National Research Council of Italy

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Environmental and social aspects of Geothermal energy

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The Concept of Sustainable Development

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

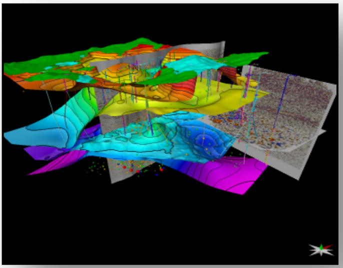
1. the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
2. the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs

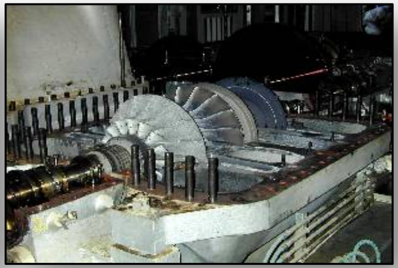
(from World Commission on Environment and Development, Our Common Future, 1987)

Environmental Impact

Most stages of development of a geothermal project potentially produce an impact on the environment

RESOURCES ASSESSMENT → WELL DRILLING AND TESTING → POWER DESIGN AND CONSTRUCTION → OPERATION AND MAINTENANCE → DECOMMITIONING




Environmental impact assessment, mitigation and monitoring

Environmental Impacts Assessment

EIA is the assessment of the possible impact (positive or negative) that a proposed project may have on the environment, together consisting of the natural, social and economic aspects.

Environmental Impacts Assessment

Power (mainly) and heat production from geothermal resources may have an impact on any environmental matrix (air, water, ground, ecosystems).

The potential impacts are:

surface-visual effects (land use, landscape, flora and fauna);

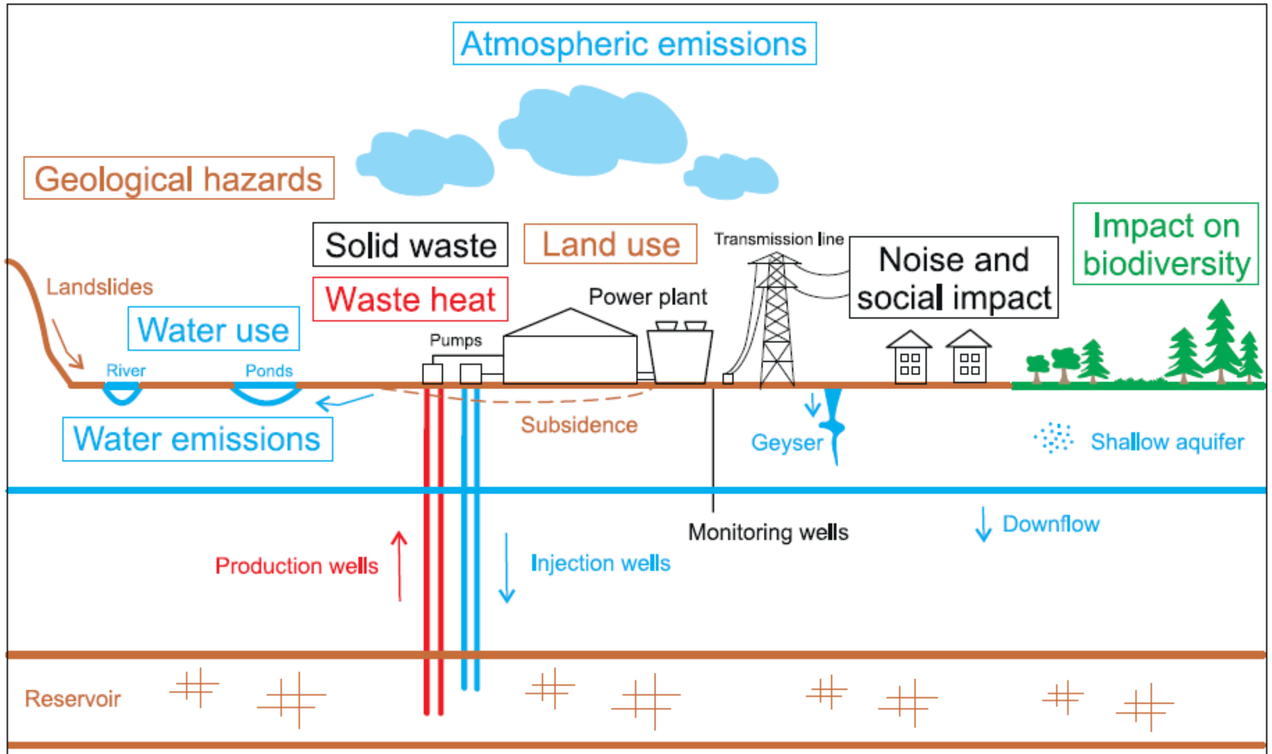
physical effects (induced seismicity, subsidence, geological hazards);

acoustic effects (noise during drilling, construction and management);

thermal effects (release of steam in the air, ground heating and cooling for fluid withdrawal or injection).

chemical effects (gaseous emissions into the atmosphere, re-injection of fluids, disposal of liquid and solid waste).

Environmental Impacts Assessment



(from Bayer et al., (2013) Renewable and Sustainable Energy Reviews)

Potential environmental impacts related to geothermal electricity production

Atmospheric emissions

Sources:

- Geyser, fumaroles, diffuse emissions
- Wells (during well testing operation)
- Power plants

High temperature geothermal fluid average composition

Water *85-98%*

Non-condensable gas *2-15%*

Particulate *0-traces*

CO_2 95%

H_2S 1%

CH_4 1%

H_2 2%

N_2 1%

O_2, Ar, He, CO, Hydrocarbons, Hg, As, B, Rd 0-traces

Atmospheric emissions

Low temperature geothermal resources have no emissions

The gaseous concentration in geothermal ***steam*** vary greatly depending on the ***characteristics of the geothermal system***, its geology (water-rock interaction, magmatic source) and is usually higher in high temperature systems (high installed capacity).

