# Sustainable geothermal production and $CO_2$ emission reduction

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## Abstract

Numerical model simulations show that geothermal resources can be utilized in a sustainable way, by applying lower production levels. Such strategies secure the longevity of the resource. Since no burning processes are involved, geothermal technologies produce little or no greenhouse gas emissions. Growth estimates show that global geothermal electricity production in 2050 could reach 1000 TWh/yr; this corresponds to mitigating hundreds of million tons $CO_2$/yr, depending on what is substituted. Direct use, including geothermal heat pumps, has a mitigation potential of 5 million tons of $CO_2$/yr in 2050.

## Geothermal sustainability

Geothermal energy is classified as a renewable resource, where “renewable” describes a characteristic of the resource: the energy removed from the underground resource is continuously replaced by more energy on time scales similar to those required for energy removal and those typical of technological/societal systems. Consequently, geothermal exploitation is not a “mining” process. The production of geothermal fluid/heat continuously creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn generate fluid/heat inflow to re-establish the pre-production state. The regeneration of geothermal resources is a process, which occurs over various time scales, depending on the type and size of the production system, the rate of extraction, and on the attributes of the resource.

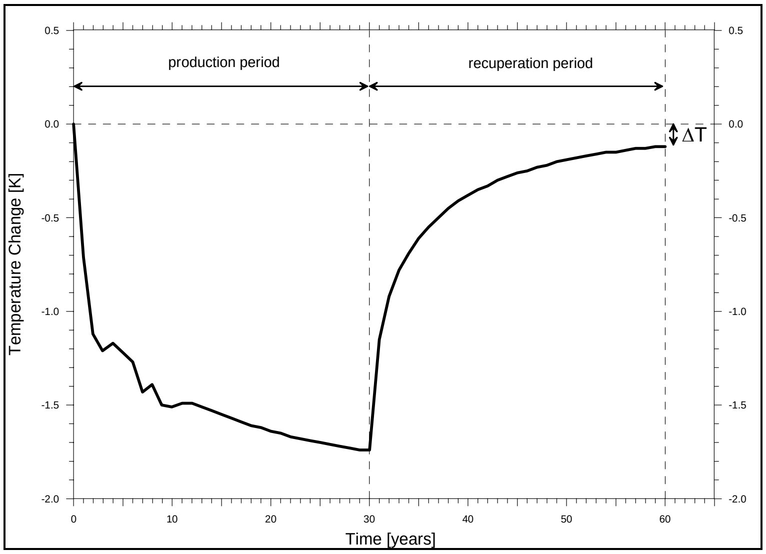

Figure 1. Calculated ground temperature change at a depth of 50 m and at a distance of 1 m from a 105 m long BHE over a production period and a recuperation period of 30 years each (from Rybach and Mongillo, 2006).

Time scales for re-establishing the pre-production state following the cessation of production have been examined using numerical model simulations for the main geothermal technologies: 1) heat extraction by geothermal heat pumps, 2) the use of a doublet system on a hydrothermal aquifer for space heating, 3) the generation of electricity on a high enthalpy, two-phase reservoir and 4) an enhanced geothermal system for co-generation. The results show that during production intermissions or after production stops, recovery driven by natural forces like pressure and temperature gradients takes place. The recovery typically shows asymptotic behaviour, being strong at the start, and then slowing down subsequently, and theoretically taking an infinite amount of time to reach its original state (see Fig. 1 for a typical example). However, practical replenishment (e.g. 95%) will occur much earlier, generally on time scales of the same order as the lifetime of the geothermal production systems.

In the framework of the IEA Geothermal Implementing Agreement a study (Rybach & Mongillo, 2006) revealed that 1) any “balanced” fluid/heat production that does not exceed the natural recharge can be considered fully sustainable, 2) production rates that exceed the rate of recharge will eventually lead to reservoir depletion, thus stopping economic production (see Fig. 2), 3) geothermal resources will attempt to re-establish their pre-production states following termination of production, 4) the post exploitation recovery exhibits an asymptotic behaviour reaching a “practical” replenishment of ~95% recovery on time scales of the same order as the lifetime of the geothermal production system, 5) geothermal resources are renewable on timescales of technological/societal systems (~30-300 years), 6) sustainable production secures the longevity of the resource at a lower production levels (Fig. 3), 7) the level of sustainable production depends on the utilization technology as well as on the geothermal resource characteristics and 8) production from geothermal resources should be limited to sustainable levels.

