Zentrum für Technologiefolgen-Abschätzung
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Electric energy from deep below

Abridged version of the TA-SWISS study «Energy from the earth: Deep geothermal as a resource for the future?»

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Stefan Hirschberg, Stefan Wiemer, Peter Burgherr (eds.)

Energy from the earth: Deep geothermal as a resource for the future?

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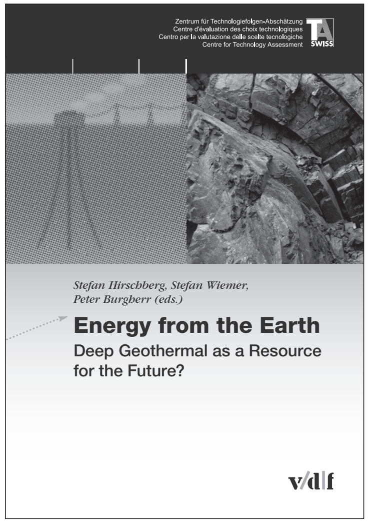

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Deep geothermal energy in a nutshell

Temperatures in rocks lying 4–5 kilometres below the Earth's surface are as high as 150°C. This represents a vast energy resource, with the potential – in principle – to meet Switzerland's electricity and heating needs many times over.

Given the lack of sites in Switzerland where underground reservoirs of hot water could be tapped to produce electricity, deep hot rocks themselves are considered the most promising potential source of geothermal energy. The so-called petrothermal approach, i.e. extraction of heat from rocks, is more commonly known as hot dry rock, deep heat mining or enhanced geothermal systems (EGS).

Opportunities…

Deep geothermal energy is environmentally friendly: it is less material-intensive than other forms of renewable energy and involves minimal emissions of CO_2 – even when plant construction, as well as operation, is taken into account in the assessment of environmental impacts.

Geothermal is one of the few "new" renewable energy sources that is not dependent on weather conditions and can produce reliable supplies of baseload power. This is all the more important in view of the future need to balance intermittent supplies from other renewable sources.

Energy from the Earth's interior could make a significant contribution to the security of supply in Switzerland and reduce the country's reliance on imported energy.

If the heat that is not required for power generation could be sold to operators of district heating networks, the costs of geothermal power would certainly be competitive on the market and could even be lower than the costs of most other renewables.

…and risks

Although a few EGS plants are already in operation, experience is still lacking. Particular challenges are posed by the need to enhance the permeability of the heat reservoir: if hot rock is to serve as a heat exchanger, it has to be fractured by injecting water under high pressure. This process can trigger felt earthquakes.

Because the geological characteristics of the subsurface remain largely unknown, exploration involves financial risks – after extensive investigations, it may turn out that a site is not suitable for commercial exploitation. Efficient development of geothermal resources may also be impeded by differences in cantonal regulations.

While public opinion on this issue is neutral to moderately positive, a certain ambivalence is also apparent, which suggests that attitudes to geothermal energy could rapidly shift.

Key recommendations

Research on the deep subsurface should be intensified. Pilot projects should be used to obtain further experience for the construction and operation of geothermal plants.

Models should be developed to facilitate geothermal projects by coordinating and harmonizing cantonal approval procedures.

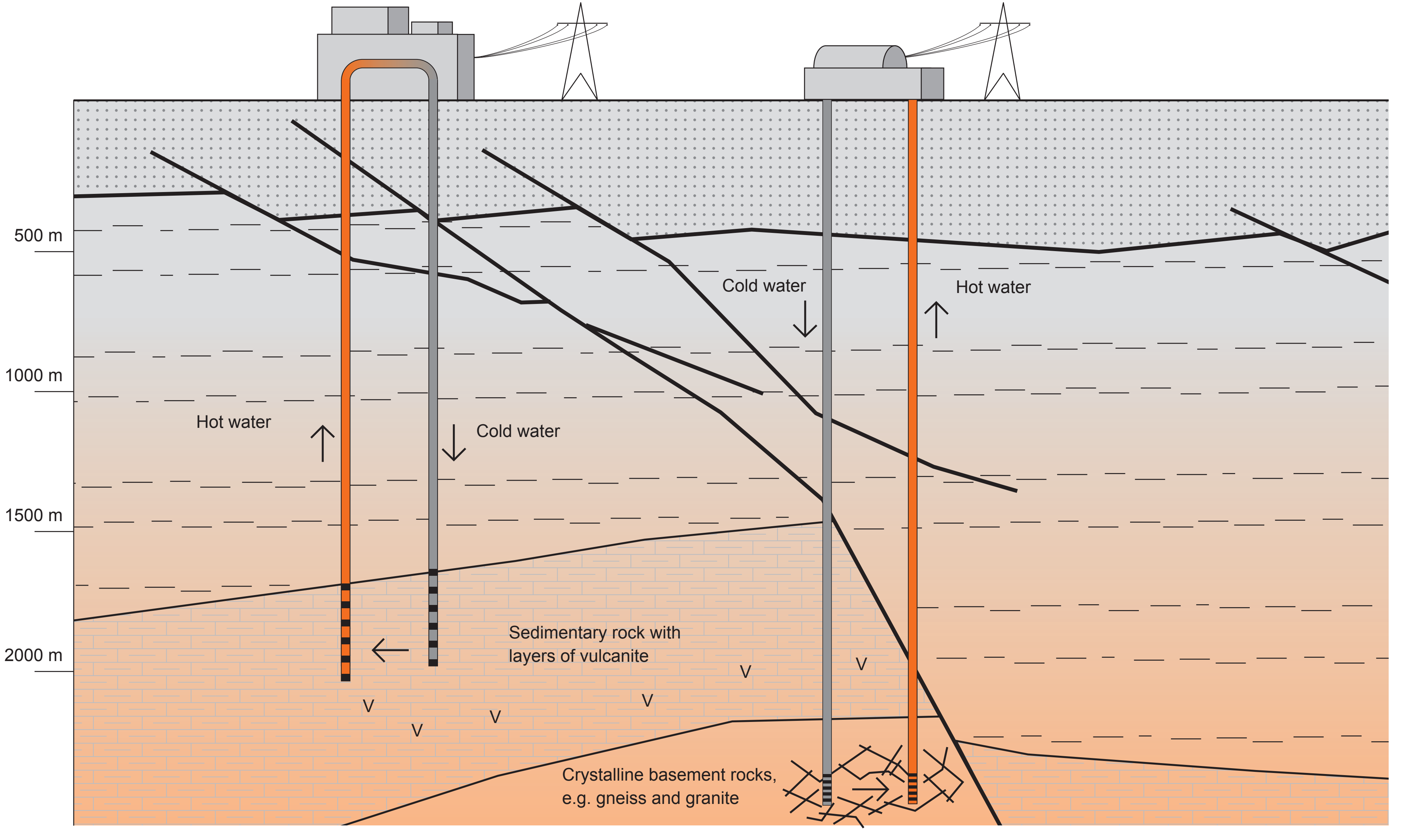
The holders of exploration permits or exploitation licences for geothermal resources could be required to make geological data publicly accessible.

