minerals, as specified in the Decree on I-Br mineralized water. Lithium is mentioned in the legislation only as a by-product of tin ore extraction, reflecting the geological and deposit-specific conditions of the Slovak Republic.

It is worth mentioning that in Slovakia, reserves of I-Br mineralized water have been registered at two deposits: Marcelová (Jezný et al. 1998) and Oravská Polhora (Zakovič et al. 1988). In both cases, the reserves of I-Br water were calculated, and their usability conditions were determined. At both deposits, an increased lithium content was identified; however, this was not the focus of the investigations then. However, it was assumed that iodine and bromine salts would be obtained through evaporation and that the remaining water would be diluted and discharged into watercourses. The discharge must meet legal requirements under Waste Act No. 238 Coll. of May 22, 1991, paragraph 2, section 1. The technical procedures were not detailed in the final reports, and the extraction of I-Br salts has not been implemented yet.

As described above, there is a considerable gap in worldwide legislation related to geothermal minerals extraction and recovery. Still, no direct legislation regulating the recovery of any elements from geothermal brine is available in Poland. Also, there are no best practices in administrative procedures for starting lithium production from geothermal facilities. The presented article begins the discussion and drafts possible formal ways of lithium extraction in Poland for the first time. For that purpose, we used the example of the geothermal heat plant operating in Pyrzyce, Poland.

Before proceeding with the formal and legal analysis, it is necessary to determine whether lithium recovery from geothermal brine is a mining operation according to Polish legislation. Based on Poland's Geological and Mining Law (Act of June 9, 2011), brine is a raw material under mining-property rights (article 10.2). Its accumulation in a rock mass from which economic benefits can be derived is called a deposit (article 6, point 19). It means that exploiting thermal water or brine deposits requires a license. However, the issue of lithium in geothermal brine becomes ambiguous. Article 10 of

the Geological and Mining Law defines strictly metal ores and native metals as raw materials under mining-property rights.

Meanwhile, due to its high reactivity, lithium does not occur in the natural environment in its elemental form. From geothermal brine, it can be separated in the form of compounds (lithium chloride), so it is neither an ore nor a native metal according to Polish law. The question arises as to how to consider lithium extraction from thermal water. There are no legal acts in Polish geological and mining law regulating the recovery of metals from water, or as in the case in question from geothermal brine, or defining recovery as a mining activity. It is often qualified as water treatment or purification when it comes to removing harmful elements or compounds from water, like metals and metalloids (Fe, Mn, As) or salts (NaCl) (Grágeda et al. 2018) or wastewater management (Góralczyk and Uzunow 2011). There are, therefore, more questions than answers regarding the legal possibility of extracting lithium from any geothermal borehole in Poland. The question arises of whether there is any way to extract minerals or elements from thermal water in an already operating geothermal heat plant. Can a recovery facility be built to extract lithium accompanying any geothermal operation?

This article is the first attempt to answer the above doubts and is based on a Master thesis by Kowalewska (2023). It presents a sequence of aspects to be considered when the feasibility of lithium production in a geothermal plant is studied, exemplified by Geotermia Pyrzyce's GT-1 BIS production borehole. The flowcharts presenting decision-making processes were developed based on formal analysis, and different paths of possible legal action were described, considering the legal status as of December 31, 2023.

2. MATERIALS

The GT-1 BIS borehole exploited by the Pyrzyce Geothermal Company was selected for analysis. The selected borehole is one of five geothermal boreholes in Pyrzyce and is the only one with a production function. The temperature at the outflow is 62 degrees Celsius. It was designed as a directional borehole (to a depth of 1671.9 m) with an "S" type trajectory with a drilling azimuth of 300°. The unique shape ensures that borehole GT-1 BIS does not interact with borehole GT-3 and GT-1, which are only 15 m further to the southwest (Noga 2015). The geological profile of the borehole comprises the Triassic, Jurassic, Cretaceous, Paleogene, and Neogene formations. The productive aquifer is lower Jurassic sandstone interlayered with siltstone and claystone layers. According to the data provided on the geological-technical profile of borehole GT-1 BIS, the exploitation capacity of the borehole is 250 m^3/h at a depression of 22.82 m, while the permissible capacity of the filter is 405 m^3/h.

