Chapter

Geothermal Power Generation

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Abstract

Bulk power system based on fossil fuels becomes less reliable and stable in economic terms, technically more labor-consuming and harmful environmental impact. These problems have led many countries to find ways to supply the electricity from a green and sustainable energy source. The electricity derived from renewable energy sources such as hydro, solar, wind, biomass and geothermal refers to as green and sustainable energy. Geothermal energy is not only utilized for electric power generation, but it is also exploited to generate environmentally friendly heat energy. As of the end of 2018, geothermal global cumulative installed capacity exceeded 13 GW, generated an energy of about 630 peta joule (PJ). This chapter presents the geothermal energy resource in terms of the types of power plants, principle of the electricity generation and current world status of geothermal resource utilization. The issues such as advantages and disadvantages of geothermal energy economically and environmentally and means to overcome shortcomings are also considered. The main barriers for the development of geothermal industry include high resource and exploration risk, overall high development cost particularly drilling, and inadequate financing and grant support. The global averaged cost of electricity for the geothermal facility is nearly 0.072 USD/kWh as compared to 0.056 for onshore wind and 0.047 USD/kWh for hydropower. However, the technology is rather competitive to other renewables such as concentrating solar power (0.185 USD/kWh) and offshore wind (0.127 USD/kWh). Meanwhile, further research and development is critically needed to eliminate the non-condensable gases (NCGs) associated with the geothermal power generation.

Keywords: geothermal energy, geothermal power plants, geothermal electricity, economic and environmental impact, geothermal worldwide status

1. Introduction

Geothermal energy is heat energy from Earth's interior which generated from radioactive breakdown and frequently recurring heat losses from Earth's formation. The Earth's heat capacity is approximately 1×10^{19} TJ or 2.8×10^{15} TWh [1]. The Earth's heat conduction is 44.2 TW [2].

The utilization of geothermal energy according to the geological conditions are categorized as:

1. High-temperature (enthalpy) geothermal systems with temperature greater than 180°C. This system depends on recent mantle hot spot anomalies and volcanos at depths over 3.5 km. Also, high-temperature geothermal systems related to rocks at depths approximately below 3.5 km.

	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	<90°C	<125°C	<100°C	≤150°C	≤190°C
Middle enthalpy resources	90–150°C	125 – 225°C	100–200°C	—	—
High enthalpy resources	>150°C	>225°C	>200	>150°C	>190°C

a) Muffler and Cataldi (1978); b) Hochstein (1990); c) Benderitter and Cormy (1990); d) Nicholson (1993); e) Axelsson and Gunnlaugsson (2000).

Table 1.
Classification of geothermal resources based on temperature [3].

2. Middle-temperature (enthalpy) systems between 100 and 180°C.

3. Low-temperature (enthalpy) geothermal systems with temperature lesser than 100°C.

Geothermal systems with middle and low-temperature are formed by decaying of radioactive isotopes and they conclude aquifers which recharge by heated water circulation. **Table 1** tabulates the classification of the geothermal resources based on temperature [3].

Geothermal energy can be utilized for both purposes – direct heat and electricity generation. As of the end of 2019, geothermal energy was used in 88 countries around the world with an annual energy consumption of around 1,020,887 TJ or 283,580 GWh [4]. According to the International Energy Agency the electricity production from geothermal energy will be increased to 1400 TWh/y and the direct use to 1600 TWh/y by 2050 [5].

The main advantage of the geothermal energy is being clean as other types of renewable sources. Other advantages include: reliability, environment-friendliness, relatively low cost of generated energy, high usage factor for the geothermal power plant operation that distinguishes the geothermal energy from other renewable energy sources. However, the heat and electricity generated by the geothermal energy should be directly utilized locally and cannot be transported.

2. Geothermal power plants

In work [6], modeled types of geothermal resources are given, as shown in **Table 2**. In general, geothermal resources under 150°C are more suitable for direct use such as heating and cooling, whereas the resource of above 150°C is exploited for electricity generation. However, modern power conversion technologies allow to generate an electricity from low temperature resources up to 150°C [3].

A steam or hydrocarbon vapor are used to generate electricity from geothermal energy. While the vapor-dominated resource is applied directly, the hot-water dominated resource should be flashed by reducing the pressure to convert a steam [7]. **Table 3** provides the basic technologies and the common applications under different temperatures of geothermal fluid.

As mentioned above, the geothermal source in view of steam or hydrocarbon vapor can be used to generate electricity. In this respect, geothermal power plants (GPPs) operation is similar to those of steam power plants. However, unlike the conventional steam power plants, the geothermal power ones use natural steam of

Type of geothermal resource	Temperature
Hot-water dominated	20–350°C
Vapor-dominated	≈240
Sedimentary basin	20–150°C
Radiogenic	30–350°C
Geopressured	90–200°C
Solidified (hot dry rock)	90–650°C
Part still molten (magma)	>600 °C

Table 2.
Types of geothermal resources for energy utilization.

Reservoir temperature	Geothermal fluid	Application proposes	Technology
High temperature, >220°C	Water or steam	Direct-in use	Heat exchangers; Heat pumps
		Power generation	Flash steam: combined cycle (flash and binary)
Medium temperature, 100–220°C	Water	Direct-in use	Heat exchangers; Heat pumps
		Power generation	Binary cycle
Low temperature, 30–150°C	Water	Direct-in use	Heat exchangers; Heat pumps

Table 3.
Frequently used technologies for geothermal energy.

earth. History of the first GPP started from 1904 at Larderello, Italy, where generator was tested to produce electricity from geothermal source. Then, it was commercialized to power plant in 1911 [7].

The simplest operational conceptualization of the GPP is presented in **Figure 1**. In this case, a natural steam from the well is directly passed to a turbine, that drives a generator for the electricity production.

