D.6.3.1. Manual on the use of the transnational tool-box

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Compiled by: Annamária Nádor (MBSZ)

Main authors:

Benchmarking: Nina Rman (GeoZS), Teodóra Szőcs (MBFSZ)

Decision tree: Annamária Nádor (MBFSZ)

Risk mitigation: László Ádám (Mannvit)

with the help of (alphabetically):

Željka Brkić (HGI), Milankovic Darko (Municipality of Sremski Karlovci), Radu Farnoaga (IGR), Nora Gal (MBFSZ), Nikolina Ilijanić (HGI), Boban Jolović (GSRS), Andrej Lapanje (GeoZS), Ozren Larva (HGI), Tamara Marković (HGI), Tamás Medgyes (InnoGeo), Dejan Milenić (FMG), Ágnes Rotár-Szalkai (MBFSZ), Natalija Samardžić (FZZG), János Szanyi (InnoGeo), Anca-Marina Vijdea (IGR),

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Contents

1. Introduction

The main aim of the DARLINGe project is to support the enhanced and efficient use of geothermal energy in Europe, in which the elaboration of a transnational tool-box (and the testing and validation of its methods in real environment on the 3 cross-border pilot areas) is a key output.

The tool-box encompasses the following three novel modules:

Benchmarking: A detailed list of parameters from currently operating thermal water wells have been defined, which will serve as a basis for the elaboration of relevant indicators, calculated on the basis these parameters. The respective values belonging to each indicator will be ranged afterwards on a scale as good, medium or poor. The purpose of this activity is to stimulate the users, regions to improve their respective activity (e.g. energy efficiency, monitoring, exploitation technology etc.) in order to achieve similar results as their neighbours exploiting the same aquifer, to whom they compare themselves.

Decision-tree: This module will apply the UNFC-2009 (United Nations Framework Classification for Mineral Reserves and Resources 2009) classification scheme for selected projects in the pilot areas. The UNFC-2009 is a universally accepted and internationally applicable system in which mineral resources-reserves / fossil energy (in this case geothermal energy) quantities associated with a certain project are classified and reported on the basis of the three fundamental criteria of economic and social viability (E), field project status and feasibility (F), and geological knowledge (G), using a numerical and language independent coding scheme. Combinations of these criteria create a three-dimensional system. Assessing various types of projects at different stages of their life-cycles (exploration, under development, in operation, expansion) will fill in the entire granularity of the UNFC-2009 scheme and will show projects the necessary steps for further developments.

Geological risk mitigation scheme: This tool provides a guideline about managing geological risks on a transparent and efficient way. On pilot areas, a theoretical geothermal project will be identified on a given location and a list of parameters needed for applying the geological risk mitigation scheme will be collected. The procedure of creating the scheme implies:

- Definition of damages, as unfavorable deviations from the expectations
- Defining the proof of a given damage
- Defining retrospectively the risk events and follow on events which might result in a given damage
- Definition of risk mitigation measures of risk events
- Defining amending activities
- Definition of timing when the given risk mitigation measure could be made
- Restructuring risk mitigation measures according to project phases

This report describes the above three methods in details and provides guidelines for their application.

2. Benchmarking

2.1. Introduction to benchmarking

A benchmarking methodology has been developed as a semi-quantifying tool which will in the long-term help to achieve and maintain good status of geothermal aquifers by simultaneously fostering an increase in efficiency of energy production (heat abstraction and decrease in amount of abstracted thermal water) and by promoting good examples in management of such exploitation.

The benchmarking methodology for geothermal usage was adapted from a pre-existing scheme developed by Lachavanne and Juge, (2009) for managing the region around Lake Geneva in Switzerland. It was first tested within the T-JAM project (Nádor et al. 2012).

Some countries have already integrated some of the indicators into their licence granting processes, e.g. Slovenia, and the management of these geothermal aquifers has significantly improved since then.

Data on thermal water wells was collected based on unified code-lists to enable a rapid and transparent comparison among the target countries: Hungary, Slovenia, Croatia, Serbia, Bosnia and Herzegovina and Romania. A detailed additional field data collection will be carried out in the pilot areas during 2018.

These results will be used in a tool for comparison of a quantitative, short and informative forward-looking results on the state of geothermal water management at different scales (pre-defined areas/regions/users) in a unique and harmonised way (Lemano approach). This will help to identify possibilities for improvement and will support the water permit/concession granting process worldwide.

The data will mostly be gathered within WP 7.1. We foresee that the following number of wells have to be included in the investigation: 2 in BH, 6 in HR, cca 30 and 100 in HU (two pilot areas), about 6 in RO, about 5 in RS and about 25 in SI.

2.2. Benchmarking methodology settings

2.2.1. Beneficiaries of the methodology

In order to most efficiently develop the benchmarking indicators it is crucial to properly identify beneficiaries of the methodology and their objectives (Table 1).

Table 1: List of beneficiaries and their objectives

Beneficiaries	Objective
Management authority, international organization	Easily comparable results between groups (e.g. countries, aquifers, users…) Identified gaps for evaluation of state (of use, of aquifers,…) Identified directions for the need for financial incentives Identified directions for legislation and regulation improvements
Licencing authority	Set of criteria for granting, sustaining and modifying water licences Identified directions for legislation and regulation improvements
Research organizations and universities	Identification of the scale of possible environmental impact (e.g. due to waste water discharge) Identification of the need for technological improvement (e.g. operational issues, increase thermal efficiency)
Investors in geothermal use	Identification of differences in results between the countries Set of goals of good practice for management of newly-developing sites
Thermal water user	Evaluation of the site management (how the management of using the water is in comparison to other users) Identified possibilities for further improvements of the site management and water exploitation

2.2.2. Criteria for methodology development

The criteria for benchmarking methodology and its result are that there should be:

- A transparent, harmonized, well-defined and understandable methodology (e.g. terminology).
- A methodology with a world-wide application, not dependent on local geothermal exploitation characteristics.
- A quantitative, short and informative forward-looking result (a table and a chart which has grouped results into five categories (bad, weak, medium, good and very good), but at the end only one weighted number which can then be shown as a traffic light. The results are generalised and should not have problems with data privacy.
- A reasonable number of indicators at various scales (object-specific, user-site specific, reservoir-specific and country-specific) and their criteria (each line is answered and points assigned, more points for better management practice).
- Indicators included only if there is available information for criteria assessment from at least 50% of the participating countries.
- Unified understanding of the individual criteria (each line is answered and points assigned).
- A clear distinction of availability of information (''no information available'' has to be distinguished from assigned zero points).
- Adjustable size testing area as analysis is valid already for one object or site.
- A comparison of management practice among multiple users and/or in neighbouring countries (sites, regions, aquifers and countries).
- The need for data collection on production, monitoring and permits at different levels: object, site, aquifer, region, country, depending what to compare.

2.2.3. Key issues

Issues which most affect the quality of the developed methodology are several and relate to the data and the methodology itself, and will need additional action to successfully mitigate them (Table 2).

Table 2: List of key issues of the benchmarking methodology

Key issues	Process
Data existence	New measurements if no data exists
Data availability	Official reporting databases have to be checked and access requested. If data is not available, additional permits for access have to be asked for, users have to be contacted (interviews and questionnaires) and new data collected.
Time and effort of data collection	Decision on most important criteria, efficient database evolved and field measurements performed
Data reliability	Expert evaluation before being included in the database
Reference date and yield	Produced and reinjected quantity in 2015 + NEWEST DATA Waste water in 2015 + new measurements Cascade use system – 2018 Monitoring system in 2018 (except HU)
Grouping criteria (one well, one site, one region…)	Clearly described at each indicator
Type of geothermal object to be included	Geothermal objects (wells and springs) with thermal water temperature at least 30 °C at the start of production; all objects with licences, and all active objects (even if no licence is granted)
Distinguish between indicators for objects, user sites, region/aquifer and country	Clearly described at each indicator
Criteria and indicator weight assignment	Sometimes the produced quantity is known only as a sum at the site but individual quantities are needed in the formulas – expert judgement will have to be used to assign a quantity to each object
Passive monitoring of observation wells managed not by thermal water user	New indicator is added and these observation wells will have to be included in the data table
Criteria applicable to springs and needed modifications	Croatia and others who have springs will carefully check the methodology
Weight of expert judgement	It will clearly be stated in the text which interpretations are not made on raw data but evaluations are done by experts
Place of measurement of thermal water temperature	Will mostly apply wellhead temperature as inflow to the system is not monitored; in special cases where temperature loss is known we will use the actual temperature (e.g. in Croatia)
Place of measurement of all waste water parameters	Large differences if there is mixing with cold water, multiple discharge sites, if discharge is continuous or sporadic; waste water will not have a specific indicator but pilot methodology will be tested at one surface water site in each country at each pilot site

2.2.4. Benchmarking indicators overview

The benchmarking indicators are developed at different data collection levels (object, user site, aquifer, region, country) and are of various types (Table 3). In order to make the final benchmarking assessment, results of all indicators will be weighted and joined according to indicator types and re-calculated into one number at the end.

Table 3: List of benchmarking indicators, data collection level and indicator type (* only in testing phase)

Name of the indicator	Smallest data collection level	Smallest data presentation level	Indicator type
Licencing procedure	Site/Country	Site or country	Management
Monitoring requirements	Site	Site	Management
Monitoring setup	Object/Site	Site	Management
Passive monitoring	Aquifer/Region	Aquifer/Region	Management
Operational issues	Object	Site	Technology & energy
Cascade use	Site	Site	Technology & energy
Thermal efficiency	Object	Site	Technology & energy
Utilisation efficiency	Object	Site	Technology & energy
Reinjection	Object/Site	Site	Environmental
Over-exploitation	Site	Site	Environmental
Status of water balance	Object/Site	Site	Environmental
Public awareness	Site	Site	Social
*Waste water management**	*River*		*Environmental*
Financial burden	*Project*		*Economic*

2.3. Benchmarking indicators description

2.3.0. Used abbreviations

i = individual geothermal object (production well or thermal spring)

I_{BAT} = indicator of operational issues

I_{CAS} = indicator of cascade use

I_i = number of assigned points to a geothermal object "i"

I_s = number of assigned points to a geothermal site "s"

I_{ENV} = summary indicator of environmental indicators

I_{GEO} = summary indicator of all other summary indicators

I_{INF} = indicator of public awareness

I_{LIC} = indicator of licencing procedure

I_{MAN} = summary indicator of management indicators

I_{MON} = indicator of monitoring setup

I_{OE} = indicator of over-exploitation

I_{REIN} = indicator of reinjection rate

I_{REQ} = indicator of monitoring requirements

I_{SOC} = summary indicator of social indicators

$I_{T\&E}$ = summary indicator of technology & energy indicators

I_{TE} = indicator of thermal efficiency

I_{UEF} = indicator of utilization efficiency

I_{WBA} = indicator of water balance assessment status

N_{tot} = total number of geothermal objects on the basin level or user site if this is evaluated in the investigated country

η_i = thermal efficiency of a geothermal object i without applied reinjection (%)

η_{ri} = thermal efficiency of a geothermal object i with applied reinjection (%)

P_i = number of assigned points to a geothermal object "i"

R_R = reinjection rate

Q_i = annual production rate of a geothermal object "i" (m^3/y)

$Q_{abs\ i}$ = annual production rate of thermal water of a geothermal object "i" used solely for geothermal heat production (m^3/y)

$Q_{cap\ i}$ = installed capacity of a geothermal site "i" (≈ maximum allowed annual production as defined in water permit) (m^3/y)

$Q_{reinj\ i}$ = annual reinjection rate of thermal water of a geothermal object i used for geothermal heat production (m^3/y)

Q_{tot} = annual production rate of thermal water at the site (sum of all objects)

$Q_{ww\ i}$ = annual discharge rate of waste thermal water of a geothermal object "i" (m^3/y)

T_o = average annual air temperature at a geothermal site, assigned as 12 °C

T_{out} = temperature of waste thermal water at an individual geothermal site (°C)

T_{whd} = outflow temperature of a geothermal object "i" (at the wellhead of a well or at a spring) (°C)

y = year

When there is no information available, the indicator should not be calculated. Alternatively, it is assigned zero points (e.g. if there are several wells only some have missing information) and the reason for poor value has to be explained in the description of results.

2.3.1. Licencing procedure

The licencing procedure indicator describes the national or regional legislation transparency and simplicity. In some countries, several types of licences can be granted (but not necessarily to one user) for geothermal heat production. For example, in Slovenia, a spa with geothermal heating and without total reinjection has to have the water concession while district heating systems with 100% reinjection follow the mining licence. As their conditions and requirements are not the same, the easiest licence may be applied for by the user.

The indicator calculation formula (eq. 1) and corresponding classification/scoring are:

$$I_{LIC} = \sum_{i=1}^{n} P_i \qquad \text{eq. 1}$$

Very good: $I_{LIC} > 15$
Good: $12 < I_{LIC} \leq 15$
Medium: $9 < I_{LIC} \leq 12$
Weak: $6 < I_{LIC} \leq 9$
Bad: $I_{LIC} \leq 6$

Table 4: Licencing procedure criteria and related points

Licencing procedure	Yes/No	Points
Licencing is required to use thermal water.	Yes	3
	No	0
At least 80% of active objects have a licence granted.	Yes	3
	No	0
Only one licence type exists to use thermal water for geothermal heat production (e.g. only mining or only water licence).	Yes	1
	No	0
Public information exists on licenced objects (names of wells and springs, location, at least as the nearest settlement if not coordinates).	Yes	1
	No	0
Public information exists on licenced quantity (either per site or per an object, either cumulative abstraction or discharge rate).	Yes	1
	No	0
Concession fee has to be paid to an authority annually after the licence is granted.	Yes	1
	No	0
Annual concession fee for heat production and cascade use of thermal water is lower than for only balneological use.	Yes	1
	No	0
Only one type of concession fee has to be paid to produce thermal water by licence annually. E.g. in Slovenia, water reimbursement for using state owned resources and the concession fee for water production both have to be paid annually.	Yes	1
	No	0
Concession fee depends on actual abstracted quantity of water in each year.	Yes	1
	No	0
Official time for a decision on granting the licence after the submitted application is complete is shorter than 2 months.	Yes	1
	No	0
Actual time for a decision on granting the licence after the submitted application is complete is shorter than 2 months.	Yes	1
	No	0
The user with a licence has to report to maximum two authorities about its actual annual thermal water abstraction in the past year (e.g. to financial ministry and to the environmental authority).	Yes	1
	No	0
Geothermal energy use (to produce more geothermal) is supported through officially declared/accepted strategies, action plans…	Yes	1
	No	0
Sustainable use of thermal water (to prevent deterioration of state) is supported through officially declared/accepted strategies, river basin management plans, action plans….	Yes	1
	No	0
Professional guidelines exist on drilling, monitoring, reinjection, observation well, liquidation of wells (at least one of this).	Yes	1
	No	0

2.3.2. Monitoring requirements

Monitoring requirements describe what the licence owners within one country are obliged to monitor and report for the licence they have. We will compare three most important empty reports which have to be submitted annually to authorities by users in each state, e.g.:

BA: Ministry of Industry, Energy and Mining (requires submission of the Book of the Reserves annually, abstracted amount of thermal water), Public Utility "Vode Srpske" (has a role of Water Agency requiring submission of PVN-2 form for water fee calculation).

HR: Croatian Waters and Ministry of Environment and Energy

HU: Different so called "OSAP" data provision within the frame of the National Data Collection Programme. Regional Water Directorates (annually, eg. on the amount of abstracted groundwater, temperature, static and dynamic groundwater level, chemistry, etc.); Hungarian Energy and Public Utility Regulatory Authority (annually, eg. abstracted amount of heat, amount of discharged used/waste thermal water, etc.). Based on the Mining Law data provision to the Mining and Geological Survey of Hungary (eg. abstracted energy through thermal water).

RO: Territorial Inspectorates of the National Agency for Mineral Resources (every six months), National Agency for Mineral Resources (annually), Financial Administration to which the license holder is assigned (every three months) for the payment of royalties corresponding to the extracted quantities. The royalties' reports are afterwards transmitted to the territorial inspectorates of the National Agency for Mineral Resources

SI: Slovenian Environment Agency, Ministry of Infrastructure, Ministry of Environment and Spatial Planning – Slovenian Water Agency

This is a national or regional (if specific conditions apply per a concession) analysis of three empty reporting forms with metadata (only if certain data is collected or not, if needed only a few more details) so that it will be clear if specific data are obliged to be collected and reported, if they do exist and where on a country-licence scale. The points have to be assigned jointly - only once for all three types of reports. For example, if ministry 1 demands regular measurement of abstracted water cumulative quantity and agency 2 not, all three points have to be assigned to this criteria as on a country (permit) level this is demanded and data is produced.

The indicator calculation formula (eq. 2) and corresponding classification/scoring are:

$$I_{REQ} = \sum_{i=1}^{n} P_i \qquad \text{eq. 2}$$

Very good: $I_{REQ} > 17$
Good: $11 < I_{REQ} \leq 17$
Medium: $9 < I_{REQ} \leq 11$
Weak: $3 < I_{REQ} \leq 9$
Bad: $I_{REQ} \leq 3$

Table 5: Monitoring requirements criteria and related points

Monitoring requirements	Yes/No	Points
Regular* measurement of abstracted water cumulative quantity (e.g m^3 in a day or year)	Yes	3
	No	0
Regular* measurement of discharge rate (e.g. l/s on an hourly interval)	Yes	2
	No	0
Regular* measurement of piezometric level in an object	Yes	3
	No	0
Regular* measurement of thermal water temperature (in the well or outflowing)	Yes	3
	No	0
Regular* chemical analysis of thermal water	Yes	2
	No	0
Regular* performance of hydraulic testing of wells to determine their maximum and/or optimal discharge rate (pumping tests, step tests,…)	Yes	1
	No	0
Regular* interpretation of measured values	Yes	3
	No	0
Regular* reporting on monitoring to an authority	Yes	1

Monitoring requirements	Yes/No	Points
	No	0
Need for approval on reported monitoring results by an authority	Yes	1
	No	0
Permanent archiving of monitoring documentation by the user	Yes	3
	No	0

* Regular is not uniformly defined as it stands for fulfilling the legislative requirements of individual countries or permits. Therefore, it may happen that two sites have assigned all points even if the first does e.g. the analyses annually and the second every three years but both according to their official requirements. However, the difference has to be clearly stated in the interpretation

2.3.3. Monitoring setup

The monitoring setup indicator is linked to the choice of parameters to be recorded at a site but data have to be available on an object level. This can be simple (eg. only water level) varying up to complex, where numerous parameters are recorded both at the production and monitoring wells. Importantly this indicator also shows whether the **monitoring at production wells at an user site or a basin** is carried out in a unified, integrated way, and also indicates the degree of groundwater abstraction monitoring. Regional evaluation of the resources of (thermal) aquifers depends on an optimally functioning monitoring system and provides a basis for issuing new water abstraction permits.

Inactive production wells with licences have to be included in the calculation.

In Bosnia and Herzegovina, no reporting is made if wells are not used. In Croatia, the situation is the same but the user has to provide a document that the objects are not in use and inspectors occasionally perform field inspection to check the situation. In Hungary, inactive wells do not need the equipment but have to report annually. In Slovenia, even inactive wells with licences have to have groundwater and temperature probes and reports every year. In Serbia, at inactive wells the users do not need measure the abstraction rate (as there is none) but they have to be able to prove that the water is not being abstracted and they still need to submit the annual report. In Romania, they need to report the utilization but do not need to prove the abstraction with measurements.

The indicator calculation formula (eq. 3) and corresponding classification/scoring are:

$$I_{MON} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}} \qquad \text{eq.3}$$

Very good: $I_{MON} > 10$
Good: $6 < I_{MON} \leq 10$
Medium: $3 < I_{MON} \leq 6$
Weak: $1 < I_{MON} \leq 3$
Bad: $I_{MON} \leq 1$

Abbreviations for this and all other equations are explained at the beginning of the paper.

Table 6: Monitoring setup criteria and related points

Monitoring setup criteria	Yes/No	Points
Active monitoring carried out by water producers: Continuous* automatic measurement of abstracted water quantity	Yes	3
	No	0
Active monitoring carried out by water producers: Continuous* automatic measurement of piezometric level in the aquifer, also as wellhead pressure	Yes	3
	No	0
Active monitoring carried out by water producers: Regular** manual measurement of piezometric level in the aquifer, also as wellhead pressure	Yes	1
	No	0
Active monitoring carried out by water producers: Continuous* automatic measurement of water temperature	Yes	2
	No	0
Active monitoring carried out by water producers: Regular** chemical water analysis	Yes	2
	No	0
Yearly report of monitoring results submitted by concessionaire/licenser and approved by granting authority	Yes	3
	No	0
Sporadic observations of any of the parameter	Yes	1
	No	0

* Continuous measurement stands for constant automatic measurements (usually, hourly or daily averages are calculated from these and stored). In this case we are not interested in the actual time-interval of the measurement, but only whether it is applied or not.

