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Environmental study on geothermal power

EXECUTIVE SUMMARY

The report gives an overview of possible environmental impact of three geothermal facilities i.e. geothermal facility for exploiting high enthalpy hydrothermal resources, medium enthalpy hydrothermal resources and Enhanced Geothermal Systems (EGS).

The impact is described in relation to different development phases of the geothermal power plant facilities. Those phases are:

- Access roads and pipe laying
- Well repair, well stimulation, well drilling and testing phase
- Plant construction and equipment installation
- Power plant commissioning and operation
- Decommissioning of facilities

Different impact is generated in different phases of the development but the following main categories were identified:

- *Surface disturbances,* such as those caused during the plant construction possibly affecting flora, fauna, surface water (access roads, pipe and power lines, plant and associated land use).
- *Physical effects*, like the effect of fluid withdrawal on natural manifestations, land subsidence, induced seismicity, visual effects (buildings, cooling towers, surface pipelines, power transmission lines etc.)
- *Noise*, such as equipment noise during drilling, construction and operation.
- *Thermal pollution*, such as due to hot liquid and steam release on the surface.
- *Chemical pollution*, like due to disposal of liquid and solid waste, gaseous emissions to the atmosphere etc.
- *Protection*, such as ecological protection (fauna and flora).

Most of the impact identified can be minimised by mitigation measures and monitoring along with proper environmental management procedures.

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1 Potential Environmental Impacts

An overview of possible environmental impact in geothermal energy utilization will be described for three geothermal facilities i.e. geothermal facility for exploiting high enthalpy hydrothermal resources, medium enthalpy hydrothermal resources and Enhanced Geothermal Systems (EGS).

Geothermal facilities using flash-steam techniques for exploiting high enthalpy resources: Mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. These facilities generally produce from very high temperatures at shallow depth (150°-300+°C) and may release geothermal steam to the atmosphere, depending on the plant design technology adopted.

Geothermal facilities using binary cycles: As for flash steam plants, this facility is mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. It is generally used for medium enthalpy resources (100°-150ºC) and can operate in a closed system where the geothermal fluid is injected into the ground.

Enhanced Geothermal Systems (EGS): An Enhanced Geothermal System is an underground reservoir that has been created or improved artificially. At present, EGS plants are mainly located in regions of elevated temperatures (caused by radiogenic heat production, elevated tectonic heat flow, or vertical heat advection through deep fault zones), where the financial performance of the corresponding investment is more favorable. EGS is typically situated in basement rock marked by relatively low natural permeability. The specific characteristics of the EGS are mainly connected to the enhancement of natural permeability. EGS geothermal power plants operating in a closed system where the geothermal fluid is reinjected into the ground have minimal emissions.

Environmental impacts of the three geothermal production systems are similar with the main exception of emission and impact on air, which will be discussed separately. In general environmental impact of geothermal facilities may be divided into the following main categories:

- *Surface disturbances,* such as those caused during the plant construction possibly affecting flora, fauna, surface water (access roads, pipe and power lines, plant and associated land use).
- *Physical effects*, like the effect of fluid withdrawal on natural manifestations, land subsidence, induced seismicity, visual effects (buildings, cooling towers, surface pipelines, power transmission lines etc.)
- *Noise*, such as equipment noise during drilling, construction and operation.
- *Thermal pollution*, such as due to hot liquid and steam release on the surface.
- *Chemical pollution*, like due to disposal of liquid and solid waste, gaseous emission to the atmosphere, natural radioactivity etc.
- *Protection*, such as ecological protection (fauna and flora).

The main activities causing environmental impact of geothermal facilities are:

- Building of access roads and drilling pads
- Well drilling and well stimulation
- Well repairs, possible additional well drilling and well testing
- Laying of pipelines, electric power transformation and transmission lines
- Plant construction and equipment installation
- Power plant commissioning and operation
- Decommissioning of facilities

In the text below appropriate environmental aspects are outlined with emphasis on associated risks, hazards and available mitigation measures and/or abatement measures as applicable.

