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A Decision Support Tool for Social Engagement, Alternative Financing and Risk Mitigation of Geothermal Energy Projects

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Abstract: This paper presents a decision support tool for promoters/investors of geothermal energy projects, based on a decision tree (DT) structure. The DT aims to assist stakeholders to select public engagement strategies, alternative financing solutions and risk mitigation measures (or options) for geothermal energy projects. Public engagement is necessary for the successful development and operation of geothermal projects. Available studies (including toolkits and protocols) commonly list a set of practices for social engagement without providing information on the factors which render certain options more suitable than others. The presented tool offers a transparent framework to how relevant decisions could be managed by providing a sequence of questions that focus on social, environmental, resource risk, and financial influencing factors and to realise community engagement into geothermal projects. This work is part of the Horizon 2020 CROWDTHERMAL project, which aims at empowering the public to directly participate in the development of geothermal projects through social engagement tools and alternative financing schemes, like crowdfunding.

Keywords: geothermal energy; decision tree; social engagement; alternative financing; risk mitigation

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1. Introduction

A wider adoption of renewable and sustainable energy solutions requires a coordinated involvement of multiple stakeholders ensuring that groups of individuals who are affected by (or perceive themselves as being affected by) such investments understand and endorse the process as well as associated risks. Social acceptance is necessary for the successful development and operation of geothermal projects. Wüstenhagen et al. discuss the three dimensions of social acceptance, i.e., socio-political acceptance, community acceptance, and market acceptance [1]. Enablers of social acceptance are the communities' intellectual and financial participation, which can increase their commitment and alleviate their environmental and social concerns. It is fair to state that high-quality participation procedures require resources in terms of personal effort, time, and money. Still, achieving social acceptance and developing trust between local communities and geothermal developers/operators helps to limit potential conflicts, time delays, and other actions that could lead to even higher costs.

Focusing on the implementation and operation of geothermal power plants, they are heavily dependent on their acceptance at the local community level where the facility is to be constructed [2]. Developers/promoters of geothermal projects have to take several factors into account to determine appropriate social engagement strategies and financial (risk mitigation) instruments, including the awareness/familiarity of the public, the public's social and environmental concerns, intellectual and financial participation appetite, resource risk of the project, legal compliance, and risk mitigation, throughout the service life of the project [3]. Stakeholders as well as risks, requirements, and opportunities differ throughout the execution of the project. For example, when considering the exploration phase, where the fate of investment remains uncertain and hence the resource risk is higher, the exposure for a bank to provide capital is high, hence their direct involvement in a project would be more difficult, rendering alternative sources of capital as more appropriate. Key research questions this paper seeks to address are the following:

- What are the most appropriate social engagement strategies for the implementation of the geothermal project?
- What are the most appropriate financial and risk mitigation methods for the implementation of the geothermal project?

Developing and implementing strategies require inclusive tools which can address multiple factors and scenarios while at the same time communicating in a transparent and easy-to-interpret way the sequence of decisions. Existing toolkits, targeted at promoting community engagement in the development of renewable energy projects, most commonly provide general guidelines on how communities could benefit from such projects and what options are available to enhance local ownership [4,5]. Other toolkits present lessons learnt from case studies showcasing different ways communities have been actively involved in different contexts [6]. Protocols have also been published providing principles of public engagement in renewable energy projects [7]. However, available studies commonly list a set of practices for social engagement/financial participation without providing information on the factors which render certain options more suitable than others. A systematic and interactive way to assist stakeholders in making relevant decisions is to adopt a DT approach, which features a sequence of nodes representing a test on an attribute value, branches denoting an outcome of the test, and tree leaves that signify classes or class distributions [8]. The key to the successful adoption of a DT is that it should assume no extensive prior knowledge or resources required for taking a decision. It is therefore often the case that DTs cannot be used to address a highly complicated problem, involving numerous aspects (reflected in nodes) simultaneously [9–12].

This paper presents a DT framework through a step-by-step approach, assisting investors/promoters of geothermal energy projects to select public engagement strategies, alternative financing solutions, and risk mitigation measures (or options) for geothermal energy projects. The decision tree is presented for the project definition and operation phases, as the options under these two phases differ substantially. Encouraging stakeholder involvement and promoting engagement of stakeholders (citizens, local authorities, associations, etc.) already in the early stages of a renewable energy project has been widely cited in literature [7,13–15], while the project definition and exploration phases of a geothermal project have been cited to have the highest risk of project failure [16]. As far as financial options are concerned, these are also quite different across the two phases; during operation of the project, resource risk has been mitigated and certain financial options become available, such as leasing or bank loans [16,17].

Development of the tool has been based on consultation from stakeholders across the supply chain, which ensures the validity of the questions selected. As mentioned earlier, a key success factor for the adoption of such a tool is the selection not only of the type but also of the number of questions to be included; hence, there is a trade-off between completeness and complexity. This tool is part of the Horizon 2020 CROWDTHERMAL project [18] and, more in specific, the CROWDTHERMAL Core Services, where key outputs of the project were converted into web tools for geothermal energy developers, policy makers, and the public [19].

The rest of the paper is organised as follows. After this introduction, Section 2 presents a review of the literature both in aspects of social acceptance strategies as well as DT as a method. Next, a framework is presented for the development of the DT (Section 3). Finally, the applicability, assumptions, and key limitations of the method are discussed in

Section 4, while the work is summarised in Section 5 with some conclusions and recommendations.

2. Literature review

2.1. Key Reasons for the Lack of Social Acceptance of Geothermal Energy Projects

Figure 1 summarises some of the most crucial factors impacting social acceptance. The experience from initial geothermal projects has shown that such initiatives did not have high levels of social acceptance, which is a trend common across renewable energy investments [20,21].

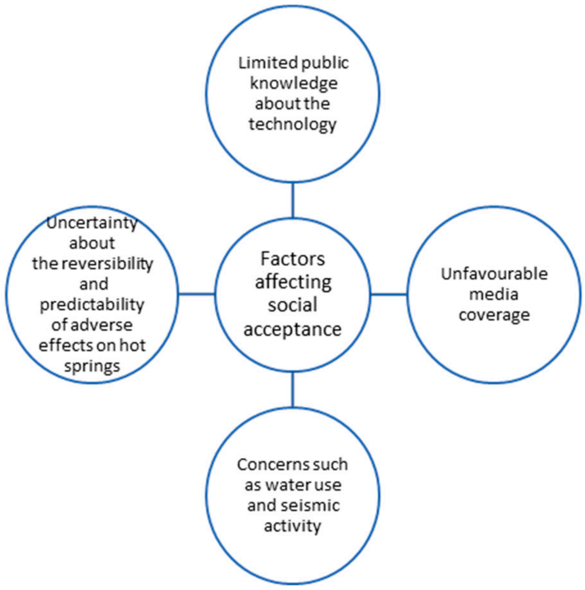

Figure 1. Factors impacting social acceptance of geothermal projects (adopted by [22]).

Lack of knowledge and appropriate information about the technology in general as well as the projects specifically is one of the key aspects related to the reduced social acceptance of energy technology, as it is a condition acting against the inertia from more established technological solutions. To this end, stakeholder identification as a first approach can allow a coordinated mapping of risks and concerns, so that developers of plants can coordinate their communication plans in a way that ensures that their concerns are addressed in a timely and sufficient manner. Risk communication and consultation is a key activity as stipulated by international standards [23] and has been discussed in multiple references as a means for promoting mutual understanding among the interested parties and ensuring two-way exchanges take place [24–26]. It is important to follow a proactive and inclusive approach to stakeholder and risk mapping, ensuring that both parties are actively listening and have the chance to articulate their concerns. A key condition of this interaction is respect for an individual’s values and beliefs. In this context, a potential side effect concerning the public is property damage, like damage to buildings [27]. Concerns, as well as supportive behaviours about aspects of geothermal energy projects, are strongly related to former experiences [28], thus experience can influence how people position themselves whether they generally have a positive or negative attitude towards something [29].

Presentation of the impact of different novel technologies from media has not always presented key features from a holistic view, often focusing on the potential negative impacts rather than the positive contribution to society [30]. A typical example is on highlighting the environmental impact of a geothermal plant [31] or the lack of effective technologies for the decommissioning of composite components of a wind farm [32], rather than providing figures and evidence of their overall positive impact in comparison to the existing solutions.