** Regular is not uniformly defined as it stands for fulfilling the legislative requirements of individual countries or permits. Therefore, it may happen that two sites have assigned all points even if the first does e.g. the analyses annually and the second every three years but both according to their official requirements, or if groundwater level at the first is measured weekly and at the second monthly but according to their official requirements the conditions are fulfilled. However, the difference has to be clearly stated in the interpretation.

2.3.4. Passive monitoring

Passive monitoring is a regionally specific indicator when there is/are observation wells monitored by a national/regional environmental agency or similar organization in an aquifer. Thermal water users have nothing to do with these wells, their monitoring or interpretation of results. According to our knowledge, it is established only in Hungary and Slovenia. N_{tot} stands for number of observation wells (not having a licence permit) in a selected region/aquifer.

Table 7: Passive monitoring setup criteria and related points

Passive monitoring setup criteria	Yes/No	Points
Passive monitoring in observation well: Continuous* automatic measurements of piezometric level in the aquifer, also as wellhead pressure	Yes	3
	No	0
Passive monitoring in observation well: Regular** measurements of piezometric level in the aquifer, also as wellhead pressure	Yes	2
	No	0
Passive monitoring in observation well: Regular** measurements of water temperature in the well	Yes	1
	No	0
Passive monitoring in observation well: Regular** sampling of groundwater for chemical and/or isotopic analysis	Yes	2
	No	0
Sporadic observations	Yes	1
	No	0

* Continuous measurement stands for constant automatic measurements (usually, hourly or daily averages are calculated from these and stored). In this case we are not interested in the actual time-interval of the measurement, but only whether it is applied or not.

** Regular is not uniformly defined as it stands for fulfilling the legislative requirements of individual countries or permits. Therefore, it may happen that two sites have assigned all points even if the first does e.g. the measurements of groundwater piezometric level daily and the second every two weeks, but both according to their official requirements.. However, the difference has to be clearly stated in the interpretation.

The indicator calculation formula (eq.4) and corresponding classification/scoring are:

$$I_{MONP} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}} \qquad \text{eq.4}$$

Very good: $I_{MONP} > 5$
Good: $3 < I_{MON\,P} \leq 5$
Medium: $1 < I_{MONP} \leq 3$
Weak: $0 < I_{MONP} \leq 1$
Bad: $I_{MONP} \leq 0$

2.3.5. Operational issues

The operational issues indicator shows whether appropriate technical parameters exist at well installations, whether cascade use is applied, how efficiently the water usage is implemented and it also describes the overall status of documentation at a user site. If good mitigation of operational issues is being implemented this will lead to a reduced operational cost, safer operation and usage efficiency. At the same time any environmental pollution will be reduced. Weighting per produced water quantity from each object has to be applied for each site.

The indicator calculation formula (eq. 5) and corresponding classification/scoring are:

$$I_{BAT} = \frac{\sum_{i=1}^{n} I_i \cdot Q_i}{\sum_{i=1}^{n} Q_i} \qquad \text{eq. 5}$$

Very good: $I_{BAT} > 5$
Good: $4 < I_{BAT} \leq 5$
Medium: $3 < I_{BAT} \leq 4$
Weak: $1 < I_{BAT} \leq 3$
Bad: $I_{BAT} \leq 1$

Table 8: Operational issues use criteria and related points

Operational issues criteria	Yes/No	Points
The well and wellhead are properly constructed (isolated, protected from unfavourable weather conditions and unauthorized persons, has enough fittings to install monitoring equipment for heads, temperature and abstraction rate).	Yes	2
	No	0
Problems of operation are successfully mitigated (scaling, blowouts, explosion zones, clogging of screens, free gases, corrosion, cavitation of pump, sand abrasion of pump particles discharge). If there are no problems, assign 2.	Yes	2
	No	0
If free gas is also produced from the well, it is used further (e.g. burning of methane for heat or electricity, bottling adn selling CO2....). If no free gas is present, assign 1.	Yes	1
	No	0
Supporting technical, lithological, hydrogeological and chemical documentation is well-kept and regularly updated. *It means that if they replace the probes or pump or re-work the well, they have a report stating when and what was done.*	Yes	1
	No	0

2.3.6. Cascade use

Cascade use is related to a site energy abstraction practice. The cascade use means utilizing geothermal resources for more than one application. Cascade use supports increased net efficiency and improves economics of the system. N_{tot} stands for number of sites in an investigated region.

Waste water temperature before being emitted to surface waters is limited to maximum 38 °C in Romania, 30 °C in Bosnia and Herzegovina, Croatia, Hungary, Slovenia and Serbia. In Serbia, the limit of 30 °C is a threshold above which groundwater can be used for heating directly. The original methodology (Szőcs et al. 2018) assumed the lowest waste water temperature of 12 °C for thermal efficiency calculation and it was planned to use the same threshold for the evaluation of surplus heat. This is an internationally acceptable limit which is the same or very close to the average air temperatures in most project countries.

The indicator calculation formula (eq. 6) and corresponding classification/scoring are:

$$I_{CAS} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}} \qquad \text{eq.6}$$

Very good: $I_{CAS}>5$
Good: $4<I_{CAS}\leq 5$
Medium: $3<I_{CAS}\leq 4$
Weak: $1<I_{CAS}\leq 3$
Bad: $I_{CAS}\leq 1$

Table 9: Cascade use criteria and related points

Cascade use criteria	Yes/No	Points
Thermal water is used based on the principles of a cascade system.	Yes	2
	No	0
There are more than three successive stages of energy extraction (delta T).	Yes	1
	No	0
Thermal water is not additionally heated prior to its use.	Yes	1
	No	0
Thermal water is not cooled down by mixing with cold water prior to its use.	Yes	1
	No	0
No surplus of unused heat: waste water temperature is 12 °C.	Yes	1
	No	0
The site has a backup energy resource –another energy source which operates if the wells are not active or in peak-load heat demands. So geothermal is only a baseline energy.	Yes	1
	No	0

2.3.7. Thermal efficiency

Thermal efficiency is determined from the ratio between the used and the available annual heat energy. The mean annual air temperature is used as a reference. Lowering the temperature of the waste thermal water through the use of e.g. cascade systems will increase the thermal efficiency. This also leads to a reduction in the total amount of abstracted thermal groundwater, and reduces the threat of thermal and chemical pollution of surface waters coming from discharge of waste thermal waters. The average annual air temperature (T_o) is site specific and in the long-term it is supposed to be very close to the average annual fresh groundwater temperature. In this methodology, we applied the same threshold as for optimum temperature of waste thermal water, and the same for all project countries: **12 °C**.

The indicator calculation formula (eq. 7.1 – 7.3) and corresponding classification/scoring are:

$$I_{TEF} = \frac{\sum_{i=1}^{n} \eta_i \cdot Q_i}{\sum_{i=1}^{n} Q_i} [\%] \qquad \text{eq. 7.1}$$

Very good: $I_{TEF} > 70$
Good: $60 < I_{TEF} \leq 70$
Medium: $40 < I_{TEF} \leq 60$
Weak: $30 < I_{TEF} \leq 40$
Bad: $I_{TEF} \leq 30$

Where:

$$\eta_i = \frac{T_{whd} - T_{out}}{T_{whd} - T_o} \qquad \text{eq. 7.2}$$

In case of reinjection :

$$\eta_{r\,i} = \frac{Q_i(T_{whd} - T_{out})}{Q_i(T_{whd} - T_{out}) + Q_{ww\,i}(T_{out} - T_o)} \qquad \text{eq. 7.3}$$

2.3.8. Utilization efficiency

The ratio of the average annual water production to the maximum water quantity that could theoretically be produced gives the utilization efficiency. A maximum value for production can be taken from:

i) the currently installed pump capacity that was actually tested, in one way or another ($Q_{cap\,i}$)
ii) the licenced allowed maximum production.

In the DARLINGe methodology, we will use the maximum annual licenced production as Q_{cap} by default. If no licence is granted, the installed pump capacity will be applied as a divider.

If the amount of water used is greater that the licenced amount, the indicator result also has to be 'bad'.

In reality, some users do not have water meters installed while others have bypasses and therefore only best, professional estimates can be used here and discussed in details in description of the results.

The indicator calculation formula (eq. 8) and corresponding classification/scoring are:

$$I_{UEF} = \frac{\sum_{i=1}^{n} Q_i}{\sum_{i=1}^{n} Q_{cap\,i}} \cdot 100\ [\%] \qquad \text{eq. 8}$$

Very good: $I_{UEF} > 60$
Good: $45 < I_{UEF} \leq 60$
Medium: $30 < I_{UEF} \leq 45$
Weak: $15 < I_{UEF} \leq 30$
Bad: $I_{UEF} \leq 15$; $I_{UEF} > 100$

2.3.9. Reinjection

An important indicator is the reinjection status at a site as it can be used as a test for sustainable thermal water exploitation. Reinjection is permitted only for non-treated and uncontaminated thermal water (i.e. used only for its heat energy). Reinjection rate (R_R) is calculated based on the ratio of the volume of re-injected and abstracted thermal water used for geothermal energy production (eq. 9). This indicator shows whether reinjection is taking place or not. It does not monitor where reinjection is performed (i.e. in the same aquifer from where the thermal water is abstracted). Unfortunately, if reinjection does operate, it is often applied to shallower aquifers. This is in direct contradiction with the guidelines of the Water Framework Directive, since shallow reinjection can lead to the introduction of higher organic matter and/or trace element content into these aquifers. A new parameter to be included in the indicator calculation will be a check if the reinjection depth is the same as the abstraction depth.

BH, HR, HU, RO, RS and SI do not have any official guidelines on reinjection. In Romania, thermal water exploitation was large prior to 1989 and at the moment no reinjection is reported in the project area.

$$R_R = \sum_1^n \frac{Q_{reinj\,i}}{Q_{abs\,i}} \; [\%] \qquad \text{eq. 9}$$

The indicator calculation formula (eq. 10) and corresponding classification/scoring are:

$$I_{REIN} = \frac{\sum_{i=1}^{n} I_i \cdot Q_i}{\sum_{i=1}^{n} Q_i} \qquad \text{eq. 10}$$

Very good: $I_{REIN} > 5$
Good: $3 < I_{REIN} \leq 5$
Medium: $1 < I_{REIN} \leq 3$
Weak: $0 < I_{REIN} \leq 1$
Bad: $I_{REIN} = 0$

Table 10: Reinjection criteria and related points

Reinjection criteria	Yes/No	Points
More than 80% of produced thermal water may be reinjected (is not polluted).	Yes	1
	No	0
Reinjection rate (R_R) is 60% or more.	Yes	4
	No	0
Reinjection rate (R_R) is between 40% and 60%.	Yes	3
	No	0
Reinjection rate (R_R) is between 20% and 40%.	Yes	1
	No	0
Water is reinjected in hydraulically connected layers so that the recovery of water is possible.	Yes	1
	No	0
Water is reinjected in layers (aquifer) with similar water chemistry (±20%) and no additional pollution threat exists e.g. phenols, organics, arsenic….	Yes	1
	No	0

2.3.10. Over-exploitation

Exploitation of thermal water can clearly have an impact on the aquifer being exploited. For this reason an over-exploitation indicator has been developed to characterise the status of the aquifer at a site. Potential impacts include disequilibrium change (showing significant trends as in the Water Framework Directive) of piezometric groundwater level, water temperature, groundwater availability, water quality change, the groundwater dependent ecosystem and subsidence. According to geothermal systems investigated in the DARLINGe project, the subsidence is not relevant and was therefore not included in the indicator criteria. The change has to be taken into account on a time-scale when the production should have already caused the establishment of a quasi-steady state in the geothermal aquifer at the site. Very good state is achieved when a new quasy-equilibrium is reached during production. Also, the points (1) should not be assigned when at least one of the wells at the site shows such changes.

The indicator calculation formula (eq. 11) and corresponding classification/scoring are:

$$I_{OE} = \frac{\sum_{i=1}^{n} I_i \cdot Q_i}{\sum_{i=1}^{n} Q_i} \quad \text{eq. 11}$$

Very good: $I_{OE} > 4$
Good: $3 < I_{OE} \leq 4$
Medium: $2 < I_{OE} \leq 3$
Weak: $1 < I_{OE} \leq 2$
Bad: $I_{OE} \leq 1$

Table 11: Over-exploitation criteria and related points

Over-exploitation criteria	Yes/No	Points
No significant decrease of piezometric level	Yes	1
	No	0
No significant decrease in water quality	Yes	1
	No	0
No significant decrease in outflow water temperature	Yes	1
	No	0
No significant decrease in groundwater availability (lower yield, pump lowering)	Yes	1
	No	0
No significant impact on dependent ecosystems	Yes	1
	No	0

2.3.11. Status of water balance assessment

The status of water balance assessment is a measure of the level of the depth and reliability of information on the water quantity status of an aquifer at a site. Reliable, good quality, regional hydrogeological data is needed in order to make an estimate on the natural recharge of a thermal aquifer. If there is an ongoing national monitoring programme, and data interpretation can be combined with data from users' 'active' monitoring, then more accurate estimates can be calculated. It is proposed that every 3 to 6 years the annual data for water balance assessment and regional hydrogeological evaluation should be assessed and evaluated since only after this period will any trends become evident (Goldbrunner et al., 2007). BA, HR, HU, RO and RS have no experience in determining the critical levels, SI some. In BA, the available quantities are evaluated every seven years but do not use or apply critical levels in the methodology.

The indicator calculation formula (eq. 12) and corresponding classification/scoring are:

$$I_{WBA} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}} \quad \text{eq. 12}$$

Very good: $I_{WBA} > 3$
Good: $2.5 < I_{WBA} \leq 3$
Medium: $1.5 < I_{WBA} \leq 2.5$
Weak: $1 < I_{WBA} \leq 1.5$
Bad: $I_{WBA} \leq 1$

Table 12: Status of water balance assessment criteria and related points. Only one criteria can be allocated to one well. If no information exists, zero points are assigned.

Status of water balance assessment criteria	Yes/No	Points
Renewable and available volume of water is assessed. Critical point of abstraction and critical level point are both defined. Study is made and updated on the basis of actual measurements.	Yes	4
	No	0
Critical level point is defined. Renewable and available volume of water is assessed. Critical point of abstraction is defined. Study is made on the basis of old / regional data and knowledge	Yes	3
	No	0
Critical level point is defined (based on average yearly minimum level value from previous years at the location)	Yes	2
	No	0
Critical level point is defined (not based upon measurements on the location but from other available data / locations)	Yes	1
	No	0

2.3.12. Public awareness

Public engagement is considered an important aspect of the exploitation of any natural resource, including thermal waters. For this reason a public awareness indicator has been developed based on a range of data which can allow the public to make an informed decision. Relevant parameters in the calculation include open-access information on monitoring, operational issues, the quantity status of aquifers, the quality of discharged thermal waste water, and thermal efficiency.

Based on discussion about existing training/education for employees which would result in a fact that at least three employees who are not in charge of wells know: how many objects they have, where are they and what is the utilization of thermal water, we realised that would take too much effort to gain reliable and objective results that we cannot include this in the evaluation for now.

For the DARLINGe project we checked user site websites and promotional materials (leaflets, booking advertising). No professional or scientific articles were checked. Points for user site should be divided by the number of user sites in a region/aquifer.

The indicator calculation formula (eq. 13) and corresponding classification/scoring are:

$$I_{INF} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}} \qquad \text{eq. 13}$$

Very good: $I_{INF} > 8$
Good: $7 < I_{INF} \leq 8$
Medium: $4 < I_{INF} \leq 6$
Weak: $2 < I_{INF} \leq 4$
Bad: $I_{INF} \leq 2$

Table 13: Public awareness criteria and related points

Information about	Yes/No	Points
There is a visitor centre at the site or the users organise guided tours where geothermal objects and use of thermal water are shown and explained to public.	Yes	2
	No	0
Public information exists on thermal water source (well or spring, approximate depth)	Yes	2
	No	0
Public information exists on thermal water temperature	Yes	2
	No	0
Public information exists on thermal water chemistry (TDS or main components or gases or special chemical parameters)	Yes	1
	No	0

Information about	Yes/No	Points
Public information exists on thermal water utilization type (for heating, balneology…)	Yes	1
	No	0
Public information exists on monitoring results (GWL or temperature or chemistry…)	Yes	1
	No	0
Public information exists on best available technology and operational issues (on any of the criteria at the operational issues indicator)	Yes	1
	No	0
Public information exists on waste water (treatment or temperature or where discharge is …)	Yes	1
	No	0

2.3.13. Waste thermal water impact

The goal is to determine if and to what extent the mineralization and temperature of waste water can affect the environment. We could study different effects at pilot areas: heating of surface waters, cooling, increase in mineralization or pollutants.

For waste water we will select one recipient stream or river per a country per a pilot area where multiple sites discharge waste thermal water and environmental problems may occur. Steps to be taken are:

1. Select a surface water body in a pilot area where multiple sites discharge waste thermal water and environmental problems may occur. Identify users and collect the average annual values during production: TDS, Q (total production of thermal water in 5.2. Current use), Na and temperature of waste water (waste water temperature in 5.2. Current use).
2. Check which data on waste water monitoring is measured and which are available for each site.
3. Decide if field measurements are needed, and how many times (seasonal abstraction, discharge time intervals). Do them.
4. Do simple mass balance for quantity, TDS, Na and temperature. Different scenarios if exact data is not known, e.g. waste water temperature scenario 1 = 25 °C (reported by the user), scenario 2 = 30 °C (max. allowed), scenario 3 = 35 °C (probably reality), scenario 4 = …45 °C. Do as many as seems feasible to reach the goal.

As there is not enough information of waste water management and values currently, we decided to make only one case study, which will be performed by HR and the results will be incorporated in their action plan and set as an example for further development of the methodology.

2.3.14. Economics of geothermal projects

Annual financial burden (concession fee…) per 1 m^3 or 1 MWt for licenced quantities for heat production (no investment or operating costs included, only what is paid to authorities) is diverse among the countries. Geothermal can be regionally promoted only if it is economically attractive, so the price in comparison to the one of fossil fuels is reasonable. As we cannot develop a specific indicator yet, we will only compare calculation of annual fees and concessions per 1 m^3 or 1 MW for those DARLINGe countries for which data is available.

Geothermal projects are considered expensive by many. However, if you compare the economics of a geothermal and a fossil fuel based project, it seems to be a valid argument that it's not so much the total costs that differ, rather the dispersion of all costs associated with exploiting earth's resources throughout the full life-cycle of the project. The full costs of a fossil fuel based project are paid for later - by the environment, by next generations to come. Geothermal projects are paid upfront, by whoever implements them. Therefore, while not passing the bill over to next generations just seems right for us, there's no denying the fact that a well-grounded, informed economic pre-assessment is vital.

But for that to happen, one has to prepare for a long and tenuous project development phase. First of all a site specific reservoir assessment is needed, to determine the highest possible yield and heat of the water to be extracted. Then a proper heat market analysis needs to be carried out, to be able to calculate the exact energy demand. If these two studies conclude that geothermal is indeed an option, a detailed feasibility study is to be conducted – the results of this study will inform decision makers whether a project is economically and environmentally viable.

In the following tables we provide reference numbers based on our assessments of actual geothermal project plans in the last decade or so. One must keep in mind though, that not two projects are the same, and while some differences are minor, it is, for instance, difficult to compare a development utilizing surface discharge with another one using injection. But there are many other variable factors too: drilling prices have increased in recent years due to high demand, while oil (and natural gas) prices are relatively low – both of these affect payback periods of geothermal investments. Therefore benchmarking needs to be used with a certain level of caution, and should neither deter developers, nor should it get unsubstantiated hopes up without site specific studies and analyses. Nevertheless, site visits, on site data collection within WP7 and face to face discussions with users will help to gain more detailed information on economical aspects of geothermal projects, some threshold values seem valid throughout more projects, and these are as follows:

Table 14: Average costs of geothermal cascade systems as in Mórahalom, Makó, Csongrád, Szeged in Hungary. Numbers stand for newly developed systems in which 1 production and 2 injection wells are drilled, 1-3 km pipeline system is used to distribute geothermal water to end users, usually with balneological / agricultural utilization at the last stop.

	Average
Investment costs (Euro)	3,159,000
Produced geothermal energy (GJ/year)	56,700
Investment costs per unit of produced geothermal energy (Euro/GJ)	55.7
Operation costs (Euro/year)	180,917
Payback period (year)	22.9
Decrease in natural gas use (million m3/year)	1.6
Decrease in CO2 emmission (tCo2/year)	3,202

Table 15: Average costs of integration of geothermal into district heating systems. Examples are four Szeged (Hungary) systems under development with 1 production and 2 injection wells drilled, geothermal energy is introduced via a short pipeline to the nearest existing heating centre of an already operating district heating circuit to provide heat and decrease natural gas use.

