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SUMMARY

GEOTHERMAL ENERGY USE IN EUROPE

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ABSTRACT

Europe is the world leader in geothermal direct uses. Geothermal is used in 32 European countries mainly for space heating, bathing and balneotherapy, than for heating greenhouses, aquacultures, and industrial uses. In a number of countries the development is based on waters exploited from deep wells. Some countries have been dynamically developing shallow geothermal based on heat pumps.

Power generation using geothermal steam takes place in six European states and contributes in ca. 12% to the world total. Recently, first small binary installations based on ca. 100-120°C waters were launched in Austria and Germany.

Except for Iceland, geothermal is not a main player among renewables in Europe, although many regions have prospective resources which can be applied on a wide scale specially for heating. In geothermal heating sector Europe has achieved a lotof experience, positive results, and developed modern and reliable technologies.

The wider development of RES (including geothermal) in space heating, as well as power generation, and biofuels is foreseen in Europe. This is an indispensable element of the EU energy strategy, i.e. to decrease the dependency of energy imports, to ensure the security of supply and competitive energy prices. The EU and its member states are also the signatories of the Kyoto Protocol and committed to reduce GHG emissions by 8% below the 1990 level in 2008 – 2012, to introduce the emissions trading scheme, energy efficiency (a 20% energy consumption cut by 2020), and a 20% reduction in CO2 emissions by 2020.

The proposal of a new EU-Directive addressing all sectors of renewables shall ease their development, including geothermal; it aims at an overall target of a 20% share of RES in energy consumption (electricity, heating and cooling) by 2020.

1. INTRODUCTION

Europe is the world leader in geothermal direct use. It occupies the first place ahead of Asia, the Americas, Oceania and Africa. According to the data presented at the World Geothermal Congress 2005 (Lund et al., 2005) geothermal energy is directly used in 32 European countries (for a total of over 70 countries reporting this type of use). Geothermal resources represent primarily low-enthalpy ones being mainly connected with sedimentary formations.

In Europe, climate, market demand, reservoir conditions, and ecological reasons favour applications of geothermal energy mainly for space heating; heating greenhouses; aquaculture; industrial uses; and bathing and balneotherapy. In a number of countries, development is based on hydrothermal resources exploited from wells up to ca. 3 km deep. Some of them have been dynamically developing shallow geothermal energy during past few years, based on heat pumps.

2. GEOTHERMAL CONDITIONS AND POTENTIAL

The European continent is characterized by low-to-moderate heat flow values. This parameter ranges from 30-40 mW/m2 within the oldest part of the continent (the Precambrian platform) to 60-80 mW/m2 within the Alpine system. Relatively high values of 80-100 mW/m2 occur within seismically and tectonically active southern areas of Europe. Similar values are reported from some other regions, i.e. the Pannonian Basin or the Upper Rhein Graben (Hurter and Haenel [eds.], 2002).

Thermal and geological conditions result in the fact that Europe possesses mostly low-enthalpy resources. They are predominantly found in sedimentary formations. However, at attainable depths in several regions, high-enthalpy resources are also found, as in Iceland, Italy, Turkey, Greece, Portugal (Azores), Russia (Kamchatka), Spain (the Canary Islands) and at some other islands and overseas territories of France (Guadeloupe). The main geothermal fields under exploitation are in the Larderello region (Italy); the Paris Basin (France); the Pannonian Basin (Hungary, Serbia, Slovakia, Slovenia, Romania); several sectors of the European Lowland (Germany, Poland); the Palaeogene systems of the Carpathians (Poland, Slovakia); and other Alpine and older structures of Southern Europe (Bulgaria, Romania, Turkey). A sketch of general distribution of main basins and geothermal resources in Europe is shown on Figure 1. It reflects the thermal and geostructural features of the continent.