1.1 Access roads, pipe laying

The predominant environmental concerns encountered during this work phase are:

a) Surface disturbance
b) Visual impact
c) Disposal of waste

Except for the visual impact, these effects are mostly temporary since they largely disappear once this construction phase is finished. Although surface disturbance can be minimized it cannot be avoided and care should be taken during construction works, in particular in ecologically sensitive areas. The associated environmental risks are quite insignificant.

a) Surface disturbance: Any permanent damage as such can be minimized with proper care, such as avoiding ecologically sensitive areas, locations of historical value and natural beauty. Attention should be paid when selecting a road location to minimize the need for significant earth removal and road fill. It is also recommended that available roads should be utilized to the fullest extent possible, widened and strengthened as needed. This is economical and also a good way to reduce permanent effects.

b) Visual impact: There is some potential visual impact associated with the wellheads and the pipelines. The plant buildings should be located close to the production wells and the pipeline from the wells to the plant should be as short as possible to cause minimal visual impact.

To minimize visual impact of the wellheads, it is recommended that each wellhead should be enclosed in a small building of a design that falls well in with the surroundings. This is normal procedure for example in Iceland and the well house serves three simultaneous purposes: it effectively hides the wellhead and the associated equipment, reduces maintenance and provides security, see figure 1.

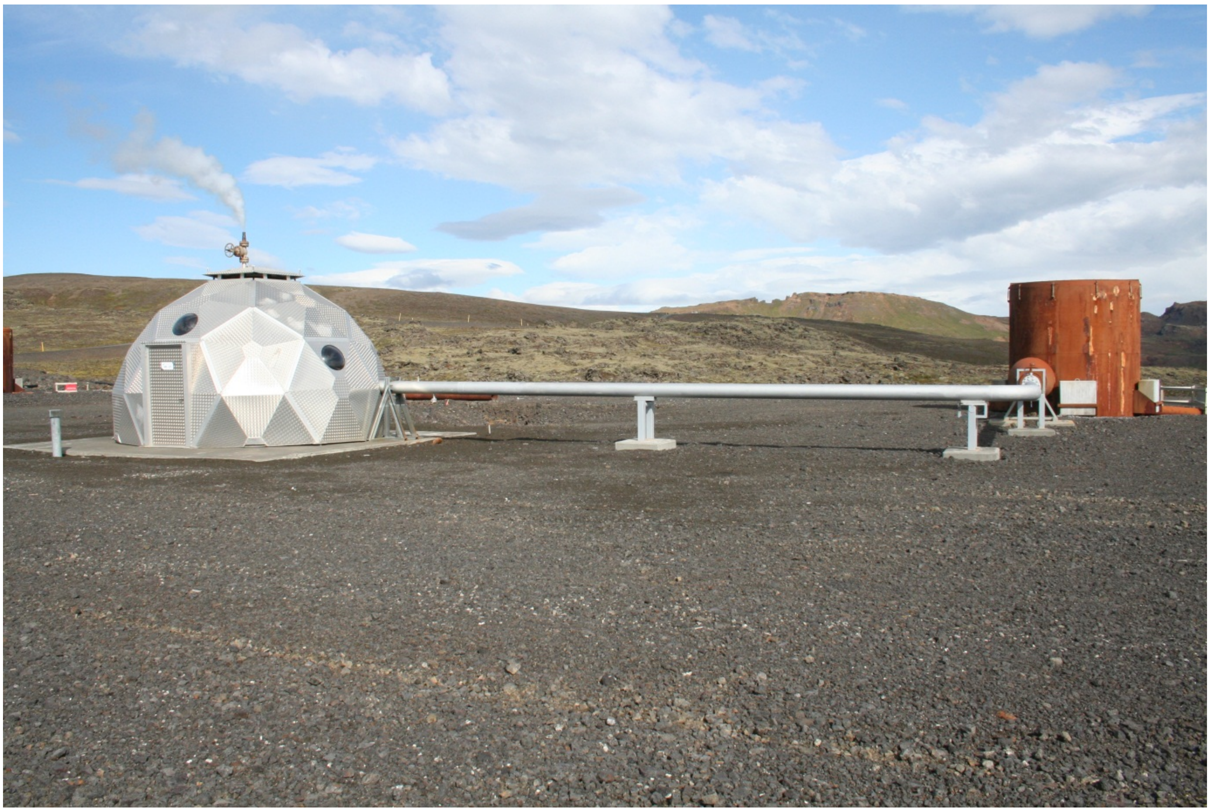

Figure 1 Enclosed wellhead (left) at Hellisheidi, power plant in Iceland, connected to a muffler (right).

c) Disposal of waste: Waste associated with this activity is typical contractor waste, mostly solid.