The entire process of planning, siting and implementing geothermal projects should be closely accompanied by a carefully planned, continuously monitored and scrupulously evaluated process of public and stakeholder engagement.

The "Energy from the Earth" project was led by Stefan Hirschberg of the Paul Scherrer Institute (PSI). For this detailed study, which yielded a 450-page report, he coordinated the work of a total of 32 scientists from the PSI, the Federal Institute of Technology in Zurich (ETHZ), the Zurich University of Applied Sciences (ZHAW) and the Dialogik research institute. As well as analysing fundamental geological conditions and the technical, economic and environmental aspects of geothermal energy, the study considers the legal framework and assesses public attitudes to this novel energy resource.

Hydrothermal Systems
Direct-use of geothermal energy (hot water from natural aquifers) for heat generation (>20°C) or power generation (>100°C)

Petrothermal Systems (HDR, EGS)
Extraction of heat and electric power from a stimulated reservoir system, mainly in crystalline basement rock



The blue planet with a fiery core

Throughout history, humans have exploited the Earth's internal heat. But harnessing thermal energy sources which are not readily accessible at the surface calls for major scientific and technological efforts. If the remaining obstacles can be overcome, a virtually inexhaustible resource could become available for clean power generation. Switzerland would then be less reliant on electricity and fuels imported from abroad.

The further one descends below the Earth's surface, the more inhospitable the environment becomes for any form of life. While amoebas and other microorganisms with modest oxygen requirements can still thrive in the soil at depths of 1–2 metres, bedrock is largely barren; at even greater depths, conditions grow increasingly difficult as temperatures rise. It is no accident that, for our ancestors, hell was located in the bowels of the earth.

From a more contemporary perspective, our planet's fiery core holds out the prospect, not of eternal torment, but of a sustainable source of natural heat which could help to meet constantly growing energy demands. The technical term for this type of energy production is geothermal (i.e. utilizing the Earth's heat). From a depth of around 10 metres – where the subsurface is no longer subject to weather-related influences – temperatures increase at a rate of about 3°C per 100 metres. In Switzerland, temperatures of up to 150°C are attained at a depth of 4–5 kilometres. With the technical means available today, this would be sufficient to permit effective operation of geothermal power plants.

A long tradition

People have probably bathed in hot springs since prehistoric times and, as we know from documentary evidence and archaeological finds, natural hot water was used for bathing and for heating buildings both in ancient China and in the Roman Empire. Towards the end of the 19th century, following in the Roman tradition, engineers in the US established the country's first district heating system at Boise, the state capital of Idaho, in 1892: here, water from the nearby Warm Springs wells was used to heat numerous buildings. In the first half of the 20th century, however, engineers seeking to obtain more heat than the Earth would provide of its own accord developed geothermal heat pumps. A system of this kind was first used at Portland, Oregon, in 1946 to supply the newly constructed Equitable Building (now the Commonwealth Building) with heat from a depth of several hundred metres.

The industrial use of geothermal energy has its origins in the Italian province of Pisa. Around 1830, the French nobleman and chemist François de Larderel drilled the world's first geothermal wells at Castelnuovo, which were designed to tap fumaroles (volcanic vents) and hot pools for boric acid production. In 1904, Prince Piero Ginori Conti showed that a dynamo driven by geothermal steam could be used to power five light bulbs. It took another 10 years, however, before geothermal electricity generated at Larderello – as the facility was now called – could be fed into a public network.

In Switzerland, experience to date has been gained primarily with "shallow" geothermal systems. For several decades, in this country as elsewhere, geothermal energy obtained from depths of up to 400 metres has been used to heat growing numbers of homes and public buildings. This direct use of geothermal energy is not, however, covered by the TA-SWISS project. The study summarized here is concerned with deep geothermal systems, i.e. energy obtained from depths of over 400 metres; in this area, experience in Switzerland remains limited. While the study focuses on the generation of electricity, the additional use of waste heat is also addressed.

Water for heat transport

The medium typically used to transport heat from the depths of the Earth to the surface is water. Conventional geothermal plants are located at sites where deep, water-bearing formations are present and the subsurface is sufficiently permeable to allow hot water to be pumped to the surface. The use of naturally occurring hot water reservoirs for geothermal energy is known as the hydrothermal approach. In Switzerland, however, the combination of factors required for this approach is rarely encountered.