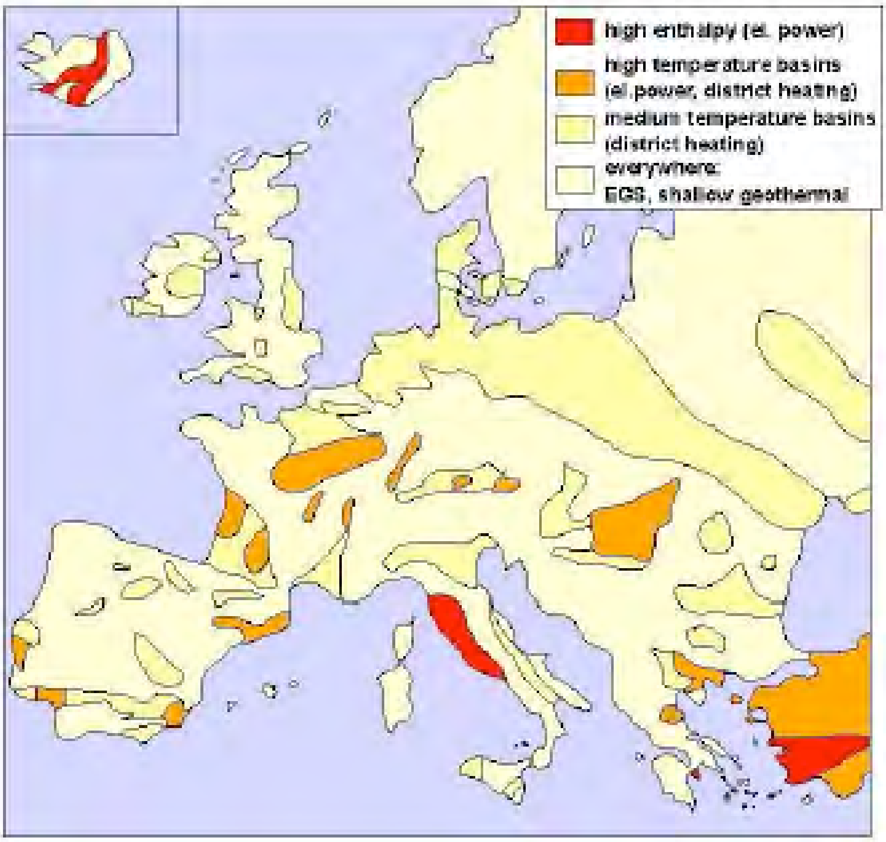

Fig. 1.: A sketch illustrating the general distribution of main basins and geothermal resources in Europe (Antics and Sanner 2007; courtesy of authors)

3. GEOTHERMAL DIRECT USES – STATE-OF-THE-ART

According to the data presented at the World Geothermal Congress 2005, direct geothermal uses take place in 32 European countries (Lund et al. 2005). The total installed thermal capacity was 13 628 MWt, while heat production amounted to 140 398.9 TJ (42916 GWh/a, i.e.

56% of the world total) (Lund et al. 2005; Table 1). These figures had almost doubled as compared with the data presented five years earlier at the World Geothermal Congress 2000 (Lund and Freeston 2001). The trend of constant increase in direct use is continuing – the relevant partly updated figures presented at the European Geothermal Congress in Germany in 2007 are 14114.1 MWt and 158743.5 TJ/a, respectively (Antics and Sanner 2007).As shown in Table 2, Sweden, Iceland and Turkey have the largest share; followed by Hungary, Italy, Georgia, Russia, Germany, Switzerland and France (each of them produce over 5,000 TJ/y).

Geothermal energy is primarily used for heating and for bathing/swimming. Each of these two types consumes around 36 – 37% of the heat (Figure 2). A significant share is also bound with horticulture (greenhouses and soil heating) – ca. 18% (Antics and Sanner, 2007). It is worth noting that high geothermal heat generation in Sweden, Switzerland, Germany, and Austria was achieved mostly by rapid heat pumps' development.

European countries dominate the list of ten top world countries in direct uses: Sweden (2), Turkey (4), Iceland (5), Hungary (7), and Italy (8) (Lund et al. 2005).

TABLE 1: Summary of geothermal energy uses by continent in 2004, showing the contribution of Europe (data from Bertani, 2005 and Lund et al., 2005)

Continent	Direct uses			Electricity generation		
	Installed capacity (MW_t)	Total production		Installed capacity (MW_e)	Total production	
		(GWh/a)	(%)		(GWh/a)	(%)
Africa	190	763	1	136	1088	2
America	8988	12119	16	3941	26794	47
Asia	5044	17352	23	3290	18903	33
Europe	**13628**	**42916**	**56**	**1124**	**5745**	**12**
Oceania	418	2793	4	441	2791	5
TOTAL	28268	75943	100	7974	56786	100

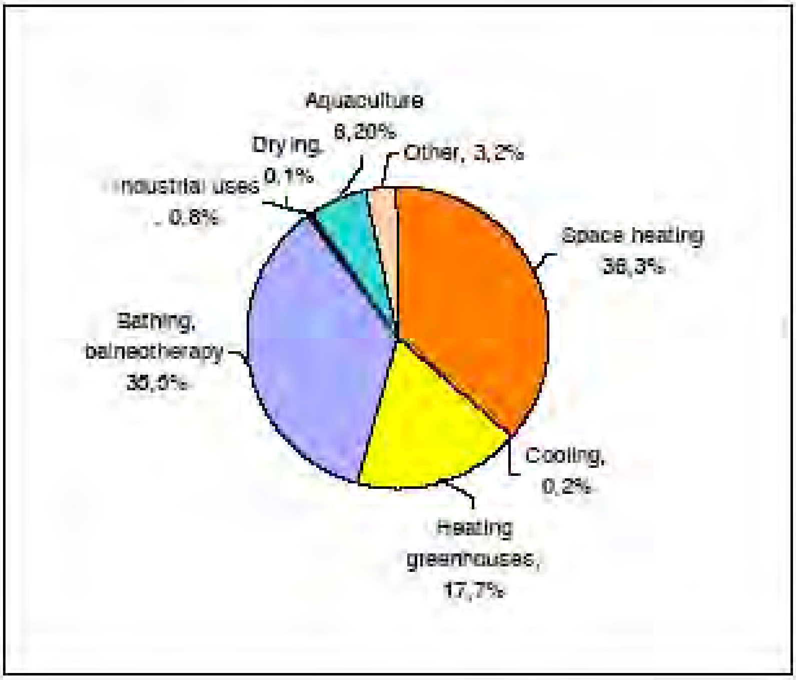

Fig. 2: Distribution of geothermal energy for direct uses in Europe (% of TJ), 2007 (based on data from Antics and Sanner, 2007)

TABLE 2: Europe – geothermal energy use, 2004 (based on Lund et al., 2005, Bertani, 2005) partly updated by data of Antics and Sanner, 2007)

