

WP4 - Proposal for a harmonized procedure on the Environmental Impact Assessment for geothermal development in Europe

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2. INTRODUCTION

The objective of this document is to provide recommendations for drafting guidelines for the Environmental Impact Assessment (EIA) report for deep geothermal projects, drawing upon the experiences of the authors and the development in Europe, taking into account the present legislation, national and European, regarding the EIA. The document aims to help prepare quality EIA reports, ensuring that the best possible and complete information is made available during the decision-making process.

This proposal for a harmonized procedure of the EIA is designed for the use of competent authorities, geothermal developers and EIA practitioners in the deep geothermal sector. The document is intended for the preparation of the complete EIA reports, but may be used as a reference also for the EIA screening documents in case these are required for drilling.

The EIA Report must be prepared in accordance with the European legislation¹. While working on this document, the authors referred to the official European EIA guidance documents².

These guidelines will identify the most significant topics to be described in a geothermal project, the socio-environmental aspects to be focused on, suggesting tools and descriptions to be prepared.

¹ Directive 2011/92/EU as amended by "2014/532/EU

² <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:C:2016:273:TOC>

3. GENERAL OBJECTIVES OF AN ENVIRONMENTAL IMPACT REPORT

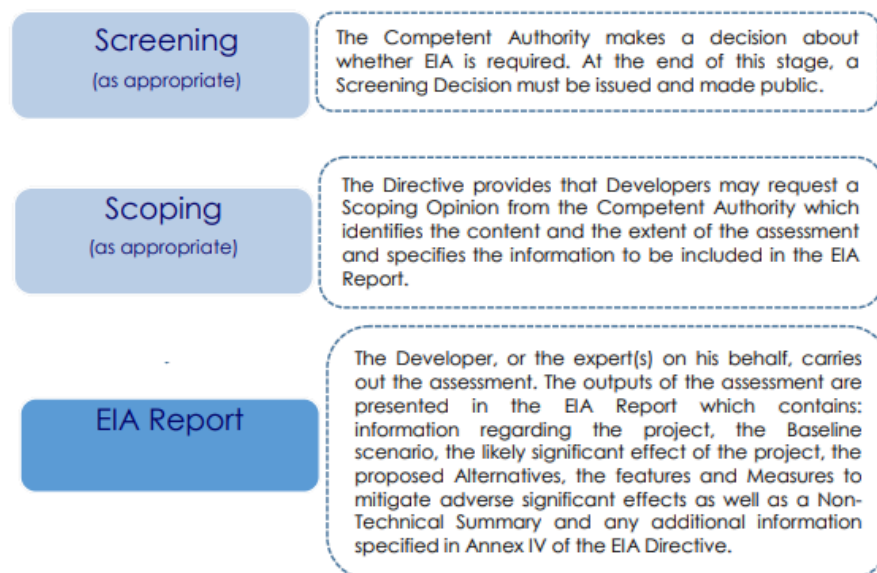
The Environmental Impact Assessment Report is a document prepared by the developer that presents the output of the project assessment. It contains information regarding the developer, the project, the likely significant effects of the project, and cumulative effects with other known projects in the area (not necessarily geothermal), the baseline scenario, the proposed alternatives, the features, and measures to mitigate adverse significant effects.

The EIA report shall attempt to answer four questions:

- 1) What effects will the project cause?
- 2) What will be the extent of the changes?
- 3) How serious are the changes?
- 4) How can these changes be addressed?

3.1 Outlines of the EIA procedures

A specific EIA report will be prepared taking into account the different stages of a geothermal project that will be developed in compliance with the overarching regulation enforced by the Directive 2011/92/EU as amended by 2014/52/EU.



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In particular, the EIA Report shall contain:

- A reference to pre-set criteria such as protected sites, features, or species;
- Identification of potential adverse temporary and permanent effects;
- Prediction and quantification of the extent of each adverse effect, including predictive numerical models whenever possible;
- Mitigation measures for each adverse effect, including economic compensation and restoration to local communities for any incurred damage or discomfort;
- Monitoring to control the predicted effects of the project;
- Compliance with non-environmental laws, regulations or accepted standards relevant to the execution of the project;
- Consultation with the relevant decision-makers;
- Consistency with government policy objectives for geothermal and other renewable energy development;
- Acceptability by the local community or the general public.

6.1 Geothermal project development stages

A typical geothermal project involves successive stages:

1. Exploration

An exploration plan is required, including:

- a) Reconnaissance and pre-feasibility study, including geophysical surveys such as electromagnetic geophysical surveys (MT), shallow (< 100 m) thermal gradient holes (TGH) and reflection seismic surveys (RSS). Since minor environmental effects are envisaged in this stage, only the EIA screening is required, except in some countries such as Italy, where the EIA report is requested for TGH and RSS.
- b) Exploratory deep drilling: the EIA screening is required except in some countries such as Italy, where the EIA report is requested.
- c) A feasibility study in which the capacity of the geothermal reservoir is assessed, type, size and location of the power plant are established, a number of necessary productive and reinjection wells and a type of gathering systems are determined.

2. Deployment

A definitive design of the project and deployment work program is required, including:

- a) Drilling and flow-testing of deep wells
- b) Plant facilities construction
- c) Connection to the electric energy grid or to district heating systems
- d) Commissioning

3. Operation

Once the wells and plant have been built and started up, the system will work at a full capacity, except during ordinary breaks for planned maintenance or extraordinary breaks due to malfunction. A description of the operation & maintenance procedures shall be provided for:

- a) Well field
- b) Power plant
- c) Infrastructure
- d) Environmental monitoring

4. Decommissioning

This phase will include all the activities necessary to remove all plant components of the plant and ensure the redressing of the site at “*ante-operam*” status. In particular, it will consist of:

- a) The cleaning of all the parts of the plant that have come in contact with pollutants, and disposal of the collected waste in accordance with the law.
- b) The recovered facilities and equipment will then be left open at the site for inspection by the competent public authorities.
- c) All hazard fluids used in the plants will be recovered and placed to the exhausted oils disposals.
- d) Other recyclable materials will be returned to their respective suppliers.
- e) Landscape will be restored to “*ante-operam*” status, including the replanting of trees or agricultural crops.

6.1 Influence and investigation area

Most of the direct environmental effects are confined to the area surrounding the project site (<1km). Only in case of the potential effects related to air emissions (often linked only to the well flow testing or a flash power plant), seismicity, subsidence and visual impacts, the influenced area can be larger.

4. PRACTICAL GUIDANCE ON THE PREPARATION OF THE EIA REPORT

4.1 Compliance with regulatory framework

The Art. 5(1), of the Directive 2011/92/EU as amended by Directive 2014/52/EU, sets out that the EIA Report shall include the following:

- **Description of the Project:** this is an introduction to the Project and includes a description of the location of the Project, the characteristics of the construction, and the operational phases of the Project, as well as estimates of the expected residues, emissions, and waste produced during the construction and operation phases.
- **Baseline scenario:** a description of the current state of the environment, and the likely evolution thereof without the implementation of the Project. This sets the stage for the subsequent EIA, and Member States shall ensure that the information for the Baseline scenario held by any authorities is available to the developer.
- **Environmental matrix affected:** a description of the environmental components impacted by the Project, with specific emphasis being placed on climate change, biodiversity, natural resources, and accidents and disasters.
- **Effects on the environment:** this section addresses the concept of 'significant effects' and the importance of cumulative effects.
- **Assessment of Alternatives:** Alternatives to the Project must be described and compared, with an indication of the main reasons for the selection of the option chosen being pursued.
- **Mitigation or Compensation Measures:** i.e. features or measures to avoid, prevent or reduce and offset adverse effects should also be considered.
- **Monitoring Measures:** should be included in the EIA Report, where significant adverse effects have been identified. This monitoring should be carried out during the construction and operation of the Project.
- **Non-Technical Summary:** i.e. an easily accessible summary of the content of the EIA Report presented without technical jargon, hence understandable to anybody without a background in the environment or the Project.