The contractor doing the work should be made responsible by contract for cleaning and transporting away all such waste to an approved waste dump after his work is completed. Such a performance should also be prescribed in a health, safety and environment (HSE) management program for the whole project.

1.2 Well drilling, repair, stimulation and testing phases

The predominant environmental concerns encountered during this work phase are:

- *a) Liquid and liquid carried pollutant release*
- *b) Environmental impact of stimulation*
- *c) Noise and vibration*
- *d) Induced seismicity and seismic hazards*
- *e) Solid waste*
- *f) Surface release of geothermal fluid*
- *g) Surface disturbances*
- *h) Visual impact*

These effects are mostly temporary since they largely disappear once this phase is completed. Providing that sound engineering practices are adopted, associated environmental risks are quite insignificant.

a) Liquid and liquid carried pollutant release: Potential pollution release is chiefly related to the well drilling and/or well repair activity. It constitutes drilling mud and other drilling fluid additives like cement slurry, diesel and lubricant leakages.

An important feature in doublet[1] well testing is to ensure that the danger of cold breakthrough is minimal during the operating life of the doublet in question. The most commonly used method to assess the likely occurrence of this is the use of tracer testing techniques. The technique involves introducing tracer chemicals such as fluorescein, rhodamine WT or naphthalein sulphonates into the injected fluid and measuring the time it takes for the tracer to reach the counterpart production well. Besides giving a measure of the cold breakthrough potential, it yields important data on well permeability.

Tracers need to be in extremely low natural concentrations in the fluid and it should be possible to detect them analytically with a great sensitivity. In the past, radioactive substances have been used with considerable success but their use cannot be recommended due to their toxicity.

Many fluorescent substances fit the above criteria. In Iceland fluorescein has been used with success, especially at relatively low temperatures but tends to break down at higher temperatures and can then only be used to find arrival time but not the recovery of the tracer. Another fluorescent tracer, rhodamine WT, has been used too and seems to withstand higher temperatures. More recently success has been claimed for the use of naphthalein sulphonates (e.g. 1.5 dianaphthalein sulphonate), which are cheaper than the above two, but need to be bought in bulk quantities. None of the above compounds are listed as toxic or damaging. Potassium iodide has also been used as a tracer in Iceland since it can be analyzed to low levels by ion chromatography. Its use has been very successful, it does not break down and its concentration can be monitored for years. It is not listed as toxic or damaging but it is the most expensive one among the considered tracers.

To mitigate the above mentioned risks and effects it is best to select only contractors that have a good environmental record to carry out the work and use modern equipment of a capacity that is not excessive to that required. The contract should state that special approved waste ponds (slurry ponds and other liquid waste disposal facilities) of the required capacity and approved design are constructed on or close to the activity site, only non-polluting drilling fluid additives will be used and care taken to minimize all unnecessary releases. The same should be applied to tracer chemicals. Such a performance should also be prescribed in an HSE management program for the whole project.

b) Environmental impact of stimulation: To create an EGS but also to improve the productivity or the lifetime of high and medium enthalpy hydrothermal systems, stimulation techniques are needed. The objective is to extract as much mass flow: geothermal brine as possible by using stimulation techniques characterized by water injection under pressure. Figure 2 describes hydraulic stimulation.

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[1] A pair of wells, one for production, the other for injection.

