Chapter 2

Geothermal energy utilization and sustainability in Turkey

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Abstract

Geothermal energy is thermal energy generated by and stored in the Earth. The Earth transfers about 40,000 GW of this heat to the atmosphere. Geothermal resources consist of thermal energy stored within the earth in rock, steam or liquid water. This energy source can be used indirectly for electricity generation, for directly heating buildings, baths, greenhouses and food processing. Geothermal power plants are typically 20-60 MW in size. Plant designs vary and are determined by local resource characteristics such as whether a well is dry or has geofluids present. Plant efficiency typically varies between 10-23% and depends on the reservoir temperature as well as the cooling system. Geothermal energy is an inexhaustible source of thermal and electrical energy on a human time scale. Its utilization is friendly to the environment and supplies base-load energy. Utilization of geothermal energy increases the regional and local net product. Electrical energy from geothermal resources can provide an important contribution to the base-load electrical energy supply.

1. Introduction

Climate change and the increasing scarcity of fossil fuels have increased the pressure worldwide for the development of alternative energy sources that can replace fossil fuels. According to the United Nations Framework Convention on Climate Change (UNFCCC), "climate change represents an urgent and potentially irreversible threat to human societies and thus the planet requires the widest possible cooperation by all countries" (UN, 2015). The Paris Agreement, signed in 2015, states that global greenhouse gas emissions must decline to ensure that temperature increases remain as close to 1.5 ^{o}C as possible. For to be feasible global carbon neutrality should

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be reached as close to 2050 as possible means that deep decarbonization of energy systems must take place worldwide (UNGA, 2015; IEA, 2020).

The United Nations Sustainable Development Goals acknowledge the need for deep decarbonization and the transformation of energy systems towards sustainability emphasizing that in addition to addressing climate change, lack of sustainability, access and affordability must be addressed (UN, 2015). In 2020 approximately 42% of all inhabitants in developing and emerging countries did not have access to high-quality cooking fuels. In Africa and Sub-Saharan Africa, 46% and 55% of inhabitants, respectively, did not have access to electricity, with overall access to electricity close to 86% in all in developing and emerging economies (REN21, 2022). Given the need to enhance access and address increased demand, the International Energy Agency expects energy demand worldwide to increase globally by 1.3% per year until 2040 (IPCC, 2012; OECD, 2020; IRENA, 2017; IEA, 2022).

On the other hand, fulfilling growing energy demand, enabling access to the millions of individuals without access to high-quality energy and reducing emissions of greenhouse gases (GHGs) requires a radical departure away from the fossil fuel focused business-as-usual scenarios of the past. What needs to replace past emphasis is a new energy paradigm that will encourage transforming our current energy systems towards relying on sustainably used low-carbon energy resources. This new paradigm, coined sustainable energy development (SED) differs from the conventional energy development paradigm in at least eight important aspects (Spittler et al., 2019; Gunnarsdóttir et al., 2021; Davidsdottir and Axelsson, 2022).

Sustaining the yield of renewable energy resources for a long time is generally agreed to be a necessary but not a sufficient requirement for the utilization of energy resources to support sustainable development. Sustainable energy development requires that energy resources are in the long run readily available and accessible at an affordable cost and where negative social or environmental impacts are minimized and positive social and economic implications amplified (Dincer, 2000; UNDP, 2000). On the other hand, geothermal energy has not until recently become a significant source of electricity and heat, with of course exceptions in countries such as the USA, Indonesia, Iceland and Italy (DiPippo, 2022). Geothermal energy is to be considered a renewable energy source, but its development and use can have significant multi-dimensional sustainability implications (Axelsson, 2010, 2021). Given the certainty that geothermal energy usage is set to increase substantially and it is important to ensure that geothermal sources are developed in a sustainable manner for electricity generation projects (Barbier, 2002; Lund, 2021). Until now no framework however exists to enable formal assessment of the sustainability of geothermal energy development and use (Fridleifsson, 2001; Fridleifsson et al., 2008; Frick et al., 2010; Axelsson et al., 2010; Kaygusuz, 2011; 2012; Baba et al., 2014; Glassley; 2015; Baba, 2019; Basosi et al., 2020). This chapter examines the role of geothermal energy in the context of sustainable energy development. Particular focus on how the use of geothermal energy can contribute to the development of sustainable energy systems. Thus aiding the transition towards decarbonized energy systems and global sustainability.

