Environmental impacts through geothermal energy provision in Europe

With the widely spread resources, geothermal energy is a resource which can noteworthy contribute to the future energy provision in Europe. However, a contribution to a sustainable heat and electricity provision is only reasonable if its use does not result in disadvantages for the environment compared to given alternatives. This has to be true for the environmental impacts connected with the whole life cycle (i. e. life cycle assessment (LCA) regarding construction, operation and deconstruction and including the respective pre-chains) but also for the effects on the natural environment, which are primarily site specific and regional. This paper will provide an insight how to approach the environmental impacts through geothermal energy provision. As the environmental impacts through the use of high-enthalpy resources has already comprehensively addressed in existing publications (such as Hunt 2000 or Kagel et al. 2005) this paper will focus on hydro-geothermal and Enhanced geothermal systems. Based on theses results, advices regarding a wider use of geothermal energy provision will be derived.

1. Introduction

Geothermal energy is a promising resource; not only due to its large and area-wide potential but also because of its base load ability. However, no energy source is free of adverse impacts on the environment. A wider use of geothermal energy is hence only acceptable does not result in harmful effects on the environment compared to the existing alternatives. Based on this, environmental impacts need to be analysed precisely at the beginning of a wider spread use in order to manage an environmentally benign development, meeting e.g. respective mitigation measures in terms of regulatory guidelines or administrative directives.

Whereas the evaluation of an environmental optimized use of geothermal high-enthalpy fields can be based on long-term experiences and thus on a largely established regulatory framework, only fragmentary knowledge exists regarding the use of low-enthalpy resources. So far, the use of low-enthalpy resources has been generally considered comparatively for the environment and therefore no holistic analyses have been conducted. "Comparatively unobjectionable" already indicates that evaluating environmental impacts is strongly related to the respective surrounding (e.g. acceptable threshold values). For this reason, it needs to be considered that the use of low-enthalpy resources is in many cases associated with projects close to the public. Against this background the Federal Environmental Agency of Germany (UBA) has commissioned a study from June 2006 to June 2007 from which preliminary results will presented in the following.

This study will provide an insight how to approach the environmental impacts through geothermal energy provision. Firstly, a life cycle assessment is conducted. Thereby, the overall consumption of finite energy carriers as well as selected airborne emissions is evaluated based on typical site specific conditions. Subsequently, the local environmental impacts, which cannot be analysed based on a life cycle assessment, will be assessed. Based on this, advices regarding an environmental optimized wider use of geothermal energy for power generation will be derived.

2. Life cycle analysis

Methodology

The methodology of the Life Cycle Analysis (LCA) is based on the fact that environmental impacts of a product – e. g. geothermal generated power – are not limited to the use of the product or the production process; substantial environmental impacts may also occur within the pre-chains. Therefore, the LCA analyses the whole life cycle "from cradle to grave" in order to include all environmental impacts (i.e. also occurring within the pre-chains) associated with the construction, operation and deconstruction of a geothermal power plant. The LCA in this paper will thereby follow the international valid standards ISO 14040 to ISO 14043 (Figure 1).

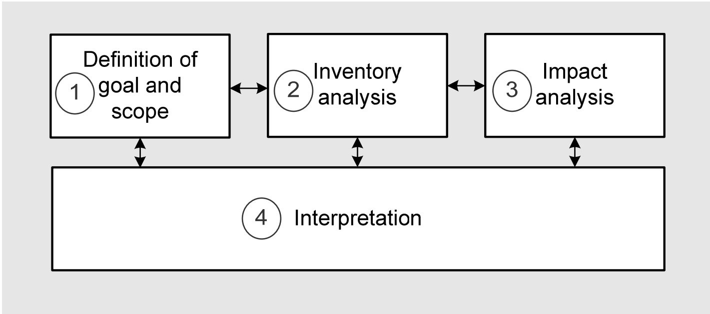

Figure 1: LCA following ISO 14040 – 14043

In the first step "goal and scope definition" among others the goal as well as the system boundaries and the depth of the LCA are defined. Considering geothermal power generation, the goal will be to analyse the use of finite energy carriers and selected airborne emissions of 1 GWh produced power. The analysis will be based on German frame conditions for the reference year 2006 (e. g. geology, status of exploration and conversion techniques, relevant electricity mix). The use of by-products, e.g. residual heat, will be credited.

The second step "inventory analysis" analyses the mass and energy flows of all products and processes needed for generating 1 GWh geothermal power. This is often done by the so called process chain analysis, which connects single processes to be assessed based on physical values (Figure 2).

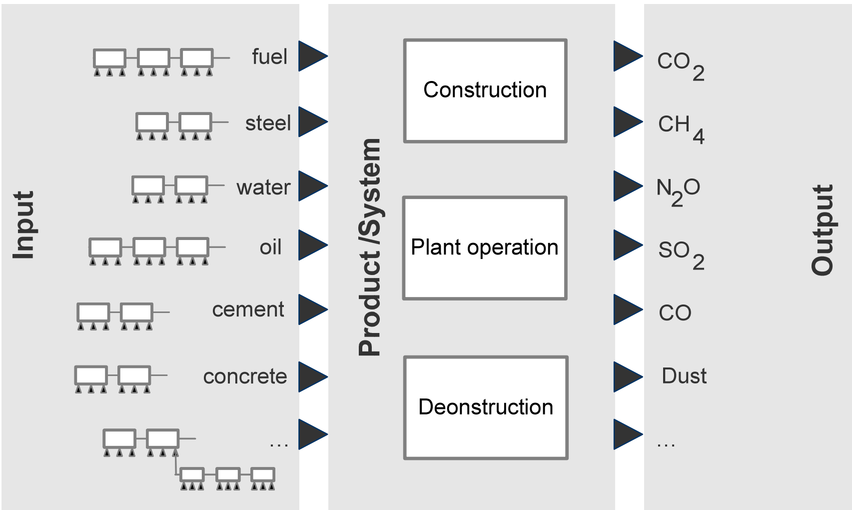

Figure 2: Scheme of an inventory analysis

In the third step, the "impact analysis", the resultant environmental impacts of 1 GWh geothermal power are analysed. Therefore the input and output values of the inventory analysis are allocated in different impact categories. Out of a number of categories, the following ones are regarded in this paper:

- Consumption of finite energy carriers, in which the overall fossil (finite) fuel input from natural gas, crude oil, hard coal, lignite and uranium, is summed up.
- Anthropogenic greenhouse effect, described with so called CO2-equivalent emissions; this category is the rated sum of CO2 from fossil fuel energy (i.e. not from biomass produced in a sustainable way), CH4 (factor 21), N2O (factor 296), CF4 (factor 5,700), C2F6 (factor 11,900) and SF6 (factor 22,200).

- Acidification of natural eco-systems, described with so called SO2-equivalent emissions; this category is a rated sum of SOx, NOx, (factor 0.7), HCl (factor 0.88), NH3 (factor 1.88), HF (factor 1.6) and H2S (1.88).

In the allocation of systems providing power and heat, the credit is related to the value, which would result from generating the same heat amount with a natural gas firing.

Interpreting the overall environmental impact of 1 GWh geothermal power in the forth step, the geothermal power generation will be put into context with other power generation technologies.

Reference Systems

To allow for a fair comparison of different options several reference systems for power generation from geothermal energy as well as from other sources of energy have to be defined. This study will have a closer look on the activities of geothermal electricity production in Germany. On the one hand, Germany comprises different geological conditions representative for other European regions, and on the other, the amendment of the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) assigned a comparatively large interest to geothermal electricity generation from low enthalpy resources. The results however can be transferred to a European scale.