Country	Direct use			Electricity generation	
	Installed capacity (MW_t)	Total production [TJ/a]	Total production [GWh/a]	Installed capacity (MW_e)	Total production (GWh/a)
Albania[1]	9.6	8.5	2.4		
Austria	352.0	2 229.9	619,4	1.2[2]	3.2
Belgium	63.9	431.2	119,8	-	-
Belarus	1.0	13.3	3,7	-	-
Bulgaria	109.6	1 671.5	464,3	-	-
Croatia	114.0	681.7	189,4	-	-
Czech Republic	204.5	1 220.0	338,9	-	-
Denmark	821.2	4 360.0	1 211,2	-	-
Finland	260.0	1 950.0	541,7	-	-
France	308.0	5 195.7	1 443,4	15.0	102.0
Georgia	250.0	6307.0	1 752,0	-	-
Greece	74.8	567.2	157,6	-	-
Spain	22.3	347.2	96,5	-	-
Netherlands	253.5	685.0	190,3	-	-
Ireland[1]	20.0	104.1	28,9	-	-
Iceland	1 791.0	23 813.0	6 615,3	202	1 406.0
Lithuania	21.3	458.0	127,2	-	-
Macedonia[1]	62.3	598.6	166,3	-	-
Germany	504.6	2 909.8	808,3	2.01[2]	1.5
Norway	450.0	2 314.0	642,8	-	-
Poland[1]	170.9	838.3	232,9	-	-
Portugal	30.6	385.3	107,0	16	90
Russia[1]	308.2	6 143.5	1 706,7	79	85
Romania	145.1	2 841.0	787,2	-	-
Serbia	88.8	2 375.0	659,8	-	-
Slovakia	187.7	3 034.0	842,8	-	-
Slovenia	48.6	712.5	197,9	-	-
Switzerland[1]	581.6	4 229.3	1 174,9	-	-
Sweden	3 840.0	36 000.0	10 000,8	-	-
Turkey[1]	1 177.0	19 623.1	5 451,3	20.0	105.0
Ukraine	10.9	118.8	33,0	-	-
Hungary	694.2	7 939.8	2 205,7	-	-
Great Britain	10.2	45.6	12,7	-	-
Italy	606.6	7 554.0	2 098,5	790	5 340.0
Total	**13 644.0**	**140 398.9**	**39 278,0**	**1 125**	**7132.7**

[1] – Data updated in 2007 (Antics and Sanner, 2007)
[2] - pilot binary power generation plants using 97 – 120°C waters as a working fluid

Power generation using geothermal steam takes place in only a few European states, i.e. Iceland, Italy, Russia (Kamchatka), Turkey, Portugal (Azores), in the overseas territories of France (Guadeloupe). In 2004, geothermal electricity in Europe contributed in 12% to the world total (Table 1). Recently, the list of geothermal power producers has been extended by Austria and Germany (binary schemes – ORC or Kalina systems). In Austria two installations based on 97 – 110°C water have been on-line since 2001 (Pernecker, 2002; Legmann, 2003). Since 2003 the first small plants (0.2 – 3 MWe) using a 97 – 155°C water have been operating in Germany. Also in other countries there are being conducted works on power generation using geothermal waters. This is a prospective line of electricity generation on a local scale but needs further works, i.e. improving the low efficiency and economic feasibility.

4. GEOTHERMAL IN ENERGY POLICIES AND STRATEGIES

Europe is the largest energy importer in the world. The import covers around 50% of its energy needs.

The forecasts show that this figure may increase up to 70% in the coming 20 -30 years (Antics and Sanner, 2007). They urge to increase the share of energy from local renewable sources, including geothermal energy. The growing interest in RES development results also from the fact that the European Union (EU) and its member states are the signatories of the Kyoto Protocol to the UN Framework Convention on Climate Change. The EU is committed to reducing greenhouse gas emissions by 8% below the 1990 level in 2008 – 2012. There are several key measures here, including the emissions trading scheme, energy efficiency which means a 20% energy consumption cut by 2020, and a 20% reduction in CO2 emissions by 2020.

The EU energy strategy has three main imperatives – to ensure the security of supply, to ensure competitive energy prices and to reduce the climate change impacts of energy use. Hence, the need to significantly increase the share of the RES energy balance is becoming obvious.

So far, Europe has developed mostly wind and biomass. Except for Iceland, geothermal has not been a main player although the continent has prospective geothermal resources which can be applied on a wide scale especially for heating – a main sector contributing to the environmental pollutions and GHG emissions. Fossil fuels (plus nuclear in some cases) will still play the main role. In 2006, the average share of all renewables in the heating sector in the EU was ca. 5% while the share of renewables in power generation was ca. 6%.

Currently there are two EU–Directives in the field of renewable energy: for electricity and for biofuels. The Renewables Directive (2001) aims to double the share of electricity production from RES to 21% by 2010 (however, this target will not be reached). For biofuels (Directive 2003) the relevant target is 5.75 (ca.1% in 2006). The third sector – heating and cooling – has not been legislated in the form of an EU–Directive so far. To change this situation, the proposal of a new Directive addressing all three RES sectors was announced in January 2008. It aims to establish an overall binding EU target of a 20% share of RES in energy consumption (electricity generation, heating and cooling) and a 10% binding minimum target for biofuels in transport to be achieved by 2020.