4.2 Description of the proposed deep geothermal project

The EIA Report for deep geothermal projects must comply with the list from the previous subchapter, providing:

4.2.1 Project's general description

- The location of each Project component must be identified, using maps (1:2000, 1:10.000), plans, and diagrams as necessary, showing the locations of the wells and plant facilities;
- geological and stratigraphical characterization of the site;
- workplan and budget, specifying the estimated length of time (e.g. expected start and finish dates) for construction, operation, and decommissioning. It should include any phases of different activity within the main phases of the Project, here distinguished as drilling, plant construction/operation, decommissioning;
- technical and financial capability of the developer.

4.2.2 Assessment of the alternatives

This section covers the selection, description, and assessment of the reasonable Alternatives required by the EIA Directive. Within the context of the EIA process, Alternatives are different ways of carrying out the Project in order to meet the agreed objective. Alternatives can take diverse forms and may range from minor adjustments to the Project, to a complete reimagining of the Project. A valid approach could be represented by the use of the SWOT analysis.

SWOT ANALYSIS



It should include a description of the reasonable Alternatives studied by the developer, which are relevant to the Project and its specific characteristics, and an indication of the main reasons for the option chosen, taking into account the effects of the project on the environment.

The Project Alternatives could concern for example:

- Drilling site location

- Well pad design
- Number of wells
- Power plant location
- Power plant design
- Path and type (underground or superficial) of the gathering system

In case of a small number of wells (doublet to quadruplet) drilled on the same site, some topics like path gathering system may not be relevant for the assessment of the Alternatives. Furthermore, it is important to consider in the EIA the 'do-nothing' scenario or the 'no Project' Alternative. The 'do-nothing' scenario is heavily based on both the Baseline and the national / European policy.

In any case, it must be underlined that any geothermal energy project can be developed only where geological characteristics (presence of a reservoir, temperature etc.) allow its economic sustainability.

4.2.3 Well field construction

Description of the activities:

- Drilling rig and ancillary equipment (layout, dimensions, characteristics)
- Layout of well pad and associated infrastructures (access road, water pond, etc.)
- Drilling site preparation
- Well design and drilling program for each well (depth, direction, operational drilling techniques, drilling mud and cement characteristics, completion schemes, etc.)
- Drilling operations procedures
- Well flow test (type of devices, procedures, duration,...)
- Water requirements and supply system for drilling
- Waste water treatment methodologies (including drilling cuttings)
- Measures adopted for shallow aquifers protection
- Measures for blow out prevention and emergency plan
- Stimulation techniques that may be applied
- Solid waste estimate, treatment and disposal
- Air emissions estimate and abatement systems
- Noise and vibration estimation and mitigation
- Radioactive materials production and treatment
- Compliance with the enforced regulatory framework and reference standards

Direct effects:

- Land take and vegetation removal
- Visual impact of drilling rig and access roads
- Traffic; noise and vibration induced by drilling and stimulation operations and production tests
- Accidental spills and discharge of contaminant liquids
- Seismicity
- Aeriform emissions and smell during well testing

4.2.4 Plant facilities construction**Description of the activities:**

- Design criteria: amount and quality of a geothermal fluid produced and reinjected or discharged, amounts and types of wastes to be produced
- Description of the selected conversion system (flash plants, ORC, partial reinjection, total reinjection, heat production) and its nominal power; the pros and cons of the choice
- Thermal and energy balances (an inlet fluid rate and thermo-dynamic characteristics, energy output)
- Plant facilities site design: maps and drawings of the plant site and related facilities
- Gathering and injection system design
- Power plant design (heat-exchangers, turboexpander or steam turbine, generator, cooling system), air emissions estimation and an abatement system
- Noise and vibration estimation and mitigation measures
- Radioactive materials production, treatment and disposal
- Discharged water chemical-physical characterization, treatment processes and disposal systems
- Non condensable gases chemical-physical characterization, treatment processes and disposal systems

Direct effects:

- Land take and vegetation removal
- Risks of spills and discharge of contaminant liquids (potential impact on soil, groundwater and surface water)
- Solid wastes disposal

4.2.5 Operation & maintenance of the project facilities

Description of the activities:

The operation & maintenance activities are related to the following facilities:

- Well field (boreholes and surface equipment)
- Geothermal fluid gathering pipelines
- Power plant components and facilities, including pollutants abatement systems
- Infrastructure (e.g. access roads)
- Environmental monitoring systems

Detailed procedures shall be provided to manage the ordinary operation and maintenance including monitoring and mitigation of the corrosion on the equipment to avoid any leak and spill of the geothermal fluid or hazardous failure of equipment. An emergency procedure shall be provided for any significant adverse impact that can cause serious damages to the environment and/or the neighboring population.

Direct effects:

- Land take and vegetation removal
- Noise and vibration induced by plant operations
- Accidental spills and discharge of contaminant liquids
- Seismicity, radioactivity, smell, aeriform emissions...

4.2.6 Decommissioning

Description of the activities:

This phase will include all the activities necessary to remove all plant components and ensure the redressing of the site at “*ante operam*” status. In particular it will consist of:

- Removal of the surface components of the plant
- Transport of all recyclable materials to their respective suppliers
- Recovery of any hazardous waste, such as lubricating oils used in the plants and their transport to a storage or treatment site for special hazardous waste
- Cleaning of all the parts of the plant site and remodeling of the surface ground to the “*ante operam*” status
- Landscape restoration including replanting of trees or agricultural crops
- Well abandonment, including well inspection and cementing

Direct effects

- Noise and vibration induced by the construction machinery for earth excavation, the traffic for removed material transportation, and the drilling rig for well abandonment
- Impact on soil and groundwater

5. BASELINE SCENARIO AND ENVIRONMENTAL FACTORS CONCERNED

6.1 Influence and investigation area

Two inherent characteristics of geothermal energy are fundamental to all considerations of environmental impact:

- site specificity and;
- the lack of many aspects of conventional fuel extraction, processing, and transportation

Therefore, the effects of a project are limited to the concession area (its present real land needed for the development), despite the potential effects related to possible air emissions, induced seismicity, potential subsidence and visual impacts. It can be concluded that influence area can be restricted to the geothermal development area and its surrounding up to 5 km.

6.1 Physical Resources

5.4.1 Geological features and geothermal reservoir characteristics

Geothermal Characterization of the Interest Area

In order to justify the criteria that led to the choice of the project, the design elements of the wells and the geothermal power plant and related works, it is important to characterize the geothermal model and to define the exploitation target.

A geological model of the geothermal resource shall be provided, including:

- A geological and/or geo-structural map
- At least two cross sections and drawings with estimation of the subsurface temperature distribution (estimated isotherms) and an approximate indication of the fluid flow directions
- A table with the description of the stratigraphic and thermal tectonic assets expected for the production area
- A numerical geothermal model based on the above geothermal definition

Seismicity

Includes the description of the previous recorded seismic events in the area and a discussion on their possible origin. It is important to define the natural seismicity of the study area through a careful analysis of events and seismic parameters (a definition of maximum and minimum

magnitude).

It should include all the information on the natural seismicity of the area, with particular reference to active faults present in the area in relation to the distribution of the epicentre quake. It is fundamental to conduct a seismic hazard and risk analysis of the area.

Subsidence

Identification of possible phenomena of subsidence shall be evaluated. In this section it is important to describe the geomorphological setting with particular attention to the presence of landslides, phenomena of a fluvial erosion, presence of debris etc...

Soil

This part includes a short presentation of the soil material and erosion risks with a particular reference to the construction of access roads and to the cut and fill operations necessary for the construction of the power plant. Description of a soil type concerning the project must be also carried out. A monitoring campaign of soil quality is required according to the existing regulation of the country hosting the project. Particular attention should be devoted to the elements that could be present naturally in the soil due to the geothermal characteristics of the area (arsenic, mercury, etc).

5.4.2 Water resources

Surface water

The hydrologic regime of the river system is not generally altered by the project; only during drilling phase water requirements could be satisfied utilizing surface water. A short description of the regional and local hydrology should be sufficient.

Surface water quality

Water quality might be influenced by blow out, spills and production tests; water quality shall be described by collecting and analysing samples of the water surrounding the proposed development. In some cases, arsenic, boric acid and mercury concentration in the surface waters have to be carefully determined for a possible comparison with the situation after the project.

