Renewable and Sustainable Energy Reviews 14 (2010) 2611–2625

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

International legal status of the use of shallow geothermal energy

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ARTICLE INFO

Article history:
Received 7 July 2010
Accepted 21 July 2010

Keywords:
Geothermal energy
Renewable energy
International legislation
Ground source heat pump (GSHP) systems
Borehole heat exchanger (BHE)

ABSTRACT

Shallow geothermal energy (<400 m depth) is used in many countries worldwide, with a rising number of installations over the last decades. The use of ground source heat pump (GSHP) and groundwater heat pump (GWHP) systems results in local temperature anomalies (cold or heat plumes). Since groundwater is used in many countries as source for drinking water a balance between its use and protection has to be found. Therefore, to avoid detrimental environmental impacts it is necessary to define groundwater temperature limits for heating and cooling and minimum distances between such geothermal systems. The aim of the present study is to provide a comprehensive overview of the current international legal status for the use of shallow geothermal energy. Therefore, an international survey was performed using a questionnaire, which was sent to more than 60 countries worldwide. The questionnaire requested information on the corresponding national legislation, temperature limits and minimum distances for GSHP and GWHP systems. The answers to the inquiry showed an extremely heterogeneous outcome. Until now national and legally binding regulations only exist in few countries such as Denmark or Sweden. However, all existing regulations show a wide range for minimum distances (5–300 m) and temperature limits for groundwater. The highest inconsistency was observed for the acceptable temperature change with 3 K in Switzerland to 11 K in France. However, most countries have no legally binding regulations or even guidelines, which highlight the urgent need for further research on the environmental impact and legal management of shallow geothermal installations.

Contents

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.07.069

1. Introduction

Energy safety, energy independence and the reduction of greenhouse gas emissions are imperative issues in current and future politics. Many countries support the development of renewable energy technologies such as geothermal energy. While deep geothermal applications (about >400 m depth) are specific and of large size, shallow systems (<400 m depth) require no extraordinary geological settings or high geothermal gradients. They are based on simple, established technological principles and therefore great in numbers and popular worldwide. Especially for domestic cooling and heating, the use of shallow geothermal energy is considered an environmental friendly alternative to traditional heating techniques such as oil or gas fired boilers [1,2]. The major technological variants are ground source heat pump (GSHP) and groundwater heat pump (GWHP) systems (Fig. 1).

GSHP systems are closed systems with a vertical borehole heat exchanger (BHE) or, less common, with a horizontal heat exchanger [3]. A heat carrier fluid is circulated within the buried closed tube system to transport heat stored in the subsurface to the aboveground heating system of a building. By using heat pumps, hot water can be generated while lowering the heat carrier fluid temperatures only by a few degrees. During warm seasons and for

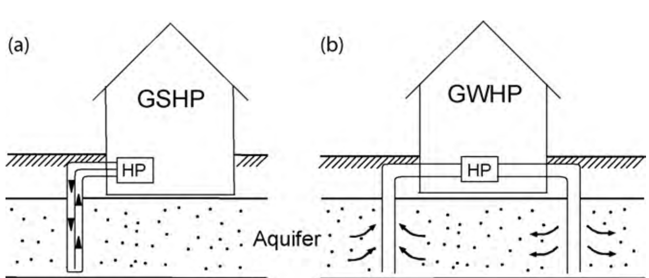

Fig. 1. (a) Ground source heat pump (GSHP) system and (b) groundwater heat pump (GWHP) system, both with a heat pump (HP).

release of waste heat in general, the fluid can also be used in reversed mode to convey heat to the ground. In comparison to the well manageable GSHP systems, GWHP systems are less frequently used. They are open systems, with circulated (ground)water between two or more wells. Though attractive because of the efficient direct use of groundwater, GWHP systems are more demanding due to the permanent maintenance of wells, induced hydraulic effects and hydrogeological requirements [4].

Many synonyms for GSHP systems are used such as closed loop systems and ground coupled heat pump systems. Equivalently, GWHP systems are also called open systems or open loop systems [5–11]. Aquifer thermal energy storage (ATES) and borehole thermal energy storage (BTES) systems are sub-groups of underground thermal energy storage (UTES) systems. The idea is to store the heat or cold when it is available and exploit it when it is needed. The technology of ATES (BTES) is the same as for GWHP (GSHP) systems. The difference is that for ATES and BTES larger systems with multiple boreholes or wells are normally installed [12]. For the sake of clarity, in the rest of the paper we only distinguish between closed and open, i.e. GSHP and GWHP systems.

The number of shallow geothermal installations has been continually increasing over the last decades with a peak in 2006 [1,5,6,9,13–17]. In 2004 the number of installed GSHP systems worldwide was roughly estimated at 1.1 million [17]. Such a number and expected proliferation in the future substantiates the need for a concerted regulative framework. This is particularly crucial, as shallow geothermal systems once installed, are operated for decades. Precautionary principles would require complying with well-defined sustainability standards while minimizing associated adverse environmental impacts [18]. From a more technical perspective, focus would be set on robustness and energy-efficiency. Appropriate directives can guide and also control, since an increase in popularity means also increase in competition, especially in urban areas [19] and for the use of productive aquifers in general. However, if implemented at all, we and others observe that existing regulations in different countries or states are very heterogeneous

[20–22]. Often the underlying scientific, technological or practical basis is not apparent and empirical motives seem to be followed. This study provides an insight into the variability of current international regulations and directives, and is meant as stimulus to attain convergence between the different frameworks that are reported for each country. For this a customized questionnaire was answered by experts from 46 countries. The persons asked are representatives from industry, academics and public authorities and listed in the acknowledgements.

2. Regulation criteria

2.1. Background

The use of shallow geothermal energy results in local temperature anomalies (cold or heat plumes) in the subsurface [23–28]. It is well known that changes in groundwater temperature can influence its physical properties, chemical reactions, microbiology and the interaction of these factors with each other [29–39]. This is important, especially because groundwater provides globally 50% of the drinking water [40,41]. Further, aquifers represent sluggish environments, with slow turn-over rates and long memory. Therefore long-term effects of shallow geothermal systems have to be carefully considered to find a balance between groundwater usage by shallow geothermal energy and groundwater protection. As technical rules, some countries, such as Sweden, Germany or Denmark, defined minimum distances between the installed GSHP systems and another point of reference such as property line or next GSHP system [24,25,42]. As ecological criteria threshold values for temperature changes in groundwater are defined for example in Liechtenstein or Austria [43,44].

Environmental, sustainability-based and/or technico-economic criteria have been proposed by various researchers and practitioners. However, embedding of appropriate criteria to control geothermal groundwater use in national and international legislation is still at an initial state. For example, in 2000 the European Union (EU) Water Framework Directive (WFD) defined the release of heat into the groundwater as pollution [45]. However, the cooling of groundwater is not especially mentioned. For the environment policy the WFD describes currently the following aim: to "ensure the progressive reduction of pollution of groundwater and prevent its further pollution". The additional European Groundwater Directive (GWD) "establishes specific measures [...] in order to prevent and control groundwater pollution" [46]. Some of the national legislations have more far-reaching definitions. For example, in Germany, detrimental changes in physical, chemical and biological characteristics have to be avoided [47]. In Switzerland, the biocenosis of groundwater should be in natural state [48,49]. However, in both examples an exact definition of 'detrimental changes' and 'natural state' is absent. And Hitherto, there are also no European wide technical standards for the BHE of GSHP systems, whereas for heat pumps (e.g. EN 378 [50]) and for the safety of drilling rigs (EN 791 [51]) there is a comprehensive set of technical statutes [52]. All these basic EN standards for testing, rating, safety have been adopted by the EU member states [53].