Following the Directive, each EU-Member State shall set out the national action plan in order to reach the targets in 2020 taking into account the availability of various types of RES in their territories. In this view one should point out that geothermal is a perspective type in several countries. The proposed overall national targets for the share of energy from renewable sources in final energy consumption in 2020 vary from 10% – 14% (e.g. Malta, Luxemburg, Czech Republic) to 34 – 49% (Austria, Sweden).

In comparison – in 2005, the share of RES in the EU-countries varied from 0.0 – 0.9% (Malta and Luxemburg, respectively) to 39.8% (Sweden).

Among the initiatives dedicated especially to the promotion of wider geothermal development for heating one should mention The Kistelek Declaration (www.egec.org) adopted in 2005. It points out good geothermal resources in many regions which can provide a considerable share in the heating sector. The Declaration indicates that to achieve such a goal the EU shall foster its Member States to adopt a coherent legislation and economic system to ease geothermal use. Following the Kistelek Declaration an EU-funded project GTR–H (Geothermal Regulation – Heat) is being carried out. It aims to propose the legal framework that would facilitate the development of the geothermal heating sector (www.gtrh.eu).

In the European countries geothermal research, R&D, and investment projects can be supported by the public sources (national budget or specialized funds) devoted for the sector of renewables, environmental protection, infrastructure, etc.

Some countries like France and Germany have special Guarantee Funds to limit the risks connected with drilling the first geothermal wells or limit the results of worsening exploitation parameters with time. Support comes also from the EU-budget in the frame of various funds and programs oriented at RES and other sectors. As an example one can give the 7th EU Framework Program for 2007 – 2012 dedicated for R&D in many fields of science and economics. The Program involves energy and its renewable part (including geothermal to some extent).

5. METHODS OF GEOTHERMAL EXPLOITATION

Geothermal resources are exploited and implemented in several ways. They mainly depend on depth of geothermal reservoir; lithology of reservoir formation; main reservoir and exploitation features and parameters. It is crucial to preserve the renewability or sustainability of a geothermal reservoir.

Generally, there are the following production and maintenance options for geothermal reservoirs and systems: (1) Exploitation of deep reservoirs; (2) Exploitation of shallow resources; (3) Enhanced Geothermal Systems (EGS; former name Hot Dry Rock Technology being in R&D stage).

5.1 Exploitation of deep reservoirs

Water temperatures at outflows are from about 20ºC to a maximum of ca. 90-130ºC; TDS varies in a wide range from 1 to 150 g/dm3. Waters are produced through a spontaneous artesian outflow or are pumped. Aquifers are connected mostly with sedimentary formations (carbonates or sandstones). Some systems are connected with crystalline or metamorphic rocks.

In the majority of cases, exploitation is carried out in closed well systems, i.e. *doublets* or *triplets* of production and injection wells. Geothermal heat is extracted through heat exchangers. Some installations base on open well systems, when only production wells (‘singlets’) are working. In some cases, when the injection is not necessary, the cooled geothermal water after passing through heat exchangers (or at least a part of it) is disposed into surface waters (i.e. rivers, ponds) or it is used for other practical purposes, for instance as drinking water or for swimming pools.

Exploitation of water from sedimentary rocks is related with some specific phenomena and problems.

They have an influence on obtaining satisfactory reservoir and production parameters, and maintenance of long-term water production. Some of them are typical of all geothermal systems, some mainly depend on the lithological type of reservoir rocks. These are, e.g. change of production and injective properties; plugging of the near-hole zone; scaling; corrosion; etc. Suitable methods for a successive treatment and maintenance of such reservoirs and wells have been worked out and implemented e.g. in France with its carbonate reservoirs and Germany with sandstones.

Depending on the temperature of the geothermal water at the outlet, the installations work as geothermal only, but sometimes they are used along with traditional fuels (integrated systems).

5.2 Exploitation of shallow resources

In this case, the heat of water, soil or rock formation is extracted through borehole heat exchangers/heat pump systems or heat pumps. Significant developments of this method started at the beginning of the 1990s in several European countries (Switzerland, Germany, Austria, Sweden), similar to the USA, Canada or Japan. It opened a new line in geothermal use, creating prospects for other countries, e.g. because of the lack of limitations in the installation and economical profitability.

Several aspects of the geothermal heat pumps’ in Europe are treated in details by Rybach (2008).

5.3 Enhanced Geothermal Systems

This method allows for the recovery of heat from the rock formations devoid of reservoir properties and waters. Usually such formations occur deeper than 3 – 5 km and reveal relatively high temperatures (over 150°C) due to the depth and to high heat generation by radioactive elements contained in some minerals. Such formations can be artificially fractured and water can be injected into the fractures through the wells. After heating to about 100°C (and more) such water (usually as a mixture of water and steam) can be pumped out to the surface and used for power generation and/or for heating. Instead of injecting water a bore-hole heat exchanger can be installed to extract formation heat. The technology is still in a stage of development.

International R&D projects on EGS (formerly named Hot Dry Rock) have been carried out in France (Soulz-sous-Forets), Germany and Switzerland. New ones are expected. They are mostly oriented to power generation. In Soulz-sous-Forets commercial electricity production was launched in 2008. This fact can be treated as a milestone in EGS development.

6. SPACE HEATING SYSTEMS BASED ON DEEP GEOTHERMAL SEDIMENTARY AQUIFERS – EXAMPLES

6.1 France

France is among the leading European countries in geothermal direct use (Laplaigne et al., 2000; Table 2.2). Geothermal waters occur within sedimentary basins. The main ones are the Paris Basin and the Aquitane Basin. The geothermal district heating systems in the Paris region are well known. The first system was opened in 1969 there. The development is related to hydrothermal resources exploited in closed systems, i.e. through the doublets or triplets of wells (1.5-2.5 km deep).