Regarding a power generation from geothermal energy, power plant configurations typical for German circumstances are defined within this paper. Thereby, a 3 MW-plant (installed capacity) located in the Upper Rhine Graben (URG), the South German Molasse Basin (SGMB) and the North German Basin (NGB) is compared (Table 2). In case of a single power production, the water cooled power plant will operate 7,500 full load hours per year. In case of an additional heat supply (i.e. CHP-production) to a low temperature heating system, the power production is assumed to be reduced in order to continuously meet the required supply temperature of the heating system.

Table 2: Geothermal reference systems

	URG [a]	SGMB [b]	NGB [c]
Exploration system			
Configuration	Doublet[d]	Doublet[e]	Doublet[d]
Borehole depth in m	3,000	3,400	4,400
Brine temperature in °C	150	120	150
Flow rate in m^3/h	300	550	300
Productivity/ injectivity in m^3/(h MPa)			
Technical lifetime in a	60	200	60
	30	30	30
Power plant [k]			
Electric capacity in MW	3 [l]	3 [l]	3 [l]
Plant efficiency in %	11,7 [f]	10,6 [f]	11,7 [f]
Elec. full load hours in h/a	7,500 [g] / 6,500 [h]	7,500 [g] / 6,100 [h]	7,500 [g] / 6,500 [h]
Heat supply [g]			
Heating system temp. in °C	70 [i] / 50 [j]	70 [i] / 50 [j]	70 [i] / 50 [j]
Thermal capacity in MW	7	13	7
Th. full load hours in h/a	1,800	1,800	1,800

[a] Upper Rhine Graben; [b] South German Molasse Basin; [c] North German Basin; [d] hydraulically stimulated; [e] chemically stimulated; [f] design point (surface part); [g] solely power provision; [h] power and heat provision; [i] supply temperature; [j] return temperature; [k] wet cooling tower; [l] gross power output;

In comparison to this a power generation based on biomass combustion and gasification, on photovoltaic modules, on on- and off-shore wind turbines, on hydro-electric power as well as on natural gas, on hard coal and on lignite (Table 3).

Table 3: Reference systems for comparison

	Capacity in MW	Efficiency in %	Full load hours in h/a	Technical life time in a
Solid Biofuels				
Gasification	20	42	7,500	15
Gasification (CHP)	0.5	27[a] / 38[b]	7,500	15
Combustion	20	30	7,500	15
Combustion (CHP)	5	7[a] / 12[b]	6,000	15
Photovoltaics				
House module	0.005		800	20
Free field	1		1,000	20
Wind energy				
Wind on-shore	2.5		1,400	20
Wind off-shore	5		2,000	20
Wind off-shore	5		4,500	15
Hydro power				
“Small”	0.3		4,300	45
“Large”	3		4,500	45
“Large”	30		4,500	45
Fossil fuel energy				
Natural Gas	800	58	5,000	25
Natural Gas (CHP)	500	48[a] / 40[b]	5,000	25
Hard coal	800	45	7,000	30
Hard coal (CHP)	800	36[a] / 30[b]	4,000	30
Lignite	800	42	8,000	30
Lignite (CHP)	800	32[a] / 30[b]	4,000	30

[a] electric efficiency; [b] thermal rate of utilization;

The results of the LCA are presented below. Power needed to operate the plant (for e.g. feed pumps and cooling system) is taken from the produced power so that only the net-power is fed into the grid. In case of an additional heat provision, only the co-produced heat is considered. Possible additional peak load units are not regarded within this study.

Results Comparison of the Geothermal Reference Systems

By comparing the CO2-equivalent emissions (Figure 3), the consumption of finite energy resources (Figure 4) and the SO2-equivalent emissions (Figure 5) of the analysed geothermal systems with power provision only, significant differences can be seen between the different investigated regions. Thereby the 3 MW-plant located in the URG leads generally to lower values compared to plants located in the SGMB and the NGB. This result is due to the larger share of the subsurface construction (mainly because of the energy use for drilling and the needed amounts of steel for the pipes) in the respective category whereby the different exploration effort (e.g. borehole depth, borehole volume) in the URG, the SGMB and the NGB becomes evident. Furthermore, it can be seen that the construction on the surface of the SGMB is larger due to the construction of a necessarily larger brine pipeline.

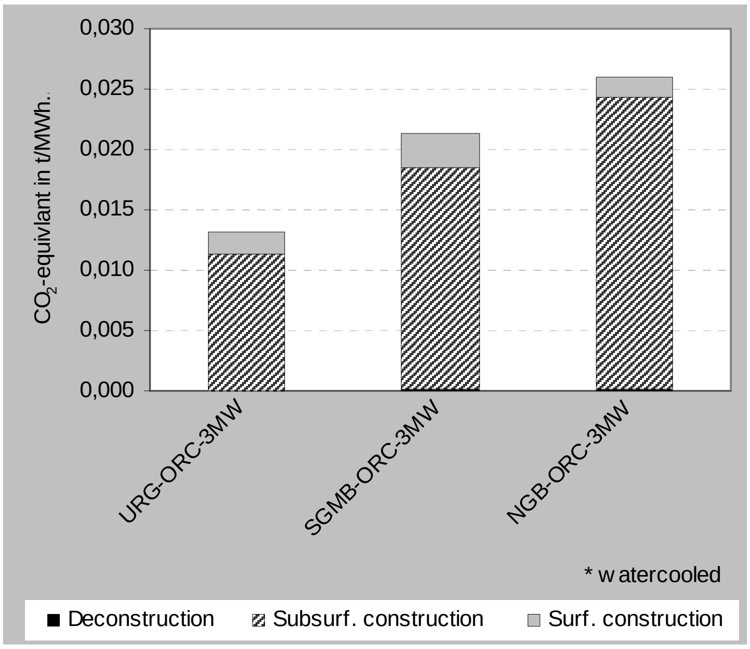

Figure 3: Comparison of site specific geothermal CO2-equivalent emissions (power production)

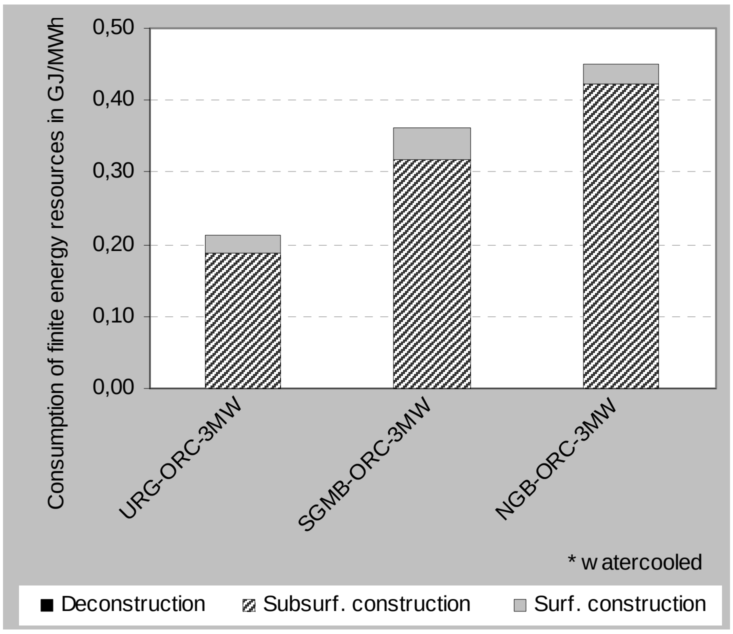

Figure 4: Comparison of site specific geothermal consumption of finite energy resources (power production)