In addition to this, concerns about water use and seismic activity as a result of geothermal activities can develop a negative perception of external stakeholders [33]. The fact that these are known risks to developers does not mean that they are perceived as such by the general public, and hence it is the responsibility of the developers to communicate openly, providing sufficient technical details on the technological solutions that have been adopted. Relative research has shown, for example, that information about the seismic risk of deep geothermal energy projects significantly influences perceptions of associated projects [34]. The risk of induced seismicity and triggering earthquakes as a consequence of the energy generation procedure is well discussed in [25,27,35], while the seismic events in Swiss Basel in 2006 and in Landau, Germany, in 2009 have increased the awareness of such incidents [36].

Finally, the uncertainty about the reversibility and predictability of adverse effects on hot springs may also influence public acceptance as it can interfere with future uses of land for different applications. Again, this is a topic related to communication and a holistic approach to the benefits and impacts of such projects to, and for, the general public. Quantitative surveys have proven that such concerns have delayed decision-making by local governments concerning drilling permits as a result of uncertainty about the reversibility and predictability of the adverse effects on hot springs and other underground structures by geothermal power production and reinjection of hot water from reservoirs [22]. Promoting mutual understanding of risk management options appears to be an essential condition again, such as risk reduction and risk transfer at times of unexpected problems, even if the risk is low.

With respect to published information, this is at large associated with environmental concerns for deep, high-temperature geothermal systems for power generation use [37]. The risks associated with this technology are more significant as the technologies are more intrusive and imply extraction of geothermal fluids, which require a higher level of safety and environmental protection procedures (due to the chemical composition, temperature, and pressure of the geo-fluids) [38]. In addition, some environmental factors have been reported for shallow geothermal systems in the literature. Relevant factors include groundwater contamination due to leakages of contaminants in vertical closed loop systems, connection of different aquifers or connecting aquifers to the surface, flooding due to artesian groundwater conditions, ground uplift due to anhydrite-bearing formations, and thermal changes of soil and groundwater causing variations in the concentration of microbes [39].

2.2. Social Engagement Strategy Options

The deployment of renewable energy projects is highly influenced by the public acceptance of renewable energy technology [40]. Therefore, it is of particular relevance to understand what the specific acceptance factors are with regard to the local geothermal project and how they can be addressed appropriately. In this context, the inclusion of the public in the planning process plays a special role. There are different strategies for the design of public participation. Fundamental to all approaches are aspects such as transparency about the project and an understanding of specific local needs. In this sense, there is no one-size-fits-all solution; rather, the respective perspectives and needs of local stakeholders must be identified at an early stage.

Figure 2 presents five social engagement strategy options. Starting from general information about geothermal energy to increase knowledge/awareness, it is important to communicate the plan and progress of the project at regular intervals through diverse communication channels to ensure transparency. Further, developers should provide information to relevant authorities/stakeholders/public about the benefits of the system, advantages and opportunities, technical information, risks, and prevention measures. Communication should involve qualified scientists to communicate the information and respond to questions. The public communication strategy should be carried out in a structured and planned way, with clear plans on when to communicate, what to communicate, to which interest groups, and how to communicate it [14].

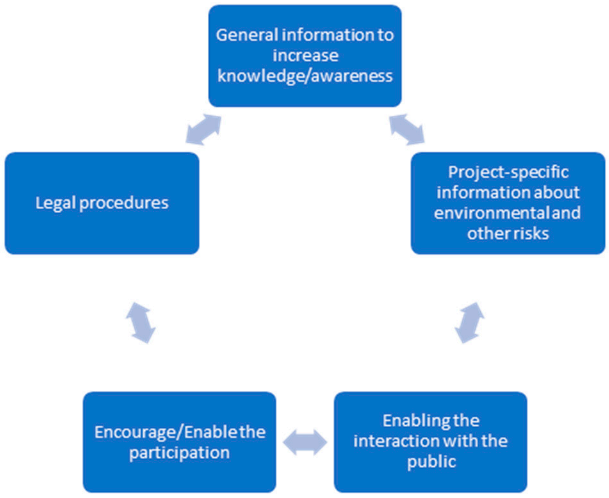

Figure 2. Social engagement strategy options.

Concerning providing project-specific information to stakeholders about environmental and other risks, project implementation works, energy production, and transparent communication should be established, including exact implementation plans, which phases are imminent, and what exactly will be done in which phases. Early and comprehensive provision of information should be in place regarding project implementation annoyances, including expected noise, steam, or odour annoyance as well as increased traffic caused by trucks because building materials need to be transported. Site visits/ short films/ virtual reality or 3D presentations of the drilling sites, flyers with images and explanations/information, or events with lectures should be offered to the public, while an online repository of information can allow for all relevant information to be located in a single place and their visibility to be monitored. Information campaigns about environmental issues such as seismic events should be organised, and provisions to increase confidence in the safety of the facility through the installation of appropriate environmental risk mitigation measures should be in place; for example, through local seismic monitoring networks that are installed to report any unwanted activities. Experts and scientists can be employed to communicate the information and address stakeholders' questions. A clear stream of communication should be established to allow stakeholders and the public to provide their inputs and observations on topics such as noise, steam, or odour annoyance as well as increased traffic caused by trucks because building materials need to be transported. Further, communication of positive aspects, such as the yielded renewable energy production (e.g., how many kilowatt hours or megawatt hours of energy were produced per day) and CO_2 savings, should be planned to enhance the perceived added value of the project after commissioning. Finally, early and transparent information about the decommissioning to stakeholders and citizens according to the legal framework should be planned in a timely manner. [14,41]

Apart from the proactive communication from the project developers, active interaction from/with the public should also be enabled. This can be achieved through setting up a project advisory board that meets at regular intervals to exchange information on the latest developments to ensure regular exchange with relevant sector agencies, nature conservation associations, or environmental protection associations; assigning and maintaining a direct and reliable contact person to whom the media and public could turn to with all their questions and concerns; and finally, ensuring that the participation and communication work does not end with the completion of the systems' construction [21].

It has been observed that enabling and encouraging participation in fundraising activities and energy use can increase the social acceptance of projects [6]. To this end, financial participation opportunities for community investors via crowdfunding can be offered; spin-off opportunities to other joint energy projects can be investigated; dialogues with citizens about ideas for local future projects should be encouraged through the participation of the municipality in the project, or through a connection to local heating networks so that citizens can be joint users of the energy generated.

Finally, to ensure transparency and governance, the appropriate legal procedures should be in place. Starting from planning permits, developers should provide access to required information/hearings of stakeholders and the public according to the legal framework. Provisions for drilling permits and construction permits should be required and include information/hearings of stakeholders and the public focusing on the construction works according to the legal framework [41,42]. Finally, the necessary decommissioning steps according to the legal framework should be put in place, even from the early stages of the project, ensuring sustainability at the end of the project.

A social engagement strategy plan should follow a proactive approach, and as such should include provisions for the management of unfavourable events [14,41].

2.3. Decision Trees in Energy Applications

Decision trees comprise a graphical representation of a sequence of possible choices and potential outcomes, which facilitates decision-making, offering a transparent approach to how decisions have been made [8,43,44]. On the other hand, the fidelity of the tree should ensure that no expertise is required to take a decision, hence DTs often cannot accommodate complex and beyond-normal complicated decisions, while experience from previous projects is required when constructing a tree for inclusion of the realistically key options and influencing factors. Indicative references documenting the method include [9–12].

DTs are often used for energy applications to facilitate decision-making from stakeholders with limited resources and knowledge around the decision-making process. Park et al. [45] used the DT method to perform a preliminary screening of remedial options to reduce the loss of gas production in liquid loading. Tan et al. [46] proposed a methodology that transforms the system dynamics model into an approximate DT, estimating the cash flow resulting from energy projects for a given predetermined sequence of decisions. Moutis et al. [47] presented a novel tool, based on DTs, with two potential applications: (i) planning energy storage systems within such MGs; and (ii) controlling energy resources for energy balancing within a PC MG. Huo et al. [48], developed a rigorous control mapping method based on DTs, demonstrating that the DT-based dispatch strategy can provide feasible and near-optimal dispatch decisions for microgrids. DTs are also used in combination with machine learning methods, primarily for classification problems. To this end, Tso et al. [49] documented a comparison between DTs and machine learning methods for the prediction of electricity consumption, while Yu et al. [50] developed a building energy demand predictive model based on the DT method, which was able to classify and predict categorical variables. Finally, Yaman et al. [51], proposed a method to estimate energy consumption and plan maintenance works on energy lines according to energy consumption, analysing parameters such as temperature, pressure, and wind, using DT methods.