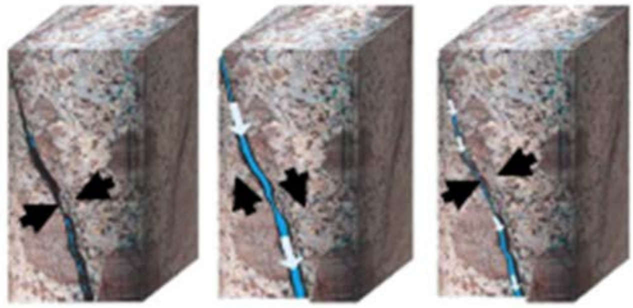

Figure 2 Hydraulic stimulation (figure:GEIE Soultz).

Contrary to hydraulic fracking for shale gas, where the goal is to produce new fractures (in sedimentary rock: shale, with low porosity/permeability and clay minerals; at a depth of: 1000-3000 m); geothermal stimulation aims at the reactivation of naturally occurring fractures in rocks like granite, in order to engineer a reservoir with high permeability and low clay mineral content at 3000-5000 m depth.

To re-open faults through dilatant shearing of natural fractures, injection is made at low pressure= 25-200 bars.[2]

Stimulation of EGS is looking at increasing the permeability and at creating a loop. Moderated quantity of water is used and it is reinjected in any case. So EGS do not produce wastewater by-products.

Hydraulic stimulation is typically done with water (at 99%) and chemicals, but no proppants. Being at 5 km depth, the risk of groundwater contamination is none. No geothermal installations have had such experience. Wells casing is crucial for respecting environmental rules and ensuring economic feasibility of the project without brine/temperature leakage. The integrity of geothermal wells is crucial.

c) Noise and vibration: The noise level associated with the drilling rig and from the associated equipment (also earth moving equipment and diesel or petroleum driven pump equipment) used during this work phase is of the order of 80 to 120 dB(A) within a 100 m radius.

Though this noise level is not a direct hazard to health, it is always necessary to have a hearing protection for those who are working on or close to the drill site. In case of proximity of residential area (within 500 m) special noise barriers may be erected. Raised noise levels may cause temporary nuisance to visitors and tourists visiting the area and also to animals crossing or living in the area. The described disturbance relates only to the drilling and testing phase (2-6 months for high enthalpy systems and around 2 months for medium enthalpy systems and well repair (a few days per year.

[2] It is different with shale gas techniques where in order to create new fractures, water injection is at very high pressure= 500-800 bars for having hydraulic compression constraints.

Typical noise levels during testing, drilling and construction.

Stage	Operation	Noise level dB(A)
Drilling	Air drilling	120
	Air drilling with suitable muffling	80
	Mud drilling	80
	Mud drilling with maximum muffling	55
Discharge	Vertical	120
	Through drum silencer	70-110
	Through new design rock muffler	65
Construction	Use of heavy machinery	90
	Use of heavy machinery muffling exhaust	Reduced
Production	Pipeline and vent discharge noise	Usually acceptable
	Cooling tower fans	To be monitored
	Steam ejectors	To be monitored
	Turbine hum	To be monitored

d) Induced seismicity and seismic hazards: Induced seismicity has occurred in the development and production of several conventional fractured geothermal resources (typically deeper than 1 km) EGS especially. Prior to EGS activities, the Project Owner will need to implement the Protocol for Induced Seismicity Associated with Geothermal Systems[3], which includes the following steps:

- Evaluation of applicable laws and governing regulations
- Establish a microseismic monitoring network
- Establish a traffic light system

A microseismic array (MSS) will need to be designed by seismologists and installed as part of operations. In most cases a permit has to be secured for installation of this network. The network should surround the target well while one network station is located close to the injection well. A minimum of 4 stations is required to detect and localize seismic events in 3D. Initially, seismometers should only be installed at permitted surface locations and in existing well bores. Data should be downloaded manually and periodically from each site to provide input to the assessment of natural seismic hazards, discussed below.

[3] http://www1.eere.energy.gov/geothermal/pdfs/geothermal_seismicity_protocol_012012.pdf

Prior to stimulation, the MSS is to be modified to include telemetry and real-time data monitoring, and may be modified with the drilling of additional bore holes with seismometers installed downhole.

