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23 November 2023, Sopron

FENNTARTHATÓSÁGI ÁTMENET: KIHÍVÁSOK ÉS INNOVATÍV MEGOLDÁSOK

SUSTAINABILITY TRANSITIONS: CHALLENGES AND INNOVATIVE SOLUTIONS

Szerkesztők / Editors:
OBÁDOVICS Csilla, RESPERGER Richárd, SZÉLES Zsuzsanna, TÓTH Balázs István

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The Use of Geothermal Energy for Sustainable Development and Economic Prosperity

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Abstract:
In terms of mitigating the threat of climate change, geothermal energy has untapped potential as a carbon-free renewable and sustainable energy source. Due to its potential for promoting economic development and environmental sustainability, geothermal systems for heating and cooling have gained increasing attention in building design and construction. Besides reducing carbon footprints, geothermal energy can create jobs to foster economic growth, reduce energy costs and improve property values by strategically deploying it. In this paper, the advantages of incorporating geothermal systems in buildings are explored through a variety of aspects, such as innovation, building sector's role in economic development. As of 2022, there are 14.9 gigawatts of geothermal energy plants installed worldwide. Sustainable building development combined with geothermal energy integration offers a cutting-edge solution to the world's growing energy needs while minimizing its environmental impact. As the world transitions toward a more sustainable infrastructure, the integration of geothermal energy can contribute to the efficiency, cost-effectiveness, and climate-resiliency of buildings. Research on geothermal energy has valuable implications for energy stakeholders and economists trying to understand how it's intertwined with economic prosperity.

Keywords: Geothermal energy, non-carbon source, Geothermal systems, economic development
JEL Codes: Q20, Q40, Q42

1. Introduction

There are three main types of energy sources: fossil, renewable, and fissile. Natural gas, petroleum, coal, tar sands, bitumens, and oil shales are examples of fossil energy sources. Renewable energy sources include biomass, solar, wind, geothermal, and hydropower. Uranium and thorium are fissile energy sources. Globally, fossil fuels have been the primary source of electrical production. According to the International Energy Agency's (IEA) World Energy Outlook 2015 report, fossil fuels account for around 67% of worldwide power generation (Dehghani-Sanij et al., 2019; IEA: Directorate of Global Energy Economics, 2015). Primarily, fossil fuels are blamed for the rise in greenhouse gases emissions, which is causing global warming, climate change, and environmental consequences (Liang et al., 2013; Nejat et al., 2015).

On economic development there are no geological constraints in the coming century. Moreover, it appears that future development will be hampered most by environmental concerns, financial constraints, and technological limitations. The need to address environmental issues and promote overall sustainable energy usage calls for more inputs of renewable and clean energy sources. In effect, numerous countries around the world have established energy programs that encourage a shift to renewable energies. Renewable energy sources are gaining popularity among governments worldwide due to the benefits they offer over fossil fuels. Renewable energy forms are those obtained from the continuous or repetitive currents of energy recurring in the natural environment, and as such cannot be depleted (Cook et al., 2015). The illustration in

Figure and

Figure show the use and forecasted contribution of the different energy sources to global consumption till 2035. Additionally, the information in Table enumerates the main renewable energy sources and how they are used.