The degree of dispersion of the gases in the environment around a geothermal power plant depends on ***climatic conditions***, the ***orography***, the characteristics of the emission point (in particular the ***height above the ground***) and from ***physical-chemical properties of the contaminant***

Atmospheric emissions

Geothermal fluids (***steam or hot water***) usually contain CO_2, H_2S, NH_3, CH_4, and traces of other gases dissolved.

CO_2, ***Hg***, and ***H_2S***, being slightly soluble in water, may become important constituents of the non-condensable fraction and be released into the atmosphere.

In the production of geothermal energy, which does not provide combustion processes, there is no formation of species NO_x, SO_2 and primary particles (PM10).

Atmospheric emissions

Air emission from binary plant is absolutely negligible, but flash plants for conventional use emit some amount of hydrogen sulfide (H_2S) and carbon dioxide (CO_2). The amount emitted into the atmosphere is much lower than the fuel sources, in particular as regards the CO_2 as seen in the following tables.

g/kWh net	NO_X	SO_2	PM	H_2S	CO_2
Fossil fuels	**0.43**	**0.37**	**0.008**	**0**	**836**
Geothermal	**0**	**0**	**0**	**2,04 in 2009 1.2 in 2013**	**375 in 2009 325 in 2013**

(from ENVIRONMENTAL REPORT ENEL, 2013)

Atmospheric emissions

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kg/MWhe	CO_2	SO_2	NO_x	PM
Coal	1012.05	8.50	0.017	0.33
Natural gas	510.75	0.0019	0.0077	0.054
Flash steam	178.65	0.16	0	NA
Dry steam	27	10^{-4}	0	NA
Dry steam - The Geysers	40	0.000098	0.00046	Negligable
Binary cycle	0	0	0	0

From GEA (2012)

Atmospheric emissions

(g/MWhe)	Min - Italy	Max - Italy	other countries
	in atmosphere		
As	0.011 [1]	0.029 [1]	
Hg	0.18 [1]	1.18 [1]	
	0.06 [2]	0.8 [2]	
NH_3	570 [1]	5300 [1]	
H_2S	1100 [1]	3200 [1]	85 - USA [a]
	300 [2]	12000 (2^{nd} highest value: 3200) [2]	6960 - Iceland [b]
CH_4	0,0013 [1]	0,006 [1]	0,75 – USA [a]
			0,85 – New Zealand [b]
	in Drift		
H_3BO_3	52 [1]	55 [1]	
As	2.7 [1]	8.1 [1]	
Hg	7×10^{-5} [1]	8×10^{-4} [1]	
NH_3	21 [1]	100 [1]	60 [a]
total drift	20.2 liters/MWhe [1]	44.3 liters/MWhe [1]	

From: (1) Regione Toscana (2010); (2) ARPAT, 2013); (a) Bloomfield (2003); (b) Saving, Iceland (2012)

:PORT ENEL, 2013)

Atmospheric emissions

Mitigation measures:

- *define environmental threshold of pollutants*
- *emission recording*
- *if emission contain critical elements ➔ monitoring (proper location and timing of recording tools)*
- *if values of critical emission > environmental limits (defined by regional, national or international rules or indications) ➔ abatement systems (washing, scrubbing). They may be located before (upstream) or after (downstream) the turbine, and produce a waste, usually reinjected with the fluid*
- *aereosol and its pollutant, if present, may be abated with Demister*

Atmospheric emissions

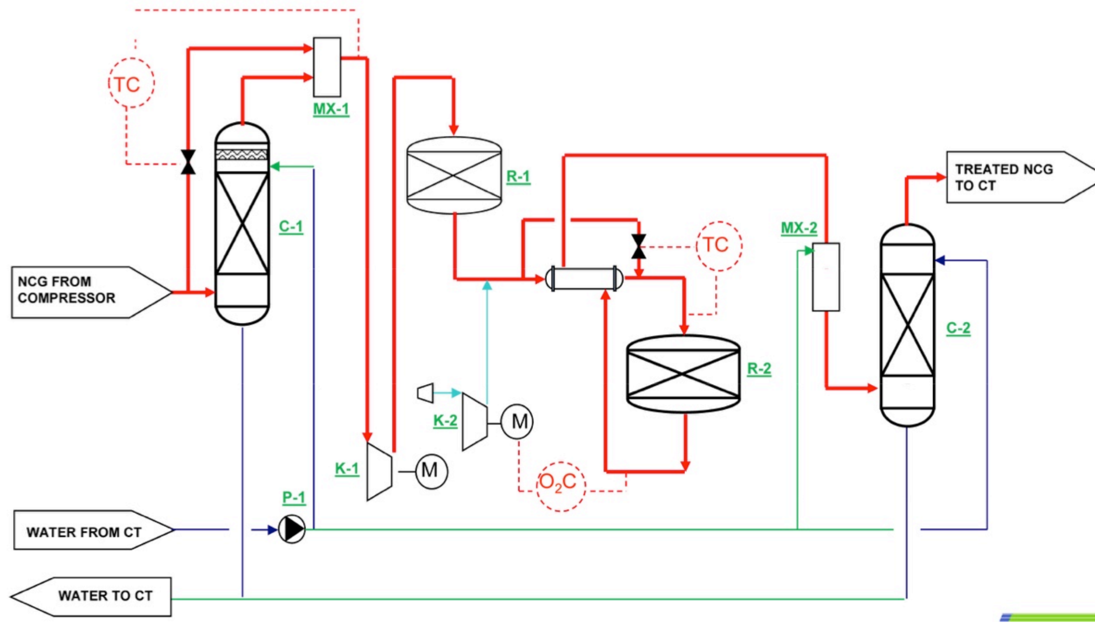
CO_2 emission are not treated, and would require total reinjection and $C0_2$ sequestration technques still to be developed at economic cost.

The null or low CO_2 emission level of the geothermal energy and its natural origin put goethermal sector out of this main discussion.

Atmospheric emissions

In order to abate these emission, Enel Green Power uses the AMIS system, developed and patented by Enel Research, which reduces practically to zero the natural gases and metals associated with geothermal steam. AMIS therefore removes the discomfort caused by the characteristic smell of hydrogen sulphide emissions, facilitating the integration of these plants into the surrounding area.