Two European research projects have studied the legislation of geothermal systems. The GeoThermal Regulation-Heat (GTR-H) project, finished in October 2009, reviewed regulatory barriers and deficiencies for geothermal heating in the four unregulated EU countries Hungary, Ireland, Poland and United Kingdom (UK) [22]. The topics were regulation/legislation, geothermal resource data and information access, incentives, taxation, fees and royalty and the last one professional code of practice. The lack of clarity in energy, water and environmental legislation and specific regulation for geothermal energy were identified as the most primary regulatory barriers in all four countries. In addition financial aspects were identified as the main barrier in Poland and resource data availability in Ireland and UK [54]. Thereby it was not distinguished between deep and shallow geothermal energy. In addition, a review of the current best practice regulatory frameworks for the use of geothermal energy in three countries (France, Germany, and Netherlands) was carried out [55]. Finally a template for a regulatory framework was published. Therein shallow and deep geothermal is defined. The draft provides advice, for example for resource ownership, licensing system, simplified regulations and administrative procedures [56].

The second European project is GROUND-REACH, completed in December 2008 [21]. Its aim was to intensive the use of shallow geothermal installations with the superordinate target to reach the Kyoto criteria. Therefore the merits, benefits and market barriers, including legislative difficulties, in numerous EU member states were outlined. It was found out that the current governmental policy does not properly promote geothermal energy and that support in general is focused on power generation. To overcome this, a short term European information and promotion campaign for a fast market penetration of GSHP systems was started. As geothermal energy in many European countries is regulated by national Mining or Water Acts and responsibilities are spread out among different ministries or institutes, international cooperation and a harmonization of legislation are found to be rather difficult. Also, inconsistent legislative frameworks around Europe in some cases represent a real barrier to finding a common way of concerted geothermal energy use. Hence, a major conclusion of this project is that it is necessary to set up clear regulation to secure an environmentally friendly use of geothermal energy, in particular concerning protection of underground drinking water resources [16,21].

2.2. Types of criteria

In Table 1 different possible types of criteria for a sustainable thermal use of groundwater are listed. Since they represent the most commonly regulated aspects, our focus is on those rules given for temperature and minimum distances between nearby shallow

Table 1
Criteria for a sustainable thermal use of groundwater.

Criterion	Purpose
Technical accurate drilling and installation	Guarantee of operation
	Protection of groundwater as a resource for drinking water
Backfilling	Avoid leakage of hazardous materials (e.g. heat carrier fluid, drilling fluid, secondary contaminants such as oil of vehicles, drilling apparatus, etc.)
	Avoid changes in groundwater ecology
	Avoid hydraulic contacts between different aquifer systems
Minimum distances	Avoid accumulation of temperature changes
	Avoid interaction with other shallow geothermal systems
	Avoid influence on other technical systems (drinking water wells, water pipes, neighboring ground)
Temperature thresholds	Avoid changes in groundwater ecology
	Guarantee of operation

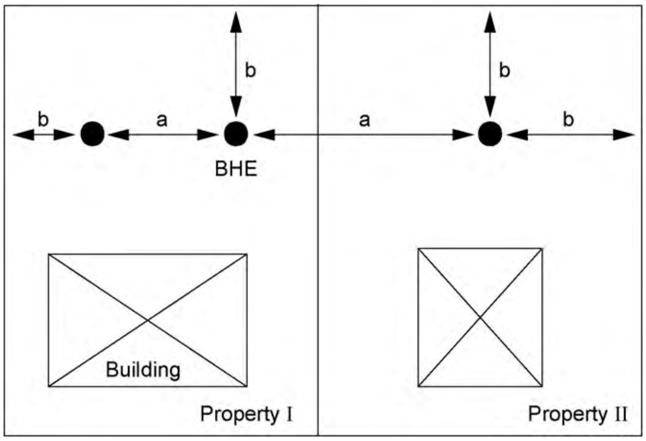

Fig. 2. Minimum distance criteria: (a) describes the distance between neighboring borehole heat exchangers (BHEs) and (b) depicts the distance from the BHE to the next property line.

geothermal installations. Minimum distances criteria between adjacent GSHP systems can be distinguished in minimum distance between technical installations and: (i) borehole heat exchanger or groundwater wells, respectively, (ii) property line, (iii) next building, (iv) drinking water well, or (v) other public installations (e.g. power line). Fig. 2 illustrates minimum distance criteria between adjacent borehole heat exchangers (BHEs) and the closest property line. Technical thresholds are also sometimes expressed with respect to energy extraction rates (''loads''). They are specified for example as allowed 'mean load' during one week or as 'peak load'. 'Peak load' describes a maximum energy extraction that is only permitted in exceptional cases [57].

Minimum distances are often favored, because thresholds can easily be defined, controlled and communicated. Such distance restrictions are intended to indirectly limit spread and intensity of local temperature anomalies. By consideration of heat extraction (or injection) rates, lateral extension and long-term development of temperature plumes can be anticipated (Fig. 3). Limits on heat extraction rates also foster thermal recovery by natural conductive and convective heat supply, and thus support robust design and operation. Interestingly, only spatial distances are regulated. However, even if a system is operated with uniform (seasonal) loads, effects on underground temperatures change over time. This is demonstrated for example in a case study by Rybach and Eugster [58]. If a GSHP is mainly run in the heating mode, temperature drops significantly in the first years. Later the generated annual deficit decreases, as the generated temperature gradients around a BHE expedite heat supply by conduction.

Especially in densely populated urban areas, distance restrictions help to avoid or minimize mutual influence between GSHP or GWHP systems on neighboring properties. However, commonly the true development of anomalies is neither known nor typically monitored. This is particularly relevant, as the generated temperature distribution is, among other factors, controlled by distinct and too some degree uncertain hydrogeological site parameters. Highly conductive aquifers with high flow velocities are more attractive since convective supply of heat can replenish local energy deficits more easily there than in low flow systems. In contrast, the more intense the flow velocity the more asymmetric plumes evolve [25]. Knowledge of groundwater flow velocity and direction would be necessary, however, to reliably predict influences on neighboring installations or properties, which might also substantially vary along the flow direction.

Definition of hydraulic criteria is principally relevant for open systems. Local groundwater extractions or injections of GWHP systems can adversely affect the local hydraulic regime. Subsidence may occur, although significant magnitudes are only observed for large installations [59]. Regulations for groundwater management, well design and operation are already established (e.g. [4]) and not further examined here. Sometimes, the hydraulic effects of GSHP systems are also of concern. For example in Sweden, backfilling of BHEs is usually not required and applied, whereas in Germany and Switzerland BHEs have to be fully backfilled with a concrete-bentonite mixture. This is to avoid artificial connection between different aquifer systems. It is also intended as safety measure to seal the boreholes and counteract potential leakage of the tubes in case of faulty design or material aging [53,60].

GSHP and GWHP systems commonly use normal groundwater temperatures between 5 and 30 °C [61]. Typical temperature ranges of a single GSHP system are around ±5 K in relation to the natural groundwater temperature. For a GWHP system the temperature range is around ±10 K. It is known that physical groundwater properties such as density, viscosity and flow velocity are temperature-dependent as well as heat capacity and thermal conductivity of the porous media [26]. Thereby, the flow velocity of water is linearly linked to the viscosity. A cooling of 2.5 °C increases the groundwater viscosity about 7% [31]. The groundwater flow velocity increases with 2-3% per one degree of temperature rise [29,30]. This is important due to the fact that the length of the temperature plume becomes shorter with increasing flow velocity [25].