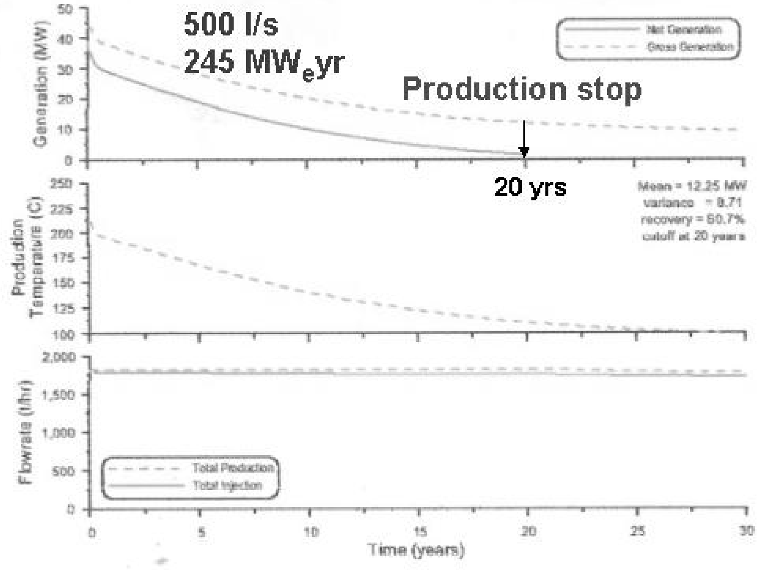

Figure 2. Power generation from an EGS system with high circulation rate (from Sanyal and Butler 2005) starts with 55 MW$_e$ capacity but terminates after 20 years.

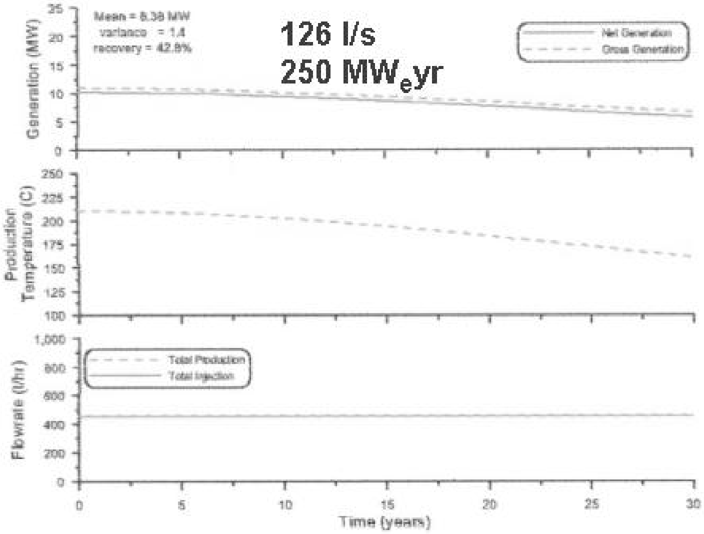

Figure 3. Lower circulation rate yields long-lasting power production (from Sanyal and Butler, 2005).

Reduction of $CO_2$ emissions

Geothermal technologies produce little or no greenhouse gas emissions since no burning processes are involved. Power generation as well as direct use already contribute to the reduction of $CO_2$ emissions. Further deployment – depending on future growth rates – could reduce $CO_2$ emissions even more significantly. The current and future potential contributions to reduce $CO_2$ emission by geothermal power generation and direct use have been assessed in a study carried out for the Intergovernmental Panel on Climate Change, IPCC (Fridleifsson et al. 2008). $CO_2$ emission from geothermal power plants in high-temperature fields is about 120 g/kWh (weighted average of 85% of the world power plant capacity). With the present engineering solutions it could be possible to increase geothermal power from the expected value of 11 GW for year 2010 up to a maximum of 70 GW in 2050; the gradual introduction of the new developments (binary plants, EGS systems) may boost the growth rate with exponential increments, thus reaching the global world capacity of 140 GW in 2050 (Fig. 4). The corresponding electricity production of about 1000 TWh/yr in 2050 will mitigate (depending on what is substituted) hundreds of million tons $CO_2$/yr. Future technology including reinjection (10 g $CO_2$/kWh) will result in negligible emissions.