An alternative approach involves injecting water into deep hot rocks at high pressure so as to create fractures and construct a heat exchanger over an area of several square kilometres. Water can then be circulated through the hot rock reservoir: cold water pumped underground extracts heat from the fractured rock and the hot water is pumped to the surface again, where it is used to produce energy. The cooled water is then recirculated. This petrothermal approach does not depend on the presence of hot water-bearing formations, nor are permeable geological structures required. All that is needed is underground heat – a potentially unlimited resource. For this reason, experts consider this approach – also known as hot dry rock, deep heat mining or enhanced geothermal systems (EGS) – to be the ultimate goal of the long-term development of Switzerland's geothermal resources. Although the technology is not yet sufficiently mature to be economically viable, the progress made since 2006 in countries such as Germany, France, Australia and the US has been encouraging. In Europe, two EGS sites are currently active – the Gross Schönebeck research platform around 50 kilometres northeast of Berlin (established in 2001) and the geothermal plant located in the Upper Rhine Graben near the Alsatian town of Soultz-sous-Forêt (in operation since 2008).

Initial setbacks

Over the past few years, two Swiss geothermal projects have made front-page news. In July 2013, following the unexpected intrusion of gas into a well at the Sittertobel hydrothermal plant near St Gallen, large volumes of water and drilling mud were pumped into the borehole. This stabilization measure triggered moderate earthquakes (up to a magnitude of 3.5 on the Richter scale). Although the test drilling was subsequently completed, the flow rate was found to be far too low for commercial geothermal use of the 140°C water – a mere 6 litres per second, compared to the required rate of at least 50 litres per second. The gas deposits, however, proved to be surprisingly abundant, and it is currently being evaluated whether these resources could be used over the longer term.

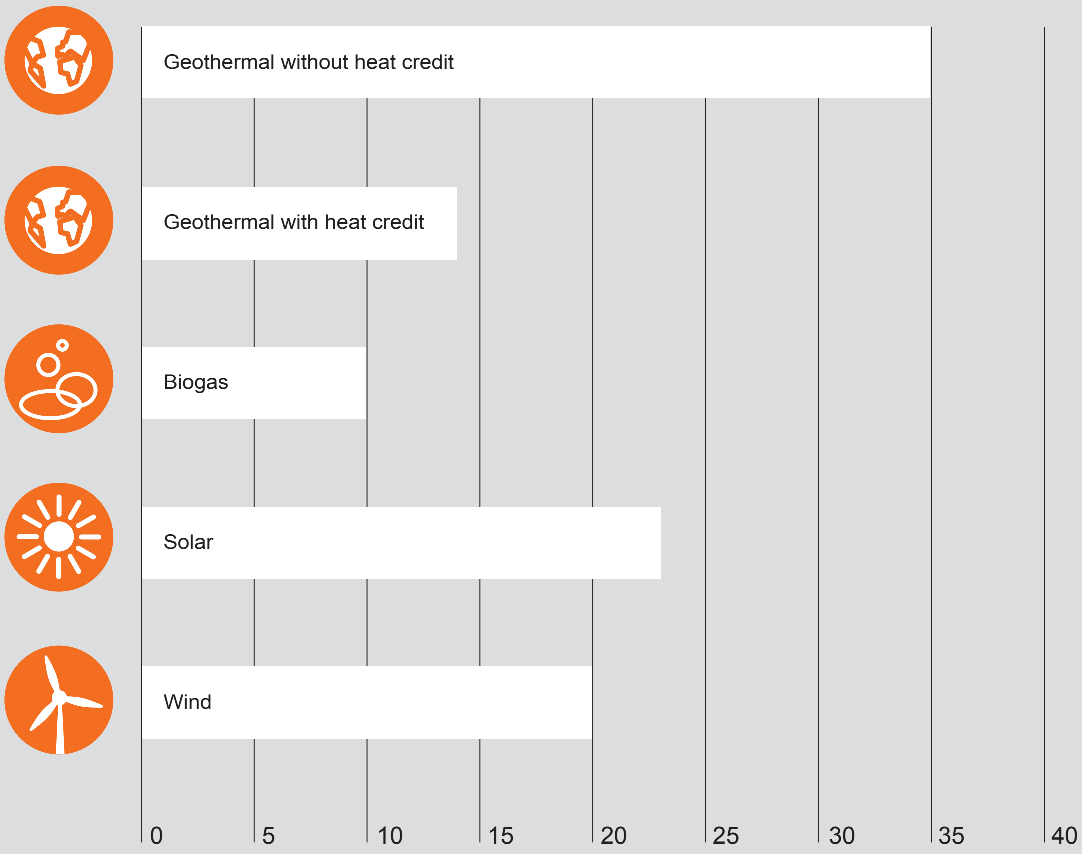
Also commercially unsuccessful was the deep geothermal drilling project initiated in Basel in 2006 – the first ever conducted in Switzerland. The injection of water at high pressure into hot dry rock triggered an earthquake in Northwestern Switzerland; further tremors occurred in the following weeks. In 2009, after a comprehensive risk assessment, the cantonal government decided that the project was to be abandoned. Experts emphasize, however, that the geological situation of the Basel deep heat mining project is not directly applicable to other sites.

A vast energy potential

The chances of success for deep geothermal projects can only be reliably estimated on the basis of a detailed knowledge of geological conditions. In Switzerland, our knowledge of the subsurface is best where tunnels have been constructed – in the crystalline rock masses of the Alps. These rocks, however, are relatively unsuitable for deep geothermal development because the conditions for fluid circulation are poor. Greater natural permeability is offered by deep Permo-Carboniferous troughs occurring within Alpine granite, but their precise location is not known. More favourable geological conditions for geothermal projects are also offered by the Molasse Basin of the Central Plateau.

