A decision support tool for geothermal energy projects

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ABSTRACT

This paper presents a step-by-step decision support tool for investors in the geothermal energy sector, based on a Decision Tree (DT) algorithm. The DT is structured by questions on the social, environmental and financial characteristics of the project, and it derives relevant possible social engagement strategies and financing schemes to be deployed.

1. INTRODUCTION

CROWDTHERMAL project aims to "empower public to directly participate to the development of geothermal projects with the help of alternative financing schemes and social engagement tools". As part of this project, a sequence of questions following a DT format that aims to assist in identifying the most efficient social engagement and financing strategies, to enable the successful implementation of a geothermal energy project was developed.

When selecting appropriate social engagement strategies and financial and risk mitigation instruments, developers/promoters of geothermal energy projects need to consider various factors, including awareness/familiarity of the public, social and environmental concerns, intellectual and financial participation opportunities, resource risk of the project, legal compliance and risk mitigation. social, environmental, legal, resource risk, and financial characteristics, throughout the service life of the project.

Depending on the stage of the project development risks, requirements, and opportunities may differ. During the exploration phase, for example, the resource risk is higher as compared to the operation phase and for this reason, it is often impossible to raise capital through traditional bank loan. Alternative sources of capital can be considered in this case.

Social engagement strategies should be implemented throughout the service life of the project, as social acceptance is needed for the successful implementation of the project. Beyond social acceptance, the community's intellectual and financial participation boosts the public's support and commitment to the project's success, and one of the contributing factors to achieve this is by removing stakeholders' environmental and social concerns.

A direct and easy-to-follow way to guide a user towards a decision is by means of a DT algorithm. It features a sequence of *nodes* which represent a test on an attribute value, *branches* denoting an outcome of the test, and *tree leaves* which signify classes or class distributions (Pegram *et al.*, 2020). The decision provides a transparent approach by means of a graphical representation assisting decision making.

The level of the tree's detail should ensure that no extensive prior knowledge or resources are required to take a decision; as such, DTs cannot be used to address a beyond-normally complicated problem, involving numerous aspects simultaneously. Indicative references documenting the method include (ISO - IEC, 2013; Pardeshi, 2019).

In energy applications, DTs have been regularly used to assist decision making using limited resources and knowledge. For example, a preliminary screening of remedial options to reduce the loss of gas production in liquid loading was realised by using a DT algorithm (Park *et al.*, 2009). DTs have also been implemented with machine learning techniques, principally in classification problems, such as the development of a building energy demand predictive model based on the DT method, which was able to classify and predict categorical variables using machine learning (Yu *et al.*, 2010). In geothermal-focused studies, tree-based methods have been used in combination with machine learning to optimise drilling costs (Höhn *et al.*, 2020) as well as to check the performance of three model classes for induced seismicity through logic tree branches that capture the epistemic uncertainty of the process for a case study in Switzerland (Mena *et al.*, 2013). Furthermore, in (Grant, 2009), DTs were developed to accommodate the question "is a newly-drilled well good enough?". The author considered the range of probable well results, the possible alternatives available (test/accept/side-track), and their cost. Finally, Van Wees et al (Van Wees, J.-D.a, Lokhorst, A.a, Zoethout, 2007) presented a techno-economic model for re-use of exploration and production wells using best practices for asset evaluation from the oil and gas industry, taking into account natural uncertainties and DTs to evaluate sensitivities and different scenarios.

2. METHODOLOGY

2.1 Scope and target group of the decision tree

Scope

The DT is intended to provide a workflow of a sequence of questions emphasising on social, environmental and financial influencing factors, following a logical order from start to end.

The DT targets at flagging likely environmental, social and financial risk mitigation concerns towards achieving a successful outcome.

The *development phase* of the project plays a significant role to the selection of appropriate social engagement and financing options. For this reason, the first node of the DT concerns the identification of the project phase.

The second question seeks to specify the user's *motivation*, among the following three options (Fig. 1):

- Enhance society's engagement with the project to ensure successful implementation.
- Identify alternative funding solutions for the project.
- Offer part of the reward to the local community.

Target group

The target group of the DT is developers/promoters of geothermal energy projects, seeking ways to enhance society's acceptance and/or engagement. Developers/promoters are assumed to have good knowledge of the project's technical characteristics along with the geology of the location. Therefore, technology and geology-specific questions (e.g., temperature range of geothermal wells), were not considered in the DT.

2.2 Methodology for the development of the DT

The key methodological steps for the development of the DT are illustrated in Fig. 2 and can be summarised as follows:

1. The *top question* determines the structure of the DT. The two key questions it addresses are the following:

- What social engagement strategies are more suitable to my project?
- What financing instruments are more relevant to my project?

2. Bottom options are the answers to the top question, and they represent the leaf nodes of the DT which consist of the set of social engagement strategies and financing instruments.

3. Social, environmental, financial and resource risk factors that influence the bottom options are accordingly identified and translated into a set of questions. The final set of questions amounted to 21 on the basis that the number of decision nodes must be kept to a minimum to result to a manageable, easy-to-use DT.