These parameters have enabled Geotermia Pyrzyce to continuously supply hot water to inhabitants, production plants, or public facilities and provide seasonal thermal

energy since 1997. The structure of the geothermal operation is schematically shown in Fig. 1. Thermal water is pumped from a production well, which then passes through a system of heat exchangers. Hot water and/or thermal energy are delivered to consumers from the heat exchangers. After being filtered, post-process water is pumped back into the injection well. Operating in this way, Geotermia Pyrzyce is not only an efficient but also an environmentally friendly heat supplier.

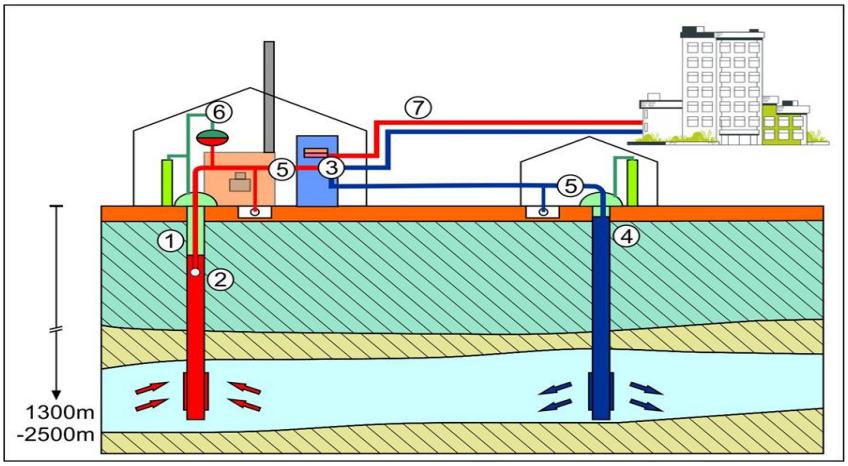

Figure 1. The principle of a closed hydrogeothermal system including the most important components: 1 – production well, 2 – production pump, 3 – heat exchangers, 4 – injection well, 5 – filtration unit, 6 – pressure control system, 7 – heat network

3. METHODS

The example of the Pyrzyce Geothermal Plant was chosen to analyze the legal aspects of lithium recovery. The authors were guided by the following criteria in their search for a suitable case: long-standing operation, a closed system with a minimum of one reinjection borehole, the availability of geological and technical data, the possibility of taking brine samples for testing, and most importantly, the company's consent to carry out the tests. Pyrzyce Geothermal Plant met all these criteria.

To describe and analyze the potential formal pathways that lead to the commissioning of a lithium recovery facility based on brine from the GT1-BIS borehole in Pyrzyce, familiarising oneself with the already available information on formal recovery steps was crucial. The authors, preparing for the analysis, performed desk research and a detailed literature review on the topic, searching publications, media information, project websites, and legal acts by specific keywords, such as *lithium recovery*, *lithium in brines*, *legal aspects of lithium recovery*, *formal-legal aspects of recovery*, *legal schemes*, *critical*

raw materials, geothermal metals extraction, geothermal lithium, combined heat and metals extraction. As was mentioned in the Introduction, several publications analyze legal situations in foreign countries, but these issues emerged in none of the thematically related Polish publications. It was, therefore, decided to base the elaboration of the formal and legal aspects of lithium recovery exclusively on the Polish legislation listed below:

- Act of June 9, 2011. Geological and Mining Law (Journal of Laws 2011 No. 163 item 981as amended) and the implementing acts/regulations,
- Act of July 20, 2017. Water Law (Journal of Laws 2017 item 1566 as amended),
- Act of April 27, 2001. Environmental Protection Law (Journal of Laws 2001 No. 62 item 627 as amended),
- Act of October 3, 2008, on the provision of information on the environment and its protection, public participation in environmental protection, and environmental impact assessments (Journal of Laws 2008 No. 199 item 1227 as amended),
- Act of July 7, 1994. Construction Law (Journal of Laws No. 89 item 414 as amended),
- The Regulation of the Council of Ministers of September 10, 2019, on projects likely to have a significant impact on the environment (Journal of Laws 2019 item 1839 as amended).