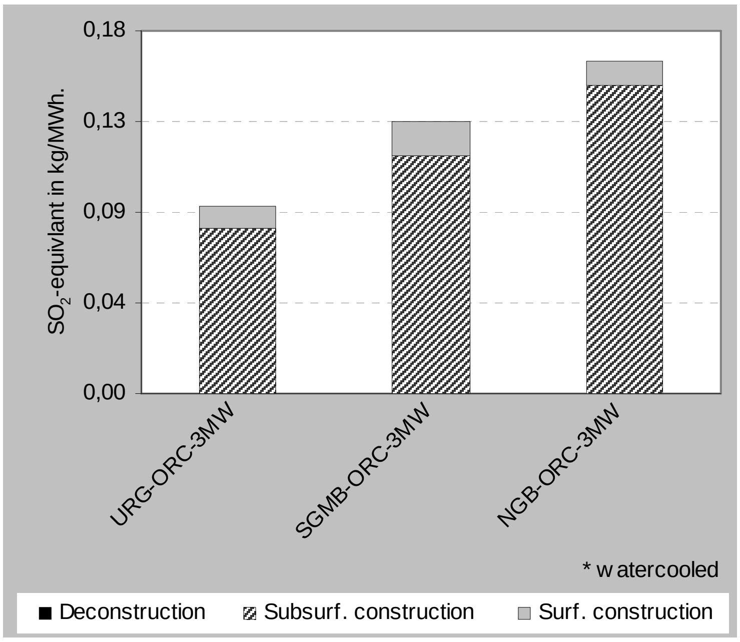

Figure 5: Comparison of site specific geothermal SO2-equivalent emissions (power production)

Having a look at the results of the geothermal reference systems with additional heat provision (Figures 6 till 8), other regional differences can be seen. In general, the credit for heat supply is the dominating factor. The provision of power and heat even results in an overall mitigation of airborne emissions and consumption of finite energy carriers. This mitigation is the largest for the 3 MW ORC plant in the SGMB due to the high flow rate and the resulting large amount of usable heat. The calculated reductions in the URG and the NGB are approximately the same because of the comparable relevant reservoir parameters (i.e. heat and flow rate).

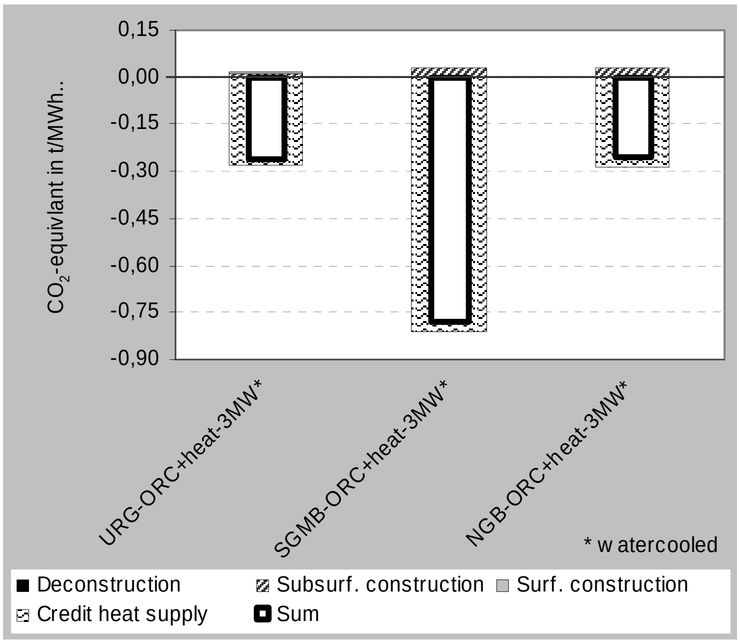

Figure 6: Comparison of site specific geothermal CO2-equivalent emissions (power & heat production)

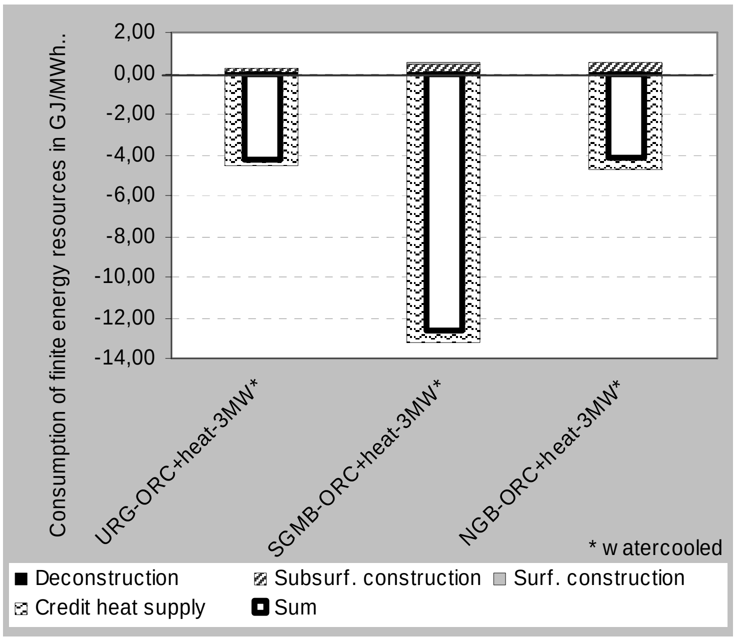

Figure 7: Comparison of site specific geothermal consumption of finite energy resources (power & heat production)

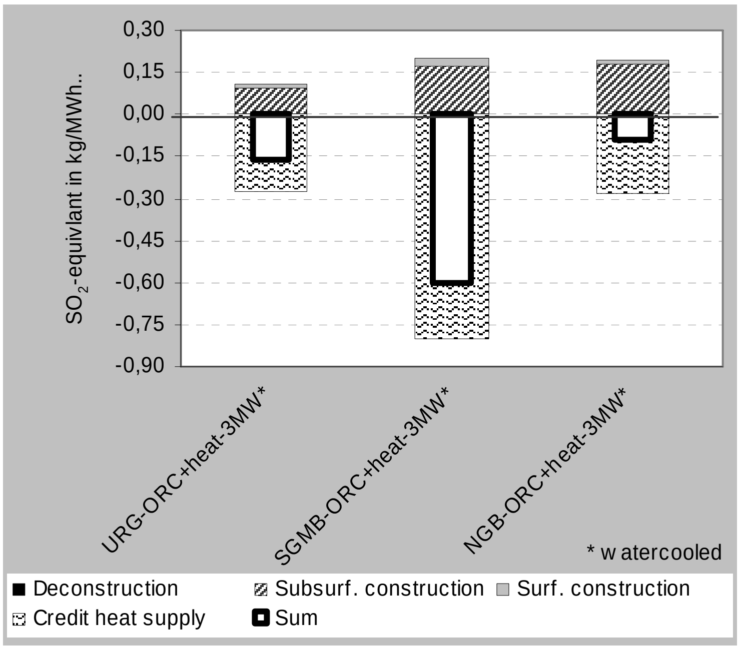

Figure 8: Comparison of site specific geothermal SO2-equivalent emissions (power & heat production)

Sensitivity Analysis of Geothermal Reference Systems

Besides the analysed geothermal power plant concepts, also other configurations are possible. In order to identify the differences due to alternative system configurations, several parameters are changed in the following. Thereby, the consumptions of finite energy resources is exemplarily discussed; airborne emissions are expected to show similar tendencies.

Comparing the more experienced ORC plant to a Kalina cycle and the thermo-dynamically advantageous water cooling to an easier admissible air cooling (more detail in chapter 4.3.2), remarkable differences become evident (Figure 9).

