DESTRESS

Demonstration of soft stimulation treatments
of geothermal reservoirs

Deliverable 2.1: Risk and time/readiness maps of all relevant keys

WP 2: Business case - key performance indicators based analysis

Lead Beneficiary	EnBW
Type	☑ R - report, document etc. ☐ OTHER - software, technical diagram etc. ☐ DEM - demonstrator, pilot etc. ☐ E - ethics ☐ DEC - website, patent filing etc.
Status	☑ Draft ☑ WP manager accepted ☑ Project coordinator accepted
Dissemination level	☑ PU - Public ☐ CO - Confidential: only for members of the consortium
Contributors	☐ 1-GFZ ☐ 5-GES ☐ 9-GTL ☐ 13-SNU ☑ 2-ENB ☐ 6-TNO ☐ 10-UoS ☐ 14-KIC ☑ 3-ESG ☐ 7-ETH ☐ 11-TUD ☐ 15-ECW ☐ 4-UoG ☐ 8-GTN ☐ 12-NEX ☐ 16-WES
Creation date	13.02.2017
Last change	27.02.2017
Version	final
Due date	28.02.2017
Submission date	28.02.2017

This project has received funding from the European Union's
Horizon 2020 research and innovation programme
under grant agreement No 691728

Systematic preparation of the techno-economic evaluation of soft stimulation

Risk and time/readiness maps of all relevant key factors

Fig. 1: Wellhead with pipeline for stimulation. © EnBW

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Publication Date

February 28, 2017

Abstract

The report at hand is part of the framing process within decision analysis. Decision analysis can be seen as a systematic approach, which is applied for the techno-economic evaluation of soft stimulation. Therefore the concept of decision analysis and its connection with risks and uncertainty is introduced in detail. Beside a general overview on the decision analysis approach and an explanation of the single steps, relevant terms are discussed. This forms an important basis for further techno-economic investigations within DESTRESS. The Framing process defines the temporal but also the areal frame of the investigation. Additionally technical and economical parameters are identified and evaluated. On the one hand they need to have an important impact on the later evaluation, but on the other hand they also need to be integrateable with reasonable effort. The focus of the following investigations is kept on the identification and semi quantitative evaluation of these parameters. To get a comprehensive access to the topic two different approaches were used. While the dependency-structure-analysis is derived from strategic corporate planning, the risk analysis approach comes from cooperate risk management. As a starting point for the dependency-structure-analysis expert knowledge was used within a simple mind map approach to identify parameters influencing the techno-economic evaluation of soft stimulation. These parameters were evaluated and later prioritized to form a sound basis for the later development of a techno-economic-model. In contrast to the dependency-structure-analysis, risk analysis has a clear focus on risk factors. Therefore the concept of risk is introduced and differentiated from uncertainty. Based on that, the methodological concept of risk assessment and risk prioritization is presented to show the results of a conducted risk assessment. The report is completed by economic investigations of soft stimulation. Based on real projects, economic data for soft stimulation has been collected so that key figures can be derived for the further techno-economic investigation of soft stimulation, when the economic input will be evaluated against the technical output of soft stimulation.

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1 Introduction

> "Soft Stimulation is a collective term for geothermal reservoir stimulation techniques that aim to achieve enhanced reservoir performance while minimizing environmental impacts including induced seismicity. Soft stimulation includes techniques such as cyclic/fatigue stimulation, multi-stage stimulation, chemical stimulation and thermal stimulation." (Ellis & Huenges, 2016)

The above cited definition shows, that theoretical and practical considerations of the technical issues of soft stimulation already exist. In contrast, techno-economic investigations of soft stimulation and related techniques, especially against the background of geothermal energy production, are rare. To anchor this promising concept within the daily business of geothermal energy production, a techno-economic evaluation is a necessary part of the whole story. Therefore the DESTRESS project wants to deliver a comprehensive techno-economic investigation of soft stimulation under consideration of uncertainty and risks. This report shall deliver a starting point.

Hereinafter a systematic preparation of the techno-economic evaluation of soft stimulation will be presented. Therefore chapter 2.1 introduces the concept of decision analysis and its connection with risks and uncertainty. Afterwards relevant parameters are identified and evaluated within a dependency-structure-analysis. Chapter 3.2 introduces the concept of risk and differentiates it from uncertainty. Based on that, the methodological concept of risk assessment and risk prioritization is presented to show the results of the conducted risk assessment. The report is concluded by economic investigations of soft stimulation in chapter 4. Based on real projects economic data for soft stimulation has been collected so that key figures can be derived for the further techno-economic investigation of soft stimulation.

2 Techno-economic evaluation of soft stimulation

2.1 Soft stimulation as part of a business case

Is soft stimulation worth its effort? From an economic point of view, is it wise to use soft stimulation in geothermal exploration? Which risk factors and uncertainties do I face while performing soft stimulation and how do they affect my project?

A sustainable acting company developing a geothermal field will ask these and more questions before performing soft stimulation. The use of a certain technology must be based on a techno-economic evaluation, which is nothing more than the often used term "business case". A business case brings transparency to an investment. It is "… the vision captured in numbers" (Lewitz, 2010). A business case combines different scenarios for a possible investment and provides a certain basement for decision within a company. Decision analysis as a structured approach of comparing different alternatives is able to integrate risks into the evaluation process and allows within its normative approach the selection of the best possible alternative.

2.2 Decision analysis as methodological frame

Within the DESTRESS-project decision analysis shall therefore give the methodological frame for investigating soft stimulation form a techno-economic point of view and in the end answer the above posed questions.

In the literature the decision analysis process is structured in five main steps which shall be explained briefly subsequently. Fig. 1 displays the five steps in the order of the process. Thereby it is important to adapt the single steps to the actual decision problem and implement a loop if necessary.

2.2.1 Frame the problem

Framing the problem is not only the first but also the most crucial step in decision analysis as the frame conditions for the following investigations have to be defined. Before defining the objective function and the key performance indicators (KPI) the investigated system has to be specified. Thereby not only the temporal but also the areal frame of the investigation has to be defined. Additionally technical and economical parameters have to be defined that are on the one hand valuable for the later evaluation but on the other hand also integrateable into the model with reasonable effort. Therefore the main sensitivities should be identified initially in a qualitative process. If the identified (qualitative) sensitivities shall be implemented quantitatively into the model in step 2, one also needs to determine whether they shall be integrated deterministically or stochastically. The stochastic approach is however richer and more comprehensive than the deterministic approach in representing risk factors and uncertainties, which shall later be treated in section 3.2. The qualitative analysis of sensitivities, uncertainties and risk factors pose a threat as by their nature these process steps are subjective. At the same time they strongly influence the frame of the problem so that these steps should preferably be a group task to reduce subjectivity. Nevertheless with considerable effort a complete objectivity can't be expected (Laux, Schenk-Mathes, & Gillenkirch, 2012; Almeida, et al., 2015; Bos & Wilschut, 2011).

2.2.2 Set-up the model

The mathematical representation of the reality within a model needs to be planned beforehand to reduce effort. First logical rules representing the processes to be simulated have to be defined. These processes define which quantitative input variables are to be formulated and how. Given quantitative values for the input variables, the processes to be simulated should result in model output: KPIs and time-series, etc. Basic questions like the programming language have to be answered and the available resources in terms of hardware and time have to be considered. The model should be as detailed as necessary to answer the posed questions. On the other hand (Bos & Wilschut, 2011) an "over modelling" should be avoided. At the same time one has to accept that models are only approximations of the reality. "All models are wrong, but some are useful" (Box, 1979).

2.2.3 Investigation of alternatives

Based on the defined frame conditions a model based simulation of the desired KPIs for the different alternatives is conducted. The type of input variables (deterministic/stochastic) thereby also decides on the evaluation process. For a stochastic survey the use of decision criteria like the μ-rule or the (μ,σ)-rules are possible. Both calculation rules are used for calculating risk in conformity with the definition in chapter 3.2.1. The difference between the two approaches is the representation of the probability distribution (Laux, Schenk-Mathes, & Gillenkirch, 2012). For the evaluation of uncertainties the Monte-Carlo-Simulation has proven itself to be a valuable methodology, through reducing the effort and at the same time creating a statistically sound basis (Bos & Wilschut, 2011).

2.2.4 Revision

The revision step is used to verify the gained results. E.g. one has to verify that the frame conditions are respected. For legal, technical or economic reasons some results may be invalid so that they shouldn't be available in the further steps. Sensitivity analysis has proven itself as very useful to assess the results and maybe adapt the frame conditions. Loops including step 1 to 4 can become necessary to improve the quality of the decision (Laux, Schenk-Mathes, & Gillenkirch, 2012; Bos & Wilschut, 2011) .

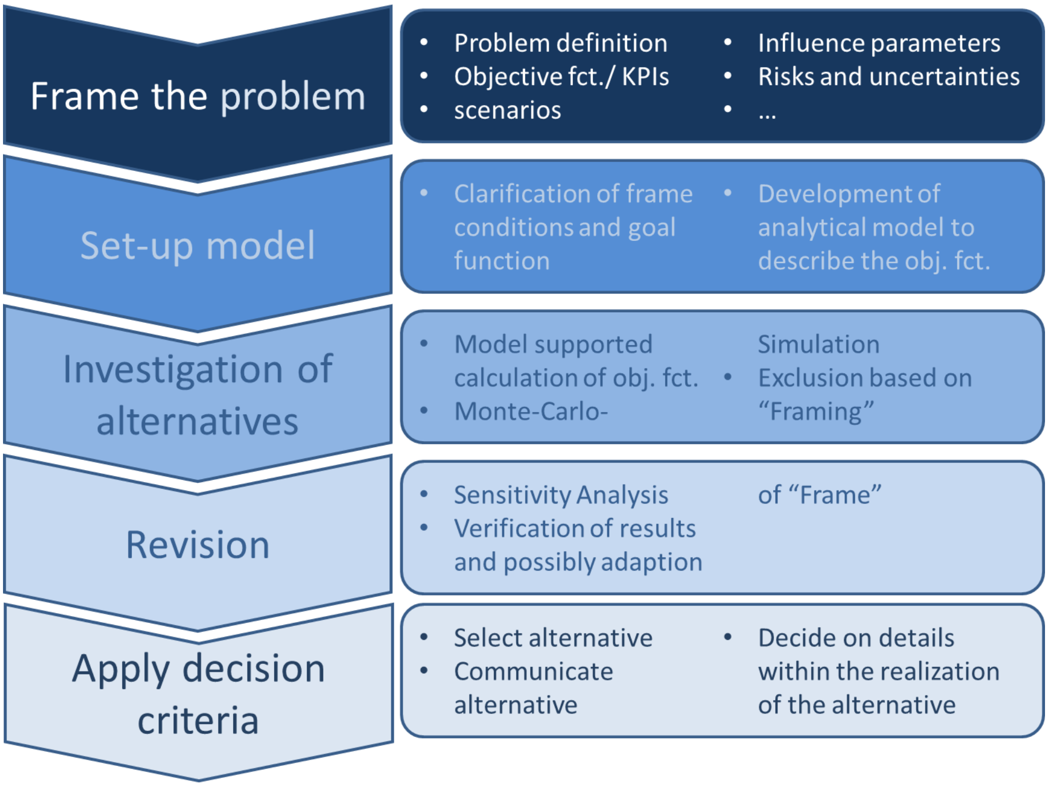

Fig. 1: Process of decision analysis © (Laux, Schenk-Mathes, & Gillenkirch, 2012; Almeida, et al., 2015; Bos & Wilschut, 2011)

2.2.5 Apply decision criteria

Based on the beforehand defined decision criteria and the calculated KPI, the best alternative is chosen. Although the general decision task has been solved, the realization of the chosen alternatives needs additional decisions in detailed questions. Besides the pure selection of a decision alternative, the communication within the organization needs special care so that the implementation becomes possible from a social point of view (Laux, Schenk-Mathes, & Gillenkirch, 2012; Almeida, et al., 2015).

Following the above described process the investigations hereinafter are part of the framing process. The identification and qualitative evaluation of sensitive parameters is a mandatory step also affecting business cases.

3 Identification and qualitative evaluation of relevant key factors

As stated in chapter 2.2.2 "All models are wrong, but some are useful" (Box, 1979). The techno-economic evaluation of soft stimulation shall give operators of geothermal sites the possibility to evaluate the pros and cons of this technology package. The evaluation is based on a techno-economic model that shall give the possibility for a sound evaluation of soft stimulation. A basis for this is a tailored representation of the real world. To guarantee an efficient modelling process the following chapter identifies relevant key factors for the techno-economic evaluation of soft stimulation. Therefore two approaches are taken. One comes from strategic corporate planning and is a combination of mind mapping and cross impact analysis while the other is derived from risk management. Both are semi-quantitative approaches. For practical reasons only a limited amount of experts was interviewed so the results are unavoidably biased by the personal knowledge of each expert. Therefore the results presented afterwards have a preliminary framing character and will surely go through an evolutionary process throughout the DESTRESS-project and therefore change in their final form.

3.1 Strategic management approach

A central aspect of strategic management is identifying and evaluating the influences of a particular course of action on a project or company. These skills are also needed, when framing a decision problem. Therefore, subsequently various strategic management tools shall be used to identify sensitive parameters.

3.1.1 Mind map

"Mind map" is a creative tool to structure a topic and identify influencing parameters (Schawel & Billing, 2014). It is used as a starting point for the following cross impact analysis. Literally the center of the mind map is the question "which parameters (including model input variables, processes and intermediate state variables) influence the techno-economic evaluation of soft stimulation". Although a sharp separation of single aspects may sometimes be difficult as technical, economic and social parameters are mixed, the approach still gives a valuable input in the identification process.

Fig. 2 shows the constructed mind map of parameters influencing the techno-economic evaluation of soft stimulation. As a base assumption hydraulic stimulation was used, as all parameters influencing hydraulic stimulation can also be found in other stimulation measures that are part of the soft stimulation approach. Parameters specific to one stimulation were highlighted (see legend in Fig. 2). All over all nine categories were identified, ranging from 1 – 28 elements. Especially the cost category attracts the attention by a sometimes very detailed breakdown. On the one hand this enlarges the later evaluation effort; on the other hand it shows the comprehensive approach and has no severe impact on the quality of the investigation. A strong influence was also put on the so called "weak", social factors of the categories "public affairs" and "PM & engineering". These parameters are difficult to be represented in an analytic model, but practical experience proves their importance. Within the group of rather technical categories the only tools that were explicitly investigated were pumps. This can be explained by their crucial position within all operation measures.

