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Perspectives for the development of geothermal energy in the context of climate change

Vasile POPA[1], Nicoleta POPA[2]

[1] Faculty of Geography, University of Bucharest, Romania
popavasile2005@yahoo.com
[2] "Principesa Margareta" Secondary School, Bucharest, Romania

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Perspectives for the development of geothermal energy in the context of climate change

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Perspective de dezvoltare a energiei geotermale în contextul schimbărlor climatice. Societatea umană se confruntă cu marea provocare de a reduce drastic emisiile de gaze cu efect de seră, concomitent cu asigurarea unor cantități sporite de energie. Deși ponderea surselor regenerabile de energie a crescut în ultimii ani, combustibilii fosili sunt încă utilizați pe scară largă și prin arderea lor se elimină în atmosferă mari cantități de bioxid de carbon. Există posibilitatea ca sursele regenerabile să nu poată furniza la timp suficientă energie pentru a înlocui combustibilii fosili. Energia geotermală este considerată o sursă de energie regenerabilă cu un potențial remarcabil de dezvoltare care ar putea contribui semnificativ la atenuarea schimbărilor climatice. Până în prezent însă contribuția energiei geotermale la producția de electricitate și căldură a fost redusă. Deși potențialul geotermal teoretic este imens, exploatarea acestuia încă se lovește de o serie de bariere, mai ales tehnologice, financiare și de mediu. Acest studiu analizează situația actuală a energiei geotermale și perspectivele de dezvoltare în contextul schimbărilor climatice.

Cuvinte cheie: schimbări climatice, energie regenerabilă, energie geotermală, perspective de dezvoltare, factori limitativi.

Perspectives for the development of geothermal energy in the context of climate change. Human society faces the great challenge of drastically reducing greenhouse gas emissions while providing increased amounts of energy. Although the share of renewable energy sources has increased in recent years, fossil fuels are still widely used and burning them removes large amounts of carbon dioxide into the atmosphere. Renewable sources may not be able to supply enough energy in time to replace fossil fuels. Geothermal energy is considered a renewable energy source with outstanding development potential that could significantly contribute to climate change mitigation. So far, however, the contribution of geothermal energy to the production of electricity and heat has been reduced. Although the theoretical geothermal potential is huge, its exploitation still faces a number of barriers, especially technological, financial and environmental. This study analyzes the current state of geothermal energy and development prospects in the context of climate change.

Keywords: climate change, renewable energy, geothermal energy, development prospects, limiting factors.

1. INTRODUCTION

It is becoming increasingly clear that the Earth is facing many environmental changes, of which climate change is a major concern. These changes can be serious for the natural environment, population and human activities. According to the 2015 Paris Agreement, in order to avoid the serious effects of climate change on the environment, global warming should be limited to well below 2°C, preferably 1.5°C, compared to the pre-industrial period (UN, 2022). To achieve this long-term goal, the states of the world must reach the global peak of greenhouse gas emissions as soon as possible to create a climate-neutral world by the middle of the century. Thus, renewable energy sources need to replace fossil fuels that continue to dominate global electricity production. The global effort to reduce greenhouse gas emissions has encouraged the search for clean and renewable energy sources.

Geothermal energy is a type of renewable energy that uses heat produced naturally by the Earth (mainly by the decay of radioactive isotopes of uranium, thorium and potassium) and can be used directly for heating or electricity. On average, at depth the Earth's temperature rises by about 25-30°C/km. Thus, at a depth of 10 km the temperature would be over 300°C (World Energy Council, 2010).
At present, geothermal wells are usually more than 2 km deep, but they can reach up to 4 km. Liquid or vaporized water carries geothermal energy to the earth's surface. In addition to high rock temperatures, crack systems or porous structures are needed through which hot fluids can move.

Geothermal resources have a wide geographical distribution. Those that are located at a relatively shallow depth (usually < 400 m) are used worldwide mainly for heating buildings, including with the help of heat pumps (Goldstein et al., 2011). Most geothermal resources with sufficiently high temperatures (above 180°C), which are best suited for electricity generation, are located in the vicinity of recent volcanic regions, such as those in the western United States, Indonesia, the Philippines, Japan, East Africa, Iceland or New Zealand. Geothermal resources can be classified into convective (or hydrothermal) systems, which are the most common, conductive systems and deep aquifers (Table 1).