The first step in the analysis was identifying the main issues related to the formal and legal aspects of geothermal lithium recovery from the GT-1 BIS borehole in Pyrzyce. Among many legal aspects, the authors distinguished three milestones, which may be the most challenging in the process. These are permitting, recovery plant construction, and post-processing brine management. Based on an analysis of the current legal basis for the operation of Pyrzyce Geothermal Plant, an analysis of the legal acts mentioned above, and the milestones identification, six variants of the lithium recovery operation were defined, for which a detailed study was done, and decision-making trees were developed.

The following is an overview of issues related to the process and defined variants, which will be described in detail in section 4.

3.1. PERMITTING

As mentioned, licensing lithium production from geothermal brine is a problematic issue. Given the regulations in force, it can be assumed that for the production of lithium from geothermal brine, if it is not necessary to drill a new borehole or make changes to the current deposit development project, it will not be required to obtain a new concession or make changes to the concession for the extraction of thermal water, which Pyrzyce Geothermal Plant already holds.

In the analysis, we assume the use of brine extracted from the GT-1 BIS borehole, for which a license has already been issued. It should be noted, however, that the cur-

rent concession of Pyrzyce Geothermal Plant No. 35/96, issued by the Minister of the Environment, Natural Resources, and Forestry on December 20, 1996, will expire in December 2026. The content of this document is relatively poor. It does not specify the exploitation capacity or the maximum quantity of water the entrepreneur is entitled to extract, nor the conditions for injecting water into the rock mass or the manner of using the extracted water. At present, concession decisions contain much more detailed information, so when applying for a new license, it is worth ensuring that its provisions do not restrict the entrepreneur's activities, which involve different methods of utilizing the extracted brine.

3.2. RECOVERY PLANT CONSTRUCTION

When thinking about building up the installation needed to recover lithium from geothermal brine, it is crucial to consider the consequences involved. Depending on the recovery technology, whether the installation will affect the environment, whether it will be located within the confines of the site in use without changing its use in terms of safety, or, on the contrary, the investor has different formal obligations. According to the construction law, if the installation will be located inside or outside the site in use and thus will not change its use in terms of fire or hygiene and sanitary safety (or any other listed in Article 71 of the Construction Law) and will not harm the environment, the entrepreneur establishing the installation should only make an entry in the building book with the relevant legal basis. In case when the recovery plant construction violates the requirements mentioned above, it is necessary to submit a notification and obtain a decision permitting the construction based on the Construction Law Act of July 7, 1994. It should also be noted that if the installation is to be built using different types of reagents and solvents, it will also be necessary to obtain a decision on the environmental conditions of the project according to the Regulation of the Council of Ministers of September 10, 2019, on projects which may likely to have a significant impact on the environment and the Act of October 3, 2008, on providing information about the environment and its protection, public participation in environmental protection and environmental impact assessments.

3.3. MANAGEMENT OF POST-PROCESSING BRINE

In today’s world, there is an increasing emphasis on ecology and the application of a closed-loop economy, so when analyzing the formal aspects of lithium recovery from brine, it is essential also to consider the management of the waste generated after the lithium extraction process. In the case of brine, there are actually three options for its management. One is to re-inject it into the rock mass. In this case, it is crucial to analyze its parameters, as it may turn out that it is unsuitable for this type of management due to poor biochemical or chemical parameters (e.g., the proportion of colmatogenic compo-

nents) (Lewkiewicz-Małysa and Konopka, 2009). Suppose chemical reagents are used in the lithium production process, which will cause a change in the composition of the water. According to Art. 16 para 61a of the Water Law Act, the post-process water will be considered as wastewater in that case. According to Article 75 of the Water Law, it is prohibited to discharge wastewater directly into groundwater. Considering Article 16 para 68 of this Act, groundwater is all water below the ground surface in the saturation zone, including groundwater in direct contact with the ground or subsoil. Given this, the injection of process water would be classified as wastewater discharge into groundwater. This results in a lack of formal and legal possibilities to inject this water into the rock mass.