3.1.2 Dependency-structure-analysis & relevance analysis

As Fig. 2 shows, multiple economical and technical parameters have an influence on a business case including soft stimulation. Without an in-depth analysis it becomes obvious that there are parameters having a strong influence but can only be influenced in a limited range and vice versa. For performing a comprehensive techno-economic evaluation of soft stimulation, it is therefore necessary to evaluate the impact of parameters quantitatively as well as the possibility to influence them. High impact parameters shall if possible be represented stochastically as in reality these parameters rarely can be defined deterministically. Influenceable parameters on the other hand, should be addressed with mitigation measures to assure a positive impact on the geothermal exploration project. Therefore, hereinafter dependency-structure-analysis as a methodology for semi-quantitative evaluation of impact and controllability is presented.

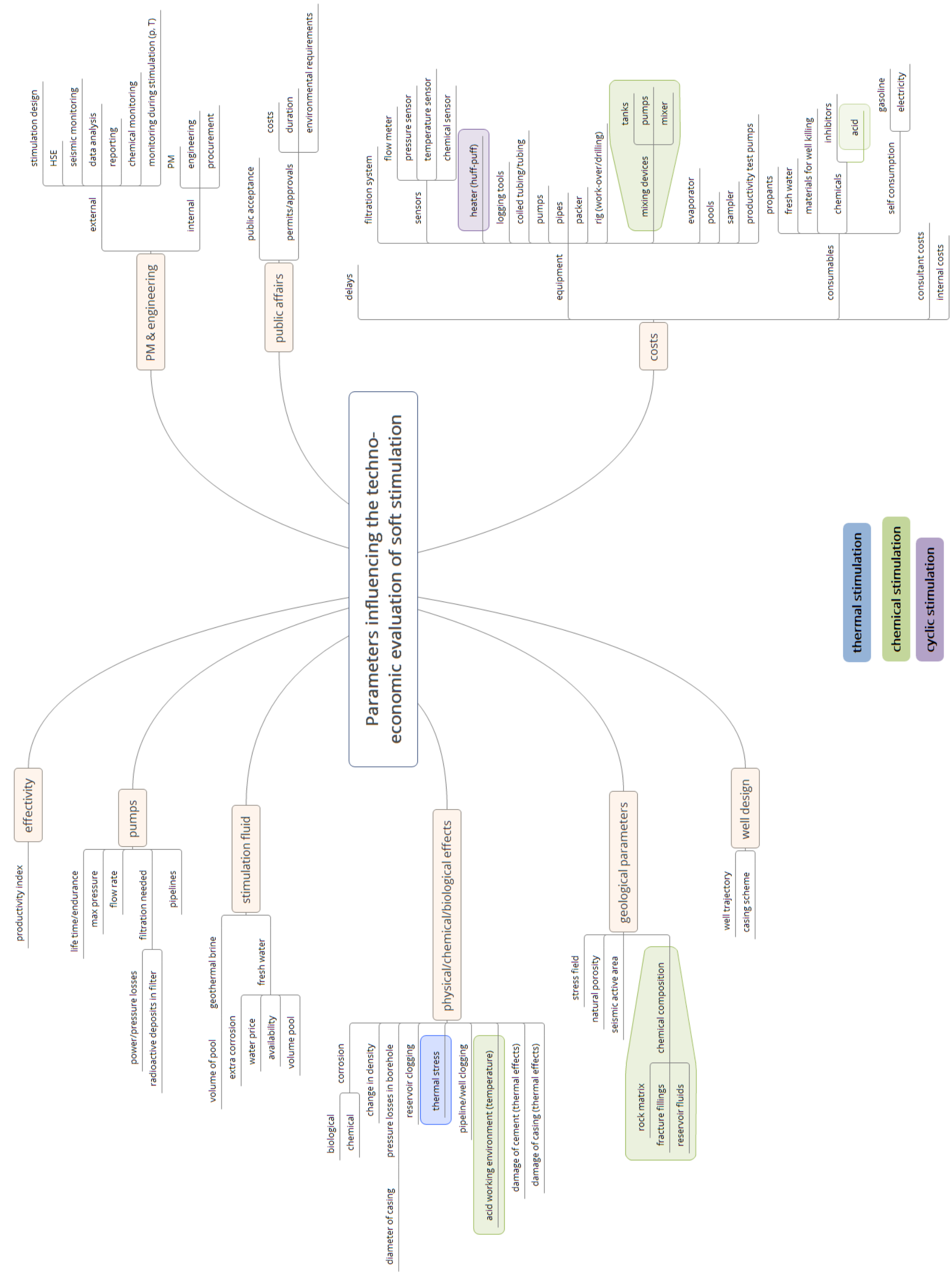

Fig. 2: Parameters influencing the techno-economic evaluation of soft-stimulation

The dependency-structure-matrix or design structure matrix (DSM) is a matrix based tool for investigating impact and controllability of complex systems. Within the matrix the mutual impact of different parameters can easily be mapped. The evaluation can either be done by analogues or through a simple, additional evaluation of the intensity. For the evaluation of the intensity a scale from 0 to 3 has been established. Thereby 0 means no dependency while 3 stands for intense dependency. The general question that has to be answered is: "If parameter A is changing, how strongly is parameter B be affected". An important point while doing a dependency-structure analysis is that only direct dependencies can be mapped. For the evaluation of indirect dependencies other tools have to be used. Table 1 shows an example for a dependency structure matrix (Herfeld, 2007; Balazova, 2004; Bilalis, Maravelakis, Antoniadis, & Moustakis, 2004).

Table 1: Example for a dependency-structure matrix

	Parameter A	Parameter B	Parameter C	…	active sum
Parameter A					
Parameter B					
Parameter C					
…					
passive sum					

Summing up the values of each column vector one gets the so called passive sum. The sum of each row vector is called active sum. Thereby the active sum shows the strength of the influence of one parameter on all the other parameters. On the other hand the passive sum gives an indication for the strength of the influence of all other parameters on a certain parameter (Balazova, 2004).

The active and passive sum can be used to map each parameter. From a strategic point of view this allows to categorize the single parameters in four different groups, to enable a strategic treatment of each parameter. Table 2 categorizes the different groups and gives an indication for their strategic significance. Additionally Fig. 3 shows the strategic categorization of parameters through active and passive sum. The calculation specification for the separation of the different categories is given through (Equation 1). (Equation 1) can be calculated with active and passive sum as input parameters and gives the crossing point of a horizontal and a vertical straight line that separate the single categories listed in Table 2.

$$x = \frac{\sum_{i=1}^{n} active\ sum_i}{n}$$

Table 2: Strategic categorization of parameters through active and passive sum (Aumayr, 2009)

Name	Characterization	Interpretation
passive	Limited influence on other parameters; strongly influenced by other parameters	Controlling parameter → good for evaluation of results
idle	Small influence on other parameters; only slightly influenced by other parameters	Uninteresting parameters → not in focus from strategic point of view
critical	High influence on other parameters; actively influenced by other parameters	Steering and controlling → dangerous as steering parameter as closely networked
active	Active influence on other parameters; modestly influenced by other parameters	Steering parameter → Ideal for changing the system

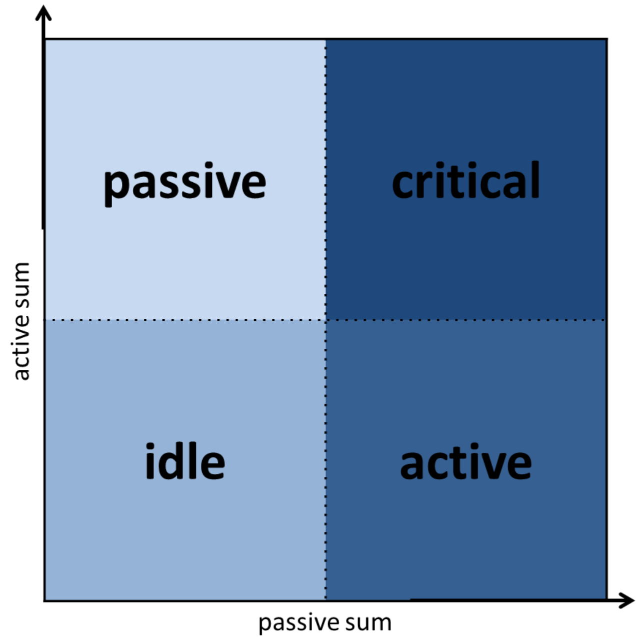

Fig. 3: Schematic representation of categorization of dependency-structure-matrix

Based on the parameters presented in Fig. 2 a dependency-structure-analysis was performed. For the mind map as well as for the dependency-structure-analysis in total seven experts were interviewed. . A bigger expert pool including different specialists covering all topics of soft stimulation is desirable and could lead to more reliable and precise results. Therefore the presented results should be called preliminary and will be updated throughout the DESTRESS project. Because of the relatively large amount of parameters investigated within the dependency-structure-analysis the results scatter over a wide range, which makes graphic representation challenging. Therefore three figures (Fig. 4, Fig. 15 & Fig. 16) with different categorization and zoom but the same results are shown.

In addition to the dependency-structure-analysis a relevance analysis was performed. Within the relevance analysis the matrix structure of the dependency-structure-analysis can be reused. The task consists of a pairwise comparison of parameters (Gausmeier, Pfänder, & Lehner, 2016). The question to answer is, which parameter is more relevant for the overarching question. The evaluation itself is again based on expert knowledge. As a result the sum of all pairwise comparisons can be calculated. The so called “relevance-value” can then be used to rank different parameters or prioritize within groups as will be done in the following investigations.

As part of the framing process, the combination of dependency-structure-analysis and relevance-analysis shall help to identify important parameters that should be represented within the model. The importance of parameters in this context means also the question whether a parameter should be modelled deterministically or stochastically. Fig. 4, Fig. 15 & Fig. 16 show the results of the dependency-structure-analysis. Although scattering of single parameters can be observed, it is still possible to drive conclusions for the classification of categories. Therefore hereinafter the single categories will be presented. Subsequently Fig. 4 shows the mean value for the investigated nine categories. Already with this superordinate visual presentation overall tendencies can be identified, while the representation is much clearer. Nevertheless, the detailed representations in Fig. 15 & Fig. 16 offer additional insight which is why the explanation for each category also includes Fig. 15 & Fig. 16.

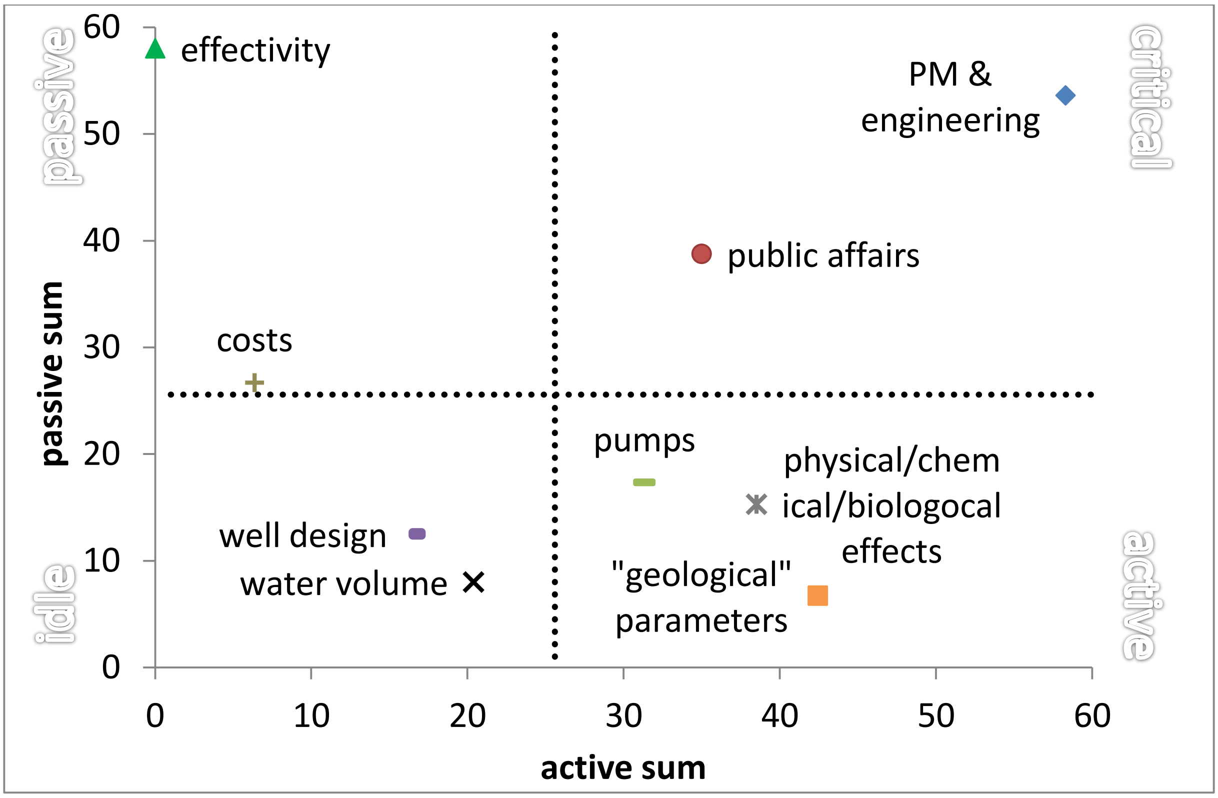

Fig. 4: Results of dependency-structure-analysis on a category basis

PM & Engineering

This category consists of parameters with a tendency towards an overarching position within a geothermal project in general or soft stimulation in special. The category “PM & Engineering” shows the biggest scatter of all categories. 40 % of the parameters take an outstanding position within the active-category. The other parameters still show high active and passive sums, but scatter over different categories. This shows the central importance of this category. The character of the single parameters and their significance suggest using the parameters for the development of decision alternatives within the decision analysis approach. The relevance-analysis in Fig. 17 is ambiguous so that a prioritization is not possible. Exclusively “HSE” stands out as a parameter with low active and passive sum but high relevance.