2. Energy demand and sustainability

2.1. Global energy demand

The current energy crisis is reshaping previously well-established demand trends. Consumers are adjusting their patterns of energy use in response to high prices and, in some cases, emergency demand reduction campaigns. Policy responses vary, but in many instances, they include determined efforts to accelerate clean energy investment. This means an even stronger push for renewables in the power sector and faster electrification of industrial processes, vehicles and heating. At the global level, primary energy demand would increase from circa 14 976 Mtoe in 2021 to 16 152 Mtoe in 2030 and further to 17 760 Mtoe by 2050 (Table 1 and Figure 1). This energy demand dynamics, driven by a growing population, further needs for energy services and increasing living standards. This high energy demand would be partially mitigated by the decline in the energy intensity of GDP (IEA, 2022; REN21, 2022).

Table 1. World energy supply (Mtoe).

	2021	2030	2040	2050
Total energy supply	14 976	16 152	16 992	17 760
Coal	3 960	3 624	3 072	111
Natural gas	3 504	3 600	3 528	3 530
Oil	4 392	4 724	4 728	4 730
Nuclear	720	888	1 032	1 104
Hydropower	384	432	504	600
Solar	120	432	864	1 248
Wind	168	408	696	912
Biomass	984	1 344	1 632	1 968

Mtoe: Million tons of oil equivalent; Source: IEA, 2022

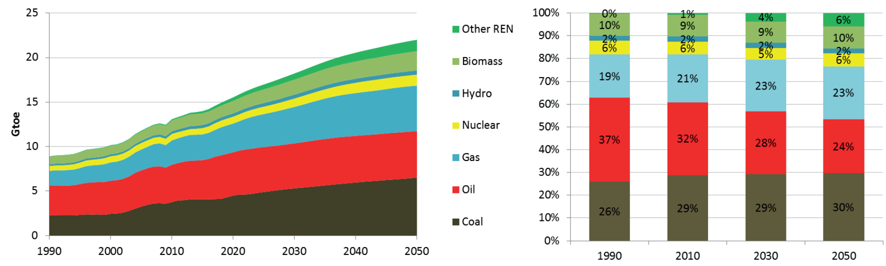

Figure 1. World primary energy demand and the share of energy sources (IEA, 2022).

2.2. Energy and sustainable development

Sustainable energy deeply influences people's lives and is an engine for poverty alleviation, social progress, women/youth empowerment, equity, enhanced resilience, economic growth and environmental sustainability. Over the centuries, energy has helped transform economies and societies, spurring industrialization and raising living standards (WCED, 1987). Energy is indispensable for fulfilling numerous basic human needs, including nutrition, warmth, light, communities and nations. It helps to realize human rights, including the right to work, the right to education and the right to better health. The global trend towards an electricity-based economy in modern society where governments, businesses and citizens rely heavily on electricity makes energy all the more relevant for accessing modern forms of communication and engaging in economic activities such as online commerce and market places (UNDP, 2000; IPCC, 2012; Shortall & Davidsdottir, 2017; UNDP, 2016; Wang et al., 2020).

Energy deficiencies can generate wide-reaching social consequences. Furthermore, energy consumption varies greatly in terms of the quality and quantity of access. Indeed, about 1.1 billion people lack access to any electricity whatsoever. Nearly 2.9 billion people use solid fuels such as wood, coal, charcoal, agricultural residues or animal waste to cook their meals and heat their homes. This exposes families to smoke and fumes, causing serious health impacts and resulting globally in more than 4 million premature deaths each year. In fact, women and children accounted for over 60% of all premature deaths from household air pollution (UNDP, 2016Pratiwi et al., 2018; Spitter et al., 2019; Paulillo et al., 2020).