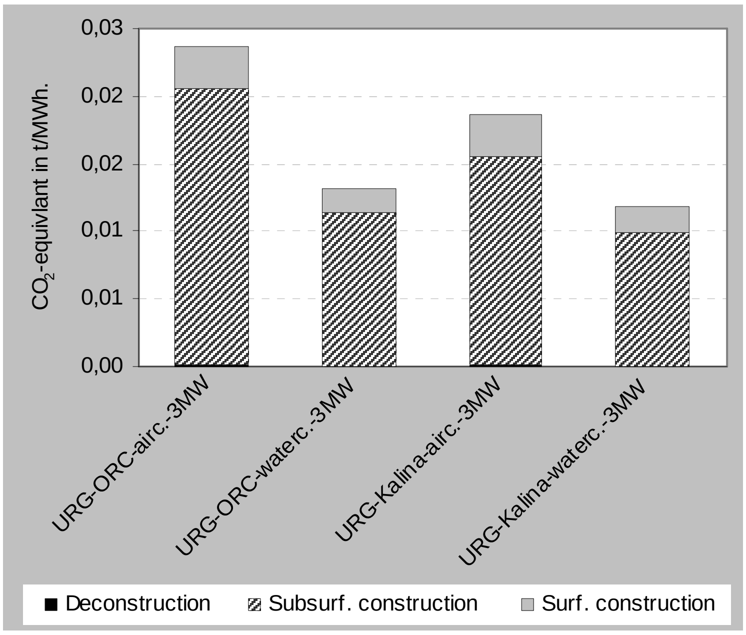

Figure 9: Comparison of technology specific geothermal consumption of finite energy resources (power production URG)

Thereby, water cooled Kalina plants are characterized by a lower consumption of finite energy carriers. Air cooled ORC plants, in contrast, need comparatively larger amounts of finite energy carriers. This is based on the fact that on the one hand Kalina cycles have a higher thermodynamic efficiency due to the use of a mixture of two working fluids with different characteristics; this can result in a higher power net-output (Köhler 2005). Thus in turn, the large specific energetical expenditures for the subsurface construction can be reduced. On the other hand, water cooled systems are advantageous. Besides the thermo-dynamically higher efficiency because of the lower realizable condensation temperatures, the need for auxiliary power is remarkably lower than for air cooled systems (e.g. Kraus and Stallmann 2006). Whereas wet cooling towers have under the assumed conditions a specific energy consumption of 6 kWel per MWth cooling capacity (condensation temperature 25 °C), air cooling systems need up to 20 kWel per MWth (condensation temperature 35 °C).

Comparing differently dimensioned ORC plants in the URG (Figure 10), it becomes evident that increasing the plant size is accompanied with lowering the specific consumption of finite energy carriers. This is due to the fact that the achievable net output rises more significantly with increasing the plant size compared to the expenditures for the subsurface construction. The upscale from 1 to 3 MW is thereby achieved with stimulating the reservoir in order to get higher flow rates due to a higher productivity respectively injectivity whereby the resultant higher power demand of the pumps needs to be considered. The upscale from 3 to 5 MW is realized by a triplet. Drilling a third borehole therefore needs comparatively more energy than the stimulation measures assumed for the 3 MW plant, which leads to a lower decline of the consumption of finite energy carriers.

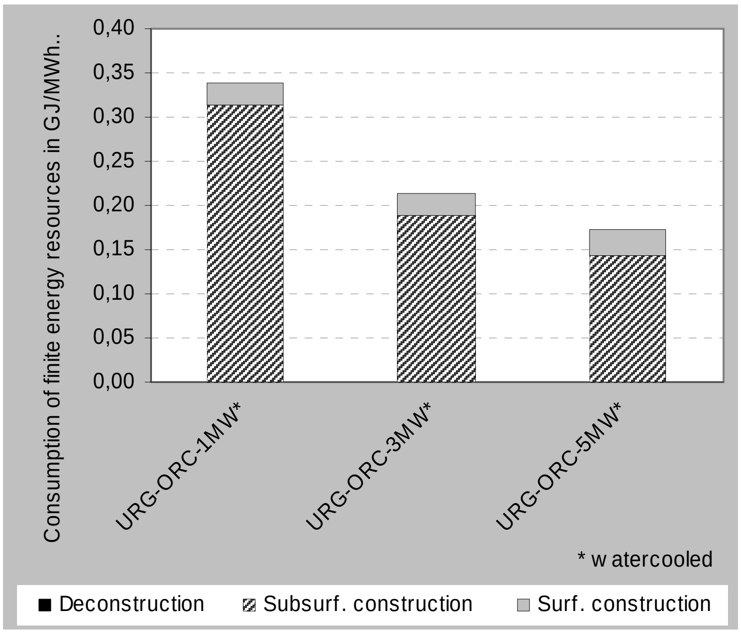

Figure 10: Comparison of size specific geothermal consumption of finite energy resources (power production URG)

Comparison of all Reference Systems

Comparing the solely power production of the geothermal to other reference systems, different facts become evident. Compared to fossil energy systems, the renewable energies, in general, show significantly less CO2-equivalent emissions (Figures 11) and a lower consumption of finite energy carriers (Figures 12).

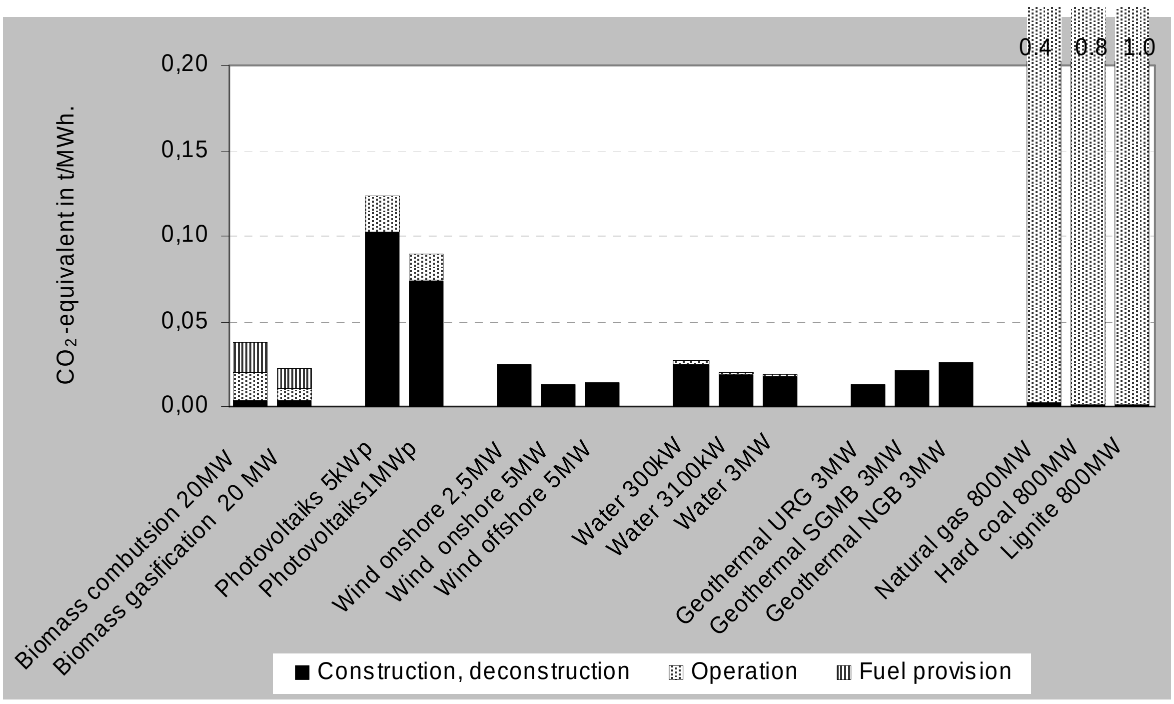

Figure 11: Comparison of CO2-equivalent emissions (power production)