In general, three types of temperature thresholds are defined: (i) an absolute allowed minimum temperature, (ii) an absolute allowed maximum temperature and (iii) a relative value describing the accepted temperature difference between disturbed and ambient undisturbed temperature. These criteria can also be distinguished in (i) technical thresholds for the heat carrier fluid in the BHE and (ii) environmentally or ecologically motivated temperature thresholds to restrain temperature changes in the aquifer. Constraints on heat carrier fluid temperature are discussed to avoid freezing and to keep temperature variations in the BHE

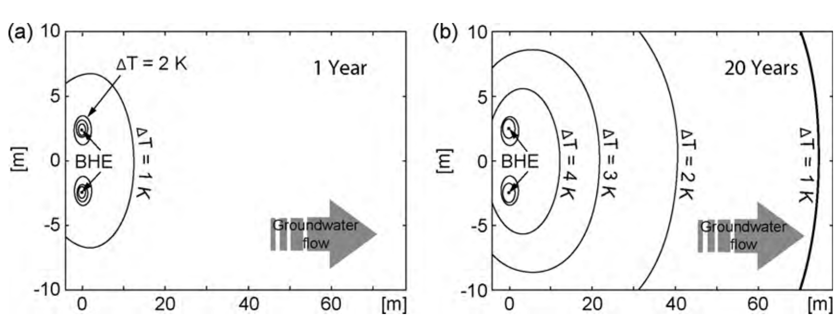

Fig. 3. Top view on simulated temperature anomalies (cold plumes) in a hypothetical aquifer: (a) depicts the length of a cold plume after 1 year, (b) after 20 years. In both cases a heat extraction of 80 W/m in 1800 h/year in low convective aquifer (groundwater flow: 1×10^{-7} m/s) is assumed. ΔT describes the difference between undisturbed and disturbed groundwater temperature.

within a defined range. This is to guarantee long-term stability and to avoid disintegration of the borehole grouting material.

Ecologically motivated or environmental criteria, even if they are taken as basis for regulations, are rarely reported. The chief concern appears to be the prevention of bacteria growth at elevated groundwater temperatures. This is also a primary reason for setting restrictions on the distance between geothermal installations and freshwater wells. Already in the 1970s, mainly caused by the 1973 oil crisis, geothermal energy use was often favored for heating and cooling [62]. The controlled change of groundwater temperature was considered as key issue for an environmental friendly thermal use of groundwater [62]. In 1978 Andrews [63] concluded that as long as surface impacts caused by lowering of groundwater temperatures are minor, groundwater can be used as a source of energy until the temperature is decreased to a point, in which energy extraction is no longer economically feasible. Meanwhile, such an opinion appears widely outdated. Although not visible, hydrogeological environments are considered as safeguard subjects themselves with their specific characteristics and importance for intrinsic and dependent ecosystems. Aquifers offer ecosystem services of high economic value and are of enormous importance as ubiquitous freshwater reservoirs. However, studies on the impact of geothermal use on groundwater ecosystem are extremely scarce [36,38,39,64]. Hence, it is still necessary to develop specific evaluation mechanisms to study such impacts [48,65].

3. Country overview

In this chapter, regulations in selected countries are separately presented and discussed. The collected information from questionnaires (Table 2) is completed with a comprehensive review of publicly available literature and legislations dealing with shallow geothermal energy. Thus, a comprehensive analysis of the current international legal state is elaborated that describes the common practice in most countries using shallow geothermal energy. The collected record is extensive, but of course not complete. It can easily be extended once further data is accessible or country specific updates are available.

Table 3 summarizes all identified laws regarding shallow geothermal energy. Furthermore, Table 4 provides an overview about the legal status of regulations for ecological and technological temperature thresholds and minimum distances for open and closed systems of the countries that answered the questionnaire.

3.1. Australia

Federal geothermal regulations are variable in Australia. Ownership and regulations of onshore resources vary with each state and territory government. Shallow geothermal systems in Australia are not comprehensively monitored or regulated by the government. Their use is currently not widespread; however, there is an increasing trend. One of the largest installations, with 350 boreholes of 100 m depth is in the Geoscience Australia headquarters near Canberra [66,67].

In Western Australia neither temperature thresholds for heating and cooling of the groundwater nor regulations for minimum distances are defined. Water usage or production of any water for the operation of such systems is subject to the more general laws such as Rights in Water and Irrigation Act of 1914. The Petroleum and Geothermal Energy Resources Act from 1967 is not valid for small-scale installations such as GSHP systems. In the federal state of Queensland, for example, also no temperature thresholds and regulations for minimum distances exist. The Water Act from 2000 is only concerned about groundwater for other uses such as stock and domestic purposes. However, there is a need to obtain a water license for geothermal purposes, if the water is to be extracted and used (i.e. for open systems). Policy and legislation in relation to domestic use of geothermal energy are currently under development in Queensland and will be enacted in 2010.

Table 2
International questionnaire.

Question	Possible answers
Are there temperature thresholds?	Yes/No
If yes:	
Please report the specific values	Technical thresholds Relative values (limit for heating/cooling) Absolute values (maximum/minimum temperature) Technical thresholds Relative values (limit for heating/cooling) Absolute values (maximum/minimum temperature)
Are the thresholds legally binding?	Yes/No; Level (state, city, etc.)
Which are the relevant laws/ordinances?	Title, year
What is the basis for these values?	Rule of thumb Scientific studies Something else
If no:	
Is there a particular reason?	Yes/No; Explanation
Are any regulations planed for the future?	Yes/No; Description
Are there regulations referring to minimum distances?	Yes/No
If yes:	
Which are the relevant laws/ordinances?	Title, year, name of the law/ordinance
What is the basis for these values?	Rule of thumb Result of research Something else
If no:	
Is there a particular reason?	Yes/No; Explanation
Are any regulations planed for the future?	Yes/No; Description
Does your country have any other laws, ordinances or regulations concerning thermal groundwater use?	Yes/No
If yes, which are the relevant laws or ordinances?	Title, year, comments

Table 3
Laws concerning the use of shallow geothermal energy.

Country	Laws (publishing date)	Country	Laws (publishing date)
Australia	Energy Resources Act (1967) The Petroleum and Geothermal Rights in Water and Irrigation Act (1914) Water Act (2000)	Indonesia	Geothermal Law (23/10/2003)
Austria	Österreichischer Wasser- und Abfallzweckverband (ÖWAV) Regelblatt 207: Thermal Use of Groundwater and Subsurface – Heating and Cooling (2009)	Lithuania	Underground Law (I-1034, 05/01/1996)
Belgium	Decree on Environmental Permits (28/06/1985)	Mexico	Water Act (1992)
Bulgaria	Constitution (1991) Law on the Renewable and Alternative Sources of Energy and the Biofuels (2007) Water Act (1999)	Netherlands	Groundwater Law (1981) Mining Law (01/01/2003)
Canada	Water Act (1985)	Norway	Neighbor Law (n.a.)
China	Renewable Energy Law (2006)	Philippines	Economic Activity Law (n.a.) Geological and Mining Law (19/11/1999) Renewable Energy Act (2008)
Czech Republic	Building and Planning Act (No 183/2006)	Poland	Water Act (1974)
Denmark	Order on Heat Abstraction and Groundwater Cooling Plants (BEK-1206, 24/11/2006) Order on Groundwater Heating BEK-1203, 20/11/2006)	Portugal	Decree-Law 87/90 (16/03/1990)
Ecuador	Water Act (n.a.)	Romania	Environment Protection Law (No. 265/2006) Mining Law (No. 61/1998) Water Law (No. 310/2004)
Finland	Environmental Protection Act (2000) Water Act (1961)	Slovakia	Water Law (2004) (Law No. 364/2004)
France	Decree 74-498 (24/03/1978) Decree 77-620 (16/06/1977) Decree 78-498 (28/03/1978) Mining Law (16/08/1956)	Slovenia	Mining Law 2004 (Official Gazette, 98/2004) Water Law 2002 (Official Gazette, 67/2002)
Germany	Mining Law (13/08/1980) Federal Water Act (27/07/1957)	Sweden	Normbrunn 97 (2002)/Normbrunn 07 (2008)
Great Britain	Water Environment Regulations (2005)	Switzerland	Water Protection Order (28/10/1998)
Greece	Decision of Minister of Development No. Δ9B, Δ/Φ166/OIK 18508/5552/207 on Installation Permits for Ground Source Heat Pumps (n.a.)		

n.a., not available.