Investors then can try to use another solution: to discharge post-process brine/wastewater into a surface watercourse. According to water law, a water permit must be obtained for this activity, as the discharge of untreated brine into a watercourse can only be used in stringent and strictly defined quantities. However, this brine utilization method is unsustainable – it can affect the quality of surface water and disturb the balance in the aquifer, destroying the geothermal deposit. Another option that is less harmful to the environment but still affects the geothermal reservoir stability is the production of salts and fresh water from the brine used for lithium recovery. Using such a solution, the plant would gain additional commercial products. Indeed, an option worth analyzing when selecting the recovery technology and designing the plant would be the possibility of recovering other than lithium elements, which were not investigated in this study but could have a market value.

It must also be emphasized that the authors do not study technological details, geological and hydrogeological conditions, or environmental impact assessment of different legal pathways introduced below in this article.

3.4. LITHIUM RECOVERY VARIANTS

After identifying the three formal milestones (licensing issues, plant construction, and post-process brine management) for the potential recovery of lithium from geothermal brine, the following six options for starting up a lithium recovery plant were defined, for which decision-making algorithms were developed:

- Geotermia Pyrzyce Sp. z o.o. extracts lithium from the brine of borehole GT-1 BIS and then discharges the brine into a watercourse or injects it into another borehole owned by Pyrzyce Geothermal Plant;
- Geotermia Pyrzyce Sp. z o.o. extracts lithium from the brine of borehole GT-1 BIS, then produces salts and fresh water from the remaining brine;
- Third-party extracts lithium from brine from borehole GT-1 BIS and injects it into another Pyrzyce Geothermal Plant's borehole;
- Third-party extracts lithium from brine from GT-1 BIS borehole and injects into new own borehole;

– Third-party extracts lithium from brine from GT-1 BIS borehole and discharges post-process brine into a watercourse;
– Third-party extracts lithium from brine from borehole GT-1 BIS, producing salts and fresh water from post-process brine.

Based on the above options, the authors analyzed legal pathways to the geothermal lithium extraction in Pyrzyce. For each variant, the analysis includes information on who is responsible for what and what needs to be taken care of in each option. It was noted that in addition to the description, it is helpful to illustrate the sequence of actions; therefore, in developing the methodology, it was decided to draw up specific procedural flowcharts/decision-making trees, which clearly show the interested party what steps need to be taken (based on the selected option) to go through the whole formal process leading to the recovery of lithium from brine. Two such diagrams have been drawn up (Figs. 2 and 3). The first is for a situation in which Pyrzyce Geothermal Plant takes all the steps, and the second is when an external entity (third party) uses brine from the GT-1 BIS borehole. The flowcharts are universal, and the whole analysis can be applied to any other already operating geothermal entity, replacing Pyrzyce Geothermal Plant and using their geothermal well instead of GT-1 BIS. The entity operating flowcharts should answer several questions:

– Which entity will source the lithium? (geothermal borehole owner or third party);
– What will happen to the post-process brine? (will it be injected into an injection well, discharged into a watercourse, or used for salt production);
– Where will the processing plant be located?

After each answer, the recipient will be directed to further detailed questions. Answering all the questions will walk one through the process and give instructions on the formal steps an entrepreneur must take to extract lithium from the brine of an exploited geothermal well in Poland.

4. FORMAL ASPECTS OF LITHIUM RECOVERY FROM BOREHOLE GT-1 BIS

The formal aspects of lithium recovery from borehole GT-1 BIS were elaborated on based on the three most essential issues identified during the development of the methodology: permitting (the lithium recoverer), plant construction (facility location issues), and post-process brine management issues. Each of the six options selected in the previous chapter is presented below, and individual descriptions are given for each. These descriptions are summarised in two diagrams (Figs. 2 and 3) to further illustrate to the reader what steps should be taken depending on the decisions.

