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WORLD GEOTHERMAL ENERGY AND ITS ROLE IN THE MITIGATION OF CLIMATE CHANGE

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ABSTRACT

Electricity is produced by geothermal in 24 countries, five of which obtain 15-22% of their national electricity production from geothermal energy. Direct application of geothermal energy (for heating, bathing etc.) has been reported by 72 countries. By the end of 2004, the worldwide use of geothermal energy was 57 TWh/yr of electricity and 76 TWh/yr for direct use. Ten developing countries are among the top fifteen countries in geothermal electricity production. Six developing countries are among the top fifteen countries reporting direct use. China is at the top of the latter list. Geothermal energy is available day and night every day of the year and can thus serve as a supplement to energy sources which are only available intermittently.

Scenarios for future development show only a moderate increase in traditional direct use applications of geothermal resources, but an exponential increase is foreseen in the heat pump sector, as geothermal heat pumps can be used for heating and/or cooling in most parts of the world. It is considered possible to increase the world installed capacity for direct use of geothermal resources from about 60 GW_{th} in 2010 to about 800 GW_{th} in 2050 (thereof 90% with heat pumps). The mitigation potential would be of the order of 300 million tonnes CO_2/yr in 2050. The mitigation potential would, however, be much higher if the electricity for the heat pumps would be produced by renewable energy sources. The CO_2 emission from low-temperature geothermal water is negligible or in the order of 0-1 g CO_2/kWh depending on the carbonate content of the water.

According to the scenarios, it is considered possible to increase the installed world geothermal electricity capacity from the current 10 GW_e to 70 GW_e with present technology, and to 140 GW_e with enhanced technology. Enhanced Geothermal Systems, which are still at the experimental level, have an enormous potential for primary energy recovery using new heat-exploitation technology to extract and utilise the Earth’s stored thermal energy. An installed capacity of 140 GW_e and a production of 1,100 TWh/yr by geothermal in 2050 would mitigate about 500 million tonnes CO_2/year if substituting natural gas and about 1,000 million tonnes CO_2/yr if substituting coal.

1. INTRODUCTION

Although geothermal energy is categorized in international energy tables amongst the "new renewables", it is not a new energy source at all. People have used hot springs for bathing and washing clothes since the dawn of civilization in many parts of the world. An excellent book has been published with historical records and stories of geothermal utilization from all over the world (Cataldi et al., 1999).

Electricity has been generated commercially by geothermal steam since 1913, and geothermal energy has been used on the scale of hundreds of MW for five decades both for electricity generation and direct use. The utilization has increased rapidly during the last three decades. Geothermal resources have been identified in some 90 countries and there are quantified records of geothermal utilization in 72 countries. Summarized information on geothermal use in the individual countries for electricity production and direct use (heating) is available in Bertani (2005) and Lund et al. (2005), respectively. Electricity is produced by geothermal energy in 24 countries. Five of these countries obtain 15-22% of their national electricity production from geothermal (Costa Rica, El Salvador, Iceland, Kenya and the Philippines). In 2004, the worldwide use of geothermal energy was about 57 TWh/yr of electricity (Bertani, 2005), and 76 TWh/yr for direct use (Lund et al., 2005). The installed electric capacity in 2004 was 8,933 MWe (Bertani, 2005). The installed capacity for direct applications in 2004 was 28,268 MW_{th} (Lund et al., 2005). Table 1 shows the installed capacity and the geothermal energy production in the different continents in 2004.

TABLE 1: Electricity generation and direct use of geothermal energy in 2004.
Data from Bertani (2005), and Lund et al. (2005)

	Electricity generation			**Direct Use**		
	Installed capacity MWe	**Total production GWh/a**	**%**	**Installed capacity MWth**	**Total production GWh/a**	**%**
Africa	136	1088	2	190	763	1
America	3941	26794	47	8988	12119	16
Asia	3290	18903	33	5044	17352	23
Europe	1124	5745	12	13628	42916	56
Oceania	441	2791	5	418	2793	4
Total	**8933**	**56786**	**100**	**28268**	**75943**	**100**

The world geothermal electricity production increased by 16% from 1999 to 2004 (annual growth rate of 3%). Direct use increased by 43% from 1999 to 2004 (annual growth rate of 7.5%). Only a small fraction of the geothermal potential has been developed so far, and there is ample opportunity for an increased use of geothermal energy both for direct applications and electricity production.