3. The Millennium Development Goals (MDGs)

3.1. Introduction

The Millennium Development Goals (MDGs) are the international community's bold commitment to halving poverty in the world's poorest countries. While some of the world's poor countries have seen tremendous success in poverty reduction over the past decades and are on track to achieve the MDGs, many others are lagging. Energy services refer to the services that energy and energy appliances provide. Such services include lighting, heating for cooking and space heating, power for transport, water pumping, grinding, and numerous other services make possible. Achieving all of the MDGs will require much greater energy inputs and access to energy services. Failure to include energy considerations in national MDG strategies and development planning frameworks will severely limit the ability to achieve the MDGs. As such, the following key recommendations point to priority energy interventions that national governments should take to support achieving the MDGs at the national level (IPCC, 2012; Martin-Ganboa et al., 2015; UNDP, 2016; Nerini et al., 2017).

3.2. Sustainable energy development (Goal 7)

GOAL 7 of the SDG's aims to "ensure access to affordable, reliable, sustainable and modern energy for all". Three core targets are to be reached under this goal; ensure universal access to affordable, reliable and modern energy services. Also, increase substantially the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency (Goldemberg, 2000; Gunnarsdottir et al., 2021). In addition, two goals address international cooperation; enhance international cooperation to facilitate access to clean energy research and technology. Also, includes renewable energy, energy efficiency, and advanced cleaner fossil-fuel technology. On the other hand, promote investment in energy infrastructure, clean energy technology, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries. Especially, in least developing countries, small island developing states, and land-locked developing countries, in accordance with their respective programs of support (UNGA, 2015; Davidsdottir and Axelsson, 2022).

Several characteristics of geothermal energy resources are particularly important when considered in the context of SDG7. These include; renewability and reliability in supply and relative independence from climatic and socio-political events, the location often in remote rural areas and the ability to be harnessed in small centralized units. These features, among others, enable unconnected remote and rural areas to gain access to reliable, and modern high-quality energy (Shortall et al., 2015; 2016). Access to high-quality energy, such as electricity is key to economic and social development. Low-enthalpy geothermal resources are widely available throughout the world, and currently at least 88 countries apply direct use of geothermal heat (Lund and Toth, 2020). Global geothermal electricity generation capacity in 2021 was 16,406 MW (REN21, 2022). Significant potential exists worldwide, not the least in areas where rural populations do not have access to electricity. This is for example the case in various countries in sub-Saharan Africa where over 55% of the population does not have access to electricity (Modi et al., 2005; Manzella et al., 2019; REN21, 2022).

As geothermal energy is considered a renewable energy source, and is in most cases produced and used domestically, investment in geothermal energy increases the fractional share of renewable energy in total primary energy use. When aiming for an improved rate of global energy efficiency, the target indicator for each nation is a metric of national economic intensity measured as primary energy per GDP. This ratio indicates the efficiency at which each nation uses its primary energy to produce economic output. While direct uses of geothermal energy are efficient, the efficiency of indirect use for electricity generation depending on the temperature of the geothermal resource and the type of plant technology used. Overall, the thermal efficiency of geothermal electric plants is relatively low, ranging from 9% to 23% (Lacirignola and Blanc, 2013; Menberg et al., 2021).

As a result, it is vital, if geothermal power is used indirectly for electricity generation to ensure that the waste fluids are utilized at cascading levels of lower heat or re-injected (Shortall et al., 2015, 2016, 2017). Direct use is more efficient than indirect use and places less demanding temperature requirements on the heat resource rendering direct use both available and competitive at many more sites than geothermal electricity generation. Heat for direct use may come from natural hot springs, boreholes, cogeneration from a geothermal power plant, or from geothermal heat pumps. In areas where natural hot springs are available to warm water can be directly pumped and used in district heating or for other uses.