Groundwater

In case of existence of a groundwater aquifer, it should be identified with the help of shallow wells (at least three). Similarly, the flow directions of groundwater, which could be used for human use

or agriculture, should be described. A map showing flow direction of the main aquifer should be presented.

Ground water quality

Data on chemical composition of ground waters should be collected. If necessary, samples should be taken and chemical analysis should be carried out in a geological context: oric acid, ammonia, arsenic, or radionuclides concentration could be detected. It must be stressed that sometimes, the underground waters in geothermal areas can be polluted by natural thermal manifestations and it is necessary to know the chemical composition of the waters before the development to clearly "predict" impacts.

5.4.3 Air

Meteorology

Long term climatological information is necessary to "predict" future impacts on air quality. Data on the wind rose, mean annual rain fall, or solar radiation are generally necessary on a ten-year basis to simulate air pollutant average annual concentrations. Very often it is not easy to find such data available. In this case, available data concerning the nearest site should be examined to verify whether they can be utilized. Such verification can be obtained by taking certain measurements with a mobile station placed on the future plant's site to measure:

- wind velocity
- wind direction
- temperature
- relative humidity
- pressure
- solar radiation

Data should be collected for a reasonable time.

Air quality

Since a complete campaign of air quality measurements can be very expensive and very long, all the existing literature information should be examined. Nevertheless, some measurements will be necessary.

Air samples must be collected in the area where the maximum contribution to air pollution from the geothermal power plant is foreseen. Collected samples must be analyzed to determine concentrations of H₂S, CO₂ and SO₂. SO₂ could be derived by the oxidation of H₂S naturally emitted by a volcanic or fumarolic activity beside emissions from diesel engines or heating systems.

H₂S and CO₂ concentration may also be determined by means of portable instruments capable of detecting concentration lower than 10 ppb (for H₂S value around 0.1 ppm) and lower than 10 ppm (for CO₂ values around 200 - 1000 ppm). One of the other main components of geothermal incondensable gases is radon. Radon can be determined by means of special sampling and analyzing methods. The concerns about radon are essentially due to its radioactive character "naturally" causing fears among people. The studies carried up until now indicate that the levels of radon emitted from most geothermal power plants are similar to natural emissions. Natural radon concentration should hence be determined only if there is a specific requirement coming from local authorities or if enough budget is available.

The same type of approach might be followed when trace elements like arsenic, mercury ammonia and boron are taken into account. Previous systematic studies showed that the contribution of geothermal energy to increase in the concentration level of these elements is generally negligible.

The number of points to be controlled and the number of the measurements necessary to characterize air quality will be determined based on the characteristics of the development area and of the available budget. A monitoring campaign appears nevertheless very important: H₂S concentration in the potential geothermal areas is sometimes high (because of natural thermal manifestations) and the knowledge of the "initial state" condition can avoid following debates on the contribution of a geothermal power plant to the overall pollution of the area. Some samples of rains should also be collected to measure the pH and evaluate a possible impact in lowering the rain pH.

5.4.4 Acoustic noise

Existing planning tools for a permitted noise level in terms of the noise disturbance descriptors established by a hosting country should be presented. A monitoring campaign will be carried out according to the national guidelines at the most probably affected receptors. As a general rule, the measurement of residual noise both during the day and night at the identified receptors shall be necessary to characterize the ambient noise of the area around the site chosen for the construction of the geothermal project. Acoustic monitoring shall be performed during drilling and operation.

6.1 Ecological resources

The primary objectives of the ecological resource assessment is (1) to identify, describe and map the major vegetation types within the geothermal resource zone, (2) to provide a check-list of

plants inventoried, (3) to identify the state of the officially listed, proposed or candidate threatened or endangered plant species within the zone (see also Directives 92/43/EEC and 2009/147/EEC), (4) to prepare a generalized description of the vertebrate or invertebrate communities, (5) to provide an annotated check list of the vertebrate species within the geothermal area, and (6) to identify listed endangered species within the area.

5.4.5 Aquatic Resources

Adverse effects on the aquatic ecology, including numerous organisms in the fish food chain, may result from potential spills or direct geothermal water discharge, although this is generally forbidden. In order to evaluate these possible impacts, an assessment of the existing aquatic ecology could be needed (including benthic organisms as well as those in the water column). Bioassay and field testing could be necessary to make reliable estimates of damage; however considerable information is available in the literature and a literature survey is often enough.

5.4.6 Terrestrial resources

Adverse effects on flora and fauna may be derived by the direct loss of habitat and destruction of native plant communities as a result of land clearing for geothermal facilities, invasion of cleared areas by weedy introduced species, and long-term effects on biota during operation phase. The description should include major ecological systems in the project area; the inventories should be carried out by a literature survey but it may be necessary to carry out some field tests if important or protected species are identified.

6.1 Human Resources

5.4.7 Archaeological

Briefly describe the history of the site to identify possible archeological impacts of geothermal development. The description will be carried out by consulting the published material on the topic. In some countries, archeological assessment on site could be mandatory.

5.4.8 Land use

All local and governmental land use laws or regulations that may affect the project should be described. A map showing the land use plans (for commercial, industrial, agricultural, conservation or other purposes) should be provided.

5.4.9 Infrastructure utilities and water supply

A description of the infrastructure and utilities present in the area (roads, electricity, gas system, water supply) should be provided. In particular the water supply system should be described in order to quantify the impact of the use of water by the plant and the drilling on the water supply resources of the area.

5.4.10 Landscape

Describe recreation and aesthetic values of the area which may be affected by the proposed project. Attention must be given to the planning tools describing the allowed activities and the land planning. Existing conditions may be described also with the presentation of pictures. Particular attention should be devoted to the type of vegetation in comparison with the characteristics of the development. A visual impact analysis is required to show the effects of the proposed development on the surrounding landscape.

5.4.11 Radiation (ionizing and not ionizing)

Study of the natural radioactivity of the area related to the geological setting should be provided. It is also important to do a review of the electric lines, substations etc. present in the reference area to identify a potential critical area of an electromagnetic field. Calculation of electric beams emitted by the instrumentation and power lines should be included.

5.4.12 Public Health

Description of the present health status of the population surrounding the project with a particular reference to the pathologies related to the emissions from the proposed facilities (e.g. respiratory diseases).

6. ASSESSING AND MITIGATING EFFECTS ON THE ENVIRONMENT

6.1 Effects on surface water quality

6.1.1 Prediction of direct effects

Water pollution may be chemical, thermal or physical. Geothermal plants may cause some during each phase of a geothermal project: exploration, development, well testing, operation of the power plant and at the end of life. Some of the important considerations to be covered include the following:

Disposal of the geothermal fluid

Natural fluids may contain a variety of substances in suspension and in solution, which are biologically harmful even in low concentrations (arsenic, mercury, lead, zinc, boron) and may interfere with growth rates and reproduction and can even produce death of aquatic species and poisoning of underground water. Potential impacts from water pollutants at individual sites is dependent on a function of the reservoir constituents and their concentration and, of course, on the quantity of the released liquid. Impacts may originate from the discharge into the surface waters either directly or accidentally.

The discharge into the surface waters occurs only in few countries such as Hungary and Turkey. Although disposal of these fluids is generally accomplished by reinjection, a chance to directly discharge in surface water may be used especially in medium enthalpy resources.

The study should therefore indicate the quantity and the quality of geothermal waters which will be possibly discarded during the production tests or which will be discharged due to accidental spills. If it is assumed that long production tests will be carried out utilizing a reinjection well, it can be assumed that only short production tests will produce impact on water resources.

As a rough figure, a short production test will last 4 days on average and a total discharged water quantity of 15000 m³ per well may be accounted. Based on these rough figures and on a rough estimate of the spill occurrence, an assessment of the concentration and temperature variation in the receiving waters may be given together with an estimate of the possible damage to the aquatic flora and fauna. If the discharge in surface waters is selected, the flow rate and chemical composition of the liquid geothermal fluid during operation and production tests must be provided. In this case, the impacts will be influenced by the water temperature rise and concentration variation in the receiving waters. The study requires an evaluation of existing aquatic ecology and

an estimate of the extent of damage, which will be imposed on the ecosystem. The presentation should show the extent and path of the heated water plume before the temperature, concentration, and the estimated alteration in the natural ecology values in the affected zone return to normal. In this particular case the utilization of a mathematical modeling to predict the extent of the temperature and plume concentration is recommended.