Geothermal-specific studies employing DTs can be also found in the literature. Hohn et al. [52] used tree-based methods, in combination with machine learning, to optimise drilling costs, while Assouline et al. [53] mapped the very shallow theoretical geothermal potential focusing on three key variables: the ground temperature and the ground thermal conductivity and diffusivity. Mignan et al. [54] combined induced seismicity time-dependent hazard with the RISK-UE macro seismic method and proposed a logic tree approach to capture epistemic uncertainties, while Mena et al. [55] tested 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. Sobradelo and Martí [56] used Bayesian event tree structures to account for external triggers (geothermal, seismic) as a source of volcanic unrest and looked at the hazard from different types of magma composition and different vent locations (as opposed to a central vent only) to overcome restrictions of conventional trees in the eruptive scenarios they considered, and/or on the possibility of having volcanic unrest triggered by other forces than magmatic. Grant [57] developed DT algorithms to assess the performance of newly drilled wells by considering the range of probable good results, the available alternatives (test/accept/side-track), as well as their cost. Finally, Van Wees et al. [58] presented a techno-economic model for the re-use of exploration and production wells using best practices for asset evaluation from the oil and gas industry, considering natural uncertainties and employing DTs to assess sensitivities across different scenarios.

3. Development of a Framework

3.1. Scope of the Decision Support Tool

The target group of the tool is promoters/developers of geothermal energy projects looking for ways to increase public engagement, offer a part of the reward in exchange for financial and/or intellectual participation, or identify alternative funding options. This target group is expected to have good knowledge of the project's technical characteristics, hence technology-/geology-specific questions (e.g., on the expected enthalpy level of the well) are not included in the DT. The target group can be expanded to communities who want to realise their own geothermal project and are looking to involve other stakeholders and/or a larger community.

Leaf nodes of the DT comprise social engagement strategies and financing options (crowdfunding and other alternative financing options) and provide a workflow, including a sequence of social, environmental, and financial-related questions, to address the questions: What are the most appropriate social engagement strategies for my project? What are the most appropriate (alternative) financing tools for my project?

The first node of the DT concerns the identification of the project phase, followed by the question regarding the user's objective, namely:

- Increase public engagement toward successful project implementation;
- Identify alternative financing options with increased community involvement;
- Share part of the reward with the local community.

3.2. Methodology for the Development of the DT

The key methodological steps for the development of the DT are summarised below (**Error! Reference source not found.**Figure 3):

1. Definition of the top question, which determines the structure of the DT and defines the range of alternative options.
2. Definition of bottom options, which comprise the leaf nodes of the DT, namely most suitable financing options (crowdfunding and other alternative financing options), social engagement strategies, and risk mitigation options.
3. Definition of social, environmental, financial, and resource risk factors affecting the appropriate bottom options.
4. Next step included the development of an extensive list of 43 relevant questions following consultation with a group of experts in social engagement and financing instruments for geothermal energy projects based on identified factors. The final set of questions was reduced to a total of 19 questions by grouping/omitting some questions towards increasing the coherence and usability of the tool.
5. Development of preliminary trees based on the shortlisted questions.
6. Refinement of preliminary DTs was carried out following further discussions with experts to ensure that all key influencing factors and bottom events have been captured. Finally, the feedback received was used for the finalisation of the DT.

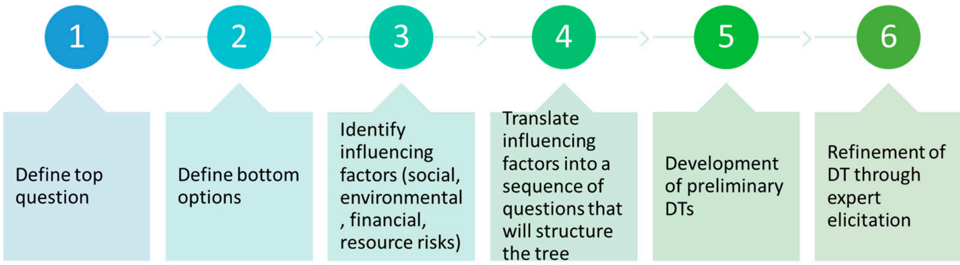

Figure 3. Decision tree development methodology (Source: [59]).

3.3. Influencing Factors and DT Questions

The phase of the geothermal project is a key factor for the selection of appropriate social engagement strategies and financial (risk mitigation) options. Each phase has an associated risk profile for involved investors, which determines the suitable kind of capital required. Hildebrand et al. suggested that social engagement strategies for geothermal energy projects should be selected based on the project phase, introducing appropriate measures per project phase [14]. However, the role of contextual factors is also emphasised.

Key social factors affecting the acceptance of the project were identified in [60]. The report classifies factors as project-, process-, and context-related across different countries. Most listed factors should be considered when selecting both appropriate social engagement strategies and financial instruments. For example, the lack of experience and familiarity with geothermal technology will affect social acceptance, public commitment, and participation in community financing schemes.

Along with social concerns, perceived environmental risks may also hamper the implementation of the project and developers should address any such issues by deploying social engagement strategies (provision of information campaigns, direct communication with relevant stakeholder groups, involvement of independent esteemed scientists to the discussions, comply to the legal procedures, etc.) in parallel with environmental risk mitigation strategies [61].

Resource risk is typically high in the early phases of geothermal project development and tends to decrease towards the end of the drilling phase, affecting the financial risk of the investment [16]. The financial characteristics of the investment also need to be specified to determine which type of financing would be suitable during a certain phase of a project. Such characteristics include the amount of capital required, financial risk, and type of capital.

In general, to choose an appropriate community investment method, all the circumstances of the project, such as the project phase, phase-related risks, regulatory framework, the overall financial position of the project, and government support, need to be carefully considered.

The list of social engagement strategies and financial (risk mitigation) strategies, as well as the set of questions developed to assess the public's awareness/familiarity with the project, project's resource risk, social risks, environmental risks, financial participation, intellectual participation, legal compliance, and risk mitigation aspects, were derived following a review of dedicated CROWDTHERMAL project deliverables [62] as well as further input from the experts, including the project partners. A summary of the DT questions is presented in Table 1.

Table 1. DT questions (Source: based on [59]).

Domain	Question
Legal compliance	Have you checked project compliance with the relevant legal procedures to promote social acceptability?

Awareness/ Familiarity	Is the public familiar with and positively inclined toward geothermal energy and the project?
Resource risk	Are you confident about the resource of your project?
	Have similar projects been successfully realised in the past in this area?
Social risks	Are there social concerns about the project?
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 in the project?
	Will the community be the geothermal energy user in the area?
	Are you interested in decreasing the financial 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 in the project?
Intellectual participation	Is the local community interested in having intellectual participation in the project?

3.4. Social Engagement Strategies

The successful implementation of a renewable energy project is highly influenced by public acceptance [40]. Effective planning of the communication and engagement strategy is necessary to improve the social acceptance of a project and ensure conflict prevention, public commitment, and intellectual and/or financial participation. Key social engagement activities include the identification of stakeholders/context of the project, establishing a multi-channel approach for the announcement and information of the project (using a broad range of communication tools, including project website, social media, and newspapers), encouraging stakeholder engagement and active participation, and communicating clear and concrete messages [14]. The various social engagement strategies suggested within the DT are grouped in Table 2. Some activities are relevant to more than one type of social engagement category; hence, they are introduced under each relevant category.

Table 2. Social engagement strategy options (based on [14]).