As a renewable source, geothermal energy could help mitigate the effects of climate change caused by burning fossil fuels if the geothermal potential were to be harnessed more intensely. An advantage of geothermal energy compared to other renewable energy sources (such as solar or wind energy, which are intermittent sources) is its year-round availability and flexibility. When electricity from intermittent sources varies throughout the day due to changing weather, geothermal power plants can increase or decrease production several times a day to balance the demand for electricity in the grid.

Table 1. Types of geothermal resources

Type	In-situ fluids	Subtype	Temperature range	Utilization	
				Current	**Future**
Convective systems (hydrothermal)	Yes	Continental	High, Intermediate Low	Power, direct use	Power, direct use
		Submarine	High	None	Power
Conductive systems	No	Shallow (<400 m)	Low	Direct use (Geothermal heat pump)	Direct use (Geothermal heat pump)
		Hot rock (Enhanced geothermal systems)	High, Intermediate	Prototypes	Power, direct use
		Magma bodies	High	None	Power, direct use
Deep aquifer systems	Yes	Hydrostatic aquifers	High, Intermediate, Low	Direct use	Power, direct use
		Geo-pressured		Direct use	Power, direct use

Note: High (>180°C), Intermediate (100-180°C), Low (<100°C)
Source: Goldstein et al., 2011

In addition to being able to provide safe, long-term basic energy and reduce greenhouse gas emissions, geothermal energy can provide heat for a variety of direct uses, such as heating buildings and greenhouses. Unlike power plants, heat pumps use low-temperature geothermal resources that are much more available. Also, in order to produce a certain amount of electricity, geothermal power plants occupy smaller land areas compared to other renewable energy sources.

2. METHODOLOGY

The statistical data used were taken from the databases of the International Renewable Energy Agency, the International Energy Agency, the International Geothermal Association or from the reports of world congresses on geothermal energy (Bertani, 2015 and Huttrer, 2021), which periodically collects and publishes energy data. Some data were plotted in order to track the time dynamics of the installed geothermal capacity. The future evolution of renewable energy is based on data published by the International Energy Agency but also on other sources. The role of geothermal energy in the global effort to combat climate change and the problems it faces have been based on a series of scientific articles published in various journals and other sources.

3. RESULTS

Geothermal waters have been used since ancient times for washing, recreation or therapeutic purposes. It was not until 1904 that Prince Piero Conti used natural steam from the Larderello geothermal field in Italy to produce electricity. In 1913, Conti completed the construction of a 250 kW commercial power plant powered by steam and in 1916 two more units of 3.5 MW each. Subsequently, the installed geothermal capacity for electricity generation has continuously increased (Figure 1). Exploitable geothermal resources are found worldwide and are used in over 80 countries (Burgassi, 1999; IGA, 2021).