There are three basic types of GPPs:

1. Dry steam plants.

2. Flash steam plants.

3. Binary cycle power plants.

2.1 Dry steam plants

Dry steam plants are simple and more efficient type of GPP. This type of power plants was firstly deployed to generate electricity in Italy in 1911. However, dry steam plants are less available in the sense that the steam should be produced from vapor-dominated reservoirs which are of few numbers in the world.

To provide a high efficiency of turbine, the steam condensation is minimized during extension of fluid fraction in steam phase. In common, isentropic efficiency

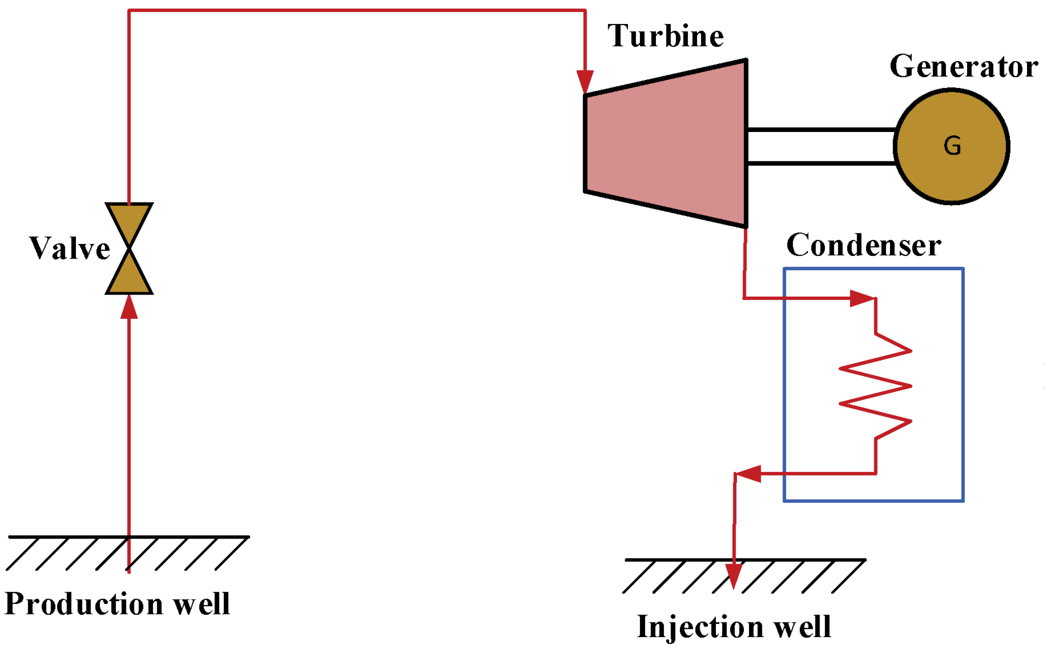

Figure 1.
Schematic diagram of dry steam power plant.

of modern dry steam plants is about 85%. According to a feasibility study to extract the maximum efficiency of these plants, the generation capacity should be at least 1 MWe [8].

Based on [9], electricity can be generated from the dry steam in the following conditions:

1. The vapor-dominated source should be closer (approximately with 5 km depth) to the surface to raise the hot water to the boiling point.

2. There should be enough opening above the geothermal fluid source to allow the vapor to drop to the surface over a long period of time by reducing the level of liquid significantly.

The schematic diagram of dry steam power plant is illustrated in **Figure 1**. The dry steam plant operation is based on the following: the water and steam flow from geothermal production wells are transmitted through valve to turbine and spin a steam turbine by converting thermal and kinetic energy to electrical energy.

2.2 Flash steam plants

Currently, most of GPPs are flash steam plants. They use geothermal reservoirs with mixture sources, i.e., vapor and liquid-dominated (water) to generate an electricity. It means that the temperature and enthalpy of vapor and waters are lesser than the critical point. Therefore, the flash units are generally basic approach to change over the geothermal energy into power. Firstly, in this system the steam is separated from water using a cylindrical cyclonic pressure tank with a base loss of pressing factor. Then, the dry steam leaves the separator, flows to powerhouse and rotates the steam turbine. The vapor quality that defines the flashed fluid is given as:

$$x = \frac{m_{vapor}}{m_{liquid} + m_{vapor}} \tag{1}$$

where: m_{vapor} – mass of vapor and m_{liquid} – mass of liquid.

The vapor quality value changes from 0 to 1 and commonly given as percentage. When vapor quality between 0 and 1, wet steam is then obtained. When the vapor quality is equal to 1, it is called "the saturated vapor" state.

There are two types of flash steam geothermal plants:

- Single-flash steam GPP
- Double-flash steam GPP

In a single-flash steam GPP the mixture fluid is flashed only in one separator. Schematic process diagram of the single-flash power plant is shown in **Figure 2**. The process of electricity generation in this power plant is accomplished as follows: hot water from production well is piped to flash separator (FS) by decreasing its pressure. In FS the steam is separated from hot water and transmitted to the steam turbine to spin it and convert mechanical energy to electrical by a generator. While the cooled steam in a turbine condenses to the water by the condenser while a part of the liquid from FS are reinjected to injection well.

Unlike single-flash steam, in double-flash steam the flash process of the fluid is applied in two separators. Although these plants are more expensive and more labor-consuming, however, they are preferable than single-flash plants as they generate 15–25% more electricity for the same states of fluid reservoirs [8, 9].

Schematic operational diagram of the double-flash power plant is illustrated in **Figure 3**. The fluid flows from well to a high pressure flash separator where from a mixture fluid the steam is separated and is piped to a two-stage turbine; another part – saline liquid is throttled down to the second separator. In the low pressure separator like the first one a partly boiled liquid again is separated to a steam and water. As a result, the steam gets directed to the low-pressure turbine. By keeping the pressure in the condenser, the steam from the low-pressure turbine is cooled using a sprayed cold water. Then, water is reinjected to injection well, as well as the cold water from the condenser.