Comply with the legal procedures (SE-L)
SE-L1.Planning/drilling/construction permits acquisition.
SE-L2.Access provision to required information/hearing of stakeholders and the public according to the legal framework.
SE-L3.Provision of monitoring information according to the legal framework.
Increase awareness/familiarity with the project (SE-A)
SE-A1. Project announcement using diverse communication channels (newspapers, websites, social media).
SE-A2. Early and transparent information about the project development progress in regular intervals to relevant authorities/stakeholders/public.
SE-A3. Communication of the yielded renewable energy production (e.g., how many kilowatt hours or megawatt hours of energy were produced per day), $CO_{2,eq}$ savings to enhance the perceived added value of the project after commissioning.
SE-A4. Development of a public communication strategy on when to communicate, what to communicate, to which interest groups, and how to communicate it.
SE-A5. Offer site visits/short films/virtual reality or 3D presentation of the drilling sites/flyers with images and explanations/information events.

SE-A6.	Provision of a public (construction/operation) diary to keep the public up to date with the progress in (construction/operation) works (this can be realised, for example, in the form of blog posts on the project´s website).
SE-A7.	Organising regional information markets and topic tables (risks, financing, environmental impacts, etc.)
Address the public's concerns about environmental and other risks (SE-C)	
SE-C1.	Information campaigns about environmental and other risks and risk mitigation measures employed.
SE-C2.	Transparent and open communication on potential disturbances during the project development, such as noise, odour annoyance, increased traffic caused by trucks, etc.
SE-C3.	Assign and maintain a direct and reliable contact person to whom the media and public could turn with all their questions and concerns.
SE-C4.	Involvement of external experts/scientists to communicate project-specific information (technical, environmental, social, financial) and address stakeholders' questions.
Provide opportunities for intellectual participation by enabling interaction with the public (SE-I)	
SE-I1.	Set up a project advisory board that meets at regular intervals to exchange information on the latest developments to ensure regular exchange with relevant sector agencies, nature conservation associations, or environmental protection associations.
SE-I2.	Structuring the communication and public participation strategy.
SE-I3.	Assignment of a direct and reliable contact person to whom the media and public could turn with all their questions and concerns.
Provide opportunities for the financial participation of the public by enabling its participation to fundraise activities (FP)	
FP-1.	Offering financial participation opportunities to community investors, for example, via crowdfunding.
FP-2.	Collaboration with the municipality by investigating opportunities for connection to local heating networks, so that citizens can be joint users of the energy generated.

3.5. Financial Instruments

As mentioned above, the selection of the most appropriate finance option depends on the development phase of the project, the type of capital required, the amount of capital required, the level of risk, and the desired level of community involvement. Table 3 summarises a set of innovative and conventional financial tools for different types and amounts of capital, along with the levels of risk and community involvement which they are associated with. The four types of capital that were identified are the following: risk-absorbing capital, risk-sharing capital, debt, and reserves [16,17,63]. The amount of capital required was classified into low, medium, or high. "Low" capital required includes amounts up to EUR 200,000, "Medium" amounts of EUR 200,000–2 million, and "High" amounts of more than EUR 2 million. The risk level of an investment is strongly related to the resource risk level that is associated with a certain geothermal project development phase [16,17,63]. The level of community involvement is related to the ownership structure of the financing scheme, for example, whether investors have a share in the investment risk and/or have voting rights. The level of commitment could also be related to non-monetary involvement, like in the case of reward-based crowdfunding, where investors usually have no voting rights but are committed to the project and its realisation as the benefits yielded for them are dependent on the success of the project [63].

Table 3. (Alternative) financial instruments (based on [16,17,63]).

Financial Tools	Capital Type	Capital Amount	Risk Level/Level of Community Involvement
FI-1. Subsidies/grants/donations	RA	SA-MA	HR/LI
FI-2. Crowdfunding (Equity)	RS	AA	HI/HI
FI-3. Crowdfunding (Reward)	RS	AA	HR/NI
FI-4. Crowdfunding (Loan)	D	SA-MA	MR/LI
FI-5. Green bond	D	AA	LR/LI
FI-6. Regular bond	D	AA	LR/LI
FI-7. Government match funding (debt, equity, or grants)	RA or RS	AA	MR/HI
FI-8. Retained profits	RS	SA-MA	LR/LI
FI-9. Leasing	AD, RS, or RA	MA	HR/HI
FI-10. Social impact bonds	RA	MA	HR/HI
FI-11. Revenue-based financing	RS	AA	HR/LI
FI-12. Steward ownership	RS	AA	HR/HI
FI-13. Pay-it-forward scheme	-	AA	LR/NI
FI-14. Guarantee schemes	RA	AA	-
FI-15. Decentralised Finance	-	-	-
FI-16. Smart contract	RS	AA	MR/LI
FI-17. Tax reliefs	RA	-	-

RS: Risk-sharing; RA: Risk-absorbing; D: Debt; AD: Asset-based debt; HR: High risk; MR: Moderate risk; LR: Low risk; NI: No involvement; LI: Low involvement; HI: High involvement; AA: All amounts; MA: Medium amount; SA: Small amount.

The financial instruments mentioned in Table 3 can be defined as follows [16,17,63,64]:

Subsidies, grants, or donations are forms of funding, usually by a government or NGO, where no repayment in any form is required.

Crowdfunding is the most commonly used form of community funding, where funds are raised directly from the community without going through a bank in return for a set interest rate (loan), dividends (equity), or rewards (reward-based). The community invests into a project or company directly, often through an online platform. This means the investment made also carries the risk of the project or company directly. So, if the project or company fails, the investors will lose their money. It also means there can be direct contact between the project or company and its investors and potential benefits can also be given to the investors directly. Depending on the contract set up, crowdfunding can either be risk-sharing or risk-absorbing.

A bond is a special form of loan. The main difference from a loan is that a bond is usually tradable. Green bonds are fixed-income instruments that are specifically earmarked to raise money for climate and environmental projects. They can be funded by the crowd, through a direct lender, or by a bank. Social impact bonds are pay-for-success financing instruments for projects that will create better social outcomes whereby the payment to investors is flexible, based on the achieved savings.

Match funding is when there is funding from a crowd, bank, or direct lender and an (often public) institution adds its own (matches) funding to increase the total amount.

Retained profits are reserves kept to cover expected costs in the future, or as a safety measure for costs that may occur.

Direct lending is lending by a financial intermediary without a banking license that attracts funding and uses this funding to give out loans to other parties.

Leasing: In operational leasing, an institution provides the funding for a project to parties who are developing the project. The parties pay it back in periodic instalments. At the end of the project, the facilities are owned by the institution. In financial leasing, a leasing company pays for assets and/or production of a project for parties who are developing the project. The parties pay it back in periodic instalments. At the end of the project, the facilities can be bought, often at a price agreed in advance.

Revenue-based financing is any form of financing (loan, equity, crowdfunding) which raises funds in return for a payment of part of the revenue generated with the investment.

Steward ownership is a way of running a company, involving all stakeholders and interests in the goals and management of the company.

A pay-it-forward scheme is a concept working in a similar way to the CO_2 rights that are traded in the EU Emissions Trading System. Each member state would get a total amount of sustainable energy units that they have to deliver to reach the European sustainability goals. A member state could invest into a geothermal project in its own state or in another state and sell the realised sustainable energy output to another member state which can use it to reach its sustainable energy goals.

Guarantees can be given by a third party (e.g., the government), which means they guarantee that they will repay, e.g., a loan if the original borrower cannot repay it. This provides more security to the lender that the loan will be repaid.

Decentralised finance and smart contracts are additional financial support instruments that can be combined with other finance schemes to increase the success of a financing approach. A smart contract has the terms of the agreement between buyer and seller directly written into lines of code. It permits trusted transactions and agreements to be carried out among disparate, anonymous parties without the need for a central authority, legal system, or external enforcement mechanism.

Tax relief is a possible fiscal instrument. If a government wants to promote the development of geothermal projects, certain tax measures could be introduced, for example, tax relief for investments into geothermal projects.

3.6. Environmental Risks and Risk Mitigation Measures

Perceived environmental factors have been cited as one of the critical reasons affecting public acceptance of geothermal energy [65]. The various environmental effects were classified in terms of environmental matrices, namely:

- Air pollution risks, including emissions to the atmosphere;
- Water risks, including water pollution and water consumption;
- Land risks, including induced seismicity, land subsidence, and solid waste;
- Noise and visual pollution and radioactivity.