4. Geothermal power to sustainable energy development

4.1 The Use of Geothermal Power

Geothermal resources have been identified in 94 countries, and there is quantified information of use in 72 countries, with 24 countries relying on geothermal power for electricity generation (Davidsdottir and Axelsson, 2022). From very early on, humans have used the geothermal energy that flows from underground reservoirs to the Earth's surface. Geothermal energy was for the first time in the twentieth century harnessed on a large scale for space heating, electricity generation, and industry. Today, geothermal energy primarily is utilized in three technology categories (Stober and Buncher, 2013):

- Heating and cooling buildings via geothermal heat pumps that utilize shallow sources;
- Heating structures with direct-use applications; and
- Generating electricity through indirect use.

The global technical potential of geothermal resources suitable for indirect use of electricity generation to be 340 GWe and use of lower temperature resources for direct use to be 240 EJ/yr. Approximately one-third of the direct use is through ground source heat pumps and by 2050 electricity generation potential may reach 70 GWe. Especially, two developing countries such as China and Turkey, the amount of geothermal electricity is growing very fast. Table 2 shows top countries in 2020 for installed capacity including geothermal heat pumps (Ogola et al., 2011; 2012; McCay et al., 2019; Lund, 2020; Toth et al., 202).

Table 2. Global installed geothermal capacity including geothermal heat pumps (> 2000 MW_{th})

Country	**Installed capacity (MW_{th})**	**Major use(s)**
China	40 600	Bathing, district heating
USA	20 700	Heat pumps, bathing
Sweden	6 680	Heat pumps, district heating
Germany	4 806	District heating
Turkey	3 490	District heating, bathing
France	2 600	Heat pumps, district heating
Japan	2 570	Bathing, heat pumps
Iceland	2 370	Bathing, district heating
Finland	2 300	Heat pumps
Switzerland	2 200	Heat pumps, space heating

4.2. Geothermal heat pumps

GHPs harness the low-temperature geothermal energy stored in soil, rock, surface water or groundwater and make this energy available for heating and cooling. Geothermal energy is any energy stored in or derived from the Earth; it is not limited to places with 'hot ground' like Rotorua or Taup□and is available nationwide. It is derived from three major sources: volcanic systems; stored energy from the sun; and energy radiated from the Earth's core. Stored energy from the sun and energy radiated from the Earth's core generate lower temperate geothermal energy that can be utilized by GHPs.

As mentioned above, GHP systems can provide space cooling also. In a moderate climate, in summer, the ground below about 15 m depth is significantly colder than outside air. Thus, a large geothermal store with favorable heat capacity is available where the heat can be exchanged. The thermal capacity of the system depends on the thermal and hydrogeologic characteristics of the installation site. So, these must be carefully considered in system dimensioning. In summer, most of the time, the HP can be bypassed and the heat carrier fluid is circulated through the ground by the BHEs and through the heating/cooling distribution. By these means, the heat is collected from the building and deposited in the ground for extraction in the next winter. In a moderate climate, BHEs deeper than about 200 m cannot cool enough in summer. Figure 2 shows the normal and reverse modes of HPs. Fig. 3 also shows the three main components of GHPs: (1) the heat source (in this case a BHE); (2) the HP; (3) the building's heating/cooling system. Small pumps, circulating the heat carrier through the HP's evaporator and the BHE and another circulating the heated/cooled medium to the user, are not shown. Table 3 also shows the leading countries in 2020 in terms of direct use annual energy use, including geothermal heat pumps.

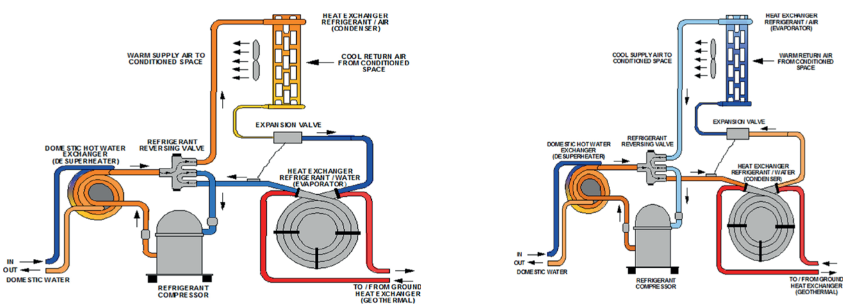

Figure 2. Heat pump in a GHP, heating mode (left) and cooling mode (right).