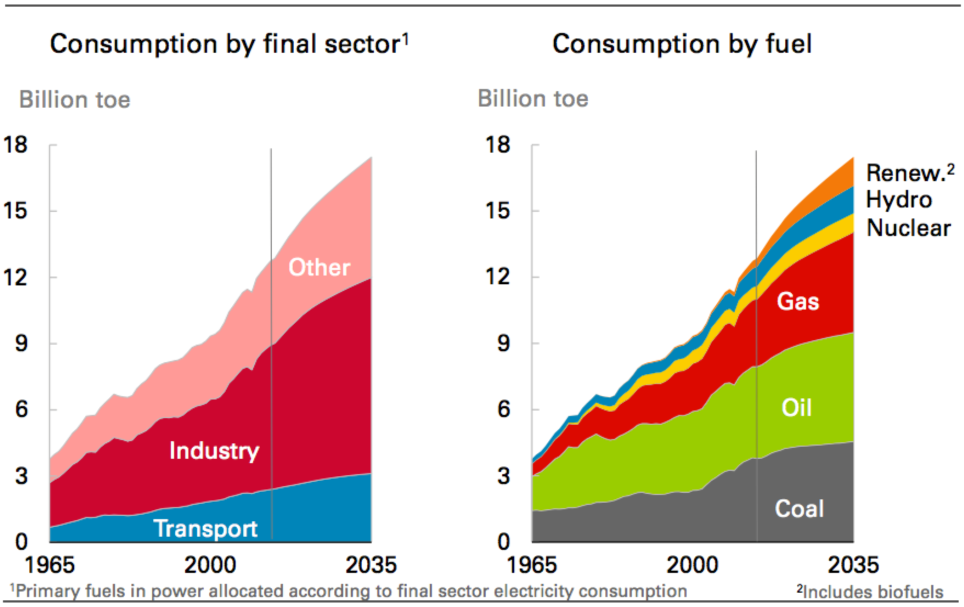

Figure 1: Various sources of energy use till 2035
Source: Dudley (2017)

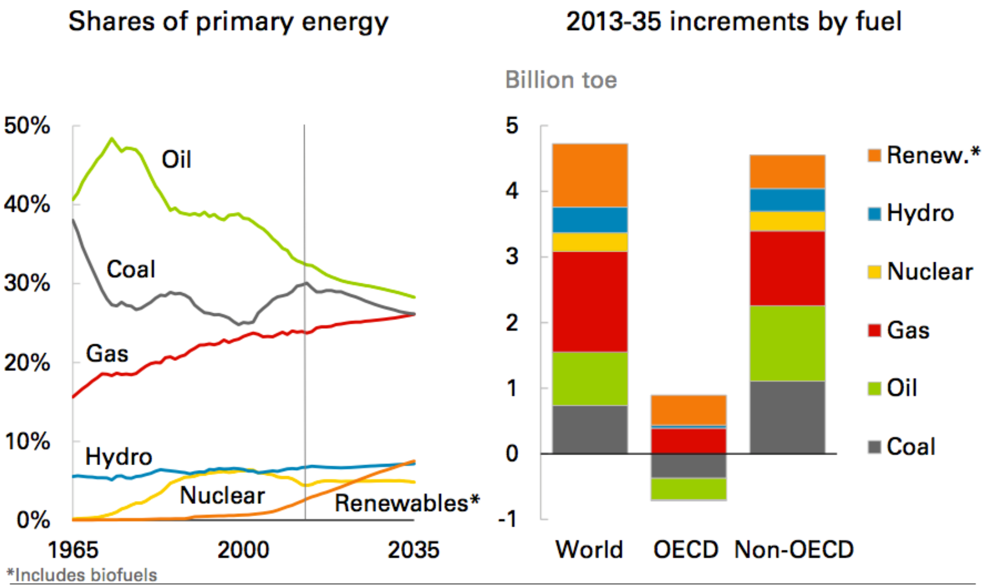

Figure 2: Contribution of each key source of energy till 2035

Source: Dudley (2017)

Table 1: Lists the major renewable energy sources and their usage forms

Source of Energy	Options for energy conversion and utilization
Hydropower	Production of electricity
Biomass	Generation of heat and power, pyrolysis, gasification, and digestion
Geothermal	Residential heating, power generation, hydrothermal and greenhouse heating
Solar	Solar home system, solar dryers and cookers, Photovoltaic, thermal power generation and water heaters
Wind	Power generating, water pumps, windmills and wind turbines
Tidal	Tidal stream and barrage

Source: Panwar et al. (2011)

According to the International Energy Agency (IEA: Directorate of Global Energy Economics, 2015) the world's total renewable-based power capacity will increase by 50% between 2019 and 2024. Several scenarios have been developed by the World Energy Council (WEC), highlighting different aspects of technological progress, international equity, environmental protection and economic growth particularly within developing countries. In all the scenarios, the share of RESs is predicted to rise dramatically in the world primary energy consumption, providing 20–40% of the primary energy in 2050 and 30–80% in 2100 (Fridleifsson, 2001, 2003).

