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Sustainability and policy for the thermal use of shallow geothermal energy

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HIGHLIGHTS

- We provide an overview of consequences of geothermal systems in shallow aquifers.
- Static regulations for heating or cooling groundwater are not recommendable.
- Temperature limits should be flexible and orientated on background values.
- Suggestions for a sustainable policy for shallow geothermal systems are provided.
- A potential legal framework for a sustainable use is presented.

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ABSTRACT

Shallow geothermal energy is a renewable energy resource that has become increasingly important. However, the use has environmental, technical and social consequences. Biological, chemical, and physical characteristics of groundwater and subsurface are influenced by the development of this resource. To guarantee a sustainable use it is therefore necessary to consider environmental and technical criteria, such as changes in groundwater quality and temperature. In the current study a comprehensive overview of consequences of geothermal systems in shallow aquifers is provided. We conclude that there is still a lack of knowledge on long-term environmental consequences. Due to local differences in geology and hydrogeology as well as in technical requirements, it is not recommendable to define only static regulations, such as fixed and absolute temperature thresholds. Flexible temperature limits for heating and cooling the groundwater and subsurface are therefore advisable. The limits should be oriented on previously undisturbed temperatures, and chemical, physical and biological conditions of aquifers. Based on these findings, recommendations for a sustainable policy for shallow geothermal systems are provided including a potential legal framework for a sustainable use.

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1. Introduction

Geothermal energy is one of the rising renewable energies. Low-enthalpy shallow geothermal energy (<400 m depth) is an attractive alternative to fossil resources, especially for the heating and cooling of buildings. The number of geothermal installations has been continuously rising for the past 15 years (Bayer et al., 2012; Lund et al., 2011, 2004; Rybach, 2010; Sanner et al., 2003). In general, it can be distinguished between open and closed geothermal systems, with the latter being mainly ground source heat pump (GSHP) systems. GSHP systems have commonly one or more vertical borehole heat exchangers (BHE) with a circulating heat carrier fluid inside one or more closed pipes that are operated in a closed loop. By continuous circulation, the fluid transports the heat from the subsurface to the heating system of the building, where a heat pump is often applied. If the hydrogeological and hydrochemical conditions are suitable, the energy can also be extracted in an open loop, directly using the groundwater. These applications are called groundwater heat pump (GWHP) systems. Another categorization can be found, which is based on the operation mode and whose variants are distinguished from GSHPs and GWHPs, which are specifically utilized for heat or cold storage. Borehole thermal energy storage (BTES) systems, equivalent to GSHP systems, and aquifer thermal energy storage (ATES) systems, equivalent to GWHP systems, are sub-groups of underground thermal energy storage (UTES) systems, which use the same technology, but are mainly designed to store energy (e.g., Palmer et al., 1992).

The geothermal use of the shallow subsurface can result in local temperature anomalies in the subsurface and the groundwater

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(e.g., Ferguson and Woodbury, 2006; Hähnlein et al., 2010b; Palmer et al., 1992; Pannike et al., 2006; Rybach and Eugster, 2010). These anomalies are often referred to as cold plumes in case of heat extraction, or heat plumes in case of heat injection (e.g., Hähnlein et al., 2010b; Pannike et al., 2006).

Decreasing or increasing temperatures influence chemical (Arning et al., 2006; Brons et al., 1991; Griffioen and Appelo, 1993), biological (Brielmann et al., 2009, 2011; Hall et al., 2008) and physical properties of groundwater (Balke, 1978; Bonte et al., 2011b). Such interventions into the environment may become critical and substantially alter the natural conditions. According to the European environmental policy, these impacts should be minimized on a low level that no detrimental effects can occur (EU-WFD, 2000). At the same time, worldwide energy demand is rising and the popularity of renewables is spurred on by the need of saving or reducing greenhouse gas emissions. Thus, a balance between these interests, i.e. minimizing detrimental effects of renewable energy technologies and rising energy demand, is desirable.

Groundwater has many functions for the biosphere. For example, in Europe about 75% of the habitants and estimated 50% of the world's population are dependent on groundwater as drinking water resource (Brandt and Henriksen, 2003; Danielopol et al., 2008; European-Commission, 2008). In addition, aquifers are habitats for flora and fauna, and is the Earth's largest reservoir of liquid fresh water (Boulton, 2005; Danielopol et al., 2003). For humans, groundwater offers a broad spectrum of ecosystem services and probably the most important one is its role as a fresh water resource. Therefore, the use of the subsurface as a fresh water and energy reservoir has to be well managed. This makes it necessary to design a sustainable use of shallow geothermal energy (Axelsson et al., 2010; Bonte et al., 2011b; Ferguson and Woodbury, 2006), which is also declared by the European Geothermal Energy Council (EGEC, 2006). This may be an intricate task, especially when different system types have to be integrated or even compete with each other. For example, in land planning of urban areas, where aquifer remediation is required, infrastructure such as transportation tunnels and sanitation are foreseen and geothermal energy systems are integrated (Brandl, 2006; Schädler et al., 2011). Bonte et al. (2011b) elaborates on the possible conflicts of use between subsurface functions and groundwater, such as ATES versus water supply or gas storage. In Bonte et al. (2011a) they focus on the effects on groundwater as drinking water source. They conclude that ATES systems have impacts on groundwater and that risk management strategies have to be developed for shallow geothermal storage systems.