- Assessment of natural seismic hazard potential
- Assessment of induced seismicity potential

Assessment of natural seismic hazards and induced seismicity potentials need to be conducted by an independent consultant approved by authorities, prior to any stimulation activities. Natural seismic hazard potential will be assessed by reviewing the seismic history available from permanent local and regional seismometer installations and from data collected from the installed monitoring seismometers.

It is common and proper practice to improve social acceptance by:

- Establishing a dialogue with regional authority
- Educating stakeholders
- Interacting with stakeholders

A public relations and outreach program should be established, intended to educate and inform authorities and other interested stakeholders, and to respond to stakeholder concerns.

It is also a good practice, in most cases required by authorities, to implement an official Procedure for Evaluating Damage.

Procedures for responding to reports of induced seismicity and evaluation of property damage should be included in a Stimulation Plan issued during planning of the project.

If water injection pressure is properly controlled injection can be stopped in time before any impact occurs.

e) Surface release of geothermal fluid: At the end of the well repair and the well drilling activity it is a fairly normal procedure to blow or air pump the well for a short period (3-5 hours). This is mainly done to clean the well of cuttings, acid or other remains left from the well stimulation, and other debris that for various reasons was left in the well after completion of the actual drilling/well repair activity. Well testing, however, requires that the well is flowed and/or pumped for a prolonged period of time or 2 to 6 months, depending on local specifics.

Short-term and/or emergency liquid releases will have to be accommodated in a special holding tank or a holding pond, see figure 3. For simplification, it is recommended that all fluid releases are conveyed into a common holding tank or pond designed to accommodate 50% in excess of a 60 hour accumulation of geothermal fluid at expected mean capacity of the production well subsequent to well stimulation. The pond must be completely watertight. The pond must be emptied periodically and the accumulated sludge disposed of into an approved waste disposal facility for polluting waste.

Figure 3 Holding pond for sludge at Miskolc Hungary.

f) Surface disturbances: The land use for the well pads and the potentially affected area is somewhere between 1 to 1.5 hectare per well. In case of multiple doublets, the production well should be connected to its injection well counterpart. If the law stipulates that the geothermal fluid must be re-injected, the injection pipeline should be laid prior to the long-term well testing.

Surface disturbance of this kind cannot be avoided, it can however be minimized if care is taken in the pipe laying and through careful landscaping once the work is finished and also to avoid ecologically sensitive areas.

Drilling of many (e.g. 2-4) deviated wells from the same pad, results in minimum surface disturbances from the geothermal installations.

Figure 4 Drill pad construction at production well site for Hellisheidi power plant in Iceland.

g) Visual impact: Once the drilling/well repair activity is finished usually only a small pump house and the injection pipeline remains. Where possible the injection pipeline can be lead in the ground, so the subsurface pipeline will not have visual impact. When situated in rocky landscape or where the pipeline cannot be lead in the ground due to other reasons there will be visual impact.

The surface mounted injection pipeline is typically mounted slightly elevated (~20 cm) above the surface and where roads have to be crossed the pipe is placed inside a suitable culvert. The visual impact can be minimized by: making the pipeline follow the contour of the land which it crosses, using colors for the aluminum sheathing that blends in well with the surroundings and ensure a low profile where small hills have to be crossed.

1.3 Plant construction and equipment installation

The predominant environmental concerns encountered during this work phase are:

a) Surface disturbances
b) Noise
c) Visual impact
d) Disposal of waste

Most of these effects are of a permanent nature except for the surface disturbance and noise associated with the construction activities of machinery, which largely disappear once they are finished. Associated environmental risks are quite insignificant.

a) Surface disturbances: The land required for a power plant exploiting high enthalpy resources like the Hellisheidi power plant in Iceland and its associated equipment and facilities, is around 5 hectares. This land is unlikely to be recoverable in its original form on decommissioning of the plant, see figure 5. Geothermal facilities using binary cycles require much less land. An example of that is the Bruchsal power plant in Germany, see figure 6.

Figure 5 120 MW_e and 300 MW_{th} Nesjavellir flash power plant in Iceland.

Figure 6 An overview of binary cycle power plant, Bruchsal in Germany.