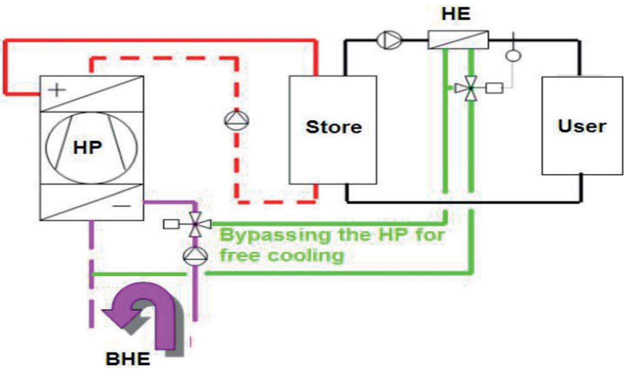

Figure 3. Scheme of free cooling with a geothermal heat pump. BHE: borehole heat exchanger, HP: heat pump, HE: heat exchanger.

Table 3. Top countries in 2020 for direct geothermal use including heat pumps (>12 000 TJ/year)

Country	Geothermal use (TJ/year)	Major use(s)
China	443 000	Bathing, district heating
USA	153 000	Heat pumps, bathing
Sweden	62 400	Heat pumps, district heating
Turkey	54 600	District heating, bathing
Iceland	33 600	Bathing, district heating
Japan	30 700	Bathing, heat pumps
Germany	29 100	District heating
Finland	23 400	Heat pumps
France	17 300	Heat pumps, district heating
Canada	14 500	Heat pumps, bathing
Switzerland	13 300	Heat pumps, space heating
Norway	12 600	Heat pump

As this lower-temperature geothermal resource is available from practically any building site in the country, GHPs have significant potential in New Zealand. They can be used for space heating and cooling in buildings, heating swimming pools, providing domestic hot water and supporting industrial heat use. GHPs are suitable for small applications (e.g. residential buildings requiring 5 kW to 30 kW systems) to large applications (e.g. large buildings and district heating schemes of 100 kW to 1000 kW). GHPs utilise a naturally replenished, renewable energy source that is available all year round; they are efficient, low maintenance, durable, quiet and reliable (DiPippo, 2016; Dincer and Ozturk, 2021).

On the other hand, GHPs work by collecting geothermal energy through a ground loop and then transferring this heat energy to an end use such as heating a building. They can also work in reverse to provide cooling by collecting heat energy from inside a building and disposing of it via the ground loop. Depending on the location and characteristics of the site, the ground loop can be installed vertically or horizontally, using straight pipe or in a series of coils, and as an open or closed (extracting/disposing of heat only) system.

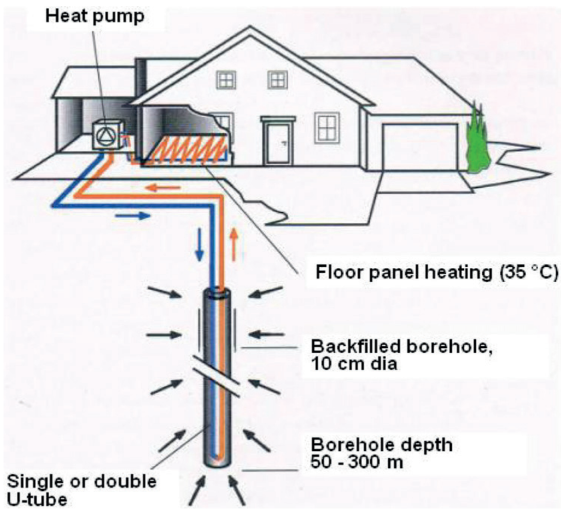

Figure 4. Sketch of a GHP system with a single BHE. Colored arrows indicate circulation in the U-tube heat exchanger, black arrows heat extraction from the ground (heating mode in winter). In summer the arrows are reversed; heat is extracted from the building and stored in the ground.