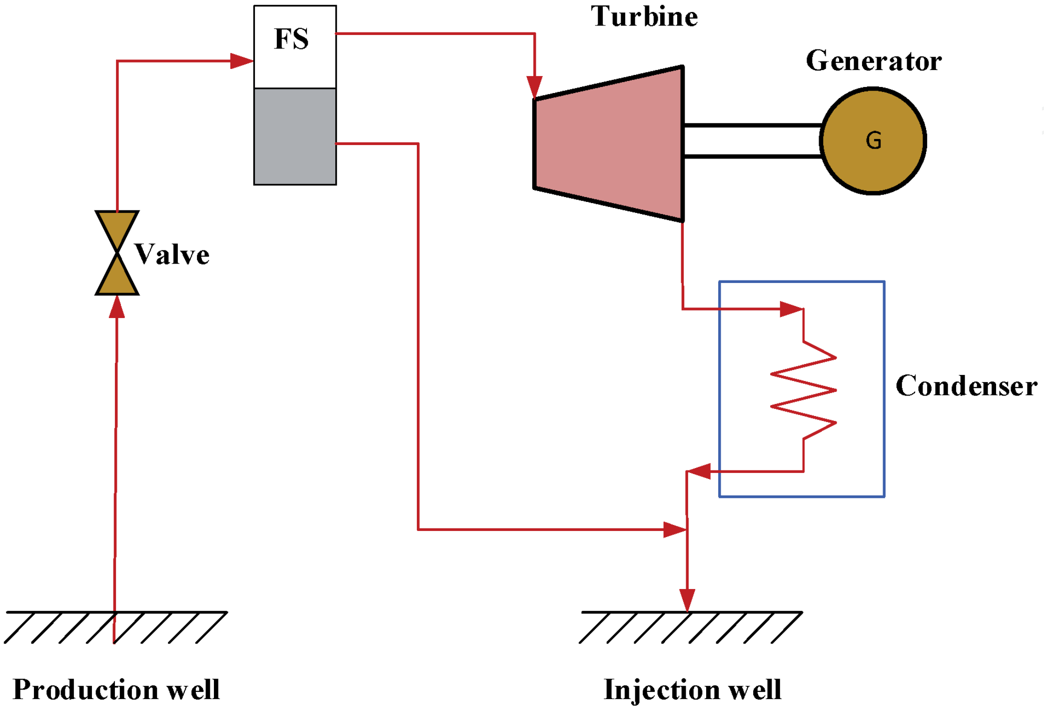

Figure 2.
Schematic diagram of single-flash power plant.

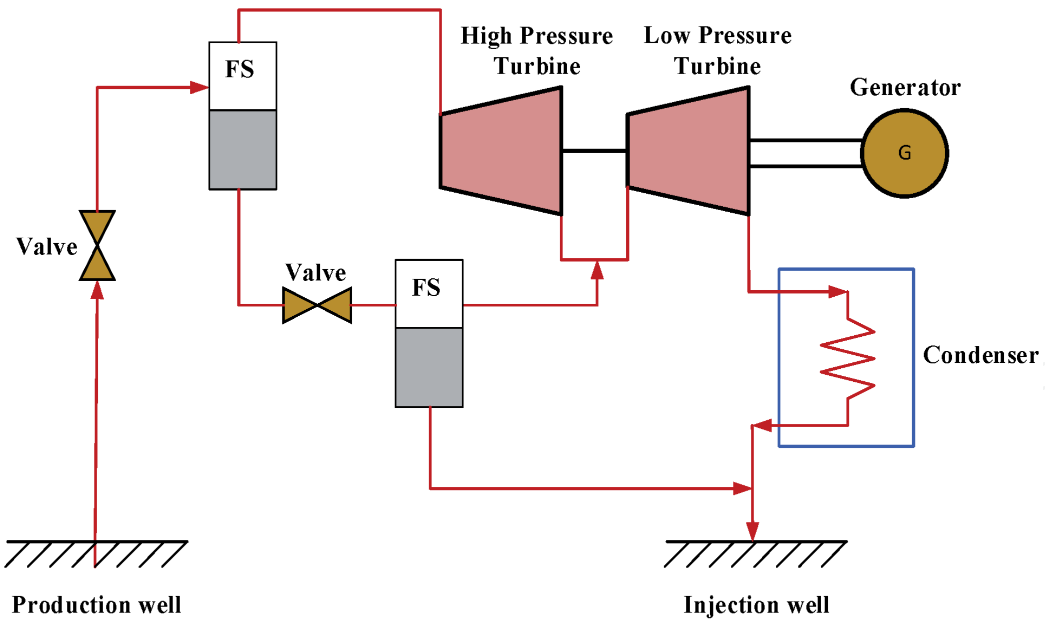

Figure 3.
Schematic diagram of double-flash power plant.

2.3 Binary cycle power plants

"Binary" cycle refers to as a secondary separate cycle. For the geothermal resource, binary indicates that the geothermal fluid (water/steam) never comes in a contact with the prime mover. Geothermal binary power systems are suitable for electricity production from low underground heat source [10]. The binary plant in Alaska, as an example, utilizes a geothermal resource of 57°C [11]; yet generally, binary system designs can exploit an inlet temperature range between 80 and 170°C [3]. The secondary fluid, known commonly as working fluid, in the binary geothermal system operates in a conventional Ranking cycle; and the binary cycle is known as an organic Ranking cycle (ORC) when the used working fluid is organic [12]. In binary ORC power plants the geothermal fluid passes through a heat exchanger to heat another working fluid of a low boiling point e.g., pentane, zeotropic mixtures, etc. which in turn vaporizes and drives a turbine [13]. Electrical production through a closed-loop binary unit is shown in **Figure 4**.