The Paris Basin is a regional structure filled with Mesozoic and Cainozoic series. They contain numerous aquifers, including geothermal. Most of geothermal space heating systems use warm water discharged by the Dogger (Middle Jurassic) limestones. Temperatures of the water produced vary between 60 and 80ºC (Ungemach, 2001). The waters have a relatively high TDS (from 5 to 35 g/dm3), and amount of gases, while the prevailing water type is Cl-Na. Owing to the chemical composition and presence of hydrogen sulfide, these waters are corrosive and must be injected back.

The peak period of geothermal space heating in France was in 1980-1986 (following the first oil crisis). During those years, 74 plants were in operation: 54 in the Paris Basin, 15 in the Aquitaine and 5 in other regions (Laplaigne et al., 2000). A decrease in development occurred in 1986-1990. It was caused mostly by the drop in energy prices, and technical difficulties affecting geothermal installations. The latter was expressed by the scaling on the metal parts of geothermal loops due to the corrosiveness of the sulphide-rich geothermal water. Several actions were undertaken to improve the economical situation of the plants, and to resolve the technical problems (corrosion and scaling) in the successive years. One of the methods successfully implemented was soft acidizing.

FIig. 3: Geothermal heating plants operating in the Paris Basin, France (source: BRGM, France)

TABLE 3: Geothermal doublets operating in the Paris Basin (compiled from Ungemach, 2001)

Drilled years	Number of doublets		Total depths of wells		Water flowrate (m^3/h)	Wellhead tempernt. (°C)	Method of product.	Remarks
	Working	Abandoned	Vertical (m)	Deviated (m)				
1981-1987	34	20	1430-1790	1710-2310	90-350	66-83	Submersible pumps, Artesian	Gas cogeneration in some cases.

Nowadays (2008), out of 74 plants operating in 1986, 61 are still on-line, the bulk of them (34) in the Paris Basin (Figure 3). Geothermal plants are based on the well doublets drilled in 1981-1987 (some new drillings were initiated in 2007). They supply space heating and domestic warm water (Laplaigne et al., 2000; Ungemach, 2001). Both vertical and deviated wells are in use. They encounter geothermal aquifers at depths between 1430 and 2310 m. Maximum water flow rates are 90 – 350 m3/h. In most cases, submersible pumps are installed. However, some of the wells are artesian. Wellhead water temperatures vary from 66 to 83ºC. Many geothermal plants work in combination with gas boilers.

After passing heat exchangers, cooled geothermal water (40 – 60ºC) is injected back (Table 3).

The case of the Paris Basin provides evidence that such basins are perspective for geothermal spaceheating and other direct uses. There are other Mesozoic sedimentary basins that cover extensive areas in Europe and contain prospective geothermal systems (still waiting to be exploited) e.g. Germany, Denmark, Poland (Kępińska, 2004, Kępińska, 2005).

6.2 Sandstone reservoirs – Germany

In Germany, geothermal direct use development is based both on shallow and deep resources. This country is one of the European leaders in geothermal production (Table 2), having great dynamics of development. At present, 140 installations are operating with total installed capacity of 177 MWt (Antics and Sanner, 2007). They mostly serve for district heating in some cases combined with greenhouses and spas. During the last few years several new space heating plants have been launched.

They are mostly located in the Munich area, S-Germany, which is characterised by good reservoir and exploitation parameters: high temperatures (up to 120°C), high water flow rates (100 – 300 m3/h), low mineralization (usually ca. 1 – 2 g/dm3). Such parameters made it possible to launch the first geothermal binary power installations (capacities 0.2 – 3 MWe) combined with heat production and supplying to the city networks. In the case of e.g. the Unterhaching co-generation plant the electric capacity is ca.3 MWe while the thermal – ca.40 MWt).

Among the geothermal space-heating plants exploiting water from deep sedimentary formations is the plant in Neustadt–Glewe. It has been in operation since 1995. The total installed thermal capacity is 16.4 MWt, out of which 6 MWt comes from geothermal while the rest from gas boilers (Menzel et al., 2000). In addition, a part for binary electricity generation (0.2 MWe) was installed. The reservoir rocks are the Triassic sandstones situated at the depth of 2217-2274 m. They are exploited through the doublet of production and injection wells. Heat is extracted by heat exchangers (Figure 4). Production amounts to about 180 m3/h of 95-97ºC water, while the TDS are high and reach 220 g/dm3 (Table 4).

The main ions are sodium and chloride, then calcium, magnesium, potassium, sulphate and some rare elements. The water contains about 10% of gas including carbon dioxide, nitrogen, and methane. The cooled geothermal water is injected back to maintain the pressure and also because of its high TDS.

To avoid corrosion and scaling problems, specific materials were applied: glass-fibre tubes, resin-lined steel tube parts and measures such as inertisation by means of nitrogen loading. The materials and equipment stand up to the extreme temperatures, aggressive brine and pressure conditions.