Geothermal energy has until recently had a considerable economic potential only in areas where thermal water or steam is found concentrated at depths less than 3 km in restricted volumes, analogous to oil in commercial oil reservoirs. This has changed in the last two decades with the development of power plants that can economically utilize lower temperature resources (around 100°C) and the emergence of ground source heat pumps using the earth as a heat source for heating or as a heat sink for cooling, depending on the season. This has made it possible for all countries to use the heat of the earth for heating and/or cooling, as appropriate. It should be stressed that heat pumps can be used basically everywhere.

2. GEOTHERMAL RESOURCES

Geothermal energy, in the broadest sense, is the natural heat of the Earth. Immense amounts of thermal energy are generated and stored in the Earth's core, mantle and crust. At the base of the continental crust, temperatures are believed to range from 200 to 1,000°C, and at the centre of the Earth the temperatures may be in the range of 3,500 to 4,500°C. The heat is transferred from the interior towards the surface mostly by conduction, and this conductive heat flow makes temperature rise with increasing depth in the crust on average 25-30°C/km. Geothermal production wells are commonly more than 2 km deep, but rarely much more than 3 km at present. With an average thermal gradient of 25-30°C/km, a 1 km well in dry rock formations would have a bottom temperature near 40°C in many parts of the world (assuming a mean annual air temperature of 15°C) and a 3 km well 90-100°C.

The total heat content of the Earth is of the order of 12.6 x 10^{24} MJ, and that of the crust the order of 5.4 x 10^{21} MJ (Dickson and Fanelli, 2004). This huge number should be compared to the world electricity generation in 2005, 6.6 x 10^{13} MJ. The thermal energy of the Earth is therefore immense, but only a fraction can be utilized. So far our utilization of this energy has been limited to areas in which geological conditions permit a carrier (water in the liquid or vapour phases) to "transfer" the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources.

It is difficult to estimate the overall worldwide potential, due to the presence of too many uncertainties. Nevertheless, it is possible to identify a range of estimations, taking also into consideration the possibility of new technologies, such as permeability enhancements, drilling improvements, special Enhanced Geothermal Systems (EGS) technology, low temperature electricity production, and the use of supercritical fluids.

In a recent study on the possible role and contribution of geothermal energy to the mitigation of climate change, Fridleifsson et al. (2008) considered it possible to increase the world installed capacity for direct use of geothermal resources from about 60 GW_{th} in 2010 to about 800 GW_{th} in 2050 (thereof 90% with heat pumps). Similarly, they considered it possible to increase the installed world geothermal electricity capacity from the current 10 GW_e to 70 GW_e with present technology, and to 140 GW_e with enhanced technology. Enhanced Geothermal Systems, which are still at the experimental level, have an enormous potential for primary energy recovery using new heat-exploitation technology to extract and utilize the Earth’s stored thermal energy.

Exploitable geothermal systems occur in a number of geological environments. They can be divided broadly into two groups depending on whether they are related to young volcanoes and magmatic activity or not. High-temperature fields used for conventional power production (with temperatures above 180°C) are mostly confined to the former group, but geothermal fields utilized for direct application of the thermal energy can be found in both groups. The temperature of the geothermal reservoirs varies from place to place depending on the geological conditions.

3. GEOTHERMAL UTILIZATION

Geothermal utilization is commonly divided into two categories, i.e. electricity production and direct application. Conventional electric power production is commonly limited to fluid temperatures above 180°C, but considerably lower temperatures can be used with the application of binary fluids (outlet temperatures as low as 70°C). The ideal inlet temperatures into buildings for space heating is about 80°C, but by application of larger radiators in houses, or the application of heat pumps or auxiliary boilers, thermal water with temperatures only a few degrees above the ambient temperature can be used beneficially.