There is great potential for the use of geothermal heat pumps as they take advantage of the fact that the uppermost 3 m of the Earth's crust maintains temperatures ranging from 10 to 15.5 °C. Consequently, most areas of the world are suitable for the installation of geothermal heat pumps. For example, European countries have good potential, especially Sweden had the largest installed heat pump capacity. A geothermal heat pump system can have different features but, for example, consists of pipes buried in the shallow upper layers of the ground, with a connection to a ventilation system of an adjacent building, relying on the ground as a heat exchanger.

A liquid is passed through the pipes, and as the ground is naturally warmer than the atmosphere in the winter, it absorbs the warmth and delivers it to the building. In the summer, the circulation can be reversed, cooling the building by bringing warmth from the building to the ground.

4.3. Direct use

Direct-use applications utilize groundwater that in most cases has been heated to less than 100 °C. Direct use of geothermal energy includes use in urban areas such as for melting of snow, in industrial processes, in agricultural and aquaculture production by heating greenhouses, soils, and aquaculture ponds. Direct use also includes use in swimming pools and spas and as such is very important to tourism, as well as in residential and regional heating. In various countries, the direct use of geothermal power significantly contributes to the total energy use. In Iceland, for example, approximately 90% of residential and commercial buildings are heated with geothermal water. Larger countries such as China have geothermal water in almost all provinces and is expanding direct utilization at a rate of about 10% per year.

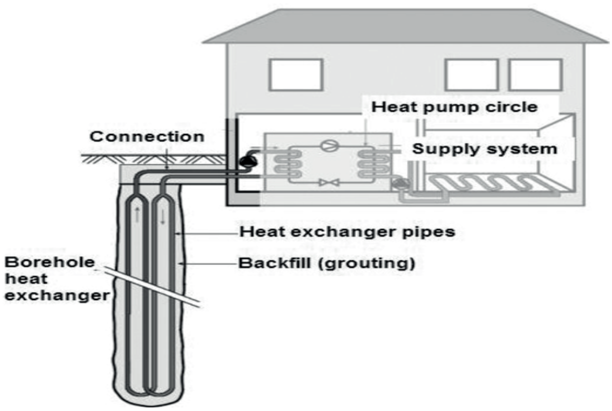

Figure 5. Ground source heat pump system.

4.4. Power generation

Indirect use of geothermal power conventionally involves the production of electricity. In 2022, 24 countries produced electricity using geothermal power. During electric power generation from geothermal power, wells are drilled into geothermal reservoirs where temperatures may exceed 360 °C, leading the steam or the water to a geothermal power plant. Three types of geothermal power plants are operating today:

- Dry steam plants are used when geothermal steam is directly used to turn turbines. In this case, steam is brought to the surface under its own pressure where the steam is utilized to turn the turbines of an electrical generator.
- Flash steam plants rely on high-pressure hot water, pulling it into lower-pressure tanks, creating flashed steam that is used to drive turbines.
- Binary cycle plants pass (in separate piping) moderately hot geothermal water by a secondary fluid, such as ammonia, with a much lower boiling point than water. This causes the secondary fluid to create steam, which then drives the turbines onward.

Five countries, Costa Rica, El Salvador, Iceland, Kenya, and the Philippines, obtain 20–30% of their national electricity production from geothermal power (Parisi et al., 2019). The United States produced 15 000 MW from geothermal power plants in 2020, supplying electricity to about 8 million people (Dinçer and Ozturk, 2021; Karlsdottir et al., 2020).

4. 5. Present situation and Future developments

Geothermal resources are distributed throughout the Earth's crust with the greatest energy concentration associated with hydrothermal systems in volcanic regions at crustal plate boundaries. Yet exploitable geothermal resources may be found in most countries, either as warm ground water in sedimentary formations or in deep circulation systems in crystalline rocks. Shallow thermal energy suitable for ground-source heat-pump utilization is available worldwide and attempts are underway at developing enhanced geothermal systems in places where limited permeability precludes natural hydrothermal activity (Bayer et al., 2013; Bravi and Basosi, 2014; Buonocore et al., 2015; DiPippo, 2016; Davidsdottir and Axelsson, 2022).