4.1. GEOTERMIA PYRZYCE SP. Z O.O. EXTRACTS LITHIUM FROM BOREHOLE GT-1 BIS AND THEN DISCHARGES BRINE INTO A WATERCOURSE OR INJECTS IT INTO ANOTHER BOREHOLE BELONGING TO PYRZYCE GEOTHERMAL PLANT

The first option assumes that infrastructure for lithium extraction will be added to the selected Pyrzyce GT-1 BIS geothermal borehole. As a mining company, Pyrzyce Geothermal Plant benefits from geological concession no. 35/96 issued by the Minister of the Environment, Natural Resources and Forestry on December 20, 1996, for the exploitation of thermal water. Since it is needless to drill a new borehole and make changes to the current deposit development project, obtaining a new concession or making changes to the current concession is unnecessary. However, it should be noted that the current concession expires in just over three years, in December 2026, and will therefore need to be renewed. Another significant factor is determining whether the post-process brine will be injected or discharged after lithium recovery from the thermal water. Suppose a company would like to opt for injection. In that case, it can only do so if the lithium recovery technology used did not use chemical reagents and the composition of the water has not changed significantly. If this were not the case, the brine would already be regarded as wastewater (sewage) (according to Article 16, paragraph 61a of the Water Law). It, therefore, cannot be injected into groundwater (Article 75, paragraph 1 of the Water Law). Pyrzyce Geothermal Plant then has the option of discharging the post-process brine in question into a watercourse. Then, it is necessary to obtain a water-legal permit, and the discharge of untreated brine into a waterway is only possible in stringent and strictly defined by the permission quantity and quality. It must be noted that due to the negative effects on the environment, especially on surface water quality, getting permission for direct brine discharge to the watercourse might be challenging.

The question of construction law and the size of the installation also remains. A geothermal plant would not have to file a notification or obtain a construction permit if the recovery installation would be inside or outside an in-use site and would not change its use in terms of fire or health and safety (or any other listed in Article 71 of the Construction Law) and would not significantly affect the environment. In such a case, it would only be necessary to make an entry in the book of the building with the relevant legal basis. If the addition of the installation violates the requirements mentioned above, following the construction law, it would be necessary to make a notification and obtain a construction permit. It should also be noted that if one decides to build an installation where the technology uses various types of reagents and solvents and can be harmful to the environment, then, following the Regulation of the Council of Ministers of September 10, 2019, on projects likely to have a significant impact on the environment, it will also be necessary to obtain a Decision on the Environmental Conditions for the investment.

4.2. GEOTERMIA PYRZYCE SP. Z O.O. EXTRACTS LITHIUM FROM BOREHOLE GT-1 BIS, THEN PRODUCES SALT FROM THE PROCESSED BRINE

As in the first case, there is also no need to change the license here. Note that it expires in three years. At this point, it must be renewed and detailed with the issues bulleted in the previous sub-chapter. The formal aspects of the construction of the technological installation also look the same as previously described. However, in the present case, there is a greater chance that the lithium recovery and salt production installation will affect the use of the site in terms of fire safety or hygiene and sanitation, which causes notification and requires a construction permit. Moreover, obtaining a Decision on Environmental Conditions for the project may also be necessary if the selected technology is likely to harm the environment.