Public affairs

“Public affairs” is a small category with only four parameters. While “public acceptance” and “environmental requirements” are clearly situated in the active part, the duration and costs of permits are evaluated as being passive parameters. This impression is strengthened through the relevance analysis in Fig. 18, which shows a relatively small relevance for duration permits and even no relevance for costs of permits. Therefore only public acceptance and environmental requirements will be modeled.

Pumps

For the category “pumps” the dependency-structure -analysis shows a clear tendency towards the “idle”-section, what can be interpreted as not being relevant. Half of the parameters can be classified as idle. As a counterpart max pressure and flow rate are active parameters, but in practice these parameters are only a question of ordering a pump with adapted parameters. As a result this category won’t be modelled in detail.

Water volume

Compared to the “Pumps” category, the parameters grouped as “water volume” can be found even more in the lower left corner of the dependency-structure-analysis. Therefore also this category won’t receive special attention while modelling.

Physical/chemical/biological effects

As explained in Table 2 active parameters are well suited for steering, as their influence is big, but they are not influenced by others. The parameters grouped under the category “physical / chemical / biological effects” mainly belong to this category. The separation between idle and active parameters in this category is also supported by the relevance analysis. All parameters in the active part have a relatively high relevance, while idle parameters don’t. The only exception “damage of casing by thermal effects” could be combined with “thermal stress” so that only the parameters in the active area will receive special attention during modeling.

Geological parameters

The group “geological parameters” includes not necessarily only parameters that can be clearly categorized as being geological in a scientific sense. Other parameters that come into effect below the surface were also attached to this group. Here all the parameters can be found in the active area so that they are well suited as steering parameters. The relevance analysis shown in Fig. 20 allows a prioritization on five parameters, so that acid working environment and rock matrix will only be taken into account as deterministic inputs.

Well design

The group “well design” with only two parameters is completely categorize as idle, so that no specific modelling efforts are necessary.

Costs

As expected the parameters within the cost group are strongly influenced by other parameters, which make them either passive or idle. This result suggests a deterministic representation of cost parameters based on functions. “Delays” is the only outlier in this picture. As most of technical equipment of stimulation measures is rented on a time basis, delays can indirectly have an immense impact on costs so that this parameter should be modelled explicitly.

Effectivity

The group effectivity consists only of one parameter, as the effect of stimulation measures can directly be measured through the change in the relationship between drawdown and production rate. As expected the PI has an active sum of zero and is therefore correctly categorized as controlling parameter.

As a contribution to the framing process, strategic management tools like mind-map, relevance-analysis and dependency-structure-analysis proved to be useful. Through these tools it was possible to identify and prioritize parameters. This leads to a list of parameters that shall be explicitly modelled in the following process step of decision analysis. This also includes the question of modelling a parameter deterministically or stochastically.

3.2 Risk identification & prioritization

Another entrance to the question of modelling parameters deterministically or stochastically is the risk assessment. This semi-quantitative approach tries to identify and prioritize risk factors. Compared to the strategic management tools used in chapter 3.1 the focus is clearly set on uncertain parameters that shall or should be modelled to support the decision analysis process. Risk as a term and investigation object is used in a diverse variety, so that in a first step some clarifications are necessary.

3.2.1 Risk in the context of decision analysis

In reality there is always an uncertainty on the data relevant for a decision. At the time a decision is made the result therefore can't be predicted deterministically, as the parameters influencing the relevant data are uncertain. (Laux, Schenk-Mathes, & Gillenkirch, 2012; Ale, Burnap, & Slater, 2012). Against the background of decisions under uncertainty quantitative risk analysis (QRA) has proven to be the foundation for sound decision making (Abrahamsson, 2002). QRA as part of decision analysis (see chapter 2.2) can be assigned to the "investigation of alternatives" step, where the stochastic nature of uncertainty is integrated into the decision analysis process.

$$R = \sum_{i=1}^{n} p_i * c_i$$

$$E[U(a_q)] = \sum_{i=1}^{n_{Oq}} p(O_i|a_q) * u(a_q, O_i)$$

Risk as an output of QRA is always a quantitative measure that combines a certain consequence with a certain probability. Mathematically this can be expressed in its simplest from through (Equation 2), where R stands for risk, c for the consequence, p for the probability of that consequence and i for the number of single discrete consequences. The evaluation/ranking of single alternatives within decision is then done based on the overall risk or more generally on the expectation value of the utility of each alternative (Equation 3). In (Equation 3) expected utilities $E[U(a_q)]$ stands for expectation value of the utility for all the different alternatives, q = 1, 2, ..n_d. Thereby n_{Oq} is the number of possible outcomes, O_i is related to the alternative a_q, while $p(O_i|a_q)$ is the probability of each of these outcomes. Finally $u(a_q,O_i)$ is the utility associated with the set (a_q,O_i). This representation also assumes a discrete set of outcomes (Faber, Maes, Baker, Vrouwenvelder, & Takada, 2007; Kroon & Maes, 2008).

Within literature a neutral and a negative definition of risk can be found. While (Deutsches Inistut für Normung e.V., 2011) and others see risk as a positive or negative deviation from a goal caused by uncertainty, (Bos & Wilschut, 2011) and others define risk in the context of an undesired impact as all consequences worse than this undesired level. The different definitions are represented in Fig. 5, through the neutral and negative definition of risk. A detailed definition of single terms in connection with risk can be found in (Bos & Wilschut, 2011).

Building on the definition of risk the process of QRA can be mapped based on (Abrahamsson, 2002) as shown in Fig. 6.

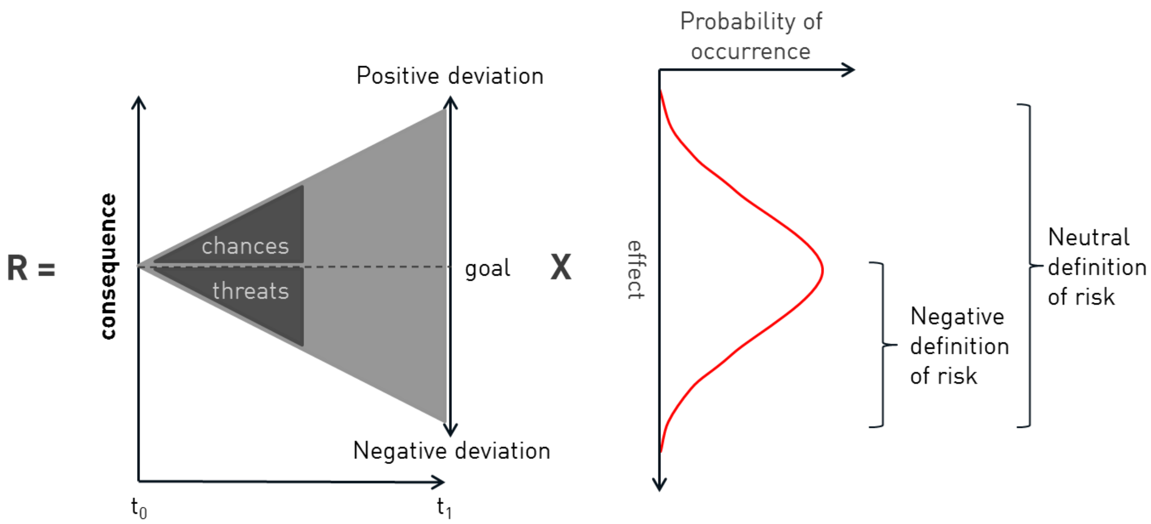

Fig. 5: Definition of risk

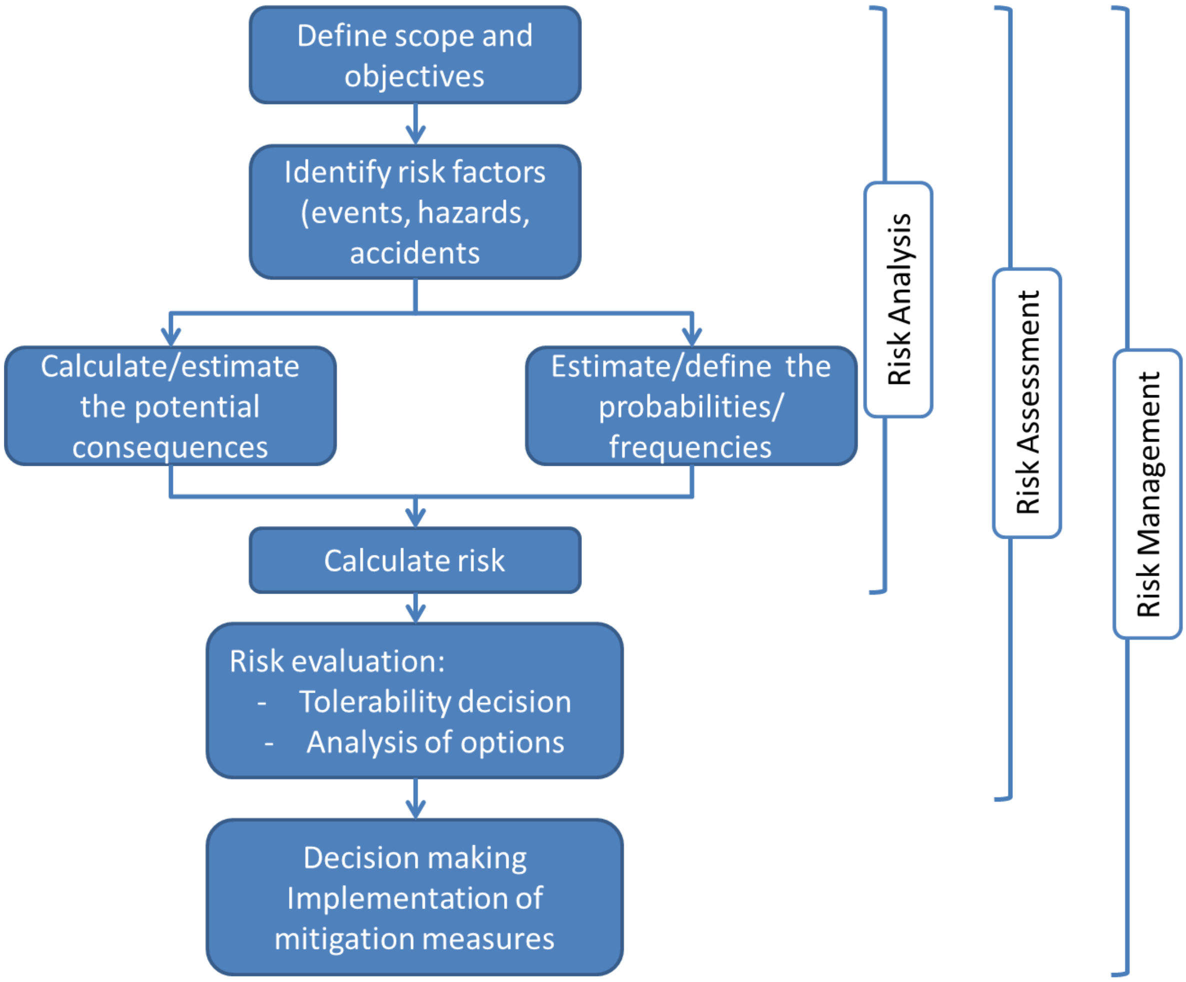

Fig. 6: Quantitative risk assessment process

3.2.2 Risk assessment process within DESTRESS

(Abrahamsson, 2002) & (Bos & Wilschut, 2011) explain within their publications the theoretic background of QRA and DA. But they also refer to the practical implementation of QRA or DA. Practical limitations in modelling (e.g. time, physical complexity …), the size of the uncertainty space or simply the availability of data limit the implementation of theoretic QRA and DA processes. Therefore a risk assessment process has been established, that is mainly based on expert knowledge. The so called educated guess is especially for events as risk factors often the only possibility to identify and quantify probabilities and consequences of single risk factors. Fig. 7 shows tailored risk assessment process with the single process steps. The process can be divided in identification, prioritization and data assessment together with simulation. While identification and prioritization can be assigned to the framing step of DA, data assessment belongs to the "set-up model" step and simulation is another term for investigation of alternatives. As this report is focused on the foundation of the framing step, in the following only the identification and prioritization steps are explained.

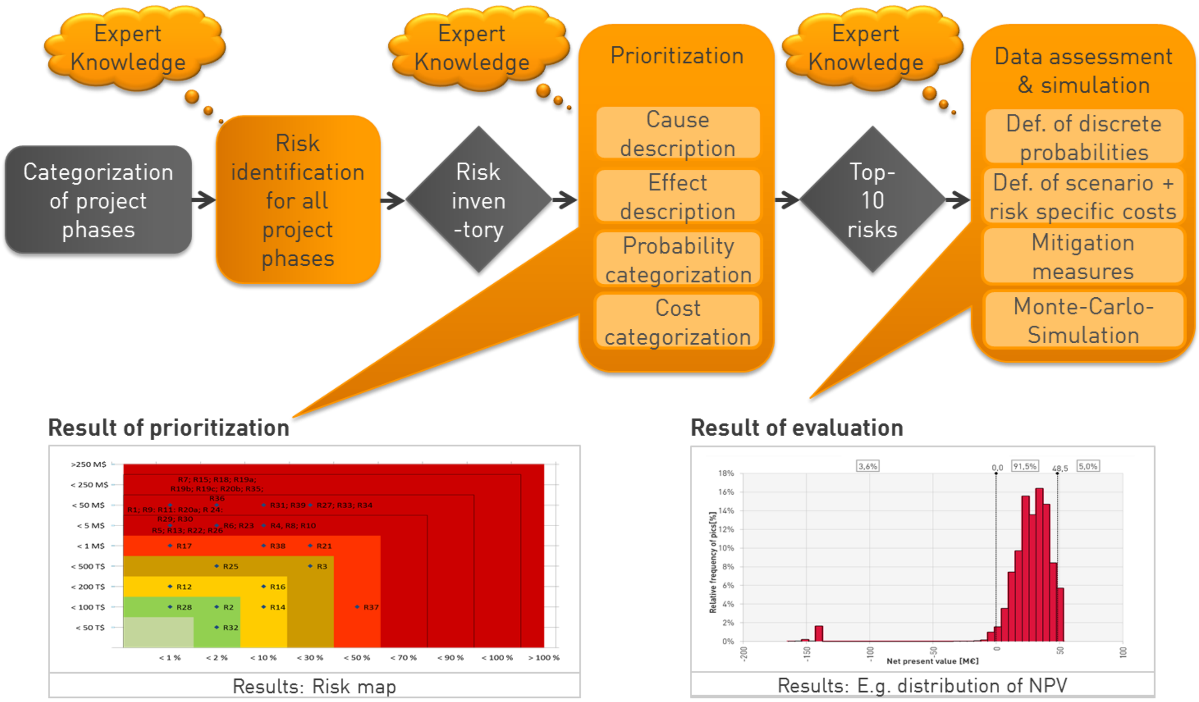

Fig. 7: Risk assessment process within DESTRESS

3.2.3 Risk identification

The identification of risk factors is the basis for any future evaluation of risk. (Jakoby, 2013) and (Holthaus, 2007) demand for a structured identification approach. As an example in- and out-flow-figures as well as process schemes are given. Both authors point out, that the identification process is a qualitative approach that should be conducted as a workshop with experts from a broad variety of disciplines.

