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The H2020 GEORISK Project – Inventory and Assessment of Risks Associated to the Development of Deep Geothermal Heating and Power Projects

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ABSTRACT

The objective of the GEORISK project in the framework of Horizon 2020, is to facilitate the development of deep geothermal projects (geothermal heating or geothermal power) by developing suitable insurance schemes to mitigate the risks inherent to geothermal drilling. The first step of the project, presented here, is to set-up a risk register and propositions to assess those risks. Based on an extensive literature review, and on the knowledge from the expert of the project, the risk register aims at defining a comprehensive list of the risks associated with the development of deep geothermal projects given the current understanding and feedbacks. Considering the knowledge at the beginning of a geothermal project, the risk register also highlights the risks that would need mitigation through insurance schemes. The register contains 54 risks which are grouped in 6 categories. On top of listing the risks associated with geothermal drilling, the register will be useful for listing associated technical mitigation measures, considering that the insurance schemes will be needed only if the technical solutions are uneconomical. In the risk analysis step, each risk is then given a score via two usual risk indicators (degree of damage and likelihood of occurrence) and ranked. This step is performed by asking stakeholders to answer a questionnaire. Risk analysis is performed for different type of energy use, different countries and different geological settings. Main results for one group are presented and show that the main risks according to the respondents are mostly related to the uncertainties of the subsurface.

1. INTRODUCTION

The H2020 project GEORISK aim is to develop new insurance schemes as a mean to mitigate the main risks faced by developers and operators of geothermal energy. In this paper, we focus on the "risk" part of the work, and it consists in answering the following question: "what are the main risks faced by developers and operators of geothermal energy?"

There is already a large literature available regarding risks and geothermal energy (see e.g. appendix I of Le Guenan et al. 2019). However, for most documents, it focused only on a partial definition of the risks (e.g. induced seismicity risks or environmental risks), or only on a context dependent analysis (i.e. focusing on a particular project or type of geothermal energy). In the GEORISK project, the goal was to take into account most types of risks, with relevance to both types of deep geothermal energy (i.e. district heating and power generation), and taking into account the main types of geothermal plays The project focuses on the countries represented in the GEORISK consortium: Belgium, France, Switzerland, Germany, Poland, Greece and Turkey. However, the risks identified should also be relevant for other European and non-European countries.

The structure of the work is based on the principles of the ISO 31000 norm on risk management. According to the norm, risk assessment is composed of three steps: risk identification, risk analysis and risk evaluation. In this paper, we will present the steps of risk identification and risk analysis. Risk identification consists in listing all the plausible risks for the defined context. In the project, this took the form of building a risk register. The following step, risk analysis, consists in ranking the risks. For this project, we used a qualitative method. We will then present some perspectives following the analysis of the risks and conclude.

2. BUILDING THE RISK REGISTER

2.1 Method

Before risk identification, it is necessary to define the context and the objectives of the whole risk assessment. As stated previously, the objectives here are to identify most of the risks faced in the development of a (deep) geothermal project in Europe. Adopting the point of view of developers or operators of deep geothermal energy, the definition formally used in this assessment is: "the events, or sources of uncertainty, preventing the proper development of the project considering the economic, technical, environmental and social points of view".

The way in which risks are identified depends on the "model" used for their representation. The initial model chosen consisted in a "top event", which was provoked by one or several "causes", and which created various types of "consequences". In addition, each risk defined as the unique combination of a triplet "cause – top event – consequence", could belong to one or several phases in the development of a geothermal project, and one or several risk factors that could modify the severity of the risk. This model of representation quickly turned out to be impractical, generating too many risks, with sometimes only slight differences between different risks. For instance, if a top event like "induced seismicity" has several consequences (e.g. damage to building or local opposition), then it would appear several times in the register.

A second and simpler model was then built, keeping only one field for the description of the risk. Consequently, each risk is described with fewer details, but with a wider range. Some risk descriptions are mostly related to a potential causes, while others are mostly related to types of consequences. This asymmetry in the description was not considered as a problem for the register, and a little level of redundancy was preferred over potential gaps. In addition to the description field, each risk belongs to one or several of the following phases:

- exploration and characterization;
- drilling;
- testing and exploitation;
- post-closure.