Blowouts and other surface leaks

The blowouts are undesirable and all geothermal well drillings incorporate the use of blowout preventers (BOP) as a standard equipment. Under most circumstances, these devices - complemented by properly trained personnel - can handle situations, which would otherwise result in a loss of control.

Nevertheless, blowouts may occur and they can produce mainly water pollution and damage to plants and animals. The particular environmental damage which can be produced is of course site specific: a blow out of a relatively clean steam in an isolated vapor dominated field presents a smaller potential hazard than a blow out of a very saline liquid within a recreation or a very populated area.

The EIA report should contain a description of the equipment utilized to minimize the likelihood of a blowout or a surface leak. In the event that geothermal wells are located in a recreation or a very populated area, the EIA report should present a short "risk assessment" devoted mainly to the evaluation of the consequences of a possible accident (blow out), bearing in mind that with the modern technology the probability of a complete blow out is very low. Surface leakage of a geothermal fluid or drilling mud are certainly more common. For example, a damaged valve can send a large quantity of geothermal water through vegetated areas and into stream channels. The EIA should report the mitigation measures taken to minimize the impact of a possible leakage. The first and simplest way to "evaluate" the impact is to perform a comparison with the law, regulations and accepted standards. The comparison may be carried out between accepted standards for discharge into surface waters and/or by comparison of the expected concentration in the surface or underground water with the recommended criteria for water. In some countries, the water discharge in the surface water is not allowed.

The following table sums up the relevant European legislation for water emissions and water quality limits:

Table 1: European Directives

#/year	Description
Directive 2000/60/EC	Water Framework Directive, partially modified by subsequent directives
Directive 2006/118/EC, modified by the Directive 2014/80/EU	Protection of groundwater resources
Directive 2008/105/EC	Water quality standards, also modifying the Directive 2000/60/EC
Directive 2013/39/EU	Priority water pollutants, including Hg

6.1.2 Mitigation and compensation measures

Impacts during drilling and exploration phases can be mitigated by reducing time for production tests and using impermeable pad to collect the geothermal fluid during short production tests and the reinjection wells for long production tests.

Furthermore, the equipment and devices used to reduce the likelihood of a blow out or spill from drilling operations should be described and included in the EIA report (for example the utilization of blowout preventers during the drilling phases) and all other measures to prevent the risk of spills.

Reinjection of stored brines back into the reservoir via injection wells is the only certain method effective not only to mitigate environmental impacts, but also to increase the reservoir life. The EIA should define reinjection wells and devices utilized to minimize spills and leakages.

6.1.3 Monitoring

Monitoring of a surface water quality should be carried out only in the case when a river or creeks are in the vicinity of drilling operations or near the reinjection wells during operation (less than 300 m).

In the latter case, a monitoring program during drilling phase should be designed and carried out to control any chemical changes in the surface water quality of the surface water bodies (river, lakes, streams etc.). The monitoring should start prior to the drilling activities in order to define the background values. Subsequently, a month-long monitoring should be done with the month measurements of certain chemical and physical characteristics in the field (temperature, pH, electric conductivity, TDS, total hardness etc.), and sampling and laboratory analysis of the major cations, anions (Ca, Mg, K, NO₃, SO₄, Na, Cl) and heavy metals (Hg, Fe etc.) shall be defined in relation to the geological setting.

The number of the stations must be defined in relation to the hydrological setting of the area, but at least two stations are necessary, one upstream and one downstream of the drilling wells along the surface water bodies present in the area. The monitoring should be protracted over the end of the drilling activities (well testing included) for a period of around 6 months.

The threshold limit is established in the EU Water Framework Directive 2000/60/EC in the section 1.2.3, which defines the “Procedure for the setting of chemical quality standards by Member States”.

6.2 Effects on groundwater quality

6.2.1 Prediction of direct effect

Deep water pollution may be caused by:

- Bad cementing operation and/or mud loss during drilling
- Spill and losses from casing during operation
- Potential contact between a geothermal aquifer and a potable aquifer due to the geothermal reservoir pressure drop or pressure increase (reinjection)

It is important to define the presence of aquifers in the vicinity of the wells (<500 m radius), and describe it (piezometric level, depth of the water table, water quality etc.). Since the potentially damaging events are related to the drilling phase of the wells, it is fundamental to describe the type of mud used for drilling and the technique of cementing, in order to obtain a well build according to the best practices.

At the same time, the cementing operation must be well described specifying the techniques used to ensure that water does not remain in the cementing annulus. For all products, the following must be specified: name, weight, name of the supplier, possible danger symbols in accordance with the current legislation. Usually, the mud is simply a mixture of bentonite, a nontoxic product that is also included in some beauty products, medicine, or wine.

To evaluate the impact on the underground water, it is important to describe the type of mud, water, plus bentonite, plus possible additives used in the drilling phase. In order to build the wells properly, the casing shall have a standard certification (manufactured with a single type of steel, hardness and resilience test, etc...). The relevant European legislation for underground water quality is shown in the previous table.

6.2.2 Mitigation and Compensation Measures

Wells

The following precautions must be taken during the well drilling operations:

- Adoption of drilling techniques used for drinking water wells in a geological aquifer layer must be adopted and it is the best practice to mitigate the risk of the groundwater pollution.
- In agreement with a constructive experience in this type of activity, the casing completion for geothermal wells, characterized by multiple concentric casings, allows for complete isolation of the aquifer crossed, both a perched and deep aquifer.

In addition, cementation of the casing is foreseen in order to implement an effective insulation against possible surface water tables. This is in accordance with a constructive experience now widely applied with success in this type of activity, able to safely isolate the different aquifers in the different strata that may be crossed.

Below is a summary of the precautions that should be taken to protect the water bodies:

- Utilizing drilling techniques used for portable water wells in a geological aquifer layer
- Multiple concentric casing completion
- Use of an absolutely intact casing
- Correct assembling of the casing under the control of a work management
- Hydraulic test after cementing operation
- Excellent execution of the cementing activities
- Verification of the quality of the cementing through well logging

Gathering system

- Above ground or buried pipelines are used to carry the geothermal fluid from the production wells to the power plant and from the power plant to the reinjection wells. The corrosion characteristics of the geothermal fluid must be carefully analyzed to select the a) proper material to be used to avoid losses and consequent spills, b) and/or cathodic protection.
- In the case of the underground pipelines, a spill detection system has to be set and periodically verified.

6.2.3 Monitoring

Only in case potable aquifers are present in a range of 500 m from the wells, a monitoring program during the different phases of the projects should be designed and carried out to control any chemical changes in the aquifer.

The monitoring should be initiated at least three months prior to the drilling activities in order to define the background values. In particular, it is advisable to do two measurement surveys per year in order to evaluate a possible chemical change in the water composition in relation to the rainfall trend during the year. The monitoring should be subsequently protracted until one year after the commissioning and operation of the power plant.

The measurement must include some chemical and physical characteristics to measure in the field (temperature, pH, electric conductivity, TDS, total hardness etc.), together with a laboratory analysis of the major cations, anions (Ca, Mg, K, NO₃, SO₄, Na, Cl) and heavy metals (Hg, Fe etc.), as well as in some cases radionuclides (to be defined in relation to the geological setting). The number of measuring points (piezometers, existing wells, springs) must be defined in relation to the hydrological setting of the area, but at least two points are necessary, one upstream and one downstream of the drilling wells.

Every three months a report summarizing the results of the chemical analyses shall be prepared and this shall be sent to the authorities. The threshold limits are established in the EU Water Framework Directive 2000/60/EC section 1.2.3 where the "Procedure for the setting of chemical quality standards by Member States" are defined.

6.3 Effects on surface water resources

6.3.1 Prediction of direct effects

The water supply is necessary for the following activities of a geothermal project:

1. Construction phase:

- drilling operation
- humidification of the construction site during the construction of the geothermal power plant

2. Operations:

- Occasional cleaning operation of the geothermal power plant equipment
- the accumulation of water in the tank of the fire extinguishing system
- potable water for sanitary facilities
- well killing and reactivation

For the construction phase, it is necessary to identify the presence of a river, wells and aquifers in the area, therefore it is important to do an assessment of natural water available in the area of the development project to identify the best ways for supply.

