Geothermal Energy: The Energy of the Future?

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Abstract —This paper begins by presenting the values obtained for heat loss of the Earth through the surface to the atmosphere and the sources of this heat. We conclude that the thermal energy of the Earth is immense. We then explain w the different uses of geothermal energy. We present the different types of geothermal plants used in high temperature reservoirs, the binary plants that can use lower temperature fluids, and hot dry rock reservoirs in regions of high heat flux but without geothermal reservoirs. In the direct use of geothermal energy we present the different types of geothermal heat pumps and how they work. Tables of installed geothermal electrical capacity in 2007 and 2010,direct use of geothermal energy in 2005, number of ground source heat pumps installed in 2007 and an estimation for 2008 in European Countries, installed capacity of ground source heat pumps in European Countries in 2008 and HDR or EGS projects show us which countries are using geothermal energy and the way it is used. In the environmental aspects we show why geothermal is a clean energy. At the end we present some forecasts for geothermal installation in the next years.

Keywords —geothermal energy, geothermal exploration, geothermal heat pumps, CO_2 emissions

1 Introduction

In general terms, geothermal energy is the thermal energy stored in the Earth's crust. The name "geothermal energy" is used nowadays to indicate that part of the Earth's heat that can be recovered and exploited by man.

The presence of volcanoes, hot springs, and other phenomena, tell us that the interior of the Earth is hot. When the first mines were excavated to a few hundred meters below ground level, men deduced that the Earth's temperature increases with depth. In the twentieth century, with the discovery of the role played by radiogenic heat, we could understand phenomena like heat balance and the Earth's thermal history. Thermal waters for baths have been used by man since Roman times . A chemical industry was set up, in the early part of nineteenth century, in Larderello (Italy), to extract boric acid from the hot waters from specially drilled shallow boreholes. The boric acid was obtained by evaporating boric waters, using wood as fuel. Between 1910 and 1940, low-pressure steam was used to heat industrial and residential buildings and greenhouses. In 1928, Iceland also began exploiting hot waters for domestic heating. The first attempt to use geothermal steam to produce electricity, was made in 1904 at Larderello. In 1942 the installed capacity at Larderello had reached 127,650 KWe [1]. Today, geothermal energy has been exploited many countries. If utilized correctly, geothermal energy could certainly assume an important role in the energy balance of some countries. In certain circumstances even small-scale geothermal resources are capable of solving numerous local problems and of raising the living standards of small, isolated communities

2 HEAT LOSS FROM THE EARTH

The total heat flow by conduction through the surface of the Earth has been calculated by several authors. To do this calculation they used heat flow density data obtained in boreholes drilled in continents and in oceanic sediments. The last value for the heat loss from the Earth was obtained by Davies and Davies [2] who used 38 347 measurements. The value obtained by Jaupart et al [3] was 46 TW. The estimate for continental heat loss was 14TW, and for heat loss by the oceans they found 32 TW. Where does all this energy come from? Radioactive sources of long life exist in the crust and mantle. They are the origin of 20 TW, 7TW originating from the continental crust and lithospheric mantle and 13 TW generated in the convecting mantle [3]. The core contributes 8 TW, and 18 TW are obtained by cooling of the mantle. There are also minor contributors, such as tidal dissipation in the solid Earth and gravitational energy (crust-mantle differentiation). The thermal energy of the Earth is immense, but only a fraction can be utilized by mankind.

3 USES OF GEOTHERMAL FLUIDS

Geothermal fluids can be used directly or can be sent to geothermal plants to produce electricity.

3.1 Geothermal plants

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There are three kinds of geothermal plants, all of which pull hot water and steam from the ground, use it to produce energy, and then return it as warm water to the soil, or send it to other applications.
In the simplest design,(dry steam power plants) the steam goes directly from the reservoir to a turbine, through a production well, to generate electricity, then into a condenser where the steam is condensed into water. This water is injected back into the Earth via a separate well called an injection well. The production well and the injection well need to be far enough apart to not interfere with each other.
Other designs (flash steam power plants) use very hot and pressurized water which is depressurized or "flashed" into steam and used to drive the turbine to obtain electricity. When placed on a coastline, these plants can be used to desalinate water supplies for drinking and irrigation. This happens because distillation occurs when water is boiled into vapour.
In the third design (binary-cycle power plants), the hot water is pumped from a production well through a heat exchanger. In the heat exchanger, heat is transferred from the geothermal water to a second fluid with a low boiling point. This fluid is pumped at high pressure through the heat exchanger, where it is vaporized and then directed to a turbine. The vapour drives the turbine and is then condensed by cold air radiators or cold water to its liquid state and cycled back through the heat exchanger. The cooled geothermal water is returned to the reservoir by the injection well.