A "consequence" field is also present in the register but is no longer described in detail. Each risks are tagged with the potential consequence generated: either "economic and performance" or "health, safety and environment" (HSE). It is important to bear in mind that most HSE risks have also an economic consequence due to remediation cost.

The sources used to fill the content of the register are the previous European project such as GEOELEC (Fraser et al. 2013), GEOWELL (Lohne et al. 2016), or DARLINGe (Nador et al. 2018). This was supplemented by an extensive literature review: see Le Guenan et al. (2019) for the full list of references. Finally, a workshop with members of the Georisk project helped to finalize the risk register.

Results

The current version of the risk register contains 54 individual risks subdivided in six categories. The description of all the risks is available in the report Le Guenan et al. (2019). The categories were created afterwards and were not used in a top-down manner for finding new risks. These categories are:

- External hazards (2 risks);
- Risks due to uncertainties in the external context (9 risks);
- Risks due to internal deficiencies (9 risks);
- Risks due to subsurface uncertainties (17 risks);
- Technical issues (9 risks);
- Environmental risks (8 risks).

"External hazards" include only 2 risks: one is a natural hazard damaging the infrastructure and the other is from anthropogenic hazard.

The risks due to uncertainties in the external context are mainly related to the socio-economic environment: some favorable factors are needed in order to make development of geothermal energy possible, so risks depend on the existence or not of these factors.

Risks due to internal deficiencies are related to several types of factors, which are in the area of responsibility of the operator or developer, which could create unwanted consequences. Examples are lack of expertise or risks due to human errors.

Risks due to subsurface uncertainties are the main focus of the GEORISK project. They include the geological and geothermal resource hazards for new drilling projects during drilling phase, also identified as the "short-term" risk and during exploitation for the "long-term" risk. In the register, the "resource" is detailed by most of its parameters, including temperature, flow rate, initial pressure, water composition, etc.

"Technical issues" include risks that appear from operational problems, mainly during the drilling phase, also including failure of material.

Environmental risks include for instance leakage, induced seismicity and ground movements.

These categories were mainly created for ease of use and communication purposes, as some risks could belong to several categories. The risk register was then communicated to various stakeholders in each country of the consortium, which allowed to get valuable feedbacks.

Discussion

Overall, the stakeholders appreciated the risk register, and highlighted only minor gaps, meaning that the list is close to be comprehensive. The main remarks were not on the content of the register but on some conclusions related to the establishment of a list of risks.

Stakeholders expressed their concerns over the fact that a list of all the risks can put a barrier to the development of geothermal energy and send an alarming message. Here, it is important to state that this risk identification phase is necessary to assess and mitigate those risks in the subsequent phases. However, the remark from the stakeholders is understandable and the register will be improved by also indicating the various existing measures and good practice applied by the geothermal operators for de-risking the projects. Moreover, a distinction should be made between the types of mitigation measures: technical measures, financial measures (such as insurances) and political measures (such as new laws or subsidies).

Another concern from some stakeholders was the fact that they thought some risks were irrelevant even if they seemed plausible. The reason behind this is that, for operators, some risks are covered by contract with their subcontractors, or other are covered by insurances, for instance during the drilling operations. This remark showed the need to highlight also the risk ownership: some risks are supported by the operator directly, but others are transferred to other stakeholders such as subcontractors or insurances. However, it is important that most of the risks are still indicated in the register as the goal of the project is to identify *all* barriers to the development of geothermal energy.

Regarding the comprehensive character of the register, the choice was made to reduce the number of risks. This does not mean that some risks are omitted, only that they are described with fewer details. A risk register is a form of communication medium and it is thus important to keep it manageable. If the level of details is too low, it is not necessary to increase it for all risks: it is sufficient to run a risk analysis first, and to work on the details of only those risks where a decision is harder to take such as the type of mitigation action to undertake. Risk analysis is described in the following section.

3. RISK ANALYSIS

After the risk identification phase, where many plausible risks are listed and described, it is often necessary to perform a risk analysis where risk are ranked and prioritized. This is because there is only limited resources that can be devoted to the reduction of these risks so it is important that these resources are put where it is the most efficient.