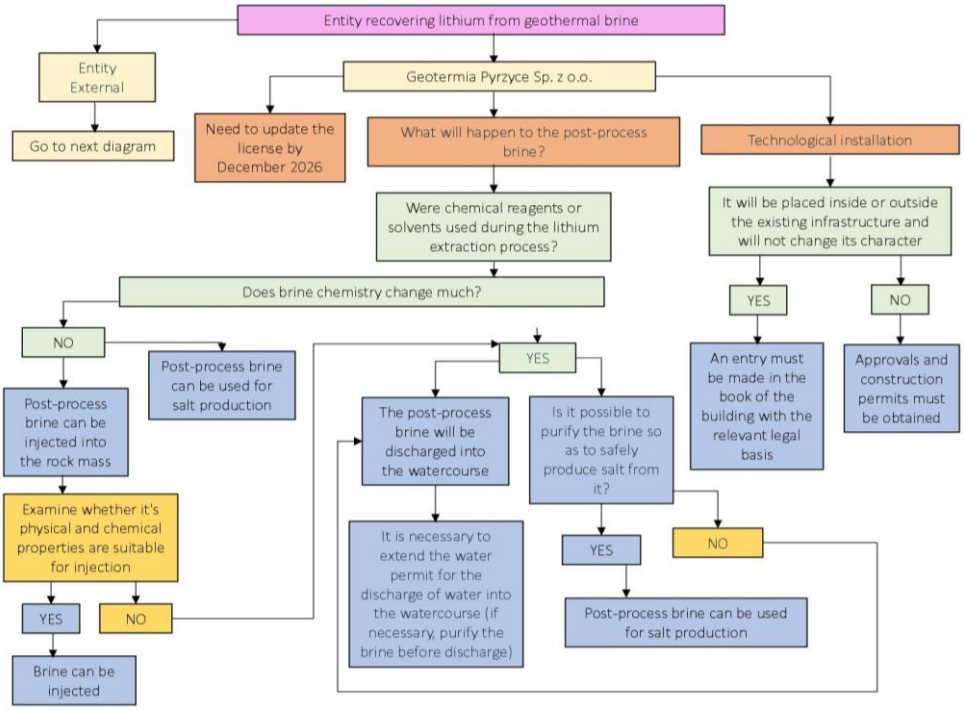

Fig. 2. Pyrzyce Geothermal Plant's procedure for recovering lithium from borehole GT-1 BIS (own elaboration)

More differences occur in post-process brine management. In the present case, the Pyrzyce Geothermal Plant utilizes post-process brine by producing salts and fresh water, using proper design technology, e.g., evaporation and crystallization supplied by renewable energy. However, it requires more detailed analysis and additional re-

search on the technology, operational capacity, final products, and marketability. In this case, there is no need for injection into the rock mass or discharge into a watercourse, which can cause depletion and instability of geothermal resources. This issue also needs additional research and detailed modelling to ensure that the designed technology will not affect the efficiency of the geothermal plant.

The described decision-making scheme for variants one and two is shown in Fig. 2.

4.3. THIRD-PARTY EXTRACTS LITHIUM FROM BRINE FROM BOREHOLE GT-1 BIS AND INJECTS IT INTO ANOTHER PYRZYCE GEOTHERMAL PLANT'S BOREHOLE

In this option, we assume that an external company would like to use the brine from the GT-1 BIS borehole, extract lithium from it, and then re-inject it into another well of the Pyrzyce Geothermal Plant. To carry this out, this company must acquire brine from the geothermal plant for which the plant already has a license. Lithium recovery installation is assumed to be built inside or outside the geothermal plant area. However, it requires additional agreements and formal procedures according to the Construction Law and environmental standards. In this case, the post-process solution will be turned back to the geothermal plant and put into the injection well, which is possible only if the lithium extraction technology does not change the brine chemistry significantly.

4.4. THIRD-PARTY EXTRACTS LITHIUM FROM BRINE FROM GT-1 BIS BOREHOLE AND INJECTS INTO NEW OWN BOREHOLE

In the given variant, the external entity, similar to the above option, obtains brine from the mining company (which has a geological license for exploitation) and injects the post-process brine through its borehole into the rock mass, provided that the brine has not been contaminated during the lithium recovery process and its physical and chemical parameters correspond to those of the groundwater within the borehole. In this case, it is necessary to prepare a geological works project and have it approved by the relevant geological administration. Suppose the entity would like to operate within the mining area of the Pyrzyce Geothermal Plant. In that case, the entire process should be carried out with its participation and within the framework of its concession. However, the possibility of injecting water into the rock mass by an entity that does not hold a license to exploit thermal water is debatable since, according to Article 6, paragrapf 1, item 16b of the Geological and Mining Law, "*the injection of water into the rock mass – is the disposal of water from the dewatering of mine workings, used therapeutic water, thermal water, brine, as well as deposit water, including water from underground hydrocarbon storage facilities, excluding technological water used in hydro-*

carbon storage facilities located in rock salt deposits, involving their introduction through boreholes into geological formations isolated from usable aquifers."