The theoretical potential of the Earth's geothermal resources is enormous when compared to its use today and to the future energy needs of mankind. Stefánsson (2005) estimated the technically feasible electrical generation potential of identified hightemperature geothermal resources (4200 ^{o}C) to be 240 GWe, which is only a small fraction of resources, assumed to be unidentified. He also indicated the most likely direct use potential of lower temperature resources (150 ^{o}C) to be 140 EJ/year. It's utilization is still miniscule compared with the Earth's potential, but estimates predict that it could fulfill around 3% of global electricity demand, as well as 5% of global heating demand by 2050 (IPCC, 2012).

The production capacity of geothermal systems is controlled by their long-term response to the production, mainly manifested by pressure decline but also slow cooling in some cases. If the pressure decline is too great geothermal wells dwindle in output, or even cease to produce. The pressure decline is determined by the rate of production, on one hand, and the nature and characteristics of the geothermal system. Geothermal resources are generally classified as renewable as they are maintained by a continuous energy current. In addition, geothermal resources simply don't fit well with non-renewable energy sources like coal and oil. Classifying geothermal resources as renewable has been disputed, however, on the grounds that geothermal energy utilization actually involves heat mining (Lund, 2021).

Classifying geothermal resources as renewable is an oversimplification and they are of a double nature; a combination of current energy development and stored. The renewability of these two aspects is quite different as the energy current is steady while the stored energy is renewed relatively slowly (Kristmannsdottir and Armannsson, 2003; Axelsson, 2011; Patiwi et al., 2018). When evaluating the contribution of geothermal energy to Sustainable Development and Sustainable Energy Development, it is useful to review the implications directly in the context of the Sustainable development goals (SDG) (Table 4) (Karlsdottir et al., 2020).

Table 4. The United nation's Sustainable Development Goals (SDG's).

Sustainable development goals	*Dimensions*
Goal 1: End poverty in all its forms everywhere	Social
Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Social
Goal 3: Ensure healthy lives and promote well-being for all at all ages	Social
Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Social
Goal 5: Achieve gender equality and empower all women and girls	Social
Goal 6: Ensure availability and sustainable management of water and sanitation for all	Environmental
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all	**Energy specific**
Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Economic
Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Economic
Goal 10: Reduce inequality within and among countries	Economic
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	Social
Goal 12: Ensure sustainable consumption and production patterns	Economic
Goal 13: Take urgent action to combat climate change and its impacts	Environment
Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Environment
Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Environment
Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Social
Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development	Overarching

The utilization of geothermal sources is an environmentally friendlier energy option and has much more diverse application areas than the other renewable sources. Moreover, it does not depend on climate conditions. Nevertheless, just like the other renewable energy production areas, geothermal facilities are also not free from negative environmental impacts. The wastes produced by geothermal systems include toxic metals. Geothermal plants may also smell and produce noise pollution during construction, drilling wells and the escape of high-pressure steam during testing. Therefore the local residents living nearby of a geothermal plant should be informed by the project owners about the benefits and potential adverse effects (Dickson and Fanelli, 2003; Karlsdottir et al., 2020; Lund and Torh, 2020; Dincer and Ozturk, 2021).

The main economic benefit of a geothermal plant can be the creation of short-and long-term employment opportunities for the local residents. Furthermore, the plant owners may purchase some necessary materials and equipment from local sources. Another benefit of a geothermal power plant can be providing district heating systems to the close residents or farms. Agricultural crop production can be benefited from the heating system.

Table 5. Environmental impacts of geothermal energy.