Based on a process scheme for stimulation measures (see Fig. 21) a risk assessment workshop was held in Karlsruhe (Germany) between the 12th and the 13th of July 2016. All over all thirteen experts (in varying constellations) from multiple project partners all over Europe followed the invitation to Karlsruhe and gave insight into their practical and theoretical knowledge on stimulation.

Fig. 8: Risk assessment workshop Karlsruhe (Germany) 12th – 13th July 2016

As a result of the workshop, a list of 37 risk factors was created, that will form the basis for further steps in the framing process. The risk factors sorted by the project phases together with a description of cause and effect can be found in Table 8.

3.2.4 Risk prioritization

Following the pareto principle, a prioritization of risk factors is efficient. (Bos & Wilschut, 2011) call it "… impractical or even impossible to study comprehensively all sources of uncertainty for their impact …". Although this causes subjectivity, they recommend expert elicitation and assumptions for limiting the uncertainty space. A tool for prioritizing risk factors is the so called risk or heat map. (Ale, Burnap, & Slater, 2012) criticise the incorrect use of risk maps for the presentation of risks and explain in detail the statistically correct illustration through F-N-curves. The methodologically unsound use of risk maps can be explained through the representation of risk as single dots. As stated in chapter 3.2.1 risks are characterized through the combination of probability distribution and consequences. If one reduces this representation to a single point, the information on the distribution gets lost as the risk is reduced to a binominal distribution (Brünger, 2011). Nevertheless, to be able to map risks with a distribution other than binominal (Brünger, 2011) suggests the use of conditional value at risk (CVaR), which describes expectation value of a loss of an investment above or below a defined percentile.

In chapter 3.2.1 two different views within the definition of risk were presented. (Bos & Wilschut, 2011) define risk as probability of occurrence times undesired impact. The term undesired is connected to a norm that states some criteria (value). Values below these criteria are undesired. Based on this methodological construct one can use the CVaR approach through the negative definition or risk (see Fig. 5). The transformation of a non-binominal distributed risk factor demands for a separated treatment of probability and consequence. The approach shall be explained with the example of a fictive, normal distributed temperature gradient.

If one assumes the mode of a distribution being a plan case defined through expert knowledge. Then one could additionally assumes that this plan case is the norm for defining the term undesired, as all consequences below that plan case would be negative. The question in a poll would be: How high is the probability that the value becomes lower than my plan scenario?

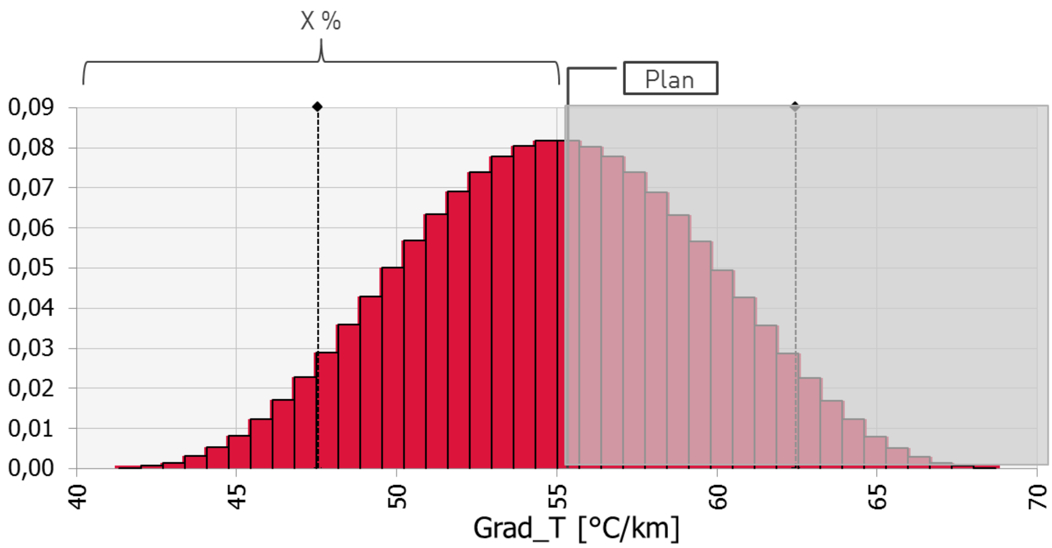

Fig. 9: Representation of a non-binominal distributed risk factor in a risk map – probability

In addition to the plan case, a worst case scenario can be defined through expert knowledge. Between the deterministic values (consequences) of these two cases a function can be spread out. With the aid of the defined function, the CVaR can be calculated as the expected value of this function.

$$\alpha \in (0,1);\ CVaR_{\alpha} = E(X|x > Plan(X))$$

Through the use of CVaR, a singular value can be constructed that describes statistical valid under the premise of the negative risk definition the distribution of the consequences of the investigated risk factor.

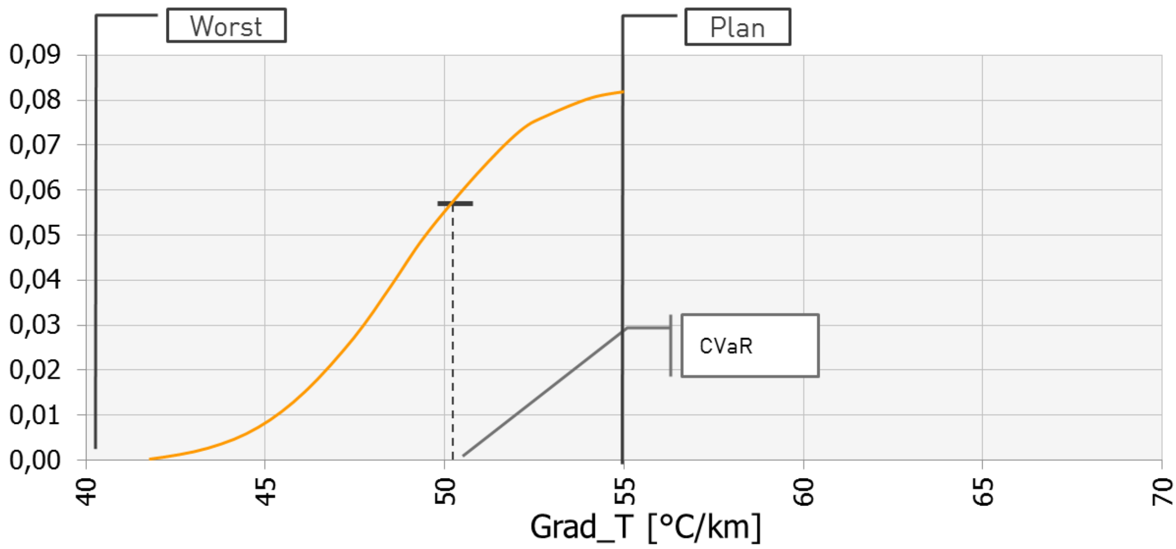

Fig. 10: Representation of a non-binominal distributed risk factor in a risk map – probability

The above explained methodology was used to construct the risk map presented in Fig. 11. Data for the calculations was collected during the risk assessment workshop as well as through a poll within DESTRESS project. For all risk factors a normal distribution was assumed. Normal distributions can be defined through standard deviation and expected value. As expected value the consequence of the base case was taken, as was defined to be zero additional costs compared to plan. Through expert election a binominal distribution for a worst case (for each risk factor) was available. Through target value search the standard deviation of a normal distribution was adapted to probability and consequences of each risk factor's worst case. As indicated in Fig. 10 the negative part of the normal distribution was reproduced through a cumulative distribution, so that the expected value can be calculated. As an extract of the prioritization process, the top-ten-risk factors are shown in Table 3.

Table 3: Results of prioritization – Top-10 risk factors

#	Phase	Code	Risk	Description of cause	Description of effect
1	ALL Phase	AP2	Public Acceptance	Citizen groups or NGO's being against the project → impact of accidents occurred in other Project sites	Loosing permission, strong delay, loss of bankability (after planning before drilling)
2	Project Development	PD1	Lack of information	Lack of information in engineering →extra data needed for planning the stimulation, →from the point of view of authorities	More/additional measuring effort →redesign based on the new information,
3	Reaction	R1	Induced seismicity (with time delay after injection)	High pressure within formation triggers seismicity	Losing public acceptance, surface damage, losing permission depending on the regulations, Project shut down
4	ALL Phase	AP3	Change in legislations	Accident occurred in another Project, additional extensive seismic monitoring and precautions etc. needed	Loosing permission, strong delay, not receiving permission
5	Injection	I6	Induced seismicity exceeding threshold	High pressure within formation triggers seismicity	Losing public acceptance, surface damage, losing permission depending on the regulations, Project shut down
6	Injection	I5	Loss of effectivity	Injection pressure damages casing cement, poor cement job	Not getting permeability increase expected, loss of project because it is economically not viable anymore
7	Reaction	R2	Fluid-rock interactions	Interactions including reactions with proppants, wrong selection of acids (concentrations of acids), inhibitors, proppants	Clogging of well, reduction of permeability, loss of project

8	Reaction	R3	Fluid-fluid interactions (thermal brine and chemicals)	Interactions including reactions with proppants, wrong selection of acids (concentrations of acids), inhibitors, proppants, microbiological processes, oxygen entrance	Clogging of well, reduction of permeability, corrosion, H_2S and other gasses production
9	ALL Phase	AP1	Political Instability	Change in the government on all levels of politics that could affect the project	Loosing permission or get extra official requirements
10	Project Development	PD2	Lost in hole (measuring tool)	Problems in additional logging with loss of tool, purely related to soft stimulation and the additional data needed	Workover or fishing needed, Losing the well, delay

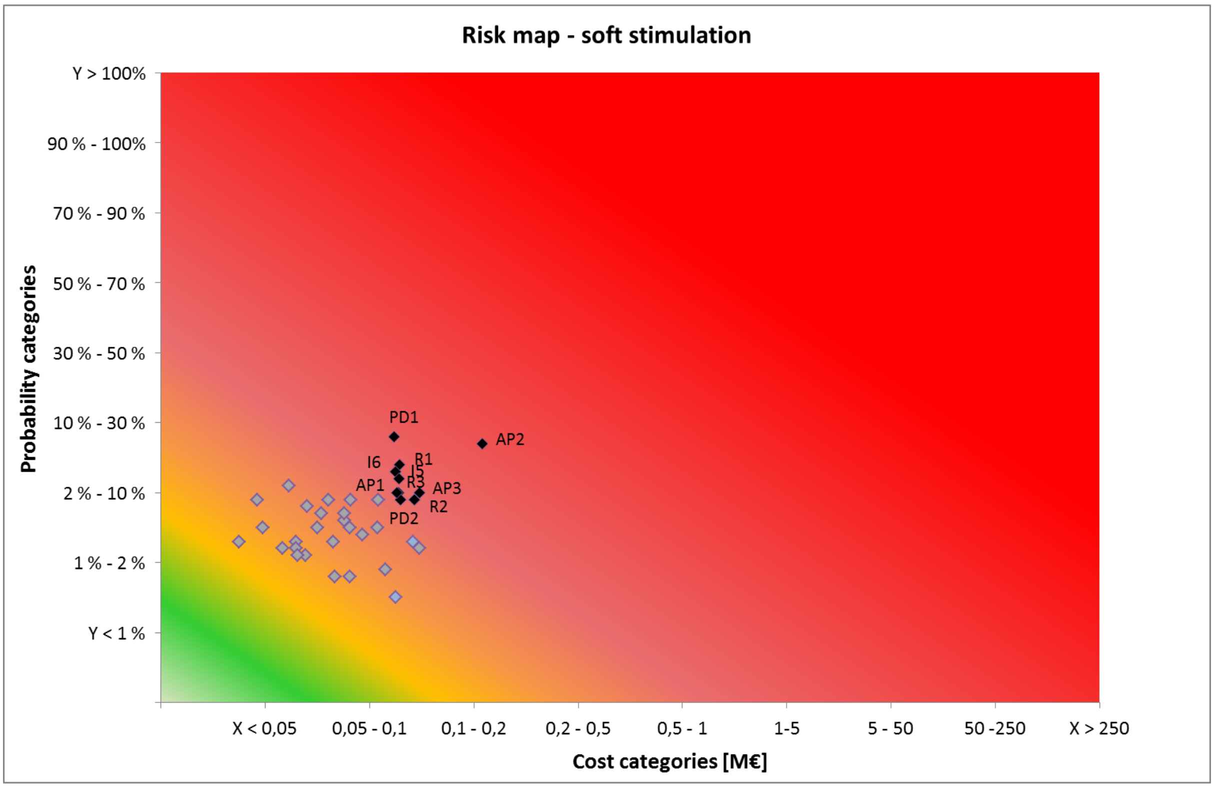

Fig. 11: Risk map – soft stimulation

Fig. 11 shows a comparison of consequences and probabilities of risk factors. The risk map is a popular tool for the prioritization of risk factors as it enables an easy visualization of results (Brünger, 2011). The risk map at hand shows the general classification of the identified risk factors according to expert judgement and names the ten most relevant risk factors. Thereby one should not forget that risk perception depends on the actual situation. Not only is the role of a stakeholder important but also the local, technical frame conditions (e.g. geology). Additionally the subjectivity in the results cannot be denied as the knowledge and number of experts is practically limited.