AMIS (Abatment of H_2S and Hg



The ***AMIS*** system allows:

- 93-94 % reduction of Hg in the NCG;
- 98-99 % reduction of H_2S.

The noise

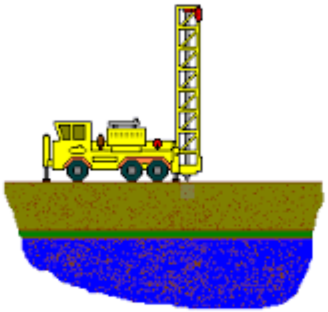
The noise pollution from geothermal plants is generally associated to the following development phases:

- ***Well drilling and testing phase***
- ***Plant construction and equipment installation***
- ***Power plant commissioning and operation***

The intensity of the generated noise depends on the installed capacity and other acoustic parameters. Depending on the type of plant, the noise emitted from these sources may be stationary or floating, alternating peaks of higher intensity.

The noise

1) Well drilling and testing phase



The noise level associated with the drilling rig and from the associated equipment used during this work phase is of the order of 80 to 120 dB(A).

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, about 2 months for medium enthalpy systems and a few days per year for well repair).

The noise

2) Plant construction and equipment installation

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.

The noise

3) Power plant commissioning and operation

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.*

The plant control room where the continuous presence of operators is necessary should be sound proved. Adequate ear protectors should always be made available to the staff. Additional sound barriers, such as trees being planted at strategic locations (in the vicinity of permanent houses, farms etc.) may be required..

Visual impact and land use

The development of a geothermal field inevitably involves the **presence** of **structures** and **components** that determine an alteration of the landscape.

The impact is very variable in the phases that characterize a geothermal project (surface and deep exploration, construction of the plant and production).

The effects are mostly temporary and with very limited effects in the phase of surface exploration.

Deep and lasting effects can be mitigated during the construction and operation of the plant.

Visual impact and land use

- In the **exploration phase**, the impact is due to the removal of vegetation, the preparation of the areas (earthworks, ground movement), the construction and/or adaptation of the access roads, the physical presence of the construction equipment and moving vehicles.



Visual impact and land use

The most significant visual impact during **operation** is determined by the presence of pipelines, power transmission lines and geothermal power plant.

Visual impact and land use

The **pipelines**, which allow the transport of the geothermal fluid from the well to the power plant, have a diameter of 150-800 mm, above the ground through appropriate supports, can be visible even at considerable distances. The height from the ground, varying between 50 cm and 5 m, is calculated in order to minimize the impact and to ensure appropriate accessibility for the necessary maintenance.

Visual impact and land use

The geothermal **power plant** occupies an area of about 5-10 ha and a maximum height of 18 m with the cooling towers. These large towers generally have an environmental impact quite important from the aesthetic point of view, although far lesser impact of a thermoelectric power plant using fossil fuels.

Technology	**Land use** m^2/MW
110 MW geothermal flash plant (excluding wells)	**1.260**
20 MW geothermal binary plant (excluding wells)	**1.415**
49 MW geothermal FCRC, Flash-Crystallizer/Reactor-Clarifier plant	**2.290**
(excluding wells)	40.000
2258 MW coal plant (including strip mining)	10.000
670 MW nuclear plant (plant site only)	1.200.000
47 MW solar thermal plant (Mojave Desert, CA)	28.000
10 MW solar PV plant (Southwestern U.S.)	66.000

Visual impact and land use

Hints to minimize visual impact:

- *avoid tourist areas of particular natural beauty, locations of historical value, ecologically sensitive areas;*
- *apply good architectural principles in the design and layout of facilities;*
- *enclose the wellheads in small structures integrated well with the surroundings;*
- *prefer areas with tall trees that mitigate the visual impact;*
- *use reforestation with native plant species type, to supplement the existing, in order to restore the environment;*

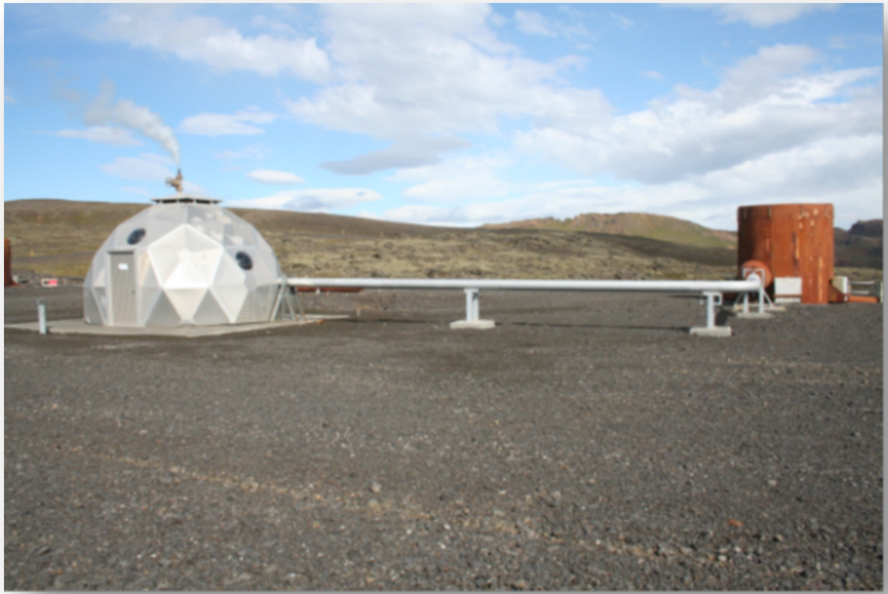
Visual impact and land use

Hints to minimize visual impact:

- *paint the pipelines green and brown (to camouflage with the ground);*
- *prefer linear pipelines, where possible;*
- *underground the power transmission lines, except in wooded areas (to limit the deforestation).*

Visual impact and land use

Some example…..