Sustainable development necessitates the development of methodologies and instruments for measuring and comparing the environmental consequences of human activities on diverse goods. The role of renewable energy has risen as a beacon of hope in the face of rising environmental concerns and the worldwide quest for sustainable development. It promises a dramatic shift in the way we generate and consume electricity. Between 2001 and 2040, the most important advancements in renewable energy generation are seen in photovoltaics (from 0.2 to 784 Mtoe) and wind energy (from 4.7 to 688 Mtoe) (Demirbas, 2009). These technologies, which have shown yearly growth rates of more than 30% in recent years, will become increasingly important in the future (Demirbas, 2009). Biomass and Hydropower are the most used renewable energy sources now whereas Geothermal and solar thermal energy sources will be more relevant in the future. Geothermal resources are abundant, non-intermittent and low carbon. It is anticipated that usage of geothermal energy will increase dramatically over the next several decades in many parts of the world. The idea that geothermal energy may help achieve the Paris Agreement's target of keeping the increase in global temperatures to 2 °C or below is becoming more and more popular (Delbeke et al., 2019). The European Union places a high priority on this energy source. Evident is the €90 million fund awarded for geothermal technology research and development in the Horizon 2020 Framework Program between 2014 and 2018 (Hoogland et al., 2019). About 40% of the total energy used in Europe is attributed to residential sector, for heating and cooling (Buffa et al., 2019; Delzendeh et al., 2017). As a matter of fact, the Renewable Heating & Cooling (RHC) Technology Platform projects a variety of trends in Europe's thermal energy consumption by 2050. The trend includes a roughly three-fold increase in cooling demand and a 20% to 30% decrease in heating demand relative to 2006 records (Buffa et al., 2019). Moreover, the 600% rise in the chilled floor area evaluated in the EU between 1990 and 2010 supports this trend (Pezzutto et al., 2016). The aim of this research is to provide an overview of the current global focus on earth’s heat as a potential geothermal energy source. Additionally, effort has been made to outline the different types of applications associated with geothermal energy sources.

2. Methodology: Literature review

Geothermal energy is in line with the global urge to shift to cleaner and more efficient energy sources. Hence, it offers a compelling path for sustainable development and economic progress. Several studies are focusing on the economic effects of using geothermal energy, with literatures examining how it affects several facets of economic prosperity. This study is a review of published research articles, governments and inter-government reports, opinions of energy experts and agencies, national and international standards and protocols related to global energy sources etc. Overall, the manuscript covers 61 documents distributed across the literature sources. Information extracted to address the aim of this study has been presented in sections and sub-sections below. There are notes to help understand the technical aspects of geothermal energy concept, its feasibility and related challenges in integrating geothermal energy into the larger energy space.

2.1. The Earth's heat

The heat of the Earth is a complex interaction of internal and external sources that regulates the temperature and climate of planet. Internally, Earth's mantle generates heat through radioactive decay of elements, fueling mantle convection and driving tectonic processes. Externally, the sun serves as a primary source of heat, with solar radiation driving the water cycle and photosynthesis and influencing the Earth's surface temperature. The distribution of heat is not uniform across the Earth. This results in regional temperature fluctuations and impact on air circulation. By trapping some outgoing infrared radiation, the atmosphere regulates heat and keeps temperature within a range that is conducive to human life.(Barbier, 2002; Muther et al., 2022) The process of heat transfer within the Earth are influenced by conduction, convection, and radiation. Play critical roles in distributing and regulating the planet's interior and surface temperatures, is inextricably linked to the Earth's heat.

2.1.1. Heat transfer within the Earth

Over a long period of time, the earth's core gathers a large amount of heat energy, resulting in a huge temperature differential between the earth's core and the surface. This temperature differential is known as Geothermal gradient and it is the source of energy (Gupta & Roy, 2006). Geothermal gradient and the thermal conductivity of rocks combine to create the Earth's conductive heat flow. Comparatively, geothermal gradient is measured in shallow holes, but rock conductivity is best evaluated in a laboratory on samples (called cores) collected from the portion of the well where the gradient was detected. Technically, there are two types of heat transfer that occur within the Earth: conduction and convection.