On the other hand, for the operational phase, considering the low water consumption, water could be provided by the national water mains, wells constructed by the developer, or a rainwater collection system. To evaluate the possible impact in terms of water supply, it is necessary to define the best ways of supplying the water.

The body of the surface water has good volume if the long-term annual abstraction rate does not exceed the minimal vital flow (MVF), on the other hand for groundwater body it is necessary to verify that the annual abstraction rate does not exceed the available groundwater resource. Abstraction must not cause permanent decrease in the groundwater level or hydraulic head.

6.3.2 Mitigation and compensation measures

In case of water supply from a surface water body, an assessment of the minimum vital flow (MVF) is important to evaluate the minimum hydrological component for the survival of biological communities and to define the quantity of water that can be withdrawn without putting the system in crisis.

On the other hand, if the supply takes place from a groundwater body, it is necessary to conduct a hydrogeological study in order to define the hydrodynamic parameters. A rainwater collection system can be utilized to supplement the water supply.

6.3.3 Monitoring

A real-time river monitoring plays a crucial role in determining sustainable abstraction levels. River monitoring station must be equipped to measure the water level, in order to stop the supply water if the MVF is not respected. The point of monitoring must be installed at the valley of the pump station.

Whether the water supply is provided by an existing or a new well, it is important to install a flow rate counter. The monitoring must be initiated together with the drilling activities and can be finished at their end.

It is not necessary to monitor during the operations phase considering the low request for water. The threshold must be defined in function of the local hydrological and hydrogeological situation.

6.4 Effects on air resources

6.4.1 Prediction of direct effect

The major impacts on the air quality are related to the following:

- Emissions of dust during construction site activities
- Exhaust gases coming from the vehicles involved in the preparation phase and from the diesel generator (if not an electrical rig) in the drilling phase (particular matter PM10 and PM2,5)
- Emissions from the geothermal fluids (water vapor and gases) during the well production flow tests
- Emissions from the geothermal fluids (water vapor and gases) during the plant operation when the cooling towers and direct contact condenser are used

The constituents released may include arsenic, mercury and even boric acid, but the main attention has been attributed to the emissions of non-condensable gases such as carbon dioxide or hydrogen sulfide. Carbon dioxide is generally released in a greater volume from fossil fuel plants, nevertheless the concerns of the public about the "green-house" effects focus again on this always present component of the geothermal activity.

A comparison between the CO₂ emissions from a fossil power plant at a given power should hence be presented in comparison with the CO₂ emissions from a geothermal power plant of the same power to show the differences. It must be underlined that the CO₂ attributed to the geothermal activities would be emitted naturally also without the presence of a geothermal plant.

Arsenic and boric acid may be emitted mainly through the drift from a cooling tower. If cooling water contains a small quantity of these substances (a concentration as high as 1mg/l of As and 0.003 mg/l of whely has been measured in cooling tower waters), an environmental impact may result. The maximum allowed drift from a cooling tower is generally lower than 0.01 % of the total mass flow rate and very low deposition rates of these compounds are generally evaluated. Nevertheless, the EIA should determine the foreseen deposition rate of metals utilizing one of the dispersion models outlined below.

The primary pollutant that would be emitted from the geothermal power plants is the hydrogen sulfide. H₂S is generally present in geothermal streams and is released to the atmosphere during

venting and/or condensing of the geothermal steam. Condensing the geothermal steam results in a condensate stream and a stream of gases which do not condense. The H₂S can be present in both the condensate and non-condensable streams. H₂S can be also emitted from the steam vented during the geothermal well drilling, well testing and during equipment malfunction.

An analysis of emissions during a system failure should be included to evaluate the worst-case scenario. The inventory of emissions should hence include:

- emissions from twin silencers (if any)
- outages of power plants
- emissions from cooling towers
- emissions from condenser discharge
- emissions from drains of steam pipelines
- emissions from short and long production tests

In case of an ORC cycle with total reinjection, no operational emissions are foreseen. The purpose of the air quality impact analysis is to estimate pollutant concentrations from the potential geothermal activities and, later, to assess its significance. Computer based dispersion modeling techniques should be applied to simulate the release of pollutants from the hypothetical sources. The pollutant to be included in the analysis is H₂S and any other component present in concentrations causing concerns. There are many models available to predict air quality. The gaussian plume model for continuous sources is surely the most applied and seems to be the best also in the case of geothermal projects. The model should be selected taking into account the characteristics of terrains surrounding the future power plant. There are in fact models taking into account the presence of buildings, wet and dry deposition and the presence of hills around the site.

All models are able to predict a receptor concentration for each type of meteorological situation which may occur (wind direction, wind speed, atmospheric stability) and calculates an annual, monthly or daily average concentration of pollutants. A model largely used is the SCREEN3, a diffusion code certified and suggested by the EPA, developed on the basis of the document "Screening Procedures for Estimating the Air Quality Impact of Stationary Sources" (EPA 1995). It is important to stress that results of this type of models are strongly dependent on the input meteorological data such as the height of the inversion layer, stability classes, a wind direction and velocity: the resulting pollutant concentrations may vary more than 1 order of magnitude depending on the parameters at the same distance from the emitting source.

Very often the meteorological data are not available or are available only for different sites or for a short period of time. In this case the utilization of the "short term" version of the above cited models can be useful: the maximum hourly ground concentration in the worst meteorological case may be determined.

"The worst-case scenario" is generally the meteorological situation in which the wind blows at 1m/s velocity from the source to the receptors in all atmospheric stability conditions with the inversion layer placed at the most frequent height in the region. Fumigation conditions are generally not taken into consideration unless this particular meteorological situation is foreseen to occur.

The first and simplest way to evaluate the impact is to perform a comparison with laws, regulations and accepted standards. The comparison may be carried out between the accepted standards for emissions and/or by comparison of the expected air concentration levels and the recommended or imposed criteria for air quality.

When such standards do not exist, an evaluation of the effects of the presence of the pollutant in the air on humans, flora and fauna should be carried out. H₂S emissions often produce concerns and citizens' complaints. This is mainly due to its offensive smell; therefore, the present H₂S concentration limits are generally designed to eliminate such odors. These limits are based on odors and not any demonstrable physiological effects and, of course, are aimed more at satisfying nearby inhabitants than protecting a power plant worker. This is one of the reasons why different countries react to H₂S release problems in different ways, depending upon the presence of people or touristic attractions in the vicinity of the geothermal power plants.

The evaluation of the effects of mercury and other metals (such as arsenic) may be carried out by comparing the calculated deposition rate from a cooling tower drift with the maximum amount of mercury or other metals, which is allowed to be spread on cultivated terrains. The following table lists the relevant European legislation for the air emissions and air quality limits.

Table 2: European Directives

#/year	Description
Directive 2003/87/EC	Target values, mitigation measures, monitoring and information requirements for a specific group of pollutants (arsenic, cadmium, mercury, nickel, benzo(a)pyrene and polycyclic aromatic hydrocarbons)
Directive 2004/107/EC	Air quality of As, Hg, Cd, Ni and PAH (Fourth Daughter Directive)
Directive 2008/50/EC	Framework Directive on Air Quality

Directive 2016/2284/EU	Reduction of national emissions of certain atmospheric pollutants (SO ₂ , NO _x , CONVNM, NH ₃ fine particulate matter (PM _{2,5}))
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6.4.2 Mitigation and compensation measures

Several processes to control or reduce hydrogen sulfide release to the atmosphere were studied and developed. The best method should be selected taking into account the emission limits, air quality standards and the overall economics of the process. Below is a brief overview of the most known processes:

- Dispersion of incondensable gases at high elevation by means of a tall chimney or in the cooling towers. This is one of the most economical ways to treat the H₂S problem and is adopted in Turkey and in Iceland. This method may be applied only if the emission and air quality limits are respected.
- Elimination of H₂S from the incondensable gases stream by chemical absorption and reaction. There are many H₂S abatement systems that can be utilized to reduce the concentration in the incondensable gas stream, among these for example the AMIS process utilized in Italy.
- Total fluid reinjection. The non-condensable gases are removed from the condenser, compressed and sent to the reinjection well.
- Regarding the dust emissions, wetting of the construction site can be performed.