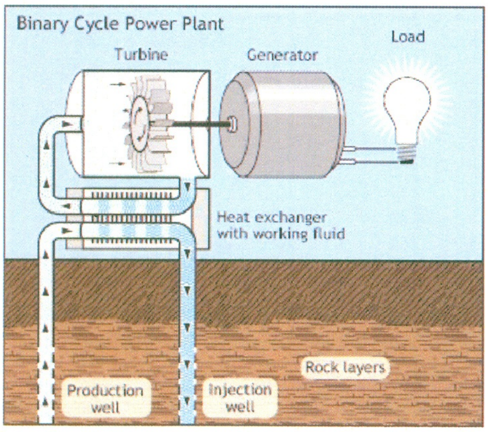

Fig. 1. A binary-cycle power plant [4]

The choice of design of a geothermal plant is determined by the characteristics of the resource. Geothermal resources, used to produce electricity, vary in temperature from 75 to 350°C . If dry steam is available in the reservoir, at temperatures of above 180°C, and can come out of the well, it can be used directly through a turbine and the first design is chosen. If the reservoir has hot water in the liquid phase but with high temperature, a flash system can be used. If the temperature is relatively low for using the flash method, with temperature values between 75 and 180°C, it is necessary to use the third design with a heat exchanger. Since there are more hot water than pure steam reservoirs, there is more growth potential in the heat exchanger design.

3.2 Hot dry rock reservoirs

Geothermal heat occurs everywhere under the surface of the Earth, but the conditions that make water circulate near the surface are found only in less than 10% of the Earth's continental surface. In order to capture the heat in hot dry rocks a method is being used known as a hot dry rock. In this method, we can consider two subsystems connected by deep wells: the power plant (on the surface) and the hot dry rock reservoir (deep in the soil under the surface). The wells and the reservoir are considered as a single system, often referred to as a reservoir system. The power plant used is a binary-cycle power plant. The reservoir subsystem is developed by drilling deep wells into hot rock. The wells are connected by hydraulic fracturing (the rocks near the wells are broken by pumping high-pressure water through them). Water is then pumped from the surface down to the broken hot rocks and the temperature rises. When the temperature of the water is high enough, it is returned to the surface through a second well and used to drive turbines to obtain electricity, or to provide heat that can be used directly.

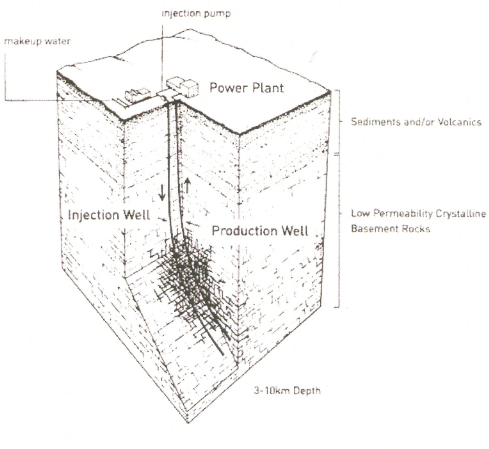

Fig. 2 A hot dry rock reservoir with the adjacent power plant [5]

The major components of a HDR system are:
-One or more hot dry rock reservoirs, created artificially by hydraulic fracturing a deep well drilled into hot, impermeable and crystalline rock. The fracture system is used to circulate water in order to absorb the heat from the rocks and bring it to the surface
-Deep wells for production and injection of water. The original well, used to originate the fracture system, is used for injection. Two additional wells

are drilled to intersect the fracture system and are used as production wells.
-During the fracturation of the rocks, seismic data appears, which is used to determine the extent and orientation of the fractures caused by the system.
-A shallow water well or other source of fresh water
-Surface pipes to transport water between the wells and the power plant
-A binary-cycle power plant

3.3 Direct uses

Direct use of geothermal energy is one of the oldest and most common form of utilization of geothermal energy [1]. Geothermal springs can be used directly for heating purposes and for spas. Hot water can be used to heat greenhouses, to dry out fish, to heat fish farms and to melt snow in the winter .It can be used also to heat isolated houses, or an entire community. Three things are needed to make direct resources available:
-A well for bringing the hot water to the surface
-A mechanical engineering system to pump and distribute the water
-A place to dispose of the used water. It can be discharged into a pond or pumped back down into the Earth.