	Average
Investment costs (Euro)	7,813,000
Produced geothermal energy (GJ/year)	65,500
Investment costs per unit of produced geothermal energy (Euro/GJ)	119.3
Operation costs (Euro/year)	141,917
Payback period (year)	22.5
Decrease in natural gas use (million m3/year)	2.2
Decrease in CO2 emmission (tCo2/year)	4,050

2.4. Quantification of indicators

For each of the 12 indicators values from available data are calculated first. If fulfilment of criteria cannot be evaluated, it should not be quantified. Resulting scores should be transformed into the corresponding five-level classification system (Table 17). To gain four topic indicators, additional calculation has to be done (eq. 14-16, Table 16). As there is only one indicator for social topic, no additional calculation is needed currently, just class value (V) has to be re-classified into a new, similar system (Table 16).

$$I_{MAN} = \frac{I_{LIC}[\%] \cdot 0.3 + I_{REQ}[\%] \cdot 0.2 + I_{MON}[\%] \cdot 0.4 + I_{MONP}[\%] \cdot 0.1}{4} \qquad \text{eq. 14}$$

$$I_{T\&E} = \frac{I_{BAT}[\%] \cdot 0.2 + I_{CAS}[\%] \cdot 0.3 + I_{TEF}[\%] \cdot 0.3 + I_{UEF}[\%] \cdot 0.2}{4} \qquad \text{eq. 15}$$

$$I_{ENV} = \frac{I_{REIN}[\%] \cdot 0.4 + I_{OE}[\%] \cdot 0.5 + I_{WBA}[\%] \cdot 0.1}{3} \qquad \text{eq. 16}$$

When these four summary indicators are calculated, they have to be weighted for the last time, to get only one final value. Eq. 17 should be used.

$$I_{GEO} = \frac{I_{MAN}[\%] \cdot 0.3 + I_{T\&E}[\%] \cdot 0.3 + I_{ENV}[\%] \cdot 0.3 + I_{SOC}[\%] \cdot 0.1}{4} \qquad \text{eq. 17}$$

Applying these five classes in such approach it is possible to get a traffic light system on a scale 1-100%, where one final value I_{GEO} (Table 16) will be used to compare any user site or reservoir or other spatial body with a benchmarking method.

Table 16: Overview of summary indicators and their classes

Summary indicator/ Class value	BAD	WEAK	MEDUM	GOOD	VERY GOOD	Example	
	0%	25%	50%	75%	100 %	Points	%
MANAGEMENT (I_{MAN})	$I_{MAN} \leq 5$	$5 < I_{MAN} \leq 10$	$10 < I_{MAN} \leq 15$	$15 < I_{MAN} \leq 20$	$I_{MAN} > 20$	*18.75*	*75*
TECHNOLOGY & ENERGY ($I_{T\&E}$)	$I_{T\&E} \leq 5$	$5 < I_{T\&E} \leq 10$	$10 < I_{T\&E} \leq 15$	$15 < I_{T\&E} \leq 20$	$I_{T\&E} > 20$	*10*	*50*
ENVIRONMENTAL (I_{ENV})	$I_{ENV} \leq 7$	$7 < I_{ENV} \leq 14$	$14 < I_{ENV} \leq 21$	$21 < I_{ENV} \leq 28$	$I_{ENV} > 28$	20	*50*
SOCIAL (I_{SOC})	$I_{SOC} \leq 0$	$0 < I_{SOC} \leq 25$	$25 < I_{SOC} \leq 50$	$50 < I_{SOC} \leq 75$	$I_{SOC} > 75$	*50*	*50*
GEOTHERMAL SUMMARY (I_{GEO})	**$I_{GEO} \leq 5$**	**$5 < I_{GEO} \leq 10$**	**$10 < I_{GEO} \leq 15$**	**$15 < I_{GEO} \leq 20$**	**$I_{GEO} > 20$**	*14,3*	*50*

Table 17: Overview of indicators and their classes with a summary value and an example

Name of the indicator	Type/	Formula/Summary class Class value (V)	BAD 0%	WEAK 25%	MEDUM 50%	GOOD 75%	VERY GOOD 100 %	Example for calcualation Points	 %
Licencing procedure	Management	$I_{LIC} = \sum_{i=1}^{n} P_i$	$I_{LIC} \le 6$	$6 < I_{LIC} \le 9$	$9 < I_{LIC} \le 12$	$12 < I_{LIC} \le 15$	$I_{LIC} > 15$	*14*	*75*
Monitoring requirements	Management	$I_{REQ} = \sum_{i=1}^{n} P_i$	$I_{REQ} \le 3$	$3 < I_{REQ} \le 9$	$9 < I_{REQ} \le 11$	$11 < I_{REQ} \le 17$	$I_{REQ} > 17$	*22*	*100*
Monitoring setup	Management	$I_{MON} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}}$	$I_{MON} \le 1$	$1 < I_{MON} \le 3$	$3 < I_{MON} \le 6$	$6 < I_{MON} \le 10$	$I_{MON} > 10$	*5.2*	*50*
Passive monitoring	Management	$I_{MONP} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}}$	$I_{MONP} \le 0$	$0 < I_{MONP} \le 1$	$1 < I_{MONP} \le 3$	$3 < I_{MONP} \le 5$	$I_{MONP} > 5$	*4*	*75*
SUMMARY ON MANAGEMENT (I_{MAN})									
Operational issues	Technology & energy	$I_{BAT} = \frac{\sum_{i=1}^{n} I_i \cdot Q_i}{\sum_{i=1}^{n} Q_i}$	$I_{BAT} \le 1$	$1 < I_{BAT} \le 3$	$3 < I_{BAT} \le 4$	$4 < I_{BAT} \le 5$	$I_{BAT} > 5$	*3.7*	*50*
Cascade use	Technology & energy	$I_{CAS} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}}$	$I_{CAS} \le 1$	$1 < I_{CAS} \le 3$	$3 < I_{CAS} \le 4$	$4 < I_{CAS} \le 5$	$I_{CAS} > 5$	*4*	*50*
Thermal efficiency	Technology & energy	$I_{TEF} = \frac{\sum_{i=1}^{n} \eta_i \cdot Q_i}{\sum_{i=1}^{n} Q_i}$ [%	$I_{TEF} \le 30$	$30 < I_{TEF} \le 40$	$40 < I_{TEF} \le 60$	$60 < I_{TEF} \le 70$	$I_{TEF} > 70$	32	50
Utilisation efficiency	Technology & energy	$I_{UEF} = \frac{\sum_{i=1}^{n} Q_i}{\sum_{i=1}^{n} Q_{cap\ i}} \cdot 100$ [%]	$I_{UEF} \le 15$; $I_{UEF} > 100$	$15 < I_{UEF} \le 30$	$30 < I_{UEF} \le 45$	$45 < I_{UEF} \le 60$	$I_{UEF} > 60$	*110*	*0*
SUMMARY ON TECHNOLOGY & ENERGY ($I_{T\&E}$)									
Reinjection	Environmental	$I_{REIN} = \frac{\sum_{i=1}^{n} I_i \cdot Q_i}{\sum_{i=1}^{n} Q_i}$	$I_{REIN} = 0$	$0 < I_{REIN} \le 1$	$1 < I_{REIN} \le 3$	$3 < I_{REIN} \le 5$	$I_{REIN} > 5$	*1*	*25*
Over-exploitation	Environmental	$I_{OE} = \frac{\sum_{i=1}^{n} I_i \cdot Q_i}{\sum_{i=1}^{n} Q_i}$	$I_{OE} \le 1$	$1 < I_{OE} \le 2$	$2 < I_{OE} \le 3$	$3 < I_{OE} \le 4$	$I_{OE} > 4$	*5.2*	*100*
Status of water balance	Environmental	$I_{WBA} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}}$	$I_{WBA} \le 1$	$1 < I_{WBA} \le 1.5$	$1.5 < I_{WBA} \le 2.5$	$2.5 < I_{WBA} \le 3$	$I_{WBA} > 3$	0.5	0
SUMMARY ON ENVIRONMENTAL (I_{ENV})									
Public awareness	Social	$I_{INF} = \frac{\sum_{i=1}^{n} P_i}{N_{tot}}$	$I_{INF} \le 2$	$2 < I_{INF} \le 4$	$4 < I_{INF} \le 6$	$7 < I_{INF} \le 8$	$I_{INF} > 8$	4.1	50
SUMMARY ON SOCIAL (I_{SOC})									

2.5. Presentation of results

Results of all indicators can be presented or its summary value can be presented numerically, as a calculated value (Table 16-Table 17). Moreover, results can be presented for one user site at minimum as a colour scale (Figure 1).

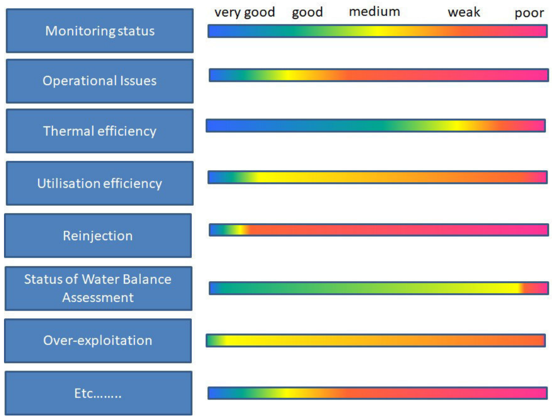

Figure 1: Application of benchmarking indicators for one set of data (e.g. at one user site or one reservoir)

Because the main idea of this approach is transboundary comparison of practice on a regional, reservoir or national scale, we will prepare also combinations of indicators. Due to generalised interpretation, the results will be given for the pilot area in each country per a reservoir, wither all reservoirs or basin fill or basement or other reservoirs. This means we can have combinations of at least six countries and two reservoirs to be able to show with the whole list of indicators. An example of the Danube basin between Hungary and Slovakia (left) and the Mura-Zala basin between Slovenia and Hungary (right) is given in Figure 2.

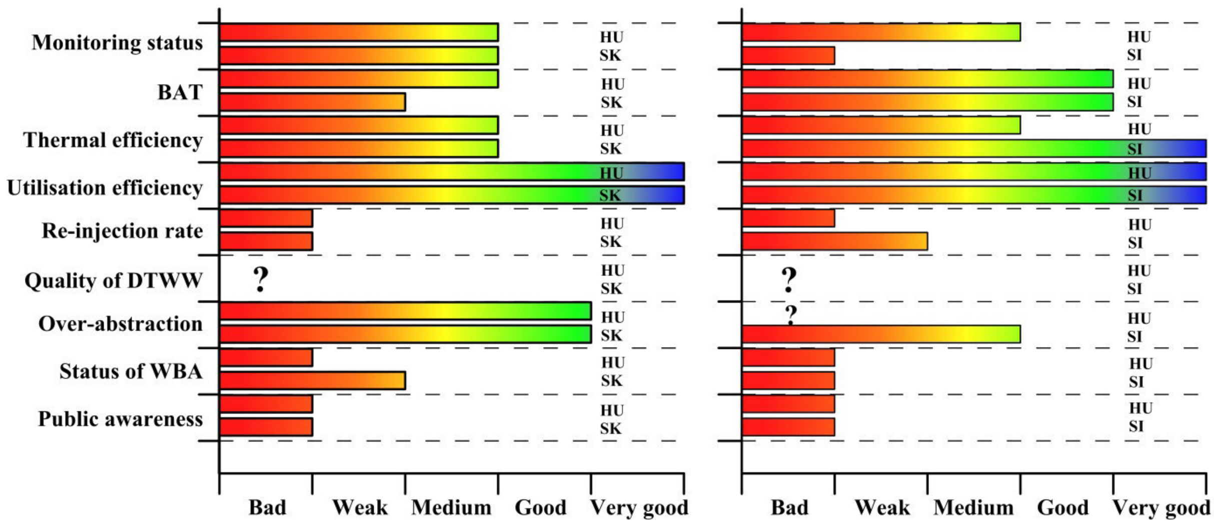

Figure 2: Application of benchmarking indicators for two transboundary areas – an example of possible view (the names of indicators will be changed). The number of regions (e.g. HU, SK,...) can be increased as needed.

Besides, there is also a possibility to show only one indicator and its results at several selected reservoirs/countries/users (Figure 3).

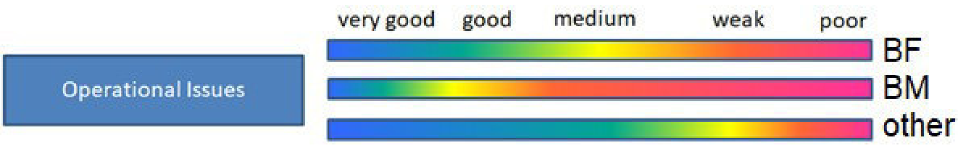

Figure 3: Example of results of only one indicator and three selected types of reservoirs.

3. Decision-tree

3.1. Introduction to the decision-tree

The method „decision-tree" is largely building on the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources (UNFC-2009) and its Specifications to Geothermal Energy Resources. The reason is that since its establishment, the UNFC-2009 classification scheme is continuously developing, and today it is rather considered as a tool for the management of various geological commodities (including solid mineral resources, fossils fuels, various renewables, as well CO_2 storage, anthropogen resources, etc.) , rather than a method for classifying a certain mining project, as it was its original goal. Therefore it has been considered as an ideal tool for assessing the transboundary geothermal resources of the DARLINGe project providing tools for the life-cycle project evaluation from exploration to abandonment, measuring the progress. The various steps, how a certain "project" is progressing along the 3 axes of the UNFC-2009 cube (E: Economic and social viability, F: Field project status and feasibility, and G: Geological knowledge) from an exploration phase to non-commercial and finally commercial projects is a result of various decisions and steps at different "decision gates", and therefore provides an ideal, moreover globally acknowledged and internationally accepted method, compliant to the requirements of a "decision-tree", as the project maturity sub-classes are based on the associated actions (business decisions) required to move a project towards commercial production/extraction.

Furthermore the UNFC-2009 is considered nowadays as a tool in policy formulation (contribution to the Transnational Danube Region Geothermal Strategy), in supporting governments by raising awareness on the national assets, as well assisting industry by helping them to make optimal investments. All these aspects are of utmost importance among DARLINGe aims and expected results.

The method presented in this report and to be applied to selected real and notional projects within the 3 cross-border pilot areas are building on 3 main documents having strong logical links that build on each other:

1. UNFC-2009 main document (United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 incorporating Specifications for its Application ECE Energy Series 42)

2. Renewable Specifications (Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 to Renewable Energy Resources)

3. Geothermal specifications (Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources)

These basic documents form Annexes of this report, and in the main text only the most important aspects are highlighted.

3.2. Basic principles of the UNFC-2009 classification scheme

The UNFC-2009 is a generic, principles-based system, that classifies quantities (geological commodities) of **a certain "mining" project** in a numerical and language independent coding scheme according to 3 fundamental criteria that are represented in 3 axes (Figue 4):

E: 'Economic and social viability' (degree of favourability of social and economic conditions in establishing commercial viability of project , e.g. market prices, relevant legal, regulatory, environmental and contractual conditions)

F: 'Field project status and feasibility' (maturity of studies and commitments necessary to implement project). These extend from early exploration efforts before a deposit or accumulation has been confirmed to exist through to a project that is extracting and selling a commodity, and reflect standard value chain management principles.

G: 'Geological knowledge' (level of confidence in the geological knowledge and potential recoverability of the quantities)

Combinations of these criteria create a three-dimensional system (Figure 4).

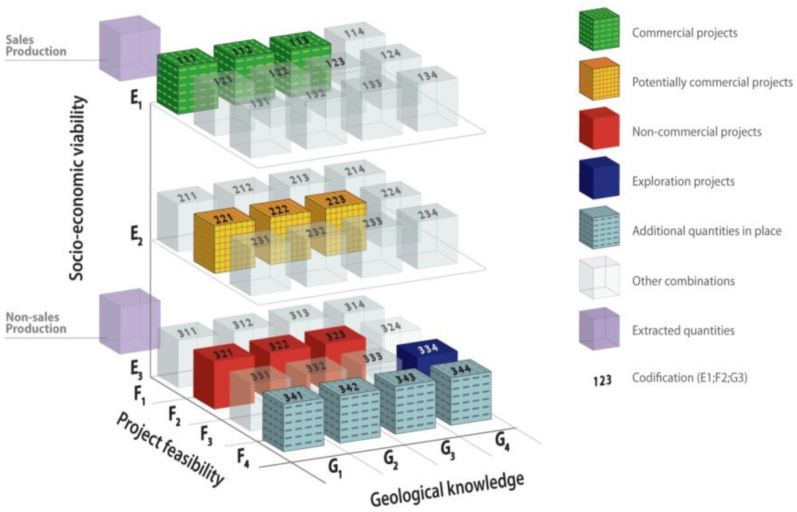

Figure 4: The UNFC-2009 system

In the case of **Commercial Projects** <u>On Production</u> is used where the project is actually producing/extracting and selling one or more commodities to market as at the Effective Date of the evaluation. Although implementation of the project may not be 100% complete at that date, the full project must have all necessary approvals and contracts in place, and capital funds committed. If a part of the project development plan is still subject to separate approval and/or commitment of capital funds such that it is not currently certain to proceed, that part should be classified as a separate project in the appropriate Subclass.

<u>Approved for Development</u> requires that all approvals/contracts are in place, and capital funds have been committed. Construction and installation of project facilities should be underway or due to start imminently. Only a completely unforeseeable change in circumstances that is beyond the control of the developers would be an acceptable reason for failure of the project to be developed within a reasonable time frame.

<u>Justified for Development</u> requires that the project has been demonstrated to be technically feasible and commercially viable, and there must be a reasonable expectation that all necessary approvals/contracts for the project to proceed to development will be forthcoming.

In the case of **Potentially Commercial Projects,** Development Pending is limited to those projects that are actively subject to project-specific technical activities, such as acquisition of additional data (e.g. appraisal drilling) or the completion of project feasibility studies and associated economic analyses designed to confirm project commerciality and/or to determine the optimum development scenario or mine plan. In addition, it may include projects that have non-technical contingencies, provided these contingencies are currently being actively pursued by the developers and are expected to be resolved positively within a reasonable time frame. Such projects would be expected to have a high probability of achieving commerciality.

Development On Hold is used where a project is considered to have at least a reasonable chance of achieving commerciality (i.e. there are reasonable prospects for eventual economic extraction), but where there are currently major non-technical contingencies (e.g. environmental or social issues) that need to be resolved before the project can move towards development. The primary difference between Development Pending and On Hold is that in the former case the only significant contingencies are ones that can be, and are being, directly influenced by the developers (e.g. through negotiations), whereas in the latter case the primary contingencies are subject to the decisions of others over which the developers have little or no direct influence and both the outcome and the timing of those decisions is subject to significant uncertainty.

In the case of Non-commercial Projects Development Unclarified is appropriate for projects that are still in the early stages of technical and commercial evaluation (e.g. a recent new discovery), and/or where significant further data acquisition will be required, in order to make a meaningful assessment of the potential for a commercial development, i.e. there is currently insufficient basis for concluding that there are reasonable prospects for eventual economic extraction.

Development not Viable is used where a technically feasible project can be identified, but it has been assessed as being of insufficient potential to warrant any further data acquisition activities or any direct efforts to remove commercial contingencies. In such cases, it can be helpful to identify and record these quantities so that the potential for a commercial development opportunity will be recognized in the event of a major change in technology or commercial conditions.

Finally quantities should only be classified as **Additional Quantities in Place** where no technically feasible projects have been identified that could lead to the extraction of any of these quantities. Some of these quantities may subsequently become recoverable in the future due to the development of new technology.

On each axes there are pre-defined classes and sub-classes (the latter only for E and F) that show the defining criteria (Tables 18-21).

Table 18: E classes and definitions

Category	Definition[b]	Supporting Explanation[c]
E1	Extraction and sale has been confirmed to be economically viable.[d]	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable timeframe. Economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.
E2	Extraction and sale is expected to become economically viable in the foreseeable future.[d]	Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future.
E3	Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability.[d]	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future; or, economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase).Also included are quantities that are forecast to be extracted, but which will not be available for sale.

Table 19: F classes and definitions

Category	Definition	Supporting Explanation
F1	Feasibility of extraction by a defined development project or mining operation has been confirmed.	Extraction is currently taking place; or, implementation of the development project or mining operation is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.
F2	Feasibility of extraction by a defined development project or mining operation is subject to further evaluation.	Preliminary studies demonstrate the existence of a deposit in such form, quality and quantity that the feasibility of extraction by a defined (at least in broad terms) development project or mining operation can be evaluated. Further data acquisition and/or studies may be required to confirm the feasibility of extraction.
F3	Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.	Very preliminary studies (e.g. during the exploration phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.
F4	No development project or mining operation has been identified.	In situ (in-place) quantities that will not be extracted by any currently defined development project or mining operation.