Hellisheidi:
Enclosed wellhead(from Geoelec, 2013)

Ahuachapan:

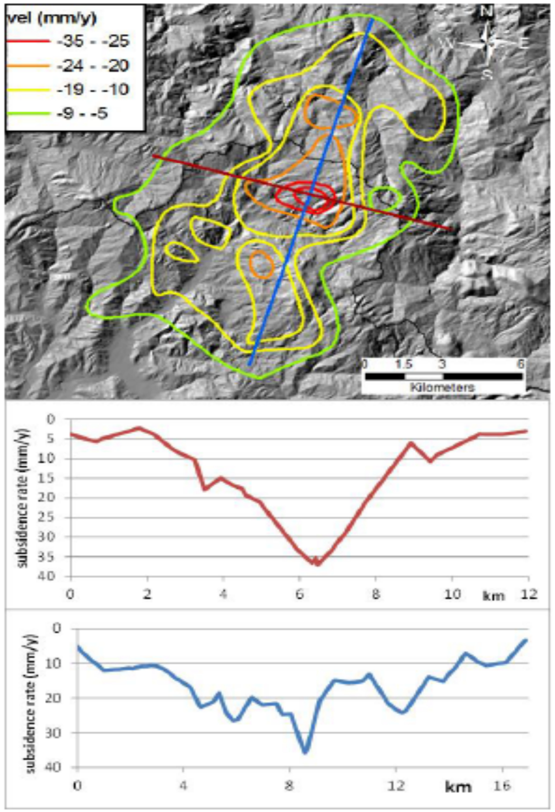
a) *impianto geotermico nel 1977 (Di Pippo, 1978)*
b) *dopo la rivegetazione nel 2005 (LaGeo, 2005)*

Subsidence

Subsidence is a phenomenon of vertical lowering of the land surface that **can *be caused by natural processes*** such as plate tectonics and volcanic eruptions, ***or induced by human activities*** such as the extraction of fluid or gas from underground mining.

The production of geothermal energy involves, especially in liquid dominated systems, the extraction of large amount of fluid from the soil. The extraction of the fluid induces a variation of the stress field in the reservoir (decrease in interstitial pressure and increase of the effective stress) with consequent deformation of the rock formation. Such deformation may transfer to the surface generating the vertical movements and/or horizontal soil.

Surface deformations can cause damage not only to facilities and infrastructure but to homes, if present in the vicinity of the field.



Larderello:
25-35 mm/a
(Rosi e Agostini, 2013)

Subsidence

Subsidence phenomena are well documented in various geothermal areas in the world, such as Wairakei in New Zealand, Cerro Prieto in Mexico, The Geysers in the United States, Larderello and Travale in Italy.

Although, the areal extent and the temporal evolution of these phenomena is influenced by the local geological features, the type of geothermal field and its management, usually the subsidence zones show good correlation with the areas of greatest exploitation.

Geothermal field	Country	Time interval	Max subsidence (m)	Max rates (mm/a)	References
Wairakei	New Zeland	1955-1998	15	480	Allis, 2000
The Geysers	New Zeland	1977-1996	0,90	47	Massop e Segall, 1997
Larderello	Italy	1923-1986	1,7	26	Dini e Rossi, 1990
		1986-1993	0,085	12	Dini et.al., 1995
Travale	Italy	1973-2003	0,50	23	Ciulli et.al., 2005
Cerro Prieto	Mexico	1994-1997	0,50	120	Glowacka et.al., 2000

Subsidence

The main actions required to mitigate the effects of subsidence in the geothermal fields are essentially three:

1) prediction

2) monitoring

3) control and prevention

Subsidence

1) **Prediction**: numerical modeling of the reservoir is a powerful tool for estimating the potential and the sustainability of a geothermal system (Axelsson, 2010). By modeling the reservoir is possible to make a long-term forecast on geothermal potential and identify the best management strategies and development, both technological and environmental;

2) **Monitoring*:*** the subsidence can be mapped continuously by monitoring the spatial and temporal evolution of surface deformation. Main techniques are:

   - ***Leveling***
   - ***GPS survey***
   - ***InSAR techniques***

Subsidence

3) Control and prevention*:* mitigation of the process can be achieved by injecting spent geothermal fluids back into reservoirs. Although reinjection does not guarantee to avoid subsidence, it reduces the risk, provided it is carried out so as to maintain reservoir fluid pressure.

This technique is practiced in many geothermal fields of the world (Stefansson, 1997) and is becoming an integral part of all modern, sustainable and environmentally friendly geothermal projects (Axelsson, 2008).

There are various examples of successful programs to re-injection into geothermal systems both at high and at low temperature.

The best example on a long period in a low-temperature geothermal field is the Paris basin in France. For fields at high temperature, a good example is in Costa Rica at Miravalles, where almost all of the extracted fluid is re-injected into the geothermal reservoir of origin, from the beginning of its use (Axelsson, 2008).

Liquid and solid waste

During well drilling and plant construction significant amounts of waste materials are produced :

- ***fluids*** (drilling mud and other drilling fluid additives like cement slurry, diesel and lubricant leakages, lubricant spill, cleaning fluid waste);
- ***solids*** (earth and rock excavation, construction wastes, like waste timber, metallic waste, packing, cement);

Generally these wastes are "not dangerous"

Liquid and solid waste

- Mixtures of water, clays and other additives are used during the drilling to control viscosity, the stability of the walls of the borehole, drilling speed, and cooling and lubricating the drill rig;
- Earth, rocks and debris are produced during the progress of the drilling.

Liquid and solid waste

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.

Normally, the waste management on site is done through the setting up of temporary bins to contain all waste materials. These, during the drilling phases, are then conveyed in the waste containment.

Liquid and solid waste

Short-term and/or emergency liquid releases will have to be accommodated in a special holding tank or a holding pond. 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.

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 provided.

Water pollution

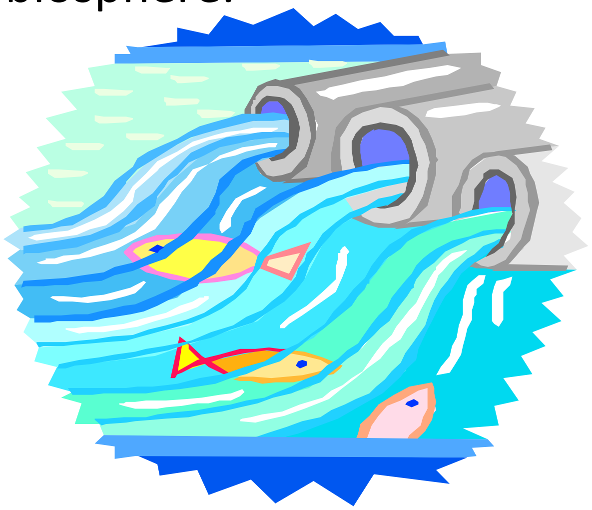
There are several places where geothermal fluids may enter the environment during field development or standard operation. Since these fluids may contain minerals and elements harmful to humans, flora, or fauna, and they may poison surface or groundwaters, plant designers are required to provide ***barriers*** to prevent these fluids from entering the biosphere.