3.3.1 Heat pumps

There are two distinct types of heat pumps: air source heat pumps or ground source heat pumps. Both work essentially in the same way, and which type is best depends on weather and environmental conditions.

3.3.1.1 Air-source heat pumps

Air-source heat pumps use ambient air to heat or cool a refrigerant contained in a compressor system. They are used especially in moderate climates for heating or cooling.
With an air-source heat pump, outside air is drawn across an exterior coil by a fan. Refrigerant fluid is run through the exterior coil and into the compressor where it is pressurized and heated. On the other side of the compressor, a closed loop of fluid is run through the interior coil and interior air is passed over this coil by the interior fan.

3.3.1.2 Ground-Source heat pumps

There are two main types of ground source heat pump systems: ground-coupled closed loop (vertical or horizontal, see Fig 3) and water-source open loop(see Fig 4), [6].
The closed loop systems use a buried earth coil as the ground heat exchanger through which a heat transfer fluid, typically an antifreeze solution, is

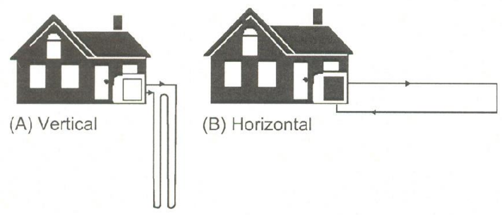

Fig. 3 Closed-loop ground-coupled systems [6].

circulated. The ground heat exchanger, installed vertically in boreholes or horizontally in trenches, exchanges heat with the ground (Fig 3). In open-loop systems the groundwater is pumped into the heat pump unit, where heat is extracted from (or rejected to) the water. The water can be released into a stream, river, pond, lake, ditch, or drainage tile. A second means of water discharge is using a return well that returns the water to the aquifer on the ground (Fig 4).

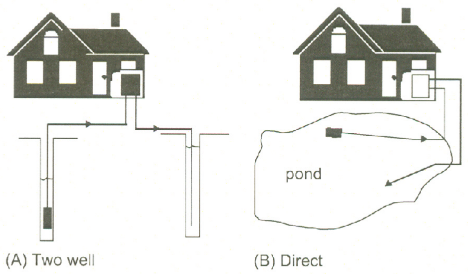

Fig.4 Open-loop groundwater systems.[6].

The ground source heat pumps use the relatively constant temperatures of the soil (between 7 and 21° C) to provide heating and cooling all through the year. They use the stable temperature of the ground as a heat source to heat buildings in winter and as a heat sink to cool them in summer. Figure 5 shows a schematic of a ground-source heat pump system. It consists of three distinct subsystems: earth connection or ground heat exchanger, heat pump unit and heat distribution.
The type of ground heat exchanger used will affect the heat pump system performance. The choice of the most appropriate type of ground heat exchanger for a site is usually a function of the available land area or specific geography. The vertical ground heat exchanger, is generally considered when land surface is limited. They can be classified into two basic categories: U pipes and coaxial pipes [7]. The first one consists of two small diameter (25-32mm) high-density tubes that are placed in a vertical borehole that is filled with a solid medium. The tubes are thermally fused at the bottom of the borehole to a close-return U-bend. Multiple wells are typically required, with well spacing not less

than 4.6 m in northern climates and 6.1 m in

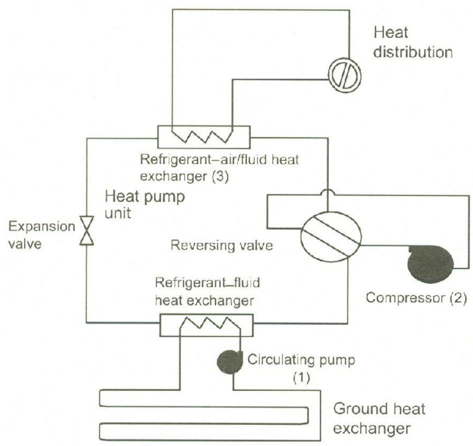

Fig 5 . Skematic representation of a ground-source heat pump system [8].

southern climates, to achieve the total heat transfer requirements. Because of the high cost of drilling, two or even three such pipes are usually installed in one hole.

Concentric or coaxial pipes, are joined in a very simple way with one straight pipe inside a larger diameter pipe or joint in complex configurations.