Table 20: G classes and definitions

Category	Definition	Supporting Explanation
G1	Quantities associated with a known deposit that can be estimated with a high level of confidence.	For in situ (in-place) quantities, and for recoverable estimates of fossil energy and mineral resources that are extracted as solids, quantities are typically categorised discretely, where each discrete estimate reflects the level of geological knowledge and confidence associated with a specific part of the deposit. The estimates are categorised as G1, G2 and/or G3 as appropriate. For recoverable estimates of fossil energy and mineral resources that are extracted as fluids, their mobile nature generally precludes assigning recoverable quantities to discrete parts of an accumulation. Recoverable quantities should be evaluated on the basis of the impact of the development scheme on the accumulation as a whole and are usually categorised on the basis of three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.
G2	Quantities associated with a known deposit that can be estimated with a moderate level of confidence.	
G3	Quantities associated with a known deposit that can be estimated with a low level of confidence.	
G4	Estimated quantities associated with a potential deposit, based primarily on indirect evidence.	Quantities that are estimated during the exploration phase are subject to a substantial range of uncertainty as well as a major risk that no development project or mining operation may subsequently be implemented to extract the estimated quantities. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty in the size of the potential deposit should be documented (e.g. in the form of a probability distribution). In addition, it is recommended that the chance (probability) that the potential deposit will become a deposit of any commercial significance is also documented.

G axis represents the degree of uncertainty associated with the estimates. The uncertainty is communicated either by quoting discrete quantities of decreasing levels of confidence (high, moderate, low) or by generating three specific scenarios or outcomes (low, best and high estimates). The former approach is typically applied for solid minerals, while the latter method is commonly used in petroleum (and also for geothermal). A low estimate scenario is directly equivalent to a high confidence estimate (i.e. G1 – P90), whereas a best estimate scenario is equivalent to the combination of the high confidence and moderate confidence estimates (G1+G2 – P50). A high estimate scenario is equivalent to the combination of high, moderate and low confidence estimates (G1+G2+G3 – P10) (Figure 5). Quantities may be estimated using deterministic or probabilistic methods.

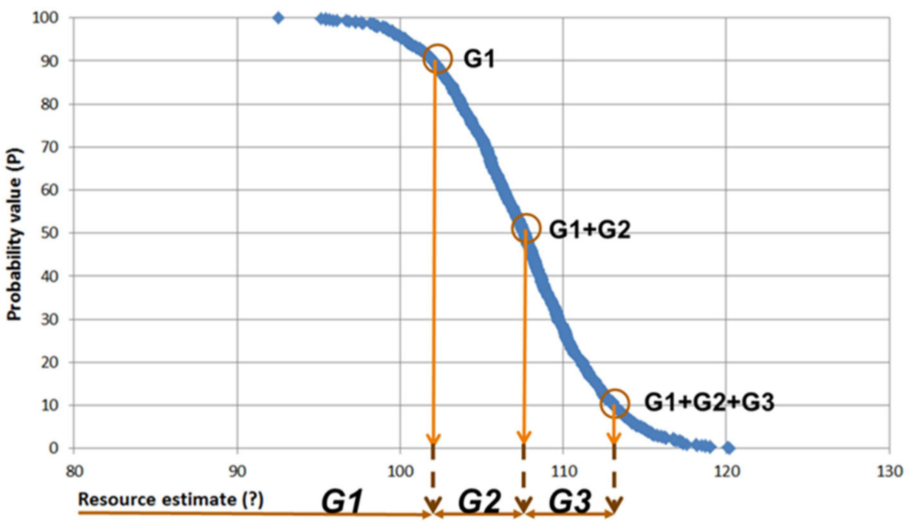

Figure 5: Probability distribution of various estimates

Table 21: E and F sub-classes and definitions

Category	Sub-Category	Sub-Category Definition
E1	E1.1	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions.
	E1.2	Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.
E2	No sub-categories defined	
E3	E3.1	Quantities that are forecast to be extracted, but which will not be available for sale.
	E3.2	Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase).
	E3.3	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.
F1	F1.1	Extraction is currently taking place.
	F1.2	Capital funds have been committed and implementation of the development project or mining operation is underway.
	F1.3	Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.
F2	F2.1	Project activities are ongoing to justify development in the foreseeable future.
	F2.2	Project activities are on hold and/or where justification as a commercial development may be subject to significant delay.
	F2.3	There are no current plans to develop or to acquire additional data at the time due to limited potential.

In some situations, it may be helpful to sub-classify Exploration Projects on the basis of their level of maturity. In such cases, the following specification shall apply:

F3.1: where site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designed to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated;

F3.2: where local geological studies and exploration activities indicate the potential for one or more deposits in a specific part of a geological province, but requires more data acquisition and/or evaluation in order to have sufficient confidence to warrant drilling or testing that is designed to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated;

F3.3: at the earliest stage of exploration activities, where favourable conditions for the potential discovery of deposits in a geological province may be inferred from regional geological studies.

In other situations, it may also be helpful to sub-classify Additional Quantities in Place on the basis of the current state of technological developments. In such cases, the following specification shall apply:

F4.1: the technology necessary to recover some or all of the these quantities is currently under active development, following successful pilot studies on other deposits, but has yet to be demonstrated to be technically feasible for the style and nature of deposit in which that commodity or product type is located;

F4.2: the technology necessary to recover some or all of the these quantities is currently being researched, but no successful pilot studies have yet been completed;

F4.3: the technology necessary to recover some or all of these quantities is not currently under research or development.

3.3. Renewable and Geothermal Specifications to be considered

The Renewables Specifications represent 'rules of application' of UNFC-2009 to Renewable Energy Resources, while the Geothermal Specifications represents 'rules of application' of UNFC-2009 to Geothermal Energy Resources, via the Renewables Specifications. Hence, these documents are to be used only in conjunction with each other. In this chapter we highlight those **key definitions and aspects** that are especially relevant for geothermal energy and should be considered when applying this scheme to case studies within the DARLINGe project pilot areas.

3.3.1. Geothermal Energy Source

In the geothermal energy context, the Renewable Energy Source is the thermal energy contained in a body of rock, sediment and/or soil, including any contained fluids, which is available for extraction and conversion into energy products. This source is termed the Geothermal Energy Source, and is equivalent to the terms 'deposit' or 'accumulation' used for solid minerals and fossil fuels.

3.3.2. Geothermal Energy Product

A Geothermal Energy Product is an energy commodity that is saleable in an established market. Examples of Geothermal Energy Products are **electricity and heat**. Other products, such as inorganic materials (e.g. silica, lithium, manganese, zinc, sulphur), gases or water extracted from the Geothermal Energy Source in the same extraction process do not qualify as Geothermal Energy Products.

In DARLINGe project area the product to be deal with is heat. Therefore purely balneological use cases should not be considered in this work.

3.3.3. Geothermal Energy Resources

Geothermal Energy Resources are the cumulative quantities of Geothermal Energy Products that will be extracted from the Geothermal Energy Source, from the Effective Date of the evaluation forward (till the end of the Project Lifetime/Limit), measured or evaluated at the Reference Point.

3.3.4. Effective date

Reported quantities are estimates of remaining quantities as at the Effective Date of the evaluation (i.e the **date when assessment is done**). The Effective Date shall be clearly stated in conjunction with the reported quantities. In other words it means that **UNFC-2009 does not deal with past production, only the evaluation and assessment of quantities that are expected to be available till the end of the project lifetime** (Figure 6)

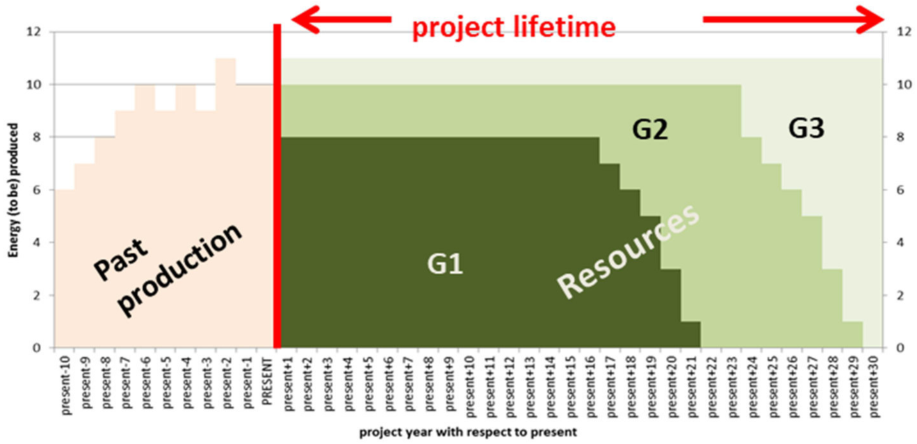

Figure 6: Concept of effective date and project lifetime

3.3.5. Project

The Project is the link between the Geothermal Energy Source and quantities of Geothermal Energy Products and provides the basis for economic evaluation and decision-making. In the context of geothermal energy, the **Project includes all the systems and equipment connecting the Geothermal Energy Source to the Reference Point**(s) where the final Geothermal Energy Products are sold, used, transferred or disposed of. The Project shall include all equipment and systems required for extraction and/or conversion of energy, including, for example, production and injection wells, ground or surface heat exchangers, connecting pipework, energy conversion systems, and any necessary ancillary equipment. In the early stages of evaluation, a Project might be defined only in conceptual terms, whereas more mature Projects will be defined in significant detail.

3.3.6. Project Lifetime

The estimated Geothermal Energy Resources for a Project shall be limited to quantities that will be produced during the Project Lifetime. The Project Lifetime will be the minimum of the (1) economic limit, (2) design life, or (3) contract period, or (4) entitlement period, till the end of which evaluation of the available resources is made (Fig. 2).

The 'economic limit' is defined as the time at which the Project reaches a point beyond which the subsequent cumulative discounted net operating cash flows from the Project would be negative. **For a geothermal project, the economic limit may be the time when the expected extraction rate declines to a level that makes the Project uneconomic,** or when it is uneconomic to invest in further extraction infrastructure such as additional wells.

The 'design life' of a Project is the expected operating life of major physical infrastructure as defined during the technical and economic assessment of the Project. The replacement of significant project components will constitute a new Project and a new evaluation and estimation of Geothermal Energy Resources shall be performed.

The **'contract period'** for a geothermal Project is the term of all existing, or reasonably expected, **sales contracts for the Geothermal Energy Products.** The contract period should not include contract extensions unless there is reasonable expectation of such extensions, based upon historical treatment of similar contracts.

The **'entitlement period'** is the term of **all licences and permits** which provide rights to access the Geothermal Energy Source, extract the Geothermal Energy Resources and deliver the Geothermal Energy Products into the market. The entitlement period should not include licence extensions unless there is reasonable expectation of obtaining such extensions, based upon historical treatment of similar licences issued by the issuing authority.

It is important to note that the geothermal energy source may be expected to last much longer than the Project Lifetime, but any future extracted quantities beyond those estimated for the Project would be assessed and classified as subsequent or additional Projects, or in-situ quantities (F4, G4).

3.3.7. Reference Point

The Reference Point is a **defined location in the production chain** where the quantities of Geothermal Energy Product are measured or assessed. The Reference Point is typically the point of sale to third parties (**in geothermal direct use cases normally heat exchanger**). Sales or production of Geothermal Energy Products are normally measured and reported in terms of estimates of remaining quantities crossing this point from the Effective Date of the evaluation.

3.3.8. Specifics related to E-axis and E classes/subclasses

In the geothermal context, the **Foreseeable Future** is within a maximum of **five years**.

In case of geothermal a variety of policy support mechanisms, regulatory instruments and financial incentives (e.g., feed-in tariffs, premiums, grants, tax credits etc.) exist worldwide. Thus, when using the subcategory E1.2, the type of government subsidies and/or other considerations that make extraction and sale viable shall be disclosed, together with their anticipated future availability as at the Effective Date.

3.3.9. Specifics related to F-axis and F classes/subclasses

A Geothermal Energy Resource associated with an **Exploration Project shall be classified as F3.** The F3 category has three sub-categories (see Chapter 2). The F3.3 sub-category relates to "the earliest stages of exploration activities." If the result of the first test well is 'dry,' 'unsuccessful,' or 'inconclusive,' the Geothermal Energy Resource estimate shall still be classified as F3, despite the presence of at least one exploration well.

Classification of projects on the F-axis is often dependent upon **'technology under development.'** Such projects **should be classified on the F-axis as F4** unless:

(i) the technology has been demonstrated to be technically viable in analogous Geothermal Energy Sources; or,

(ii) the technology has been demonstrated to be technically viable in other Geothermal Energy Sources that are not analogous, and a pilot project is planned to demonstrate viability for this Geothermal Energy Source.

3.3.10. Specifics related to G-axis and G classes/subclasses

The G-axis categories are intended to reflect all significant uncertainties impacting the estimated Geothermal Energy Resources quantities that are forecast to be extracted by the Project.

A **Known Geothermal Energy Source** is one where one or more wells have established through testing, sampling and/or logging the existence of a significant quantity of potentially recoverable heat. In this context, 'significant' implies that there is evidence of a sufficient quantity of recoverable heat to justify estimation of the Geothermal Energy Resources demonstrated by the well(s) and for evaluating the potential for economic development. 'Recoverable' implies that the depth and the thermal, permeability and fluid properties of the Geothermal Energy Source have been shown, or are expected, to be suitable for recovering heat at rates which have a reasonable chance of being sufficient to support a commercial project. Estimated Geothermal Energy Resources associated with Known Geothermal Energy Sources **shall be classified and reported using the 'G' categories, G1, G2 and G3**, according to the respective confidence level of assessment, as described in chapter 2.

A **Potential Geothermal Energy Source** is one where the existence of a significant quantity of recoverable thermal energy has not yet been demonstrated by direct evidence (e.g. drilling and - in some cases - well testing, sampling and/or logging), but is assessed as potentially existing based primarily on evidence from geophysical measurements, geochemical sampling and other surface or airborne measurements or methods. Estimated Geothermal Energy Resources associated with Potential Geothermal Energy Sources **shall be classified and reported using the 'G' category G4 or its sub-categories G4.1, G4.2 and G4.3.**

3.3.11. Units

Estimated quantities shall be reported in **Joule (J) or multiples of the Joule.** However, it is recognized that there are traditional measurement units that are widely used and accepted in the geothermal energy sector; such units can therefore be added in parenthesis next to the Joule value.

The geothermal specific E,F and G definitions are shown in Table 22.

Table 22: E, F,G definitions specific to geothermal

Category	Definition	Supporting Explanation (UNFC-2009, Part I, Annex I)	Sub Categories	Definition	Additional Renewable Energy Context	Additional Geothermal Energy Context
E1	*Extraction and sale has been confirmed to be economically viable*[(a)]	*Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals/ contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable timeframe. Economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.*	**E1.1**	*Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions*	*Extraction is the process of converting a Renewable Energy Source into Renewable Energy Product(s).*	In the geothermal context, heat is extracted from the Geothermal Energy Source. In most projects, this heat is carried from the Geothermal Energy Source to the surface via a fluid, typically brine or steam. At surface, the heat may be transferred to another working fluid through heat exchangers and may also be converted into electricity.
			E1.2	*Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.*		This includes subsidies needed for present or future operation. If subsidies were used in the past (e.g. to drill a well), they are no longer relevant to the classification of the Geothermal Energy Resource.
E2	*Extraction and sale is expected to become economically viable in the foreseeable future.*	*Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future.*	*None*	---	---	---
E3	*Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability*	*On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future; or, economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the assessment phase). Also included are quantities that are forecast to be converted, but which will not be available for sale.*	**E3.1**	*Quantities that are forecast to be extracted, but which will not be available for sale.*	---	For example, quantities produced and used internally (e.g. parasitic use, such as well pumping, power conversion loss, etc.)
			E3.2	*Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase)*		For example, pre-successful well drilling exploration complete (if a drilled 'dry' or unsuccessful, but further drilling is planned, this sub-category is still appropriate). Or, Where there is an active effort to obtain approval, the outcome is unknown or unclarified.
			E3.3	*On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.*		Uneconomic sites, for example sites far from transmission and/or demand Or Where there is an active effort to obtain approval, the likelihood of receiving approval is low.

Category	*Definition*	*Supporting Explanation (UNFC-2009, Part I, Annex I)*	*Sub Categories*	*Definition*	*Additional Renewable Energy Context*	*Additional Geothermal Energy Context*	
F1	*Feasibility of extraction by a defined development project or mining operation has been confirmed.*	*Extraction is currently taking place; or, implementation of the development project is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a development project or mining operation.*	***F1.1***	*Extraction is currently taking place.*	*The term development project is the renewable energy Project as described in Part II.*	Successful sustained operation of the Project up to Reference Point. For power projects, this typically includes wells and plant. For direct-use projects, this typically includes the wells, piping and ancillary equipment up to the heat delivery point. For GSHP projects, this typically includes wells or ground heat exchangers, piping, heat pump unit(s) and ancillary equipment up to the user heat delivery point.	Any adverse operational issues (e.g. chemistry, gas content, scaling, corrosion) can be managed.
			F1.2	*Capital funds have been committed and implementation of the development project or mining operation is underway.*		---	
			F1.3	*Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.*		---	
F2	*Feasibility of extraction by a defined development project or mining operation is subject to further evaluation.*	*Preliminary studies demonstrate the existence of a project in such form, quality and quantity that the feasibility of extraction by a defined (at least in broad terms) development Project or mining operation can be evaluated. Further data acquisition and/or studies may be required to confirm the feasibility of extraction.*	***F2.1***	*Project activities are ongoing to justify development in the foreseeable future.*	---	For direct use and electricity projects, at least one well drilled indicating potential for production. For GSHP, studies are still ongoing (no drilling needed)	
			F2.2	*Project activities are on hold and/or where justification as a commercial development may be subject to significant delay.*			

Category	*Definition*	*Supporting Explanation (UNFC-2009, Part I, Annex I)*	*Sub Categories*	*Definition*	*Additional Renewable Energy Context*	*Additional Geothermal Energy Context*
F3	*Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.*	*Very preliminary studies (e.g. during the assessment phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a project in such form, quality and quantity that the feasibility of production can be evaluated.*	***F3.1 (*)***	*Where site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designed to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated;*	---	Pre-successful well drilling exploration complete (if a drilled well is 'dry' or unsuccessful, but further drilling is planned, this sub-category is still appropriate).
			F3.2 (*)	*Where local geological studies and exploration activities indicate the potential for one or more deposits in a specific part of a geological province, but requires more data acquisition and/or evaluation in order to have sufficient confidence to warrant drilling or testing that is designed to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated;*	---	Pre-drilling exploration in progress
			F3.3 (*)	*At the earliest stage of exploration activities, where favourable conditions for the potential discovery of deposits in a geological province may be inferred from regional geological studies.*	---	Regional geothermal potential studies
F4	*No development project or mining operation has been identified.*	*In situ (in-place) quantities that will not be produced by any current development project or mining operation.*	***F4.1***	*The technology necessary to recover some or all of the these quantities is currently under active development, following successful pilot studies on other deposits, but has yet to be demonstrated to be technically feasible for the style and nature of deposit in which that commodity or product type is located;*	*Category F4 can be used to classify the currently non-extractable quantities at the geographical location of the defined Project due to, for example, site/area constraints, technology limitations and/or other constraints*	---
			F4.2	*The technology necessary to recover some or all of the these quantities is currently being researched, but no successful pilot studies have yet been completed;*		---
			F4.3	*The technology necessary to recover some or all of these quantities is not currently under research or development.*		---

Category	Definition	Supporting Explanation (UNFC-2009, Part I, Annex I)	Sub Categories	Definition	Additional Renewable Energy Context	Additional Geothermal Energy Context
G1	*Quantities associated with a known deposit that can be estimated with a high level of confidence.*	*For in situ (in-place) quantities, and for recoverable estimates of fossil energy and mineral resources that are extracted as solids, quantities are typically categorized discretely, where each discrete estimate reflects the level of geological knowledge and confidence associated with a specific part of the deposit. The estimates are categorized as G1, G2 and/or G3 as appropriate.* *For recoverable estimates of fossil energy and mineral resources that are extracted as fluids, their mobile nature generally precludes assigning recoverable quantities to discrete parts of an accumulation. Recoverable quantities should be evaluated on the basis of the impact of the development scheme on the accumulation as a whole and are usually categorized on the basis of three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.*	---	*High-confidence estimate (low estimate)*	*The G-axis reflects the level of confidence in the potential recoverability of the quantities. Thus, the G-axis categories are intended to reflect all significant uncertainties impacting the estimated Renewable Energy Resources quantities that are forecast to be extracted by the Project and typically would include (but not be limited to) areas such as meteorology, climatology, topography and other branches of geography, ecology and, for geothermal Projects, geology. Uncertainties include both variability in the Renewable Energy Source and the efficiency of the extraction and conversion methodology (where relevant).* *Typically, the various uncertainties will combine to provide a full range of possible outcomes, comparable to the extraction of fluids in the petroleum sector. In such cases, categorization should reflect three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.*	---
G2	*Quantities associated with a known deposit that can be estimated with a moderate level of confidence.*		---	*Moderate-confidence estimate (best estimate) incremental to G1*		---
G3	*Quantities associated with a known deposit that can be estimated with a low level of confidence.*		---	*Low-confidence estimate (high estimate) incremental to G2*		---
G4	*Estimated quantities associated with a potential deposit, based primarily on indirect evidence.*	*Quantities that are estimated during the exploration phase are subject to a substantial range of uncertainty as well as a major risk that no development project or mining operation may subsequently be implemented to extract the estimated quantities. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty in the size of the potential deposit should be documented (e.g. in the form of a probability distribution). In addition, it is recommended that the chance (probability) that the potential deposit will become a deposit of any commercial significance is also documented.*	*G4.1*	*High-confidence estimate (low estimate*	*Category G4 is equally applicable to renewable energy, for "Estimated quantities associated with a potential Renewable Energy Source, based primarily on indirect evidence" (e.g. mapping studies).*	For example, delineation by surface surveys; evidence, of rock-water interactions, spring analysis, temperature gradient, regional heat-flow maps, etc. For GSHP projects, G4 does not apply.
			G4.2	*Moderate-confidence estimate (best estimate) incremental to G4.1*		
			G4.3	*Low-confidence estimate (high estimate) incremental to G4.2)*		

3.4. The classification process – practical steps

The resource classification process consists of:

1. defining a Project, or Projects, associated with a Geothermal Energy Source,
2. estimating the quantities of energy that can be recovered and delivered as Geothermal Energy Products by each Project,
3. classifying the Geothermal Energy Resource based on the criteria defined by the E, F and G categories.