Nevertheless, Fig. 11 shows that the identified risk factors only have a probability of deviating from the plan case within the very low double digit percent range. From public point of view only two out of the ten most relevant risk factors have an influence on the public. The consequences of the investigated risk factors moreover only show a small financial effect. The expected value as a statistical key figure thereby maps the combination of probability distribution and consequences on a sound basis. All risk factors are evaluated with costs below 200 k€ which can be classified as controllable compared to drilling rig day rates of 50 k€. For a more detailed view on the prioritization of risk factors, Fig. 22 shows a zoomed representation with additional details.

4 Economic evaluation of soft stimulation

4.1 Introduction

Stimulation costs are not really documented or published in literature, but they considerably influence the business plan of EGS projects. They can be expensive, risky and have hazardous efficiency, but are sometimes the only way to enhance properly the hydraulic performance of geothermal wells for reaching an economically sustainable use of the resource.

This report presents a database of the costs of some selected stimulations that have been made in the granitic reservoir of deep wells drilled at Soultz-sous-Forêts and Rittershoffen (France) in the Upper Rhine Graben. The purpose of this cost estimation database is to serve the techno-economic study of soft stimulation, providing realistic, robust but simple figures for financial analysis. In a further step the presented data has to be combined with models representing the technical effects of soft stimulation to evaluate financial input against technical output.

In this database, 5 stimulation events from Soultz and Rittershoffen have been added:

- A chemical stimulation of the deep geothermal well GPK3 (Soultz-sous-Forêts) done in 2003.
- A chemical stimulation of the deep geothermal well GPK4 (Soultz-sous-Forêts) done in 2005.
- A thermal stimulation of the deep geothermal well GRT-1 (Rittershoffen) done in 2013.
- A chemical stimulation of the deep geothermal well GRT-1 (Rittershoffen) done in 2013.
- A hydraulic stimulation of the deep geothermal well GRT-1 (Rittershoffen) done in 2013.

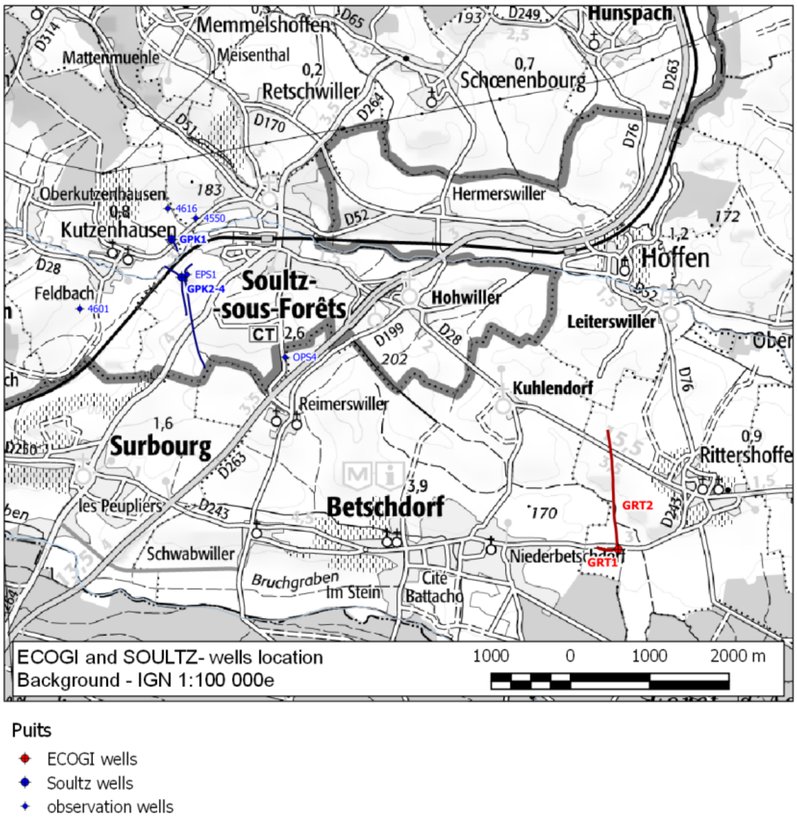

Fig. 12: Detailed location of the Rittershoffen and Soultz-sous-Forêts deep geothermal sites in Northern Alsace (France).

Those geothermal sites have been chosen because of their representativity. Soultz was a research project for more than 25 years and its wells have undergone many stimulations, with various designs and different purposes. At this EGS reference site, 15 hydraulic and chemical stimulation procedures and experiments were performed in geothermal wells at three different reservoir levels located between 2 km and 5 km depth. These measures enhanced significantly the hydraulic yield of these reservoirs, in some instances by about two orders of magnitude (Schill, Cuenot, & Kohl, 2015). In this stimulation cost analysis, we only considered the deepest Soultz reservoir between 4500 and 5000 m depth. Thus, we selected the chemical stimulations done just after the drilling of the GPK3 and GPK4 wells. The impacts of the selected stimulations on hydraulic well performances can then be used more easily to link the stimulation cost with the productivity/injectivity index improvements. The chemical and thermal stimulations of GRT-1 well have been carried out in a row, providing economies of scale that will be more representative for the costs of a full well development program. Moreover, the selected stimulations were financially documented in detail, which allowed going more in detail concerning the cost item categorization. Rittershoffen stimulation could be classified as a soft stimulation because biodegradable products were used for chemical treatments. Moreover, after chemical treatment, hydraulic stimulation was successfully performed with quite a low well-head over pressure (Baujard, et al., 2017). Through hydraulic stimulation, induced seismic activity was observed but with very low magnitude so that no micro earthquake was felt on surface.

4.2 Methodology of cost classification and evaluation

4.2.1 Data gathering:

For GRT-1 well and the Rittershoffen site: a folder containing the quotes and invoices related to well development program has been extracted from the financial archives. The technical quotes and invoices were classified according to the name and the type of the company which was subcontracted to do the stimulation job.

- The first step was to define to which stimulation each company was referring to (thermal, chemical or hydraulic).
- The second step was to find and go through the final invoices, recording each cost item and its associated price.
- The third step was to evaluate some costs that were not listed in the archive. Indeed, in some invoices much information was missing such as human resources, technical assistance, scientific support and environmental monitoring. An internal brain storming was done internally with ESG team in order to identify some forgotten items. The associated costs were evaluated by the technical experts in charge or involved in each cost items.

At this point, the results were compiled into a database, listing the different cost items (396 for GRT-1 well), with the associated parameters: cost item description, company name, well name, stimulation type (thermal, chemical or hydraulic), year, unit cost, unit, number, final cost and comment.

For GPK3 and GPK4 wells, and the Soultz-sous-Forêts site: an Excel sheet compiling the different costs per project phase has been found in the administrative digital archives under the form of an accounting summary. The final costs were already listed and categorized. As it was an accounting extract, we assumed that no cost item was missing.

At this point, the results were compiled in another database, listing the different cost items (about 250 for each well), with the associated parameters: partial cost item description, well name, stimulation type (thermal, chemical or hydraulic), year and final cost.

4.2.2 Data homogenisation

The principal issue to build a global cost item database for different stimulations is that the cost data come from various wells, different companies and are spaced by a decade. Thus, the proposed cost classification is quite heterogeneously classified. It means that the costs of two different stimulations cannot be easily compared to each other.

At this step, all the cost items have been separated into 4 different categories:

- Equipment: characterising each cost item related to the purchase or rental of technical equipment or suppliers except fluids or chemicals.
- Fluid and chemicals: characterising each cost item related to the purchase or rental of fluids (water, fuel, etc.) or chemicals (acid, salt, etc.).
- Staff: characterising each cost item related to employed staff for supervision, technical support, etc.
- Study: characterising each cost item related to any scientific or technical report.

Finally, the costs that were related to several stimulations were duplicated for each concerned stimulation. The final costs were equally divided by the number of concerned stimulations e.g. a third of the price of the stimulation program design of GRT-1 has been associated to thermal stimulation, another third for the chemical stimulation and the last third for the hydraulic stimulation. This choice has been made to simplify the discussions and the cost repartition scheme. As the global price of the concerned invoices is relatively low, the cost approximation is not significant.

4.3 Final stimulation costs for Soultz and Rittershoffen

As first result, it can be observed that the chemical stimulation is much more expensive than the thermal or hydraulic stimulation. Table 4 summarises the global costs of the different stimulations.

Table 4: Global costs of the considered stimulations in euro.

Wells	Costs in €
GRT-1	
Chemical	926 537
Hydraulic	89 005
Thermal	100 875
GPK3	
Chemical	1 069 571
GPK4	
Chemical	1 061 929
Total	**3 247 917**

The chemical stimulations are about the same order magnitude in terms of cost: 1 million euros, but the internal repartition of costs is not always similar. For the chemical stimulation of GPK3 and GPK4 wells, the cost repartition is globally the same for each category but for GRT-1 well, the staff is responsible for only 18% of the total cost, against 46% for the Soultz wells. This apparent decrease is balanced by the cost of the Fluid and chemical products, which is about 31% for GRT-1 well, against around 10% for the Soultz wells. The variation in chemical product costs is explained by the nature of the acid that has been used for GRT-1 well, which was biodegradable and consequently more expensive than the standard HCl acid used in the Soultz wells. On the other hand, for Soultz stimulations, the staff cost were higher because the operational time was longer and needed more preparation time for supervision. Moreover, the wages of all employees during the design, the preparation of the stimulation and the operations have been assigned to the stimulation staff cost.

tions of the three wells.

Table 5 summarises the repartition of the costs for the chemical stimulation of GPK3, GPK4 and GRT-1 wells. Fig. 13 shows the detailed cost repartition for the chemical stimulations of the three wells.

Table 5: Repartition of costs for the chemical stimulations of GRT-1, GPK3 and GPK4 wells.

	GRT-1		GPK3		GPK4	
	Costs in €	% of total costs	Costs in €	% of total costs	Costs in €	% of total costs
Equipment	364 497	39.34%	394 429	37.23%	344 871	32.48%
Staff	167 633	18.09%	491 607	46.41%	462 474	43.55%
Study	108 757	11.74%	92 154	8.70%	114 473	10.78%
Fluid & Chemicals	285 650	30.83%	81 111	7.66%	140 111	13.19%
Total général	**926 537**	**100.00%**	**1 059 301**	**100.00%**	**1 061 929**	**100.00%**

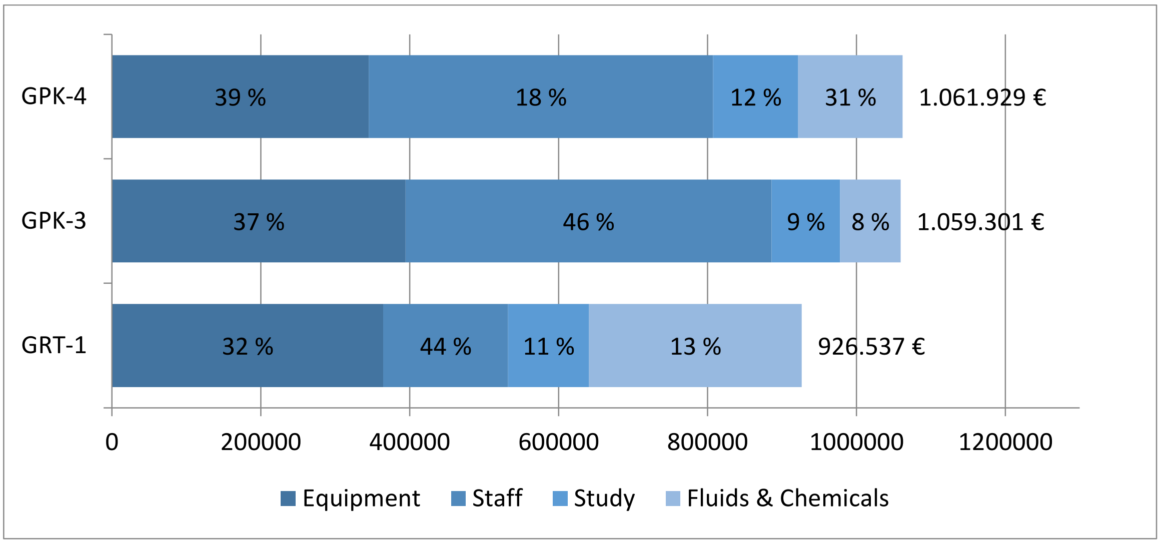

Fig. 13: Economic comparison of stimulation measures in GPK-4, GPK-3 and GRT-1

For GRT-1 well, a comparison of the three stimulations shows that the cost repartition fluctuates a lot. For the chemical stimulation, the equipment costs are lower than for the other stimulations but the fluid and chemical part is significant because of the use of biodegradable acid. For the thermal stimulation, the equipment costs represent a lower proportion of the total costs than for the hydraulic stimulation, because of the need of pumps, flow rate and pressure control is less important. On the other hand, the staff costs are higher because thermal stimulation took more time (Table 6).

Table 6: Cost repartition for the stimulations of GRT-1 well.

	Chemical		Hydraulic		Thermal	
	Cost in €	% of total cost	Cost in €	% of total cost	Cost in €	% of total cost
Equipment	364 497	39.34%	66 188	74.36%	54 445	53.97%
Staff	167 633	18.09%	11 560	12.99%	30 573	30.31%
Study	108 757	11.74%	11 257	12.65%	15 857	15.72%
Fluid & Chemicals	285 650	30.83%		0.00%		0.00%
Total	**926 537**	**100.00%**	**89 005**	**100.00%**	**100 875**	**100.00%**

For a complete stimulation program, the study of costs based on GRT-1 well gives a global proportion of 83 % for the chemical stimulation, 8 % for the hydraulic one and 9 % for the thermal stimulation (Table 7). The global cost repartition for the complete stimulation program is shown in Fig. 14.

Table 7: Cost repartition for the complete stimulation program of GRT-1 well.