Method

In this project, risk analysis is somewhat different from a "regular" risk analysis: it is not applied to a particular project with its own data but on the deep geothermal energy industry as a whole. Moreover, the intent is to be able to make distinction from country to country so different risk analyses should be run for each target country in the project. The objectives of the project, and the resources available for performing this task excluded the possibility of running a quantitative risk analysis based on data and modelling. Instead, it was decided to perform a qualitative risk analysis, and to rely on the expertise of national stakeholders in order to assess the risks. This was also justified by the fact that most data regarding risks are not published and are only available through the experience of the practitioners of the geothermal energy sector. A questionnaire was thus built and sent to a list of stakeholders from the GEORISK countries. In some cases, workshop were organized in order to assist in answering the questionnaire and to promote the activities of the project.

According to the ISO 31000 norm on risk management, "risk is often expressed in terms of a combination of the consequences of an event and the associated likelihood of occurrence". Likelihood is often expressed numerically in the form of a probability or a frequency, often depending on the type of risk and on the common practice of the industry. Consequences can be expressed by many indicators, but it is often expressed in losses or equivalent losses which are commonly evaluated in monetary terms (euros or dollars).

In order to keep the analysis simple, both likelihood and consequences are expressed with a score from a 4-point scale: 1 corresponding to least likely and least severe, and 4 corresponding to most likely and most severe. See Figure 1.

Risk/Likelihood Level	Damage Value	Likelyhood
1	X < 10.000 €	Not likely to occur
2	10.000 € < X < 100.000 €	Mild chances of occurrence
3	100.000 € < X < 1.000.000 €	Moderate chances of occurrence
4	X > 1.000.000 €	High Chances of occurrence

Figure 1: table explaining the scoring system for risk analysis

Regarding consequences (or "damage value" in the table), loss thresholds were indicated, but the respondents were asked to adjust these values in order to better correspond to the national context. Not all consequences are of economic nature, so for scoring, the table should be interpreted as "equivalent losses". For instance, regarding an environmental loss (such as pollution), it can be converted to equivalent monetary loss by answering one of the following question:

- "price you are willing to pay in order to avoid this consequence" (corresponding to the cost of preventive mitigation actions)
- "price you will need to pay in order to remediate the consequences" (corresponding to the cost of remediation or repair).

The principle of the questionnaire is that for each risk in the register, the respondent should indicate two scores between 1 and 4: one corresponding to the perceived likelihood of the risk, and one corresponding to the perceived losses of the occurrence of the risk.

Another field in the questionnaire asked to give a score (again in a 4-point scale) in relation to the relevancy of the risk. This was judged necessary in order to distinguish risks that are known and easily mitigated (hence "not relevant" with respect to the goal of this risk analysis) with risks that creates problems irrespective of the actual level of the risk (for instance the "induced seismicity" risk is certainly highly relevant but is potentially low in many geological context). This was also a way to take into account the remark from the stakeholders' workshops regarding risk ownership (see the discussion of the risk register section). Figure 2 provides the details regarding this field.

Risk Relevance in the local geothermal Market	
A	Extremely relevant/ Is the major issue in local geothermal sector (Show stopper)
B	Highly Relevant/ Considerably impedes the development of the projects
C	Moderately Relevant/ Delays the development of projects
D	Low Relavance/There is standardtized methods of effective solution

Figure 2: Table provided to respondents for assessing the risk relevance

In addition, respondents were asked to provide further information: type of output, reservoir type, country / region, and level of expertise. Type of output is either heat or electricity (including Combined Heat and Power, CHP). For reservoir types, it was also decided to keep things simple, and the following choices were proposed:

- Basement rocks;
- Volcanic zones:
- Sedimentary.

For sedimentary reservoirs, it was also possible to indicate a range of depth.

The idea behind this information is that each questionnaire should correspond to one type of project according to the subdivision provided. It was judged as a good compromise between the project level and the generic level.

The last distinction necessary corresponds to the respondents themselves. Not all stakeholders have the same level of knowledge or the same expertise, and the register covers a very wide range of topics from socio-economics to technical issues. The solution was thus to ask to each respondent to auto-assess its own level of expertise regarding the following areas of expertise:

- Geology;
- Social / Economic;
- Drilling;
- Operation / Development.

Another 4-point scoring scale was used for this, corresponding from “scarce understanding of the field” to “professional understanding of the field”. Each risk in the register was then classified according to these levels of expertise, and the respondents could choose to answer only part of the questionnaire.