6.4.3 Monitoring

For safety reasons, the H₂S and CH₄ monitoring must start during drilling. During the production test, should there be a suspicion of the presence of the H₂S in the geothermal fluid, a monitoring of the H₂S concentration in the atmosphere must be carried out, considering a limit value of 150 µg/m³ in an average of 24 hours³. The monitoring can be executed using devices able to measure the instantaneous concentration. These devices should be installed at the most sensitive locations around the emission point. The distance at which these devices should be installed must be determined after a short-term model has been run about 1000 m from the emission point. It is also strongly advised to sample the geothermal fluid, liquid and gas phases, in order to quantify the risk of aeriform emissions during the operation.

In case of a geothermal power plant with the technology of the total geothermal fluid reinjection, no monitoring is required during the operation phase. On the contrary, in the traditional geothermal plants a monitoring of gas emission (H₂S, Hg, As, Sb and NH₄) must be carried out

³ WHO Guidelines ed. 2000

through the cooling towers. To determine the H₂S in the aeriform of the tower, the method UNICHIM n°634 (Enel method) could be adopted. The sampling of the aeriform is done inside the tower, below the extractors for ventilation. To determine the Hg, As, Sb, the method EPA29 could be adopted. The sampling is done below the induced draft fans, or in case of a tower with natural draft towers, below the entrance to the extractor unloading tower. To determine the presence of ammonia in the gas phase in the aeriform of the tower, the UNICHIM 632 method could be adopted.

The following table shows the threshold, emission limits and air quality standards:

Table 3: Emission limits

Parameter	Concentration	Reference
H ₂ S	150 µg/m ³ average of 24 hours	WHO guidelines ed.2000
	100 µg/m ³ >1-14 days (maximum average over the period)	WHO - IPCS
	20 µg/m ³ Up to 90 days (maximum average over the period)	WHO - IPCS
As	6 ng/ m ³ yearly average	Directive 2004/107/EC
Hg	0,2 µg/m ³ yearly average	Guidelines significant for health developed by the US government agency ARSDR, in analogy at the EPA threshold values
B	20 µg/m ³ daily average	Adopting a confidence interval 100 with respect to the value of 2 mg/m ³ referred to TLV-TWA (Time weighted average) the ACGIH (American Conference of governmental Industrial Hygienist)
	10 µg/m ³ >1-14 days (average over the period)	Guidelines significant for health developed by the US government agency ARSDR, in analogy
NH ₃	170 µg/m ³ daily average	Adopting a confidence interval 100 with respect to the value of 17 mg/m ³ referred to TLV-TWA (Time weighted average) the ACGIH (American Conference of governmental Industrial Hygienist)
	10 µg/m ³ >1-14 days (average over the period)	Guidelines significant for health developed by the US government agency ARSDR, in analogy at the EPA threshold values
Sb	5 µg/m ³ daily average	Adopting a confidence interval 100 with respect to the value of 0,5 mg/m ³ referred to TLV-TWA (Time weighted average) the ACGIH (American Conference of governmental Industrial Hygienist)

6.5 Acoustic noise

6.5.1 Prediction of direct effects

Controlling noise from the development of a geothermal resource is important to ensure both workers' health and safety, and community acceptance.

The activities that can modify the acoustic climate are indicated below:

- Drilling of wells
- Well production flow test
- Construction of the geothermal power plant
- Geothermal plant operation

Noise sources (without mitigation measures) generally associated with geothermal development are specified in the table below together with typical values of sound pressure. The reported values are based on personal measurements of a typical equipment, however they are only indicative and may be very different from site to site, depending on the used equipment.

It is suggested to consult manufacturers of the different equipment to identify the sound power of the different noise source equipment.

Activity	Typical sound pressure level at 30 m from the geometric center dB(A)	Sound power dB(A)
Geothermal well drilling (as a whole)	80-85	
Site preparation – road construction ,construction of power plant	Depending upon the used machinery (see typical value from literature data)	
Geothermal well production equipped with twin silencer	80-85	
Induced drat Cooling Tower	70 -75	
Turbine generator building	60-70	
Steam vent gas ejector (no silenced)	90-110	
Air condenser		104-110

Sound level at the receptor may be predicted by using many existing models such as the calculation code IMMI and software Sound Plan by Sound Plan LLC 80 East Aspley Lana Shelton, WA 98584 USA.

The calculation codes are developed to supply the value of sound pressure in different points of the space in relation to the type of sound sources as well as meteorological conditions and land morphology. For the assessment of the industrial sound, the ISO 9613-2 is used. The first and simplest way to evaluate the impact is to perform a comparison with the law, regulations and accepted standards.

In the following table the relevant European legislation for noise is outline:

Table 4: European Directives

#/year	Description
Directive 2000/14/EC	Framework directive – harmonisation of emission standards, methods, etc
Directive 2002/49/EC	Assessment and management of environmental noise
Directive 2015/996/EU	Directive establishing common noise assessment methods according to Directive 2002/49/EC

The above Directives are implemented base on a national norm. Each country has a different law and different noise levels.

6.5.2 Mitigation and compensation measures

Most geothermal sites are distant from populated areas and on-site construction workers and operators must take protective measurements as necessary. If a receptor is close to the area of the activity, the following mitigation measures can be taken:

- a) **drilling**: using sound barriers around the air compressor, diesel generator (if drilling rig is electric), and hoist;
- b) **production tests**: conventional mufflers are not used because debris is vented with the steam. Using of either a perforated steel pipe at least 1 m under the surface of a pond, a vertical twin cyclone, a horizontal straight-through silencer, or a rock muffler;
- c) **operational**: avoiding venting to a well. During emergency, the steam flow should be deviated to the well sized silencer. Installation of a well sized silencer on a potential gas ejector system. Separation of the noise sources from people who are likely to be annoyed: avoiding construction of the cooling towers or aero condenser at a distance lower than 400 m from a receptor.

6.5.3 Monitoring

Noise monitoring before and during the different phases of the geothermal projects is required. The survey must be performed according to the current national legislation requirements of the host country. The sound pressure level must be measured at the nearest receptors (or other required noise descriptor) in the daytime and nighttime. The monitoring during the drilling activities and the construction of the power plant must be performed during the noisiest activities, at the same receptors investigated in the first stage.

Monitoring during the operation of the geothermal plant shall take place within the first year of commissioning according to the same methods (stations and measurement times) used for the characterization of the residual noise referred to in the first phase.

6.6 Seismicity

6.6.1 Prediction of direct effects

The high enthalpy geothermal resources are generally located in areas characterized by a high heat flow along thinning crustal zones. Thus, areas which are geothermally active also have a high likelihood of being seismically active.

Since the early '70s of the last century, the numerous bibliography available has documented that the activities of exploitation of a geothermal field can cause phenomena of induced seismicity, mainly related to EGS projects.

The publications essentially show that the stimulation and reinjection of a geothermal fluid into wells could trigger this phenomenon, however only under thermo-dynamic conditions. However, it has also been verified that the induced seismicity is characterized by levels of energy release typical of micro-seismicity, with a frequent tremor and low magnitude, usually below the threshold of human perceptibility.

Currently, there are no analytic elements that allow to distinguish clearly and unequivocally the induced seismicity from the natural one. In order to establish and verify a correlation between the geothermal exploitation and the induced seismicity in a geothermal field involved in reinjection of the fluid, a micro seismic monitoring capable of detecting seismic events (even if of a very small magnitude) should be set up. Permanent micro seismic control networks are necessary to stop reinjection when the activity exceeds a prefixed value.