As oil or gas drilling has rarely been carried out in Switzerland, the data available on deep subsurface geology is very limited. Estimates of the country’s geothermal resources are therefore based on international experience. According to these figures, Switzerland harbours a vast geothermal energy potential: the heat stored in rocks at depths between 3 and 10 kilometres is of the order of 28 million terawatt-hours (i.e. 28 billion gigawatt-hours), or around 100,000 times Switzerland’s total energy demand for 2013. The estimates of realizable potential prepared by the Swiss Federal Office of Energy are much more modest: they suggest that, by 2050, deep geothermal energy could contribute 4 to 5 terawatt-hours per year to electricity generation – approaching 10% of projected annual demand.

Average Generation Cost (Rp./kWh) in Switzerland



Mapping the subsurface

The method of choice for geological surveys of extensive areas is high-resolution reflection seismic imaging. This technique – measuring how seismic waves from an artificial source at the surface are reflected at the boundaries between rock layers – is used to map complex layer and fault structures. For the Seismic Atlas of the Swiss Molasse Basin, more than 1200 kilometres of reflection seismic profile data was analysed. Electromagnetic methods are used to determine the temperature and permeability of geothermal reservoirs, while self-potential surveys (measuring naturally occurring voltage differences at the surface) are used for geothermal exploration.

The most precise information on local geological conditions is, however, provided by exploratory drilling, which is essential, in particular, to clarify the geothermal conditions. Our current knowledge of surface heat flows in Switzerland is based on data from 150 boreholes, but no such measurements have been performed in Valais or the eastern Alps. All available data is ultimately fed into a 3D model of the subsurface. This is a prerequisite for any deep geothermal project, as it combines information on local rock formations, underground water resources and temperature conditions – and also makes it possible to assess the impacts of a geothermal project on the surrounding area.

High costs, substantial gains

Geothermal energy requires significant investments, but at the same time it offers the prospect of affordable power supplies and environmental benefits. Given the growing importance of solar and wind power – where output is intermittent, depending on weather conditions – an additional advantage of geothermal energy is its continuous availability.

In order to extract heat from granite rock at a depth of around 2.5 kilometres, the costs of drilling alone are estimated to be at least CHF 10 million on average. Experts agree that drilling expenditures will account for the largest proportion – up to 70% – of the total costs of a geothermal plant.

These estimates are based on experience in the oil and gas sector. However, geothermal drilling projects are technically more challenging and therefore more expensive: they often involve drilling in hard granite rocks, with high wear rates for drill bits. Because of the high temperatures, special cables and materials are also required to protect electronic equipment. In addition, the diameter of a geothermal borehole ranges from roughly 22 to 34 centimetres, while oil and gas well diameters are normally less than 20 centimetres. Geothermal operations also require more powerful pumps than are used in oil or gas production.

The lifetime of a geothermal well depends on how long heat can be efficiently extracted from an underground reservoir. Although heat is continuously replenished from below, experience shows that, over time, efficiency declines to a level which is not economically viable. The operation period for a well in Switzerland is expected to be about 30 years. The reservoir would then have to be allowed to regenerate for a lengthy period.

Cost-competitive power generation

In the TA-SWISS study, the costs of power generation are modelled on the basis of the investments required for geothermal plants. For the reference base case, the average costs are estimated to be 35 Swiss cents per kilowatt-hour; however, between the best and worst cases, the costs vary from 18 to 61 Swiss cents per kilowatt-hour. The wide variation is due to the fact that these estimates cover various cases with more or less favourable conditions: for example, the deeper the well and the shorter the well life, the higher the costs to be expected. Power will also be more expensive if higher returns are sought.

If waste heat from geothermal power generation could also be sold, the costs would be reduced – from 35 to 14 Swiss cents per kilowatt-hour for the reference base case. Geothermal power would then be competitive with other forms of renewable energy: for comparison, the estimated generation costs (in Swiss cents per kilowatt-hour) are 23 for solar, 20 for onshore wind and 14 for offshore wind. Only the costs of biogas combined heat and power (10 Swiss cents) are estimated to be lower than those calculated for the geothermal base case. In the study, the economic analysis focuses on new forms of renewable energy. Hydropower is not taken into consideration – partly because, in some cases, investments in plants have already been recouped and the economic conditions can thus scarcely be compared with those applicable to newly constructed plants. In addition, looking ahead, it needs to be borne in mind that there are limits to the further expansion of hydropower capacity.

The use of waste heat from geothermal plants, however, poses a dilemma. For efficient operation, not only is a district heating network required, but the plant should be located as close as possible to the customer – i.e. in the immediate vicinity of residential or commercial areas. Also advantageous would be a constant demand for heat throughout the year, which would make industry, in particular, an attractive partner for geothermal plants. However, there is a tension between the need for proximity to heat markets and the desirability of constructing geothermal plants at a safe distance from population centres and expensive infrastructure, in view of the risk of induced seismic events.

Low impacts with high-capacity plants

The environmental impacts of geothermal plants were estimated by means of a life cycle assessment (see text box). This is coupled to economic modelling insofar as numerous parameters are incorporated into both analyses: for example, the same assumptions are involved concerning the number and depth of the boreholes required or the lifetime of the plant. It is thus possible to combine the economic and environmental perspectives.