Conduction. Regarding heat conduction, kinetic energy is transferred randomly between two objects. Molecules in motion collide with other nearby molecules, forcing them to vibrate more quickly and therefore transmit heat energy. Conduction is the principal method of heat transport among solids. Metals carry heat very well, but most rocks do not. (Barbier, 2002)

Convection. In fluid mechanics, the transfer of thermal energy associated with the transport of matter in the fluid state (either gas or liquid) is named by convection. Convection causes an overall movement of materials. Comparatively, it is far more efficient to transfer heat via convection than via conduction, since motion occurs in the material during the process (Barbier, 2002).

2.1.2. The geothermal gradient of the Earth and rocks' thermal conductivity

Studies of the thermal behavior of the Earth determine the variation of temperature with the depth and how such temperature changes may have evolved over time (Agarwala et al., 2024; Barbier, 2002).Certainly, these investigations are exclusively dependent on observations taken on or near (few km) the Earth's surface. The typical gradient at the surface is around 30°C/km, although ancient continental crust has values as low as about 10°C/km and current volcanism has very high values (>100°C/km) (Barbier, 2002; Gao et al., 2024). A measured geothermal gradient may be used to calculate the rate at which heat moves upwards through a specific region of the Earth's crust. Geothermal gradients and constants of proportionality, such as rock thermal conductivity, determine how much heat flows by conduction through a unit area of 1 m^2 of solid rock in a given period of time. A measure of rock thermal conductivity with a unit of W/(m K) (watt per meter per degree kelvin, or per degree centigrade) is the amount of heat carried in seconds through an area of 1 m^2, and at a temperature gradient of 1°C/m. Because there are no reliable methods for measuring thermal conductivity downhole, gradients are measured in wells with electrical (platinum- resistance) thermometers. Assuming that temperature gradient lies in °C/km (degrees Celsius per km) and conductivity lies in W/(m°C), heat flow will lie in mW/m^2 (milliwatts per square meter) (Barbier, 2002).

2.2. Geothermal energy for sustainable development

American Paleo-Indians used geothermal energy, for the first time, more than 10,000 years ago in North America (Kagel et al.,2005. The earliest industrial application of geothermal energy occurred in the late 18th century in Pisa, Italy. Steam from natural vents or dug holes was used to collect boric acid from the hot pools known as Larderello fields. Further, Prince Piero Ginori Conti conceptualized and explored the utilization of geothermal resources for electricity generation in the early 20th century. On July 4, 1904, he commissioned the inaugural experimental plant that aimed at demonstrating the feasibility of harnessing geothermal energy from a site in close proximity to Larderello, Tuscany, Italy. The setup involved a binary water cycle, generating pristine steam to propel a piston engine linked to a 10-kW dynamo generator. This generator, in turn, supplied power to illuminate four light bulbs (5 watt) interconnected electrically (Lund et al., 2022). The 1973 international oil crisis gave much-needed momentum for the development of geothermal energy. In effect, most geothermal power plants were built in the 1970s and 1980s. The Larderello region in Italy, the Paris Basin in France, the Pannonian Basin (Hungary, Serbia, Slovakia, Slovenia, Romania), various areas 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) are the main geothermal fields currently under exploitation (Kępińska, 2009). Given the significance of energy to the environment and economic growth, energy policy has emerged as a crucial instrument for long-term development. Currently, emphasis is on green and alternative energies such as geothermal. Geothermal energy was documented to have a total installed capacity of Geother10,897 MWe worldwide in 2010; 12,283 MWe in 2015 and 15,950 MWe in 2020 (Huttrer, 2020). In 2025, the global total installed capacity is expected to reach 19,361 MWe. Ten nations have been identified as having installed the greatest number of geothermal powers producing facilities by the year 2020. United States leads with an installation of 3,700 MWe followed by Indonesia with 2,289 MWe. Philippines, Turkey, Kenya, Mexico, New Zealand, Italy, Japan, Iceland with 1918 MWe;1549 MWe; 1,193 MWe; 1,105 MWe; 1,604 MWe; 916 MWe; 550 MWe and 755 MWe respectively (Huttrer, 2020).