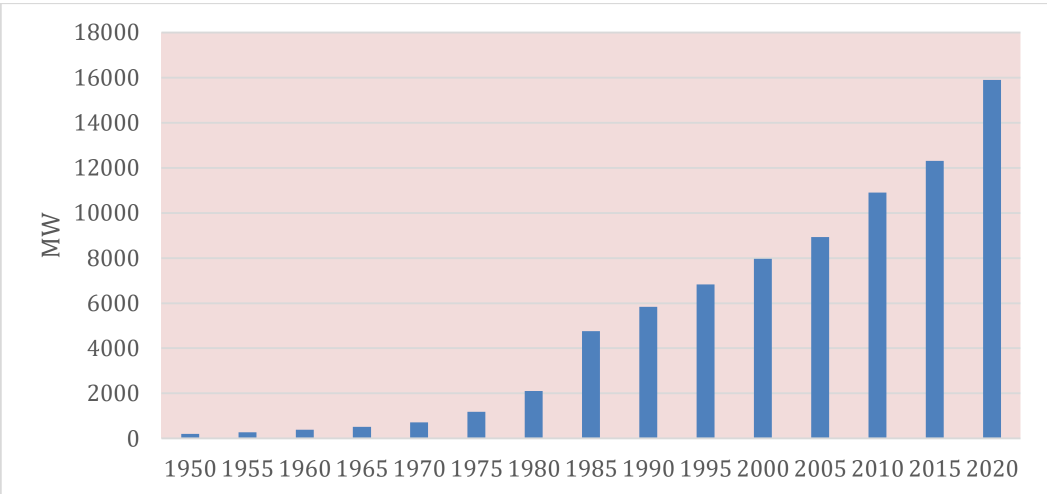

Figure 1. Global geothermal power capacity (1950-2020)
Source: Bertani, 2015 and Huttrer, 2021

The main geothermal fields are: CA-The Geysers, CA-Salton Sea, CA-Coso (USA), Cerro Prieto (Mexico), Tongonan/Leyte, Mak-Ban/Laguna (Philippines), Larderello (Italy), Java-Gunung Salak, Java-Darajat, Java-Wayang Windu (Indonesia), Hellisheidi (Iceland) or Wairakei (New Zealand) (Bertani, 2010).

Since the advent of the first such plant, the use of geothermal energy has become increasingly efficient. Electricity is obtained through several technological solutions:

Flash plants (are the most common types of geothermal power plants and work best for geothermal resources at temperatures above 180°C), *Direct dry steam plants* (type of geothermal power plant that uses steam with a temperature above 150°C), *Binary plants* (usually used for geothermal resource temperatures between 100°C and 170°C) and *Combined-cycle* or *hybrid plants* (S&P Global Platts, 2016).

In 2020, the global installed geothermal capacity was about 15.9 GW, about 5 GW more than in 2010 (Figure 2). The amount of electricity generated by geothermal power plants in 2020 was about 95 TWh/year (Huttrer, 2021). Within renewable energy sources (non-fuels), which provide about 23% of global electricity production, the contribution of geothermal energy is only 1.4%. If we refer to heat production, the share of geothermal energy in renewable sources (including industrial waste) is 5%, which is about 46 000 TJ (IEA, 2021a).

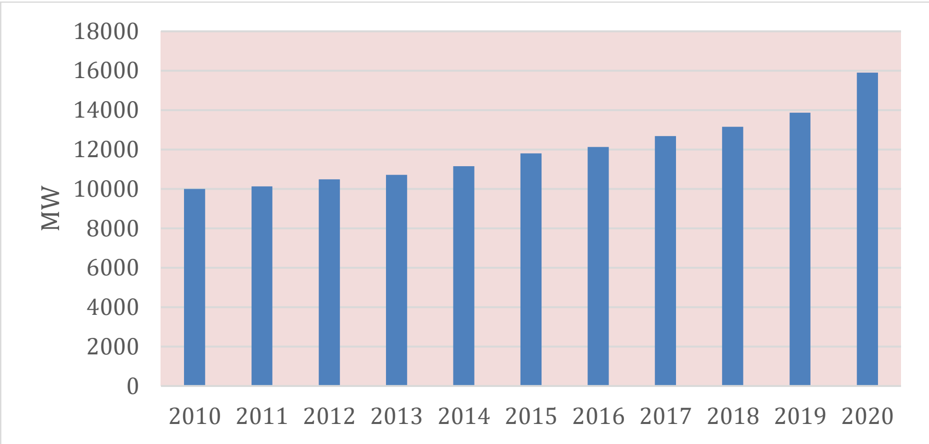

Figure 2. Global installed geothermal capacity (2010 - 2020)
Source: IRENA, 2021

Of the 29 states that owned geothermal power plants in 2020, the top ten together had more than 94% of global installed capacity (Table 2). The vast majority of geothermal power plants are quite small, the average geothermal capacity for the units in operation (over 500 units) being about 21 MW (Bertani, 2010).