Vertical loops are generally more expensive to install, but they use less pipe than horizontal loops because temperatures in the earth are cooler in summer and warmer in winter, compared to the ambient temperature.

Horizontal heat exchangers, are most often used for small installations where space is not a problem. Pipes are buried in trenches typically at a depth of 1,2 to 3,0 m in the ground and usually a series of parallel plastic pipes is used. Fluid runs through the pipes in a closed system. A typical horizontal loop is 35-60 m long per KW of heating or cooling capacity [7]. Horizontal ground loops are the easiest to install while a building is under construction.

Fig 6 . A horizontal heat exchanger is being mounted in Barcelos (Portugal) [9].

3.3.1.2 Soil characteristics

The operation of the heat exchanger induces a simultaneous heat and moisture flow in the surrounding soil. The transfer of heat between the soil and the heat exchangers is primarily by conduction and to a certain degree by moisture migration. Therefore, heat transfer depends strongly on the soil type, temperature and moisture gradients. With horizontal heat exchangers the task is facilitated because it is possible to obtain samples to analyse in the laboratory and the soil can be inspected and tested.

To study the problem we must know the thermal diffusivity of the soil, and this property is the ratio between the thermal conductivity, the specific heat and the density. So, we must know three properties of the soil to predict the thermal behaviour of the heat exchanger.

4 GEOTHERMAL EXPLORATION

4.1Electricity production using geothermal fluids

The use of geothermal energy has been growing in the last years. In 2004, the worldwide production of electricity by geothermal energy was 57TW/year. The installed electric capacity in that year was 8,933MWe. The world geothermal electricity production increased by 16% from 1999 to 2004. The installed electrical capacity achieved an increase of about 800 MWe in the years 2005-2007. The total installed capacity in 2007 was 9.7 GW. In 2010 IGA reports that 10,715 MW were on line generating 67,246 GWh. This represents a 20% increase in geothermal power on line between 2005 and 2010. IGA projects this will grow to 18,500 MW by 2015. Figure 7 shows a graph of the installed capacity for electricity production since 1975 to the end of 2007 and a forecast to 2010 [10].

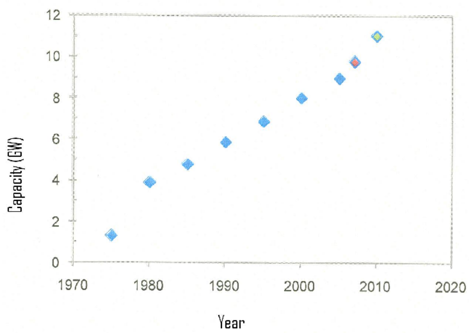

Fig 7. Installed capacity for electricity production (Bertani,2007)

In 2009, twenty four countries used geothermal fluids to produce electricity; five of these countries obtained 15-22% of their national electricity production, from geothermal energy.

Figure 8 shows the top fourteen countries with the

highest % share of geothermal energy in their national electricity production. El Salvador was the first country with more than 20% of electricity production obtained from geothermal energy [Fried...,2007].USA was the country with the highest geothermal electricity production in GWh in 2004.
In 2010, the USA led the world in electricity production using geothermal fluids, with 3,086 MW of installed capacity from 77 power plants. The

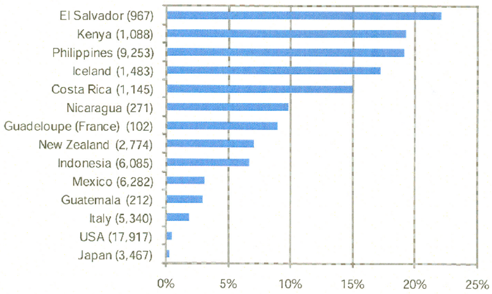

Fig 8. The fourteen countries with th highest % share of geothermal energy in their national electricity production [11]

Philippines was the second highest producer with 1,904MW of capacity online. The countries with the greatest increase in installed capacity between 2005 and 2010 are, in first place U. S. A. with 530 MW followed by Indonesia with 400 MW and Iceland with 373 MW. In terms of percentage increase, we have at the top Germany with 2,774%, followed by Papua-New Guinea with 833% and Australia with 633%. While power online grew 20% between 2005 and 2010, countries with projects under development grew faster. In 2010, Holm Alison [12] identified 70 countries with projects under development or projected. This represents an increase of 52% since 2007.
Projects under development grew especially in two regions of the world, Europe and Africa. In 2007, there were 10 projects under development in Europe, and in 2010 this number increased to 24. In 2007, there were in Africa six countries with projects and in 2010 there were eleven countries considering the utilization of geothermal power.
Despite the growth, it appears there are still many countries with geothermal power potential that are not developing their resources.
In Table 1 we can see the installed geothermal electric capacity in the 24 producing countries, in 2007 [10] and 2010 [12]. The total installed in 2007 was 9,731.9 MW and in 2010 10,709.7 MW. This represents an increase of 10%.