The standard working mechanism of a basic geothermal binary system can be summarized as: when the geothermal brine is pumped through the production well,

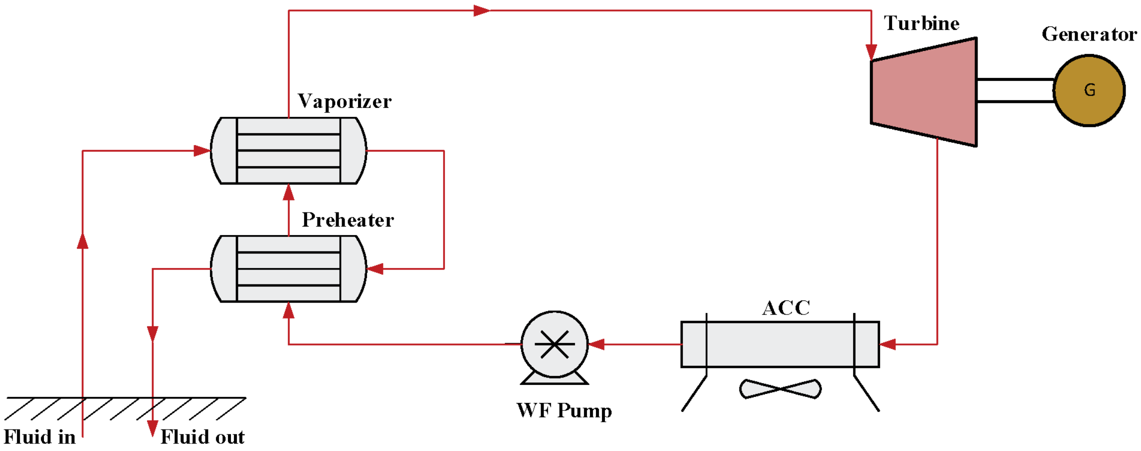

Figure 4.
Illustrative schema for a binary geothermal plant.

the heat extraction process is accomplished after passing through different components of the primary cycle. The geothermal fluid is initially filtered via sand removers to pass through the heat exchanger i.e., the evaporator/vaporizer and preheater, and finally pumped back into the reservoir by the injection well. On the other side of the secondary cycle, the pressurized working fluid turns into boiling state in the preheater. It then exits the vaporizer as a saturated vapor that subsequently expands in the turbine driving a power generator. The low-pressure working fluid vapor exiting the turbine is finally condensed in the ACC (air-cooled condenser) and pumped back to the vaporizer, closing the loop system and repeating the process continuously. Thus, the thermodynamic process of the low-boiling-point working fluid starts when it expands into the turbine in saturation vapor state, and completed when it is cooled through the condenser and pumped back (as a saturated liquid fluid) to the heat exchanger to emerge as a saturated vapor again [14, 15].

The efficiency of geothermal ORC, for high enthalpy field, can go as high as 23% [16]. However, cycle configuration plays a key role in thermodynamics of a binary power plant. Many performance and optimization studies have been recently carried out to examine the optimal configuration of ORC geothermal power facilities [17, 18] as well as on the investigation of optimal working fluids in ORCs [19–21]. In Ref. [22], the researchers investigated the performance of three configurations of ORC for binary geothermal power plants; simple ORC, regenerative ORC and ORC with Internal Heat Exchanger (ORC-IHE). It is concluded that the ORC-IHE outperforms the other configurations from the thermodynamic perspective while the simple ORC had the highest value of net output power. The 2-stage designs of a binary cycle yield higher net electrical power output and thermal and exergy efficiencies than the 1-stage counterparts [23].

As the thermal energy extracted from underground field is conveyed to a second working fluid; therefore, selection of such working medium plays an important role on the system design, performance, and economics. The optimal choice of the working fluid for a binary cycle must consider the thermodynamic characteristics of both geofluid and working fluid, safety of use, health and environmental impact [9]. Various objective functions have been used in literature for working fluid selection, such as the net power output [24], ratio of net power output to heat exchanger area [25], first or second law efficiencies [26] and volumetric expanders [27]. In [28] the authors conducted a comparative study of several working fluids, such as water, coolants and some hydrocarbons, for a Rankine cycle operating at low temperature. The study concluded that using organic working fluids, the Rankine cycle achieved good efficiencies for the recovery of low enthalpy resources. An optimization study conducted by [29] revealed that the n-pentane working fluid produced the highest first and second law efficiencies for a binary ORC plant. The study in [29] explored the thermodynamic performance of 20 working fluids for a binary ORC and found out that R123, R141b and ethanol are the most appropriate for small scale domestic Combined Heat and Power (CHP) applications. CHP or cogeneration plants are efficient technology that produces both electricity and thermal energy at considerably higher efficiency than its counterpart of only-electricity or only-heat systems.

It was reported that the operational parameters of a binary plant (such as air mass flow rate, mass flow rate of organic medium and inlet turbine pressure) and plant performance i.e., net power output degrade over the plant lifetime [14]. In order to maintain the plant performance over its life span, the mass flow rates of organic fluid and air cooling should be adjusted. In addition, the plant design can be modified by placing a recuperator and reducing the heat transfer area of vaporizer and preheater.

Besides the standard binary geothermal power system, advanced configurations of geothermal energy conversion systems have been also well investigated. This includes: hybrid single-flash and double-flash systems, hybrid flash-binary configuration and hybrid fossil geothermal technology [23, 30]. In addition, the development of hybrid power systems integrating geothermal plants with biomass, fuel cells, wind, solar systems and waste-to-energy (WTE) technologies has been gaining a lot of interest [31–35].

When compared to single-flash and double-flash cycles, the binary ORC plant attained the highest thermal efficiency and output power among the three geothermal power plants [36]. An exergoeconomic investigation between double-flash and single-flash/ORC combined cycles revealed that the single-flash/ORC integrated cycle offers the highest energy and exergy efficiencies [37]. Based on a comparison between various types of geothermal power plants in terms of energy and exergy metrics, it was concluded that the combined flash-binary cycle with R123 working fluid, at a temperature 230°C and mass flow rate of geothermal heat source 1 kg/s, has the highest amount between various investigated configurations with a maximum thermal efficiency of 11.81% [38].