Geothermal heat pumps provide space heating, cooling and domestic hot water. When driven by fossil fuelled electricity they already reduce the $CO_2$ emission by at least 50% compared with fossil fuel fired boilers. If the electricity that drives the geothermal heat pump is produced from a renewable energy source like hydropower or geothermal energy the emission savings are up to 100%. The total $CO_2$ emission reduction potential of geothermal heat pumps has been estimated to be 1.2 billion tonnes per year or about 6% of the global emission. The $CO_2$ emission from low-temperature geothermal water is negligible or in the order of 0-1 g $CO_2$/kWh depending on the carbonate content of the water.

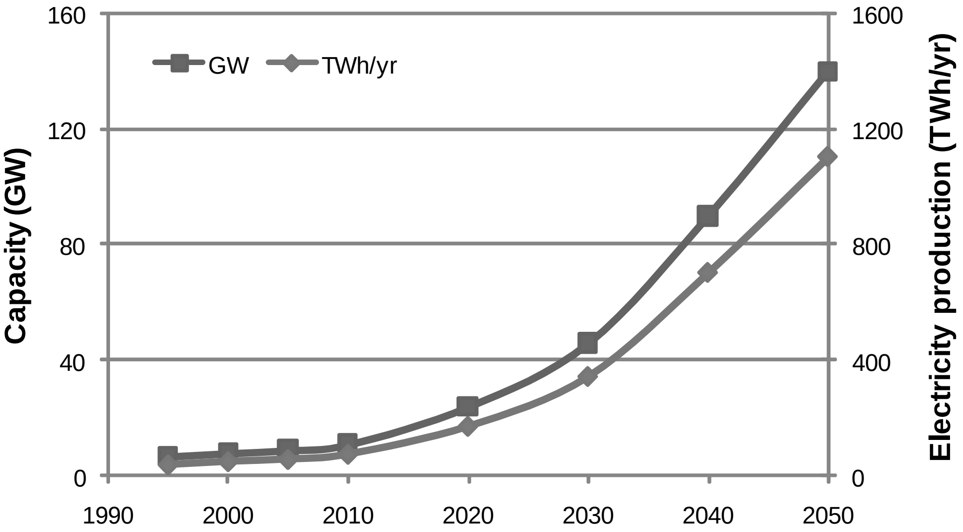

Figure 4. Installed global geothermal capacity and electricity production 1995-2005 and forecasts for 2010-2050 (from Fridleifsson et al. 2008).

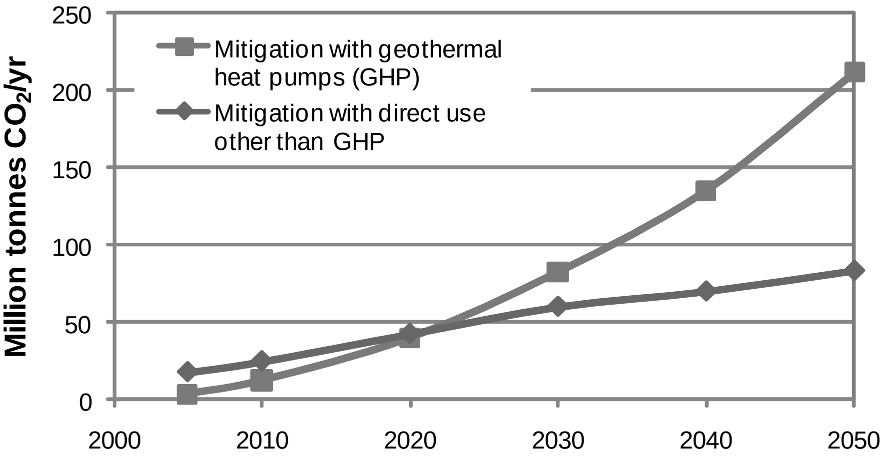

Figure 5. Estimated mitigation potential of geothermal direct heating use in the world. The upper line shows the estimated mitigation from GHPs assuming an emission of 50 tonnes $CO_2$-equivalent/TJ (from Fridleifsson et al. 2008).

## Conclusions

Geothermal energy is available day and night every day of the year and can thus serve as a supplement to energy sources, which are only available intermittently; sustainable production can be achieved. Likely growth scenarios for electricity production and direct use of geothermal energy until 2050 indicate substantial $CO_2$ mitigation potential.

References

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