When the questionnaires are returned, they are grouped by countries/geology/type of energy representing one type of project. Inside each group, an average risk score is computed for each risk in the register. The risk score is computed using the following formula:

$$\mathrm{RS} = L + \mathrm{D} \tag{1}$$

Where *RS* is the risk score, *L* is the averaged likelihood and *D* is the averaged damage level. The averaged likelihood is computed from several respondents in the following way:

$$L = \frac{\sum_i w_i L_i}{\sum_i w_i} \tag{2}$$

Where i corresponds to the ith respondent, L_i is his estimation of the likelihood (a number between 1 and 4), and w_i is the weight corresponding to his level of expertise:

- The highest level of expertise has a weight of 1;
- The second highest a weight of 0.875;
- The third highest a weight of 0.75;
- The lowest level of expertise a weight of 0.5.

This weight varies depending also on the risk because the level of expertise vary from an area to another (e.g. a drilling expert may not be an expert in the socio-economic area). Using this formula, the average is slightly modified by giving more weight to the persons with the highest level of expertise and less weight in the average to the persons with the lowest level of expertise.

The averaged damage level *D* is computed in a similar way, using the same weights.

Regarding the relevance score, for the average, all the weights are set to 1, meaning that all respondents have the same weights irrespective of their level of expertise.

In equation (1), the operator used is a sum, but a product is sometimes used for computing the risk score. The reason is that the score for damage level is proportional to a power of ten (see figure 1). It is also similar for likelihood (e.g. the score corresponds roughly to probabilities of 10%, 1%, 0.1% and 0.01%). The actual product of likelihood and damage level, corresponding to the computation of the expected loss, is thus proportional to the sum of the score (see equation (3)).

$$10^a \times 10^b = 10^{a+b} \tag{3}$$

Another reason is that using a product with the likelihood and the damage scores would change the ordering: a risk with scores [3,3] would score higher than a risk with scores [2,4] with the product whereas they would be ranked similarly with the sum (Figure 3).

	1	2	3	4
1	2	3	4	5
2	3	4	5	6
3	4	5	6	7
4	5	6	7	8

	1	2	3	4
1	1	2	3	4
2	2	4	6	8
3	3	6	9	12
4	4	8	12	16

Figure 3: comparison between the sum (left) and the product (right) for computing the risk score from a couple of likelihood and damage values

Results

At the time of writing the paper, not all the results were collected. We present here only the results for one of the groups for which 7 questionnaires were returned. All the respondents filled all the required fields. The results correspond to the case of heat generation, in the country of Hungary, in sedimentary reservoirs with a depth inferior to 2 km.

By using the formula of equation (2), there were fifteen risks which obtained a score of 5 or more:

- "Low financing for work leading to low safety standards" (5.2)
- "Demand analysis and forecast are inaccurate" (5.1)
- "Flow rate lower than expected (reservoir)" (5.1)
- "Pressure lower/higher than expected" (5.2)
- "Neighboring operators cause negative changes to the reservoir parameters" (5.1)
- "Fluid chemistry / gas content / physical properties are different from expected" (5.1)
- "Target formation is missing in the well (unexpected geology, insufficient exploration)" (5.7)
- "Target formation has no/insufficient fluid for commercial production" (5.8)
- "Geological lithology or stratigraphy is different than expected" (5.1)
- "Particle production ("sanding")" (5.3)
- "Hydraulic connectivity between wells is insufficient for commercial use" (5.0)
- "Re-injection of the fluid is more difficult than expected" (5.2)
- "Degradation of the reservoir (structure, properties, deteriorating whole-scale further commercial utilization)" (5.9)
- "Loss of integrity of surface equipment (leakage from the tanks, pipeline, heat-exchanger, etc.) (5.4)
- "Damage to the well/reservoir while drilling or testing" (5.4)

Considering the categories introduced in the risk register, most (10) of these "top risks" are from the "risks due to subsurface uncertainties" category.

