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Geothermal Energy Development in Türkiye: A Review

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Abstract

Türkiye possesses abundant geothermal resources. It is ranked seventh globally for this particular energy resources and grade among the first 5 in utilizing geothermal and thermal springs for various purposes such as electricity generation, residential cooling and heating, greenhouse operations, desiccating processes, thermal recreation, therapeutic applications, mining, agricultural uses, and aquaculture. The government's endorsement from renewable power sources is fueling growing interest on this particular energy sector. This article provides a comprehensive analysis of geothermal energy in select locations of Türkiye, including an assessment of its potential and various applications. The study seeks to provide a valuable involvement to the future advancements of a geothermal technology on Türkiye.

Keywords: Turkey Renewable Energy, Geothermal Resources, Geothermal Energy, Geothermal Technology, Geothermal Heat Pumps, Geothermal Power Plants.

تطوير الطاقة الحرارية الأرضية في تركيا: مراجعة

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الخلاصة:

تمتلك تركيا موارد وفيرة من الطاقة الحرارية الأرضية. وهي تحتل المرتبة السابعة عالميًا بالنسبة لمورد الطاقة هذا تحديدًا، وهي من بين الخمسة الأوائل في استخدام الطاقة الحرارية الأرضية والينابيع الحرارية لأغراض مختلفة مثل توليد الكهرباء، والتدفئة والتبريد السكني، وعمليات الدفيئة، وعمليات التجفيف، والسياحة الحرارية، والتطبيقات العلاجية، واستخراج المعادن، الاستخدامات الزراعية وتربية الأحياء المائية. إن تأييد الحكومة لمصادر الطاقة المتجددة يغذي الاهتمام المتزايد بقطاع الطاقة هذا على وجه الخصوص. تقدم هذه المقالة تحليلا شاملا للطاقة الحرارية الأرضية في مواقع مختارة من تركيا، بما في ذلك تقييم إمكاناتها وتطبيقاتها المختلفة. وتسعى الدراسة إلى تقديم مساهمة قيمة في التطورات المستقبلية لتكنولوجيا الطاقة الحرارية الأرضية في تركيا.

1. Introduction

As part of the Paris Agreement, which calls for reducing carbon emissions and achieving net zero by 2050, the energy transition is one of the most important issues on national agendas at the moment. Countries are racing to innovate modern technologies that ensure the integration of renewable energy sources into the grid and enhance the flexibility of such energy systems, in parallel with scenarios of eliminating fossil fuels. Geothermal energy is a renewable resource necessary to provide a constant supply of energy that allows electricity to be generated year-round, come rain or shine.[1]. Numerous environmental concerns have surfaced in the past several decades, encompassing global warming, weather change, ozone diminution, harsh rain, air contamination, leftover management, water contamination, and seismic activity, all of it substantially impact the Earth. [2-5]. Also, there is a growing worldwide need for power and energy [6-7]. Hence, pursuing clean and sustainable energy, such as renewable energy, has gained significance. This method is widely regarded as the most efficacious means to address air pollution by abstaining from the burning of fossil fuels. [8-9] A process for energy production engenders environmental changes and necessitates engineering and building activities, hence resulting in many forms of environmental consequences. Despite being regarded as a clean form of energy, the geothermal energy necessitates release of certain gases and the disposal of wastewater. Geothermal energy is considered a more ecologically friendly energy source in comparison to nuclear and fossil fuels [10-11]. The proportion of greenhouse gas emissions attributed to geothermal electricity is relatively minor compared to those resulting from the combustion of fossil fuels. Additionally, geothermal energy exhibits emissions levels comparable to another renewable power sources, including hydro, wind, and solar power (see Figure 1). [12-13].

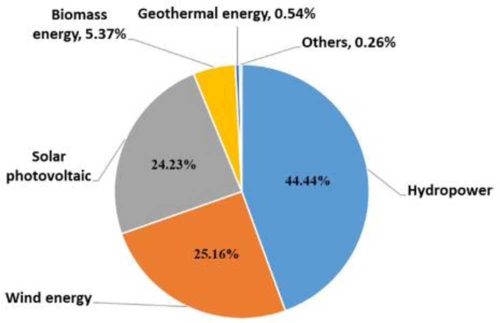


Figure (1): Renewable power resources in electricity generation 2022 [13-14]

In numerous industrial applications, the dependence on electricity container is mitigated through employing renewable thermal energy causes [15-17], recuperating waste heat, and improving process and energy efficiency [18-23]. GTE, encompassing normal vapor and hot water had long been harnessed to produce electricity and supply heat for industrial processes. [24]. GTE is heat that comes from the Earth. It is made in two ways: first, from earth forming and minerals breaking down, and second, from the sun heating the earth's surface. People have used this energy since the Stone Age for bathing and cooking. [25].