The risk is mainly connected to the phases of:

Drilling well

Extraction

Reinjection



Water pollution

Recommended measures to prevent and control impacts include:

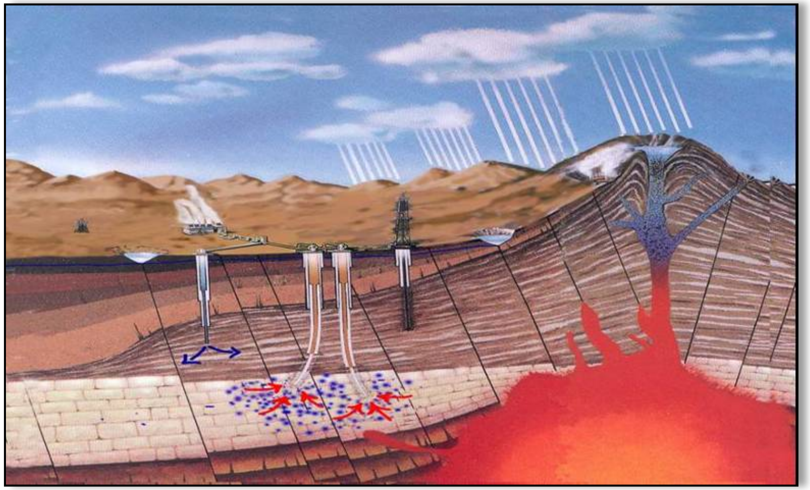
- *fluids discharging during well testing must be stored in impermeable holding ponds;*
- *steam pipelines are fitted with traps to remove condensate and that liquid must be sent by pipelines to holding ponds. Later the collected fluids are reinjected deep underground;*
- *it is prudent to have monitoring wells strategically located in the well field to rapidly detect any problems with subsurface leakage and permit prompt remediation;*

Water pollution

- *avoiding negative impacts on surface water by following strict discharge criteria and appropriate means to bring water quality and temperature to acceptable standards*

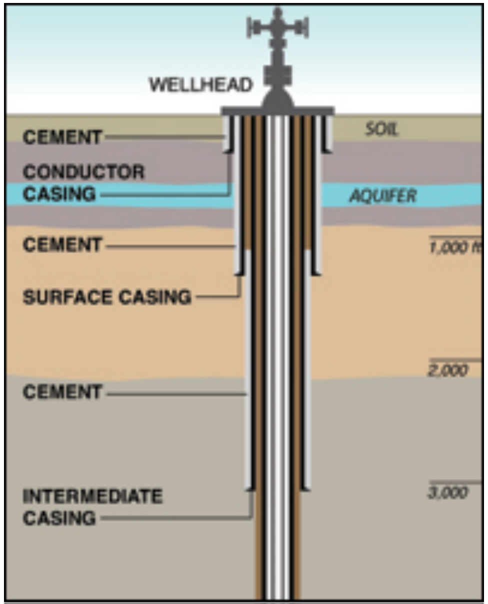
Water pollution

The **extraction, reinjection,** and **discharge** of geothermal fluids may affect both the **quality** and **quantity** of surface and groundwater resources. Specific impacts include:



- the inadvertent introduction of geothermal fluids at surface or well leakage at intermediate underground levels during extraction and/or reinjection activities;

Water pollution



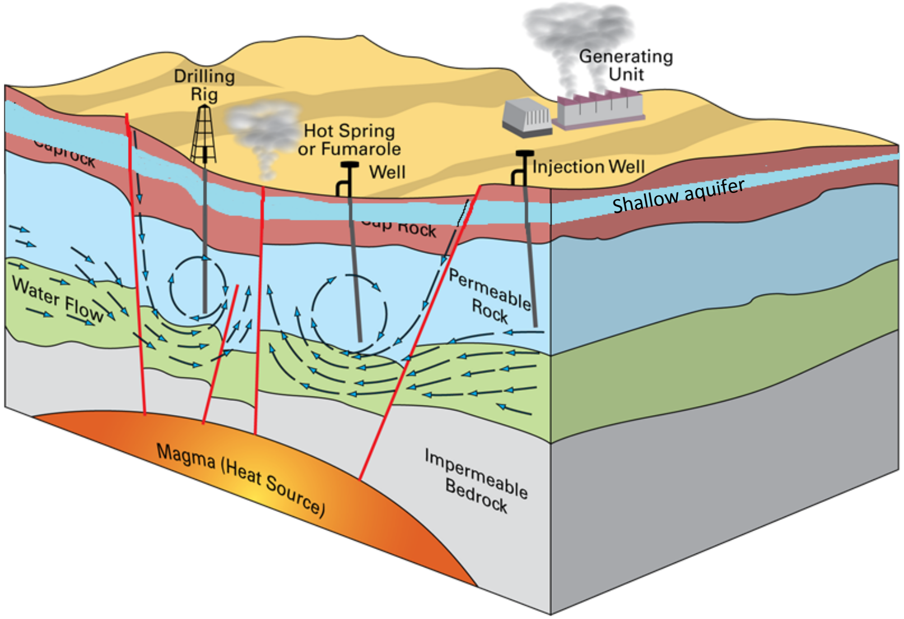
*The **well casing** is the first barrier against pollution of groundwaters. Damaged casings may allow brines to mingle with fresh water aquifers. Therefore, particular care is taken to install and cement multiple casings at shallow depths to provide extra barriers. Cement-bond logs (integrity tests) are performed to assure the driller that there are no blind spots behind the casing that could rupture under thermal stress caused by repeated opening and closing of the well.*