A relevance score was also computed for all the risks. 12 risks have a score of 3 or higher (out of 4):

- "Lack of financing for the next phases" (3.3)
- "Significant changes of energy costs" (3.3)
- "Unanticipated delays and costs in operations (materials, services, maintenance)" (3.1)
- "Unsuitable contracts (roles and responsibility not clearly defined) leading to suboptimal performance or exploding costs" (3.6)
- "Fluid chemistry/ gas content / physical properties are different from expected" (3.4)
- "Target formation is missing in the well (unexpected geology, insufficient exploration)" (3.4)
- "Target formation has no/insufficient fluid for commercial production" (3.6)
- "Geological lithology or stratigraphy is different than expected" (3.6)
- "Particle production ("sanding")" (3.1)
- "Degradation of the reservoir (structure, properties, deteriorating whole-scale further commercial utilization)" (3.1)
- "Damage to the well/reservoir while drilling or testing" (3.1)
- "Well casing collapse" (3.1)

Only 7 risks are present in both lists. In fact, the correlation coefficient between both indicators (risk score and relevance score) is 0.64, showing that despite the tendency for respondents to give a high relevance to the highest risks, the difference between the indicators is not negligible and so both bring a different point of view on the risks. It is not clear however how the relevance score can be exploited in the final ranking.

Discussion

The results show that the initial objective of the project is achieved and that a ranked list of risk can be obtained for many contexts in Europe. Moreover, the contact with stakeholders from all the studied countries has been excellent with many useful and constructive feedbacks. It is not yet possible to give a precise number but the response rate to the questionnaire has been impressive considering it is quite lengthy and not trivial.

However, the qualitative method presented in this paper introduces some biases or errors. The main source of errors is the fact that the analysis relies almost exclusively on experts' judgment for computing the scores. A weighted average has been introduced in order to take account of different level of expertise but this cannot correct all the biases, including the possible misunderstanding of some risk descriptions, the biases due to the ordering of the risks which was the same for all respondents, and the possible confusion between the risk score and the relevance score. This last indicator was proposed in order to overcome some shortcomings, but the exact use of the values is not clear at the moment and from a preliminary analysis of the questionnaires, there seems to be a high discrepancy in the way the respondents interpreted this field.

Moreover, the scoring system can introduce additional errors: only considering the likelihood, the most robust mathematical representation is with probabilities (i.e. a real number between 0 and 1), that our system "downgrades" to a natural number between 1 and 4. Necessarily, some nuances are lost in this process, and the same observation is valid for damage values as well.

This means that the results presented here should be interpreted with caution. Each risk is associated with numbers but those numbers should not be seen as proportional to the actual level of risk, rather they are representative of the opinion of stakeholders (at least the one who responded) regarding the risks. In this regard, it would be interesting to assess – at least qualitatively – the representativeness of the respondents with respect to the whole cartography of professional stakeholders in the geothermal energy sector.

4. PERSPECTIVES

The next step is to analyze the data from the questionnaires from the different countries and geological settings, and to extract the commonalities as well as the main differences between the groups. One remark received from a respondent was that the study should not lead to the conclusion that one country or one type of geothermal energy has "more risks" than other countries or types of geothermal energy. This could be avoided for instance by normalizing the results (i.e. all values for the risk score are converted to a number between 0 and 1, with 0 corresponding to the lowest risk and 1 to the highest risk).

After the finalization of the risk analysis step, the stated objective of the GEORISK project is to provide an online tool. This tool will present the main results as showed in this paper: the risk register and the result of the risk analysis. In addition, an important focus will be put on possible measures for de-risking the projects. The possibility of financial mitigation will then be improved by further work from the GEORISK project.

5. CONCLUSION

Despite the quantity of previous work existing on the topics of risks and geothermal energy, the work presented here is to our knowledge one of the most comprehensive as it tackles many kinds of risks (including socio-economic risks, geological risks, environmental risks), and many contexts that are mainly relevant to Europe but non only. In a first step, an important synthesis of available knowledge has been performed in order to build a generic risk register. The following step consisted in giving a score to these risks, in the risk analysis step. The analysis considers different kind of energy use, different geological settings and different countries. The scoring relies on experts' judgment and a questionnaire was built and sent to stakeholders from the studied countries. The results from one group showed that that risks due to uncertainties in the subsurface, also known as geological risks, are perceived as the most impacting, and should thus be the focus of the development of innovative de-risking measures, including financial measures, such as insurance schemes, which is the main purpose of the GEORISK project.

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