Bathing, therapeutic uses, and water heating have all been done using geothermal energy for centuries. Space heating, industry and the production of electricity have all been harnessed exclusively in the 20th century. The development of enhanced geothermal systems (EGS) has recently attracted attention in this field, which welds hot and dry rocks with water to extract heat even in places lacking geothermal resources on to geothermal power plants, fossil plants require 30–35 times more space, photovoltaic (PV) solar plants require 50 times and solar plant requires 20(Rohit et al., 2023). In general, it is mainly the temperature of a geothermal resource that determines the methods for using it (Bronicki & Schochet, 2003).

3. How to tap into geothermal energy source

Some applications of geothermal energy depend on the earth's near-surface temperatures whereas others require drilling into the earth. There are three main types of geothermal energy systems:

3.1. Direct use and district heating systems

Utilizing heat directly from the earth for a variety of purposes without the aid of a heat pump or power plant represents the direct use of geothermal energy. This technique is frequently used to heat industrial operations, greenhouses, and buildings. District heating systems use a network of pipes to transmit steam or water that has been heated geothermally to provide hot water and space heating for several buildings. Both the direct use and district heating systems utilize the inherent heat of the earth to improve energy efficiency and lessen their impact on the environment. They provide an environmentally friendly substitutes for traditional heating techniques (Dincer & Ozcan, 2018). Hot mineral springs were utilized for bathing, cooking, and heating in ancient Roman, Chinese, and Native American societies. Several hot springs are still utilized for bathing today, as many people trust that the hot mineral-rich waters are beneficial to their health; a typical balneological application (Mahala, 2019; Voudouris et al., 2023) .However, the trust in mineral-rich thermal water may not be generally true. Individual buildings can also be directly heated by geothermal energy, or a district heating system can be used to heat multiple buildings simultaneously. Geothermal energy has industrial uses as well, such as food dehydration (drying), gold mining, and milk pasteurization. Global capacity for geothermal direct consumption grew from an estimated 2.2 GW (Gigawatts), or roughly 8%, in 2019, to an estimated 30 GWth (Gigawatts-thermal). During the same year, geothermal energy usage for thermal purposes increased from an estimated 10 TWh to 117 TWh (Terawatt hour) (421.2 PJ [Petajoule]) (Avci et al., 2020).

China, Turkey, Iceland, and Japan were the biggest nations for geothermal direct use in 2019, accounting for nearly 75% of the worldwide total (Beerepoot, 2011). In the last five years, China has grown by over 20% annually on average, making it both the biggest user and the fastest-growing market (47% of the total). Geothermal energy use, especially for heating applications, has experienced rapid expansion during that period, coinciding with the announcement of the government in 2017 about is the first geothermal industry strategy (Avci et al., 2020; Bronicki, 2018). Bathing and swimming were the most popular categories of direct use, accounting for 44% of total usage in 2019 and expanding at a rate of nearly 9% each year. The second fastest rising category, with an annual growth rate of roughly 13%, was space heating (around 39% of direct usage). Among the remaining 17% of direct use was appropriated to greenhouse heating which accounted for 8.5%, industrial uses with 3.9%, aquaculture with 3.2%, agricultural drying with 0.8%, snow melting with 0.6%, and other uses with 0.5% (Avci et al., 2020). Data from the World Geothermal Congress in 2005 indicates that 32 European nations employ direct geothermal energy. Among the European countries Iceland, Turkey and

Sweeden are the largest in the use of Geothermal energy, followed by Italy, Hungary, Russia, Switzerland, France and Germany (Kępińska, 2009).