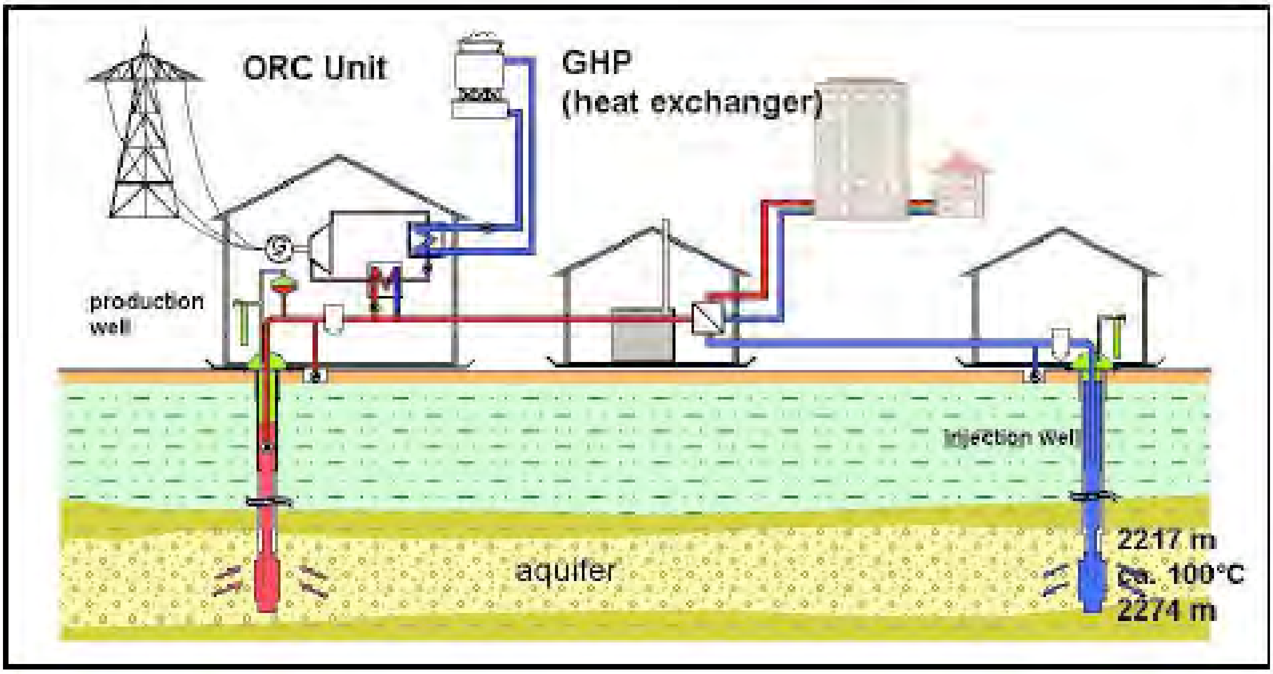

FIGURE 4: A scheme of the Neustadt-Glewe geothermal space heating plant, Germany
GHP – geothermal heating plant, ORC – Organic Rankine Cycle turbine for electricity generation
(Courtesy P. Seibt)

TABLE 4: Main data on the sandstone geothermal reservoir in Neustadt–Glewe, Germany (Menzel et al., 2000)

Depth of the aquifer	2217-2274 m
Lithology	Sandstones
Stratigraphy	Triassic (Keuper/Rhetian)
Temperature gradient	4.06°C/100m
Effective porosity	22%
Permeability	0.5-0.8 x 10^{12} m^2
Reservoir temperature	98°C (2223 m)
Number of wells	2 (1 production and 1 injection)
Distance between wells	1,350 m
Productivity	183 m^3(h·MPa)
Injectivity	265 m^3(h·MPa)
Wellhead temperature	95 - 97°C
TDS	220 g/dm^3

However, the injection pressure has been increasing during the course of exploitation. This problem was caused by the sedimentation of solid particles on the filter section of the injection well. The removal of these components was done by using the soft acidizing method – i.e. by adding highlydiluted HCl lowering the pH value of the injected cooled geothermal water. As a result, the injectivity index of the injection well was considerably decreased (Menzel et al., 2000).

The soft acidizing method gives good results in sedimentary geothermal environments, both for rehabilitation of well casings, and the reservoir rock formation itself. It can be applied during the geothermal doublet exploitation (no breaks in their operation), and does not require using heavy equipment and rigs. This economically profitable method gives more permanent results than other well and reservoir rehabilitation and maintenance methods. The method and related problems and technologies applied to carbonate and sandstone geothermal reservoirs and adequate study cases are descrybed in details in specialist papers (e.g. Seibt and Kellner, 2003, Seibt and Wolfgramm, 2008, Ungemach, 2001, Ungemach, 2003).

6.3 Cooled geothermal water disposal

In a majority of space-heating systems, after heat extraction the geothermal water is injected back into the reservoir. Sometimes it is disposed to surface reservoirs (rivers). However, in some particular situations, spent water after passing through heat exchangers or heat pumps is not re-injected, but applied for some practical needs. In the operational European cascaded or multipurpose plants, the water is applied in pools or for balneotherapy purposes. In a smalller number of cases, such water may meet some standards and is used as tap water (i.e. TDS less than 1 g/dm3 and appropriate chemical composition). Presently, and in the coming years, closed geothermal exploitation systems will prevail.

This is caused by the necessity to preserve the renewable features of reservoirs, to conduct long-term exploitation in a sustainable manner and to meet the environmental requirements.