As mentioned in the Introduction, geothermal resources have been identified in some 90 countries and there are quantified records of geothermal utilisation in 72 countries. Electricity is produced from geothermal energy in 24 countries. The top fifteen countries producing geothermal electricity and using geothermal energy directly in the world in 2005 (in GWh/yr) are listed in Table 2. It is of great interest to note that among the top fifteen countries producing geothermal electricity, there are ten developing countries. Among the top fifteen countries employing direct use of geothermal energy, there are six developing and transitional countries. China is on top of the list of countries on direct use (Table 2). Some 55% of the annual energy use of geothermal energy in China in 2005 was for bathing and swimming, 14% for conventional district heating, and 14% for geothermal heat pumps used for space heating (Zheng et al., 2005).

Table 2: Top fifteen countries utilizing geothermal energy in 2005.
Data on electricity from Bertani (2005) and on direct use from Lund et al. (2005).

Geothermal electricity production		**Geothermal direct use**	
	GWh/yr		**GWh/yr**
USA	17,917	China	12,605
Philippines	9,253	Sweden	10,000
Mexico	6,282	USA	8,678
Indonesia	6,085	Turkey	6,900
Italy	5,340	Iceland	6,806
Japan	3,467	Japan	2,862
New Zealand	2,774	Hungary	2,206
Iceland	1,483	Italy	2,098
Costa Rica	1,145	New Zealand	1,968
Kenya	1,088	Brazil	1,840
El Salvador	967	Georgia	1,752
Nicaragua	271	Russia	1,707
Guatemala	212	France	1,443
Turkey	105	Denmark	1,222
Guadeloupe (France)	102	Switzerland	1,175

Figure 1 shows the direct applications of geothermal energy worldwide by percentage of total energy use. The main types of applications are space heating 52% (thereof 32% using heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4%, and aquaculture (mainly fish farming) 4% (Lund et al., 2005). The main growth in the direct use sector has during the last decade been the use of geothermal (ground-source) heat pumps. This is due, in part, to the ability of geothermal heat pumps to utilize groundwater or ground-coupled temperatures anywhere in the world.

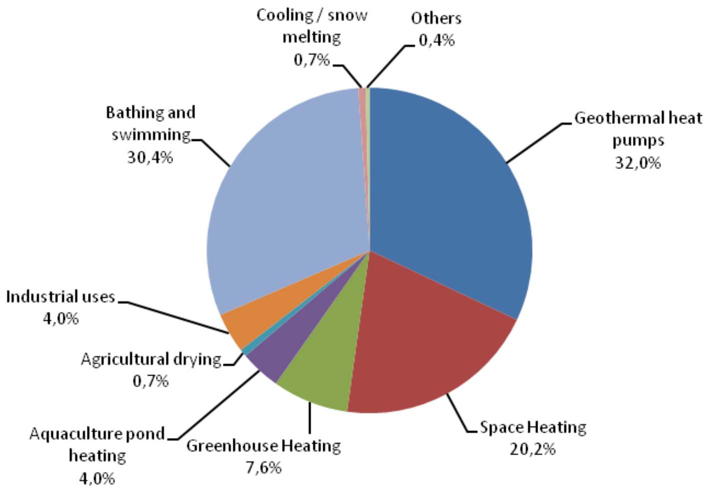

FIGURE 1: Direct applications of geothermal worldwide in 2004 by percentage of total energy use (data from Lund et al. 2005).

Space heating, of which more than 80% are district heating, is among the most important direct uses of geothermal energy. Preferred water delivery temperature for space heating is in the range 60-90°C and commonly the return water temperature is 25-40°C. Conventional radiators or floor heating systems are typically used, but air heating systems are also possible. If the temperature of the resource is too low for direct application, geothermal heat pumps can be used, as will be discussed below. Space cooling can also be provided by geothermal systems; geothermal heat pumps can heat and cool with the same equipment.

Geothermal heat pumps (GHPs) are one of the fastest growing applications of renewable energy in the world today (Rybach, 2005). They represent a rather new but already well-established technology, utilizing the immense amounts of energy stored in the Earth´s interior. This form for direct use of geothermal energy is based on the relatively constant ground or groundwater temperature in the range of 4°C to 30°C available anywhere in the world, to provide space heating, cooling and domestic hot water for homes, schools, factories, public buildings and commercial buildings.