A combined flash-binary ORC power unit is schematically shown in **Figure 5**. The working mechanism of the plant is as follows; firstly, the geofluid is throttled in a valve to a lower pressure (point 2), then the obtained two-phase fluid is decomposed into saturated liquid and saturated steam by getting through the flash chamber i.e., separator (3 and 4). The extracted saturated steam drives a prime mover that is connected to a power generator (5); the steam turbine exhaust is then cooled in the condenser (6). On the other hand, the saturated liquid of the separator enters the heat exchanger to give off heat to the binary unit (7). The exit mixed stream of condenser and heat exchanger is then injected back into the ground (8). The pump

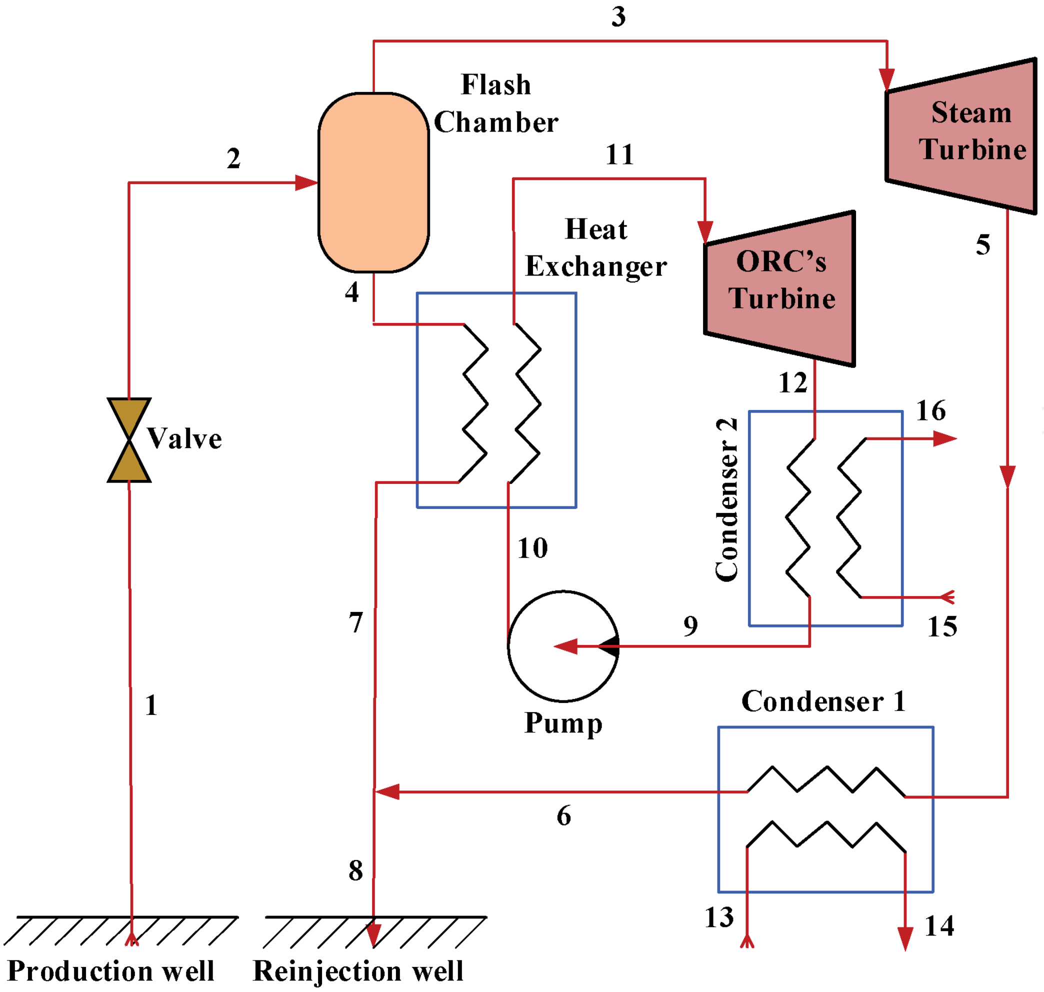

Figure 5.
Schematic diagram of the single flash/ORC combined cycle.

within the binary ORC pressurizes the organic working fluid to a high level (10), that is in turn be in a form of saturated vapor when thermally exchanged with the heat of saturated geofluid stream in the evaporator (11). The saturated vapor is expanded into the steam turbine and delivers work to produce further electricity (12). Finally, water flow in the condenser condenses the superheat vapor and exits as a saturated liquid (9) [39].

As mentioned earlier, integration of multiple generators of different technologies especially of renewable ones has been attracting a considerable attention. The synergy offers cost competitiveness, greater overall efficiency and a higher capacity factor as compared to a single source power supply [40]. For instance, hybridization of geothermal with concentrating solar power (CSP) can overcome several challenges encountered by standalone geothermal plants [41]. The concept is that as the ambient temperature increases with the progress of the day the hourly output of a standalone geothermal plant decreases. Nevertheless, CSP involvement can handle this issue as its output increases with a rise in the ambient temperature and more than 70% in annual energy output could be attained [42]. Generally, CSP can be incorporated in the geothermal plant both in the preheating or the superheating configuration [43].