As in the case of economic costs, the drilling of boreholes accounts for the bulk of the environmental impacts. Whichever LCA impact category one considers – climate change, water depletion, particulate matter formation or human toxicity – the drilling phase is the dominant contributor, exceeding by far the impacts caused by stimulation of the deep reservoir or construction of surface installations. Over the entire life cycle, depending on plant efficiency, greenhouse gas emissions are estimated to range from 8 to 46 grams of CO_2-equivalents per kilowatt-hour; in other words, geothermal power generation causes virtually no CO_2 emissions.

Environmental impacts per unit of output are much lower with high-capacity than with low-capacity geothermal plants. The efficiency of a plant depends directly on the geothermal gradient: the more slowly rock temperature increases with depth, the deeper the well will need to be – and the more energy and materials will be required for drilling. A longer well lifetime also has favourable effects. Another factor affecting the environmental impact is the fluid flow rate: if the amount of water pumped exceeds the optimum rate, more pumping power will be required, and if the flow rate is too low, the capacity of the plant will be reduced (see illustration page 12).

Hydropower: geothermal's only rival

Geothermal power performs significantly better than most other forms of renewable energy – only with hydropower are the environmental impacts somewhat lower. The adverse impacts of photovoltaic systems include metal depletion and the use of relatively large amounts of toxic substances such as cadmium; biogas is associated with particulate emissions and is less climate friendly than geothermal power. Wind power also involves metal depletion.

But – no less than in its environmental impacts – there is another respect in which geothermal energy outperforms other renewables: apart from hydropower and biomass, it is the only renewable source that can produce continuous baseload power. For Switzerland's future power supplies, this represents a major advantage: given the intermittent nature of (weather-dependent) solar and wind power, there is a clear need for reliable and predictable energy sources.

Life cycle assessment

Life cycle assessment (LCA) is a standard method used to analyse the environmental performance of products or plants from manufacture to disposal or decommissioning ("cradle to grave"). LCA determines the impacts associated with various phases of the life cycle, analysing the resources consumed during production, operation and the end-of-life phase. In the case of a geothermal power plant, large amounts of energy and materials are required during the drilling, reservoir stimulation and construction period. In contrast, the impacts of plant operation are minimal, as no fuel is required and emissions are correspondingly low. Greater environmental impacts are, however, associated with the end-of-life phase.

A hazardous enterprise?

Earthquakes are – if not the only – certainly the most spectacular adverse events that may be associated with deep geothermal projects. Based on experience with oil and gas production, precautionary measures can be taken to prevent many risks. Public opinion is ambivalent, although it is accepted that this new energy source could make an important contribution to the energy transition.

In Switzerland, experience with deep geothermal energy to date has been far from encouraging. Public attention has focused in particular on induced earthquakes. Here, seismic events of this kind are an unfamiliar risk, while traditional mining communities have long had to live with them. However, whereas in the extraction of coal, potash or other mineral resources, such events are undesired by-products, in enhanced geothermal systems they are a necessary tool: the vibrations caused by high-pressure fluid injection create fractures and thus increase the permeability of the rock reservoir, so that it can serve as an effective heat exchanger.

Managing induced seismicity

Earthquakes are among the most traumatic events anyone can experience – feeling the ground give way beneath our feet leaves us (literally) shaken to the core. "Natural" earthquakes – generally due to the shifting of tectonic plates – are beyond our control and, if they strike, all we can do is try to flee. In contrast, induced (man-made) earthquakes are more "controllable" since experts can – to a certain extent – predict how the subsurface will react to human interventions. It is known, for example, that the risk of seismic events tends to increase the deeper one drills and the greater the volume of the rock mass stimulated for use as a heat exchanger. Likewise, hard crystalline granite is more prone to seismicity than softer, layered sedimentary rock, such as shale. In addition, experience shows that, with deep geothermal installations, earthquakes are more likely to be triggered during construction, whereas with hydrothermal plants the operational phase is more critical.

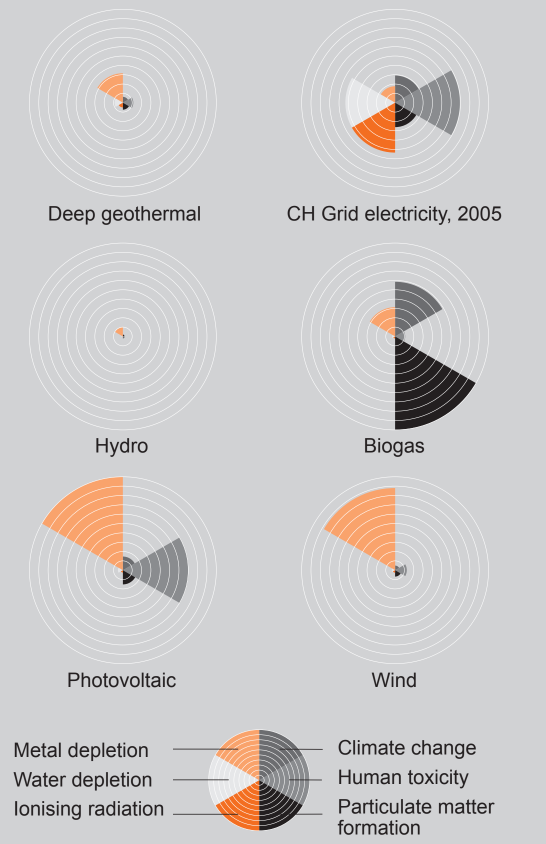
However, much remains unpredictable, especially since natural underground stresses may hold surprises at the local level, and the extent of faults and fissures can never be precisely estimated. Accordingly, as well as early detection, measures to mitigate and manage adverse impacts are of crucial importance. For integrated risk management, a "traffic light system" has been developed and adopted as standard. As long as the lights are green, the construction or operation of an installation can continue as planned, but if certain thresholds are reached, the lights change to yellow or even red; operations then have to be limited – e.g. by turning off pumps – or stopped altogether, and it may be necessary to stabilize an installation by pumping fluids out of the borehole. At the hydrothermal plant in St Gallen, for example, the lights went from green to yellow as a result of a weak (magnitude 1.6) earthquake.