Table 1. Installed geothermal electric capacity

Country	Capacity(MW) in 2007 [10]	Capacity(MW) in 2010 [12]
USA	2687	3086
Philippines	1969.7	1904
Indonesia	992	1197
Mexico	953	958
Italy	810.5	843
New Zealand	471.6	628
Iceland	421.2	575
Japan	535.2	536
El Salvador	204.2	204
Kenya	128.8	167
Costa Rica	162.5	166
Nicaragua	87.4	88
Russia	79	82
Turkey	38	82
Papua-New Guinea	56	56
Guatemala	53	52
Portugal	23	29
China	27.8	24
France	14.7	16
Ethiopia	7.3	7.3
Germany	8.4	6.6
Austria	1.1	1.4
Australia	0.2	1.1
Thailand	0.3	0.3
Total	9,731.9	10,709.7

4.2 Direct use of geothermal energy

Worldwide direct utilization of geothermal energy in 2005 was 273,372 TJ/year (75,943 GWh/year) (Lund et al, [13]) This number includes the values reported from seventy two countries. The main types of direct applications of geothermal energy are space heating (52%), bathing and swimming (30%), greenhouses and soil heating (8%), industry (4%) and aquaculture (4%). Figure 9 shows geothermal direct applications in 2005 and percentage of total energy use (Lund, [13]). We can see that geothermal heat pumps and space heating cover more than 50% of the utilization. 80% of space heating is district heating.

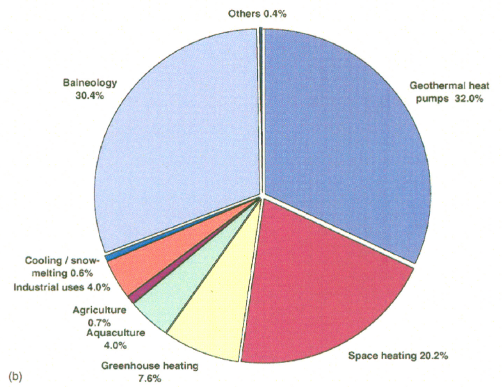

Fig 9. Geothermal direct applications worldwide in 2005. Percentage of total energy used.(Lund,2005)

Among the top fifteen countries employing direct use of geothermal energy (see Table 2) there are six developing countries. China is on the top of the list with 12,605 GWh/year in direct utilization; 50% of this value is used for bathing and swimming, 14% for district heating and 14% for geothermal heat pumps.

Table 2 Direct use of geothermal energy in 2005 [13]

Country	GWh/yr
China	12,605
Sweden	10,000
USA	8,678
Turkey	6,900
Iceland	6,806
Japan	2,862
Hungary	2,206
Italy	2,098
New Zealand	1,968
Brazil	1,840
Georgia	1,752
Russia	1,707
France	1,443
Denmark	1,222
Switzerland	1,175

The main growth in the direct utilization during the last decade has been the use of geothermal (ground-source) heat pumps. This is due, in part, to the fact that geothermal heat pumps use groundwater temperatures that can be achieved anywhere in the world. Table 3 shows the number of geothermal heat pumps installed in the EU countries in 2007 and 2008 [2009]. We can see that the total number of geothermal heat pumps installed increased from 102385 in 2007 to 112157 in 2008. This represents an increase of 10%. For the first time Germany is the first country in the table with an increase of 28%. Poland, Estonia, Slovenia and Greece show a decrease in 2008.

Table 3. Number of ground source heat pumps installed in 2007 and an estimation for 2008 in European Countries [14]

Country	2007	2008
Germany	26887	34450
Sweden	27938	25138
France	18600	19430
Austria	8288	8566
Finland	5300	7500
United Kingdom	3000	5000
Netherlands	3529	4098
Czech Republic	1792	2203
Ireland	2608	2095
Belgium	1200	1300
Poland	1700	1000
Estonia	1123	972
Slovenia	420	405
Greece	65	n. a.
Total	102385	112157

In Table 4 we can see the capacity of ground source heat pumps in the European Union till 2008 (2009).