Table 4 summarises some key environmental risk mitigation measures as per group of environmental risks [61].

Table 4. List of Environmental risk mitigation measures (based on [61]).

	Environmental Risk Mitigation Options (ER)
Atmosphere	ER-1. The geothermal plant should be designed to avoid any steam releases into the atmosphere and NCGs should be treated at the cooling tower .
Water	ER-2. Installation of wells casing to prevent groundwater contamination. ER-3. Grouting the Borehole Heat Exchangers (BHE) or sealing the annulus. ER-4. Legal constraints on the installation of geothermal systems (especially open loop) in water protection areas for drinking waters.
Land	ER-5. Project owner to implement the Protocol for Induced Seismicity Associated with Geothermal Systems. ER-6. Align the boreholes through a cement-based backfill. ER-7. Installation of local seismic monitoring networks that report any unwanted activities.

Solid waste	ER-8. Selection of contractor(s) with good environmental record. ER-9. State in contract requirements on special waste ponds. ER-10. Consider thermodynamic scaling control rather than inhibitors to minimise hazardous substances in the geothermal fluid. ER-11. Important to select only contractor(s) that have a good environmental record. State in contract requirements on special waste ponds.
Noise, visual pollution, and radioactivity	ER-12. Careful siting of the plant to avoid ecologically and historically sensitive areas. ER-13. Minimise surface disturbance and visual impact during construction. ER-14. Careful landscaping during operation. ER-15. Application of sound barriers, such as the plantation of trees at adjacent locations. ER-16. Ear protective equipment for the workers. ER-17. Use of inhibitors to keep the radioactive nuclides in solution. ER-18. Application of hearing protection for the workers. ER-19. Noise barriers to avoid disturbances in residential areas. ER-20. Avoiding ecologically sensitive areas where possible.

3.7. Development of the DT

The construction of the DT should follow a logical order from start to end and should end up with a reasonable solution.

The DT starts by asking about the phase of the project, as this is a key determinant for the available options. The second node of the path refers to the user's objective, identified above.

For the first objective, social engagement strategies need to be employed; the decision nodes to select which strategy is most appropriate are explained in Section 3.7.1. The second and third objectives can be addressed by employing appropriate financial instruments, as explained in Section 3.7.2. Environmental risk mitigation options are also provided; financial risk mitigation options are provided as per financial instrument in [16,17].

3.7.1. Selection of Social Engagement Strategies

Figures 4 and 5 illustrate the DT branches for a project during the development and operation phase. Focusing on the first objective, to enhance public engagement in the project (to increase social acceptance), the selection of appropriate social engagement strategies is required. Subsequent questions trigger several branches to reflect the screening criteria as determined from the literature/discussion with experts. The first question is about social awareness, followed by questions regarding compliance with the relevant legal requirements, public perception of environmental and social risks, and the public's appetite for financial and/or intellectual participation in the project.

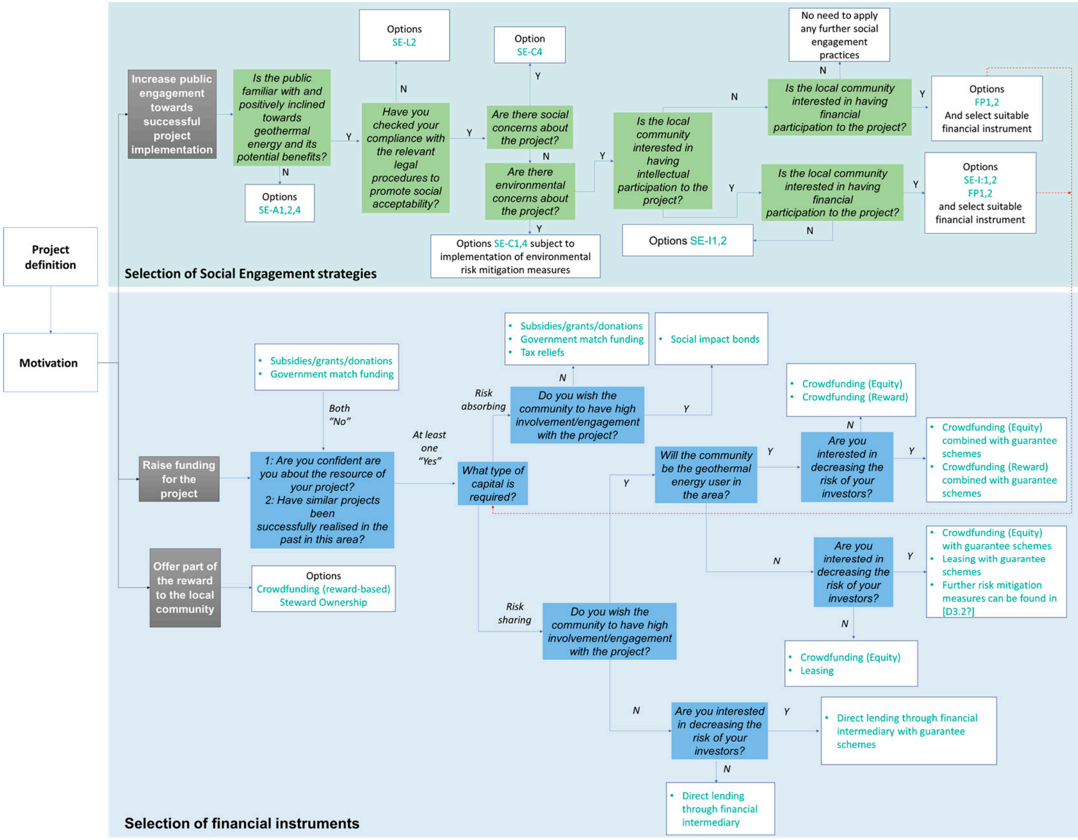

Figure 4. DT—Project definition phase.

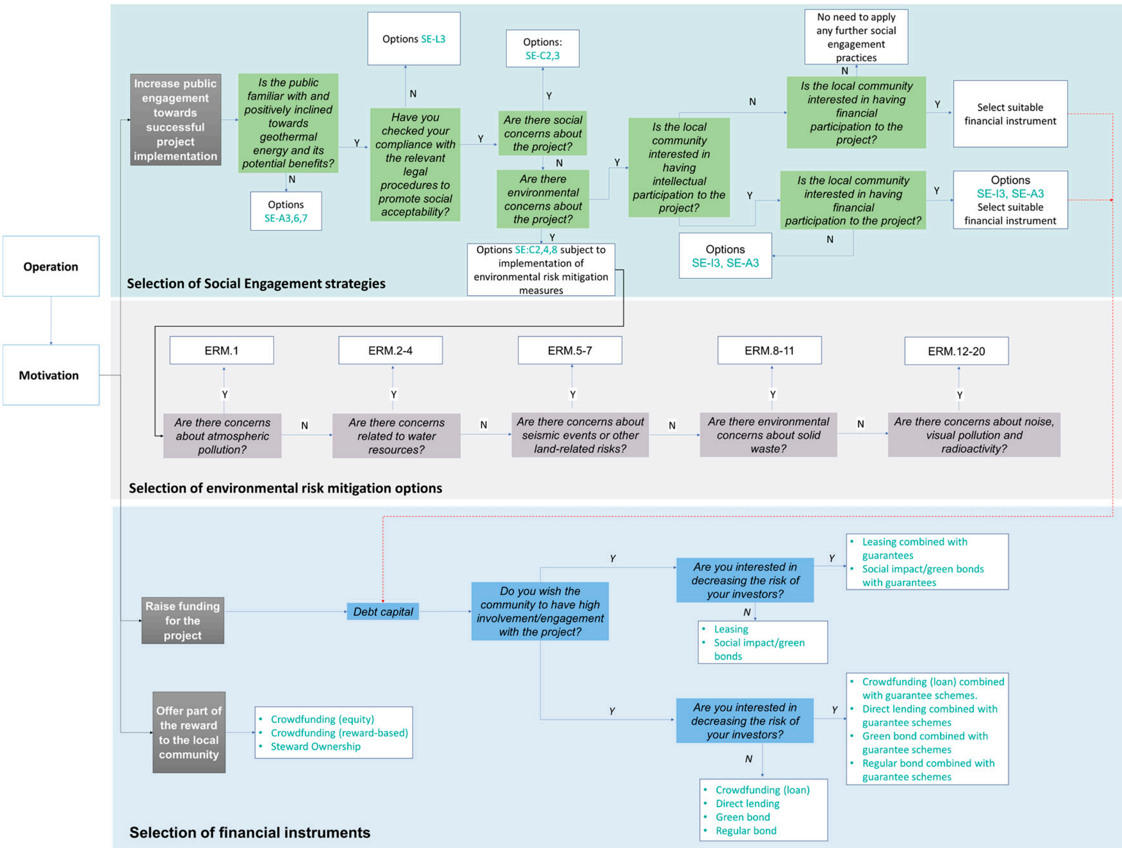

Figure 5. DT—Operation phase.