Water pollution

Recommended measures to prevent and control these impacts also include:

- *Elaboration of a comprehensive geological and hydrogeological model including overall geological, structural and tectonic architecture, reservoir size, boundaries, geotechnical and hydraulic host rock properties;*

- *Completion of a hydrogeologic and water balance assessment during the project planning stage to identify hydraulic interconnections between the geothermal extraction and reinjection points and any sources of drinkable water or surface water features;*

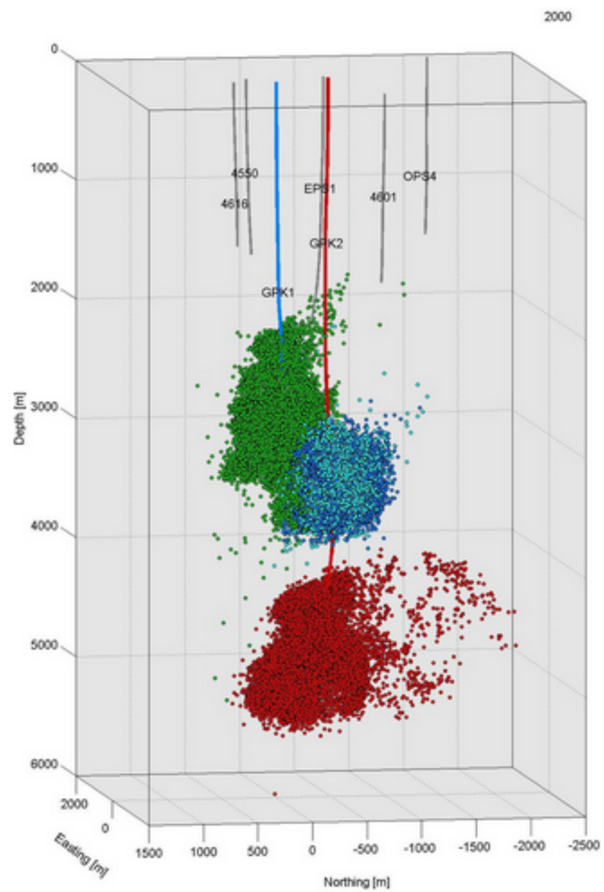


Induced seismicity

It is a phenomenon in which a change in fluid pressure within a stressed rock formation leads to movement of the fractured rocks. The energy released is transmitted through the rock and may reach the surface with enough intensity to be heard or felt by persons in the area.

Injection of fluids in the underground induces seismic activity. The likelihood and the severity of the event depend on the local state of stress within the formation, geomechanical characteristics of the geological formations and the injection pressure.

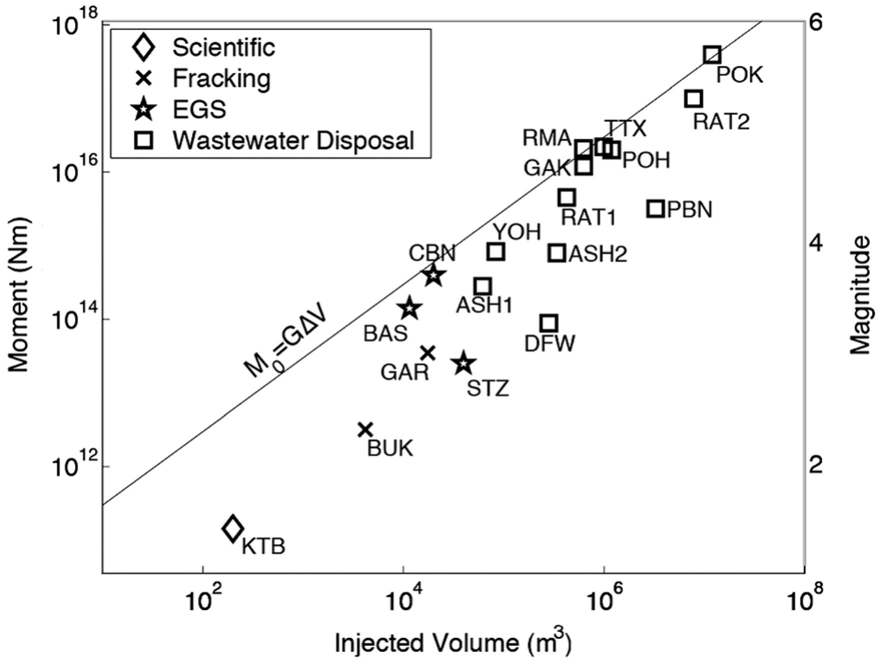
Normal operation produces microseismic activity (low magnitude events), at no risk



Induced seismicity

Observed induced seismicity:

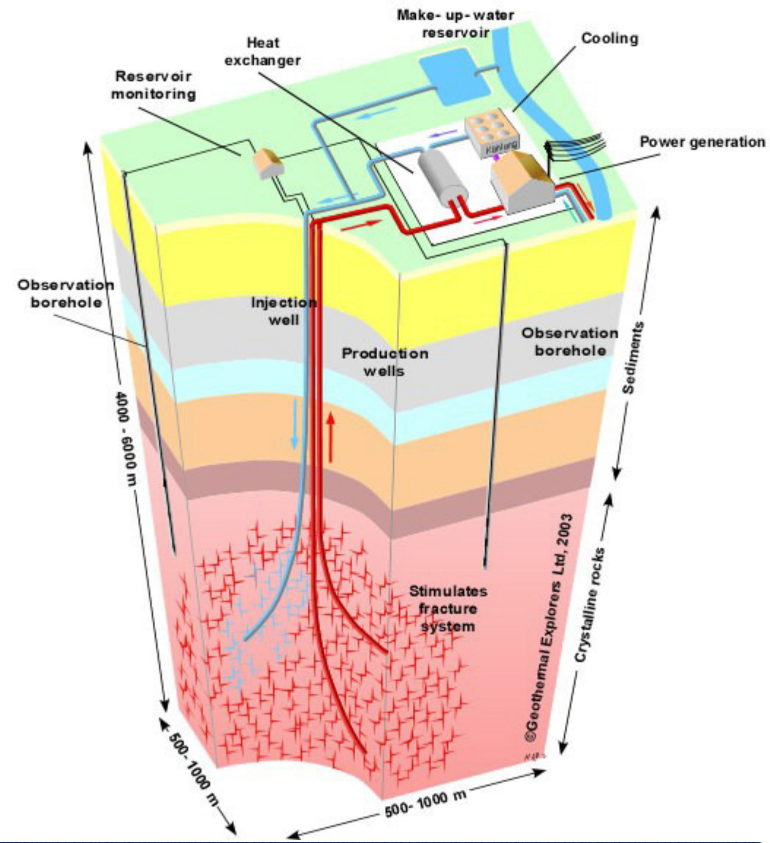
- first filling hydroelectric station reservoirs;
- during extraction from oil and gas fields, especially using fracking techniques;
- underground fluid injection at high pressure (EGS and scientific experiment)