Table 4 Installed capacity of GSHP in European countries in 2008 (adapted from [14])

Country	Installed Capacity (MWth)
Sweden	2909.0
Germany	1652.9
France	1340.7
Finland	857.9
Austria	544.8
Netherlands	508.0
Poland	180.0
Ireland	157.0
Italy	150.0
Czech Republic	147.0
United Kingdom	134.6
Denmark	123.8

Belgium	114.0
Estonia	63.0
Hungary	15.0
Slovenia	12.2
Lithuania	4.3
Romania	2.0
Greece	1.9
Slovakia	1.4
Bulgaria	0.3
Latvia	0.2

We can see that although Germany was the country with the highest number of GSHP installed in 2008, Sweden is still the country with the largest installed capacity. Denmark, Hungary, Lithuania, Romania, Greece, Slovakia, Bulgaria, Latvia and Portugal have not installed GSHP in 2008. The United Kingdom had a 100% increase in the number of GSHP installed and in the capacity.

4.3 Hot Dry Rock or Enhanced Geothermal Systems

There are HDR or EGS systems currently being developed and tested in France, Australia, Japan, Germany and the USA. The largest EGS project in the world is a 25 MW demonstration plant currently being developed in the Cooper Basin, Australia. The Cooper basin Project has the potential to develop 5-10 GW.
In Table 5, we can see ten developing projects . We must mention a project in Basel (Switzerland) cancelled due to induced seismicity. We also have notice about a project developing in Portugal in an area of about 500 square kilometres located in the Beiras region [15].
Table 5. HDR or EGS projects

Project	Country	Size (MW)
Paralana	Australia	7-30
Cooper Basin	Australia	250-500
Soultz	France	1.5
Landau	Germany	3
Ogachi	Japan	Unknown
Desert Peak	USA	11-50
The Geysers	USA	Unknown
Bend, Oregon	USA	Unknown
United Downs, Redruth	United Kingdom	10
Eden Project	United Kingdom	3

5. ENVIRONMENTAL ASPECTS OF GEOTHERMAL ENERGY

Fluids coming from the deep earth contain a variable quantity of gases, namely nitrogen and carbon dioxides with some hydrogen sulphide and ammonia, mercury ,radon and boron. The amounts found depend on the geological conditions of different fields. These gases contribute to global warming, acid rains and noxious smells, if released. Most of the chemicals are dissolved in the disposal

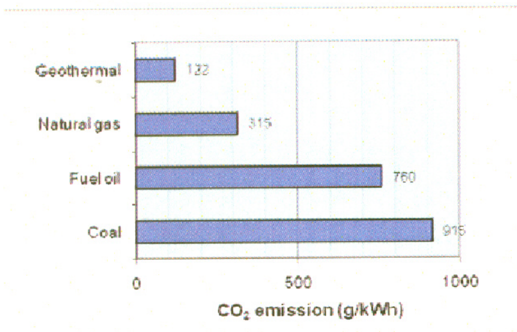

Fig. 10. CO_2 emission from electric plants using different energy sources [17]

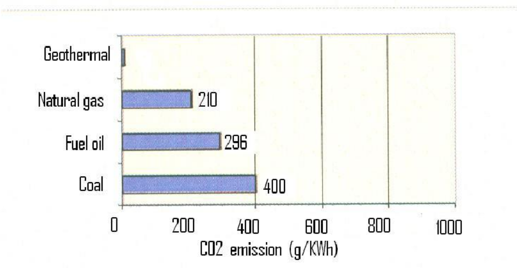

Fig 11. CO_2 emissions obtained from heat generation using different energy sources [17]

water which can be reinjected into drillholes. Hydrogen sulphide released from geothermal power plants can be routinely treated and converted to elemental sulphur. Binary power plants and direct use projects normally do not produce any pollutants, as the water is injected back into the ground after use , without exposing it to the atmosphere.CO_2 emission from geothermal power plants in high-temperature fields is about 120 g/ KWh (weighted average of 85% of the world power plant capacity) (Fridleifsson et al, [16]). Figure 10 shows typical values of CO_2 emission (g /KWh) from electric power plants using different energy sources, and in Figure 11 we can see the CO_2 emission obtained from heat generation using different energy sources. We can see in both figures that CO_2 emissions from geothermal facilities are less than those obtained using fossil fuels. The CO_2 emissions from low-temperature geothermal water is negligible or on the order of 0-1g/ KWh depending on the carbonate content of the water. Geothermal heat pumps driven by fossil fueled electricity reduce the CO_2 emissions by at least 50% compared with fossil fuel fired boilers. If the electricity that drives the geothermal pump is produced from a renewable energy source like hydropower, solar or geothermal, the emission savings are up to 100%.