The impact can be minimized through careful siting of the plant, avoiding ecologically and historically sensitive areas.

b) Noise: The noise associated with this work phase is a typical construction noise, such as from drill rigs, power tools of various kinds, concrete mixers, cranes and various lifting equipment. The noise is temporary and its general level does not exceed 80 dB.

To avoid danger to hearing it is advised that equipment operators wear ear protectors. Otherwise the effects are within acceptable working levels.

c) Visual impact: Most power plants house its envisaged equipment, at least electrical and control equipment and in most cases also the turbine. Still for example heat exchangers can in suitable climate be situated outside of the power plant housing. There is also a tower either air cooled or water cooled to cool the working fluid and a substation for connection to the electrical grid situated nearby the rest of the power plant equipment. The other equipment involved in geothermal utilization (constructions) is associated with well enclosures and pipelines.

Visual impact of various buildings and equipment can be minimized through careful layout of the power plant buildings and landscaping once the construction phase is over. Applying good architectural principles in the design and layout of the power plant facility is also important in order to ensure that it falls in with the surroundings in the best possible way.

d) Disposal of waste: The waste that accumulates is normal construction waste, like waste timber, lubricant spill, cleaning fluid waste, metallic waste, packing, cement etc.

The contractors involved in the construction and equipment installation should be provided with a storage area for their equipment and the location of the nearest approved waste disposal areas should be given, see figure 7. They should then be made responsible by contract to observe environmental rules of conduct specified by the plant owner and clean up their own waste when their work is done. A description and monitoring of such procedures should be a part of an HSE management program for the development.

Figure 7 Geothermal power plant construction site (Hellisheidi, 303 MW power and 133 MW heat).

1.4 Power plant commissioning and operation

The predominant environmental concerns encountered during this work phase are:

a) *Emission and injection of geothermal fluids*
b) *Emission of geothermal gases*
c) *Noise*

These effects are all temporary during the operation of the plant. Associated environmental risks are quite insignificant.

a) Emission and injection of geothermal fluids: During operation it is necessary to prevent and avoid scaling in the system (pipes, mechanical equipment…etc.). The usual method for avoiding scaling is to add inhibitor chemicals to the fluid which could cause environmental risks to the geological environment. For mitigation of this risk thermodynamic scaling control could be applied where possible since the risk of pollution is negligible in this case. Where thermodynamic scaling control is not possible the chemical inhibitor should be chosen with great care considering the environment. The emission of geothermal fluids and subsequent potential risk of pollution is only related to surface effects, since in any case it is strictly required to avoid any contact with groundwater and wells are always cased to prevent effect to water bearing layers.

Injection of geothermal fluids can lead to induced seismicity and property damage. Procedures for responding to reports of induced seismicity and evaluation of property damage should be included in an HSE management program.

b) Gases and hazardous emissions to the atmosphere: Hydrogen sulfide (H_2S) remains the pollutant generally considered to be of greatest concern for the geothermal community. For instance Hellisheidi geothermal power plant (303 MW_e) in Iceland emits around 16,000 t/year H_2S. The concern is due to its effect on the general public through odor pollution even when it is in quantities insufficient for chemical pollution. This can be mitigated through information and good public relations. When this is not enough, specific abatement equipment may be added to the plant to capture and treat chemicals, and to re-inject them together with the rest of the fluid. In Italy, for example, abatement equipment are installed to power plants to capture and reinject mercury (Hg) and hydrogen sulfide (H_2S), with an abatement rate of 94.7% and 98.9%, respectively. Drift eliminators may also be installed in the cooling towers to catch the condensed fluids (drift) and reduced emitted drift, therefore the chemicals, boric acid and arsenic. Note that binary plants and EGS power plants do not emit hydrogen sulfide when operating a closed loop for the geothermal fluid.

Another pollutant release through ventilation into the atmosphere is CO_2 gas from the fluid through the de-gassing of the geothermal fluid before re-injection. The quantities are very small if any for binary plants. The quantities of CO_2 emission from flash geothermal power plants can be high, since the high enthalpy fluids may have natural content of this gas. The amount of CO_2 in a geothermal plant is, in any case, much lower than the corresponding (for comparable power production) fossil fuel plant. The capture of CO_2 has a very high cost, so that it is not common practice to include it in a plant. In some cases, such as in Turkey, the CO_2 is captured, cleaned and then used for producing soda water.