3.2. Austria

In Austria no federal law for shallow geothermal energy has yet been defined. However, in Upper Austria technical temperature thresholds apply for the heat carrier fluid and minimum distances for adjacent GSHP systems. The technical thresholds are ±15 K as temperature difference and 35 °C as maximum temperature. The recommended minimum distance to the property line is restricted to 2.5 m. For open GWHP systems there are temperature limits for heating and cooling of the groundwater. These legally binding thresholds of 6 K, 5 and 20 °C for temperature difference, minimum and maximum are average values compared with international practice (Table 7). To estimate the length of cold or heat plumes of open systems an analytical model is recommended by Rauch [68].

There are also some general national industry standards relevant for GSHP systems, which concern the heat pump (ÖNORM M 7753, ÖNORM M 7755-2+3) and the 'systems for the exploitation of geothermal heat' (ÖWAV RB 207) [52]. In addition, some regions such as Carinthia and Vorarlberg have their own recommendations for minimum distances. Here, in Carinthia, a minimum distance of 4 m to the neighboring property is binding [69].

3.3. Belgium

For Flanders, the Flemish Region in northern Belgium, no general law for the thermal use of groundwater exists at this time. Hence, there are neither temperature limits for the change of groundwater temperature, nor minimum distances. Permissions are regulated in the Decree on Environmental Permits from 1985. Here, no specific aspects of thermal use of groundwater or the subsurface are included. Decisions are based on general permit rules, depending on the local situation of the aquifer.

3.4. Bosnia and Herzegovina

There are currently no special regulations for shallow geothermal installations in Bosnia and Herzegovina. The main reason is that there is no financial support from the authorities for the development of geothermal energy. Hence, there is currently hardly any motivation of the population or the financial sector to invest in such renewable energy systems.

3.5. Bulgaria

In Bulgaria, there is the recent Water Act – following the EU-WFD – where the injection of heat in water is defined as pollution [70]. The use of thermal waters is included in the Water Act and Constitution (1999); they are owned by the state or by municipalities [71]. The use of renewable energy including geothermal energy is however presently promoted with the Law on the Renewable and Alternative Sources of Energy and the Biofuels [72]. For obtaining permits and concessions, some regulations exist and also guidelines for geothermal exploration. There is no specific law that controls shallow geothermal energy. Temperature limits for groundwater use and minimum distances are therefore missing [73].

Table 4
International legal situation for closed and open shallow geothermal energy systems (according to questionnaire response).

	Open systems			Closed systems		
	Ecology	Technology	Minimum distances	Ecology	Technology	Minimum distances
Albania	–	–	–	–	–	–
Australia	–	–	–	–	–	–
Austria	+	–	–	–	+	+
Belgium (Fl.)	–	–	–	–	–	–
Bosnia and Herzegovina	–	–	–	–	–	–
Bulgaria	–	–	–	–	–	–
Canada	–	–	–	–	–	–
China	–	–	–	–	–	–
Costa Rica	–	–	–	–	–	–
Czech Republic	–	–	+	–	–	+
Denmark	+	–	–	–	+	+
Ecuador	–	–	–	–	–	–
El Salvador	–	–	–	–	–	–
Finland	–	–	–	–	–	o
France	+	–	–	–	–	–
Germany	o	o	o	–	o	o
Great Britain	o	o	?	?	?	?
Greece	–	–	+	–	–	–
Honduras	–	–	–	–	–	–
Hungary	–	–	–	–	–	–
Iceland	–	–	–	–	–	–
India	–	–	–	–	–	–
Ireland	–	–	–	–	–	–
Japan	–	–	–	–	–	–
Korea	–	–	–	–	–	–
Latvia	–	–	–	–	–	–
Liechtenstein	+	–	–	–	–	+
Lithuania	–	–	–	–	–	–
Macedonia	–	–	–	–	–	–
Mexico	–	–	–	–	–	–
Netherlands	+	–	–	–	–	–
New Zealand	–	–	–	–	–	–
Norway	–	–	–	–	–	–
Philippines	–	–	–	–	–	–
Portugal	–	–	–	–	–	–
Romania	–	–	–	–	–	–
Saudi Arabia	–	–	–	–	–	–
Scotland	–	–	–	–	–	–
Slovakia	–	–	–	–	–	–
Slovenia	–	–	–	–	–	–
Spain	–	–	–	–	–	–
Sweden	?	?	o	?	?	o
Switzerland	+	?	?	+	?	?
Turkey	–	–	–	–	–	–
USA	?	?	+	?	?	+
Vietnam	–	–	–	–	–	–
Summary	6 + 2 o	2 o	3 + 2 o	2 +	2 + 1 o	5 + 3 o

?, no information available; –, No regulations; +, Legally binding; o, Recommended.

3.6. Canada

Shallow geothermal installations have a long tradition in Canada. Nevertheless, there are no regulations from the federal government, due to the fact that some natural resources such as geothermal energy and groundwater are generally property of the Queen of Canada; however these resources are managed by Canadian provinces. The general Water Act regulates concessions for the direct use of groundwater. As of now, thermal impacts have not yet been investigated or documented, so there are no defined temperature action values or minimum distances. Guidelines for the design and implementation of GSHP systems are given in standard CSA-448-02 (Design and Installation of Earth Energy Systems). In the province of *Ontario* there is currently an initiative to develop regulations for shallow geothermal energy use.

3.7. China

Research on GSHP systems and their commercial use started in the 1980s [17]. In 2006 the China Renewable Energy Law and also the first technical standard for geothermal heat pump systems (GB50366-2005) was enacted. It is valid for open and closed systems and also for surface water heat pumps and it contains project investigation, general information for such systems, for example system design or backfilling material. As distance between each BHE for GSHP systems 3 and 6 m are recommended [74]. Since 2006 general documents on renewable energy have increasingly been issued by the Chinese authorities [17]. In practice a minimum distance of 4 m between individual BHEs is usually applied. However, there are not yet any regulations for temperature thresholds or minimum distances for closed and open systems.

Table 5
International technical temperature limits for the heat carrier fluid inside the borehole heat exchanger of a GSHP system.

Country	Temperature difference [K]	Temperature maximum [°C]	Temperature minimum [°C]
Austria	±15	35	0[a]/−5[b]
Denmark	–	25	2
Germany	±11 [a]/±17 [b]	–	–

[a] With weekly mean load.
[b] With peak load.

3.8. Costa Rica

Costa Rica is a tropical country with an average temperature of about 20 °C throughout the year. Thus, geothermal energy is currently only considered for electricity production. At present there are five power plants and one under construction. Shallow geothermal utilization is mainly for swimming pools and balneology, for which no special legislation applies.

3.9. Czech Republic

In the Czech Republic the same procedures are valid for open and for closed groundwater systems. Regulations do not distinguish between planning, permission, control, evaluation and monitoring. All systems with quantitative or qualitative impact on the groundwater resource need permission from the regional water authority. They decide each single case based on hydrogeological assessment from an external expert. Hence, considerable differences exist between the 13 different regions and general valid temperature thresholds are mostly not available. Nevertheless, the minimum distance of 5 m between a geothermal system and the next property line is regulated by the federal Building and Planning Act of 2006 (Table 6).