Until recently, almost all of the installations of the ground source heat pumps have been in North America and Europe, increasing from 26 countries in 2000 to 33 countries in 2005 (Lund et al., 2005). China is, however, the most significant newcomer in the application of heat pumps for space heating. According to data from the Geothermal China Energy Society in February 2007, space heating with ground source heat pumps expanded from 8 million m^2 in 2004 to 20 million m^2 in 2006, and to 30 million m^2 in 2007 (Keyan Zheng, personal communication 2008). Conventional geothermal space heating in the country had grown from 13 million m^2 in 2004 to 17 million m^2 in 2006. The numbers reflect the policy of the Chinese government to replace fossil fuels where possible with clean, renewable energy. The "Law of Renewable Energy of China" came into implementation in 2006.

In Iceland, the geothermal water is commonly piped 10-20 km from the geothermal fields to the towns. Transmission pipelines are mostly of steel insulated by rock wool (surface pipes) or polyurethane (subsurface). However, several small villages and farming communities have successfully used plastic pipes (polybutylene) with polyurethane insulation as transmission pipes. The temperature drop is insignificant in large diameter pipes with a high flow rate, exemplified by a 1°C drop in a 27 km steel pipeline with 800 mm diameter and a flow of 1500 l/s and (Gunnlaugsson, personal communication 2008), and 3.5 °C in a 10 km steel pipeline with 200 mm diameter and a flow of 45 l/s (Baldursson, personal communication 2008).

4. WORLD ENERGY SOURCES

Table 3 shows the world primary energy consumption in 2001 (WEA, 2004). Fossil fuels provide 80% of the total, with oil (35%) in first place, followed by coal (23%) and natural gas (22%). The renewables collectively provide 14% of the primary energy, mostly in the form of traditional biomass (9%) and much less by large (>10MW) hydro power stations (2%) and the "new renewables" (small hydro, biomass, geothermal, wind, solar and tidal energy, 2%). Nuclear energy provides 7% of the world primary energy.

TABLE 3: World Primary Energy Consumption in 2001.
Source: World Energy Assessment (WEA, 2004)

Energy Source	Primary energy (exajoules)	Percentage
Fossil fuels	**332**	**79,4**
Oil	147	35,1
Natural gas	91	21,7
Coal	94	22.6
Renewables	**57**	**13,7**
Large hydro (>10 MW)	9	2,3
Traditional biomass	39	9,3
"New renewables" (biomass, geothermal, solar, small hydro (<10MW), tidal, wind)	9	2,2
Nuclear	**29**	**6,9**
Total	**418**	**100**

It is clearly an enormous task to increase the share of the renewables significantly and thus reduce the emission of CO_2 into the atmosphere.

5. POSSIBLE CONTRIBUTION OF GEOTHERMAL ENERGY TO THE MITIGATION OF CLIMATE CHANGE

One of the major concerns of mankind today is the ever increasing emission of greenhouse gases into the atmosphere and the threat of global warming. It is internationally accepted that a continuation of the present way of producing most of our energy by burning fossil fuels will bring on significant climate changes, global warming, rises in sea level, floods, droughts, deforestation, and extreme weather conditions. And the sad fact is that the poorest people in the world, who have done nothing to bring on the changes, will suffer most. One of the key solutions to these difficulties is to reduce the use of fossil fuels and increase the sustainable use of renewable energy sources. Geothermal energy can play an important role in this aspect in many parts of the world.

At the turn of the millennium, two billion people, a third of the world´s population, have no access to modern energy services. World population is expected to double by the end of the 21st century. A key issue to improve the standard of living of the poor is to make **clean energy** available to them at prices they can afford. Energy affects all aspects of modern life (WEC, 1993). There is a strong positive correlation between energy use per capita in a country and issues that we value highly such as life expectancy and productivity per capita in the country.

In the **geothermal direct use sector**, the potential for replacing fossil fuels is very large as space heating and water heating are significant parts of the energy budget in many parts of the world. In industrialized countries, 35 to 40% of the total primary energy consumption is used in buildings. In Europe, 30% of energy use is for space and water heating alone, representing 75% of total building energy use. The recent decision of the Commission of the European Union to reduce greenhouse gas emissions by 20% by 2020 compared to 1990 in the member countries implies a significant acceleration in the use of renewable energy resources. Most of the EU countries already have some geothermal installations. The same applies to the USA and Canada where the use of ground source heat pumps is widespread both for space heating and cooling. The largest potential is, however, in China. Due to the geological conditions, there are widespread low-temperature geothermal resources in most provinces of China which are already widely used for space heating, balneology, fish farming and greenhouses during the cold winter months and for tap water also in the summer.