Even though guidelines developed on the basis of growing experience with geothermal energy can help to mitigate the impacts of induced earthquakes, experts agree that the seismic risk can never be completely eliminated. This needs to be openly discussed by policymakers and society. It is also clear that damage from induced earthquakes can most readily be limited by constructing geothermal plants as far away as possible from densely populated areas or expensive infrastructure – although this makes it more difficult to feed waste heat into district heating networks.

Risks to the environment and health

Seismic hazards are not, however, the only risks involved: in fact, geothermal energy shares a number of risks with oil and gas production. For example, methane may leak into a well from rock formations under high pressure; this is known as a "kick". Unless the gas flow can be controlled, there is a risk of a water-gas

Environmental impact per technology



mixture rising to the surface and being released into the atmosphere in an uncontrolled manner (i.e. a blowout). To counter this risk, a blowout preventer – a sophisticated system comprising a number of fast-reacting valves – is installed on top of the borehole. Accidents of this type are particularly serious as they can directly threaten human life and health.

The environment and human health may also be threatened by less dramatic events. For example, saline aquifers are found deep underground, especially where salts are leached from minerals by hot water percolating through porous rock. As a result of poor drilling practices or defective well casings, this saline solution (brine) may be transported upwards and contaminate shallower aquifers or even drinking water.

Problems may also arise from incorrect handling of certain chemicals which are required for the operation of so-called binary cycle geothermal plants. At these plants, hot water pumped from underground is used to heat another liquid, which is kept completely separate. The working liquids used in this process – e.g. benzene, toluene or isopentane – boil at a lower temperature than water and thus efficiently supply the vapour which turns the turbines for power generation. If these chemicals are released into the environment, they can cause skin and mucosal irritation, nausea and even, with prolonged exposure, serious conditions such as leukaemia or liver and kidney damage. Risks are also associated with the use of caustic soda, which is sometimes added to the drilling fluid. As the name suggests, this substance is highly corrosive to organic materials and metals.

The handling of these widely used industrial chemicals is well regulated, and the control authorities have considerable experience in this area. Nonetheless, as accidents can never be ruled out when these substances are transported or stored, the associated risks need to be taken into account.

Public opinion: not polarized, but ambivalent

Whether a new technology can be deployed depends not least on the level of public acceptance. Social scientific methods can be used to assess public opinion, and in the TA SWISS study, two approaches were pursued. Firstly, the types of argument associated with geothermal energy were explored in focus groups. Secondly, the social network Twitter – which has almost half a million users in Switzerland – was analysed as a barometer of opinion on this topic.

Although both of the Swiss pilot projects were unsuccessful and media coverage of geothermal energy was correspondingly critical, the social scientific studies of public opinion revealed a surprisingly relaxed attitude to this issue. The majority of tweets posted in Europe between April 2013 and August 2014 express neutral to moderately positive sentiments. Less than an eighth of the tweets recorded came from Switzerland, which suggests that geothermal energy is not a controversial and hotly debated topic in this country.

A more detailed picture was provided by the total of five focus groups, which confirmed that public opinion in Switzerland is not polarized between supporters and opponents of geothermal energy. Rather, many people share an ambivalent attitude: while recognizing the potential and the advantages of this new form of energy, they are also concerned about the risks. Among the positive arguments associated with deep geothermal power are “endless energy from the ground”, “the chance that geothermal power could contribute to renewable energies” and “low impact on the environment”. Among the negative points raised were “financial risks if the water temperature in deep rocks is too low for sufficient production of heat and power”, “technical and environmental risks that first need to be researched” and “potential damage to buildings and infrastructure”. From the social scientists’ perspective, the fact that public opinion is at present largely free of polarization provides a good starting point for a dispassionate and evidence-based debate on the new technology. At the same time, the widespread ambivalence suggests that opinion on this topic could rapidly shift.

Negotiating the legal obstacles

In Switzerland, questions of land use are determined by the cantons. While certain guiding principles concerning spatial planning, water use and energy transport are laid down in the Federal Constitution, the cantons have sovereign authority in the practical implementation of these principles. Consequently, procedures for the planning and possible operation of geothermal plants in this country are not currently harmonized.

Ownership is regulated by the Swiss Civil Code, and the demarcation of private property on the surface poses few legal problems. But how far do property rights extend in the vertical dimension – upwards into the air and downwards into the ground?

Who owns the subsurface?

Legislators have been compelled to address this question in connection with aviation. The crucial factor is the legitimate interest of owners in using or controlling the space themselves. In a number of cases relating to the expansion of airports, the question has arisen to what extent land owners' rights are infringed by overflying aircraft. The Federal Supreme Court has always declined to make any general ruling with regard to the height at which an aircraft penetrates into the owners' sphere of interest. However, in the case of two plots of land situated close to the end of a runway which were regularly traversed by wide-bodied aircraft at a height of 75–100 metres, it confirmed a violation of property rights.

Similar considerations apply to the subsurface. As a result of the increasing use of geothermal probes for heating, land owners' interests in exploiting the subsurface have increased considerably. Their legitimate interest may thus extend several hundred metres into the ground. This does not, however, mean that the entire subsurface up to that depth below their land becomes private property; ground can only be considered private if it is actually occupied by a geothermal probe. The law takes a more restrictive approach in the case of underground property rights than for airspace – not least so as to ensure that the construction of infrastructure important for the community (such as tunnels) is not unduly impeded. In a case involving agricultural land, for example, the Federal Supreme Court ruled that, from a depth of 5 metres below the surface, a tunnel is part of the ownerless subsurface and is thus subject to the sovereignty of the state.