	GRT-1	
Stimulations	Costs in €	% of total costs
Chemical	926 537	82.99%
Hydraulic	89 005	7.97%
Thermal	100 875	9.04%
Total	**1 116 417**	**100.00%**

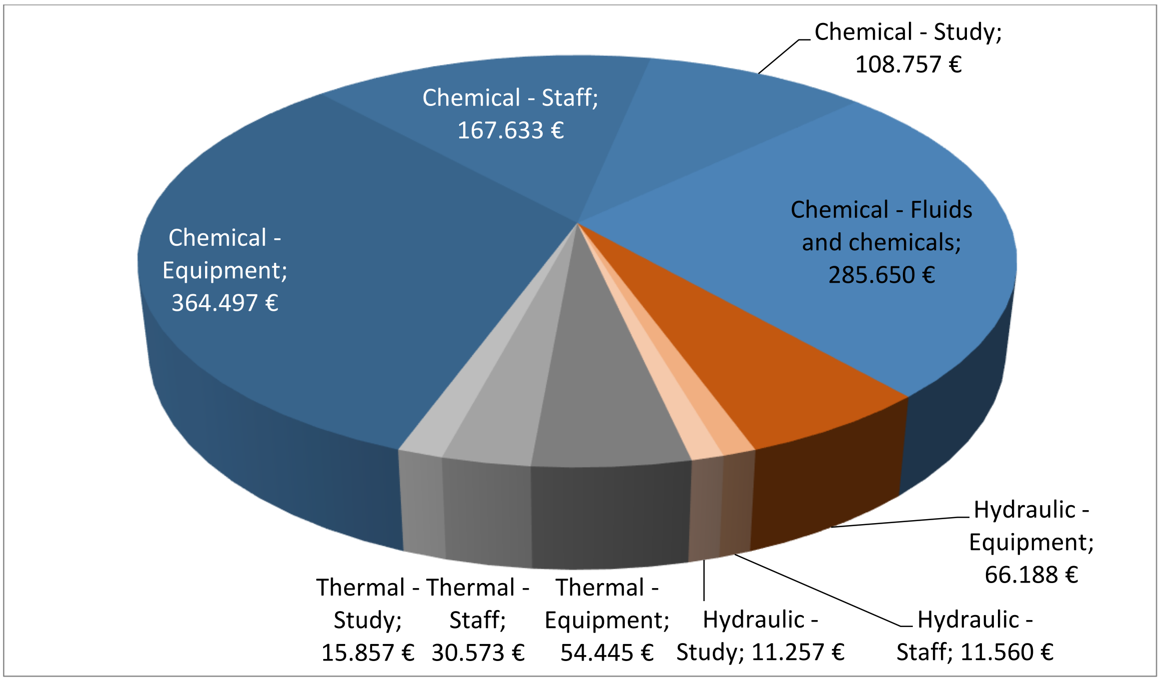

Fig. 14: Cost distribution for the complete stimulation program of GRT-1 well

4.4 Conclusion

On a global scale, the chemical stimulation is about ten times more expensive than the thermal or the hydraulic one (100 k€ for thermal or hydraulic stimulation compared to 1 000 k€ for chemical stimulation). This difference comes from the higher prices for equipment renting, the larger time needed and the higher prices of chemicals used for achieving the chemical treatment, especially for Rittershoffen where biodegradable products were used for environmental purposes.

For all stimulations, the scientific studies represent about 10% of total costs. The Equipment is always above a third of the total cost of stimulation. Fluid and chemical products can cost up to one third of total cost of a chemical stimulation. Finally, depending on the time needed to prepare and realise the stimulation, the staff costs can range from 13 to 46% of the global costs.

It is interesting to put in parallel the price of a stimulation and corresponding improvement in well productivity or injectivity. The GPK3 stimulations costed about one million euros but achieved no significant improvement of the hydraulic well characteristics. For GPK4 well, the cost of the stimulation is in the same order of magnitude but the injectivity increased by 50% (Nami, Schellschmidt, Schindler, & Tischner, 2008). However, it was mentioned that this increase could be partially related to the hydraulic contribution of some casing leaks observed after the stimulation operation at depth in the pipes close to the casing shoe.

For GRT-1 well, the injectivity index between each stimulation can be extracted from (Baujard, et al., 2017):

- The thermal stimulation costed 100 k€ for an increase of 0.7 L/s/bar (from 0.6 L/s/bar to 1.3 L/s/bar) at a low flowrate.
- The chemical stimulation costed 926 k€ for an increase of 0.7 L/s/bar (from 1.3 L/s/bar to 2.0 L/s/bar) at a low flow rate.

- The hydraulic stimulation costed 90 k€ for an increase of 0.5 L/s/bar (from 2.0 L/s/bar to 2.5 L/s/bar) at a high flow rate.

The increase between the different TCH stimulations has to be compared carefully because the injectivity index was not measured at the same flow rate. Moreover, the aim of each individual stimulation was not the same. The chemical stimulation was designed to improve near-well connection to the reservoir and to decrease the skin effect. The other stimulations were designed to improve more distant connections between the well and the fractured reservoir in the granite.

5 Summary and outlook

The report at hand deals with two different tasks. On the one hand it shows the current status of research activities within the DESTRESS project WP2, on the other hand methods have been developed as well as data and results presented, that are a considerable step forward in techno-economic evaluation of geothermal energy.

The report itself is also an input to the first step of decision analysis. Decision analysis as a structured approach of evaluation of different alternatives has been introduced as a methodological framework for WP2. It can be clustered into five different steps that serve as a guideline for making high quality decisions. This methodology was developed for research but found its way especially into oil and gas industry. Therefore this methodology offers a close to industry approach for evaluating the market uptake of soft stimulation. The first step, the so called "framing" plays an important role as e.g. (Bos & Wilschut, 2011) and (Spetzler , Winter, & Meyer, 2016) emphasize in their publications. To define a clear frame for the further investigations within the project, very deliberately two different approaches were used to identify important parameters within techno-economic evaluation of soft-stimulation. The results presented in this report are a central step in finalizing the framing activities.

Although dependency structure analysis and risk assessment don't have much in common at a first glance, the two approaches have the same goal. The identification and prioritization of parameters influences the techno-economic evaluation. Dependency-structure-analysis is only the central of three methods from strategic management that have been used. The results on the one hand support the necessity of decision analysis for investigation soft stimulation but also reveal categories and parameters that require in deep investigation. It was shown, that pumps, water volume or well design only have a minor influence on soft stimulation, while geological parameters and physical, chemical or biological effects are important for the techno-economic evaluation. On the parameter level, public acceptance was identified as only interesting parameter from public affairs category and PI as a valuable controlling parameter.

As stated in chapter 3.2.1 there is always uncertainty in data relevant for a decision, therefore the consideration of risks is a key point within DESTRESS. For identification and prioritization of risk factors a semi-quantitative approach based on expert knowledge was used. Besides a comprehensive list of possible risk factors for future project development, a prioritization of risk factors was also achieved. A mixture of industrial and scientific experts drew the conclusion that soft stimulation is already today a controllable measure for enhancing geothermal energy provision. Public acceptance, a lack of information and induced seismicity were evaluated as being the most relevant risk factors.

While chapter 2 and 3 can clearly be characterized as part of the framing process, the "Economic evaluation of soft stimulation" in chapter 4 is already an anticipation of the "model set-up" phase that will follow the framing process. The presented data is based on actual costs of stimulation measures realized in French geothermal projects. This data is essential for the realistic economic evaluation of technical measures and is a novelty in existing literature.

As a next step the framing process has to be completed. Therefore stochastically and deterministically represented parameters have to be selected, decision alternatives have to be agreed and the requirements for the model have to be clarified. An integrated model approach will be the objective. Existing models as presented through (Reith, 2015) could be updated through future research within DESTRESS. Part of these improvements will be the investigations on power plant technology in task 2.3 or the reservoir management topic in task 6.5.

Appendix

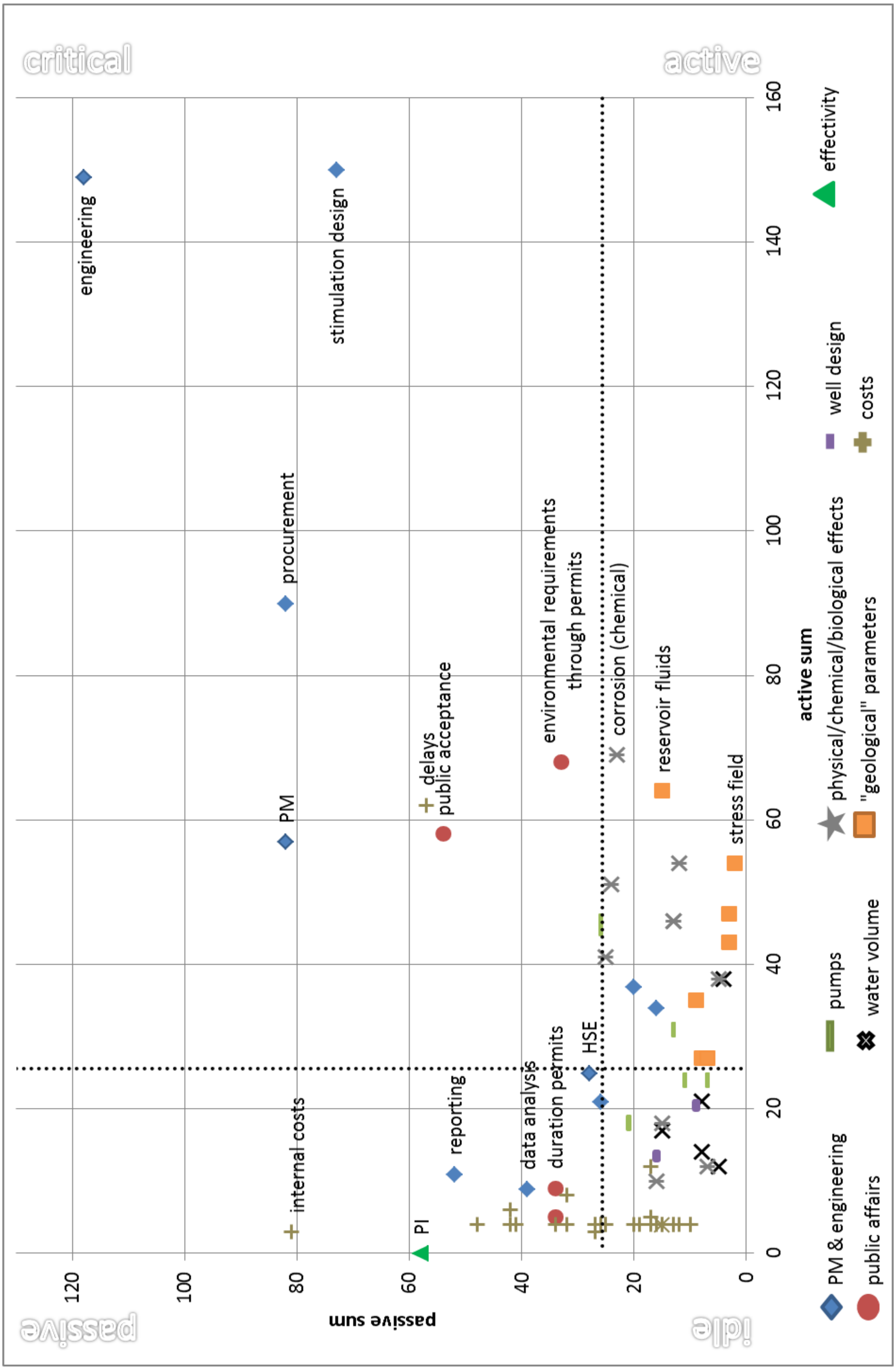

Fig. 15: Dependency-structure-matrix for soft stimulation (full figure)

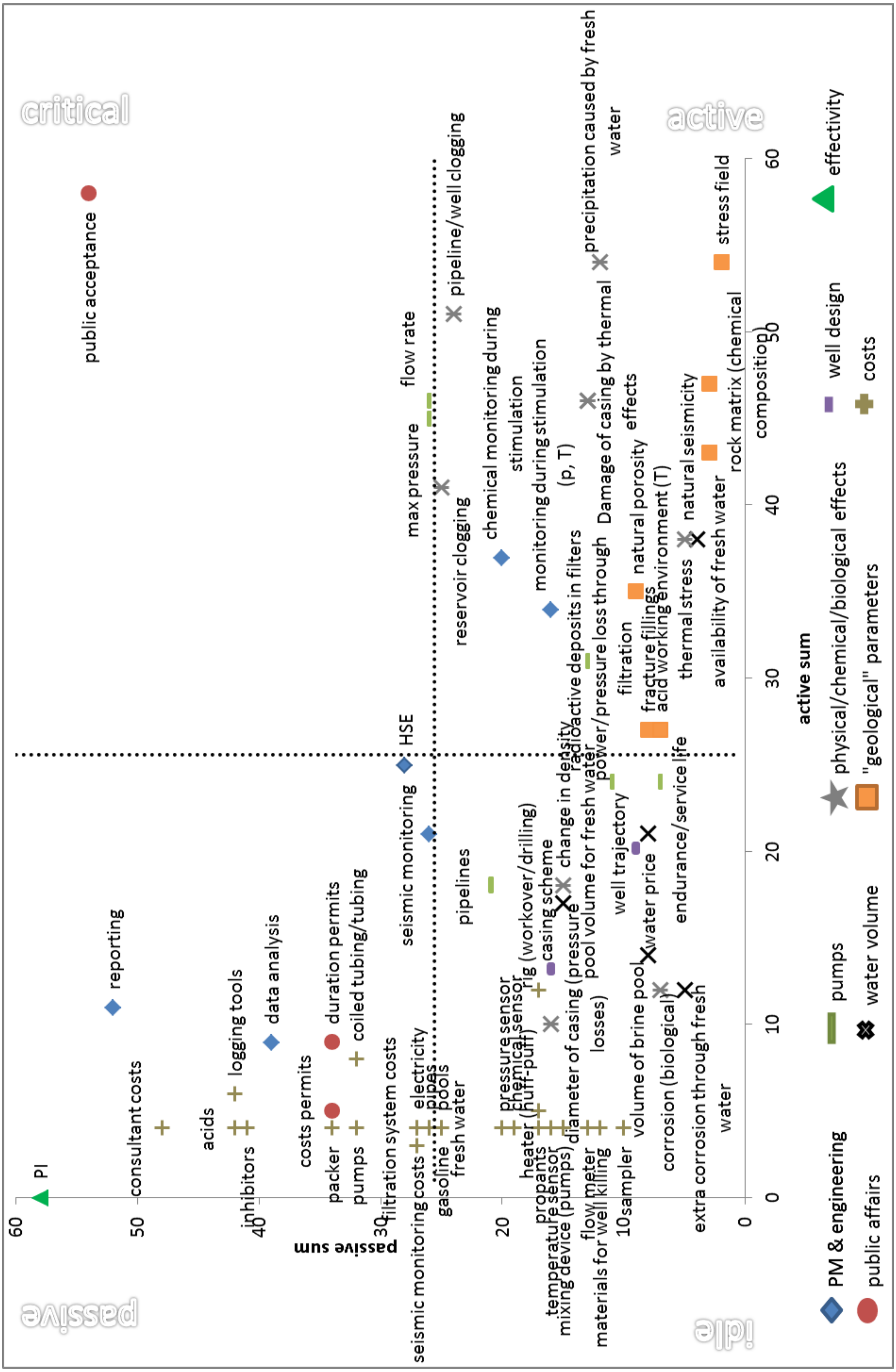

Fig. 16: Dependency-structure-matrix for soft stimulation (zoom)