4. Compile preliminary trees and sense-check results to ensure that most important influencing factors have been integrated.

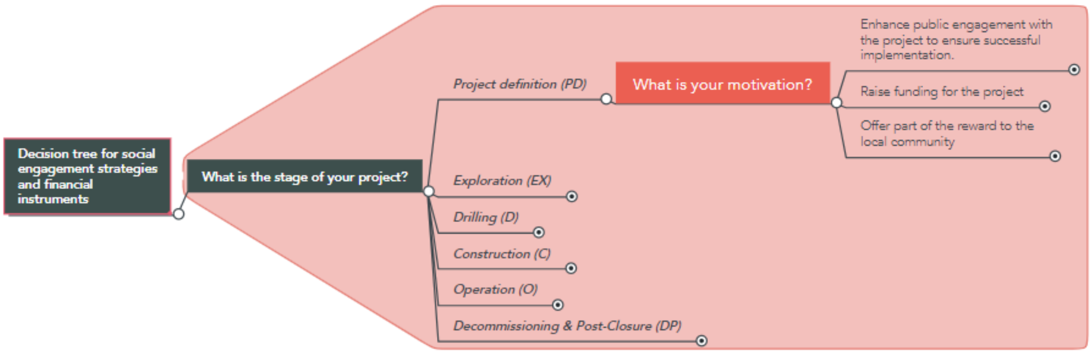

Figure 1: Decision tree's first two questions (source: (Ioannou *et al.*, 2021))

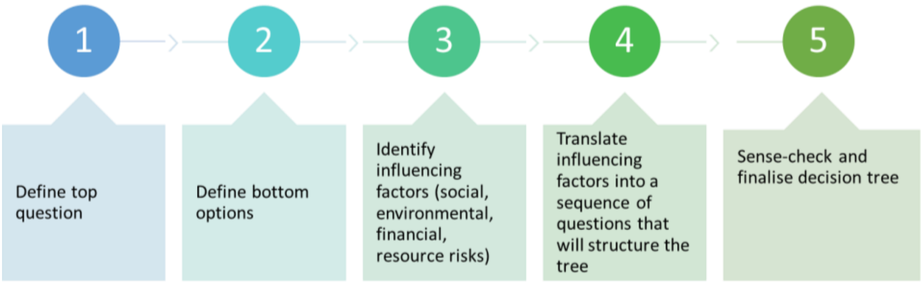

Figure 2: Methodology for the development of the decision tree (source: (Ioannou & Falcone, 2021))

3. INFLUENCING FACTORS AND DECISION TREE QUESTIONS

As a considerable number of factors affect the selection of social engagement and financial instruments, it was evident that a prioritisation of factors needed to take place.

The list of social engagement strategies and financial and risk mitigation strategies was compiled from the outputs of the project (CROWDTHERMAL, 2022) and discussion with project experts. Targeted questions reflecting the awareness/familiarity of the public, resource risk, social risks, environmental risks, financial participation, intellectual participation, legal compliance and risk mitigation aspects leading to the identification of most appropriate social engagement and financial instruments was also supported by discussions within the consortium. An overview of the questions can be found in Table 1.

Table 1 Questions included in the Decision Tree (source: partly adopted from (Ioannou & Falcone, 2021))

Domain	Questions
Awareness/ Familiarity	Is the public familiar with and positively inclined towards geothermal energy and the project?
Resource risk	Are you confident about the resource of your project?
	Have similar projects been successfully implemented in the past in this area?
Social risks	Are there social concerns about the project?
	Is the geothermal construction close to a residential area?
	Will the community be the geothermal energy user in the area?
Environmental risks	Are there environmental concerns about the project?
	Are there concerns about atmospheric pollution?
	Are there concerns related to water resources?
	Are there concerns about seismic events or other land-related risks?
	Are there environmental concerns about solid waste?
	Are there concerns about noise, visual pollution, and radioactivity?
Financial characteristics	Is the local community interested in having financial participation to the project?
	Are you interested in decreasing the risk for your investors?
	What is the size of capital required?
	What type of capital is required?
	What is the level of financial risk?
	Do you wish the community to have high involvement/engagement with the project?
Intellectual participation	Is the local community interested in having intellectual participation in the project?
Legal compliance	Have you checked your compliance with the relevant legal procedures to promote social acceptability?

4. APPLICATION OF THE DECISION TREE TO IDENTIFY APPROPRIATE FINANCIAL INSTRUMENTS

In this section, the steps followed towards reaching a decision regarding the most appropriate financial instrument are documented. The user's motivation (second step of the DT), therefore, lies on "raise funding for the project". The sequence of questions following the definition of the user's motivation are illustrated in Fig. 3.

To identify the most appropriate financial instrument, the level of risk of the investment needs to be estimated. Therefore, next decision node involves questions regarding the resource risk of the project. In case no similar projects have been developed in the area in the past and/or existing resource data of the location are not available or of sufficient credibility, the resource risk of the project is considered to be high. If both answers are negative, the resource risk is deemed to be high and the recommended financial instruments are *subsidies/donations* and *crowdfunding equity*. In case, at least one answer is positive, the resource risk is considered moderate or low, which leads the user to the next decision node concerning the expected financial characteristics.