While the mere injection of water into the rock mass is not a licensed activity listed in Article 21 of the above law, it is an activity related to the exploitation of deposits, the conditions of which should be defined in the exploitation license based on the criteria specified in the Hydrogeological Documentation defining hydrogeological conditions in connection to the intended injection of water into the rock mass under paragraph 10 of the Regulation of the Minister of the Environment dated November 18, 2016, on hydrogeological documentation and geological-engineering documentation. Thus, applying the law literally, an external entity may not be authorized to inject post-process water, even with appropriate chemical parameters, into the rock mass. However, it cannot be ruled out that brine injection into an external borehole would be successful based on cooperation with the geothermal plant.

4.5. THIRD-PARTY EXTRACTS LITHIUM FROM BRINE FROM GT-1 BIS BOREHOLE AND DISCHARGES INTO A WATERCOURSE

The third party acquires brine (as in the third and fourth variants) from the Pyrzyce Geothermal Plant, which already has a mining license. After recovering the lithium, it intends to dump the post-process brine into a watercourse like a nearby river. In such a case, the third party is required under the Water Law to obtain a water permit to discharge untreated brine into the watercourse. The competent authority issuing such permits is the Regional Water Management Authority Director. It evolves similar challenges related to the geothermal reservoir stability and the environment to these described in Subsection 4.1.

4.6. THIRD-PARTY EXTRACTS LITHIUM FROM BRINE FROM BOREHOLE GT-1 BIS AND THEN PRODUCES SALTS FROM THE REMAINING BRINE

In the last case, the external entity recovers lithium from the brine of the GT-1 BIS borehole, like in the three options above, from Pyrzyce Geothermal Plant, which has the corresponding license. As part of the post-process brine management, the entity produces salts and freshwater using adequately tailored technology. This process involves challenges that have already been introduced in sub-section 4.2. However, it requires more detailed analysis and additional research on the technology, operational capacity, final products, and marketability.

According to the Construction Law, in each case where an external entity appears, it is necessary to make a notification and obtain a decision allowing the recovery plant and infrastructure needed for lithium production construction. In each of these variants

(3-6), receiving an Environmental Decision for the project may also be necessary if the selected technology uses chemical reagents and may harm the environment.

The decision-making process for variants 3-6 is presented in Fig. 3.