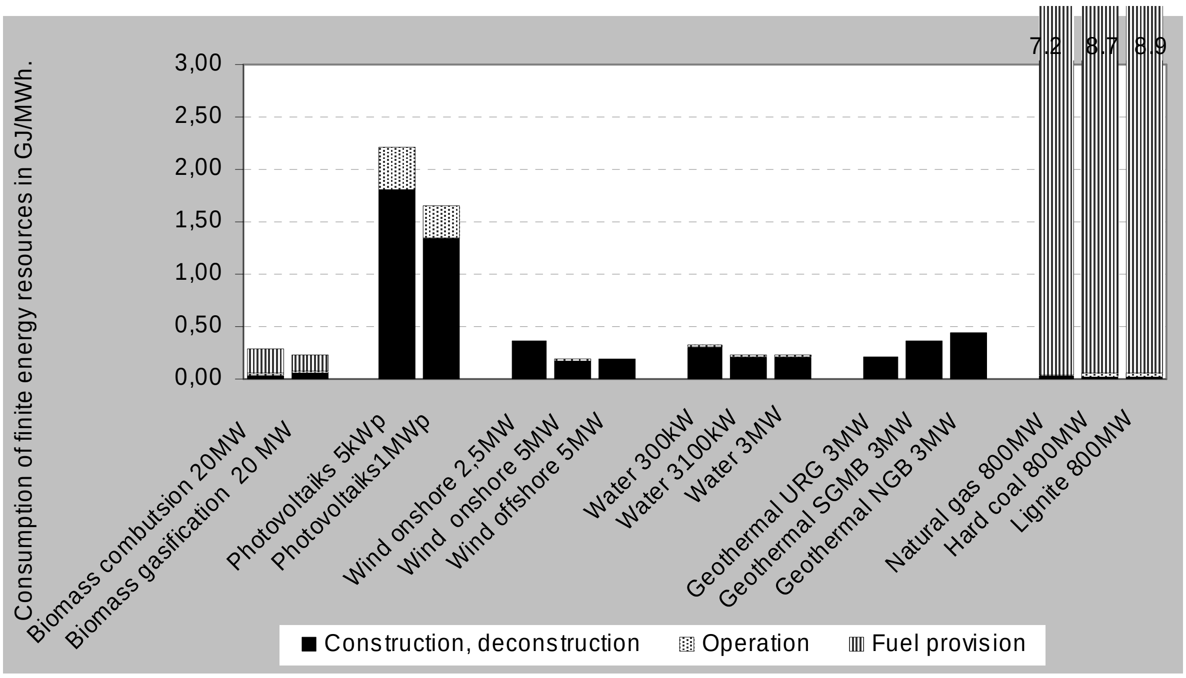

Figure 12: Comparison of consumption of finite energy resources (power production)

Whereas these environmental impacts result in case of the fossil reference concepts from plant operation and fuel provision, the renewable energies – except biomass – have most of their impact during the construction phase. Deconstruction plays only a minor role. Geothermal power plants (also regarding the results of the sensitivity analysis) are placed in the range of the other renewable energies.

Evaluating the SO2-equivalent emissions, basically the same statements can be made (Figure 13). Geothermal energy, again, lies within the scale of the renewable energies. Only the difference between renewable and fossil energies in this category is not that evident. The use of biomass and photovoltaic can lead to higher SO2-equivalent emissions compared to natural gas.

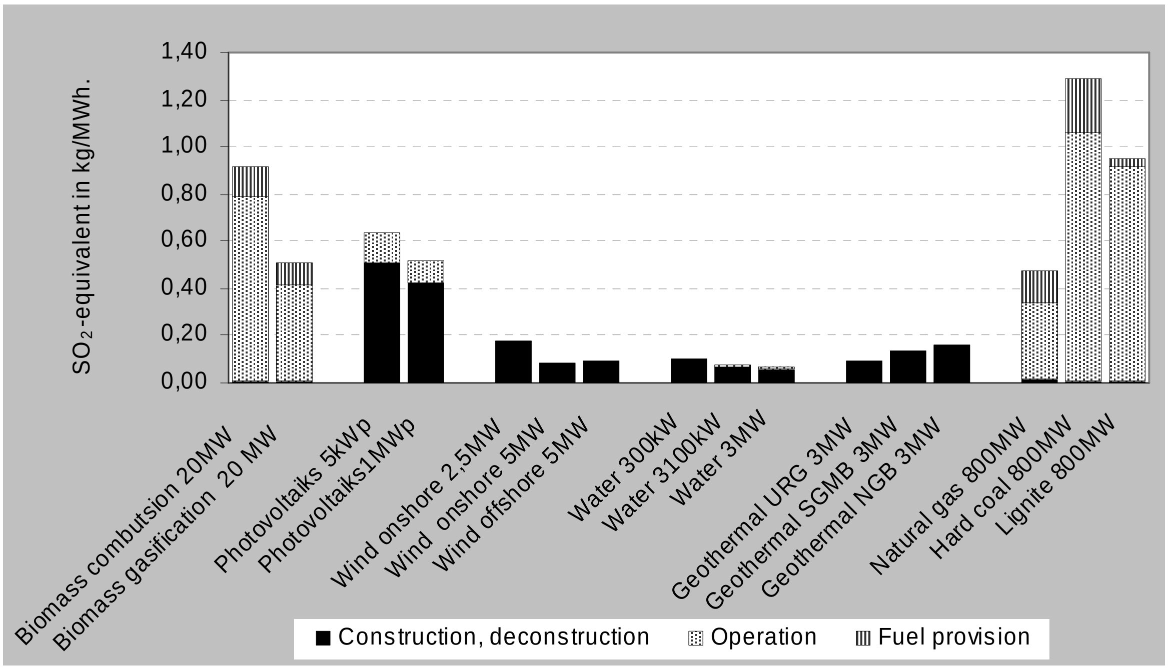

Figure 13: Comparison of SO2-equivalent emissions (power production)

The comparison of power and heat providing systems shows that renewable energies, in general, lead to a saving of finite energy carriers and the analysed airborne emissions whereas fossil CHP-systems only realizes respective reductions (Figure 14 till 16). Geothermal energy thereby has in case of the SDMB the largest saving potential. Additionally it must be mentioned that innovative heat supply concepts (e.g. heat and cold supply, room heating in cascades in order to lower the return temperature and use more energy from the residual heat in the brine), an even higher advantage of geothermal energy is achievable.

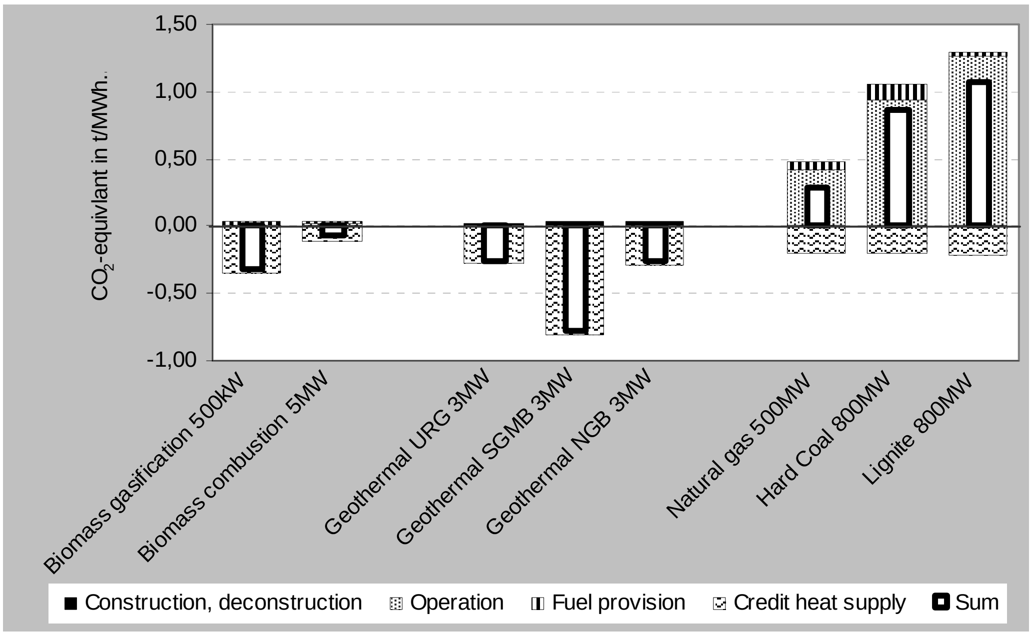

Figure 14: Comparison of CO2-equivalent emissions (power & heat production)