Financial characteristics include questions about the *type and size of capital (financial risk)* required to narrow down the list of available financial instrument options. Potential choices include *risk-sharing*, *risk-absorbing*, *debt*, *reserves*, which can be also influenced by the development stage and the financial risk of the project.

Community funding is typically associated with high community involvement. As such, a subsequent question concerns the desired *level of community involvement* to the project. If the answer is positive, next step is to specify if the community is going to be the geothermal energy user in the area. This question determines whether financial instruments, such as crowdfunding (reward-based), crowdfunding (equity) or steward ownership schemes would be reasonable to be considered.

Final question specifies whether there is *interest to decrease the level of investors' risk*. If a positive response is provided the combination of an alternative financing instrument with a Guarantees scheme appears to be a reasonable way forward.

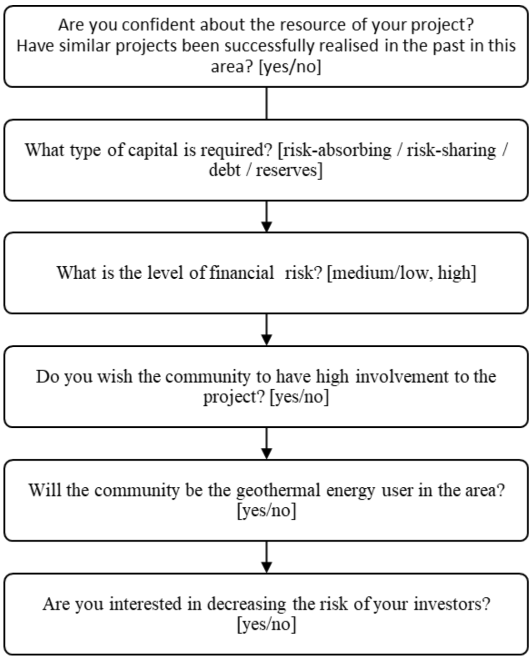

Figure 3: Sequence of Decision Tree questions

As previously mentioned, during the early phases of the project, the resource risk is typically high, especially if no similar projects have taken place in the approximate area. At that stage, the developer should investigate whether subsidies/grants/donations are provided by the Government for clean energy projects. Alternative finance methods (other than bank loans) for these high-risk and cost intensive project phases can include governmental lease and crowdfunding (equity). With crowdfunding equity, resource/investment risk is shared with the community investors, while the "return on equity is not payable until a profit is realized" (Baisch et al., 2020). However, this financing option requires handing over a part of the ownership while the return is proportional to the profit.

Financial instruments are screened in terms of the size and type of the capital required, as different finance methods are best suited to the respective project phase and financial characteristics. Naturally, higher capital induces higher risk, hence higher discount rates if direct lending is considered, which increases the need for introducing risk mitigation solutions. "

Risk mitigation strategies should include insurance or/and guarantee schemes to protect against financial losses reducing investors' risk.

In case there is interest in community financial participation through risk-sharing capital, Crowdfunding (Equity) and direct lending combined with governmental guarantees can be used. In case of debt capital, Crowdfunding loan and direct lending (with guarantees) in the early stages of the projects, together with Green bonds, regular loans and regular bonds during later stages of the project may be used for financing the project.

If the community is the geothermal energy user in the area, reward-based risk-sharing solutions include crowdfunding (reward), which promotes local project ownership and public engagement.

The Decommissioning & Post-Closure (DP) phase of the project is typically financed by Government funds and retained profits.

Finally, in case the aim of the user is to ensure community receives a part of the reward, reward-based crowdfunding and steward ownership are appropriate options.

CONCLUSIONS

DTs offer a graphical representation to facilitate decision-making and a transparent approach on how certain decisions have been made. The DT presented in this paper aims to support developers/operators of geothermal energy projects to:

• Improve the social acceptability of the project to ensure successful implementation,

• Raise (community) funding for the project,

• Increase engagement with the public to provide a part of the reward.

As the selection of social engagement strategies and financing instruments highly depends on the project's phase, the latter is first identified by the root node and separate branches are then developed accordingly. Leaf nodes of the DT algorithm comprised social engagement strategies and (alternative) financing options, while the decision nodes consisted of questions related to social, environmental, resource risk and financial aspects of the project.

The project phase determines the level of investment risk of the project, hence the suitability of the available financing options. For example, before assessing the resources associated with a geothermal well, the resource-risk of the project is typically high; therefore, raising capital through traditional bank loan is often not possible. The type of capital (equity, debt, risk-sharing, risk-absorbing or asset-based), amount of capital, desired level of public involvement and the risk appetite are key factors considered by the DT for the selection of an appropriate financing instrument.

It should be highlighted that the DT does not aim to provide quantitative answers, but rather, a workflow with a sequence of questions associated with the social, environmental, and financial background of the project, while the list of questions is not to be considered exhaustive.

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