Geothermal plants use about 20 litres of freshwater per MWh, while binary power plants use no freshwater. Coal power plants use 1,370 liters per MWh. An oil plant uses 15% less than a coal plant and a nuclear plant uses 25% more than a coal plant [18].

Typically, a geothermal facility uses 404 square

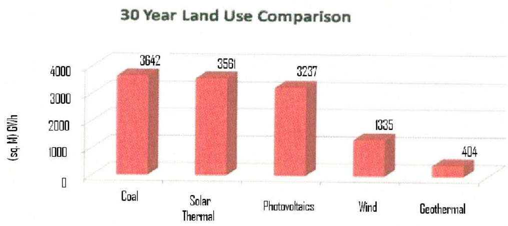

Fig 12. Land use with different sources of energy [18]

meters of land per GWh compared to a coal facility, which uses 3,632 square meters per GWh and a wind farm that uses 1,335 square meter per GWh (Lund,2007). Figure 12 shows a graph with the land used with different sources of energy.

Subsidence and induced seismicity are two problems that must be considered. Subsidence has occurred in the Wairakei field in New Zealand and in Germany. The project in Basel (Switzerland) was suspended because more than 10,000 seismic events measuring up to 3.4 on the Richter Scale occurred over the first 6 days of water injection. Neither of these potential problems are associated with direct-use projects.

We must say that no transportation of geothermal resources is necessary, because the resource is tapped directly at its source.

Any site considered for a geothermal power plant must be reviewed and considered for the impact on wildlife and vegetation, and if significant, provide a mitigation plan. Direct use projects are usually small and thus have no significant impact on natural features.

6. SUSTAINABILITY

Geothermal energy is generally classified as renewable and sustainable [19]. The term renewable means that the energy removed from the resource is continuously replaced by more energy on time scales similar to those required for energy removal. The term sustainable applies to how a resource is utilized. Rybach et al ,[19] showed that proper design, taking into account local conditions and building needs, ensures the sustainability of production using geothermal heat pumps in Switzerland. Fridleifsson et al ,[20] showed using an example from Iceland, that geothermal energy can be used in a sustainable manner, which means that the production system applied is able to sustain the production level over long times (in the example chosen the system has been working since 1943).

7. ENERGY COSTS

The investment costs, mainly in drilling and equipment for the wells and the pumping of the water are high (between 1000 and 7000 euros per kW installed) . On the other hand, running costs are very low. In total, the cost per kWh produced is 0.03 euro for a geothermal power plant of 55 thousands kilowatts, which means that geothermal energy is one of the least expensive renewable energies.

Two recent reports, by Credit Suisse (2009) and ESMAP World Bank Group (2007) [17] conclude that the least expensive electricity comes from geothermal flash cycle plant (50 MW). They show also that electricity generated from a geothermal binary cycle plant (20MW) is 50 to 60% more expensive than electricity from a conventional flash cycle.

Figure 13 shows the costs of renewable energies in US dollars / MWh.

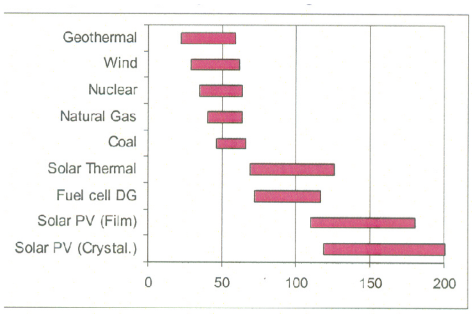

Fig 13 Cost of electricity generation in US dollar/MWh [17].

The price of a geothermal heat pump system is nearly twice the price of a regular heat pump system. The costs of drilling depends on the depth needed and the type of terrain in the area. In general, an efficient geothermal system saves enough on utility bills to recoup the investment in five to ten years.