To estimate the future development of the worldwide geothermal utilization, Fridleifsson et al. (2008) prepared three scenarios which include the installed capacity and annual energy production in heat pump applications and other direct use applications separately. The most likely case shows that while only a moderate increase is expected in direct use applications, an exponential increase is foreseen in the heat pump sector. The reason is that geothermal heat pumps (GHPs) can be used for heating and/or cooling in most parts of the world. The most critical issue here is the source of electricity providing 25-30% of the energy supplied by the heat pumps. An electrically driven heat pump reduces the CO_2 emission by 45% compared with an oil boiler and 33% compared with a gas fired boiler. If the electricity that drives the heat pump is produced from a renewable energy source like hydropower, wind or geothermal energy, the emission savings are much higher. It is considered possible to increase the world installed capacity for direct use of geothermal resources from about 60 GW_{th} in 2010 to about 800 GW_{th} in 2050 (thereof 90% with heat pumps). The mitigation potential would be of the order of 300 million tonnes CO_2/year in 2050. The mitigation potential would, however, be much higher if the electricity for the heat pumps would be produced by renewable energy sources. The CO_2 emission from low-temperature geothermal water is negligible or in the order of 0-1 g CO_2/kWh depending on the carbonate content of the water.

In the electricity sector, the geographical distribution of suitable high-temperature hydrothermal fields is much more restricted than low-temperature fields and mainly confined to countries or regions on active plate boundaries or with active volcanoes. According to the scenarios presented by Fridleifsson et al. (2008), it is considered possible to increase the installed world geothermal electricity capacity from the current 10 GW_e to 70 GW_e with present technology, and to 140 GW_e with enhanced technology. Enhanced Geothermal Systems (EGS), which are still at the experimental level, have an enormous potential for primary energy recovery using new heat-exploitation technology to extract and utilise the Earth’s stored thermal energy. An installed capacity of 140 GW_e and a production of 1,100 TWh/yr by geothermal in 2050 would mitigate about 500 million tonnes CO_2/yr if substituting natural gas and about 1,000 million tonnes CO_2/yr if substituting coal.

It should be pointed out that some of these "new technologies" are already proven and are currently spreading fast into the market, like the binary plant ("low temperature electricity production"), whereas the EGS are just entering the field demonstration phase to prove their viability.

6. CONCLUSIONS

Geothermal energy is a renewable energy source that has been utilized economically in many parts of the world for decades. A great potential for an extensive increase in worldwide geothermal utilization has been proven. This is a reliable energy source which serves both direct use applications and electricity generation. Geothermal energy is independent of weather conditions and has an inherent storage capability which makes it especially suitable for supplying base load power in an economical way, and can thus serve as a partner with energy sources which are only available intermittently. The renewable energy sources can contribute significantly to the mitigation of climate change and more so by working as partners rather than competing with each other.

Presently, the geothermal utilization sector growing most rapidly is heat pump applications. This development is expected to continue in the future making heat pumps the major direct utilization sector. The main reason for this is that geothermal heat pumps can be installed economically all over the world.

One of the strongest arguments for putting more emphasis on the development of geothermal resources worldwide is the limited environmental impact compared to most other energy sources. The CO_2 emission related to direct applications is negligible, and very small in electricity generation compared to using fossil fuel.

The geothermal exploitation techniques are being rapidly developed and the understanding of the reservoirs has improved considerably over the past years. Combined heat and power plants are gaining increased popularity, improving the overall efficiency of the geothermal utilisation. Also, low-temperature power generation with binary plants has opened up the possibilities of producing electricity in countries which do not have high-temperature fields. Enhanced Geothermal Systems (EGS) technologies, where heat is extracted from deeper parts of the reservoir than conventional systems, are under development. If EGS can be proven economical at commercial scales, the development potential of geothermal energy will be limitless in many countries of the world.

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