3. Worldwide status of geothermal power production

By the end of 2018, the cumulative global installed capacity of geothermal power amounted to 13.28 GW generated an annual electrical energy of about 86 TWh. Geothermal resource has contributed significantly in electricity production in some regions; 17% of New Zealand's electricity production and 31% of Iceland's electricity production was met by geothermal in 2018 [44]. In 2020, the global additions of geothermal capacity are estimated at 300 MW. Indonesia and Turkey led the new development, with 145 MW and 70 MW of capacity added for the two countries, respectively. The technology is forecast to reach 16.5 GW of aggregate capacity worldwide by 2022 [45]. While United Stated of America has been at the top world rank in terms of geothermal power capacity [46], Turkey, Kenya, Indonesia and the Philippines would be responsible for most of the technology growth and continue to lead capacity additions beyond 2022. Geothermal power cumulative capacity and additions in leading countries are depicted in **Figure 6** [44].

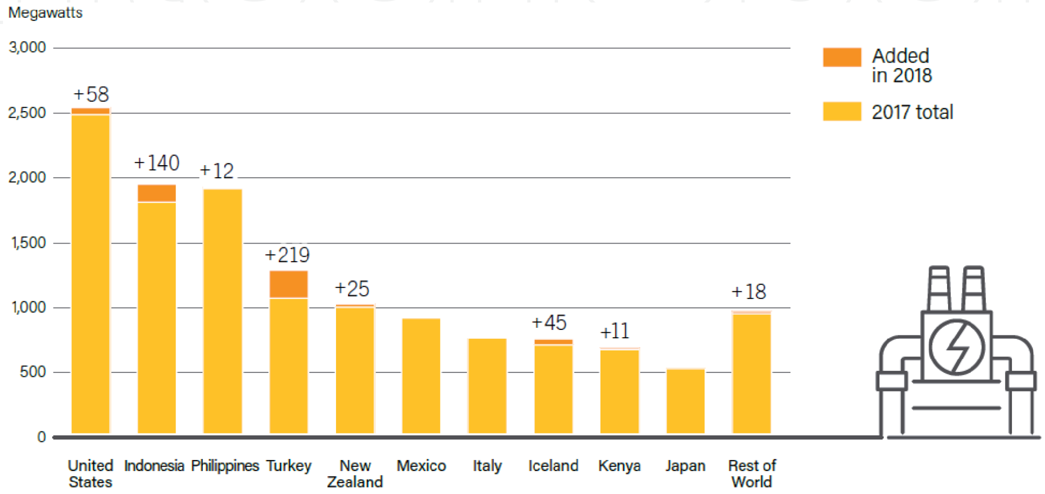

Figure 6.
Geothermal power capacity and additions in top countries by 2018 [44].

Geothermal technology exploitation depends primarily on the resource potential and economic considerations, but generally, most existing geothermal facilities worldwide use flash or dry-steam technologies. However, on global scale, binary-cycle technology has been the fastest progressing technology in recent time, due in part to rising utilization of relatively low-temperature resources [44]. Direct Use i.e., thermal energy consumption of geothermal energy technology is one of the common and versatile form of utilizing the underground heat [47]. The installed global total of geothermal power capacity for Direct Use sectors is estimated at 26 GWt at the end of 2018 [44].

The distribution of geothermal Direct Use applications is categorized as: 58.8% for heat pumps, 18% for bathing and swimming, 16% for space heating, 3.5% for greenhouse heating, 1.6% for industrial applications, 1.3% for raceway heating and aquaculture pond, while the remainder goes to other applications such as agricultural drying and snow melting and cooling, etc. [47]. Geothermal heat pumps have the greatest geothermal utilization worldwide, accounting for 59.2% of the annual energy use and 71.6% of the installed capacity by 2020. The installed capacity for geothermal based heat pumps approaching 77,547 MWt mostly built in North America, Europe and China. The size of individual systems ranges from 5.5 kW for residential installation to greater than 150 kW for commercial and institutional units [47]. Most heat pumps systems in Europe are sized for the heating load that are designed to meet the base load, with surging by fossil fuels. In Finland, as an example, some of these units reached an operation of up to 3,000 equivalent full-load heating hours per year i.e., a capacity factor of 0.34.

Space heating, including district heating and individual space heating, has now an installed capacity of 12,768 MWt and an annual energy use of 162,979 TJ/yr. In terms of annual energy use, the leaders are Turkey, Russia, Japan, the United States,

Utilization	Installed Capacity (MWt)	Capacity Factor	Leaders in annual energy utilization (TJ/yr)
Geothermal heat pumps	77,547	0.245	United States, China, Germany, Sweden and Finland
Space heating	12,768	0.405	Turkey, Russia, Switzerland, the United States and Japan
Greenhouse heating	2,459	0.462	China, Turkey, Netherlands, Hungary and Russia
Aquacultural pond heating	950	0.463	United States, China, Italy, Iceland and Israel
Agricultural drying	257	0.435	China, Hungary, France, Japan and United States
Industrial uses	852	0.610	New Zealand, China, Russia, Iceland and Hungary
Bathing and swimming	12,253	0.473	Japan, China, Turkey, Mexico and Brazil
Snow melting	435	0.189	Iceland, Japan, United States, Argentina and Slovenia
Other	106	0.584	New Zealand (irrigation and frost protection), Japan (cooking) and Kenya (boiling water)
Total	**107,727**		

Table 4.
MWt and leading states for various categories of direct-utilization for the year 2020 [4].

and Switzerland, accounting for about 75% of the world's individual space heating and nearly 90% of the world's total use in district heating. Deep Direct Use or what is alternatively called Cascaded Use offers large-scale viable systems that optimize the value stream of lower temperature resources through a multiple of purposes, from electricity production to direct cooling and heating, commercial and industrial applications, etc. [46]. **Table 4** provides a summary of the installed capacity factor (in MWt), and leading states for various categories of Direct Use for the year 2020.