3.4.1. Project selection for DARLINGe assessment

The aim is to cover the full granularity of the „UNFC Cube" (exploration, development (green-field, brown-field), expansion, full-operation commercial projects, etc.). Projects delivering heat (as a product) should be selected, 2-3 from each pilot area. Purely balneological projects are not suitable. Selecting projects from the "best practice examples" (Act.5.3.) are recommended, however other projects (real ones or notionals), can be considered as well.

In case of cascaded systems the reference points hav to be defined carefully and furthermore it has to be considered how to quantities for each sequence are reported (separate, or disclosed together). Cascaded systems haven't been assessed so far in UNFC-2009, so this should be achallenge and a new added value to the system at the same time.

When selecting projects it should be considered that all necessary information required for the assessment and classification to the relevant E and F categories should be available.

3.4.2. Estimation of quantities to be reported

It is very important to note, that **quantification of the geothermal energy** source delivered as a product by the selected project **should not be mixed up with its classification in the relevant G categories.** With other words **quantification is not equal with its qualification (when the amount of geothermal energy expressed in Joule is classified in the relevant G-category according to the confidence level of estimation)** (see also Fig. 2).

The method, how the amount of the energy product of the selected project is estimated is of free choice. Normally there are 2 types of estimation methods:

- The **"scenario" approach**, which is based on three discrete scenarios that are designed to reflect the range of uncertainty in the possible outcomes (e.g. production forecast).
- The **"probabilistic" approach**, where multiple possible scenarios are generated (e.g. by Monte Carlo analysis) from input distributions of parameter uncertainty associated with the Project extracting energy from the Renewable Energy Source.

Estimates	Probablistic example
Low estimate (high level of confidence) = G1	-P90
Best estimate (moderate level of confidence)= G1 + G2	-P50
High estimate (low level of confidence) = G1 + G2 + G3	-P10

3.4.3. Classification

In the last step the quantified geothermal energy resource (4.2) of the defined project (4.1) is classified into the relevant E, F and G classes/sub-classes. E.g. “Project X” produces 5 PJ (low estimate), 10 PJ (best estimate), 19 PJ (high estimate).

4. Geological Risk Mitigation

4.1. Introduction to geological risk mitigation

One module of the tool-box is the Geological Risk Mitigation Scheme tailored to the needs and to geological as well as socio-economic conditions of the Danube Region. The present chapter describes the methodology of the scheme, which is focussing on how to mitigate the entire spectrum of geological risk during exploration and operational phase.

The scheme will be tested on a future hypothetical site at each pilot area during completion of WP7.

The main aim of the methodology is to collect and describe a series of mitigation measures to avoid possible damages during the completion of a conventional geothermal project in the Danube Region. The initial activity of the collection is the identification of damages and to evaluate what kind of risk events might result a given damage. When a risk event is known, the connected risk avoiding, and mitigating measures could be described including conditions, timing etc. The application of the risk mitigation measures is a user-friendly description and manual about how to deal with subsurface uncertainties during a geothermal project development and what kind of measures could be taken at what project phases to avoid failures originated from geological aspects. First the basic concepts of risk management will be described, which provides a better understanding where is the role of mitigation measures in the whole risk management process.

4.2. Basic concepts of risk management

The description of concepts is based on the next guidelines: ISO/IEC Guide 51, ISO 73-2009, ISO 31000-2009.

The concept of risk has several definitions. The most general definition of risk is the "effect of uncertainty on objectives". In this phrasing the effect is the deviation from the expected, the uncertainty is the state, and the objective is an imagined, future result.

A more concrete definition of risk is the combination of the consequences of an event (including changes in circumstance) and the associated likelihood of their occurrence. The term of event corresponds to occurrence or to change of particular set of circumstances, the term of likelihood is the chance of something happening. This definition is similar to the first one, because one might describe an objective as a set of circumstances and the deviation because of uncertainties, in other words the possible change in circumstance, which has effect on the implementation of an objective, manifests the likely event with its consequences.

In geothermal projects there are manageable circumstances, mostly connected to manmade activities, while there are natural circumstances as well, what one must endure. The risk itself is negligible, or hardly known, if it has no observable negative consequence, or its occurrence is way too unlikely. Using this explanation there are **two methods to reduce a risk:** on one side there is an opportunity **to reduce the size of negative consequences,** on the other side **the likelihood of occurrence could be decreased** as well. The observable or measurable character of an event and its consequences are also important factors to evaluate a given risk. In geothermal projects, especially in case of a geothermal wells the measuring of a risk event is a great challenge, because one measured parameter in a well is a result of combination of numerous properties, and these properties could be affected by numerous other risk events as well.

The measurable form of a risk is, when it is expressed as the **combination of the probability of occurrence of the harm and the severity of that harm.** The term of **harm corresponds to damage to property, and the severity of harm is the cost of damage.** The probability is the measure of chance expressed as a number between 0 and 1. **By the identification of cost of damages and the probability of occurrences one might create ranked lists** according to costs or to likelihoods. The result of **multiplication of cost and likelihood is the risk factor**. By the **sorting of all risk factors according to theirs size, one can create a ranked risk profile.** By the help of these three lists, one can evaluate what are the costliest risks, what are the most probable risks, and what are the most problematic risks, which should be handled during the implementation of a project.

The connection between the risk event and the damage might be direct or indirect. In the first case the probability of a risk event is equal with the probability of a damage. In the latter case there are follow-on events between the risk event and the damage, which are in causal connection from the risk event to the damage. The probability of damage is the product of multiplication of probabilities of risk events and follow-up events. This also indicates that an observed risk event does not necessarily result in a damage. In general, risk event is part of a root activity, which ensures the condition of presence of a given risk event.

The **risk management** is the coordination of activities to direct and control an organization, or a project with regard to risk. The person or entity, who has the accountability and authority to manage a risk is the **risk owner**. In geothermal projects the risk owner is the project owner, or the project developer. The approach of risk owner to asses and eventually pursue, retain, take or turn away from risk is the risk attitude. Due to high level of uncertainties connected to geological features, the risk-taking attitude is an indispensable ingredient of risk management.

The process of risk management in broad terms is a systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risks. In a geothermal project this corresponds to the following activities:

- Communication among stakeholders
- Collection of information about risks
- Evaluation of risks
- Risk treatment activities
- Decisions
- Monitoring of processes and effect of treatment

The key activity is **risk assessment**, which is an overall process of **risk identification, risk analysis and risk evaluation.** During the identification, the main tasks are the finding, recognizing and describing risks, which involves the description of risk events and their consequences. In this phase the stakeholder's needs, especially the interests of risk owner are taking into consideration, too. The risk analysis is a process also, in which the nature of the risk is comprehended, and the level of risk is determined. During the process of risk evaluation, one might compare the result of risk analysis with the risk criteria to determine whether the risk and/or its magnitude is acceptable.

There is no proper risk management without the use of monitoring and reporting. The aim of monitoring is to identify change from the performance level required or expected by the help of continual checking, supervising, critically observing or determining the status of progress. The monitoring provides indispensable information about the quality of risk management. The reporting is a form of communication for informing internal and external stakeholders by providing information regarding the current state of risk and its management. The appropriate information towards the risk owner is the prerequisite of risk acceptance, because only informed decisions belong to risk acceptance. The decisions made on the basis of lacking of or partial information, might remain disputable points for the risk owner, especially when the management of a project is shifting on the field of limited opportunities, when the fulfilment of different necessities takes over the management of the project.

The **risk treatment is the process to modify the risk**. This is a two-way process, on one side the risk can be reduced, on the other side the risk might be managed towards increase. The risk treatment might involve:

- avoiding the risk by deciding not to start, or continue with the activity that gives rise to the risk,
- taking or increasing risk in order to pursue an opportunity,
- removing the risk source,
- changing the likelihood,
- changing the consequences,
- sharing the risk with another party or parties (risk sharing),
- retaining the risk by informed decision (risk acceptance).

4.3. Geological risk mitigating activities

Risk mitigation is a type of risk treatment that deals with avoiding the negative consequences. In general, everyone thinks at first that the aim of risk treatment is risk mitigation. This is seemingly true, because the active steps of risk treatment are mostly mitigating activities, and the associated risk increasing activities are less pronounced. For example, the decisions initiated by cost and time constraints one way or another are used to decrease the original technical risk of a project, which will result higher uncertainties, and thus higher likelihood of damages.

All risk mitigation activity is a costly measure. While the actual cost of an activity could be defined by a relatively good accuracy, as it consists of some services and of use of some devices and materials, the evaluation of real contribution of a mitigating measure to the success of a project is problematic. This is quite a difficult task during geothermal exploratory activities, because on one side the confirmation of success is available at a late stage of the project after performing numerous costly construction activities, while on the other side the limited access to the subsurface hardly ensures obvious verifications. Due to complexity of measures and deficient visibility of subsurface, it is way too difficult to decide the exclusive role of a mitigation measure in the success of the project. In addition, there are numerous mitigating measures, whose usefulness could be decided adequately only after long term operation. The only adequate way of measuring the real value of a mitigation measure is, if there is an opportunity to measure the value of the project without the given measure. Unfortunately such an opportunity is almost non-existent in exploratory work. Besides the cost, the mitigation activities have effect on the project timeline, the application of a given measure might call for special conditions and might have adverse effect on the success of other activities, including risk avoiding measures.

The risk mitigating activities have three groups. The first group is when the measure aims the avoidance of risk source, the element which alone, or in combination has the intrinsic potential to give rise to the risk. For example, when external casing packer is used at the top of the production zone, this device prevents the contamination of production zone from particles fallen from the loose part of overlying formations. Another example when the use of clay mineral as mud additives is banned, this eliminates the possible clog of pores in the production zone during drilling.

The second group of activities concentrates on the decrease of likelihood of risk event. When the poorly explored character of an area could not allow the adequate geological evaluation, the performance of new measurements decreases the likelihood of misinterpretation. The reliability of a geological interpretation could be checked by requesting independent, second opinion. The likelihood of misinterpretation is decreasing if the second opinion supports the findings of original evaluation.

The third group contains those activities which are decreasing the size of negative consequences. For example, using under-reaming and gravel pack, the moveable particles of the formation remain in the formation or in the gravel pack, and this will increase the efficiency of filtering of produced water at the surface, which will manifest in decrease of operational costs. Another example is when the discontinuous use of a geothermal well at low production rate indicate significant cooling from the resource to the surface, and the rate of cooling could be decreased using cement with increased heat insulation properties.

There are kind of amending activities which might cure given damages. In geothermal, the lack of water-bearing layers in the already drilled production section might be amended by further drilling, if conditions allow this opportunity. The underperformance of wells might be amended by use of stimulation methods, like thermal, chemical or hydraulic stimulations. These activities are not part of risk mitigating measures, because these are performed after the damage has been observed. But these activities could be performed if certain conditions have been fulfilled previously. So, the integration of conditions of amending measures during the completion, as precautionary activity is indispensable prerequisite to decrease the size of negative consequence after it has been observed. For example fractured reservoirs have a less predictable nature, concerning the position of water bearing fracture, which might result in the lack of permeability at the originally planned production section. If the drilling of production section does not verify the presence of permeable fractures, the further drilling towards deeper section increase the likelihood of intersecting fractures. The further drilling requires technical conditions concerning the abilities of the rig, design of contingency liner and well structure. These conditions should be implemented into the design of construction work well-before the proof of missing permeability is observed. Another opportunity of amending is the stimulation. This activity can hardly be successful, if the reservoir formation is a brittle rock, but there are loose, hardly consolidated, clayey formations in the 6” open hole section of the well, especially close to the shoe of the deepest casing. There is high probability that during chemical or hydraulic stimulation the collapse of loose part will occur, which will likely clog the well itself. The mentioned geological setting is quite common in the Pannonian Basin, when the open hole intersects the bottom of Neogene layers and the underlying pre-Cainozoic rocks.

Another less appropriate “mitigation” activity could be the postponing of adverse effects of exploration phase to operational phase, or when an issue to be possibly raised is simply passed away to cause a threat for another field, or for a third party. An example for the first case is the lack of hydraulic connection between the members of the doublet. This way the water of one aquifer is transferred to another separated aquifer, which might not indicate problems at the very beginning of the operation, if both reservoirs are big enough and possess significant recharge. But on long term it is only a question of time, when the misuse appears unquestionably. An example for the second case is the skipping of injection of produced thermal water, which would create significant cost increase, and the release of salty thermal water into surface water causing contamination. These kind of activities are unfortunately quite common practices, however far from sustainable use of renewable energy resources.

Concerning activities like estimation, evaluation and design, which are based on geological data, a request for second independent opinion is always an available tool for increasing the reliability of geological knowledge, which will decrease the risk stem from the uncertainty of subsurface data.

4.4. Decisions during phases of a geothermal project

The application of a given risk mitigation measure is the result of a decision. The development of a geothermal project is full of opportunities, when these actions could be made. The subsequent phases of a project together with changes of all kinds of risks and project costs are presented on Figure 7.

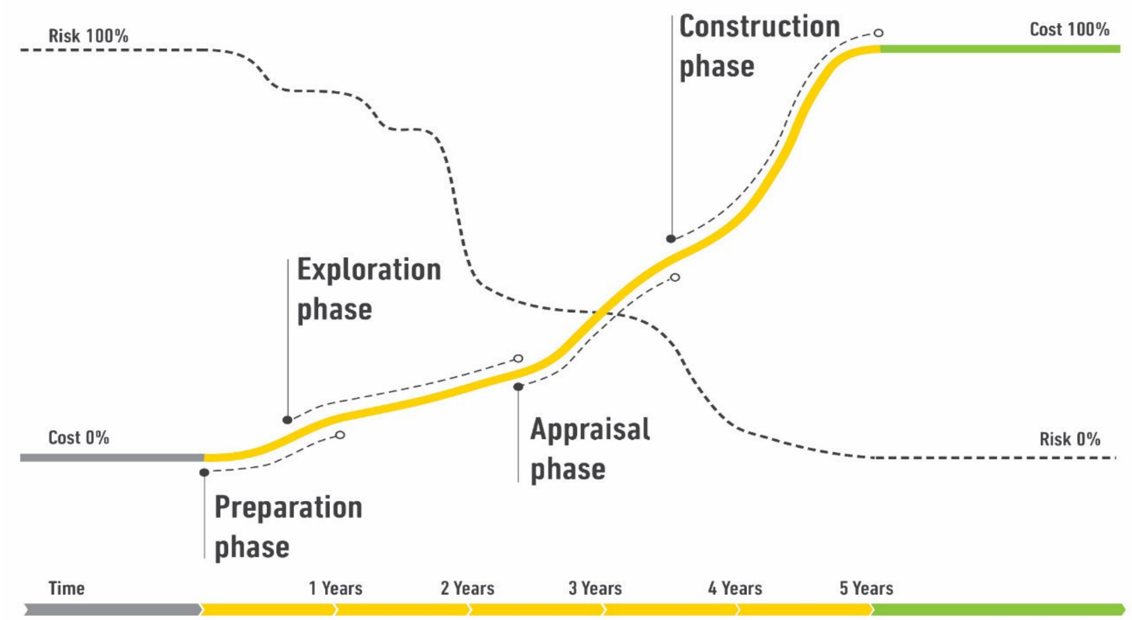

Figure 7: Development of an average geothermal project

In the preparation phase the collection of geological data, the evaluation of resource parameters and the conceptual design of possible development are the main tasks. This phase is the cheapest one, which will result quite limited decrease of risks. The next phase is the exploration phase, which is full of design work and this includes the first exploratory drilling, which will verify the presence of the resource in the form of outflow temperature and yield in function of drawdown. When a geothermal project constitutes simply the completion of a doublet and heat station with heat exchangers, the activities of first drilling are disproportionally costly, but the successful testing of the well will cause significant drop of risk, especially geological risk. The appraisal phase covers the drilling of next wells and the preparatory, design work for construction. The success of drillings will decrease further the risks. In the construction phase the completion of surface works, like building of pipelines, connection roads, grids and the construction of power plant, will be performed, which are quite costly, but predictable activities implying small decrease in project risk. The operation phase starts when the facility is working officially according to permits and producing energy regularly.

Concerning risk management, the main activity during preparation phase is the assessment of risks. This is such an early phase, that meaningful risk mitigating measures can hardly be taken. During the process of collection of geological data, the reliability of data could be estimated, and proposal could be made for further data collection or data acquisition. When the resource parameters and the geology are evaluated, a high-level description could be provided about the expected difficulties.

In the exploratory phase the concrete design of drilling works starts, which will include clear description of series of activities. All these descriptions are based on a geological forecast, which consists of expected geological layers and their properties, which might affect the process of drilling. As the subsurface features are associated with uncertainties, the drilling program must handle this unpredictable nature with certain flexibility adapting to circumstances to be encountered during drilling. The design of drilling works is the period when numerous decisions could be made to integrate a wide variety of many risks mitigating measures. The duration of drilling is quite short (several months), and in good case there will be a production test at the end, which provides the confirmation of the resource and/or the damage. Due to the short and complex drilling activity, and the high cost of operating drilling rig, the planning of new risk mitigating measures is quite rare during the completion of drilling. Only the previously designed and well-prepared risk mitigating activities could be applied during drilling. Of course, in case of unforeseen geology during the drilling, the management should re-consider the drilling program and apply new risk mitigation measure.

The geological risks of the appraisal phase are mostly associated with the presence of hydraulic connection besides the successful drillings. The activities should focus on locating the wells into the same hydrogeological unit, and to collect confirmation by different test methods that hydraulic connection exists between the wells. This is the phase together with exploration, when the properties and the way of production of fluid is measured and evaluated, which provides instructions for the design of construction work, by which the appearance of long term, operational risks (e.g. calcite scaling, corrosion, cooling of produced fluid etc.) might be avoided.

By the start of the construction phase, all geological data should have been collected and evaluated, thus all expected short term risk is known prior to the design and construction of power plant and surface pipes. So this is not the phase when a damage could appear suddenly, because of unknown geological features.

During operation the so called long term risks, like adverse pressure change and temperature might turn up, which can hardly be mitigated during this phase. The successful avoidance of long term risks could be made during the exploration and appraisal phases, see above. It is possible, that the risk owner has an intention to accept the long-term risk, by which the cost of construction could be decreased, and some time savings could be made as well. When this decision is made on an informed way, knowing the pros and cons, and consequences of decision, is called risk acceptance.

As it was mentioned previously, the risk owner is responsible for the decisions, which impacts the project development, and thus the success of the project. The risk owner should make an informed decision, which might contain risk acceptance, or risk mitigation measures. The decisions should be documented and contain reasoning, which helps later to follow-up the conditions and considerations when the decision was made. The latter will provide indispensable information to evaluate what kind of lessons was learnt after the completion of the project. When a mitigation measure is applied, the monitoring of completion of the measure and its consequences is strongly recommended.

Decisions during the project development might have such a consequence, which is narrowing down future opportunities. The risk owner should be aware of irreversible or quasi irreversible character of consequences to accept them, and to arrive on a decision accordingly. In general, the project sponsor, as risk owner has no accurate view on the possible consequences of different decision due to limited knowledge connected to the handling of uncertainty of subsurface features. Professional experts working on the field of exploration have the knowledge to explain possible consequences of different decisions, and they can provide consultancy service towards the risk owner. In this constellation the expert is responsible for his suggestions, while the risk owner is responsible for his decisions. For making a defensible decision by the risk owner based on the suggestion of expert, it is necessary to have accurate, unambiguous conversation between the parties, and the flow of communication should be bilateral, and as open as possible. This way the quality of suggestions will be increased, because of the integration of considerations by the risk owner. Both parties could treat the decision as their own contributions to the success of the project, and both are able and ready to defend it, when it is necessary.