The United States has the highest installed geothermal capacity of about 3.7 GW, which is almost 23% of the global geothermal capacity. Over 90% of this capacity is in California and Nevada (U.S. Department of Energy, 2021). The second place is followed by Indonesia, the country with the highest geothermal potential in the world estimated at about 29 GW. Indonesia also has the largest geothermal power plant in the world, the 375 MW Gunung Salak. Iceland is also in the top ten, with geothermal energy supplying over 60% of the country's electricity (Huttrer, 2021). Iceland has been using geothermal energy for heating buildings for electricity generation and other direct uses since 1969. Although there are few states that use geothermal energy to generate electricity, their number is growing. Between 2015 and 2020, five new states completed their first geothermal power plants: Belgium, Chile, Croatia, Honduras and Hungary. Geothermal power plants are also planned for the short term in Argentina, Australia, Canada, China, Ecuador, Greece, Iran, Taiwan and the Caribbean (Dominica, Saint Lucia, Montserrat or Saint Vincent) (Huttrer, 2021).

Table 2. Top ten states after installed geothermal capacity (2010 – 2020)

	Country	Installed capacity in 2010 (MW)	Installed capacity in 2015 (MW)	Installed capacity in 2020 (MW)
1	USA	3098	3098	3700
2	Indonesia	1197	1 340	2289
3	Philippines	1904	1 870	1918
4	Turkey	91	397	1549
5	Kenya	202	594	1193
6	Mexico	958	1017	1105
7	New Zealand	762	1005	1064
8	Italy	843	916	916
9	Iceland	575	665	755
10	Japan	536	519	550

Source: Bertani, 2015 and Huttrer, 2021

The total heat content of the Earth is estimated at 12.6 x 10^{12} EJ, and that of the Earth's crust at 5.4 x 10^{9} EJ (Dickson and Fanelli 2003). This is the theoretical potential. Based on it, at current global consumption, geothermal energy could meet the world's energy needs for thousands of years (Bertani, 2010). However, only part of this resource can be extracted based on current technologies and limitations on rock permeability. The technical geothermal potential of the identified resources, suitable for electricity generation, was estimated by Stefansson (2005) at 200 GW (equivalent to 5.7 EJ/year), with a lower limit of 50 GW (1.4 EJ/year). Stefansson assumed that unidentified resources are 5 to 10 times more abundant than those identified, being estimated at over 1000 GW (28.4 EJ/year). Regarding the direct use of geothermal energy, the global technical potential was estimated at 5000 GW (IRENA et al. 2021) and the economic one at 800 GW (which means 10 EJ/year) until 2050 (Bertani, 2010). Till now, commercial exploitation has focused on areas where geological conditions create convective hydrothermal reservoirs and drilling to depths of up to 4 km can access fluids at temperatures from 180°C to more than 350°C (Goldstein et al. 2011).

4. DISCUSSION

Although the vast majority of geothermal energy currently comes from hydrothermal resources, it is believed that there is great potential for Enhanced Geothermal Systems (EGS), which are in the experimental phase in several countries such as the United States, Iceland, Great Britain, Germany, China, Portugal or the Netherlands (Huttrer, 2021). New technologies aim to extract energy from hot dry rocks with low natural permeability from depths of up to 10 km by improving rock permeability using hydraulic fracturing (Hébert et al. 2010, Carrara et al. 2020, Goldstein et al. 2011). If EGS technologies prove economically viable, it is believed that the development potential of geothermal energy will be enormous in many countries of the world and could reach 1200 GW (Bertani, 2010). According to Goldstein et al. (2011), with a view to 2050, geothermal energy could meet more than 3% of global electricity demand and about 5% of global heat demand.