February 2014 paper by Art McGarr, courtesy of Andy Jupe

Induced seismicity

In a normal hydrothermal system this has not been a problem since high pressures are not needed for the reinjection of residual brines. This may be a more important problem development and production of ***EGS*** where high pressure water, through the classic technology of hydraulic fracturing, is pumped in the wells.



Induced seismicity

Since it is often difficult to discern natural from induced seismic events:

- *it is wise to collect baseline data prior to field development and drilling at a selected site;*
- *a thorough scientific study should be carried out before drilling to determine the geologic and tectonic conditions existing at the site. This should provide the data needed to avoid the inadvertent lubrication of a major fault that could cause a significant seismic;*
- *it is useful also to monitor the site for any unexpected natural or induced microseismic events after field work commences;*

Induced seismicity

To reduce the sesmic risk, prior to EGS activities is necessary to implement the Protocol for Induced Seismicity Associated with Geothermal Systems, which includes the following steps:

- *Evaluation of applicable laws and governing regulations*
- *Establish a microseismic monitoring network*
- *Establish a traffic light system (threshold definition, Go-No GO set up)*

Induced seismicity

- *if there are residents in the neighbourhood of the site, an educational program should be put in place to inform people of the possibility, unlikely though it may be, of felt seismic events, and to set up a hotline where they can report such occurrences.*
- *official Procedure for Evaluating Damage and an insurance or damage cost coverage is a good practice. However, it requires transparent rules of application, especially in areas where natural seismic events may occur.*

Induced seismicity

=

x

r i s k =   p r o b a b i l i t y   x   d a m a g e)

When probability is very low (little stress field, low injection pressure) or damage is very low (microearthquake activity) the risk is low

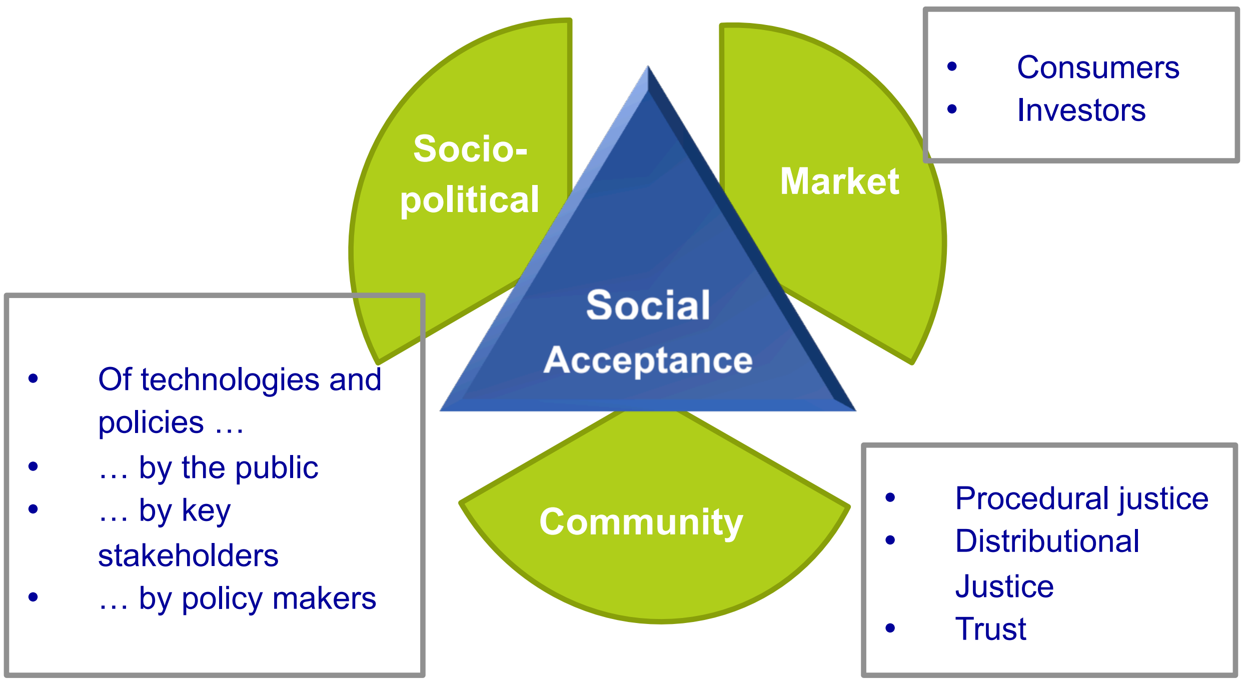
Social acceptance

Renewable energies are often associated with **sustainability or environmental friendliness.**

But renewable energies, like geothermal power, **also have environmental impacts** and have the potential to **cause social resistance.**

Environmental issues are normally negative, which leads to a further investigation of negative acceptance issues.

Social acceptance



Social acceptance of renewable energy innovation (from Wüstenhagen, Wolsink and Bürer 2007)

Social acceptance

Four categories have the potential to cause social resistance:

- Environmental issues
- "Missing-involvement" issues
- Financial issues
- NIMBY issues

Social acceptance

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.

Social acceptance

2) "Missing-involvement" issues:

The so called turnaround in energy policy requires a high adaption effort of the citizens.