7. SPACE HEATING SYSTEMS BASED ON SHALLOW GEOTHERMAL RESOURCES – EXAMPLES

7.1 Geothermal heat pumps – Switzerland

Switzerland belongs to the world's leaders in shallow geothermal resource applications through heat pumps. Statistically, it was estimated that one shallow heat pump was installed within every two km^2 of country area (Rybach et al., 2000). Significant and rapid development of geothermal direct uses has been made in the last decade or so. Numerous promotions, economical incentives, research, and technology make Switzerland an example for others to follow.

Specifically for Switzerland – as an Alpine country – a prospective field of geothermal heat pump usage represents the implementation of thermal energy contained with drainage waters met during the tunnelling of new roads and railways through mountain massifs, or drained constantly out of already existing tunnels. The temperatures of such waters are in the range from 10-25ºC. About 1,200 tunnels with a total length of 1,600 km have been built in the country. Several new ones are being constructed, the longest of which will be over 50 km (Wilhelm and Rybach, 2003).

In several cases, the temperature and flow-rate of tunnel water led to the use of their potential for small space-heating and domestic warm water preparation systems of residential buildings in sites located close to the tunnel portals. Because of economic reasons, the distance between portal and consumer should be shorter than 1–2 km. A significant number of existing tunnels represents a total thermal poten-tial of 30 MWt, enough to provide several thousand people with thermal energy. Moreover, about 40 MWt are estimated to be available from drainage water at the portals of two new tunnels under construction: with lengths of 35 km and 57 km. This theoretical potential is a subject of detailed modelling and evaluation, to give more realistic values which could be used for planning of the socalled portal-near heating systems (Wilhelm and Rybach, 2003).

The Swiss case of the geothermal heat pumps' development forms a perfect example to follow by many countries (Rybach, 2008).

7.2 Coal mines and salt dome structures as potential geothermal energy reservoirs

In recent decades, coal mining has declined in many regions of the world, causing the abandonment of underground mines, e.g. in France, Germany, Great Britain, the Netherlands, Poland, Spain, Slovakia and Ukraine. Abandoned, water-filled mine workings contain tens of millions of cubic meters of warm water. They constitute a significant, but little-studied, geothermal resource that can be used with the application of heat pumps for space-heating, recreation, agriculture, and industry. Several installations, based on geothermal heat pumps, are already working in Canada, Germany, and Scotland. These show that mines that have extracted fossil fuels in the past can produce clean and renewable geothermal energy (Małolepszy, 2003).

Generally, coal fields are located in areas of a mean geothermal gradient varying from 17 to 45°C/km. These values give temperatures of 30-50°C at the deepest levels of the mines (1000 –1200 m). Water reservoirs can be found in almost all kinds of underground mines after termination of exploitation and abandonment of mine workings.

Geothermal heat contained in water and

ventilation air pumped out from the underground mines can be used for space-heating based on heat pumps. On an international scale, the Minewater project oriented to geothermal heat extraction from closed underground mines is being carried out by a consortium of partners from the Netherlands, UK, France and Germany. The project focuses on a pilot station in the city of Heerlen (Netherlands) that will use water from the local abandoned coal mines for a space heating system in this town. It is estimated that the concept implemented in Heerlen will give a CO_2 reduction of 50% in comparison with conventional fuels (www.minewaterproject.info).

Salt domes and diapirs – specific tectonic structures formed of Permian (Palaeozoic) saline formations – are found in some European countries (e.g. Germany, Poland). They reveal specific thermal features and may be treated as potential heat sources, e.g. for local heating (Bujakowski [ed.] et al., 2003).

Such diapers have their roots at 5 to 8 km b.s.l., whereas their roof parts are often some hundred to some tens of metres from the surface only. Sporadically, their top parts, the so-called gypsum caps, may manifest as outcrops.

As compared to other rocks, salt has exceptionally good thermal properties, i.e. high thermal conductivity from 6 to 7 W/mK, exceeding 2-3 times the values for the neighbouring rocks (limestones, sandstones, siltstones) therefore heat is accumulated in the saline structures. Diapirs are migration paths ('thermal bridges') facilitating the Earth's heat transport from greatest depths to the surface. Increased temperatures can be observed within the diapirs to about a depth of 4 km.

In case of Poland salt from several diapirs has been exploited on an industrial scale by the leaching method. It lies in the injection of water and undersaturated brine through the wells to a depth of some hundred to 1.2 km (at such depths, temperatures are higher by several degrees centigrade than in the neighbouring rocks). These fluids dissolve salt, and the produced 28-30°C brine is pumped to the surface. The studies (Pajak et al., 2003) have shown that a thermal capacity of 1 MWt can be yielded from the saline rooms at about 30oC of the carrier. Thermal energy enclosed in the brine can be used for heating, swimming pools, soil heating, etc. The subject of geothermal energy evaluation and production from salt domes will be continued. It remains as an interesting and site-specific proposal for future harnessing of geothermal energy for heating.

8. ECOLOGICAL EFFECTS

Ecological benefits are among the main and the strongest arguments for introducing the geothermal space heating within any region. Such systems always brings measurable results in the elimination of a significant part of fossil fuels (often coal and coke) burnt for heating which results in essential decrease in related emissions of greenhouse gasses, dusts and solid particles.