3.2. Geothermal electricity generation

Geothermal power facilities, which draw energy from subterranean steam or hot water reservoirs, are commonly used in this procedure. The most popular technique is steam turbines, which turn thermal energy into electrical power by using high-pressure steam drawn from geothermal reservoirs to power turbines attached to generators. Geothermal power plants are classified into three categories: binary cycle, flash steam, and dry steam(Anderson & Rezaie, 2019). Whereas flash steam power plants use hot water under high pressure to make steam (Mehtari et al., 2023; Mondal et al., 2022), dry steam power plants obtain their steam from subterranean resources (Rudiyanto et al., 2023; Vaccari et al., 2023). Hot water is used in binary cycle power plants to evaporate a working fluid, which powers a turbine (Baydar et al., 2023; Sharifi & Eskandari, 2023). Geothermal reservoirs with temperatures surpassing 90°C have demonstrated viability for electricity generation. It typically necessitates extensive drilling at depths ranging from 1500 meters to 4500 meters, or as deep as 2 miles beneath the Earth's surface (Energy, 2017). Water or steam at high temperatures (300° to 700°F) is required for geothermal energy generation. Electricity is generated by geo-fluid (water or steam) pumped underground by a turbine. This will be done using an organic fluid with a lower boiling point vaporized by the hot pressurized geothermal fluid in a binary turbine cycle. Otherwise, steam is extracted directly from geothermal fields to run the turbine. The world's minimal quantity of geothermal energy for electricity generation should be 1TW. Yet only 32% of the world's geothermal resources are appropriate for energy production (Moya et al., 2018). Table below outlined the evolution of geothermal power capacity between 1960 and 2018 and (Barasa Kabeyi, 2019) indicates that the data was not accessible at the time of publishing.

Table 2: A summary of the capability of geothermal energy between 1960 and 2018

Year	Production of Electricity (GWhr/year)	Installed Power Gigawatt electrical (GWe)	Capacity Factor (Percent)
1960	2,600	0.386	77
1995	38,035	6.8	64
1999	49,000	7.979	70
2000	49,261	8.0	71
2005	56,786	8.9	73
2010	67,246	10.7	71
2014	73,300	11.62	72
2015	73,549	12.60	75
2017	84,800	13.28	73
2018		14.6	

Source: Barasa Kabeyi (2019)

According to

Table, geothermal power capacity increased by 115% between 1995 and 2018. According to estimates by the IEA (Beerepoot, 2011), the generation of geothermal electricity will reach 1400 TWh by 2050, a share of 3.5% of global electricity production, and the generation of geothermal heat will reach 611 TWh. The United States leads the world in geothermal electricity generation. In 2022, there were geothermal power plants in seven states, which produced about 17 billion kilowatthours (kWh). This was equal to about 0.4% of total U.S. utility-scale electricity generation.

3.3. Geothermal heat pumps

Geothermal heat pumps (GHP) or Ground source heat pump (GSHP) use the constant temperatures near the surface of the earth to heat and cool buildings. GHP can move heat in either direction. It transfers heat from the ground (or water) into buildings during the winter and reverses the process in the summer. This means that it may be used for both heating and cooling in an effective and environmentally friendly manner (Y. Li et al., 2022). This method comprises of straight or coiled tubes buried at a depth of roughly 1.6-2.0 m in a trench (Pulat et al., 2009). The cost of excavation and pipe length may be critical factors in the design. This technology is gaining popularity because it permits loop fields to be built beneath existing structures and minimizes ground surface disturbance (Huttrer, 1997). In terms of energy and CO_2 savings, GHP might be highly beneficial in reducing the requirement for peak power and hence replaces new electric producing capacity. According to a GSHP investigation conducted in Shanghai, China, the use of this technology results in a 40.2% energy savings, it is estimated that in 2002 there were 750,000 GSHP units installed in the US, saving 1 900 megawatts (MW) of electricity demand. Additionally, over 50 000 GSHP units were deployed in European Union nations in 2002 (Huang & Mauerhofer, 2016). Several studies have been done in this field to provide various benefits in terms of technological, environmental and economic (Dincer & Rosen, 2015). In a comparison of different conventional heating systems including coal, natural gas, Liquid Petroleum Gas (LPG), fuel oil, and electrical resistance for the mild climate of Turkey, Pullat et al. (2009) concluded the GSHP was the most cost-effective. In another research (Tong et al., 2012), GHP was compared with kerosene heater to analyze how much energy was consumed and carbon dioxide was emitted in greenhouses when HP was used for heating. They determined that using HP results in up to a 65% decrease in energy consumption and a 79% reduction in CO_2 emissions. Lei et al. (2018) conducted a techno-economic analysis of GSHP systems utilized in Chinese office buildings and concluded that these systems save considerable energy practically in every location. Another study (Luo et al., 2015) looked at the cooling and heating performance of GSHP in the Southern part of Germany. The Coefficient of Performance (COP) of such a system for a normal winter day was found to be about 3.9, whereas the energy efficiency ratio for a typical summer day was predicted to be 8. As a result, it was determined that the system efficiency in cooling mode was greater than that in heating mode. In their investigation, Lim et al. (2016) assessed the impacts and hindrances associated with the adoption of GSHP systems in individual American households across the nation. The primary impediment identified in their findings was the substantial initial installation cost. The study indicated that these systems have the potential to yield significant benefits, including up to 1.33 exajoules of energy savings and a reduction of 64.8 million tons of CO_2 annually. The performance of GSHP was maintained after 5 years of operation according to Montagud et al. (2011) who also found that ground thermal response does not appear to be significantly affected. According Kapıcıoğlu and Esen (2022) the assessment of the performance of GSHP was noted to reduce CO_2 emissions by 36.7 % compared with air source HP, and 28.9% compared with natural gas systems.