Hence, the necessary instruments are studies on the seismological characteristics of the geothermal area to be exploited and preparation of an adequate local seismic monitoring system in order to evaluate the seismic phenomenology in the area. The recommended sequence of actions to well understand the possible triggering of an earthquake induced by reinjection are:

- 1) Geological mapping: development of detailed geological maps of the site area to assess specific hazards such as landslides, surface fault rupture, etc.
- 2) Conducting of a detailed subsurface exploration (sample collection) to determine potential hazards
- 3) Geophysical surveys to determine performance of the site material during an earthquake
- 4) Setting up a seismometric station close to the reinjection well during tests in order to identify the ipocentral coordinates of microseismic events and hence to spot the possible migration of seismic focuses and verify the possible correlation between reinjection and a seismic activity.
- 5) Seismic monitoring during operations

Currently there is no European legislation for a risk connected to induced seismicity.

6.6.2 Mitigation and compensation measures

In order to reduce the seismic hazard, the main recommended actions should be as follows:

- Conduct a seismic hazard and risk analysis. It can be done stepwise, starting with screening, followed by more in-depth studies in areas presenting a potential hazard;
- Adopt good practices for fluid injection or reinjection (flow rate, reservoir overpressure, reservoir temperature and geology, location etc.);
- Define a seismic velocity model for the project and the layout of a suitable monitoring network, install it. And control that it remains operative;
- Permanent micro seismic control networks are necessary to monitor and enable comparison of values of specific parameters (e.g. magnitude, peak ground velocity/acceleration, number of quakes per unit of time) with the ones for which thresholds are defined and used in the traffic light system. The parameters in the geothermal power plant such as the flow rate and the injection pressures can be adapted when one or more of the parameters exceed the prefixed values. In such cases, the plant operating parameters can be either gradually reduced or the plant can be temporarily shut down.

In case of seismic risk:

- Define contingency plans, accounting for local liability regulation;

- Conduct seismic baseline measurements for 6-12 month before drilling or stimulation or operation with the installed local network, and establish detection thresholds (minimum magnitude and/or peak ground velocity/acceleration); as an alternative, use data from an existing seismometer network to define the baseline;
- Define preliminary thresholds (magnitude and/or peak ground velocity/acceleration) for further actions (i.e., drilling, well testing...).

6.6.3 Monitoring

In order to understand the relationship between the seismicity and the cultivation activity, it is necessary to prepare an adequate monitoring system.

The monitoring could be organized in two different phases:

- Phase 1: should be initiated 12 months before the start of the activities in order to define the natural seismic background of the area;
- Phase 2: real-time monitoring starting with the drilling activities and finishing one year past the end of the exploitation period.

The seismic network should have the following characteristics:

- a 3-component seismometer per station;
- at least one accelerometer may be prescribed for the operation phases;
- data sampling frequency of at least 100 Hz (accelerometer) and 200 Hz (seismometer);
- at least 4 stations around the project.

The installation of the networks monitoring will be planned and installed after an accurate scouting to verify that:

- all stations must be located within a maximum distance of about 8 km from the production/reinjection area, with a station located near the reinjection poles;
- the configuration of the network ensured homogeneous coverage of the production-reinjection pole;
- each station must be covered by a good cellular telephones signal for data transmission and by a good GPS satellite signal necessary for the time synchronization of the individual data loggers;
- areas devoid of vegetation, due to the seismic noise generated by shaking of tall trees under the action of the wind;
- a traffic light system with green-orange-red will be foreseen.

The parameters of the traffic light system are site specific, they usually include the calculated magnitude of the earthquake and the peak ground velocity (PGV) / acceleration (PGA) measured by the seismometers in the monitoring network. In addition, they can include parameters such as the epicenter or the number of seismic events per unit of time.

In any case, the limit values are defined for each parameter of the traffic light system - a green, an orange and a red zone. If any one of the parameters is in the orange zone, the operating parameters in the geothermal power plant such as the flow rate and injection pressure are gradually reduced. If any one of the parameters is in the red zone, the plant is temporarily shut down.

6.7 Subsidence

6.7.1 Prediction of direct effects

Geothermal development and operation may cause deformation of the ground surface that subsides (lowers) or uplifts, generally in response to pressure and/or temperature changes within the geothermal reservoir. Fluid extraction from the underground can lead to a decrease in both pressure and temperature within the geothermal reservoir, thereby causing subsidence. Conversely, re-injection of geothermal fluids can induce a pressure increase within the geothermal reservoir, resulting in a ground uplift. This latter may be partially counteracted by the rocks and sediments contraction as they cool down due to the temperature decrease.

6.7.2 Mitigation and compensation measures

Prediction and monitoring are the main approaches to control and mitigate the effects of ground surface deformation in the geothermal fields. Information regarding the geothermal reservoir modifications can be inferred by a numerical modelling, which simulates the complex interactions between heat and mass transfer processes according to the reservoir properties (i.e., permeability and porosity), and the geomechanical characteristics of the rock.

Reinjection of fluids in the geothermal reservoir proved to be a very effective way to control and mitigate land subsidence in geothermal systems, since in many cases it compensates for mass deficit and pressure decline induced by fluid extraction. In case the prevention by reinjection is not enough and ground deformation appears, the best recovery measure is to reduce the rate of the geothermal fluid extraction or raise the re-injection temperature.

6.7.3 Monitoring

Spatial and temporal evolution of surface deformations is very slow and can be monitored using several geodetic techniques. Currently the SAR satellite interferometry (InSAR), global navigation satellite systems (GNSS), and levelling are the main techniques used. InSAR provides a good spatial coverage of geothermal fields and their surroundings thanks to different available SAR satellite platforms. InSAR is sensitive to snow and vegetation, which can limit the long-term monitoring of an area. However, it is possible to bypass this limitation by installing corner reflectors at specific points of interest.

A GNSS permanent station provides a continuous monitoring of the deformation in all directions (East, North, Up). Its limitation is that it measures only one specific point and it is expensive to run multiple stations within a geothermal field. Benchmarks can also be installed throughout the geothermal field and surveyed at regular interval using GNSS, levelling, or total stations. This allows to monitor specific points of interest than cannot be monitored by InSAR or permanent GNSS stations, at the cost of sending a team to the field to do measurements. A combination of all techniques is usually the best way to ensure a detailed monitoring of surface deformation within geothermal fields. Monitoring should start before geothermal development and continue through development of the resource with biannual frequency.

6.8 Effects on ecological resources

6.8.1 Prediction of direct effects

Potential environmental impacts on biota include:

- Direct loss of habitat and destruction of native plants communities as a result of land clearing for geothermal facilities. Setting up of roads and well sites during the exploration phase as well as transmission lines, power plant and other facilities during the later construction and operational phases should be examined to determine the quantity and quality of vegetal and animal species which will be disturbed.
- Invasion of cleared areas by weedy introduced species. Undisturbed sites such as unpaved road margins and open roadsides are prime sites for weed establishment. From such areas, the weedy species may move into small openings in the possible surrounding forests, occupying space once utilized by native species. Invasion by introduced plants may also reduce the habitat quality for native birds and invertebrates, thus affecting the distribution of these organisms.
- Long term effects on biota during the operational phase may be due to: air emissions, water spills, noise from day-to-day operations

- A small list of possible effects on flora and fauna of emitted substances were indicated in the previous paragraphs.
- The presence of endangered or rare species, forests and plantations living in the impacted area shall be investigated.

6.8.2 Mitigation and compensation measures

Mitigation measures are crucial in areas where geothermal facilities would impact forests or endangered species. Among the possible mitigation measures are:

- limiting vegetation removal to only absolutely necessary: directional drilling in a way to drill up to 5 wells in less than 1 ha; to construct all transmission lines along existing road corridors to minimize vegetation removal;
- revegetation with native material as soon as possible:
 - quick revegetation of the disturbed areas, thus reducing weed population;
 - continual monitoring of developed areas for weeds and appropriate method of weed control.

6.8.3 Monitoring

Specific monitoring plan could be established case by case according to the Geothermal Authority

6.9 Land use

6.9.1 Prediction of direct effect

Land use during a geothermal development can be temporary (construction and drilling phase) and permanent (operational phase):

- temporary land take:
 - drilling site: generally involves an area of half a hectare per well which must be cleared and graded. Adjacent to the drill rig are mud pumps, mud tanks, generators, drill pipes racks, tool house, storage tanks, a collecting pit for production tests. In addition to all these land requirements, drilling presupposes access and therefore road construction. A figure of land requirement for drilling wells has to be provided, bearing in mind that land take for drilling work is temporary. At the same time a list of the vegetation species which will be destroyed has to be made as described above.
 - Production tests may affect large areas around the collecting pit by provoking vegetation damages because of the heat delivery and entrained droplets deposition. As a rough figure an area of more or less 100 meters of radius may be affected during production tests. Also, this zone has to be accounted when land needs are calculated.