3.10. Denmark

In Denmark ecological temperature thresholds for closed systems are embedded in the Order on Heat Abstraction and Groundwater Cooling Plants from 2006 (Table 5). They are legally binding on a state level [75]. Heat extraction, and consequently the cooling of groundwater, is not considered an environmental problem. However, there is a minimum distance of 300 m between a GSHP system and a drinking water supply well (Table 6). This value is based on estimated degradation times of bacterial parameters and embedded in the National Order on Groundwater Heating (2006). In contrast, for open systems an empirical temperature maximum of 25 °C and minimum of 2 °C for the groundwater is defined, which are legally binding on state level (Table 7). For both national orders a revision is currently planned.

Table 7
International groundwater temperature thresholds for open geothermal systems.

Country	Temperature difference [±K]	Temperature maximum [°C]	Temperature minimum [°C]
Austria	6[a]	20[a]	5[a]
Denmark	–	25[a]	2[a]
France	11[a]	–	–
Germany	6[b]	20[b]	5[b]
Great Britain	10[b]	25[b]	–
Liechtenstein	−3/+1.5[a]	–	–
Netherlands	–	25[a]	5[a]
Switzerland	3[a]	–	–

[a] Legally binding.
[b] Recommended.

3.11. Ecuador

Due to the geological conditions in Ecuador the focus is predominantly on the use of high temperature geothermal energy. The actual government is willing to develop geothermal resources for electricity generation and direct use [67]. The actual water law allows the use of thermal waters only for social purposes, especially swimming pools and spas. According to our knowledge no geothermal heat pumps are used for heating or air conditioning. Therefore no regulations exist for closed and open geothermal systems. However, the situation might change in the near future, due to the new water law, which is under discussion at the National Congress of Ecuador. In the latter important issues are ecological aspects and ancestral rights.

3.12. El Salvador

According to our knowledge in El Salvador groundwater is not used for domestic heating and cooling. Thus, no laws, ordinances or regulations on the use of shallow geothermal energy are yet defined. Until 2005 only some interest in the direct use of geothermal heat for drying grains, coffee beans and fruits was

Table 6
Recommended and legally binding minimum distances for closed and open geothermal systems.

Country	Closed systems	Open systems	Legal status
Austria	2.5 m to the next property line	–	Recommended
China	3–6 m to the next BHE	–	Recommended
Czech Republic	5 m to the next property line	5 m to next property line	Legally binding
Denmark	300 m to drinking water well	–	Legally binding
Finland	30 m to all wastewaters, 20 m to the onsite wastewater treatment system, 5 m to the sewers and water pipes, 20 m to the dug or energy well, 40 m to the bored well, 3 m to the next building, 10 m to the next property line	–	Recommended
Germany	5 m to the next property line, 10 m to the next installation	–	Recommended and state specific
Greece	–	5 m to the neighboring buildings, 20 m to the next power line	Legally binding, if included in permission
Liechtenstein	3 m to the next property line, 6 m to the next installation	–	Recommended
Sweden	10 m to the next property line, 20 m to the next installation, 30 m to the next drinking water well	10 m to the next property line, 20 m to the next installation, 30 m to the next drinking water well	Recommended
Switzerland	3–4 m to the next property line, 5–8 m to the next installation	–	Recommended/Legally binding

reported [67]. Only high temperature geothermal resources (>150 °C) from depths between 600 m and 2.5 km are used for electricity production in the geothermal power plants of Ahuachapán and Berlín.

3.13. Finland

In Finland there are no national regulations on temperature thresholds as of now. Before 2009 only two municipal guidelines with recommended minimum distances between two BHE used for GSHP systems existed. In 2009 the Finnish Environment Institute (SYKE) published a guidebook with regulations for GSHP systems regarding recommended minimum distances between a GSHP system, a well building and property line [76]. The distance between two boreholes (BHE) used for GSHP systems should be 15 m. The distance between BHE and property line is 5 m in Tampere and 7.5 m in Helsinki. Related laws are the Water Act (1961) and the Environmental Protection Act (2000). However, these are general regulations without direct reference to the thermal use of groundwater.

3.14. France

There is a legal framework defined by several French laws and regulations. Geothermal energy is mainly embedded in the mining law (Code Minier). The resource belongs to the state and therefore a permission is necessary (Decree 77-620 (16/06/1977) and Decree 74-498 (24/03/1978)) [14,53]. Low-enthalpy geothermal deposits (drilling depth less than 100 m, maximum possible heat extraction rate is less than 200 Thermies per hour, with 1 Thermie = 1.128 kJ = 0.3 kWh) are exempt of these authorizations according to Decree 78-498 (28/03/1978 – Section 17).

For closed systems no explicit temperature limits for the groundwater are defined. Nevertheless, there applies a liberal temperature limit of 11 K for the change in groundwater temperature as stipulated by the Water Law, which is part of the Environmental Code (Table 7).

3.15. Germany

According to the German mining law (Bundesberggesetz, BBergG) shallow geothermal energy belongs to the federal state [77]. The state can allow the extraction of geothermal energy, if groundwater is concerned, then the federal Water Act (2002) is applicable. According to this law detrimental changes in chemical, biological and physical characteristics have to be avoided. However, no clear definition of these detrimental changes exists yet [47]. For the application of GSHP systems, currently 15 out of 16 federal states have their own guidelines (e.g. [78–81]). They describe the permission process and local regulations for the use of vertical and horizontal GSHP systems. They also include recommended minimum distances that range between 5 and 10 m between two BHE and 3 and 5 m between BHE and property line. An overview of these processes and regulations is given in Ref. [82]. In the state of Baden-Württemberg a guideline for open systems was published in 2009 [83], which is the first one in Germany. It also includes an analytical solution for calculating the length of cold plumes for open geothermal systems.

In addition, there are some technical and general guidelines such as the VDI 4640 and VBI-guideline [57,84–87]. They provide advice, for example, for planning and design of such shallow systems. The VDI 4640 includes different recommendations for maximum temperature and temperature difference for heating and cooling of the heat carrier fluid and for the groundwater (Tables 5 and 7).

3.16. Great Britain

The Environment Agency (EA) in Great Britain is in charge of England and Wales, whereas Scotland and Northern Ireland have their own agencies. There are currently no national regulations on geothermal energy in Great Britain [14].

In *England* and *Wales* no emperature thresholds and minimum distances for the use of closed systems are yet defined. Furthermore, no license is necessary for GSHP systems. The direct use of groundwater for GWHP systems has to be announced to the Environmental Agency; the purpose and the amount of extracted groundwater must be indicated. However, for an abstraction volume less than 20 m^2 per day no abstraction license is needed [88]. The existing temperature thresholds such as the 25 °C for the maximum temperature for the injection well are internally set as an initial starting point to control the local discharge of heated up groundwater to the confined Chalk in London (Table 7). However, they are not part of any law and therefore recommended but not legally binding thresholds.

In *Scotland* there are also no individual regulations on temperature changes or minimum distances for closed and open systems. The Water Environment Regulations (2005) includes General Binding Rules for specific low risk activities such as shallow open loop ground source heat/cooling systems, i.e. to a maximum of approximately 100 m depth. General Binding Rule 17 concerns the abstraction and subsequent return of groundwater for the purpose of extracting geothermal energy. It states that the abstracted water must be returned to the same geological formation from which it was abstracted. The volume of injected water must be the same as the extracted volume. The chemical composition of the abstracted water must not be altered prior to its return to the geological formation. Future regulations on shallow geothermal systems are planned.