Twenty-three (23) social engagement strategies have been identified, summarised in Table 2 (although this is by no means an exhaustive list). Some social engagement strategies focus on the dissemination and provision of information about the project, increasing social awareness and outreach. Other strategies emphasise promoting the interaction with the public and/or the participation of the public in fundraising activities and the decisions of the project. Finally, other options refer to compliance with the relevant legal procedures as a means to promote social acceptance.

- The first decision node asks: *"Is the public familiar with and positively inclined towards geothermal energy and its potential benefits?"*

In the case of "No", the tool proposes specific social engagement activities focusing on educating and informing the public about geothermal energy in general, as well as the specific project under development. Indicative activities include the "Announcement of the project through diverse communication channels" and "Communication of project development progress in regular intervals to relevant authorities/stakeholders/public", among others depending on the phase of the project.

- Once the awareness of the public has been verified, the next decision node checks the compliance with the relevant legal procedures (e.g., licences, formal sharing of project information): *"Have you checked your compliance with the relevant legal procedures to promote social acceptability?"*

This is an important question to make sure that all necessary actions (announcement, licences, information) with all related stakeholders (local communities, local authorities, direct users, scientists/local universities, and local NGOs) have been conducted. Depending on the project phase, indicative actions include ensuring the planning permit is in place and providing access to required information/hearings of stakeholders and the public according to the legal framework. Another relevant strategy is setting up a project advisory board that meets at regular intervals to exchange information on the latest developments and interacts with relevant sector agencies, nature conservation associations, or environmental protection associations.

- Although society may be aware of the benefits of the geothermal project, there may still be a reluctance to support its development due to social and environmental concerns. The next node of the DT asks: *"Are there social concerns about the project?"*

Social conflicts/concerns may also prevent a geothermal energy project from advancing to the next phase and influence the public´s acceptance of geothermal energy projects. Social concerns may originate from project-, process-, and context-related factors [60]. For example, a key social concern includes the lack of trust in individuals that are part of the decision process of the geothermal energy project. A significant strategy to avoid distrust is through the provision of information about geothermal projects from diverse sources independent of the official information provided by the responsible operator (e.g., assign and maintain a direct and reliable contact person to whom the media and public could turn to with all their questions and concerns). Information coming from independent scientists is often perceived by the public as more reliable compared to energy companies or national governments: "Hiring external experts/scientists to communicate project-specific information (technical, environmental, social, financial) and to address stakeholders' questions".

Project developers should also develop a public communication strategy of when to communicate, what to communicate, to which target groups, and how. Encouraging active citizen participation—i.e., through the participation of the municipality in the project, or a connection to local heating networks so that citizens can become joint users of the energy generated—tends to increase the feeling of ownership from the public, thus enhancing social acceptability. Awareness-raising activities and information campaigns may also be relevant to address social topics associated with perceived advantages and disadvantages of the project, as well as the wider socio-political context.

- Perceived environmental factors have been cited as one of the critical reasons affecting public acceptance of geothermal energy. The next node of the tool asks: *"Are there environmental concerns about the project?"*

In case the public has expressed concerns about environmental issues associated with the project, the developer/promoter should first ensure that appropriate environmental risk mitigation measures are in place, including against noise, visual, and odour annoyances (further activities are summarised in Table 4 as per type of environmental risk). More information about the environmental risk mitigation options as a function of the project phase can be found in [50]. Under this node, the user is redirected to the Environmental Risk Mitigation (ERM) DT algorithm to obtain tailored information about risk mitigation options against the relevant environmental risk. Providing extensive information about the environmental risks and prevention measures to relevant authorities/stakeholders/public should be a priority to reassure the public that the drilling and construction works are safe and will not induce any damages, losses, health, and life quality degradation of the local population. Information campaigns aim to address environmental and other risks and risk mitigation measures employed. Independent scientists should be invited to respond to stakeholders' questions about technical and environmental issues to increase the public's confidence. At later project phases, the public should also be offered an area where questions can be stated and collectively answered by a reliable contact person via FAQ videos on the website or social media. During project implementation (mainly drilling and construction), the public should be informed about the exact implementation plan, which phases are imminent, and what exactly will be done in these phases, as well as potential annoyances, including expected noise, steam, or odour annoyance, traffic caused by trucks at the construction site, as well as information about noise peaks and about how long the drilling phase is planned to last. Transparent and open communication on potential disturbances during the project development should always be a priority.

Ensuring that there are no social or environmental concerns about the project significantly enhances its social acceptance and the developer/promoter can proceed to the next decision node that focuses on enhancing the engagement of the public.

- Next questions allow screening of social engagement options in terms of whether the developer/promoter has engaged with the local community to identify if there is interest in intellectual participation (*"Is the local community interested in having intellectual participation in the project?"*) and, accordingly, financial participation (*"Is the local community interested in having financial participation to the project?"*) to the project.

To enable intellectual participation, similar measures to the previous questions are proposed together with measures to increase awareness. During the implementation of the project, the developer/promoter can develop a public construction/operation diary to keep the public up to date with the progress in construction works; the facility should also offer site visits/short films/virtual reality or 3D presentations of the drilling sites/flyers with images and explanations/information events. During the operation of the plant, citizens should be informed about the yielded renewable energy production (e.g., how many kilowatt hours or megawatt hours of energy were produced per day) and the $CO_{2,eq}$ savings to enhance the perceived added value of the project after commissioning. Another way to increase public participation in the project is by investigating opportunities for connection to local heating networks so that citizens can be joint users of the energy generated.

In case there is interest in financial participation in the project, developers/promoters should offer financial participation opportunities to community investors, for example, via crowdfunding platforms, as well as increase the public's knowledge through regional information markets and topic tables (risks, financing, environmental impacts, etc.). During the operation phase, opportunities for a spin-off to other joint energy projects (RES, efficiency) and dialogues with citizens about ideas for local future projects could be considered. In general, during the decommissioning phase of the project, stakeholders and citizens should be given early and transparent information about all activities according to the legal framework. For the selection of the most appropriate financial instrument, the user is redirected to the DT algorithm for financial instruments (described in Section 3.7.2).

3.7.2. Selection of Financial Instruments

Figures 4 and 5 illustrate the DT branches for the selection of appropriate financial instruments for the project definition and operation phases. DTs have been developed for the other projects phases too and can be navigated through the CROWDTHERMAL online core services [19]. In case the user is interested in raising funding (community or other forms) for the project, the focus of this path lies in estimating the level of risk and type of capital required for the investment.

- To this end, the subsequent decision node aims to specify the resource risk of the project. Resource risk is checked by asking two questions: "*Are you confident about the resource of your project?*" and "*Have similar projects been successfully realised in the past in this area?*"

This is an important step considering that resource risk has a direct impact on the community investors' exposure to financial risk, as well as the financial development and success of the project. For example, in cases where no similar projects have already been developed in proximity to the installation area before and/or existing resource data of the location are not credible/confirmed, the geothermal resource risk is typically high. Resource risk is checked by asking two questions:

If the answer to both questions is "No", then the resource risk is considered very high, and the most appropriate financial instruments are subsidies/donations and crowdfunding equity. In cases where at least one question is "Yes", the resource risk is considered moderate or low and the user can proceed to the next decision nodes to determine the expected financial characteristics for the project.

- Accordingly, questions about the size ("*What size of capital is required?*") and type of capital required ("*What type of capital is required?*") further narrow down the range of financial instrument options appropriate.