4.5. Procedure of creating Geological Risk Mitigation Scheme

The geological risk mitigation scheme is a tool which provides guidelines about the management of geological risks on a transparent and efficient way. For the sake of efficiency and clear understanding, several conditions have been established. First condition is that the scheme itself deals with purely geological risks, which is evaluated by geoscientific experts, e.g. drilling technical issues stem from inadequate drilling operation are not part of the scheme. Another restriction is connected to type of geothermal projects. The scheme is focussing on conventional use of geothermal energy, so artificial reservoir creation, like EGS (Engineered Geothermal System) is not part of the discussion. Further consideration is, that risk transfer and sharing are not discussed, because these are not mitigating activities.

Within conventional geothermal projects there might be numerous variations, so the scheme is dealing with one idealised project, which consists of planning and drilling of a doublet (one production and one injection well), connecting the wells and circulating the fluid via heat exchangers for heat and/or electricity production. The scheme is handling separately the two types of reservoirs of the Pannonian Basin, the fractured and porous aquifers, as defined during the delineation and characterization of potential reservoirs in WP5. Most of the measures are identical for the two kinds of reservoir, but there are several, which are different, and these are labelled accordingly.

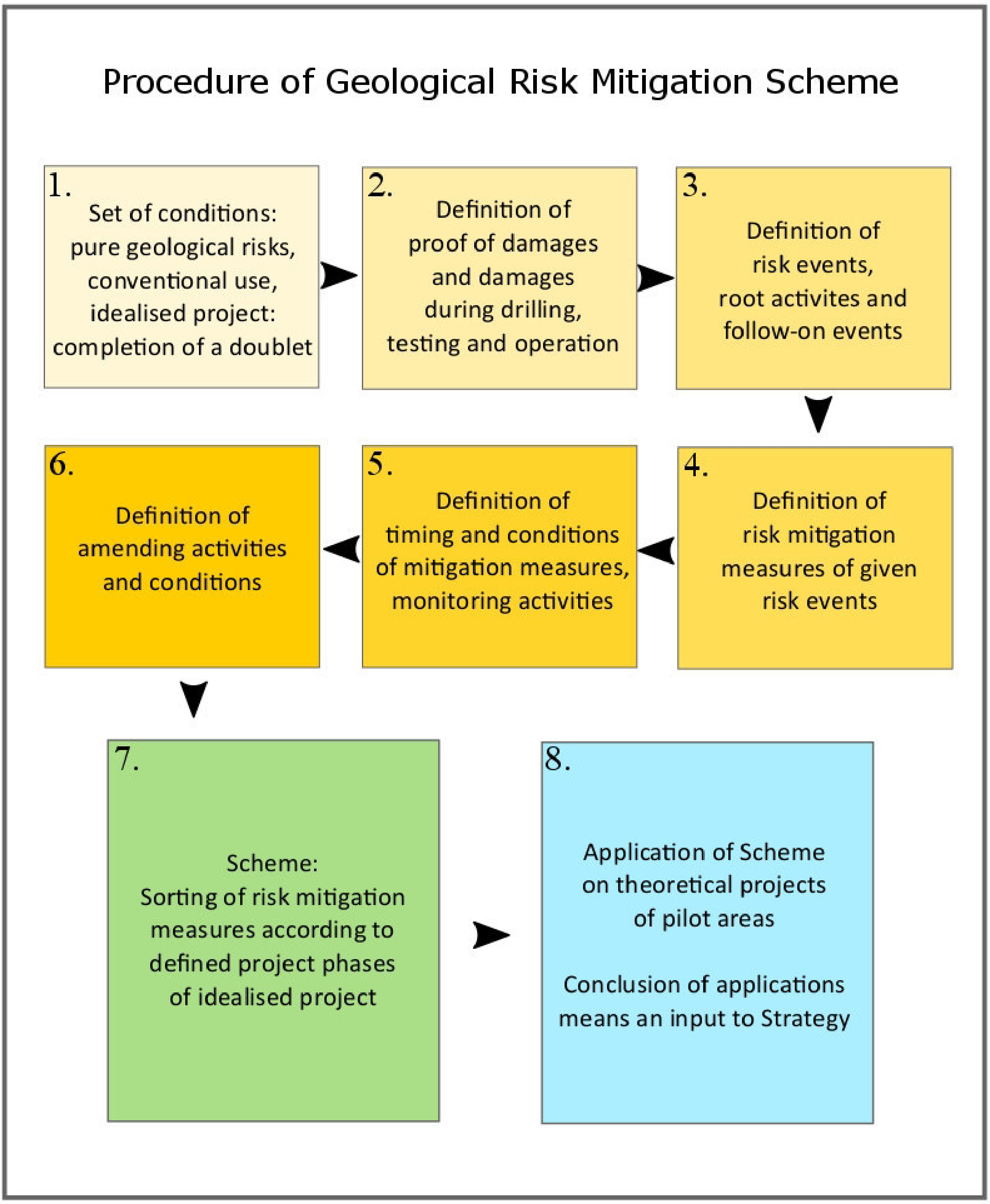

Figure 8: Procedure of creating of Geological Risk Mitigation Scheme in DARLINGe project

After the setting of above-described conditions, the first step of creation of the scheme is the identification of damages (Figure 8). The damage is defined as a result, which differs from the expected results, and creates increase in original project costs, or decrease in future planned income of the project. Damage could be observed during drilling process, during production testing, or during operation. The declaration of a damage is based on the observation of some proofs, which verifies its presence. One damage could be verified based on different proofs, of during different project phases.

The next step is the retrospective identification of risk events and theirs follow on events from the direction of a given damage. There are numerous risk events, which might result the same damage, and there are risk events, which might result different damages. The risk events are defined as pair of “if” and “then” relation. The pre-condition of a given risk event, like a root activity is defined as well.

When a risk event is known, then the connected risk mitigation measure(s) could be defined. For the design of a measure, the timing of application and the conditions are indicated as well. A suitable monitoring activity for the controlling of the given mitigating measure is indicated, too.

There are several amending activities by which some damage might be cured. These activities are listed, and the preconditions for the application are indicated too.

When the content of the above listed items is available, then the re-structuring of the risk mitigation measures could be made according to project phases. This form of the Scheme will give a guideline for a project developer to identify what kind of mitigation measure could be made in due time to avoid different possibly appearing damages. The content of the Scheme and the restructured version of the Scheme are described in two separate chapters below.

4.6. Content of the Scheme

4.6.1. Damage

The identified damages for an idealised project are listed in Table 23. The damages are indicated according the time when the proof is available for a given damage. At early phases, at drilling and at testing of the well, the short-term risks are threatening the success of the project. During drilling the proof of the costliest damage, the loss of well could appear when an irreversible technical failure happens, or the targeted formation is missing in the well, or such a high overpressure was measured, which makes impossible the safe and economic use of well. During testing the possible damages are more various kinds. The loss of well could happen, if the well is not able to produce or inject any fluid. It might turn up that the amount of energy to be produced is lower than it was expected, which could be the result of low temperature, low yield, or lack of connection between the wells. The latter one would be verified by the testing of the second member of the doublet. Cost increase in investment and operation might be the result of unexpectedly high gas content, corrosion and scaling nature of the produced fluid. The observation of unusual pressure changes at receptors nearby during testing might result in pending of operation permit. During operation the so called long term risk might create unfavourable results one way or another. The damage of decreased energy production could be verified by experiencing unusual cooling of produced fluid. The cost increase in operation takes place, when continuous, unidirectional pressure change, or increased scaling or corrosion activity is observed at the wells, or when the particles of produced fluid clog the heat exchanger of the geothermal loop. The pending of operation could be triggered by unusual induced temperature or pressure change at protected receptors nearby, like spring, operating water or hydrocarbon well.

Table 23: Identified damages and proof of damages of an idealised project

Damage	Proof of damage
During drilling	
The loss of well.	Technical failure. An irreversible technical failure occurs at the drilling.
The loss of well.	Missing formation. The targeted reservoir formation is missing in the well.
The loss of well.	Overpressure. The formation pressure is much higher as it was originally expected.
During testing	
The loss of well.	No production/injection. The well is not able to produce/inject any fluid.
The amount of energy is lower than it was expected.	Low temperature. The temperature is lower, what was expected.
The amount of energy is lower than it was expected.	Low yield. The yield (production or injection) is lower, what was expected.
The amount of energy is lower than it was expected.	No connection. There is no hydraulic connection between the members of the doublet.
Cost increase in investment and operation.	High gas content. The amount of gas observed in the produced fluid is much higher as it was anticipated originally.
Cost increase in investment and operation.	Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.
Cost increase in investment and operation.	Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.
Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.
During operation	
The amount of energy is lower than it was expected.	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.
Cost increase in operation.	Pressure drop. Continuous pressure drop is observed at the production well.
Cost increase in operation.	Pressure increase. Continuous pressure increase is observed at the injection well.
Cost increase in operation.	Increased scaling. Increased scaling activity of produced fluid is observed.
Cost increase in operation.	Increased corrosion. Increased corrosion activity of produced fluid is observed.
Cost increase in operation.	Clogged heat-exchanger. The particles of produced fluid clogs the pores of heat-exchanger.
Pending of operation.	Induced temperature change. Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby
Pending of operation.	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby

4.6.2. Root activity

The scheme contains 69 risk events, whose root activities are listed according to frequency in Table 184. The most frequent root activity is when the development is running on an inadequately explored area. This is the activity where some mitigation measure could be taken by further measures and more accurate evaluations. The next in the row is the drilling into unknown area, this is the situation when the unpredictable character of geology might appear even on well explored area, or the procurement of needed data is so costly, that is comparable with the cost of a newly drilled production well. This is the field of risk acceptance, because financial burdens of mitigating activities are extremely high. The sum of the number of risks event belonging to these two items is 33, so the improper geological evaluation and the unknown geology might be responsible for half of the risk events, and for most of the damages verified during drilling and testing phases. Six risk events are associated with inadequate drilling of production section, the consequences appear in the testing phase. The inadequate modelling of subsurface environment, new development nearby and inadequate testing are quite frequent roots of risk events, the unfavourable consequences of these activities might appear during operation. The remaining activities are partly connected to geological evaluation and partly technical.

Table 184: Root activities of risk events

Root activity	Frequency
Drilling into inadequately explored area	22
Drilling into unknown area	14
Inadequate drilling of production section	6
Inadequate modelling of subsurface environment	6
New development nearby	6
Inadequate testing	5
Inadequate water treatment	3
Malfunction during the completion of the well	3
Inadequate evaluation	2
Inadequate measurement	2
Selection of inadequately identified target	1
Inadequate completion of injection well	1
Misinterpretation of groundwater flow	1
The production well is operated at low yield	1

4.6.3. Risk event

The list of risk events is presented in Table 25. The most frequent events are connected to unforeseen subsurface condition, poor exploratory data and inaccurate evaluation of subsurface data. All these conclude different damages via different set of follow-on events. The location of wells of doublet might be improper due to inaccurate modelling, or inaccurate verification of reservoir model, or inadequate testing. Similarly, the different set of follow-on events will result different kind of damages in these cases. The remaining risk events are more concrete, and one possible activity has one direct consequence, which is the damage itself in some cases. In case of missing cement behind the casing two kinds of consequence might be: 1. the well will produce partially cold groundwater decreasing the outflow temperature, and thus decreasing produced energy, 2. the induced pressure change could affect another aquifer, which might trigger the pending of operation permit. The inaccurate chemical sampling has adverse effect on the evaluation of scaling and corrosion potential, which might conclude the increase of the operation costs.

When a damage is result of chain of events, the mitigation measure should avoid the evolvement of the chain by the breaking the chain at the most critical and most managable link. When a risk event directly results the damage, the mitigation should focus on the risk event itself.

Table 25: Possible risk events of idealised project

Risk event - IF member	Risk event - THEN member	Frequency
If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	10
If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	10
If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be	10
If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	5
If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	5
If the modelling is inadequate,	then the modelled effect of new development will be misleading.	3
If the testing is inadequate,	then the verification of reservoir model is inaccurate.	3
If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	2
If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	2
If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the cold groundwater could be produced.	1
If bacterias are invading the surface of formation,	then the injectivity will decrease.	1
If clayey drilling mud is used during the drilling of production	then drilling mud will contaminate the pores.	1
If LCM (loss control material) is used during the drilling of production section,	then LCM will contaminate the pores.	1
If previous exploratory data are poor and rare,	then the forecast of drilling difficulties will be inaccurate.	1
If significant recharge of groundwater takes place around the	then the production zone is colder what was expected.	1
If the chemical analysis is inaccurate,	then the evaluation of scaling potential is inaccurate.	1
If the chemical analysis is inaccurate,	then the evaluation of corrosion potential is inaccurate.	1
If the definition of location of target is inaccurate,	then the drilling will miss the target.	1
If the diameter of production section is too narrow,	then the openhole section will have limited capacity.	1
If the drilling runs into unforeseen subsurface condition,	then the forecast of drilling difficulties will be inaccurate.	1
If the evaluation of corrosion potential is inaccurate,	then the corrosion activity is higher than it was expected.	1
If the evaluation of scaling potential is inaccurate,	then the scaling activity is higher than it was expected.	1
If the evaluation of subsurface data is inaccurate,	then the forecast of drilling difficulties will be inaccurate.	1
If the flow in the well is very slow,	then the produced fluid will be cooled.	1
If the injected water contain particles,	then the pores will be clogged.	1
If the position of the well was designed too close to receptors,	then the induced pressure change will be higher than it was expected.	1
If the previous casing section is cemented and intersects the production section,	then the cement will contaminate the pores.	1
If the produced water contain particles,	then the pores of heat exchangers will be clogged.	1
If the production section is short,	then the production section will have limited capacity.	1
If the scaling potential is changing during the production	then the scaling activity might be inreased with time.	1
If the corrosion potential is changing during the production	then the corrosion activity might be inreased with time.	1
If the particle content of produced water is changing,	then the pores of heat exchangers might be clogged.	1

4.6.4. Mitigation measures

The list of mitigation measures possibly applied during an idealised project is presented in Table 26. The measures are sorted according to the damages to be avoided by the application of relevant measures. Taking into consideration of the gravest damage, the loss of well, the mitigation measures are almost exclusively focussing on proper data collection, interpretation and on procurement of new geoscientific data by new measurements in case of poor exploratory data. The reliability of exploratory data and its interpretation is quite relative, but the use of second opinion gives an opportunity for the risk owner to decide need on further analyses and measurements. The situation, when the proven amount of energy is lower than previously expected, calls for numerous mitigation measures of different kinds. Besides the increase of reliability of data and its interpretation, there are numerous technical considerations, whose application decreases the likelihood of having risk events. The temporary damage, the pending of operation might be avoided by proper hydrogeological modelling, which is based on sound data collection, especially during the production test of well(s). The cost increase in operation might be avoided mostly by technical measures and accurate data collection and interpretation.

Table 26: List of mitigation measures to be done to avoid different possible damages

Mitigation	Damage
Accurate collection and interpretation of geological layers and features for securing information about forecasted drillign difficulties.	The loss of well.
Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).	The loss of well.
Accurate collection and interpretation of geological layers and features for securing information about	The loss of well.
Accurate collection and interpretation of pressure data measured in existing wells for securing information	The loss of well.
Doing new pressure measurements at old wells for securing information about hazard of overpressure.	The loss of well.
Doing new surface geophysical measurements for better understanding of geological layers and for securing	The loss of well.
Doing new surface geophysical measurements for better understanding of geological layers for securing	The loss of well.
Doing new surface geophysical measurements for better understanding of geological layers for securing	The loss of well.
Try to identify and aim more than one target for the drilling.	The loss of well.
Accurate collection and interpretation of productivity data of wells for securing information for the expected yield of the well.	The amount of energy is lower than it was expected.
Accurate collection and interpretation of temperature data measured in existing wells for securing information for temperature forecast.	The amount of energy is lower than it was expected.
Accurate data collection and interpretation for securing information for realistic structural evaluation.	The amount of energy is lower than it was expected.
Accurate hydrogeological modelling including data collection and interpretation.	The amount of energy is lower than it was expected.
Avoid the cementing of previous casing string in the production section.	The amount of energy is lower than it was expected.
Avoid the use of LCM during drilling of production section.	The amount of energy is lower than it was expected.
Designing the production section of the well with 8 1/2" diameter.	The amount of energy is lower than it was expected.
Doing new measurements in existing wells for securing information for realistic structural evaluation.	The amount of energy is lower than it was expected.
Doing new measurements in existing wells for securing information for the expected yield of the well.	The amount of energy is lower than it was expected.
Doing new temperature measurements in existing wells for securing information for temperature forecast.	The amount of energy is lower than it was expected.
In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	The amount of energy is lower than it was expected.
In case of porous aquifer use of underreaming and gravel pack in the production section.	The amount of energy is lower than it was expected.
Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	The amount of energy is lower than it was expected.
Professional service provider and supervised cementing activites for appropriate isolation.	The amount of energy is lower than it was expected.
Try to drill long enough production section for securing the expected yield.	The amount of energy is lower than it was expected.
Use of cement with increased heat insulation properties for cementing of casings of production well.	The amount of energy is lower than it was expected.
Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.	The amount of energy is lower than it was expected.
Use of external casing packer between the loose formation and productive layer.	The amount of energy is lower than it was expected.
Accurate data collection and interpretation for the purpose of hydrogeological modelling.	Pending of operation.
Accurate hydrogeological modelling including data collection and interpretation.	Pending of operation.
Accurate hydrogeological modelling.	Pending of operation.
Doing new measurements in existing wells for securing information for hydrogeological modelling.	Pending of operation.
Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	Pending of operation.
Professional service provider and supervised cementing activites for appropriate isolation.	Pending of operation.
Accurate hydrogeological modelling including data collection and interpretation.	Cost increase in operation.
Accurate hydrogeological modelling including data collection and interpretation.	Cost increase in operation.
Adequate filtering of produced water before the heat-exchanger	Cost increase in operation.
Adequate filtering of re-injected water	Cost increase in operation.
Doing regular logging, evaluation and maintenance of the well.	Cost increase in operation.
In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	Cost increase in operation.
In case of porous aquifer use of underreaming and gravel pack in the production section.	Cost increase in operation.
Monitoring of change of produced fluid's particle content	Cost increase in operation.
Monitoring of corrosion potential of produced fluid	Cost increase in operation.
Monitoring of scaling potential of produced fluid	Cost increase in operation.
Performing adequate chemical sampling and analysis of produced fluid	Cost increase in operation.
Performing adequate evaluation of corrosion potential	Cost increase in operation.
Performing adequate evaluation of scaling potential	Cost increase in operation.
Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	Cost increase in operation.
Use of external casing packer between the loose formation and productive layer.	Cost increase in operation.
Use of killing agent to inhibit the invasion of bacterias in productive layers of injection well.	Cost increase in operation.
Accurate collection and interpretation of chemical data for securing information about the forecasted corrosion potential of the produced fluid.	Cost increase in investment and operation.
Accurate collection and interpretation of chemical data for securing information about the forecasted gas content of the produced fluid.	Cost increase in investment and operation.
Accurate collection and interpretation of chemical data for securing information about the forecasted scaling potential of the produced fluid.	Cost increase in investment and operation.
Doing new chemical sampling and analysis at existing wells for securing information about the forecasted corrosion potential of the produced fluid.	Cost increase in investment and operation.
Doing new chemical sampling and analysis at existing wells for securing information about the forecasted gas content of the produced fluid.	Cost increase in investment and operation.
Doing new chemical sampling and analysis at existing wells for securing information about the forecasted scaling potential of the produced fluid.	Cost increase in investment and operation.

4.6.5. Amending activities

When a damage was observed, there are several activities which's application might amend the situation. These activities provide quite limited opportunities compared to mitigation measures, in addition many of them could be completed only when certain conditions are fulfilled previously. The list of amending activities is indicated in

Table 27 according to the observed proof of damage. The application of further drilling, stimulation and coil tubing have technical preconditions, while other measures, like decrease of production or compensation of receptor(s) have no such. Of course, all the amending activity has financial consequences.