3.17. Greece

There are no regulations or recommendations for temperature thresholds in the legislation of Greece. Groundwater with temperatures below 25 °C is not considered as a mineral resource. However, a water permit is needed for GSHP systems using groundwater temperature below 25 °C, according to the Minister's Decision (Table 3). It also recommends a minimum distance of 5 m to the neighboring buildings [89].

3.18. Hungary

There is no specific act for shallow geothermal energy. However, existing regulations consider facilities using ground heat as water facilities, for which an installation and operation license is needed. The national Water Act defines geothermal water as the water from the underground with temperature of 30 °C or higher. Extraction of geothermal energy from the ground is embedded in the Mining Act of 1997 [90].

3.19. Iceland

Because of the extraordinary geological conditions with shallow high temperature ground, over half of Iceland's energy demand is satisfied with geothermal energy. Already, more than 88% of all homes use geothermal energy. It is also preferably used for the heating of swimming pools, greenhouses, fish farming, as well as de-icing pavements, sidewalks and parking lots [67]. However, Iceland has no specific law or regulation for the thermal use of shallow geothermal energy.

3.20. Indonesia

Indonesia has the largest geothermal energy potential worldwide. The current focus is on the generation of electricity [91] and until 2005 only 3–4% of the reserves were used for power generation [92]. The first Indonesian geothermal plant for power generation has been in operation since 1978. The Geothermal Law (2003) provides safety to the industry and describes the contribution of geothermal energy to energy security and independence of fossil fuels [93]. There are not yet any regulations referring to shallow geothermal installations.

3.21. Ireland

Ireland has the highest level of energy import dependence in the European Union. Thus, renewable energy is intensively promoted. A recent study showed that a significant geothermal potential (deep and shallow) exists, which may help the Irish government to achieve its goal to generate 33% of Ireland's electricity from renewable sources by the year 2020 [94]. There are 42 reported warm springs, but geothermal energy is mainly used for space heating by shallow geothermal installations [95]. At this time Ireland does not have any federal regulations or standards for temperature thresholds or minimum distances. Some planners use the German VDI 4640 [57,85–87] as a primary technical guideline, which currently serves as an established European code; and is also available in English. There is also no general law for the regulation of geothermal energy. However, groundwater extraction and injection require permission [14].

3.22. Japan

The number of shallow geothermal installations is still very low. As of 2005 only 41 heat pump projects were reported, mainly installed by industrial companies, with an estimated installed capacity of about 1.7 Mwt [67]. The government recently recognized the advantages in saving energy and avoiding additional CO_2 emissions by using shallow geothermal energy for cooling and heating. They have now started to encourage people to use such systems, and therefore do not yet have any limits for the usage. In essence, there are no regulations pertaining to thermal use of groundwater and the subsurface. However, open geothermal systems are not always feasible. In many large urban areas, it is strictly forbidden to extract groundwater, due to serious subsidence problems in the past.

3.23. Korea

The number of installed shallow geothermal systems has been continuously rising since 2004. New installations between 2000 and August 2008 consist of about 70% closed systems and 30% open systems. There are no regulations concerning minimum distances and temperature limits. There are only some standards for location and design of GSHP systems [96].

3.24. Liechtenstein

Although the Principality of Liechtenstein is rather small with only around 35,500 inhabitants, it is one of the most regulated countries in the use of shallow geothermal energy. In July 2009 the government defined temperature thresholds for groundwater. In comparison to the undisturbed groundwater temperature, groundwater is not allowed to be cooled more than 3 K. The maximum heating of groundwater is set to be 1.5 K. The use of groundwater for heating and cooling is only allowed as long as it is comprehensively demonstrated that no detrimental impact for groundwater, surface and surface waters occurs. Still detrimental impacts are not further defined. Existing minimum distances for closed systems with 3 m to property line and 6 m to next installation are recommended (Table 6).

3.25. Lithuania

In Lithuania neither temperature limits nor minimal distances exist. The legislation concerning the underground (Underground Law of 1996 [97]) is only very general. For the future it is planned to develop regulations for utilization of geothermal energy. Discussions between specialists are currently taking place and a committee was established by the Ministry of Energy.

3.26. Mexico

In Mexico there is only a minor number of shallow geothermal energy applications. Geothermal resources are mainly used to generate electricity and also for bathing, spas and therapeutic purposes [67]. Only few installations for heating and cooling exist in the private sector and only few pilot industrial projects are reported [98]. Thus, there is presently no urgent need identified for legislation. The National Water Act refers to groundwater temperature, if it is higher than 80 °C. It is stated that groundwater at >80 °C is mainly for the generation of electricity; it can only be used for other purpose if it is not being used for the generation of electricity.

3.27. Netherlands

The use of shallow geothermal energy started in the early 1980s. Due to the fact that aquifers can be found almost everywhere in the country, almost all early installations are GWHP systems. From the 1990s on GSHP systems became more important [99]. Geothermal energy in general is embedded in the Mining Law. So far, there are no regulations or requirements for closed systems. However, starting in 2011 there will be a new Ministerial Regulation for closed systems under the Soil Protection Act. From then on permission is needed. For open systems a permit requirement under the Water Act defines temperature thresholds for groundwater. As maximum temperature for groundwater 25 °C is defined, allowed minimum temperature is 5 °C. These values are legally binding on regional level based on the regulations of Drinking Water Act for Legionella. Probably these values will be defined in a Ministerial Order starting in 2011. There are no regulations for minimum distances. The Water Act is a distribution act for groundwater, on the principle first come first serve. With the extraction permission one is allowed to extract water also from the subsoil of the neighbor. Starting in 2010 or 2011 provinces and municipalities are allowed to develop ''ambition areas'' for ATES systems. To regulate the underground within these ambition areas master plans will be made soon.

3.28. New Zealand

Shallow geothermal heat pump systems have made hardly any impact on the energy market in New Zealand [67]. Thus, New Zealand has currently no federal law concerning shallow geothermal energy. No temperature thresholds are defined. Rules for minimum distances for deep geothermal systems are formulated by regional councils. These regulations are very diverse and strongly depend on the extracted amount of energy.

3.29. Norway

The Norwegian energy demand is traditionally met by developing hydropower as renewable resource. In 2005 a limit was already more or less reached for developing further hydropower without detrimental environmental changes [100]. Thus, geothermal energy became progressively more attractive. In 2003, for example, there were 55,100 heat pumps installed mainly for heating [67]. Meanwhile, various famous buildings are supplied by GSHP systems for heating and cooling, including Norway's international airport terminal and a commercial building in Nydalen, Oslo [9]. No law for the thermal use of groundwater is defined, neither for closed systems nor open systems. The Water Resource Law (2001) does not mention thermal groundwater use for any purpose. Also, no explicit regulations on temperature thresholds or minimum distances exist. Of relevance in this context is the Neighbor Law. It generally states that nobody should have, do or initiate anything that unnecessarily induces damage or inconveniences to the neighboring ground.

3.30. Philippines

The Philippines defined the first Renewable Energy Act in Southeast Asia. It considers geothermal energy as renewable and therefore the Renewable Energy Act is applicable, if it is produced through natural or enhanced recharge [101]. Until now shallow geothermal installations are not well developed and consequently no regulations are yet defined.

3.31. Poland

In Poland no specific law for geothermal energy exists. According to the Geological and Mining Law (Official Journal No. 27, item 96 with amendments), deposits of useful minerals, including geothermal waters, belong to the state. The Polish Mining Law controls exploration and usage of thermal water. The Water Act is in charge of heat production with groundwater extraction [14]. The Economic Activity Law from 1999 (Official Journal No. 101, item 1178 with amendments) claims that exploration and exploitation of natural resources requires a concession [53].