As such, financial instruments are screened in terms of the required capital size and type, as the suitability of different finance methods highly depends on the life-cycle phase and financial characteristics of the project [16]. For example, in the case of low-to-medium required capital and risk-absorbing capital type, government match funding, leasing, social impact bonds, and guarantee schemes can be considered. However, for high required capital, leasing and social impact bonds may not be appropriate options. In cases of small-to-medium, where debt capital is required, a crowdfunding loan can be used. However, this may be challenging in the early project phases [16]. Furthermore, it lacks the flexibility of crowdfunding equity since it comes with a fixed interest rate which must be paid irrespective of a potential delay in project implementation. Direct lending combined with governmental guarantees can be easier-to-raise capital compared to a bank loan, especially in the early phases of the project. It is a less complex financial option since the project developer must deal with only one financial intermediary, who nevertheless is likely to ask for higher collateral during project phases with high risk (for example exploration) [16].

Available types of capital include debt, risk-absorbing, risk-sharing, and reserves. As already mentioned, the life-cycle phase of the project has an important effect on the selection of financial instruments. During the initial phases of the project, the developer should investigate whether subsidies/grants/donations are provided by the government for clean energy projects. The decommissioning and post-closure phase of the project may be financed via government funds and retained profits.

In cases where there is interest in financial participation through risk-sharing capital, crowdfunding equity/reward, revenue-based financing, and smart contracts can be used, depending on the respective project phase. In the case of debt capital, crowdfunding loans and direct lending (with guarantees) should be considered for financing the project, especially in the early stages of the project. Green bonds, regular loans, and regular bonds without guarantees should be considered during the later stages of the project. Governmental guarantees can be used as a risk mitigation measure.

- In cases where the risk-sharing type of capital is selected, subsequent questions aim to assess the desired level of public involvement/engagement ("*Do you wish the community to have high involvement in the project?*") and whether the community is going to be the geothermal energy end-user in the area ("*Will the community be the geothermal energy user in the area?*").

Following the specifications summarised in Table 3 for each financial instrument about the level of community involvement, as well as taking into account the project phase, the tool provides the options that would be most appropriate for the specific setting. Accordingly, the tool checks whether the community will be the geothermal energy end-user in the area. If yes, for example, the reward-based crowdfunding option would be considered a relevant alternative. Reward-based crowdfunding promotes local project ownership, public engagement, as well as the acquisition of a social licence to operate.

After the decision tree tool has provided the financial instruments options that are most appropriate for a specific setting, the user can follow further links to CROWDTHERMAL wiki sites listing the potential risks and possible risk mitigation measures per financial instrument. The risks and risk mitigation options for a specific financial instrument are displayed both for the project developers' and for the community investors' perspectives. The wiki sites' contents are based on the compilation of key advantages, risks, and risk mitigation measures for the most common alternative financial instruments in the CROWDTHERMAL alternative finance risk and risk mitigation inventory [16,63]. This inventory allows project developers and community investors alike to systematically improve their risk management and decision-making processes when choosing a specific alternative finance instrument for fundraising or as an investment.

Finally, if the user aims at ensuring the community receives a part of the reward, steward ownership and reward-based crowdfunding are the most appropriate options.

The advantages, risks, and risk mitigation measures of each alternative financial instrument are documented in [16,17,63].

3.8. DTs for the Project Definition and Operation Phase

In Figures 4 and 5, the decision trees for the project and operation phases are illustrated. These two project phases were selected because they exhibit significant differences both in terms of effective strategies for social engagement and financial instruments that would be more appropriate to be investigated.

3.8.1. Selection of Social Engagement Strategy

During the project definition phase, a common way to increase awareness/familiarity with the project is the project announcement using diverse communication channels as well as the early and transparent information sharing about the project development progress in regular intervals. During the early stages of the project, the developer should come up with a public communication strategy on when to communicate, what information to communicate, to which interest groups and how to communicate it. The legal procedures that the developer has to follow mainly concern providing access to required information and offering opportunities for hearings of stakeholders and the public according to the legal framework. Even at this early stage, the public might have concerns about environmental and other risks associated with the project. To this end, information campaigns about environmental and other risks as well as the risk mitigation measures employed to address them should be carried out. External experts and scientists should be part of this communication campaign to provide project-specific information about technical, environmental, social, and financial aspects of the project and finally to address stakeholders' questions. If there is an interest in further intellectual participation on the part of public, the developer can set up a project Advisory Board that meets at regular intervals to exchange information on the latest developments and to make sure there is a regular exchange with relevant sector agencies and environmental associations providing transparency on the decisions taken at this early stage of the project.

On the other hand, during the operation stage of the project and assuming that the previous phases of exploration and construction have been successful, a key measure to increase awareness and familiarity about the project is to communicate the yielded renewable energy production and carbon emissions savings to enhance the perceived added value of the project after its commissioning. More direct ways for the local community to increase familiarity are to offer visits to the site and provide a direct way for people to learn and get educated about the benefits of sustainable energy. Further, the developer can organise regional information markets and topic tables (risks, financing, environmental impacts, etc.). It is very important throughout all phases to provide transparent and open communication on potential disturbances during the project operation, such as increased traffic caused by trucks or any other incidents taking place during the operation of the plant. It is also important to have assigned, and maintain, a direct and reliable person with whom the media and the public can communicate any questions and concerns.

3.8.2. Selection of Financial Options

The resource risk of a geothermal project is typically high during the early stages of the project [16]. Therefore, the first question of this DT branch seeks to determine the level of resource risk of the project. If there is no record of similar projects in the area, and at the same time the existing local resource data are unavailable or of insufficient credibility, the project is characterised as highly risky and the recommended type of financing is risk-absorbing capital, including subsidies/donations and grants. On the other hand, if at least one of the arguments above is positive, the resource risk is considered moderate, leading the user to the next decision node, which refers to the financial characteristics of the required capital.

During the project definition phase, risk-sharing and risk-absorbing capital are more relevant, while during the operational phase, the resource risk has been addressed and the financial risk is lower, hence debt capital can be raised, with a lower associated weighted average cost of capital [16]. As such, during the project definition phase, if risk-absorbing capital is required, the next decision node refers to the desired level of community involvement. If the answer is positive, the next step is to specify if the community is going to be the geothermal energy user in the area. This question determines if financial schemes, such as crowdfunding (equity), crowdfunding (reward-based), or steward ownership schemes would be reasonable to be considered. Subsidies/grants/donations, reward-based funding, government match funding, and tax relief could be appropriate options to investigate. Social impact bonds would be more relevant for a higher level of community involvement. For risk-sharing capital and high involvement of the community, crowdfunding equity and leasing could be appropriate options, as well as reward-based crowdfunding in cases where the community would also be the geothermal energy user. In cases where the developer is not interested in giving away ownership of the project, another option would be direct lending. The final decision node asks if there is interest to decrease the level of investor risk. In the case of a positive answer, risk mitigation strategies could include insurance or/and guarantee schemes to protect against financial losses.

3.8.3. Selection of Environmental Risk Mitigation Options

The decision tree also provides information about relevant environmental risk mitigation options, depending on the type of environmental risk as well as the phase of the project. Environmental risks during the project definition phase are minimal, and to this end, they are not included in the decision tree. Environmental risks are more evident during the drilling, construction, operation, and decommissioning phases, as documented in [61]. It is highlighted that environmental risks vary greatly with the technology type of the geothermal plant. Therefore, depending on the geothermal plant type, during the operational phase, environmental risks can be classified as:

- Atmosphere: fugitive emissions from open systems, leakage of inflammable and poisonous working organic fluid.
- Water: water use for the water-air cooling/air cooling tower, the release of water vapour from cooling towers, groundwater contamination from geo fluids, and make-up water requirements.
- Land: the disappearance of geysers, induced seismicity, and land subsidence.
- Solid waste: hazardous solid waste produced by scaling in the system
- Noise, visual pollution, and radioactivity: visual impact during operation, noise from cooling towers and generator.

Depending on the type of environmental risk, the corresponding risk mitigation strategy is proposed by the tool (Table 4).