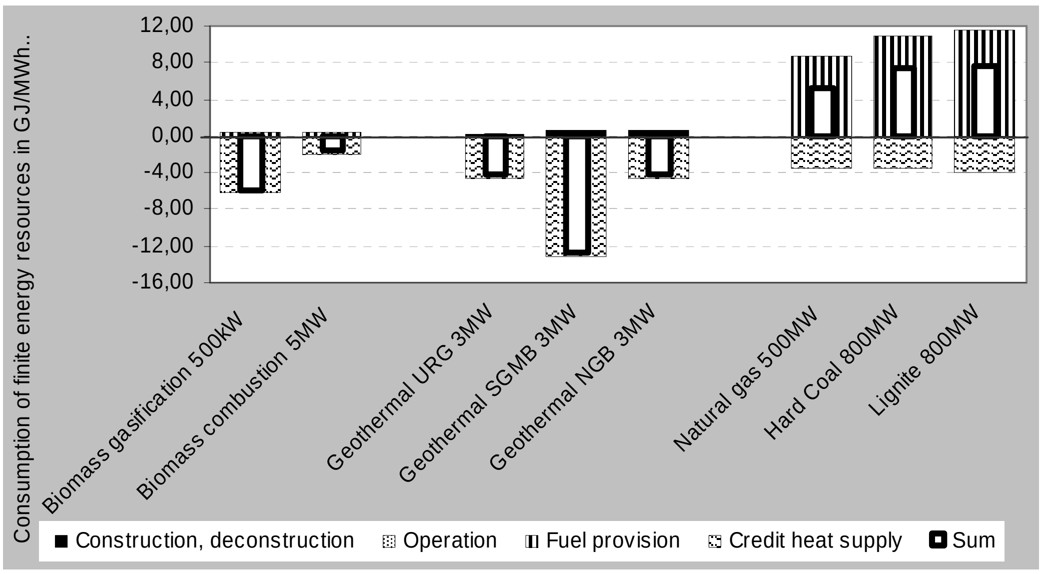

Figure 15: Comparison of consumption of finite energy resources (power & heat production)

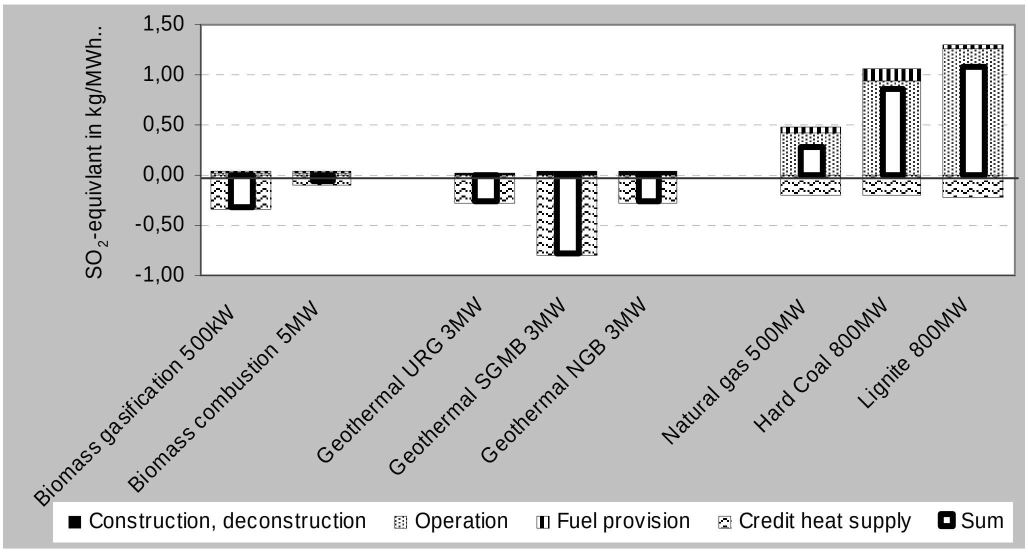

Figure 16: Comparison of SO2-equivalent emissions (power & heat production)

3. Local environmental impact analysis

Methodology

Geothermal power production is associated with a massive engagement in the surface and subsurface environment. Due to methodological reasons, these impacts are in most cases linked to local site-specific conditions and therefore can, if any, only by analysed restrictedly within an LCA. Possible local impacts and resultant effects on the environment hence need to be analysed qualitatively. In the following, the regarded environment – based on to the German Act of Environmental Impact Assessment (Umweltverträglichkeitsprüfungsgesetz, UVPG) – refers to plants, animals, humans, landscape, air, and climate. Because protecting the environment is one fundamental part of the German legislation (in 2009 the government is going to adopt an environmental code), evaluating its validity for geothermal power production is the goal of the local environmental impact analysis within this paper.

Firstly all possible local environmental impacts associated with a geothermal power production from hydro-geothermal systems in Germany are identified and evaluated regarding their possibility of appearance under site-specific conditions (i.e. failure or normal operation). Afterwards, a closer look is taken on the state of the art and possibly existing mitigation measures and respective directives. The resultant effects on the environment are thereupon analysed and the existing legislation evaluated regarding its applicability on a hydro-geothermal power generation.

Administrative Frame Conditions

In order to analyse the local environmental impacts following Figure 17, the administrative frame conditions – relevant for constructing, operating and deconstructing a hydro-geothermal power plant – need to be assessed. In general, the German legislative exists on a federal and state level so that according to the respective site, different regulations may be valid. The basic intentions however are stated in the state law. Thereby, following legislations need to be considered for geothermal power generation:

- Federal Mining Act (Bundesberggesetz, BBergG). Geothermal energy is part of the BBergG. Its function is to guarantee security of supply of raw material and protection of deposit on one hand as well as security of life and health on the other. Therefore, all actions associated with exploring and exploiting geothermal energy need admission by the Federal Mining Board requiring all work steps to be precisely defined beforehand. An Environmental Impact

Assessment is only mandatory for boreholes in FFH-areas (flora-fauna-habitat areas) deeper than 1,000 m or a water extraction from the underground of over 1,000 m3/h.
- Federal Water Household Act (Wasserhaushaltsgesetz, WHG). The brine itself is part of the BBergG. However, the objective of the WHG – to assure waterproofing and water management aspects – is considered. Generally relevant issues within the WHG are the use and alteration (i.e. thermal, morphological, physic-chemical alteration) of water bodies. Geothermal power plants need ground- or surface-water for drilling, stimulation and circulation activities during the construction phase. In case of water-cooled power plants also cooling water is required during plant operation.
- Federal Immission Control Act (Bundesimmissions-schutzgesetz, BImSchG). The BImSchG defines general duties for different kinds of installations basically referring to mitigating and minimizing environmental impacts according to the state-of-the-art. Regarding geothermal power plants, especially noise immission needs to be considered carefully. Thereby the Technical Instructions on Noise (Technische Anleitung Lärm, TA-Lärm) are valid.
- Nature Conservation Act (Bundesnaturschutzgesetz, BNatschG). Geothermal power production is associated with several interferences with the environment which are regulated and considered within the BNatschG – especially in case of environmental sanctuaries. Thereby avoidable environmental impacts need to be refrained; unavoidable impacts have to be set off with respective nature conservation measurements. In case, environmental impacts are inevitable and cannot be compensated, the interests of nature conservation prevail over the interests associated with geothermal power generation.