3.32. Portugal

Only deep geothermal energy is included in a law [14]. There are no regulations for closed systems. For open systems there are minimum distances depending on the perimeter of protection defined for the resource and (hydro-) geological factors. An existing Decree-Law from 1990 regulating geothermal resources research and exploitation is applicable only to 'high temperature' resources. It regulates exploitation of open systems, which cover high or medium temperature resources, direct heating or for power generation. As a rule of thumb, only water with temperature higher than 40 °C is expected to be commercially exploited. The need for a more comprehensive law including shallow geothermal installations is perceived; no short term plans for the implementations of new laws are currently being considered.

3.33. Romania

Mineral resources in Romania, including heat contained in mineral, plain and thermal waters, are public property. The National Agency for Mineral Resources defined geothermal water as underground water with a wellhead temperature higher than 20 °C. The Mining Law regulates mining activities in Romania. The utilization of renewable energy is supported by a government decision with a utilization strategy, in which geothermal energy, referring to hydrothermal reservoirs, is mentioned in general. As GSHP and GWHP systems are not yet eminent, shallow geothermal installations are not considered important to regulate. Therefore, there is no specific geothermal legislation defined. Existing guidelines are dedicated to geothermal exploration permits and licensing exploitation. Well drilling for underground fluids is involved in the Environment Protection Law. As an exception, groundwater wells for domestic use with depths less than 50 m are excluded from the authorization procedure [53].

3.34. Slovakia

In Slovakia no general law for thermal use of groundwater exists. Furthermore, no temperature thresholds or recommendations for minimum distances for closed and open systems are provided. The Water Law (2004), based on the EU-Water Framework Directive [45], regulates licensing of (thermal) water quantity and used water quality. It does not contain any specific requirements that deal with shallow geothermal installations. However, it states that exploited geothermal water should not deteriorate the existing surface water quality.

3.35. Slovenia

Slovenia has not yet defined a federal law on geothermal energy. There are no temperature limits or recommended minimum distances. The Water Law (2002) and water rights concern concessions for balneology, touristic use of thermal groundwater and water permits for heating and cooling with GWHP systems. Concessions for geothermal energetic source (doublet system) and borehole drilling permissions are regulated by the Mining Law (2004). At the moment there is an initiative to prepare some guidelines, which will adopt the best practice from Swiss standard for GSHP systems (SN 565/384/6) and Austrian guidelines for closed systems [44]. Some proposals of criteria for a revision of groundwater permits have already been made [102].

3.36. Switzerland

Switzerland has no specific law for geothermal energy and also no federal mining law [14]. In Switzerland there is the general Water Protection Order from 1998 [103]. It is valid for the federal state and includes temperature thresholds for an accepted temperature difference of the groundwater of 3 K (Table 7). It is not specific for closed or open systems. The regions (canton) are generally responsible for the enforcement of the water ordinance, though some have further delegated the regulation of groundwater use to the municipalities. Hence, in some regions there are more regulations and also additional values for minimum distances, for example in the region of St. Gallen and Zug. Finally, there are standards of the Swiss engineer and architect association (SIA) for other shallow geothermal techniques such as energy piles (SIA D 0179, SIA D 190) [52].

3.37. Sweden

The boom of shallow geothermal installations in Sweden started in the early 1980s. The total number of installations in the year 2004 was already around 200,000. Sweden is therefore one of the foremost countries in the use of shallow geothermal energy [9]. One reason is probably the liberal legislation for such systems. General regulations apply to any type of activity that may have detrimental impact on the environment. Normbrunn 97 [104], replaced in 2008 by Normbrunn 07 [105], is a quality standard for wells for BHE and contains requirements for the borehole itself, equipment and competence of drillers. In addition, some recommendations for minimum distance between the borehole and property line are included (Table 6) [53,89]. However, legally binding regulations do not exist in Sweden.

3.38. USA

In the USA shallow geothermal systems are mostly sized for cooling load. The number of geothermal heat pumps has increased continuously in the past 15 years up to an estimated number of 120,000 systems. 70% of geothermal heat pumps are installed in residential buildings. 90% of these pumps are closed systems (ground coupled, here: GSHP) and 10% open systems (here: GWHP). The remaining 30% are installed in commercial and institutional buildings [106]. However, despite the rising numbers no federal law or guideline for shallow geothermal energy use is defined. Each state has its own laws and restrictions. For minimum distances there is only a general regulation, which states that vertical boreholes have to be 5–7 m apart. Geothermal energy is sometimes considered as a water resource and in some cases as a mineral resource. Other states regulate it by temperature criteria. In the state of *Oregon*, for example, if the water temperature is below 250 F (121 °C), it is regulated by the Department of Water Resources. On the other hand if the temperature is above 121 °C, the Department of Geology and Mineral Industries is responsible.

3.39. Vietnam

In Vietnam there are about 300 hot springs, but the geothermal water is exploited for mineral water bottling, spa, salt drying and medical purposes. As of now no regulations concerning temperature thresholds and minimum distances for the use of shallow geothermal energy are defined yet.

In *Honduras*, *India*, *Latvia*, *Macedonia*, *Saudi Arabia, Valencia* Region (Spain), *Spain* [89] no laws, regulations or ordinances concerning the legislation are available and published. Possible reasons are as follows:

- Only deep geothermal reservoirs are used.
- There are currently only few or no shallow geothermal installations.
- Thermal use of groundwater for heating and cooling is not common.
- Temperature changes in groundwater caused by the use of geothermal energy are not of major concern.

In *Albania* there are also no regulations, however, these are in process. *Turkey* has not yet defined a specific law for geothermal use of groundwater and there are neither temperature thresholds nor minimum distances, although there are a large number of shallow and deep geothermal energy installations.

4. Discussion and conclusions

The presented survey shows a rather diverse international legal status of the use of shallow geothermal energy. European countries are in particular more heavily regulated with a variety of laws, regulations, standards, guidelines and certificates. Liechtenstein and Finland are among the most regulated countries. The European situation is most likely due to the fact that in Europe shallow geothermal energy is very popular and commonly used more often than deep geothermal energy systems, whereas in New Zealand, El Salvador, Indonesia and Central America deep geothermal energy is more commonly used. In contrast, China and Korea, where shallow geothermal installations dominate, weak and partial vague standards are still applied.

In most countries, there are no regulations or recommendations on temperature limits for the thermal use of groundwater and the shallow subsurface (<400 m depth). If considered, minimum distance criteria can vary substantially (Table 5), and appear to be empirically defined rather than scientifically evaluated. For example, the minimum distance of closed geothermal systems to the next property line is set 2.5 m in Austria, 5 m in Germany and 10 m in Finland and Sweden. Some countries distinguish in their regulations between open and closed systems (e.g. Greece) while others do not (e.g. Sweden). For open geothermal systems, often established regulations for well installations and groundwater use come into force. Not only threshold values, but also the definition of the point of compliance is often country-specific. For example, in Finland one has to obey distances to the next building, sewer and water pipe, in Sweden and Denmark to the next drinking water wells and in Greece even to the next power line.

Ecological thresholds, for heating and cooling the groundwater with open geothermal systems, vary between 15 and 25 °C for maximum temperatures and 2 and 5 °C for minimum temperatures. For example, a comparatively large range from 2 to 25 °C is accepted in Denmark. Such fixed absolute values only exist in few countries, while acceptable temperature differences are more common. The allowed temperature difference between undisturbed and influenced groundwater temperature varies from ±3 °C (e.g. Switzerland) to ±11 °C (France), reflecting significant national differences.