Citizens and communal decision makers have to make decisions under time pressure and with only limited or no information on long term consequences of their decisions for or against renewable energies.

Decisions under insecurity can lead to emotional reactions, when citizens feel overstrained and overrun.

Leucht 2012, Cataldi 2001 and Devine-Wright 2007 recommend an involvement of local citizens into project planning and implementation.

Social acceptance

3) *Financial issues:*

People can see investment costs of geothermal power plants as a negative social acceptance issue. Municipalities or municipal undertakings are often involved in geothermal projects.

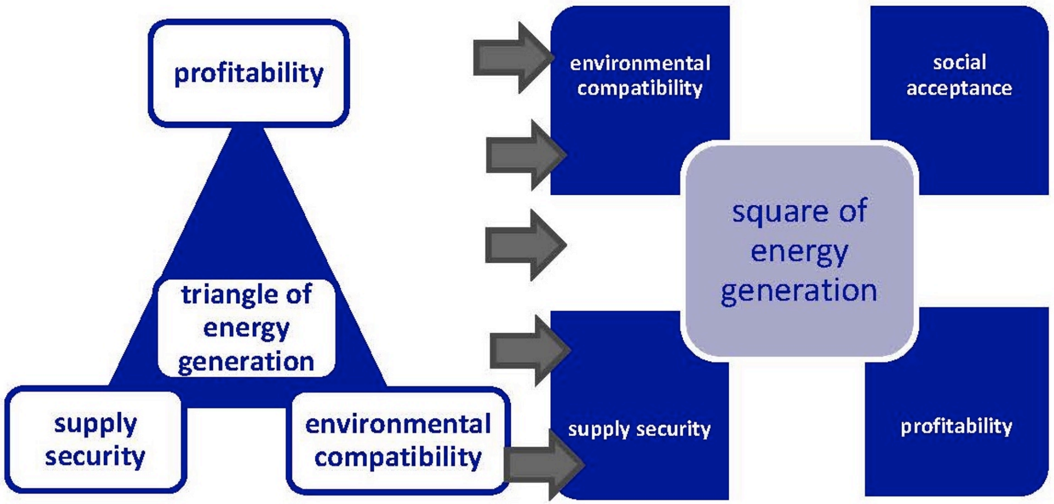
4) *Nimby issues:*

The ***Not-in-my-backyard-issue*** (NIMBY) can be defined as follows:

"The NIMBY syndrome, which arises with any effort to site locally undesirable but socially beneficial facilities" (Richman and Boerner 2006).

So the NIMBY-syndrome describes local resistance against socially beneficial facilities.

Social acceptance



Square/ Triangle of energy generation (from Hauff, et al. 2011)

Social acceptance

The integration of the public and thus social acceptance can be reached through three steps (Hauff, et al. 2011):

- ***Communication and information:***

Affected citizens have to be informed openly and in advance about costs, risks and benefits of a technology.

- ***Integration and involvement***

Additionally one could think about models of direct financial participation in a project or other local benefits like heat supply in case of geothermal power plants.

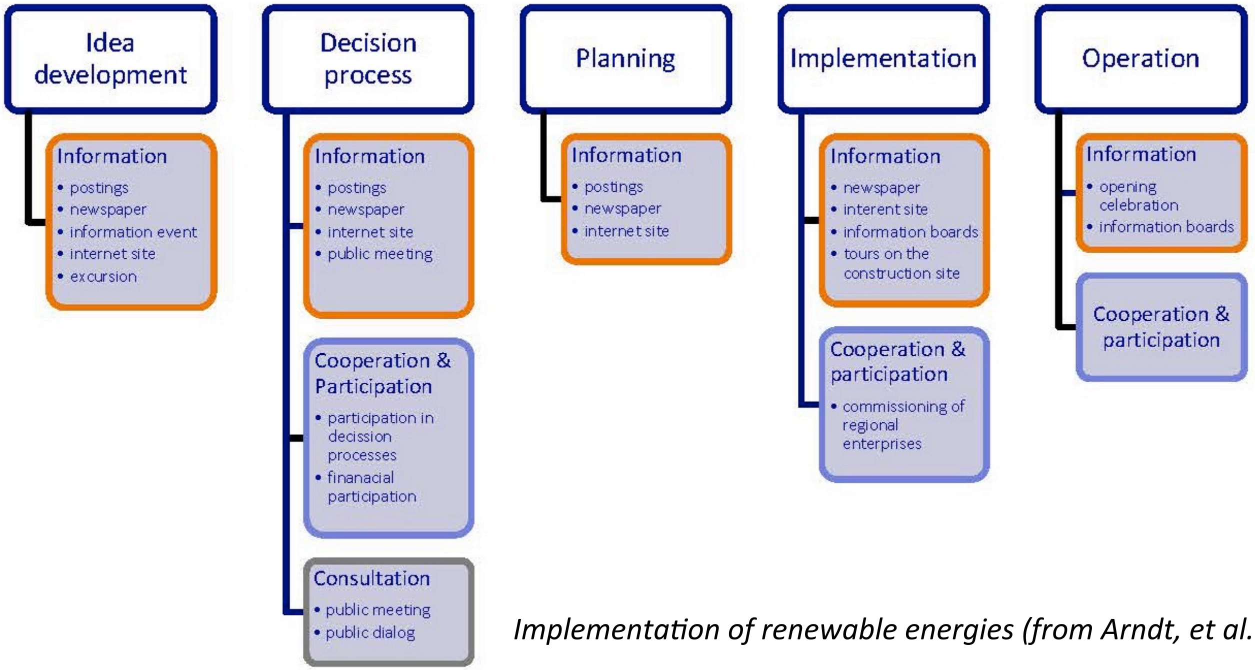
- ***Balance of interests and conflict resolution***

If conflicts occur, the project developer should try to find a dialogue without predefined results.

Social acceptance

the ideal implementation of a project

This diagram shows the different steps of project implementation and the actions that should be taken in social acceptance issues.



Implementation of renewable energies (from Arndt, et al. 2013)

From the beginning the project should be offensively communicated within the public and up to the completion of the power plant, with a ceremonial opening and the visit to the power plant.

Jigokudani Hot Springs – Japan