Land Use	Land use varies between 200-30,000 m^2/MW, or 0.04-6 m^2a/MWh.
Geological Hazards	Geothermal energy production is associated with extensive extraction or circulation of geofluids and/or steam, large-scale and local manipulation of the shallow and deep ground. Landslides, subsistence, fractures, explosions and changes in natural seismicity have been connected to geothermal facilities.
Noise	High noise levels are associated with drilling and well testing.
Thermal Effects	The energy lost in the form of waste heat is around 4-10 times that in the electricity generated, and is hence higher than for fossil fuel power plants of similar capacity.
Atmospheric Emissions	Geofluids contain many contaminants. Pollutants such as hydrogen sulphide (H_2S), CO_2, and CH_4 are often discharged to the atmosphere. These non-condensable gases (NCG) are released from flashsteam and dry-steam power plants, because in contrast to steam, the gases do not condense at the turbine outlet. Emissions may also include trace amounts of mercury (Hg), ammonia (NH_3), radium (Ra) and boron (B).
Solid waste emissions	Liquid-dominated high temperature geothermal fields can result in significant waste of geothermal fluids. Critical contaminants of steam emissions, such as H_2S, B, NH_3, Hg often occur in the fluids, as well as metals such as arsenic (As), lead (Pb), cadmium (Cd), iron (Fe), zinc (Zn), antimony (Sb), lithium (Li), barium (Ba) and aluminium (Al).
Water use	Water is used extensively in geothermal generation, especially for drilling, cooling, and to supplement steam production. The extent of cooling water use depends on the technology; air-cooled systems having a much lower water use, but also a lower efficiency and higher energy cost.

5. Conclusions

Geothermal energy is a type of renewable energy which is generated within the earth and can be used directly for heating or transformed into electricity. An advantage of geothermal energy over some other renewable energy sources is that it is available year-long and can be found around the globe. However, for electricity generation, medium- to high-temperature resources, which are usually close to volcanically active regions, are needed. Geothermal power has considerable potential for growth. The amount of heat within 10 000 metres of the earth's surface is estimated to contain 50 000 times more energy than all oil and gas resources worldwide. Moreover, there is a strong economic case for the deployment of geothermal energy. The costs for electricity generation from geothermal technologies are becoming increasingly competitive, and they are expected to continue to drop through 2050.

Geothermal resources can significantly contribute to sustainable energy development and thereby contribute to reaching Sustainable Development Goals. Geothermal energy is considered renewable, affordable and a stable energy source that can be utilized in small-scale units in remote areas. The geothermal reservoir must be carefully managed to avoid a reduction in overall yield and should be rested at times. If used in direct-use applications such as for district heating, the efficiency of use is relatively high. However, in indirect-use applications, the efficiency is significantly lower, and therefore cogeneration, and reinjection is recommended (Buonocore et al., 2015; DiPippo, 2022; Dinçer and Oztürk, 2021).

The social and economic implications of utilizing geothermal energy are likely to be significant and positive if properly managed. The impact on local communities can be profound in particular if cascading use is applied creating abundant local employment opportunities and value creation. GHG emissions are on average lower when compared to emissions from the burning of fossil fuels and if the Carbfix method is applied, all operational GHG emissions can be mitigated from geothermal power plants. Other environmental impacts of geothermal development can be mitigated, but if left untreated can become significant. This includes the potential for air pollution such as H_2S emissions and the potential for water and thermal pollution but all can be mitigated with proper management.

Geothermal energy is widely used for many applications such as power generation, district heating, chemical production, greenhouse application, snow melting, fish production, industry and thermal tourism. However, geothermal brine can be extremely difficult to handle. Geothermal fluids display high contents of elements and gases. Therefore, they can severely affect the environment such as air, soil and water resources. In essence, with its high dissolved constituents and thermal content, geothermal fluid is known to have significant impacts on the environment when disposed of in an uncontrolled manner. In parallel to developing geothermal energy applications, many countries start to find innovative solutions for minimizing the environmental problem and using waste from geothermal fluid for the economy. The recovery of valuable elements and minerals from geothermal fluid has been studied for years and new methods have been developed recently. Mineral recoveries such as lithium, boron, gold, mineral extraction from geothermal fluid and return water is an advanced method of mining and in some way reducing environmental impact.

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