Further regulations need to be considered constructing the surface part of a geothermal power plant. The Regional Planning Act (Raumordnungsgesetz, ROG) thereby considers the competition of use of a hydrothermal plant compared to other utilization claims (e.g. social and environmental ones). Because of the working pressures and working fluid, ORC as well as Kalina cycles need technical safety precautions. Temporarily, this legislative situation is not clearly defined yet due to the New Approach of the EU to technical legislation (Gaßner et al. 2007). If hazardous material is used to a certain amount, the Statutory Order on Hazardous Incidents (Störfallverordnung, StFV) may be valid. The regulations of the Directive for Pressurized Apparatus (Druckgeräteverordnung, 14. GWSGV) and the Directive for Operating Safety (Betriebssicherheitsverordnung, BetrSichV) have to be considered anyway. For the construction of the building, the German Statutory Code on Construction and Building (Baugesetzbuch BauGB) needs to be taken into consideration. In case of an additional heat supply, an Environmental Impact Assessment according to the Act of Environmental Impact Assessment (Umweltverträglichkeitsprüfungsgesetz, UVPG) of the heating supply system is necessary. Regarding waste disposal, the directives of the Waste Avoidance and Management Act (Kreislaufwirtschafts- und Abfallgesetz, KrW-/AbfG) are mandatory.

Local Environmental Impacts during Construction

In a geothermal project, the construction phase is dominated by the drilling operations which are generally followed by the surface construction of the power plant. Drilling and stimulating hydro-geothermal wells are basically not different to operations executed in the oil and gas industry. Also constructing the surface part is not a specific task for geothermal projects. Based on these facts, the construction of hydro-geothermal power plants can be based on longtime experiences. This is true from a technical viewpoint as well as from a legislative angle. The possible local environmental impacts and resultant effects hence are sufficiently considered by respective laws and directives (Figure 18).

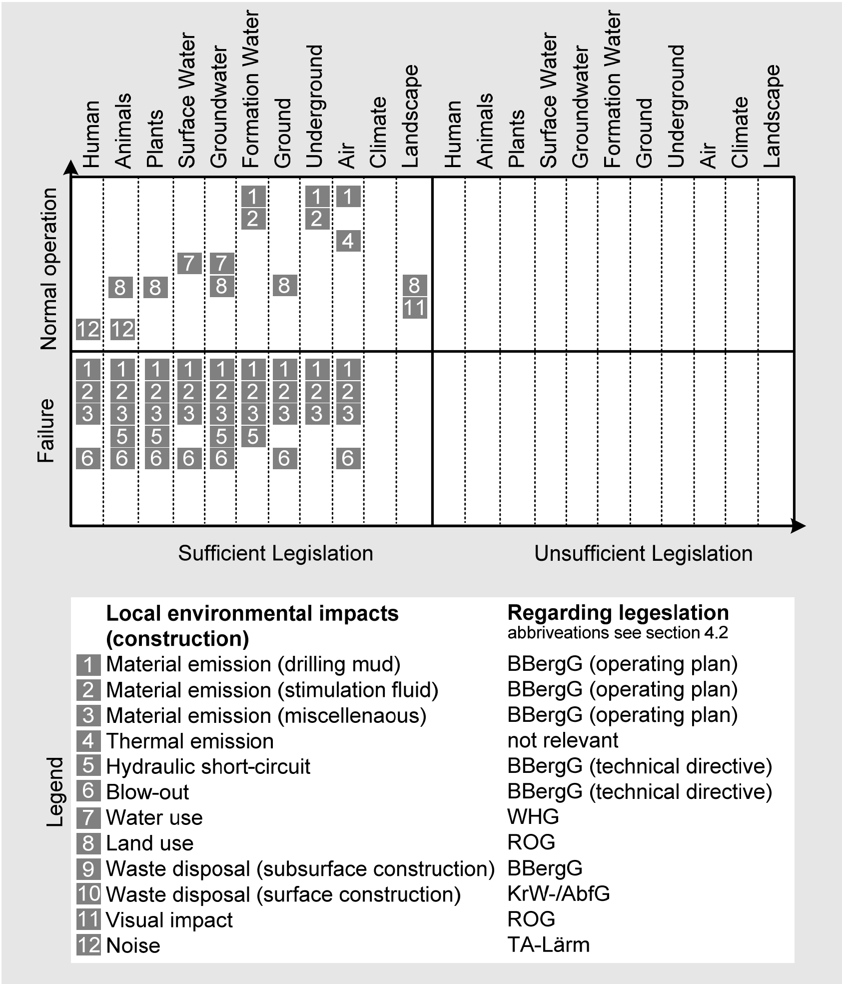

Figure 17: Local impact analysis – construction

Material emissions, for example, regularly are caused by drilling mud and stimulation fluids to formation waters, the underground and the air in case of air contact at the surface. The used materials however have to be indicated in the operating plan, which needs admission by the Board of Mines. Therefore, no environmentally harmful effects have to be expected during normal operation. Material emissions to the groundwater are limited to failure because the BBergG contains a directive which instructs that groundwater-bearing formations need to be tubed and cemented properly before drilling the next section. Due to this, also hydraulic short-circuits occur only in case of failure. The disposal of waste, as another example, is restricted to the need of disposal space. This is based on the BBergG and the KrW-/AbfG, which are focusing on recycling as far as possible and admit dumping only on adequately designated disposals. Land use for constructing the plant is no special concern for the environment.

Local Environmental Impacts during Operation

Whereas the construction of hydro-geothermal power plants and the therefore needed regulations can be based on adequate experiences, comparatively little experience and therefore regulations exist for the operation phase. However, the environmental impacts are expected to be low; this is due to fact that injection of the used brine is compulsory (BBergG) and several long-term hydro-geothermal systems for balneological applications and district heating have been operated or are running without any known impacts on the environment. Assured predication of possible environmental impacts and effects by operating hydro-geothermal power plants can not yet be made (Figure 19).