- construction of a power plant and gathering system:

It is during this phase that land disruption is more noticeable and probably most significant. Pipes themselves are built at present on the surface, although there has been some consideration of underground pipes in some countries (USA, Italy). A figure of land requirements and cleared vegetation species has to be provided. As a rough figure, total land needs for a power plant located in a steam dominated reservoir can vary from 11 to 35 ha per drilled well. It is important also in this case to stress that once the wells are drilled and construction phase is completed the effects on land take begin to diminish.

- Permanent land take:

Permanent land needs must be considered: the access roads, power plant, cooling towers, and production and reinjection well equipment site. The existence of transmission pipes at geothermal sites does not influence appreciably land use. Farming, for example, can continue also among pipelines. In summary, a prediction of land take may be easily taken when feasibility study is completed, and a plant type and size and reservoir temperature are known.

The prediction of direct effects should be carried out taking into account present land use around the area of the future development.

6.9.2 Mitigation and compensation measures

The main mitigation measure is the adoption of a project design solution which minimizes the of land use by:

- Utilizing of the directional drilling, which is the most used way to reduce land take. Up to 5 wells may be accommodated in an area only slightly larger than that previously needed for one wellhead. The additional cost which results from this type of drilling is partially offset by the lowering cost in pipelines and, of course, in land.
- Utilizing of the underground pipelines, which could in principle be used to reduce land take. At present, they are not utilized due both to the high cost and the difficulty in maintenance.

The compensation measures can be the economic reimbursement to the owners of the land used as well as the loss of income for the yields of products grown in the land used.

6.9.3 Monitoring

No specific monitoring plan is required

6.10 Impacts on socio-economics

6.10.1 Prediction of direct effect

Impacts on a socio-economic situation strongly depend on regional characteristics of the area to be developed and on the attitude of people towards a geothermal activity. As a general rule, an investigation on the economy of the area and opinion survey among people attitude towards geothermal development can provide a good tool for evaluation of the impact. Most of the direct effects are positive, including:

- Significant increase of jobs during the construction stages (> 100 unit-work-years) for 3-4 y;
- Moderate increase of jobs during the operation (>20 unit-work-years) for 20-30 y;
- Economic benefits expected on the territory:
 - Direct: lease fees and royalties, land rights;
 - Indirect: increase of the income for hotels, restaurants and other commercial activities;
 - Touristic attractiveness for visiting geothermal facilities.
- Increase in population according to the different phases of the project development.

Possible adverse effects could lead to minor decrease in agricultural activity due to a very limited land take of the project (1-2 ha).

6.10.2 Mitigation and compensation measures

Economic compensation shall be envisaged for losses in an agricultural activity.

6.11 Public Health and safety, emergency plans

6.11.1 Prediction of direct effect

General public health conditions in the development area should be described utilizing health statistics on endemic diseases and potential health problems, which may be enhanced by the proposed project.

No particular disease is reported to be accelerated in the area surrounding geothermal power plants, even in the case of air contaminants (generally H₂S at the low concentration). Noise can be easily controlled by means of mitigation measures shortly described above. No hazards to the public safety during power plant operations are generally reported. Blow outs can very rarely occur, although the consequences do not put at risk the safety of the population living in the immediate surrounding of a well.

6.11.2 Mitigation and compensation measures

Wells and plants are not usually located at a short distance (< 1-2 km) of populated areas and no specific safety measures have to be taken. In some cases, wells and plants are erected very closely to a town (e.g. in France or Germany) to provide heat and power for industry facilities. However, an emergency plan should be foreseen in case of the well blow outs or negative atmospheric conditions. In this case, an evacuation plan for population shall be agreed with public authorities.

6.12 Visual impact

6.12.1 Prediction of direct effect

A visual impact analysis is required to show the effects of the proposed development on the surrounding landscape. In general, the physical characteristics of each subzone of the proposed development should be identified and evaluated and afterwards related to the characteristics of the proposed power plant and associated facilities. The worst case for a visual impact is generally considered the situation, when a power plant and associated facilities are completely visible from access roadways and from scenic roads.

6.12.2 Mitigation and compensation measures

Mitigation measures such as vegetation screens should also be adopted as well as a site specific design of the plant to ensure the best integration into the landscape.

6.13 Radiation (ionizing and not ionizing)

6.13.1 Identification and prediction

The presence of the Naturally Occurring Radioactive Material (NORM) in the reservoir fluid pumped to the surface is one of the risks to be evaluated in the Environmental Impact Assessment.

Geothermal projects are added to the list of professional activities in which there is a risk of natural radiation. Such activities are obliged to have a NORM-file issued to the Federal Agency of Nuclear Control (FANC) concerning general regulations for the protection of the population, employees and the environment to the hazards of ionizing radiation (ARBIS). This regulation is not regional and is therefore not directly linked to the first two (regional) permitting systems.

The main sources of NORM are indicated below:

- possible enrichment of radionuclides in drilling mud;
- possible formation of scales caused by precipitation processes within the equipment used for the extraction and distribution of power systems;
- radon gas emissions, which can occur at any stage of the process.

The following table outlines values of concentration of NORM measure in the water of the geothermal energy production plants.

Table 5: Concentration of Norm in geothermal waste (ISPRA, 2014)

Radionuclides	Activity concentrations (Bq/kg)
²²⁸ Th	930
²²⁸ Ra	3440
²²⁶ Ra	4880
²¹⁰ Po	3550
²¹⁰ Pb	3550

Another source of radiation is represented by the electromagnetic field emitted by a power line and some components of the geothermal power plant.

The first and simplest way to evaluate the impact is to perform a comparison with the law, regulations and accepted standards. Thresholds for dynamic and cumulative radioactive doses are established at the European level by a European Directive 2013/59/Euratom (Safety standards and threshold for dynamic and cumulative radioactive doses for any planned, existing or emergency exposure situation with involves a risk from exposure to ionizing radiation).

6.13.2 Mitigation and compensation measures

In case of an identified risk of NORM, a periodic dose measurement of the surface installation must be performed. A measurement plan and measurements frequency must be defined by the operator. The locations, where measurements will be performed, are marked on the installation. Measurements will be compared to the maximum radiation dose, but also relatively to the previous measurements. Monitoring of radionuclide in a drilling mud and other equipment during maintenance of the geothermal power plant should be performed. A respected area for an electromagnetic field should be identified.

Mitigation measures are described in the relevant paragraphs and are summarized here according to the recommendations given in the general EIA guidelines (Box 34). Compensation

measures must be described: generally, selling of energy at low price to the impacted population, plantation of trees and vegetation, creating cultural centers near the geothermal development etc.

6.13.3 Monitoring

It is important that in order to dispose of waste and mud and during the maintenance of the power plant and the equipment, the radiological aspect is also taken into consideration, and a plan of management will be carried out to do a qualitative-quantitative analysis of the scale inside the pipes or in the waste. In this case, the waste must be treated as radioactive waste and a waste management plan is mandatory.

Thresholds for dynamic and cumulative radioactive doses are established at the European level by a European Directive that applies to any planned, existing or emergency exposure situation which involves a risk from exposure to ionizing radiation. Council Directive 2013/59/Euratom of 5 December 2013 laid down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealed Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. The European Directive is then translated into the national regulations. Depending on a country, the topic of radioactivity is often mentioned in the Public Health Code, the Labour Code, and the Environment Code and in some cases, in the Mining Code (as it is the case in France since 2018). In most European countries, the maximum cumulative dose for human exposure is fixed to 1 mSv (milli-Sievert) over 12 consecutive months. National recommendations on radioactivity may be a part of the Environmental Impact Assessment procedure for permission to operate a geothermal plant, and necessary provisions are established. They are usually based on the worst-case scenario. At the plants' level, recommendations and obligations regarding the management of radioactivity may be expressed in the local (region, county, and municipality) authorizations for utilization.



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