Table 27. List of amending activities by observations

Proof of damage / Observation	Amending activity	Conditions of amending activity
	During drilling	
The targeted reservoir formation is missing in the well.	Finding suitable water bearing formation in the already drilled section.	Proper logging data for identification of auxiliary targets.
The targeted reservoir formation is missing in the well.	Drilling further	The design of the well and the used rig should be suitable for the activity
	During testing	
The well is not able to produce/inject any fluid.	Drilling further	The design of the well and the used rig should be suitable for the activity
The temperature is lower, what was expected.	Drilling further	The design of the well and the used rig should be suitable for the activity
The temperature is lower, what was expected.	Increase of yield, when the cooling up to surface is high	The design of well should allow the lowering of pump
The yield (production or injection) is lower, what was expected.	Cleaning of well from LCM and cuttings by airlifting	
The yield (production or injection) is lower, what was expected.	Acidizing and cleaning by airlifting	
The yield (production or injection) is lower, what was expected.	Drilling further	The design of the well and the used rig should be suitable for the activity
The yield (production or injection) is lower, what was expected.	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity
Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Decrease of production rate (temporary solution)	
Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Compensation of affected receptor(s)	
There is no hydraulic connection between the members of the doublet.	Drill another well to be located in the same hydrogeoloigcal unit as the pair of well.	
There is no hydraulic connection between the members of the doublet.	Decrease of production rate (temporary solution)	
The amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Re-design of depth of pump and pressure of surface system according to measured values.	The bottom of pump chamber should be designed and completed deep enough.
The observed scaling activity of produced fluid is higher as it was anticipated originally.	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration
The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration
	During operation	
Unusual cooling of produced fluid is observed at the production well.	Decrease of production rate (temporary solution)	
Unusual cooling of produced fluid is observed at the production well.	Drill a new production well at larger distance from injection well.	
Continuous pressure drop is observed at the production well.	Decrease of production rate (temporary solution)	
Continuous pressure drop is observed at the production well.	Drill a new well, which is presumably not affected by the pressure change.	
Continuous pressure drop is observed at the production well.	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity
Continuous pressure increase is observed at the injection well.	Decrease of production rate (temporary solution)	
Continuous pressure increase is observed at the injection well.	Drill a new well, which is presumably not affected by the pressure change.	
Continuous pressure increase is observed at the injection well.	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity
Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Decrease of production rate (temporary solution)	
Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Compensation of affected receptor(s)	
Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Decrease of production rate (temporary solution)	
Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Compensation of affected receptor(s)	
Increased scaling activity of produced fluid is observed.	Decrease of production rate (temporary solution)	
Increased scaling activity of produced fluid is observed.	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration
Increased corrosion activity of produced fluid is observed.	Decrease of production rate (temporary solution)	
Increased corrosion activity of produced fluid is observed.	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration
Particles of produced fluid clog the heat exchanger.	Use of filter system at the surface	

4.7. Result of the Scheme

The previous chapters described the process of identification of mitigation measures. The starting point was the identification of damages, than on a retrospective way the risk events and root activities were defined. When the risk event has been known, the mitigation measure(s), which decreases the likelihood of having a risk event, or the size of consequence of risk event were identified. In the next step the timing and conditions of mitigation measures are defined. The timing follows the expected phases of idealised project, which phases are listed below:

- Reconnaissance phase
- 1st geological evaluation phase
- 1st design phase
- 1st drilling phase

- 2nd geological evaluation phase
- 2nd design phase
- 2nd drilling phase
- 3rd geological evaluation phase
- Completion phase
- Operation phase

The indicated project phases are not exactly subsequent phases. Most of them are running parallel, but at given periods, these have definite roles, which are described in the subchapters below. Figure 9 presents the defined phases of an idealised project, when the below described mitigation measured could be performed. The work of each phase might start earlier, or last later compared to the period, when the actual, responsible work is performed.

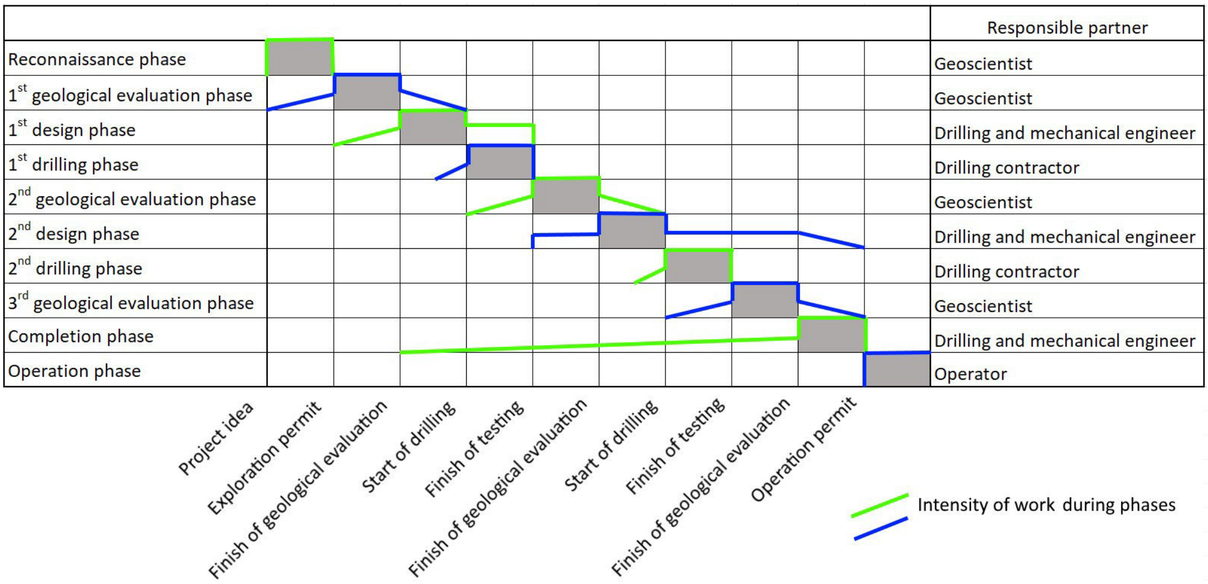

Figure 9: Phases of an idealised project

The result of the Scheme is the listing of mitigation measures according to project phases instead of damages. This way the planner of a geothermal project could follow what kind of measures he could integrate during the project development to avoid definite damages to be appeared possibly later. The mitigation measures are described in sub-chapters indicating the name of relevant project phase.

4.7.1. Reconnaissance phase

The reconnaissance phase is the earliest phase of development, which starts from the project idea and lasts until the decision to obtain an exploration permit, or not. During this period the collection of easily procurable existing data, maps, literature, reports and performance of quick and cheap chemical analysis are part of data gathering. Based on above-mentioned data and site visits, an evaluation is made about the features of a resource and profitability of a theoretical development. The evaluation might include proposal concerning further steps and exploration activity. The risk owner can use the result of reconnaissance study to justify his decision on securing exploration permit by further investment. As the main challenge of this phase is to accept the financial risk of exploration permit based on available data, the mitigation measures have very limited role during this time, thus these measures are not described here. If a risk owner is not satisfied with the outcome of the study, he can ask for an independent second opinion.

4.7.2. 1st geological evaluation phase

This phase covers data gathering and interpretation activities made exclusively by geoscientists. This phase theoretically starts in the reconnaissance phase and last until the drilling, but the main activity is made between the approved exploration permit and the start of the design phase. The main challenge of geological evaluation during this period is to provide reliable data for the design of first drilling and of surface systems.

Table 28: Mitigation measures to be done in 1st geological evaluation phase

Mitigation measures
Accurate collection and interpretation of chemical data for securing information about the forecasted corrosion potential of the produced fluid.
Accurate collection and interpretation of chemical data for securing information about the forecasted gas content of the produced fluid.
Accurate collection and interpretation of chemical data for securing information about the forecasted scaling potential of the produced fluid.
Accurate collection and interpretation of geological layers and features for securing information about forecasted drillign difficulties.
Accurate collection and interpretation of geological layers and features for securing information about identification of target formation.
Accurate collection and interpretation of pressure data measured in existing wells for securing information about hazard of overpressure.
Accurate collection and interpretation of temperature data measured in existing wells for securing information for temperature forecast.
Accurate data collection and interpretation for the purpose of hydrogeological modelling.
Accurate hydrogeological modelling including data collection and interpretation.
Doing new chemical sampling and analysis at existing wells for securing information about the forecasted corrosion potential of the produced fluid.
Doing new chemical sampling and analysis at existing wells for securing information about the forecasted gas content of the produced fluid.
Doing new chemical sampling and analysis at existing wells for securing information about the forecasted scaling potential of the produced fluid.
Doing new measurements in existing wells for securing information for hydrogeological modelling.
Doing new pressure measurements at old wells for securing information about hazard of overpressure.
Doing new surface geophysical measurements for better understanding of geological layers and for securing information about forecasted drilling difficulties.
Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target reservoir.
Doing new temperature measurements in existing wells for securing information for temperature forecast.

The measures, which are due to be performed in this phase is listed in Table 28. All activity is connected to data, the main message of the list is: if one ensures high quality data, that will have significant risk decreasing effect.

4.7.3. Geological evaluation phases

In this subchapter those mitigation activities are collected, which are common in all geological phases during the idealised project development (Table29). Similarly, to the previous subchapter, the emphasise is on the collection of high quality data also.

Table 29: Mitigation measures to be done in geological evaluation phases

Mitigation measures
Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).
Accurate data collection and interpretation for securing information for realistic structural evaluation.
Doing new measurements in existing wells for securing information for realistic structural evaluation.
Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target feature (fault, karstified surface).
Try to identify and aim more than one target for the drilling.

4.7.4. 1st design phase

The design phase comes after the geological evaluation, in which the drilling engineers and mechanical engineers have the leading role. The most important outcome of this phase is the plan of drilling or drilling program. The measures are listed in Table 30. It is necessary to bear in mind that most of the mitigation measures to be completed in drilling phases (see e.g. next subchapters) should be designed in advance, in the relevant design phase.

Table 30: Mitigation measures to be done in 1st design phase

Mitigation measures
Accurate collection and interpretation of productivity data of wells for securing information for the expected yield of the well.
Accurate hydrogeological modelling.
Designing the production section of the well with 8 1/2" diameter.
Doing new measurements in existing wells for securing information for the expected yield of the well.

4.7.5. 1st drilling phase

The drilling phase is when the active onsite work of drilling is running. It starts from the mobilization of the rig and lasts until the finish of operation of end of drilling (OED), which covers the testing activities in general. During the operation, the drilling contractor has the highest responsibility to secure the safe and professional work, while the risk owner has the right to supervise the activity of the drilling company. This way the risk owner can check the compliance of planned and performed activities, and he can act in due time, when decision is needed to deviate from the planned activities triggered by the appearance of a new information. The mitigation measures to be done in this phase are listed in Table 31. The listed measures are technical activities, which should be designed and procured prior to the actual application.

There are two additional conditions to the previously described idealised project. On one hand the production well will be designed and drilled at first. On the other hand, following the everyday practice in the geothermal developments made in the Pannonian Basin, the first drilling is a confirmation drilling instead of exploratory drilling, because the latter cannot provide the desired yield.

Table 31: Mitigation measures to be done in 1st drilling phase

Mitigation measures
Performing adequate chemical sampling and analysis of produced fluid
Use of cement with increased heat insulation properties for cementing of casings of production well.

4.7.6. Drilling phases

The common mitigation activities of drilling phases are listed in Table32. All of them are technical measures, which call for design and procurement in advance.

Table 32: Mitigation measures to be done in drilling phases

Mitigation measures
Avoid the cementing of previous casing string in the production section.
Avoid the use of LCM during drilling of production section.
In case of porous aquifer use of underreaming and gravel pack in the production section.
Professional service provider and supervised cementing activites for appropriate isolation.
Try to drill long enough production section for securing the expected yield.
Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.
Use of external casing packer between the loose formation and productive layer.

4.7.7. 2nd geological evaluation phase

The 2nd geological evaluation is based on the data collected during the completion of first drilling. The responsible person of the evaluation is a geoscientist. The result will be used in the planning of next drilling and surface facilities. The mitigation measures of this phase are listed in Table 33, while the measures of all geological evaluation phases, which should be applied as well is indicated in Table29.

Table 33: Mitigation measures to be done in 2nd geological evaluation phase

Mitigation measures
Accurate hydrogeological modelling including data collection and interpretation.
Performing adequate evaluation of corrosion potential
Performing adequate evaluation of scaling potential

4.7.8. 2nd design phase

The second design phase is based on the data of 2nd geological evaluation. There is no explicit mitigation measure which might be performed during this phase. Meanwhile, the design of technical measures of subsequent drilling phase should be done in this phase.

4.7.9. 2nd drilling phase

The period of 2nd drilling is like 1st drilling's one, it starts from the mobilization of the rig and lasts until the finish of OED. Besides the general technical measures of drilling phases (see Table32), there are two measures, which are recommended to imply (Table34).

Table 34: Mitigation measures to be done in 2nd drilling phase

Mitigation measures
In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.
Performing adequate interference or tracer test for securing information for verification of hydrogeological model.

4.7.10. 3rd geological evaluation phase

The 3rd geological evaluation is based on the data collected during the completion of second drilling. The only one and most important mitigation measure of this phase (Table35) is the update of hydrogeological model by the help of data procured during the interference and tracer tests. The general geological evaluation measures (Table28) are not implied here, because these are connected to better identification of drilling targets.

Table35: Mitigation measures to be done in 3rd geological evaluation phase

Mitigation measures
Accurate hydrogeological modelling including data collection and interpretation.

4.7.11. Completion phase

The completion phase covers the activities of surface works excluding drilling activities. During this phase only one mitigation measure might be made (Table36).

Table 36: Mitigation measures to be done in completion phase

Mitigation measures
Adequate filtering of produced water before the heat-exchanger

4.7.12. Operation phase

The operation phase is when the construction is finished, and the plant is working continuously according to the approved operational permit. The mitigation measures of this phase (Table37) are technical activities connected to regular control and maintenance.

Table 37: Mitigation measures to be done in operation phase

Mitigation measures
Adequate filtering of re-injected water.
Doing regular logging, evaluation and maintenance of the well.
Monitoring of change of produced fluid's particle content.
Monitoring of corrosion potential of produced fluid.
Monitoring of scaling potential of produced fluid.
Use of killing agent to inhibit the invasion of bacterias in productive layers of injection well.

4.7.13. 3rd party's drilling phase

There might be new operations which might have adverse effect on the idealised geothermal project of the risk owner. In this case the developer of the new operation has the responsibility to avoid such a negative consequence, that the cost of operation is increasing at the neighbouring facility. The most indispensable mitigation activity of the 3rd party is the performance of interference or tracer test for verification of the hydrogeological model (Table 38).

Table 38: Mitigation measures to be done in 3rd party's drilling phase

Mitigation measures
Performing adequate interference or tracer test for securing information for verification of hydrogeological model.

4.7.14. 3rd party's geological evaluation phase

The collected data during testing should be used for upgrade and verification of hydrogeological model to evaluate the effects, the rate of pressure and temperature change on existing facilities (Table39). By the help of modelled effects the authorities can define the reasonable amount of production of new operation to avoid long-term adverse effects.

Table 39: Mitigation measures to be done in 3rd party's geological evaluation phase

Mitigation measures
Accurate hydrogeological modelling including data collection and interpretation.

4.8. Steps of implementation

In the next phase of implementation of DARLINGe project, the above described Geological Risk Mitigation Scheme will be tested on pilot areas (WP7 Transboundary pilots). The completion of testing includes the below listed activities:

1. Definition of a theoretical geothermal project, including production parameters, expected damages, type of aquifer etc.
2. Definition of needed data and data collection
3. Geological evaluation
4. Reservoir estimate
5. Geological prognosis for drilling of a well
6. Conceptual and hydrogeological model
7. Definition of risk mitigating activities according to the time line of a project

The table of geological risk mitigation scheme is found in Appendix 1.

References

NÁDOR, A., LAPANJE, A., TÓTH,Gy., RMAN, N., SZŐCS, T., PRESTOR, J., UHRIN, A., RAJVER, D., FODOR, L., MURÁTI, J., SZÉKELY, E. (2012): Transboundary geothermal resources of the Mura-Zala basin: a need for joint thermal aquifer management of Slovenia and Hungary – Geologija 55/2, 209–224, Ljubljana 2012, doi:10.5474/geologija.2012.013

NÁDOR, Annamária, SZŐCS, Teodóra, ROTÁR-SZALKAI, Ágnes, GÖTZL, Gregor, PRESTOR, Joerg, TÓTH, György, CERNAK, Radovan, ŠVASTA, Jaromír, KOVÁCS, Attila Csaba, GÁSPÁR, Emese, RMAN, Nina, LAPANJE, Andrej, FUKS, Tadej, SCHUBERT, Gerhard*. 2013: Strategy paper on sustainable cross-border geothermal utilization*. Ljubljana: Geological Survey of Slovenia; Bratislava: Štátny geologický ústav Dionýza Štúra; Budapest: Magyar Földtani és Geofizikai Intézet; Vienna: Geologische Bundesanstalt.

PRESTOR, Joerg, SZŐCS, Teodóra, RMAN, Nina, NÁDOR, Annamária, CERNAK, Radovan, LAPANJE, Andrej, SCHUBERT, Gerhard, MARCIN, Daniel, BENKOVÁ, Katarína, GÖTZL, Gregor. 2015: Benchmarking - indicators of sustainability of thermal groundwater management. V: HORNE, Roland (ed.), BOYD, Toni. *Views from down under - geotermal in perspective : proceedings*, World Geothermal Congress, 19-24 April 2015, Melbourne.

RMAN, Nina, GÁL, Nóra, MARCIN, Daniel, WEILBOLD, Julia, SCHUBERT, Gerhard, LAPANJE, Andrej, RAJVER, Dušan, BENKOVÁ, Katarína, NÁDOR, Annamária. 2015: Potentials of transboundary thermal water resources in the westernpart of the Pannonian basin. *Geothermics*, 55:88-98, doi: 10.1016/j.geothermics.2015.01.013.

RMAN, Nina, LAPANJE, Andrej, PRESTOR, Joerg. 2011: Water concession principles for geothermal aquifers in the Mura-Zala Basin, NE Slovenia. *Water resources management*, 25/13: 3277-3299, doi: 10.1007/s11269-011-9855-5

SZŐCS, Teodóra, RMAN, Nina, ROTÁR-SZALKAI, Ágnes, TÓTH, György, LAPANJE, Andrej, CERNAK, Radovan, NÁDOR, Annamária. 2018: The Upper Pannonian thermal aquifer: cross border cooperation as an essential step to transboundary groundwater management. *Journal of hydrology, Regional studies,* doi: 10.1016/j.ejrh.2018.02.004.

SZŐCS, Teodóra, TÓTH, György, NÁDOR, Annamária, RMAN, Nina, PRESTOR, Joerg, LAPANJE, Andrej, ROTÁR-SZALKAI, Ágnes, CERNAK, Radovan, SCHUBERT, Gerhard. 2015: Long-term impact of transboundary cooperation on groundwater management. *European geologist*, 40: 29-33.