4. Geothermal energy benefits and risks

Inarguably, research shows that there are benefits associated with the development and utilization of geothermal energy. This includes environmental sustainability, economic growth and social well-being. Embracing energy from geothermal systems helps to create a more balanced and sustainable energy portfolio, which aligns with global efforts to combat climate change and promote equitable development.

4.1. Ecological and Environmental aspects

Geothermal energy offers several good environmental attributes, including lower greenhouse gas emissions which eventually contribute to climate change mitigation efforts. Binary geothermal power plants are setups that function in a closed-loop mode with a direct return of fluids to depth. It does not emit liquid or gaseous pollutants. However, some levels of potential negative consequences must be considered. For instance, drilling processes can disrupt sub-surface ecosystems and may lead to the depletion of geothermal reservoirs. Also, there are exhaust emissions from wells, transportation, and construction equipment are present in geothermal power facilities. But frequently, these emissions pale in comparison to fugitive ones (Dehghani-Sanij et al., 2019; IEA: Directorate of Global Energy Economics, 2015). Primarily, fossil fuels are to blame for the rise in greenhouse gases emissions, which is causing global warming, climate change, and environmental consequences (Liang et al., 2013). Unlike solar and wind (renewable), geothermal energy source offers stable power generation, immune to fluctuations in weather conditions. This feature improves energy security while decreasing the need for backup power sources. Obviously, power back-ups may have greater environmental costs. Additionally, compared to traditional fossil fuels, geothermal energy emits less air pollution unlike the traditional fossil fuels (Kagel & Gawell, 2005). Specifically, geothermal plants either release extremely little or no NOx at all (Shortall et al., 2015).

4.2. Economic benefit of using geothermal energy source

Undoubtedly, the economics that surround every technology influences its consumer or societal acceptance. The geothermal energy market contributes significantly to the Gross Domestic Products (GDP) of nations actively associated. Six major manufacturers dominate the geothermal steam turbines industry. This demonstrates that the geothermal technology market is competitive, even though there are fewer companies (Barasa Kabeyi, 2019). The worldwide geothermal power industry was worth around 11.6 billion euros in 2012, which equated to approximately 11,456 MWe of installed capacity, 71,997 GWh, and 7.2 billion euro in investments (Karytsas & Mendrinos, 2013). Henceforth, the progression of geothermal energy development serves not only as a viable alternative to fossil fuels in electricity generation. It also assumes a substantive role in fostering economic development through its contribution to the gross domestic product. Geothermal power plant development and operation produce jobs at many phases, including construction, exploration, maintenance and drilling. This green energy sector boosts local economies by attracting investment and encouraging the expansion of associated enterprises. Geothermal energy projects provide a consistent and dependable supply of energy, decreasing reliance on fluctuating fuel markets. Besides reducing dependence on imported fuels, geothermal energy can also positively affect trade balances as it is harnessed locally.