According to the IEA (2021b), geothermal energy is not on track with the Net Zero Emissions by 2050 Scenario, which requires average annual increases in newly installed capacity of about 3.6 GW. In the last five years, the newly added geothermal capacity has averaged 500 MW/year and in 2020 only 200 MW. It is believed that this situation is caused by certain technical, financial, institutional or environmental barriers but also by strong competition from wind, solar and natural gas installations, which have lower pre-development risks and costs per kWh. These barriers include: insufficient funding for exploration operations (which are risky), lack or slow duration of the adoption of geothermal energy legislation in some countries, bureaucratic delays in obtaining licenses or authorizations that greatly increase the time and cost of geothermal energy development, land use constraints in protected or tourist areas (such as spas), the level of acceptance by locals, or the negative impact on the environment (Goldstein et al., 2011; Huttrer, 2021). Regarding the risk of exploration in geothermal projects, which refers to the risk of not producing an economically feasible flow or temperature of thermal water, the current success rate is about 50% in green fields and 75% in exploited fields (Dumas, 2016; Carrara et al., 2020).

Geothermal projects usually have high initial investment costs and relatively low operating costs. The investment costs of a geothermal project are composed of the following components: exploration and confirmation of resources, drilling of production and injection wells, surface installations and infrastructure and the power plant. It is encouraging that the costs of generating electricity from geothermal technologies are increasingly competitive and are expected to continue to decline until 2050 (Sigfusson and Uihlein, 2015). The costs of geothermal projects differ quite a bit, ranging between USD 1870 and USD 5050 per kilowatt (kW), with binary plants being the most expensive (IRENA, 2017).

Geothermal projects can have a number of negative effects on the local environment by changing land use and groundwater exploitation. Although it is considered a renewable energy source, the operation of geothermal power plants over several decades leads to the depletion of geothermal fluids. It takes decades or even centuries to restore them (Steingrímsson et al., 2005, Shortall et al., 2015). An environmental problem associated with geothermal power plants is the possibility of land instability. Because geothermal power plants extract fluids from underground tanks, the soil above them can settle over time, especially if the cold water is not reinjected.

Hydraulic fracturing is required to create deep geothermal reservoirs in low-permeability hot rocks. Injecting large amounts of cold water under pressure into the hot rock can cause earthquakes (usually micro-earthquakes). The case of the 2006 Basel Deep Heat Mining Project for the construction of a pilot EGS geothermal power plant is well known. The injection of high-pressure water into the crystalline rock, at a depth of more than 4 km, has caused thousands of earthquakes, some with a local magnitude of more than 3 on the Richter scale, which have been recorded over several years. The material damage amounted to about CHF 7 million (Swiss Seismological Service, 2017).

The impact of geothermal energy on the climate is low, especially compared to fossil fuel power plants. Geothermal energy is considered an ecological energy source because there is no combustion process that emits carbon dioxide, the only direct emissions being associated with underground fluids. These fluids can contain varying amounts of gases, mainly CO_2 and small amounts of hydrogen sulfide (H_2S) or methane (CH_4), but also boron or arsenic, which can be harmful to ecosystems if they reach the surface. Lifecycle greenhouse gas emissions are estimated to be less than 80 g CO_2eq/kWh for geothermal power plants and less than 202 g CO_2eq/kWh for district heating systems and geothermal heat pumps (Goldstein et al., 2011). Values lower than 100 g CO_2eq/kWh (for geothermal power plants) were also estimated by Marchand et al., 2015. Therefore, geothermal power plants produce low greenhouse gas emissions during their operation.

5. CONCLUSIONS

The prospect of serious effects of climate change on the environment requires an urgent shift to a low-emission greenhouse gas economy. This can be achieved by massively replacing fossil fuels with renewable energy sources or low-carbon sources. Although the share of renewable energy sources has increased in recent years, fossil fuels are still widely used. Renewable sources, along with fuel efficiency measures, may not be able to supply enough energy in time to replace fossil fuels.

Although geothermal energy has remarkable theoretical potential, which could significantly contribute to climate change mitigation, it is still under-exploited, mainly due to technological and financial barriers. Improved geothermal systems, although known for some time, are still in the experimental phase. High investment costs and exploration risks make it difficult for geothermal projects to find sources of funding, especially in the private sector. In addition, some negative effects on the environment at the local level could create a state of unrest and discontent among the population, which could delay or block some projects.

Till now, the contribution of geothermal energy to the production of electricity and heat has been reduced. Most likely, this energy source will be a viable alternative to electricity and heat in the long run.

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