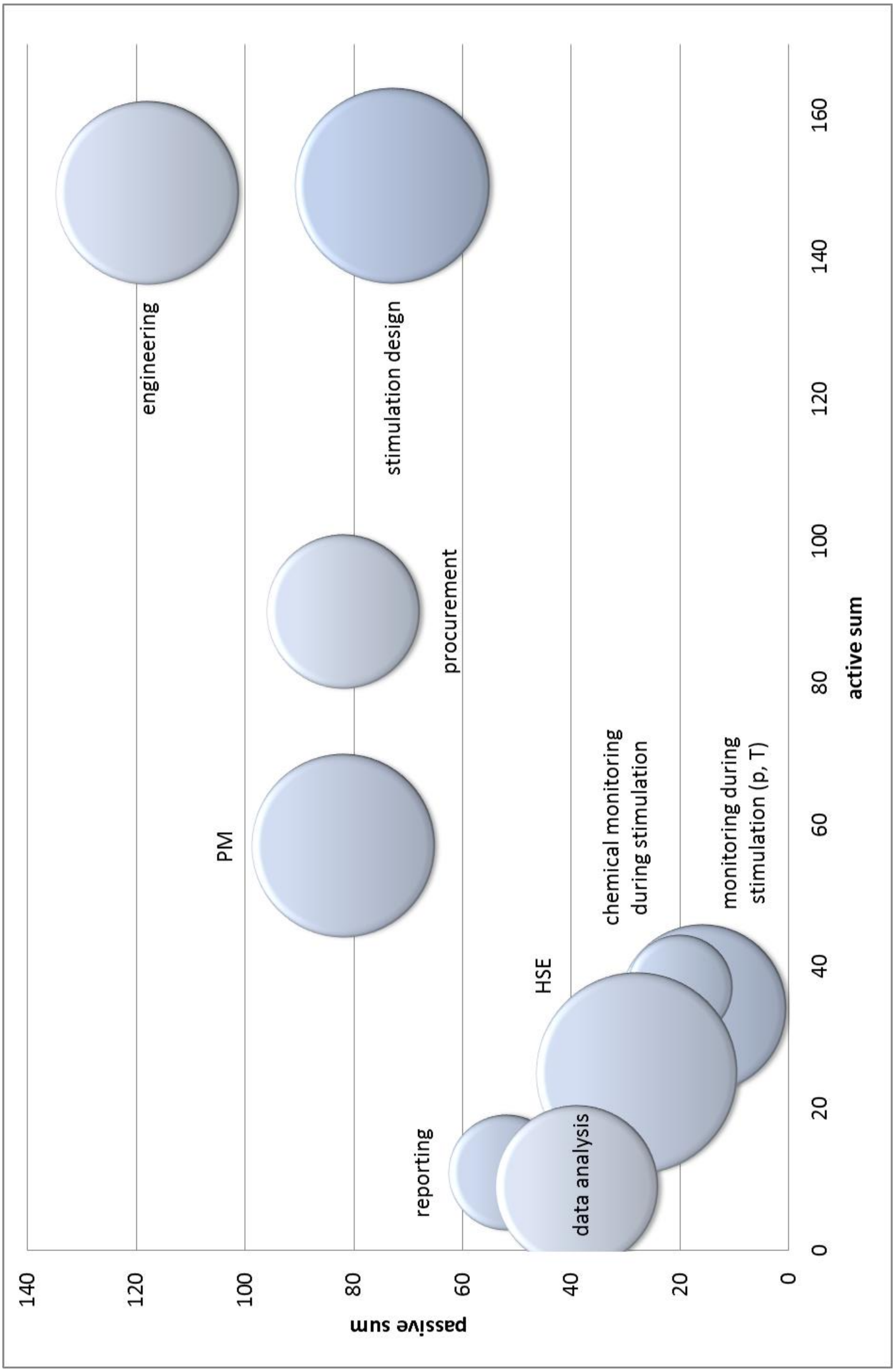

Fig. 17: Relevance-analysis: „PM & engineering“

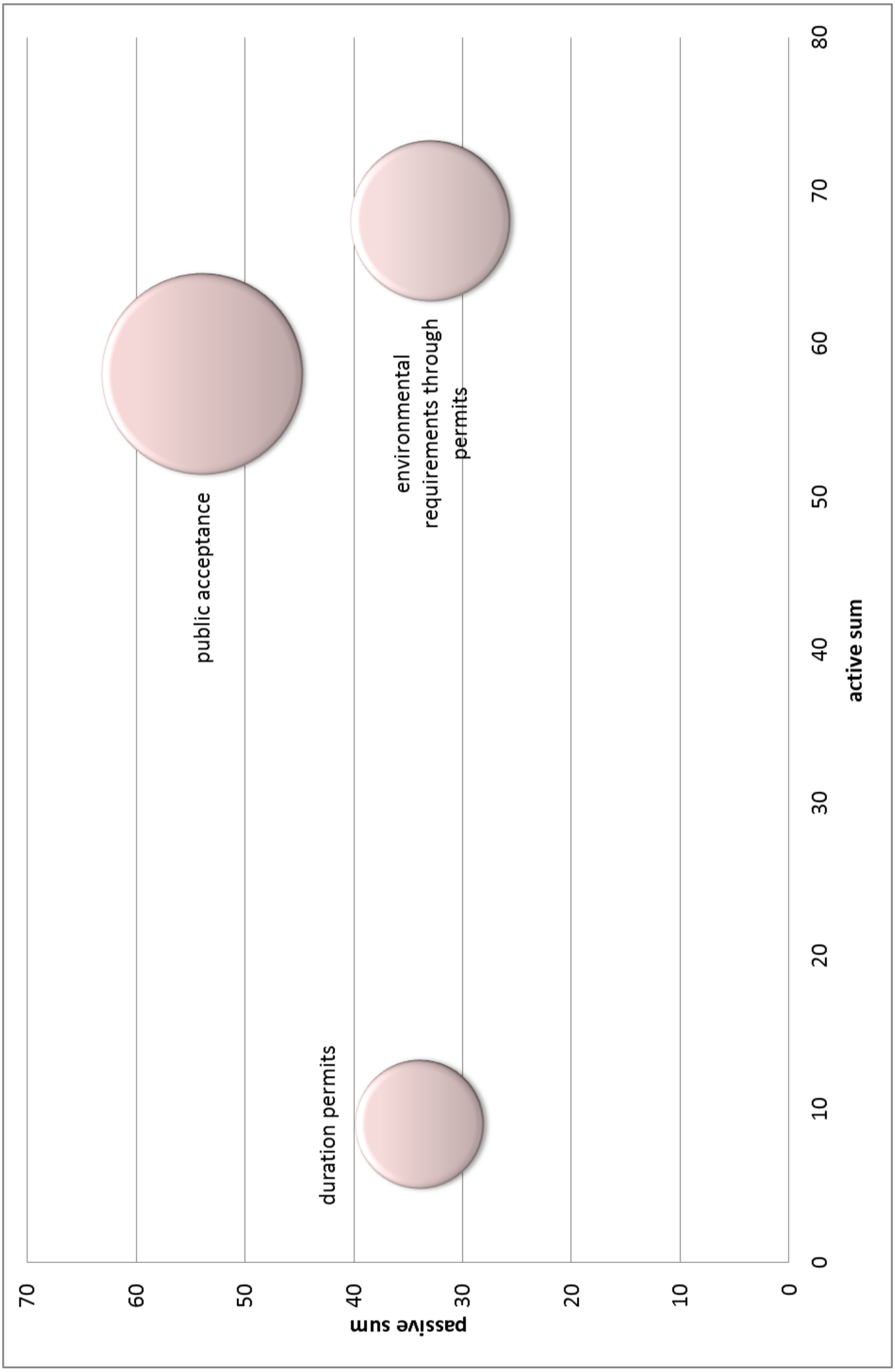

Fig. 18: Relevance-analysis: „public affairs“

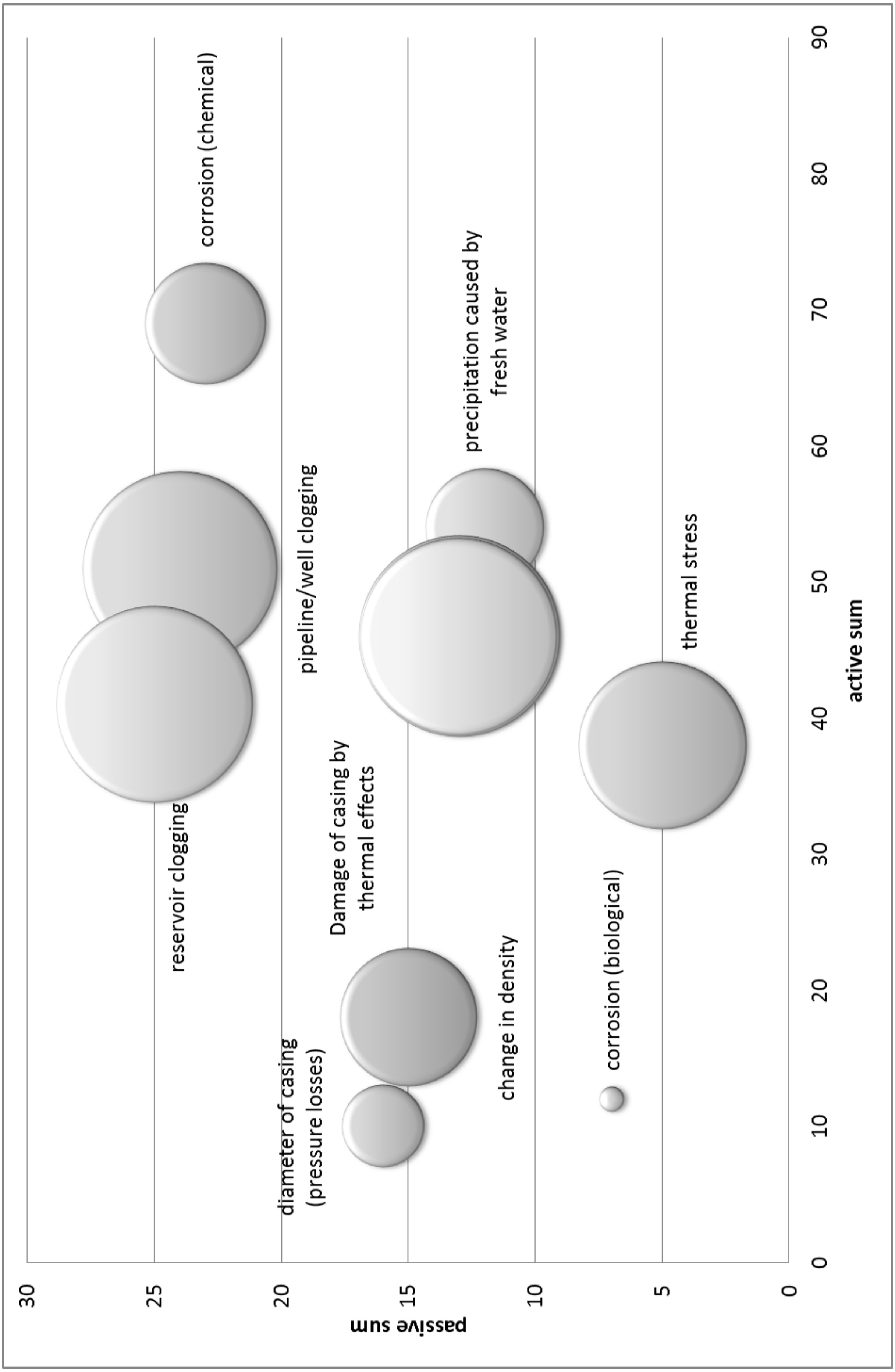

Fig. 19: Relevance analysis: „physical/chemical/biological effects“

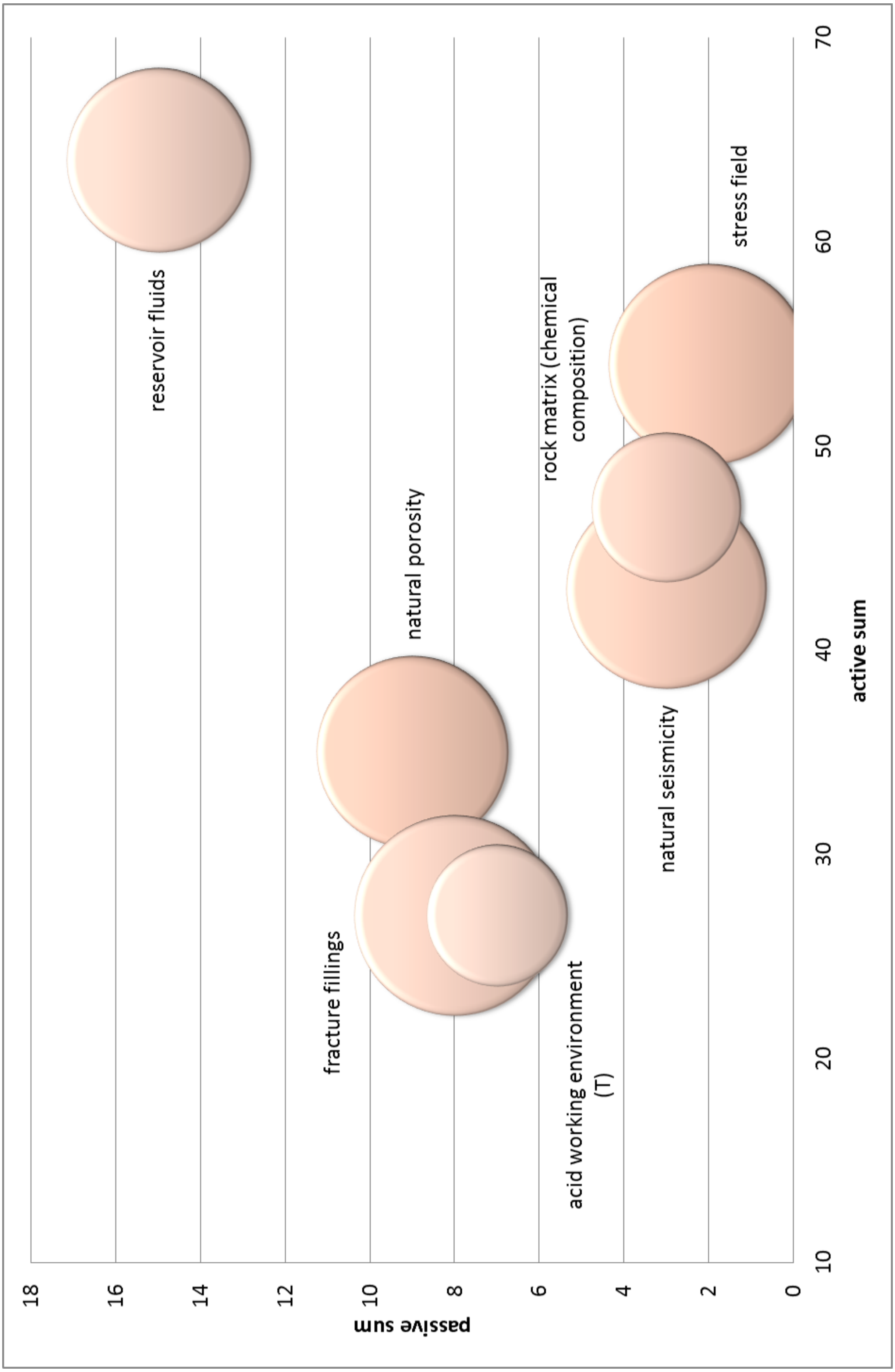

Fig. 20: Relevance analysis: „geological-parameters“

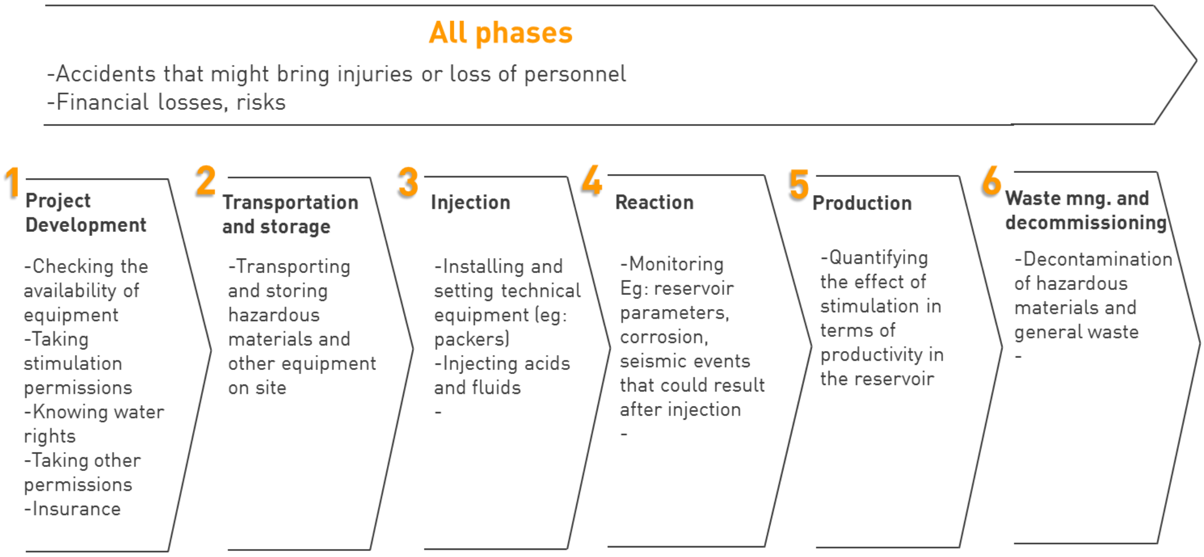

Fig. 21: Process phases of stimulation measures

Table 8: Risk factors of stimulation measures

Phase	Code	Risk factor	Description of cause	Description of effect
All Phases	AP2	Public Acceptance	Citizen groups or NGO's being against the Project --> impact of accidents occurred in other Project sites	Loosing permission, strong delay, loss of bankability (after planning before drilling)
All Phases	AP1	Political Instability	Change in the government on all levels of politics that could affect the project	Loosing permission or get extra official requirements
All Phases	AP3	Change in legislations	Accident occurred in another Project, additional extensive seismic monitoring and precautions etc. needed	Loosing permission, strong delay, not receiving permission
Project Development	PD1	Lack of information	Lack of information in engineering --> 1) extra data needed for planning the stimulation, 2) from the point of view of authorities	More/additional measuring effort --> redesign based on the new information,
Project Development	PD2	Lost in hole (measuring tool)	Problems in additional logging with loss of tool, purely related to soft stimulation and the additional data needed	Workover or fishing needed, Losing the well, delay
Project Development	PD4	Need for multiple permissions	Dependence of stimulation permissions on other permissions e.g. allowance for water usage	Reapplying for single permissions, delay, losing/not receiving all permission

Project Development	PD3	Permission overrun	Time limit of permissions; Taking too long for Project development	Loosing permission
Project Development	PD5	Non availability of equipment	Equipment is not available	Strong delay while waiting for the equipment (< 1 month)
Transport and Storage	TS4	Leakage in flowback reservoir	Leakage through corrosion or mechanical damage	Environmental contamination
Transport and Storage	TS1	Accidental disperse of hazardous materials (acids, fuel, flowback) on public ground	Traffic accident	Environmental contamination, delay
Transport and Storage	TS2	Casualties through traffic	Traffic accident on public streets or on site	Dead or injured people through an accident
Transport and Storage	TS6	Loosing hazardous material during unloading	Accidents or untrained staff	Environmental contamination and injured staff
Transport and Storage	TS3	Delay in delivery of equipment for waste management	Traffic jam and not enough storage space	Waste management doesn't work --> negative effects on borehole; corrosion, scales
Transport and Storage	TS5	Leakage in storage tank (all liquids)	Leakage through damaged container	Environmental contamination
Injection	I6	Induced seismicity exceeding threshold	High pressure within formation triggers seismicity	Losing public acceptance, surface damage, losing permission depending on the regulations, Project shut down
Injection	I3	Ground water contaminatio n	Injection water migrates towards higher formation	Loss of Project or extra costs for cleaning and closing
Injection	I5	Loss of effectivity	Injection pressure damages casing & cement, poor cement job	Not getting permeability increase expected, loss of project because it is

				economically not viable anymore
Injection	I8	Interruption while proppant frac	Operational disruptions, pump failure	Proppants block the well, workover is needed