4.3. Social advantage

Geothermal energy initiatives can have a good societal impact. Community involvement is often integral to the development of geothermal resources. This collaboration has the potential to result in the formation of community partnerships and the production of shared advantages such as revenue sharing, job creation, and community development projects. Geothermal plant development can enhance energy availability in rural locations, contributing to social fairness by supplying electricity to areas that may have been neglected or deficient in reliable power sources. Furthermore, by lowering the emission of pollutants associated with the combustion of fossil fuels, geothermal projects can enhance air quality and public health, helping the well-being of local communities (Soltani et al., 2021).

5. Challenges associated with Geothermal energy

The most frequent operational issues with geothermal sources are as follows: (1) corrosion, (2) scale development in the production and re-injection wells due to calcite, silica, and metal sulphide deposition, (3) inadequate water supply, and (4) micro-earthquakes (i.e., magnitude less than 4.5) (Lee et al., 2015). Closed-loop systems of GSHP may incorporate potentially hazardous thermal transfer fluids, posing a risk of groundwater pollution in the event of a leakage. In the case of Enhanced Geothermal Systems (EGS), the most significant technological obstacles are the uncertainties and information gaps around the artificially produced subterranean geothermal reservoir (DOE, 2008). Because of the high initial cost of EGS, lengthy construction and payback periods, difficulty in assessing available resources, and difficulties in modularizing geothermal energy systems, geothermal power is growing at a slower rate than wind and solar energy (K. Li et al., 2015). Barbier (2002) asserts that the risk involved with exploratory drilling, high project development expenses, and extended project development durations significantly drive-up geothermal pricing. Furthermore, drilling and re-injection of the geofluid may cost up to 50% of the entire project (K. Li et al., 2015); 40% is for the construction and the remaining 10% is attributable to other expenses including maintenance. For electricity generation, the entire price might range from $2000 to $6000 per kW. Depending on the well size and development requirements, drilling and development costs can range from $500 to $4000 per kW produced and the cost of the plant's construction is between $1500 to $1700 for each kW generated (Kanoglu & Çengel, 1999).

6. Future outlook and opportunities

Geothermal energy may have a future with increased interest and funding in the sector. After solar, wind, and hydropower, geothermal energy is frequently ranked as the third or fourth most significant renewable energy source. Energy experts predict that geothermal power will become more significant in the future, potentially making up one-sixth of the world's power supply (Ganesh Bedre et al., n.d.). EGS have the potential to create enormous new sources of sustainable energy (Lin et al., 2023). Developing at a 6.3% annual growth rate, the geothermal energy industry is expected to reach $95 billion by 2030. A more robust and sustainable energy mix will be possible with the continuous development of drilling technology and the integration of geothermal energy with other renewable energy sources, such wind and solar power. Geothermal energy is essential to building a more sustainable future.

7. Conclusion

Generally, geothermal energy is clean and opportunities within this energy space remain not fully tapped. The heat from the earth can be harnessed to the benefit of mankind from just the surface even before drilling begins. Space heating and cooling, domestic hot water, greenhouses and agriculture, snow and ice melting and the balneological are the shallow geothermal energy application and electricity generation, industrial processes, desalination are the deep geothermal energy utilization. The implementation of a pollution fee (carbon taxes) on Sulphur and CO_2 emissions, as has been recently considered globally, would greatly enhance both the environment and the economic viability of geothermal resources. Energy independence and the prevention of climate change are two benefits of using geothermal energy. Geothermal energy is a renewable and low greenhouse gas emissions source that serves both heat (direct use applications) and electricity consistently and reliably. It is an ecologically beneficial and economically feasible alternative for conventional fossil fuels. It has an extended lifespan, low operating costs, and wide range of uses. The adoption of effective case studies, enacting supportive laws, and encouraging international cooperations, could help the global community to fully utilize geothermal energy. Geothermal energy provides a lighthouse that guides us through the challenges of the energy transition and points the way to a more prosperous and sustainable future. Heat pump applications are now the geothermal application sector that is developing at the fastest rate. It is anticipated that this trend will continue, making heat pumps the primary direct utilization industry. The primary cause of this is the global affordability of installing geothermal heat pumps. The use of binary plants for low-temperature power generation has expanded the potential for energy production in nations lacking high temperatures. Recently, combined heat and power plants are becoming common, and that raises the total geothermal utilization efficiency.

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