Multiple approvals required

The extraction of resources such as metals or fossil fuels is governed by the "Bergregal" (mining rights) system. The notion of regalia (royal privileges), dating back to medieval times, relates to how monarchs distributed the rights to exploit limited natural resources – not just mining, but hunting and fishing rights – by granting concessions. In Switzerland, salt extraction and mining rights are subject to cantonal sovereignty. Unlike scarce resources, the extraction of widely available materials such as gravel or sand is not generally subject to mining rights; there is thus some room for manoeuvre in the regulation of geothermal power production.

The legal situation varies from one canton to another. Some cantons have delegated mining rights to the communes and not issued any legislation themselves. Others have adopted provisions on mining rights in the cantonal Introductory Act to the Swiss Civil Code. Most, however, have specific legislation on mining rights. In some cases, this has been extended to cover the exploitation of geothermal resources.

Apart from any provisions concerning the use of geothermal resources, however, numerous other regulations – also varying from canton to canton – have to be complied with in the planning and construction of geothermal plants: for example, approval is required for water withdrawal or groundwater use, forest clearance may need to be authorized, and the proposed plant must comply with the Federal Act on the Protection of Nature and Cultural Heritage and with the cantonal structure plan prepared under the Spatial Planning Act. Lastly, the results of the environmental impact assessment required under the Environmental Protection Act must be positive.

As regards preliminary exploration of a potential geothermal resource, however, the legal hurdles are somewhat lower than for the planning of a plant: for test drilling, a permit is sufficient, while for operation a concession is required. Problematic from a legal perspective is the fact that the granting of an exploration permit does not necessarily confer an automatic right to a subsequent concession for exploitation of the resource. This is a disadvantage for a permit holder who has invested in exploration and discovered a resource but may not be able to reap the fruits of his efforts.

Planning driven by the energy transition

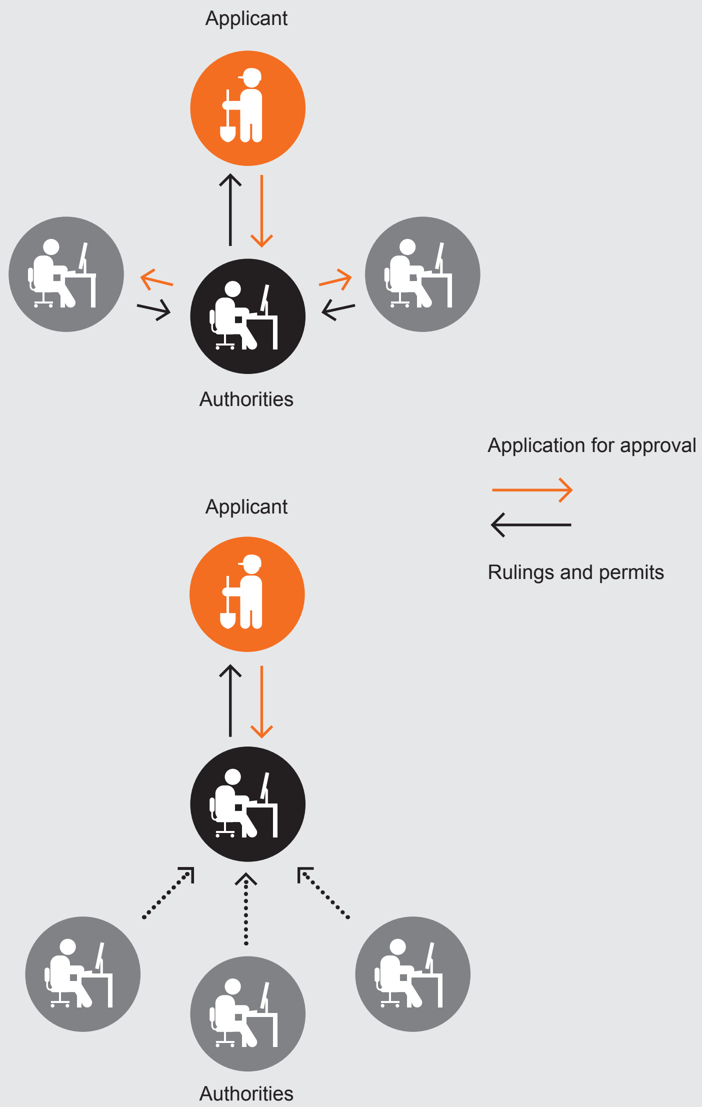
Under the first Action Plan for the Energy Strategy 2050, approved by the Federal Council in a Dispatch issued in September 2013, the cantons are required to develop a concept for the expansion of renewable energies. This will include the designation of areas which are in principle suitable (and, where appropriate, areas not suitable) for the use of renewable energy sources. Energy planning is thus to become an integral part of spatial planning.

In addition, the cantons are requested to expedite approval procedures for the construction of renewable energy installations – no easy task given the numerous regulations to be complied with. This difficulty is to be alleviated by the adoption of the “coordination model”: the cantons are to appoint an authority responsible for coordinating and streamlining the various approval procedures. The “concentration model” would go further: rather than the competent authority merely being responsible for ensuring that the approval process operates effectively, decision making power is concentrated within a single authority, which grants a licence that includes all permits and rulings by other authorities. Today, most cantons use the coordination model. According to legal experts, the federal government could play an important role in the future planning of geothermal projects by creating a platform that would provide support for cantons in implementing and enforcing relevant acts, ordinances and guidelines.