8.GEOTHERMAL ENERGY IN THE FUTURE

The exploration and utilisation of geothermal energy will have a tendency to increase in the coming years due to the high prices of conventional energy sources like oil and coal. The exploitation of geothermal energy in regions lacking traditional

fluids at high temperatures will require the resolution of various technical problems that are currently under investigation. Another reason that promotes the use of geothermal energy is the increase in emissions of greenhouse gases to the atmosphere and the need to reduce them.
Fridleifsson et al, [16] prepared three scenarios to estimate the future development of the worldwide geothermal utilization. The most likely scenario says that a moderate increase is expected in direct use applications, but the use of geothermal heat pumps will have an exponential increase. The reason for this increase is the fact that geothermal heat pumps can be used for heating or cooling in most parts of the world. Figure 14 shows the growth in direct use and energy production using geothermal heat pumps, from 2005 to 2050.We can see a value of over 4,000000 TJ/yr for the energy production by geothermal heat pumps in 2050 and a value close to 1,000000TJ/Yr for the same year in direct use utilisation.
The localisation of places with geothermal reservoirs

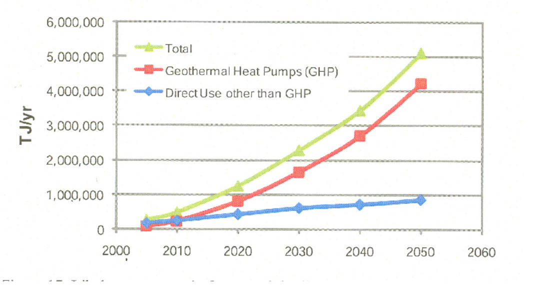

Fig 14 Scenario for growth in direct use and geothermal heat pumps energy production [16].

suitable for electricity production is more confined. With present engineering solutions, it is possible to increase the value of 11 GW (see Table 1) up to a maximum of 70 GW in 2050. Technology improvement in the next 10-20 years will make it possible to reach a global heat production of 140 GW in the year 2050. Table 6 shows the forecasts for 2010-2050.

Table 6.Forecasts for world installed capacity, electricity production and capacity factor of geothermal power plants (Adapted from [16])

Year	Installed Capacity (GW)	Electricity Production (GWh/yr)	Capacity Factor (%)
2010	11	74,669	77
2020	24	171,114	81
2030	46	343,685	85
2040	90	703,174	89
2050	140	1,103,760	90

The capacity factor will increase from 77% in 2010 to 90% in 2050. This fact is due to the use of better technical solutions for power plants including reinjection, use of products against corrosion, better knowledge of the field properties and performances using advanced geophysical surveys. This value of 90% is presently reached by many geothermal fields in operation. The values in the table suggest an exponential increase in parameters.
According to the report, Global Geothermal Power and Heat Pump Market Outlook (2010-2015) [20] the total geothermal energy market is expected to grow from 61,200 MW in 2010 to 120,300 MW in 2015. Europe leads the geothermal market with 37% of the world's geothermal energy supply. The global geothermal electricity market will grow from 10,500 MW in 2009 to 19,200 MW in 2015.
Global installations of geothermal heat pumps will grow from 2.94 million in 2010 to 5.66 million in 2015. The major countries using geothermal heat pumps are Germany, the Netherlands, Norway, Sweden and the U.S.A.. Geothermal heat pumps use 67% of geothermal energy available for direct use.
The Americas region is leading in geothermal power installed capacity (43%). Europe leads in geothermal direct use installed capacity (42%). The major countries involved in geothermal power generation are the U.S.A., Philippines and Indonesia.

9. CONCLUSIONS

Geothermal energy is a renewable and sustainable energy source. Its use has increased in recent years and is expected to grow exponentially in the coming years. Geothermal energy serves both direct applications and electricity generation. It is independent of weather conditions, can be used night and day, and can be used to supplement other forms of energy.
The geothermal utilisation sector that has grown in recent years and will grow more in the coming years is geothermal heat pumps. This is due to the fact that they can be used everywhere and also that they have low costs of utilisation.
Geothermal exploitation techniques are being rapidly developed. The use of binary plants has made possible the production of electricity in countries that do not have reservoirs with high temperatures. The study of HDR (Hot Dry Rock) reservoirs and the associated technology has evolved in recent years and it is thought to be possible to use these reserves in regions where, traditionally, geothermal energy has not been explored.
Geothermal energy is a clean energy compared to other energy sources. The CO_2 emission associated with direct applications is negligible or null and very small, for electricity generation, when compared to fossil fuels. These are some of the reasons to say that geothermal energy is, in fact, an energy of the future.

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