Other gases emitted from geothermal facilities to the atmosphere are methane (CH_4) and nitrogen oxides (NO) but in considerably small quantities.

Designing the geothermal power plant and associated facilities in such a way, so that there are zero steam emissions (with the exception of steam escaping from bursting safety valves), effectively minimizes air pollution from the geothermal installation. Non condensable gases from the steam turbine, should be either treated as mentioned above, or conveyed to the cooling tower for dilution with large air quantities, so that their concentration in the air is below the ones allowed by environmental protection legislation.

Table 1 gives an example of emission from various power plants.

Table 1 Gaseous emission from various power plants[4].

Plant type	CO_2 Kg/MWh	SO_2 kg/MWh	NO_x kg/MWh	Particulates kg/MWh
Coal-fired	994	4.71	1.955	1.012
Oil-fired	758	5.44	1.814	N.A
Gas-fired	550	0.0998	1.343	0.0635
Geothermal-flash-steam, liquid dominated-USA	27.2	0.1588	0	0
Geothermal-The Geysers dry steam field-USA	40.3	0.000098	0.000458	negligible
Geothermal-closed-loop binary/EGS	0	0	0	negligible
Geothermal-flash steam-Hellisheidi-Iceland[5]	21.6	17.6*	0	0
Geothermal-flash steam-Tuscany-Italy[6]	324	1.65	-	-
Average. All European plants[7]	369.7	1.1	0.5	0.1[8]

*Assuming 100% conversion of H_2S to SO_2.

Care must be taken in ventilation of all enclosed spaces where there is risk of hydrogen sulfide (H_2S) gas.

In the case of a power plant operating an Organic Rankine Cycle (ORC) plant there is the binary working fluid to consider. The binary working fluid is a low boiling temperature organic fluid, often isopentane. The binary fluid does not pose danger to the environment though it is poisonous to humans in high concentrations and within closed spaces. Isopentane is an inflammable liquid.

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[4] Massachusetts Institute of Technology, 2006. *The future of geothermal energy. Impact of enhanced geothermal systems (EGS) of the United States in the 21 st century*.

[5] http://www.or.is/media/PDF/ORK_59142_UMHVERFISSKYRSLA_2011_O_PRINT_web.pdf. (Environment report of Reykjavik Energy company from 2011.)

[6] http://www.enel.com/it-IT/doc/report2011/Rapporto_ambientale2011.pdf. (Environmental report of Enel company from 2011).

[7] All gases, numbers from 2009: http://www.eurelectric.org/media/44323/powerstats2010synopsis_final-2010-180-0002-01-e.pdf

[8] Numbers from 2001: http://ec.europa.eu/environment/archives/cafe/activities/pdf/case_study4.pdf

Care must be taken in ventilation of all enclosed spaces where the organic fluid has access, and fire control measures must be adequate to meet such emergencies. The amount of CO_2 released into the atmosphere from binary plants in geothermal industry is very small and there are no known economically viable countermeasures.

Geothermal energy from EGS systems comes from the heat of radioactive rock deep down in the earth. Unlike nuclear power plants, geothermal wells produce no dangerous radioactive waste that needs to be transported and stored. Regular monitoring is needed to ensure that levels will not reach limits.

c) Noise: The equipment noise levels in binary plants are generally somewhat higher than in flash-steam power plants. Noise levels of 85-90 dB are common.

The risk of serious noise impacts from geothermal power facilities is rather small. The only financially viable and reasonably effective countermeasure against noise is through appropriate sound insulation. That can be done by using sound insulation on the machines that emit high sound levels. The plant control room where the continuous presence of operators is necessary should be especially sound proved. Adequate ear protectors should always be made available to the staff. Exposure to high levels of noise should also be taken into account when setting up work schedules for the staff. That might require additional sound barriers, like trees being planted at strategic locations etc. where permanent domiciles (farms, businesses, etc.) are located in the vicinity.