4. Economic and environmental impacts of geothermal energy

In addition of being harnessed for the production of electrical energy, geothermal energy can also be utilized for various thermal applications including industrial heat input and space heating. Geothermal waters are highly beneficial for health and well-being, treat arthritis and skin diseases. Production of freshwater and minerals exploiting the hot reinjected brine of geothermal resource is also a viable and economic option [4]. Furthermore, geothermal energy resources improve the security and defense of the country through their exploitation in military facilities such as heating of runways and heliports and wide range applications of heat pumps [48]. For the above-mentioned advantages, many countries offer incentives for the use of the technology. For instance, Switzerland raised its geothermal power Feed-in Tariff (FiT) from USD 0.48 to USD 0.54 per kWh [44].

Nevertheless, the main barriers for the development of geothermal industry include high resource and exploration risk, overall high development cost particularly drilling, economic risk associated with long project lead-times and inadequate financing and grant support, as well as lack of clear policy and regulatory frameworks. Indonesia, for example, did not meet its 2018 targets for investment acceleration in geothermal due largely to drilling delays by developers. The economic recession stemming from COVID-19 crisis has enormously affected the technology progress even for the pioneered geothermal energy users such as Italy, the United States and New Zealand that have not witnessed significant growth in recent years [44]. The global crisis has caused deferrals of strategic decisions such as financing and disruptions to the global supply chain for materials and machinery. On the other hand, it is reported that the availability of better data about geothermal resources facilitates attracting new investors and developing new projects [49].

The per MW cost of geothermal power unit hits USD 7 million [44]. Global range of electricity cost and its weighted average of various technologies are tabulated in **Table 5**. As can be seen, renewable technologies are competing with fossil fuels, while geothermal projects are not far behind (at USD 72/MWh). Because of its adequacy for relatively low-temperature resources and applicability for both power and heat, among the key players of geothermal binary technology are Exergy (Italy), Ormat Technologies (United States), and Turboden (Italy, a subsidiary of Mitsubishi Heavy Industries of Japan) [44].

An economic analysis performed by [23] indicated that the economic performance of the Rankine cycle depends greatly upon the type of working fluid and cycle configuration. The results also showed that a standard Rankine cycle with a 2-stage turbine using n-pentane is the most thermo-economic design for the particular brine resource and re-injection conditions. For binary ORC plants, the simple ORC offers the lowest total capital investment and the shortest payback period as compared to the regenerative and the one with internal heat exchanger [22]. An economic assessment of double-flash geothermal power cycle and single-flash-ORC combined cycles showed that the former configuration attains the minimum unit cost of produced power [37]. In another economic analysis

Technology	COE 5th and 95th Percentiles (USD/kWh)	Global Weighted-Average COE(USD/kWh)	Change in COE 2017–2018
Geothermal	0.060–0.143	0.072	−1%
Hydropower	0.030–0.136	0.047	−11%
Onshore wind	0.044–0.100	0.056	−13%
Offshore wind	0.102–0.198	0.127	−1%
Solar Photovoltaic	0.058–0.219	0.085	−13%
Concentrating Solar Power	0.109–0.272	0.185	−26%
Bioelectricity	0.048–0.243	0.062	−14%
Fossil fuels	0.049–0.174	0.049–0.174	N/A

Table 5.
Global electricity cost of different technologies as of 2018 [44, 50].

of a hybrid CSP-binary geothermal power plant showed that the levelized cost of electricity can be reduced by 2% for the hybrid system in comparison to the stand-alone geothermal system [51].

Land requirement of geothermal power plant is relatively much lower than other technologies. For example, a single-flash geothermal unit needs approximately 1200 m^2 per MW installation as compared to coal-fired facility which requires 40,000 m^2/MW and a photovoltaic plant requirements of 66,000 m^2/MW [9]. On the contrary, this economic advantage in land aspect is challenged with other environmental concerns such as water usage and its pollution, visual and noise pollution, greenhouse gas emissions, and loss of natural beauty. However, methods to alleviate these environmental concerns include reinjection for surface water pollution, the use of silencers for noise pollution and air-cooled condensers for water usage [52].

The great benefits of increased implementation of geothermal technology include the high reliability and the feasible functionality over 7000 h per year, which is a crucial issue for electrical utility grids. If the reservoir is appropriately managed i.e., the reservoir water balance, then the sustainability of geothermal power plants is guaranteed [53]. However, the release of NCGs to the environment has become a critical factor for a geothermal power plant. NCGs are naturally found in geothermal reservoirs and can contain several types of pollutants, dominantly carbon dioxide (CO_2), in addition to ammonia (NH_3), hydrogen sulfide (H_2S) and heavy metals. Although CO_2 production of the geothermal power plants is much lower than fossil fuel generation units, they still emit averagely 400 g CO_2/kWh and may be higher depending upon the chemical composition of the reservoir and the conversion technology [54].

Treatment of NCGs has been a hot topic in the industry world and research community. After segregation of the NCGs, geothermal fluids are reinjected into the reservoir. This is a demonstrated design in geothermal power plants. The Sinem ORC geothermal power plant rated at 24 MW and located in Aydın province, Turkey re-injects about 70% of the heat drawn fluid, after being condensed at 70°C, into re-injection well whereas the remaining 30% is emitted to atmosphere as NCGs [55]. However, an emerging technology based on reinjection of NCGs is still under development intending to minimize the environmental footprint, handling the emissions of H_2S and CO_2 [53]. It is confirmed that complete reinjection of NCGs using binary ORC geothermal power plant assures the sustainability of geothermal resource [56]; in this regard, some advancements have been achieved in Iceland geothermal plants [57]. More funds are dedicated for eliminating the environmental effect of geothermal industry. The European Commission, for example, awarded the Geothermal Emission Control (GECO) project, USD 18.3 million to advance research on reinjection of harmful gases such as CO_2 and H_2S from open-loop geothermal plants [44].