Injection	I4	Well damage	Injection pressure damages casing cement, poor cement job, through shearing process	Workover (squeeze job) is needed, delay (1 month), groundwater contamination if damage close to surface, loss of hole
Injection	I2	Accident with the pumps on the surface	Mechanical failure (pressure issues)	Injured people, delay, replacement of pump
Injection	I1	Lost in hole (packer or other equipment)	Tubing string breaks, instability of the well	Packer gets stuck, fishing or workover is necessary, delay
Injection	I7	Casualties through pipe failure	High pressure pipe failure	Through high pressure coupling breaks --> staff get's injured
Reaction	R2	Fluid-rock interactions	Interactions including reactions with proppants, wrong selection of acids (concentrations of acids), inhibitors, proppants	Clogging of well, reduction of permeability, loss of project
Reaction	R3	Fluid-fluid interactions (thermal brine and chemicals)	Interactions including reactions with proppants, wrong selection of acids (concentrations of acids), inhibitors, proppants, microbiological processes, oxygen entrance	Clogging of well, reduction of permeability, corrosion, H_2S and other gasses production
Reaction	R1	Induced seismicity (with time delay after injection)	High pressure within formation triggers seismicity	Losing public acceptance, surface damage, losing permission depending on the regulations, Project shut down
Reaction	R5	Unwanted subsurface hydraulic connections	Too effective stimulation, wrong doublet design (wrong orientation), highly conductive fault planes	Connectivity between geothermal reservoir and unwanted layers, contamination of/through geothermal brine, loss of project

Reaction	R4	Hydraulic shortcut	Too effective stimulation, wrong doublet design (wrong orientation), highly conductive fault planes	Producing cold water, bypass hot water, poor sweep efficiency
Reaction	R6	Increase in gas content	Connection to gas reservoir	Reduction of effective permeability due to free gas in the reservoir, deepening the well, side-track
Production	P1	Blow out	Due to gas migration	Closing the well, loss of Project, injuries/fatalities
Production	P2	Gas kick	Due to gas migration	Producing methane instead of geothermal brine, closing the well, loss of Project, injured people
Production	P3	Producing corrosion products	Reaction between casing, acids, thermal brine	Toxic gases, casing failure (lifespan)
Production	P4	Producing acids before reaction	Ineffective use of acids	Getting acids on surface, ineffective stimulation, redoing stimulation
Production	P5	Acids not reaching near wellbore area	Too high pressure result in acids going in to new fractures instead of stimulating near well area	Ineffective stimulation, not reducing skin factor
Waste Mng. And Decommissioning	WMD1	Not getting license for brine disposal into surface water bodies	Not fulfilling the governmental obligation	Extra cost for storing and treating flowback
Waste Mng. And Decommissioning	WMD4	Violation of regulations	Regulatory violations through incorrect treatment of flowback and incorrect reporting	Stop of operations, delay
Waste Mng. And Decommissioning	WMD3	Casualties (acids treatment)	Pipe or device failure	Injuries through contact with acids, contamination of soil
Waste Mng. And Decommissioning	WMD2	Inappropriate basin volume	Volume of waste water / flowback is higher than expected, basin is too small	Delay, stop in production, additional treatment

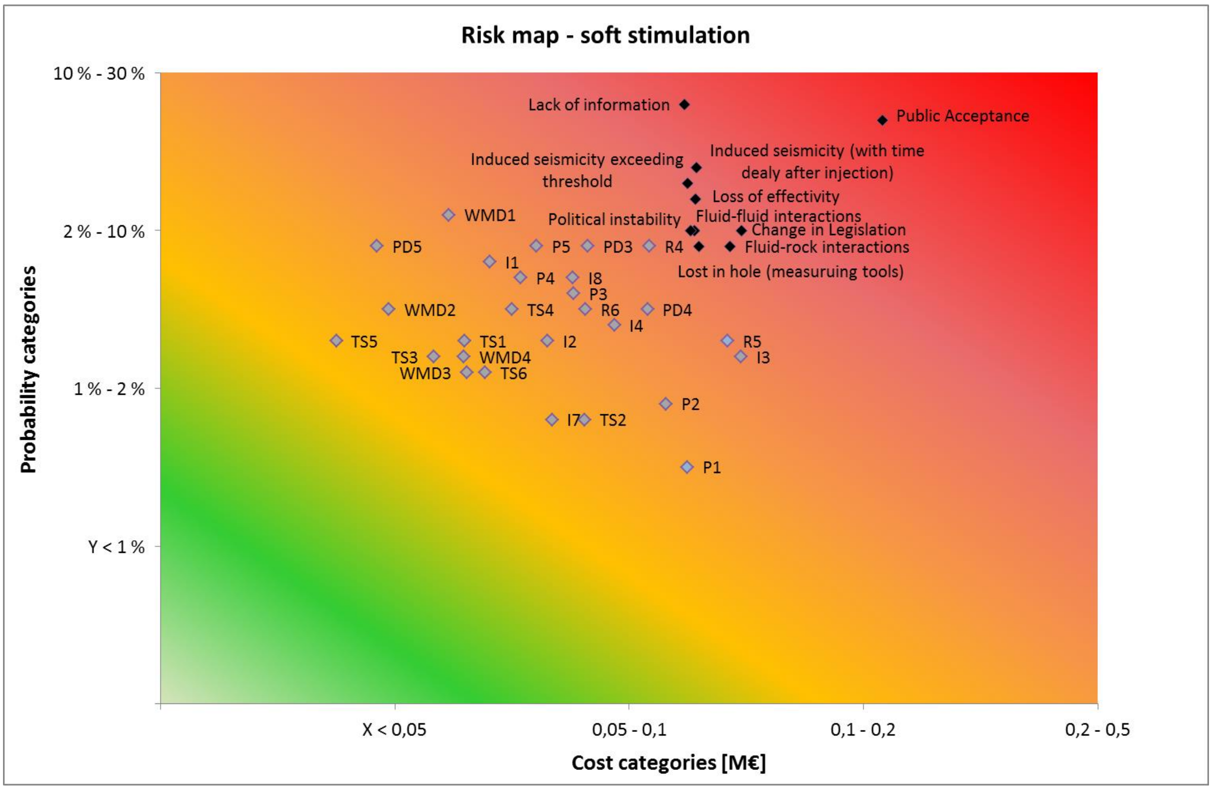

Fig. 22: Risk map – soft stimulation (zoom)

Figures

Tables

Literature

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Imprint

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Liability claim

DESTRESS is co-funded by

National Research Foundation of Korea (NRF)
Korea Institute for Advancement of Technology (KIAT)
Swiss State Secretariat for Education, Research and Innovation (SERI)