Coordination model vs. concentration model

Coordination model: Different authorities are in charge of approval procedures, but there is a leading authority ensuring coordination.

Concentration model: One single authority grants a licence including all permits and rulings by other authorities.



Geothermal power: part of Switzerland's future energy mix

There is a strong case for geothermal generation potentially making a significant contribution to Switzerland's future energy supplies. However, this would require substantial investments in research and development. It is also essential to improve the transparency and efficiency of the complex approval procedures for planning and construction of geothermal plants. In addition, if wider use of geothermal energy is contemplated, it will be important for the public to be involved in the process at an early stage.

Unlike other "new" forms of renewable energy, geothermal power is not weather-dependent, and its output is continuous and reliable. This means it is one of the few "new" renewable options that could meet market demand for baseload power, thus contributing significantly to the security of supply. With virtually no greenhouse gas emissions, geothermal is also a clean energy source. However, considerable preliminary work will be needed to develop this highly promising resource.

Exploring the subsurface

Current estimates of geothermal energy potential are essentially based on surveys of surface heat flows. However, many geological factors – such as the volume and permeability of rock formations and precise temperature conditions at depth – remain unknown. Scientific surveys are essential in order to improve quantitative modelling. The growth of geological knowledge could be decisively improved by a policy ensuring open access to subsurface data. This could conceivably be modelled on the Australian approach, whereby companies granted a concession to exploit geothermal resources are required to publish their data after a certain time.

Testing the technology

In various respects, the preferred option for Switzerland – EGS – has yet to be adequately tested. A major challenge lies in the close interplay between this technology and geological structures. In the case of reservoir stimulation, in particular, it is difficult to predict the behaviour of the rock – especially since its reaction to high-pressure water injection cannot be directly observed. Here, methods for the characterization of rock masses need to be developed. Also required is a better understanding of heat flows within the reservoir. In addition, conventional drilling methods employed in oil and gas production need to be further developed for use in hard granitic rock.

The considerable uncertainties associated with the EGS approach can only be resolved through pilot projects. A large-scale research initiative, involving demonstration plants, would be needed to facilitate the construction of a cost-effective petrothermal system.

Harmonizing approval procedures and planning regulations

Exploitation of the subsurface is a cantonal responsibility, and the planning and construction of geothermal plants is hampered by inconsistent regulations. Procedures could be simplified and expedited by concentrating responsibilities within a single authority. The so-called concentration model – already adopted by a number of cantons – could offer a practical and effective solution.

In land use, the – sometimes conflicting – interests of a wide variety of stakeholders are in play. Here, it would be useful to link the locations of geothermal potential, political regulation and public concerns to the economic model within the framework of a geographical information system: this could help to calculate the costs of geothermal electricity more precisely and to identify the best potential locations in a transparent manner.

Learning to manage seismic risks

Recent years have seen considerable improvements in methods for the prediction of induced seismicity, but these methods need to be further developed. Although this means that earthquakes can be better controlled, it will not be possible in the future either to reduce the risk to zero or to predict such events over the longer term. The success rate and economic viability of deep geothermal projects therefore depends strongly on the level of seismic risk that society is willing to accept. This debate needs to be conducted at an early stage and without bias.

Early and open communication

Public attitudes to geothermal energy are neutral to moderately positive. However, public perceptions are inevitably influenced by the tendency of the mass media to focus on spectacular events such as induced earthquakes. Early communication and engagement with the public is the most effective way of addressing concerns. In this process, industry members should inform the public openly about the risks and uncertainties involved, while scientists, who currently emphasize risks and uncertainties, could also focus on the potential of geothermal energy. The information provided must be clear, comprehensible and balanced.

Study «Energy from the earth: Deep geothermal as a resource for the future?»

Advisory group

Gunter Siddiqi, Swiss Federal Office of Energy SFOE, Bern, chairman of the advisory group

Jürg Balmer, Swiss Federal Office for Civil Protection – BABS, Bern

Willy R. Gehrer, Siemens Schweiz AG, Electrosuisse, Zürich, SATW Delegate

Monika Gisler, Unternehmen Geschichte & Entrepreneurial Risks, ETH, Zürich

Elmar Grosse Ruse, WWF Switzerland, Zürich

Rolf Hügli, Swiss Academy of Engineering Sciences SATW, Zürich

Peter Meier, Geo-Energie Suisse AG, Zürich

Thomas Müller, Editor Schweizer Radio SRF, Bern Steering committee TA-SWISS

Kurt Nyffenegger, Groundwater & Water Supply Section, WWEA, Zürich

Etienne Poltier, Faculty of Law, University of Lausanne

Katharina Prelicz-Huber, VPOD, Zürich, Steering committee TA-SWISS

Berthold Schmidt, KTI Delegate, Bern

Jörg Uhde, Axpo Power AG | Neue Energien, Glattbrugg

Pascal Vinard, BKW Energie AG (until April 2014), Geospace Experts GmbH

Felix Würsten, Science Editor, Zürich

Roland Wyss, GEOTHERMIE.CH, Swiss Society for Geothermal Energy SVG - SSG, Frauenfeld

Olivier Zingg, Geo-Energie Suisse AG, Zürich

TA-SWISS Project Management

Sergio Bellucci, Director TA-SWISS, Bern

Christina Tobler, Project manager, TA-SWISS, Bern (from August 2013)

Emiliano Feresin, Project manager, TA-SWISS, Bern (until July 2013)

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TA-SWISS
Centre for Technology Assessment
Brunngasse 36
CH-3011 Bern
info@ta-swiss.ch
www.ta-swiss.ch

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