Feasibility of hydrogen production by means of geothermal resource has been also explored. In [58] the authors conducted a thermo-economic cost assessment of electrolysis based hydrogen production powered via a binary geothermal unit. The analysis argues that for a geothermal heat of 160°C and a flow rate of 100 kg/s, hydrogen can be obtained at a level of 0.253 g per kilogram of geothermal water. It was also found that unit exergetic costs of electricity and hydrogen are 0.0234 $/kWh 2.366 $/kg H_2, respectively. Koroneos et al., [59] demonstrated the technical feasibility (based on efficiencies and exergy indicators) of installing a 2.1 MW binary geothermal power plant at in Nisyros Island, Greece. The proposed facility could reach up to 10 MW of total installed capacity in the future and capable of supplying a substantial amount of electricity thereby reducing the reliance of the island to the diesel power generation thus the gain from an environmental point of view is guaranteed.

Energy savings from utilizing Direct Use geothermal energy amounts to 81 million tonnes (596 million barrels) of equivalent oil yearly. This eventually prevented 78.1 million tonnes of carbon and 252.6 million tonnes of CO_2 from being released to the atmosphere [4]. Geothermal technology based freshwater production is one of the most economic renewable and clean production alternative [60].

Hybrid geothermal-fossil fuel power system, for low-enthalpy geothermal resources, is a practical alternative to reduce the extensive use of fossil fuels and associated emissions. The research study in [61] analyzed a 500 MW combined geothermal-coal power plant with a 210°C geothermal temperature and 400 kg/s brine flow rate. The study claimed that up to 0.3 million tonnes of coal can be saved per year in addition to annual reductions of up to 0.72 million tonnes of greenhouse gas emissions. Economically, a drop of 33–87% in energy cost is reachable in comparison to a sole geothermal power unit. A study conducted by [51] revealed that the hybridization of binary ORC with CSP system decreases the levelized energy cost by 2% and when the ORC geothermal configuration is optimized an 8% drop in the levelized energy cost is achieved.

In [55], an exergoenvironmental analysis is performed from the perspective of environmental impact. The study came to a conclusion that 98% of total environmental impact for the geothermal power system is caused by exergy destruction of the equipment involved; and as a treatment, exergetic efficiency for equipment should be improved rather than construction, operation/maintenance and disposal changes of facility equipment. The study advices obtaining a higher capacity plant by having a better condenser performance and enhancing the efficiency of the vaporizers and the pumps.

5. Conclusion

The population's growth and economic development in many countries require an increase in demand for electrical energy. On the other hand, meeting the need for electric energy society in the future should consider the limitations of non-renewable resources while providing energy sustainability and significantly reducing the negative impact on the environment. In this case, the role of renewable energy resources should thus be a priority.

The geothermal energy is one of the sustainable and environmentally friendly sources. Also, it is of a high usage factor and reliability. While geothermal dry steam and flash power plants utilize medium to high enthalpy underground source to generate electricity, geothermal binary power systems are suitable for electricity production from low underground heat source; generally, an inlet temperature range between 80 and 170°C. The secondary working fluid in the binary geothermal system operates in a conventional Ranking cycle. The main feature of the working fluid is having a low boiling point. The configurations of the cycle and the type of working fluid should be optimized for the sake of obtaining the best possible thermodynamic performance and efficiency of the geothermal binary facility. The binary Rankine cycle that used an organic working fluid has demonstrated its efficiency and practicality. Among the reported configurations of ORC for binary geothermal power plants include simple ORC, regenerative ORC and ORC-IHE.

Besides the standard binary geothermal power system, advanced configurations of geothermal energy conversion systems have been also well investigated. They include hybrid single-flash and double-flash systems, hybrid flash-binary configuration and hybrid fossil geothermal technology. In addition, the development of hybrid power systems integrating geothermal plants with biomass, fuel cells, wind, solar systems, and WTE technologies has been gaining a lot of interest. It is reported that the binary ORC plant, when compared to single-flash and double-flash cycles, attains the highest thermal efficiency and output power. On the other hand, the single-flash/ORC integrated cycle offers the highest energy and exergy efficiencies as compared to double-flash counterpart.

The accumulated global installed capacity of geothermal power amounted to 13.28 GW by the end of 2018 and is forecast to reach 16.5 GW worldwide by 2022. United Stated of America has been standing at the top world rank in terms of geothermal power capacity. On the other hand, Turkey, Kenya, Indonesia and the Philippines would be responsible for most of the technology growth and continue to lead capacity additions beyond 2022. Although most existing geothermal facilities worldwide use flash or dry-steam technologies, binary-cycle technology has been the fastest progressing technology in recent time. Direct Use of geothermal energy technology is one of the common forms of utilizing the underground heat. The distribution of geothermal Direct Use applications, relative to their widespread use, are: heat pumps, bathing and swimming, space heating, greenhouse heating, industrial applications, raceway heating and aquaculture pond, agricultural drying and snow melting and cooling, etc.

The main barriers for the development of geothermal industry include high resource and exploration risk, overall high development cost particularly drilling, economic risk associated with long project lead-times and inadequate financing and grant support. In addition, the global crisis COVID-19 has caused deferrals of strategic decisions such as financing and disruptions to the global supply chain for materials and machinery. The economic feasibility of the geothermal power plants depends greatly upon the type of working fluid and cycle configuration. Geothermal power plants have relatively much lower land requirement than other technologies. Methods to alleviate the environmental concerns of geothermal power systems include reinjection for surface water pollution, the use of silencers for noise pollution and air-cooled condensers for water usage. NCGs accompanying the geothermal power generation can be alleviated by reinjecting geothermal fluids into the reservoir.

As a future work, an optimized hybridization of geothermal energy with other renewables needs further exploration and demonstration, either for small scale CHP or cascaded applications. As the availability of better data about geothermal resources facilitates the attraction of new investors and developing new projects, more deeper studies and financial support is critical to assess sites of appropriate geothermal potential. This is of significance to make the cost of geothermal electricity more competitive to conventional and other cheaper renewable electricity. Advanced technologies to eliminate the environmental effect of geothermal power plants are also required including complete reinjection of NCGs that needs further research, fund, and practical demonstration.

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