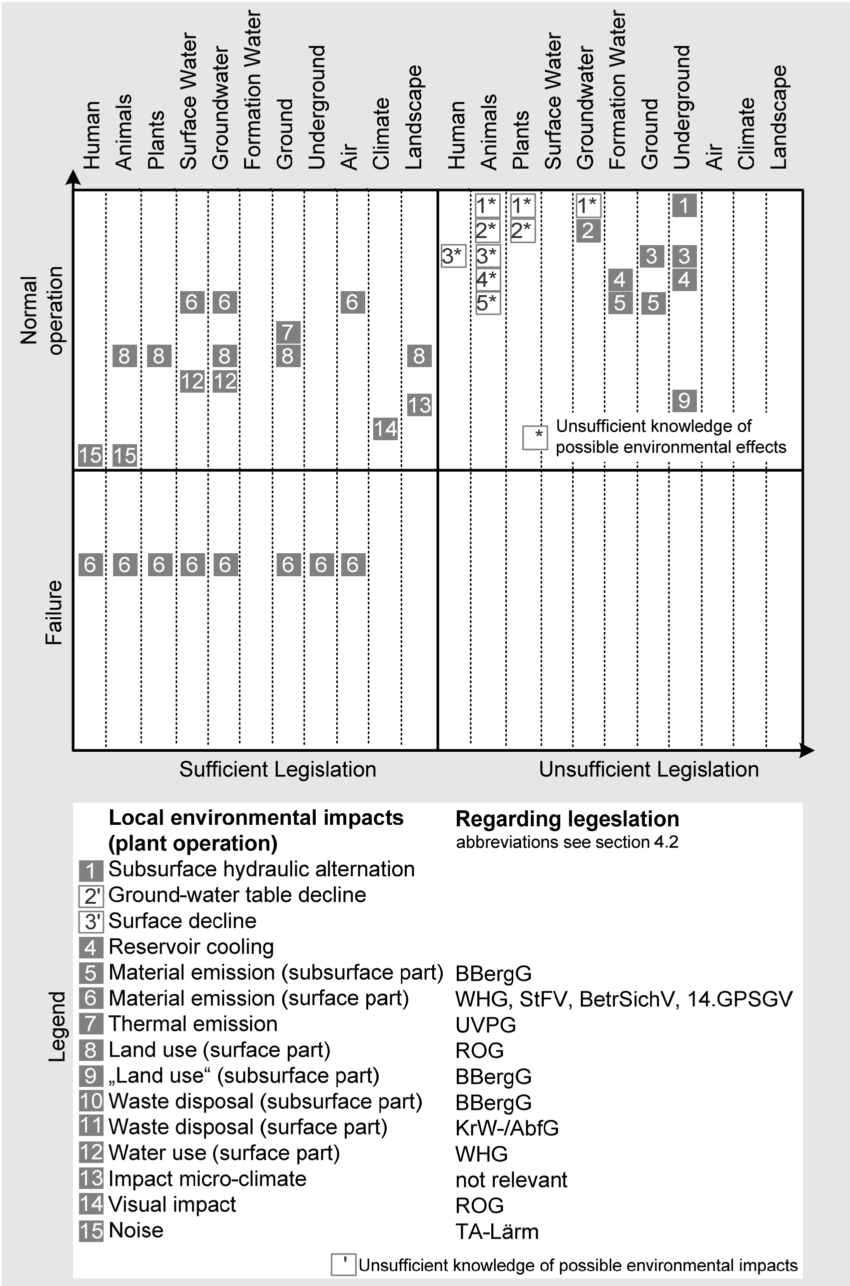

Figure 18: Local impact analysis – plant operation

Concerning the primary cycle (i.e. brine cycle), on one hand, the decisive reservoir parameters leading to e.g. groundwater or surface decline are not finally understood to derive respective administrational directives; on the other, evaluating all possible resultant effects – e.g. caused by hydraulically altering and cooling the reservoir – is not feasible because of insufficient knowledge of the biocenosis in the deep underground. Concerning the binary cycle, also experience is lacking; but more in terms of clarifying legal aspects (see chapter 4.1) than basic researching environmental impacts. However, environmental impacts can occur due to the huge waste heat streams in consequence of the presently unavoidably low electrical efficiencies. Because of the low temperature of this waste heat, a conventional CHP (combined heat and power) is not economically feasible (e.g. Kraus and Stallmann 2007) so that cooling devices are needed which lead to different interfaces with the environment depending on the cooling system (Figure 20). The resultant environmental impacts are thereby regulated in different laws and directives. Research has shown hence that getting permission for air cooled geothermal systems is much easier than realizing water cooling (LAWA 2007). Based on the fact that hydro-geothermal power plants are restricted to a specific geology, site-specific conditions needed for wet cooling towers (i.e. sufficient availability of surface or groundwater) can be met only in few cases. Once-through water cooling even seems to be irrelevant talking about hydro-geothermal power plants.

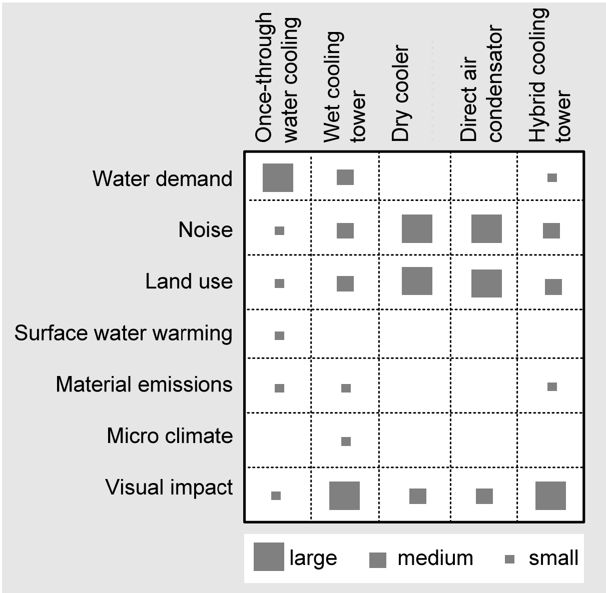

Figure 19: Local impacts of different cooling systems

Compared to other technologies, geothermal power plants have in general a relatively small demand for land compared to the yearly produced amount of power (approx. 0.1 to 0.4 m2/MWh (Kagel et al. 2005, Siemens AG 2007).This demand is mainly stated by the power plant building and the cooling system which are normally built near the resource so that no additional land needs to be used for fuel provision (e.g. mining for coal and nuclear plants, energy crops cultivation for biomass plants). In case of additionally providing the residual heat, the needed pipelines are usually oriented at the existing infrastructure (e.g. roads, power transmission). Concerning the environment, use of land is generally connected to competition respectively conflicts of use. The Regional Planning Act (ROG) therefore observes a sustainable spatial planning, coordinating the divers demands. The subsurface land use, observed by the Boards of Mines, however is much larger than the one on the surface. The subsurface competition of use is thereby stated by different storages supporting an environment friendlier energy supply (i.e. compressed-air, gas- and possibly CO2-storage). The validity of sizing the permission fields in case of a neighboured use without compromising each other or the environment (possibly because of an amplified exposure of the hydrothermal reservoir) needs to be proven. In this case the legislative is rated as insufficient.

Local Environmental Impacts during Deconstruction

Compared to constructing hydrothermal power plants, there are only little environmental impacts caused by deconstructing them. Furthermore these impacts are sufficiently considered in respective directives. The Federal Mining Law (BBerG) e.g. envisions a proper backfilling of the bore holes and an appropriate disposal of accumulating waste products. Deconstructing the surface part is comparable to other power plant units.

4. Conclusions

Geothermal energy is a promising resource because of its large and area-wide potential as well as its base load ability. However, also the use of geothermal energy is not free of adverse impacts on the environment. Concerning a sustainable energy supply and an environmental optimized wider use of geothermal energy for power generation, following conclusions can be drawn:

- Regarding the consumption of finite energy resources, CO2- and SO2-relevant emissions over the whole life cycle, power generation from geothermal energy is stated within the range of other renewable energies and therefore much more environmentally friendly than a fossil power production. However, there is still saving potential considering an optimized net-power output.
- Geothermal concepts with power and heat provision are characterized within the LCA by a significant saving of finite energy carriers and airborne emissions. Thereby, also additional saving potential exists because the residual heat in the brine is not fully utilized in most cases. Innovative heating concepts (e.g. heat and cold supply, room heating in cascades) in order to lower the return temperature and use more energy from the residual heat could even realize higher advantages from geothermal energy in contrast to other CHP options.
- Considering local environmental impacts, the construction phase is associated with many impacts on the environment. Due to the existing experience from the oil- and gas-industry however, the resultant effects are not of concern because of respective regulations and directives. It has to be considered though that the requirements of environmental protection are closely associated with the surrounding and that hydro-geothermal power plants will often-times be constructed near the public.
- The environmental impacts resultant from operating the primary cycle (i.e. brine cycle) – even if expected to be low – cannot be finally evaluated because of lacking experience and knowledge on reservoir behaviour on the one hand, and the biocenosis in the deep underground on the other. To environmentally optimize a wider use of geothermal energy for power production, further research is needed in terms of technical aspects as well as regulatory facets (i.e. competition of use in the deep underground regulated by the BBergG).
- Considering the operation of the subsurface part, coping with the presently unavoidable waste heat is a complex aspect within an environmentally optimized geothermal power production. On one hand, the LCA has shown that water cooling is the most advantageous cooling concept concerning the use of finite energy resources and the regarded airborne emissions. However, the needed water is – among others because of environmental concerns – not sufficiently available on every site. Air cooling systems, in contrast, are easier to implement under water management aspects but lead to other local impacts (e.g. noise) and because of the comparatively low net-output to worse LCA-results. Further research about innovative concepts using the waste heat and therefore improving the environmental performance of geothermal systems is needed.

Based on these results, geothermal energy can be evaluated as promising resource also from an environmental viewpoint. However, for an environmental optimized development, approaching open questions and optimising the still existing saving potential is an important task for the years to come.

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