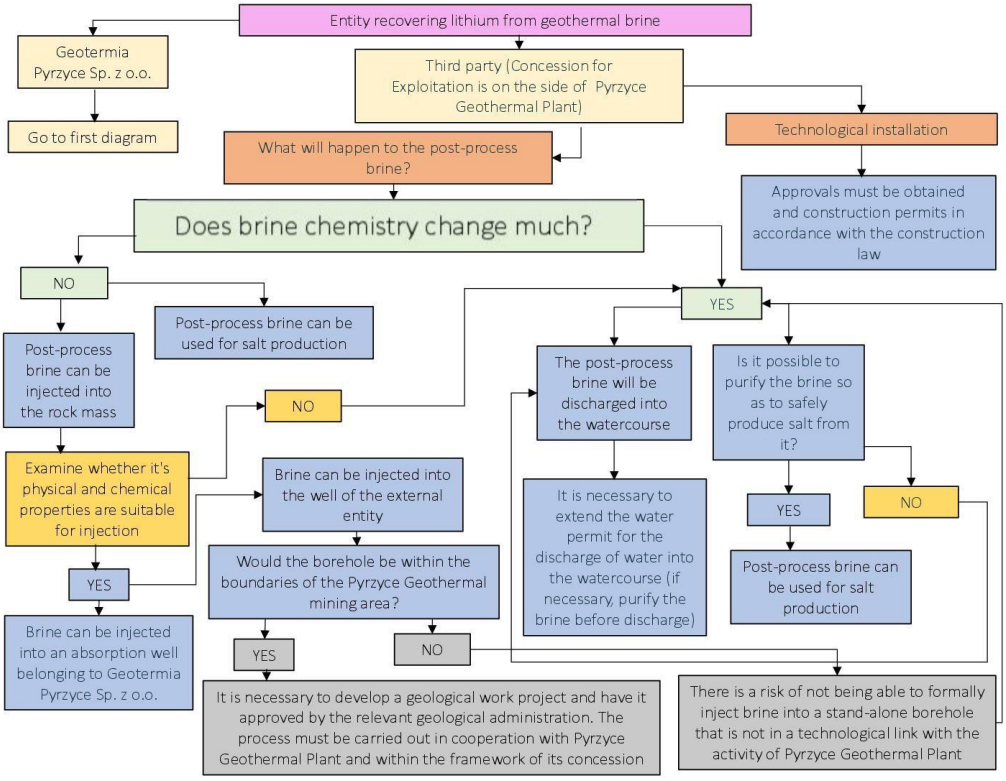

Fig. 3. Decision-making tree for the third party to produce lithium from geothermal brine derived from the GT-1 BIS borehole (own elaboration)

5. SUMMARY AND CONCLUSIONS

With the development of high-tech industries, there is an increasing demand for lithium, one of the main ingredients needed in producing glass, ceramics, and aluminium alloys used in aviation. It is also primarily one of the main ingredients necessary for making lithium-ion batteries for electric cars, among other applications. Zero-emission lithium recovery from thermal water could become an attractive source of this element for automotive manufacturers looking for green supply chains of battery metals. Such pilot facilities are already operating in Germany (Vulcan Energy Resources Group). Their launch required the completion of many individually negotiated formal proce-

dures and was the starting point for various analyses of legal conditions in other countries.

This study aimed to analyze the formal aspects of the possibility of recovering lithium from geothermal brine in Poland. This is a vital topic because, so far, it has not been addressed in the national literature due to the lack of activities of this type in the country. This work selected six variants of the formal process of lithium recovery from borehole GT-1 BIS based on legal acts, procedures, and technical aspects of water documentation. In each of these variants, issues related to obtaining a concession, constructing the plant, and managing waste (process water) were addressed. During the writing of the paper, the exploitation concession issued for the Pyrzyce Geothermal Plant was analyzed, and it was noted that due to its age, it has some shortcomings and does not accurately specify issues related to, among other things, the injection of post-process brine into the rock mass. Since the concession expires in three years, the necessity of renewing it if Pyrzyce Geothermal Plant wants to undertake elemental recovery was highlighted. It also pointed out what measures should be taken to build a technological installation for lithium extraction and the issues of managing post-process brine. Two algorithms were also drawn up for the formal and legal aspects developed, as shown in Figs. 2 and 3.

Preparing the above aspects was challenging due to the lack of available literature in this area. The workflows developed are so universal and easy enough to adapt to other geothermal projects that their use should quickly answer many of the fundamental questions entrepreneurs face wishing to carry out lithium recovery. It is worth noting that this work is an initial step in developing the feasibility of extracting lithium from a selected geothermal borehole. The work highlights the need for legislative changes in Poland to unambiguously regulate the formal and legal aspects of elemental recovery (not just lithium) from geothermal brine.

In conclusion, we can assume that lithium extraction as an accompanying process to geothermal heat production is formally feasible. However, the procedures can be challenging and may depend on individual interpretations of the legal acts by the administration and authorities. This increases the uncertainty of such projects. With this paper, we hope to have an open discussion on legislation related to unconventional mining methods and sources of critical raw materials, like geothermal brines.

Back to Slovakia's case, an intriguing possibility could involve utilizing spa water for lithium recovery. This mineral-rich thermal water, currently extracted for spa purposes, is disposed of according to regulations without further utilization of valuable elements like Sr, Br, B, I, and Li. However, before initiating the extraction of elements from these geothermal wells, a new evaluation of resources would be required. Nonetheless, it is already evident that the definition of reserved minerals within Slovak mining legislation needs revision, and the conditions governing such extraction must be clarified.

Still, having no strict regulations for “aqueous mining” not only in Poland but worldwide, it is worth thinking about how to organize laws not to overregulate geothermal

extraction of metals and not to block its development. On the other hand, investors and industry need clear legal pathways to minimize the risk of investments and speed up the piloting to benefit the European development and economy.

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