There are no absolute temperature limits for heating and cooling of groundwater for closed geothermal systems. Only few countries such as Austria and Denmark define technical temperature thresholds for such systems. The defined thresholds refer to the heat carrier fluid inside the borehole heat exchanger. As maximum temperature Austria defines 35 °C and Denmark 25 °C. The accepted temperature minimum is between −5 °C for the peak load in Austria and 2 °C in Denmark. Similarly to open geothermal systems, acceptable temperature differences are given for closed systems. They range between ±11 K for the weekly mean load in Germany and ±17 K for the peak load in Germany.

A major finding of this review is that if the use of shallow geothermal energy is regulated, applied criteria and defined thresholds vary considerably, which can be explained by many factors. In many countries, the use of shallow geothermal energy is not so significant in comparison to other renewable energy resources. Thus, there is little or no experience with such shallow geothermal systems, and therefore there is no perceived need for regulations. Furthermore, less preventive boundary conditions for closed or open geothermal systems might be stimulating for the market development. Additionally legal restrictions might also be considered as unwanted barriers that could decelerate the development of such shallow geothermal systems.

The focus in some countries is on open geothermal systems, in others on closed systems. The characteristic physical, chemical and biological effects of both technologies might explain the individual management of these systems. However, even if one technology is favored in one country, a neighboring country or region with similar climate and hydrogeological conditions might formulate completely dissimilar regulations, recommendations, codes and technical guidelines. For example, one of the main aims of minimal distances between geothermal installations and neighboring properties or buildings clearly is to minimize potential thermal influence on the neighboring property. Thus, a person or company should not be negatively influenced, i.e. experience a decrease in efficiency of his installation due to an adjacent geothermal system. The defined regulations seem often to be subjective and show a major deficiency in the use of scientific studies and understanding of the main underlying processes. Meanwhile, in countries such as Germany and Austria, the use of simple analytical models, for example, for the estimation of the temperature development in the subsurface due to the use of shallow geothermal system is recommended using site-specific hydrogeological conditions and case-specific energy extractions.

One of the main purposes of environmental regulations is to control and to avoid unwanted potential irreversible effects on and misuse of the environment and future generations. In almost all cases, regulative frameworks are based on technical considerations and a concern for property rights. In contrast, the environmental impacts of changing groundwater temperatures due to the thermal use of the subsurface are rarely discussed or considered. Instead, in some countries such as Denmark and Austria, regulations and threshold values for closed geothermal systems are defined for the heat carrier fluid in the borehole heat exchanger, apparently to only guarantee the technical performance of the system. In contrast, open geothermal systems are mainly controlled by regulations that are established for the supply of drinking water using groundwater wells. This indicates that technical aspects such as land subsidence or distance to the next power line are mainly considered. Environmental aspects seem to be of minor importance. This does not inevitably mean ignorance, as there might be some other reasons. One reason could be that groundwater ecosystems are currently not well understood and studied. The development of generally valid environmental indicators is at an initial stage and no consensus on practical guidelines to save and sustain these groundwater ecosystems exists. Furthermore, the importance of groundwater flora and fauna in aquifers is identified, but public awareness has not yet been stimulated.

Finally, often temperature anomalies caused by seasonal applications of GSHP or GWHP systems are, if in any way, only pronounced in the proximal zones around the borehole heat exchangers or wells respectively and diminish rather fast with increasing distances [24–26]. Significant increase or decrease of aquifer temperatures is mainly restrained due to techno-economic performance of the systems, as for example the efficiency of heating decreases with aquifer temperature. Thus, the necessity to save and protect the environment does not guide the formulation of current national regulations. Instead, an incentive to embed environmental criteria in legal national or international frameworks is to avoid apparent threads such as unwanted bacteria growth in heated aquifers [36].

In principle it would be desirable for the different regulative frameworks to converge, and to establish more objective and scientifically motivated environmental, technical and economical criteria. Thus, country-specific differences in subsurface and climatic conditions, the different practice of the use of shallow geothermal energy and the individual social, cultural or political priorities should define the baseline for the formulations of legal regulations. Preferably, static as well as dynamic aspects and the resulting spatial and temporal changes in subsurface temperature due to cooling and heating should also be considered.

Acknowledgements

The authors would like to thank the following people who replied to our international questionnaire, without whom the current review would have not been possible: Ramadan Alushaj (Polytechnic University, Albania), K. Ameed R. Ghori (Western Australia), Peter Green (Queensland, Australia), Anthony Budd (Australia), Hans Aschauer (Austria), Didier D'Hont (Belgium, Flandern), Neven Miosic (Federal Geological Survey, Bosnia and Herzegovinia), Valeri Trendafilov (Ministry of Environment and Water, Bulgaria), Philippe Pasquier (Golder Associates, Canada), Grant Ferguson (St. Francis Xavier University, Canada), Zhaohong Fang (GSHP Research Center, Shandong Jianzhu University, China), Alfredo Mainieri Protti (Service Centre for Geothermal Resources, Costa Rica), Josef Datel (Charles University, Prague, Czech Republic), Gunver Heidemann and Martin Skriver (Ministry of the Environment, Denmark), Bernardo Beate (National Politechnical School, Ecuador), Julio Guidos (LaGeo, El Salvador), Janne Juvonen (Finnish Environment Institute, Finland), Florence Jaudin (BRGM – GTH, France), Victoria Fry (Environment Agency, UK), Brighid Ó Dochartaigh (British Geological Survey, Scotland, UK), Dimitrios Mendrinos (Centre for Renewable Energy Sources and Energy Savings, Greece), Cesar Augusto Lagos (Geotermica Platanares, Honduras), Larus Olafsson (National Energy Authority, Iceland), Dornadula Chandrasekharam (Indian Institute of Technology, India), Eamon Ryan (Ministry of Communications, Energy and Natural Resources, Ireland), Kasumi Yasukawa (Institute for Geo-Resources and Environment, Tsukuba, Japan), Youngmin Lee (Korean Institute of Geosciences & Mineral Resources, Korea), Erika Ulane (Latvia), Egon Hilbe (Amt für Umweltschutz, Liechtenstein), Kaspar Papritz (Dr. Bernasconi AG, Liechtenstein), Juozas Mockevicius (Geological Survey, Lithuania), Sanja Popovska-Vasilevska (University St. Kliment Ohridski, Macedonia), Luis C.A. Gutiérrez-Negrín (Mexican Geothermal Association), Marc Koenders (IF Technology, Netherlands), Katherine Luketina (Waikato Regional Council, New Zealand), Björn Frengstad (Geological Survey, Norway), Fernando S. Penarroyo (National Geothermal Association, Philippines), Carla Lourenco (National Institute of Energy, Technology and Innovation, Portugal), A. Rodrigues da Silva (Ministry of Economy and Innovation, Portugal), Marcel Rosca (University of Oradea, Romania), Shafiqu Rehman (King Fahd University of Petroleum and Minerals, Saudi Arabia), Peter Malik (Geological Survey, Slovakia), Andrej Lapanje (Geological Survey, Slovenia), Göran Risberg (Geological Survey, Sweden), Roger Nordman (Technical Research Institute, Sweden), Umran Serpen (Turkey), John W. Lund (Geo-Heat Center, Oregon Institute of Technology, USA), Tran Trong Thang (Vietnam Institute of Geoscience and Mineral Resources, Vietnam). Furthermore, we thank our colleagues from the hydrogeothermics group in Tübingen. This work was financed by a scholarship from the German Federal Environmental Foundation (DBU) to S. Hähnlein. This work was also supported by a research grant from the GWAT-LCA project within the 7th Framework Program of the EU (Contract no. PIEF-GA-2008-220620). We thank Margaret Hass for her valuable help during the preparation of the manuscript.

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