As an example one can give the Podhale geothermal heating project, Poland (Kępińska, 2004). Its realization brings measurable results in the elimination of a considerable part of over 200 000 tonnes of coal and coke burnt per year in that region. In 2007 geothermal heat production was 300 TJ (www.geotermia.podhalanska.pl). Work to connect new consumers is underway. In the case of Zakopane – the main city supplied by geothermal (population 30,000, over 3 million tourists/a) thanks to the successive introduction of geothermal heating in 1998-2007, annual average concentrations of particulate matter (PM10) and SO2 have dropped by about 50% in comparison to the situation before geothermal heating was started. Total CO_2 reduction in 2007 was over 29,000 tons. Figure 5 shows ecological effect expressed as a limitation in SO_2 emissions generated so far mostly by coal-fired heating systems while Figure 6 shows the limitations of CO_2 emissions achieved thanks to geothermal heating introduction in the city.

9. FUTURE PROSPECTS

In Europe, space heating belongs to the most important types of geothermal energy uses at present and in the future. Systems based on deep hydrothermal resources, as well as on shallow groundwater and rock formations, are successfully exploited. The variety of reservoir conditions and production methods proves the variety of possibilities in which geothermal energy can be used, adjusted to local conditions and needs. They are reliable and economically viable.

The future development of the geothermal heating sector will involve the progress in existing and in new technologies and types of use (Antics and Sanner, 2007): improved and innovative methods in exploration, technologies, materials; construction of new district heating networks, improvement of existing networks and plants; increased applications and innovative concepts for geothermal energy use in horticulture, aquaculture, industrial drying processes; further increase of efficiency and technologies in geothermal heat pumps; demonstration of new applications (de-icing and snow melting on roads, airport runways, sea water desalination). The anticipated progress in geothermal development shall also be facilitated by adequate legal and economical measures both at the levels of the European Union and particular European countries.

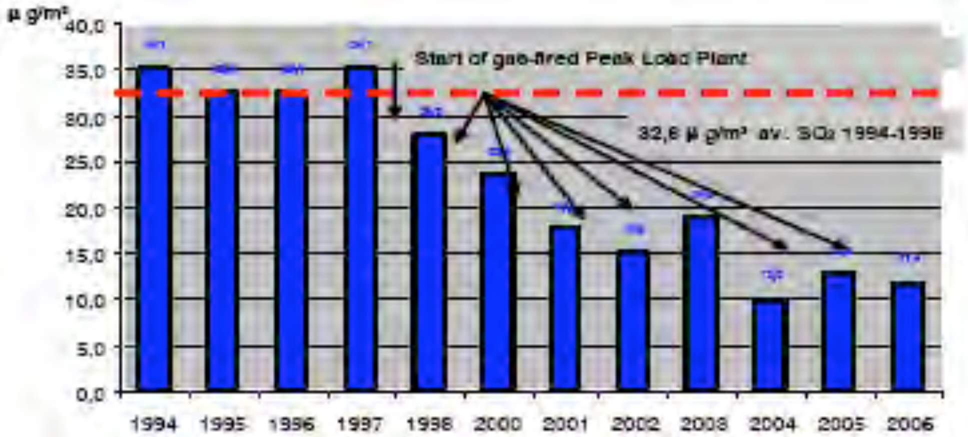

Fig. 5: Limitation of average annual SO2 emissions thanks to the introduction of geothermal space heating system in Zakopane, Poland (source: PEC Geotermia Podhalanska SA)
1994-1998: situation prior to geothermal project development - space heating based on hard coal and other fossil fuels, 1998-2000 – bulk of coal-based systems replaced by gas-fired Peak Load Plant, since 2001 – development of geothermal space heating system

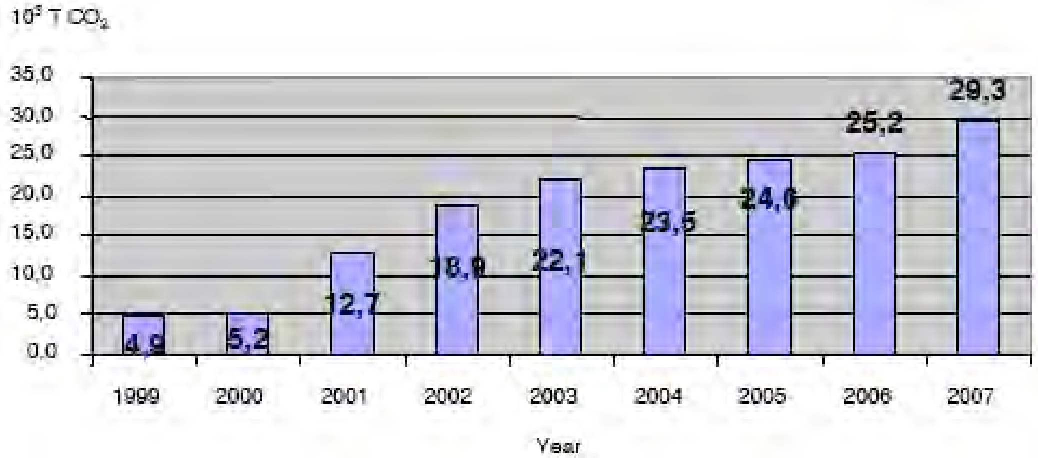

Fig. 6: Limitation of CO2 emissions thanks to geothermal heating

Many experts point out that faster and wider geothermal development in Europe is possible thanks to international cooperation and the transfer of good practices and technologies. Such cooperation has been ongoing but there are many more opportunities to extend its scope, also with the participation of UNU-GTP Staff and Fellows.

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