In our study, environmental and technical, as well as social and policy aspects are reviewed, which are relevant for the entire spectrum of sustainable thermal use of the shallow groundwater and subsurface. Subsequently, different definitions of sustainability are discussed, and then a possible policy framework is developed that is based on the precautionary principle. Finally, recommendations for a legal policy are deduced.

2. Definition of sustainability

Geothermal energy is regarded as an environmentally friendly (Axelsson and Stefánsson, 2003; Blum et al., 2010), renewable and sustainable energy (Rybach and Mongillo, 2006). *Environmental friendliness* of a potentially green technology is commonly quantified within a life cycle assessment (LCA) framework, including, for example, a CO_2 balance (Bayer et al., 2012; Saner et al., 2010). *Renewable* refers to the natural state of the energy and describes a characteristic of the resource (Rybach and Mongillo, 2006). *Sustainable* applies to the way of how the resource is used (Axelsson, 2010). However, there are diverse and controversial definitions of sustainability (e.g., Mihelcic et al., 2003; Wright, 1998). In fact, the terms renewable and sustainable are dependent on each other, and the difference is not that apparent, for instance, when the geothermal resource is overexploited. In such a case, the extracted energy cannot naturally be replenished, and through this unsustainable use, the geothermal source becomes exhaustible, which is typical for non-renewables. Consequently, the use-mode defines the renewability of the source. Further, the environmental performance is often included in definitions of sustainability, which is expanded to include environmental impacts or merits (e.g., Preene, 2008; Younger, 2008). This reflects that the way a resource is used, and the applied technology and strategy, are determining for the associated primary or secondary environmental impacts. This overlap, therefore, is inevitable and a combined view of sustainability and renewability is reasonable, as a technology with poor environmental performance can hardly be evaluated as sustainable. In the following we categorize technical, ecological and social sustainability. Technical sustainability refers to the production ability and ecological sustainability to the effect of primary environmental consequences. The original idea of social sustainability refers to the social life of state or society. This can be broken down to the level of direct neighborhood and then includes neighborhood dissent, potentially caused by interferences between geothermal systems. This can also be expanded to all social effects, such as financial, caused by the use of shallow geothermal energy.

In the sense of the European Groundwater Act, the aim of sustainable use of shallow geothermal energy is maintaining a good status of the resources (subsurface and groundwater) (EU-GWD, 2006). This leaves considerable freedom for the selection of indicators that measure a satisfactorily “good status”. The original definition of a “good status”, given by the Brundtland Commission (World Commission on Environment and Development, 1987) is: “Meeting the needs of the present generation without compromising the needs of future generations”. This definition also includes economical, ecological and social aspects (UN, 2002). However, referring to geothermal energy, an eminent definition is related to the production ability and thus, represents a technical perspective: “sustainability means the ability of the production system to sustain production levels over long periods” (Rybach, 2003; Rybach and Mongillo, 2006). Preene (2008) adds to this definition the requirement of flexibility in response to any future changes in operation. Rybach and Eugster (2010) suggest that “for each geothermal system and for each mode of production, there exists a certain level of maximum energy production, below which it will be possible to maintain constant energy production from the system for a very long time (100–300 years)”. This technical interpretation of sustainability is oriented at the extractable energy of the natural system and is suitable especially for deep production systems. In Axelsson (2010), four modes for sustainable deep and/or high enthalpy geothermal utilization, based on the definition above, are presented: (i) constant production on the sustainable level, where sustainability is related to the production ability of the system over a long period; (ii) stepwise increasing of production until sustainable level is achieved; (iii) cyclic production (with an alternation of excessive production and periods of dormancy to allow for recovery); and (iv) an excessive production followed by a reduced, steady production. In principle, these modes can be adapted to the production of shallow geothermal energy with shorter production cycles and lifetimes.

Above mentioned descriptions of sustainability are all focused on reaching and maintaining a high efficiency by a technically robust geothermal system (technical sustainability). For a specific case, this requires energy-balance calculations, consideration of normal, peak demand and paused operation mode, and reliable predictions for the entire lifetime of a system. Social and ecological aspects are not covered in this definition. According to Rybach and Eugster (2010), this is due to the time-variability of these criteria, having in mind that shallow geothermal installations usually operate for decades. Another reason is that productivity and

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