1.5 Decommissioning of facilities

The predominant environmental concerns encountered during the decommissioning phase are:

a) Chemical pollution and disposal of hazardous and other waste
b) Surface disruption

a) Chemical pollution and disposal of hazardous and other waste: Chemical pollution is a potential risk when the binary power plant is emptied of its binary working fluid. The main risks are fire hazard and poisonous effects in enclosed spaces. Great care should be taken in the cleanup of such substances and they must only be carried away for dumping or other use in tankers approved for transportation of such fluids. They must also not be allowed to egress into the ground or be released into the atmosphere. Other waste materials can be surplus chemical inhibitors, tracer materials, chemical reagents etc. These must all be removed and disposed of in an approved manner. Both production and injection wells pose a risk to the ground water if they are out of operation for a long period of time. Corrosion may cause damage to the wells, leakage to the surface of hot fluid and steam may occur and leak into the groundwater. It is also a potential danger to humans and animals. They should therefore be properly plugged and closed up.

b) Surface disruption: Surface disruptions always accompany decommissioning of facilities. Proper care, efficient clean-up procedures and careful landscaping should serve to prevent permanent scarring of the location.

2 Overview of environmental impacts and mitigation measures

Table 2 Summary of the possible impact of geothermal projects with regard to different development stages

Development stages	Impacts to be considered	Possible mitigation measures
Access roads, pipe laying	Main anticipated impacts are caused by **surface disturbance, disposal of waste and visual impact.** Except for the visual impact, these effects are mostly temporary since they largely disappear once this construction phase is finished.	Any permanent damage as such can be minimized with proper care, such as avoiding ecologically sensitive areas, locations of historical value and natural beauty. To minimize visual impact of the wellheads, it is recommended that each wellhead should be enclosed in a small building of a design that falls well in with the surroundings.
Well repair, well stimulation, well drilling and testing phase	The predominant environmental concerns encountered during this work phase are **liquid and liquid carried** pollutant release, **noise and vibration**, **induced seismicity**, **solid waste, surface release of geothermal fluid**, **surface disturbance** and **visual impact**.	Important to select only contractor(s) that have good environmental record. State in contract requirements on special waste ponds. With regard to noise impact, workers will need to apply hearing protections. Noise barriers will need to be erected if residential areas are being affected. Surface disturbance and visual impact can be minimised if care is taken during construction and careful landscaping once the work is finished. Also important to avoid ecologically sensitive areas where possible. Prior to EGS activities, the Project Owner will need to implement the Protocol for Induced Seismicity Associated with Geothermal Systems.

Development stages	Impacts to be considered	Possible mitigation measures

Plant construction and equipment installation	The predominant environmental concerns encountered during this work phase are **surface disturbance**, **noise**, **visual impact** and **disposal of waste**.	The impact can be minimized through careful siting of the plant, avoiding ecologically and historically sensitive areas. To minimize visual impact it is important to apply good architectural principles in the design and layout of facilities.
Power plant commissioning and operation	The predominant environmental concerns encountered during this work phase are **emission** and **injection of geothermal fluids**, **gases** and **noise**. Air emission from binary plants is minimal but flash plants for conventional use, emit some amount of hydrogen sulfide (H_2S) and carbon dioxide (CO_2).	To minimize the number of hazardous substances in the geothermal fluid return stream it is recommended to consider thermodynamic scaling control rather than inhibitors where possible. The geothermal plant should be designed avoiding any steam releases to the atmosphere. Non condensable gases should be either treated or diluted with large air quantities at the cooling tower. For mitigation of emission of H_2S from flash geothermal power plants it is important to monitor the release and apply appropriate measures if emission numbers are above environmental limits. Ventilation should be applied to avoid gases in confined spaces. In terms of mitigation for noise, adequate ear protectors should always be made available to the staff. Additional sound barriers, like trees being planted at strategic locations etc., could be required where permanent domiciles (farms, businesses, etc.) are located in the vicinity.
Decommissioning of facilities	The predominant environmental concerns encountered during the decommissioning phase are **chemical pollution and disposal of hazardous and other waste** and **surface disruption**.	In general proper care should be taken when disposing of chemicals, during cleaning up of equipment and in landscaping during this project phase.