United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 incorporating Specifications for its Application (ECE Energy Series 42) https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/pub/UNFC2009_Spec_ES42.pdf

Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 to Renewable Energy Resources https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC_specs/UNFC.RE_e.pdf

Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources https://www.unece.org/fileadmin/DAM/energy/se/pdfs/egrc/egrc7_apr2016/ECE.ENERGY.GE.3.2016.6_e.pdf

Prevention (Chain of events and preventive measures to avoid risk events)												**Proof**			**Amendment**	
Code of proof	Root activity	Risk event - IF member	Risk event - THEN member	Mitigation	Timing of mitigation	Condition of mitigation	Monitoring activity of mitigation	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Proof of damage	Definition of damage	Amending activity	Conditions of amending activity
												During drilling				
PD.D.1.TeF	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the forecast of drilling difficulties will be inaccurate.	Accurate collection and interpretation of geological layers and features for securing information about forecasted drillign difficulties.	1st geological evaluation phase		Reporting	Drilling difficulties	Unsuccessful handling of drilling difficulties	The production section of the well can not be completed.		PD.D.1.TeF	Technical failure. An irreversible technical failure occurs at the drilling.	The loss of well.		
PD.D.1.TeF	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then the forecast of drilling difficulties will be inaccurate.	Doing new surface geophysical measurements for better understanding of geological layers and for securing information about forecasted drilling difficulties.	1st geological evaluation phase		Reporting	Drilling difficulties	Unsuccessful handling of drilling difficulties	The production section of the well can not be completed.			Technical failure. An irreversible technical failure occurs at the drilling.	The loss of well.		
PD.D.1.TeF	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the forecast of drilling difficulties will be inaccurate.	-				Drilling difficulties	Unsuccessful handling of drilling difficulties	The production section of the well can not be completed.			Technical failure. An irreversible technical failure occurs at the drilling.	The loss of well.		
PD.D.2.MiF	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of geological layers and features for securing information about identification of target formation.	1st geological evaluation phase		Reporting					PD.D.2.MiF	Missing formation. The targeted reservoir formation is missing in the well.	The loss of well.	Finding suitable water bearing formation in the already drilled section.	Proper logging data for identification of auxiliary targets.
PD.D.2.MiF	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target reservoir.	1st geological evaluation phase		Reporting	There is a significant difference between the interpretation and the reality.					Missing formation. The targeted reservoir formation is missing in the well.	The loss of well.	Drilling further	The design of the well and the used rig should be suitable for the activity
PD.D.2.MiF	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									Missing formation. The targeted reservoir formation is missing in the well.	The loss of well.		
PD.D.3.OvP	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of pressure data measured in existing wells for securing information about hazard of overpressure.	1st geological evaluation phase		Reporting	The pressure forecast was inaccurate				PD.D.3.OvP	Overpressure. The formation pressure is much higher as it was originally expected.	The loss of well.		
PD.D.3.OvP	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new pressure measurements at old wells for securing information about hazard of overpressure.	1st geological evaluation phase		Reporting	There is a significant difference between the interpretation and the reality.	The pressure forecast was inaccurate				Overpressure. The formation pressure is much higher as it was originally expected.	The loss of well.		
PD.D.3.OvP	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									Overpressure. The formation pressure is much higher as it was originally expected.	The loss of well.		
												During testing				
PD.T.1.NoP	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).	Geological evaluation phases		Reporting	The target is missing in the drilling				PD.T.1.NoPI	No production/injection. The well is not able to produce/inject any fluid.	The loss of well.	Drilling further	The design of the well and the used rig should be suitable for the activity

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
Code of proof	Root activity	Risk event - IF member	Risk event - THEN member	Mitigation	Timing of mitigation	Condition of mitigation	Monitoring activity of mitigation	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Proof of damage	Definition of damage	Amending activity	Conditions of amending activity
PD.T.1.NoP	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new surface geophysical measurements for better understanding of geological layers for securing information about identification of target feature (fault, karstified surface).	Geological evaluation phases		Reporting	There is a significant difference between the interpretation and the reality.	The target is missing in the drilling				No production/injection. The well is not able to produce/inject any fluid.	The loss of well.		
PD.T.1.NoP	Selection of inadequately identified target	If the definition of location of target is inaccurate,	then the drilling will miss the target.	Try to identify and aim more than one target for the drilling.	Geological evaluation phases		Reporting						No production/injection. The well is not able to produce/inject any fluid.	The loss of well.		
PD.T.1.NoP	Selection of inadequately identified target	If the definition of location of target is inaccurate,	then the drilling will miss the target.	Accurate collection and interpretation of geological layers and features for securing information about identification of target feature (fault, karstified surface).	Geological evaluation phases		Reporting	There is no permeable layer in the openhole.					No production/injection. The well is not able to produce/inject any fluid.	The loss of well.		
PD.T.1.NoP	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-				The target was reached, but it is not working according to expectations					No production/injection. The well is not able to produce/inject any fluid.	The loss of well.		
PD.T.3.LoT	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of temperature data measured in existing wells for securing information for temperature forecast.	1st geological evaluation phase		Reporting	The temperature forecast was inaccurate				PD.T.3.LoT	Low temperature. The temperature is lower, what was expected.	The amount of energy is lower than it was expected.	Drilling further	The design of the well and the used rig should be suitable for the activity
PD.T.3.LoT	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new temperature measurements in existing wells for securing information for temperature forecast.	1st geological evaluation phase		Reporting	There is a significant difference between the interpretation and the reality.	Misinterpretation of temperature values	The temperature forecast was inaccurate			Low temperature. The temperature is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.3.LoT	The production well is operated at low rate	If the flow in the well is very slow,	then the produced fluid will be cooled.	Use of cement with increased heat insulation properties for cementing of casings of production well.	1st drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Low temperature. The temperature is lower, what was expected.	The amount of energy is lower than it was expected.	Increase of yield, when the cooling up to surface is high	The design of well should allow the lowering of pump
PD.T.3.LoT	Misinterpretation of groundwater flow	If significant recharge of groundwater takes place around the well,	then the production zone is colder what was expected.	Accurate hydrogeological modelling including data collection and interpretation.	1st geological evaluation phase		Reporting	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.				Low temperature. The temperature is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.3.LoT	Malfunction during the completion of the well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the cold groundwater could be produced.	Professional service provider and supervised cementing activites for appropriate isolation.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Cold groundwater appears at the production section.	The cold groundwater cools down the produced water.				Low temperature. The temperature is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.3.LoT	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									Low temperature. The temperature is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Inadequate drilling of production section	If clayey drilling mud is used during the drilling of production section,	then drilling mud will contaminate the pores.	Use of clay minerals-free drilling mud, which is properly treated in the mud system by removal of cutting particles.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The solid particles of the mud decrease the permeability of the layer				PD.T.4.LoY	Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.	Cleaning of well from LCM and cuttings by airlifting	

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PD.T.4.LoY	Inadequate drilling of production section	If LCM (loss control material) is used during the drilling of production section,	then LCM will contaminate the pores.	Avoid the use of LCM during drilling of production section.	Drilling phases		Drilling supervisor, daily reports of activity	The LCM decreases the permeability of the layer					Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Inadequate drilling of production section	If the previous casing section is cemented and intersects the production section,	then the cement will contaminate the pores.	Avoid the cementing of previous casing string in the production section.	Drilling phases	The forecasted production section cannot be intersected by the previous section.	Drilling supervisor, daily reports of activity	The cement decreases the permeability of the layer					Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.	Acidizing and cleaning by airlifting	
PD.T.4.LoY	Inadequate drilling of production section	If the production section is short,	then the production section will have limited capacity.	Try to drill long enough production section for securing the expected yield.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.	Drilling further	The design of the well and the used rig should be suitable for the activity
PD.T.4.LoY	Inadequate drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	1. Use of external casing packer between the loose formation and productive layer.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The production zone has decreased permeability.					Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Inadequate drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	2. In case of porous aquifer use of underreaming and gravel pack in the production section.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Inadequate drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	3. In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Inadequate drilling of production section	If the diameter of production section is too narrow,	then the openhole section will have limited capacity.	Designing the production section of the well with 8 1/2” diameter.	1st design phase		Drilling supervisor, daily reports of activity	The narrow openhole section has limited capacity.					Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of productivity data of wells for securing information for the expected yield of the well.	1st design phase		Reporting	The yield forecast was inaccurate					Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity
PD.T.4.LoY	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new measurements in existing wells for securing information for the expected yield of the well.	1st design phase		Reporting	Very simlified geological interpretation of layers	There is a significant difference between the interpretation and the reality.	The yield forecast was inaccurate			Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		
PD.T.4.LoY	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-				The real situation is fully different from interpreted conditions					Low yield. The yield (production or injection) is lower, what was expected.	The amount of energy is lower than it was expected.		

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
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PD.T.5.InP	Inadequate modelling of subsurface environment	If the position of the well was designed too close to receptors,	then the induced pressure change will be higher than it was expected.	Accurate hydrogeological modelling.	1st design phase		Reporting					PD.T.5.InP	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Pending of operation.	Decrease of production rate (temporary solution)	
PD.T.5.InP	Malfunction during the completion of the well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	Professional service provider and supervised cementing activites for appropriate isolation.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Pending of operation.	Compensation of affected receptor(s)	
PD.T.5.InP	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate data collection and interpretation for the purpose of hydrogeological modelling.	1st geological evaluation phase		Reporting	Inadeqaute interpretation and modelling of subsurface environment	The position of the well was designed too close to receptors				Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Pending of operation.		
PD.T.5.InP	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new measurements in existing wells for securing information for hydrogeological modelling.	1st geological evaluation phase		Reporting	Very simlified geological interpretation of layers	There is a significant difference between the interpretation and the reality.	Inadeqaute interpretation and modelling of subsurface environment	The position of the well was designed too close to receptors		Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Pending of operation.		
PD.T.5.InP	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-				The real situation is fully different from interpreted conditions					Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby.	Pending of operation.		
PD.T.6.NoC	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate data collection and interpretation for securing information for realistic structural evaluation.	Geological evaluation phases		Reporting	The design of location of wells of doublet is inadequate.				PD.T.6.NoC	No connection. There is no hydraulic connection between the members of the doublet.	The amount of energy is lower than it was expected.	Drill another well to be located in the same hydrogeoloigcal unit as the pair of well.	
PD.T.6.NoC	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new measurements in existing wells for securing information for realistic structural evaluation.	Geological evaluation phases		Reporting	The design of location of wells of doublet is inadequate.					No connection. There is no hydraulic connection between the members of the doublet.	The amount of energy is lower than it was expected.	Decrease of production rate (temporary solution)	
PD.T.6.NoC	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									No connection. There is no hydraulic connection between the members of the doublet.	The amount of energy is lower than it was expected.		

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
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PD.T.7.HiG	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of chemical data for securing information about the forecasted gas content of the produced fluid.	1st geological evaluation phase		Reporting	The gas content forecast was inaccurate				PD.T.7.HiG	High gas content. Th amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Cost increase in investment and operation.	Re-design of depth of pump and pressure of surface system according to measured values.	The bottom of pump chamber should be designed and completed deep enough.
PD.T.7.HiG	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted gas content of the produced fluid.	1st geological evaluation phase		Reporting	There is a significant difference between the interpretation and the reality.		The gas content forecast was inaccurate			High gas content. Th amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Cost increase in investment and operation.		
PD.T.7.HiG	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									High gas content. Th amount of gas observed in the produced fluid is much higher as it was anticipated originally.	Cost increase in investment and operation.		
PD.T.8.InS	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of chemical data for securing information about the forecasted scaling potential of the produced fluid.	1st geological evaluation phase		Reporting	The forecast of scaling potential was inaccurate				PD.T.8.InS	Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.	Cost increase in investment and operation.	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration
PD.T.8.InS	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted scaling potential of the produced fluid.	1st geological evaluation phase		Reporting	There is a significant difference between the interpretation and the reality.		The forecast of scaling potential was inaccurate			Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.	Cost increase in investment and operation.		
PD.T.8.InS	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									Increased scaling. The observed scaling activity of produced fluid is higher as it was anticipated originally.	Cost increase in investment and operation.		
PD.T.9.InC	Drilling into inadequately explored area	If the evaluation of subsurface data is inaccurate,	then the geological features and layers will be misinterpreted.	Accurate collection and interpretation of chemical data for securing information about the forecasted corrosion potential of the produced fluid.	1st geological evaluation phase		Reporting	The forecast of corrosion potential was inaccurate				PD.T.9.InC	Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Cost increase in investment and operation.	Use of inhibitors	The design of the well should be suitable for the activity
PD.T.9.InC	Drilling into inadequately explored area	If previous exploratory data are poor and rare,	then a very simlified interpretation of geological features and layers will be made.	Doing new chemical sampling and analysis at existing wells for securing information about the forecasted corrosion potential of the produced fluid.	1st geological evaluation phase		Reporting	There is a significant difference between the interpretation and the reality.		The forecast of corrosion potential was inaccurate			Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Cost increase in investment and operation.	Use of corrosive resistant inner casing	The design of the well should be suitable for the activity
PD.T.9.InC	Drilling into unknown area	If the drilling runs into unforeseen subsurface condition,	then the real situation will be fully different from interpreted conditions	-									Increased corrosion. The observed corrosion activity of produced fluid is higher as it was anticipated originally.	Cost increase in investment and operation.		

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
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												During operation				
PD.O.1.CoP	Inadequate testing	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	Premature cold break through between production and injection well				PD.O.1.CoP	Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	The amount of energy is lower than it was expected.	Decrease of production rate (temporary solution)	
PD.O.1.CoP	Inadequate modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	Accurate hydrogeological modelling including data collection and interpretation.	2nd geological evaluation phase		Reporting	Premature cold break through between production and injection well					Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	The amount of energy is lower than it was expected.	Drill a new production well at larger distance from injection well.	
PD.O.1.CoP	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The location of wells of new development's doublet will be improper.					Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	The amount of energy is lower than it was expected.		
PD.O.1.CoP	New development nearby	If the modelling is inadequate,	then the modelled effect of new development will be misleading.	Accurate hydrogeological modelling including data collection and interpretation.	2nd geological evaluation phase		Reporting	The location of wells of new development's doublet will be improper.					Cooling of production well. Unusual cooling of produced fluid is observed at the production well.	The amount of energy is lower than it was expected.		
PD.O.2.PrD	Inadequate testing	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The produced aquifer suffers from lack of water, the injected water is not reaching the production well.				PD.O.2.PrD	Pressure drop. Continuous pressure drop is observed at the production well.	Cost increase in operation.	Decrease of production rate (temporary solution)	
PD.O.2.PrD	Inadequate modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	Accurate hydrogeological modelling including data collection and interpretation.	2nd geological evaluation phase		Reporting						Pressure drop. Continuous pressure drop is observed at the production well.	Cost increase in operation.	Drill a new well, which is presumably not affected by the pressure change.	
PD.O.2.PrD	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The location of wells of new development's doublet will be improper.					Pressure drop. Continuous pressure drop is observed at the production well.	Cost increase in operation.	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity
PD.O.2.PrD	New development nearby	If the modelling is inadequate,	then the modelled effect of new development will be misleading.	Accurate hydrogeological modelling including data collection and interpretation.	2nd geological evaluation phase		Reporting	The location of wells of new development's doublet will be improper.					Pressure drop. Continuous pressure drop is observed at the production well.	Cost increase in operation.		
PD.O.2.PrD	Inadequate drilling of production section	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	Doing regular logging, evaluation and maintenance of the well.	Operation phase		Reporting						Pressure drop. Continuous pressure drop is observed at the production well.	Cost increase in operation.		

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
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PD.O.3.PrI	Inadequate testing	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The produced aquifer suffers from surplus of water, the injected water is not reaching the production well.				PD.O.3.PrI	Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.	Decrease of production rate (temporary solution)	
PD.O.3.PrI	Inadequate modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	Accurate hydrogeological modelling including data collection and interpretation.	2nd geological evaluation phase		Reporting	Premature cold break through between production and injection well					Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.	Drill a new well, which is presumably not affected by the pressure change.	
PD.O.3.PrI	Inadequate water treatment	If the injected water contain particles,	then the pores will be clogged.	1. Adequate filtering of re-injected water	Operation phase	The service should be designed and procured in advance.	Monitoring of parameters of groundwater						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.	Stimulation (thermal, chemical or hydraulic)	The design of the well should be suitable for the activity
PD.O.3.PrI	Inadequate water treatment	If the injected water contain particles,	then the pores will be clogged.	2. In case of porous aquifer use of underreaming and gravel pack in the production section.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	Inadequate water treatment	If bacterias are invading the surface of formation,	then the injectivity will decrease.	1. Adequate filtering of re-injected water	Operation phase	The service should be designed and procured in advance.	Monitoring of parameters of groundwater						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	Inadequate water treatment	If bacterias are invading the surface of formation,	then the injectivity will decrease.	2. Use of killing agent to inhibit the invasion of bacterias in productive layers of injection well.	Operation phase	The service should be designed and procured in advance.	Reporting						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	Inadequate completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	1. Use of external casing packer between the loose formation and productive layer.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The particles from the less consolidated sediments cloggs the pores.					Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	Inadequate completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	2. In case of porous aquifer use of underreaming and gravel pack in the production section.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	Inadequate completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	3. In case of porous aquifer the production section of injection well should not contain fine grained sediments, only pure sandstone members are recommended.	2nd drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	Inadequate completion of injection well	If the drilled production section contains less consolidated fine grained sediments,	then the loose, clayey sediments will contaminate the production zone.	4. Doing regular logging, evaluation and maintenance of the well.	Operation phase		Reporting						Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
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PD.O.3.PrI	New development nearby	If the testing is inadequate,	then the verification of reservoir model is inaccurate.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	3rd party's drilling phase	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity	The location of wells of new development's doublet will be improper.					Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.3.PrI	New development nearby	If the modelling is inadequate,	then the modelled effect of new development will be misleading.	Accurate hydrogeological modelling including data collection and interpretation.	3rd party's geological evaluation phase		Reporting	The location of wells of new development's doublet will be improper.					Pressure increase. Continuous pressure increase is observed at the injection well.	Cost increase in operation.		
PD.O.4.InT	Inadequate testing	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.						PD.O.4.InT	Induced temperature change. Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Pending of operation.	Decrease of production rate (temporary solution)	
PD.O.4.InT	Inadequate modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	Accurate hydrogeological modelling including data collection and interpretation.	3rd geological evaluation phase		Reporting						Induced temperature change. Significant induced temperature change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Pending of operation.	Compensation of affected receptor(s)	
PD.O.5.InP	Inadequate testing	If the verification of reservoir model is inaccurate,	then the location of wells of doublet will be improper.	Performing adequate interference or tracer test for securing information for verification of hydrogeological model.	2nd drilling phase	The service should be designed and procured in advance.						PD.O.5.InP	Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Pending of operation.	Decrease of production rate (temporary solution)	
PD.O.5.InP	Inadequate modelling of subsurface environment	If the modelled effect of the development is inaccurate,	then the location of wells of doublet will be improper.	Accurate hydrogeological modelling including data collection and interpretation.	3rd geological evaluation phase		Reporting						Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Pending of operation.	Compensation of affected receptor(s)	
PD.O.5.InP	Malfunction during the completion of the well	If the cement behind the casing is (partially) missing and there are water bearing layers above the production zone,	then the induced pressure change could affect another aquifer(s).	Professional service provider and supervised cementing activites for appropriate isolation.	Drilling phases	The service should be designed and procured in advance.	Drilling supervisor, daily reports of activity						Induced pressure change. Significant induced pressure change is observed at existing production facility (water well or spring, hydrocarbon well) nearby	Pending of operation.		
PD.O.6.InS	Inadequate measurement	If the chemical analysis is inaccurate,	then the evaluation of scaling potential is inaccurate.	Performing adequate chemical sampling and analysis of produced fluid	1st drilling phase	The service should be designed and procured in advance.	Reporting	The scaling activity is higher than it was expected.				PD.O.6.InS	Increased scaling. Increased scaling activity of produced fluid is observed.	Cost increase in operation.	Decrease of production rate (temporary solution)	

Prevention (Chain of events and preventive measures to avoid risk events)												Proof			Amendment	
Code of proof	Root activity	Risk event - IF member	Risk event - THEN member	Mitigation	Timing of mitigation	Condition of mitigation	Monitoring activity of mitigation	Follow on event 1.	Follow on event 2.	Follow on event 3.	Follow on event 4.	Code of proof	Proof of damage	Definition of damage	Amending activity	Conditions of amending activity
PD.O.6.InS	Inadequate evaluation	If the evaluation of scaling potential is inaccurate,	then the scaling activity is higher than it was expected.	Performing adequate evaluation of scaling potential	2nd geological evaluation phase		Reporting						Increased scaling. Increased scaling activity of produced fluid is observed.	Cost increase in operation.	Use of chemicals via coil tubing.	During the design of the well the use of coil tubing should be taken into consideration
PD.O.6.InS	Drilling into unknown area	If the scaling potential is changing during the production	then the scaling activity might be inreased with time.	Monitoring of scaling potential of produced fluid	Operation phase		Monitoring of parameters of groundwater						Increased scaling. Increased scaling activity of produced fluid is observed.	Cost increase in operation.		
PD.O.7.InC	Inadequate measurement	If the chemical analysis is inaccurate,	then the evaluation of corrosion potential is inaccurate.	Performing adequate chemical sampling and analysis of produced fluid	1st drilling phase	The service should be designed and procured in advance.	Reporting	The corrosion activity is higher than it was expected.				PD.O.7.InC	Increased corrosion. Increased corrosion activity of produced fluid is observed.	Cost increase in operation.	Decrease of production rate (temporary solution)	
PD.O.7.InC	Inadequate evaluation	If the evaluation of corrosion potential is inaccurate,	then the corrosion activity is higher than it was expected.	Performing adequate evaluation of corrosion potential	2nd geological evaluation phase		Reporting						Increased corrosion. Increased corrosion activity of produced fluid is observed.	Cost increase in operation.	Use of inhibitors	The design of the well should be suitable for the activity
PD.O.7.InC	Drilling into unknown area	If the corrosion potential is changing during the production	then the corrosion activity might be inreased with time.	Monitoring of corrosion potential of produced fluid	Operation phase		Monitoring of parameters of groundwater						Increased corrosion. Increased corrosion activity of produced fluid is observed.	Cost increase in operation.	Use of corrosive resistant inner casing	The design of the well should be suitable for the activity
PD.O.8.HeE	Inadequate water treatment	If the produced water contain particles,	then the pores of heat exchangers will be clogged.	Adequate filtering of produced water before the heat-exchanger	Completion phase	The service should be designed and procured in advance.	Monitoring of parameters of groundwater					PD.O.8.HeE	Clogged heat exchangers. Particles of produced fluid clog the heat exchanger.	Cost increase in operation.	Use of filter system at the surface	
PD.O.8.HeE	Drilling into unknown area	If the particle content of produced water is changing,	then the pores of heat exchangers might be clogged.	Monitoring of change of produced fluid's particle content	Operation phase		Monitoring of parameters of groundwater						Clogged heat exchangers. Particles of produced fluid clog the heat exchanger.	Cost increase in operation.		