4. Discussion

4.1. Conceptualization

A decision tree is a valuable tool for mapping possible strategies that can be affected by several influencing factors. One of the key benefits of the method lies in the fact that decision-making follows a transparent approach, which can be easily explainable and traceable back to the stakeholder with no technical expertise, as required inputs relate to information specific to the project. In this work, we presented the DT branches for two project phases of a geothermal energy plant, focusing on the social, environmental, resource-related, and financial characteristics of a project rather than the technological specificities. Nevertheless, similar trees have been developed for other phases and objectives of the decision-making process for geothermal energy projects [66].

Although a decision tree should aim for simplicity to achieve usability from different stakeholders, it is imperative that it is constructed in a way that incorporates stakeholders' expertise. For this work, questions corresponding to decision nodes have been defined following a case-study analysis of multiple projects, a thorough review of the literature, and expert consultation, which has been part of the CROWDTHERMAL project [62]. This project aims at empowering the public to participate in the development of geothermal projects through social engagement tools and alternative financing schemes like crowdfunding [18]. For the development of the DT tool, a consortium workshop took place prioritising objectives that could be solved through the tool. Following consultation, a large number of questions were identified (stemming from the identified influencing factors), which then had to be reduced to lead to a manageable number of questions and a cohesive structure. To achieve this, questions had to be consolidated where possible. Accordingly, a set of preliminary decision trees was developed and communicated with the consortium to validate the sequence of questions and composition of the tree, as well as to ensure that it adds value to different groups of stakeholders.

The DT is not intended to provide quantitative answers; namely, it is a categorical variable DT, including categorical target variables. It is, rather, intended to provide a workflow, including a sequence of questions that focus on social, environmental, resource risk, and financial influencing factors, following a logical order from start to end, to screen which strategies would be most appropriate for a specific setting. A continuous variable decision tree could quantify the risk for each of its branches, accounting for the likelihood and associated cost (consequence). This type of DT requires data specific to each of the questions and is difficult to incorporate social factor-related questions. Often, Key

Performance Indicators (KPIs) are used to aggregate the impact of multiple numerical features, such as gross value added (GVA) and net present value (NPV), among others [67].

It is important to mention that the type of geothermal energy technology is also a determining factor in choosing the most appropriate social engagement strategy, financial instrument and, most importantly, environmental and other risk mitigation measures. Environmental concerns associated with geothermal energy projects differ substantially among deep and shallow geothermal systems; for example, induced seismicity is a risk associated with deep geothermal projects. Environmental concerns for shallow geothermal (<500 m, such as horizontal closed-loop heat exchangers) are commonly less major and may mostly involve concerns about groundwater contamination due to the concentration of bacteria and leakage of additives and other compounds to aquifers due to potentially poorly sealed boreholes [61]. Incorporating technological characteristics would, however, largely increase the complexity of the tool as it would require technology-specific information about the impact of the technology type on social and financial factors, shifting the focus from the integration of social, environmental, resource risk, and financial characteristics, which is the scope of this paper. Rather, this tool offers an overview of the spectrum of factors (and their meaningful sequence) that a developer/promoter of geothermal energy should consider towards achieving a successful outcome. Nevertheless, the DT can offer shallow- vs. deep-geothermal-specific information on environmental risks and risk mitigation options, as shown in [61].

As mentioned above, key stakeholders of the DT tool are developers/promoters of geothermal energy projects seeking alternative funding solutions or social engagement strategies for their projects. These are knowledgeable people on the project specificities, its technical characteristics, and the geology of the location. To this end, more specific questions about technology and geology, addressed already by the feasibility study, were not included.

Another aspect to highlight is the ability of the DT to accommodate different socio-political contexts. In countries where geothermal energy is a mainstream energy resource, such as Iceland, public familiarity is expected to be high and the project is likely to receive high public acceptance [41], even for deep geothermal energy plants for power generation use, involving more intrusive technology and extraction of geothermal fluids [61]. On the other hand, in other countries, such as Greece, there are strong reactions from the residents against the large-scale exploitation of deep, high-temperature geothermal resources (above 90 °C) as a result of lost confidence from deficiencies of past projects; nevertheless, low-temperature geothermal (temperatures between 25–90 °C) utilization is perceived much more positively [68]. The DT tool seeks to provide flexibility to accommodate different socio-political contexts by not including context-specific questions, such as national legislation, which is country-specific and also tends to change over time (e.g., energy subsidies are typically phased out). Rather, it seeks to provide an overall framework that can be used across different socio-political contexts.

4.2. Implementation

For the application of the DT to a concrete case, the categories presented (see Figure 4) provide an orientation for the procedure right from the beginning, with the project definition phase. In order to select the appropriate social participation strategy, the first step is to identify the central characteristics of the project municipality and the local actors. This includes, among other things, what information is needed, whether there is experience with geothermal or other energy infrastructure, and whether conflicts or specific fears, concerns, and needs exist. Likewise, interests regarding an active participation in the planning of the geothermal project or related compensatory measures as well as any financial participation can be inquired. This can be done by a stakeholder analysis in the run-up to the strategy planning. Possible instruments for this analysis are qualitative interviews, quantitative questionnaire surveys, or media analyses. Based on the results, information and communication measures as well as concrete participation opportunities can be defined. Within the framework of participation, individual questions of the DT can then also be discussed together with the local actors, so that, in combination with the stakeholder analyses and participation formats based on them, the DT can also be used as an interactive participation instrument, in addition to its function as planning support. In this way, the DT can contribute to more transparency and comprehensibility and thus have a positive effect on the perceived procedural justice. Depending on the concrete project, its geological conditions, the knowledge of the geothermal resource, the geothermal energy technology used, and the current project phase, the most suitable financial participation and financial risk mitigation strategies will largely vary.

In the CROWDTHERMAL case study in Madrid, Spain, for example, two housing co-operatives are using shallow geothermal to provide heating, cooling, and domestic hot water to their building blocks [69]. As shallow geothermal energy projects with closed-loop systems, there was only very little risk associated with the geothermal resource. It was therefore possible to co-operatively finance the projects without any specific financial risk mitigation instruments. For deep geothermal projects, on the other hand—especially in areas with no reference projects in the vicinity—the risk of not finding a geothermal resource in sufficient quantity for economically viable operation is much higher. In such cases, project developers who wish to use community funding in early project phases should carefully consider financial risk mitigation options like loan guarantees.

The DT reflects these project-specific risk considerations by asking questions on the project phase, on the confidence about the resource, on any reference projects in the area, on the financial risk level, and on the interest to decrease the financial risk for the investors. Depending on the project-specific answers given, the DT suggests the most suitable financial instruments as end nodes, where appropriate, in combination with the proposed financial risk mitigation strategy.

5. Conclusions

This paper presents a decision support tool based on a decision tree structure for developers/promoters of geothermal energy projects seeking ways to achieve one of the following objectives:

- Increase public engagement towards successful project implementation;
- Identify alternative financing and risk mitigation options with increased community involvement.

While available studies (including toolkits and protocols) commonly list a set of practices for public engagement and financing without providing information on the factors which render certain options more suitable than others, the presented tool offers a framework for mapping possible strategies and reaching to a well-informed decision after consideration of key influencing (resource risk, environmental, social, and financial) factors. It follows a transparent approach, which can be easily traced back by the stakeholders without technical expertise. The presented tool is not intended to provide quantitative answers; rather, it offers a workflow, including a sequence of questions originating from the social, environmental, resource-related, and financial background of the project. It follows a logical order and screens available options/strategies to address the above-listed objectives. The questions included were shortlisted with the aim to increase the usability of the decision tree and consider the necessary steps toward reaching a decision. However, this list is not to be considered exhaustive.

As mentioned above, social engagement strategies and financing instruments highly depend on the project life-cycle phase as it affects the level of investment risk. To this end, the root node first identifies the project phase and, accordingly, separate branches are developed per project phase. The leaf nodes of the DT algorithm are social engagement strategies and (alternative) financing schemes, while the decision nodes include questions related to social, environmental, resource risk, and financial aspects of the project.

It is important to note that the options in the leaf nodes may also be affected by the type of geothermal technology, as well as the socio-political context of the investment. Going into specific socio-political contexts was beyond the scope of this study (instead, questions included in decision nodes were kept general enough to not restrict the application of the tool to a specific country but to fit different socio-political contexts), while the distinction of strategies in terms of the technology type was realised to the degree possible only for the environmental risk mitigation strategies.

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