Geothermal resources can be categorized into shallow and deep, with the boundary between them defined at a depth of 400 m [26]. Systems using shallow geothermal resources are classified to open and closed systems; the latter can also be split into horizontal and vertical systems, shown in Fig. 2.[27]

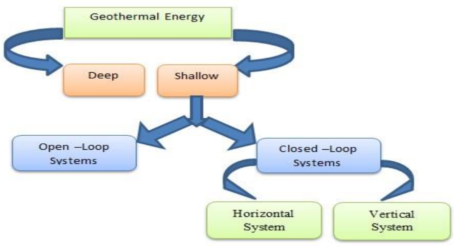


Figure (2): Categorization of GTE.

Table 1 demonstrations the top 10 countries producing GTE based on their installed power generation capacity in 2019. This data is from the Think Geothermal website, and according to the source, it is hard to gather information about geothermal plants since each country shares data differently. In 2019, 759 MW were added, making it the largest annual growth in geothermal energy in about 20 years. The all established geothermal energy generation capability at the end of 2019 was 15,406 MW [28].

Table (1): Statistics of 10 countries in the field of geothermal energy until 2019, according to the established generation capacity (MWE). [28]

Country	2019 MWE	Country	2019 MWE
USA	3676	**Italy**	944
Indonesia	2133	**Kenya**	861
Philippines	1918	**Iceland**	755
Türkiye	1526	**Others**	1025
New Zealand	1005	**Total**	15406
Mexico	963		

It is noted from Table No. 1 that Türkiye is one of the countries producing thermal energy with an amount of 1526 megawatts. This research will focus on some areas in Türkiye that use geothermal energy and its applications, given that Türkiye has great potential in the field of geothermal energy because it is located on profound geological burdens and can be used in designated position, covering a required of electricity claim. Evaluations had been conducted numerous times through the Mineral Investigation and Exploration Institute of Türkiye MTA. It is situated on the mountain girdle of the Alps and Himalayas. It will also present a synopsis of the development of GTE strategy throughout history in Türkiye. Turkey aims to diversify clean energy sources, as geothermal energy represents a great and promising path towards obtaining sustainable and reliable energy and reducing dependence on energy sources that increase unwanted emissions and cause environmental pollution. Studies and research in the field of geothermal energy are in line with the country's promising strategy. The research gap lies in the need to discover and exploit this energy to address financial, technical and environmental challenges and ensure the exploitation of terrestrial energy in the long term.

2. Overview Methodology

2.1. Geothermal energy applications in Türkiye: Case study in different regions

Türkiye is one from the 7 richest countries in GTP. Over 1,000 hot and mineral springs with temperatures between 80°C to 128°C have been found. In recent years, Türkiye has rapidly climbed the ranks in direct use geothermal countries [29]. GTE is immaculate, affordable, and sustainable. It can be secondhand in many ways, counting heating, home warm water, CO_2 and dry-ice manufacture, swimming, greenhouses, heat pumps, therapeutic baths, industrial operations, and electricity production. Türkiye is in great need of this energy because of a rapid rise in energy shortage. In the extended run, GTE will continue to provide clean and reliable power for Türkiye. In total, Türkiye's GTP is approximately $38*10^3$ MW. Out on this, about 88 % are suitable for thermal usage, with temperatures under 200°C. The remaining 12% are ideal for electricity production, with temperatures above 200°C. (Ediger and Kentel, 1999). As shown in Table 2

Table (2): Geothermal energy potential in Türkiye.[29]

	Sticky(MW)	*Possible and perhaps*
Heat (<473K, Low enthalpy fields)	*2250MWe*	*31100MWe*
Electricity (>473K, High enthalpy fields)	*200MWe*	*4500MWe*

Türkiye is on Mediterranean region in the Alpine and The Himalayan tectonic and Alpine belts are among the top seven countries in terms of the availability of GTS worldwide. However, the utilization of its latent is about 2%. Conducting extensive research on geothermal energy in Türkiye can significantly enhance energy source and decrease atmospheric pollution, Murat [30].

Hebasli et al [31] focused on the geothermal heating system in Izmir-Balkova and discussed the latent of GTE generation in Türkiye, a growth of geothermal heating systems, and their utilization for direct uses. They emphasized its cost-effectiveness and environmental benefits and highlighted its ability to reduce atmospheric pollution and greenhouse gas emissions. Specifically, one of Türkiye's major geothermal fields with great potential is the Ömer-Gecik area in Afyon. From bottom to top in the stratigraphic sequence are the schist and marble known as the "Afyon metamorphic", the Neogene deposits, the trachytes and trachytes - products of the trachyte volcanism of Afyon - and the Karakaya basalts. Basalt flows represent the most recent stage of volcanic activity. The geothermal system gets its heat from pockets of magma that form volcanic rock. Basadaji marble is made from ancient aquifer rocks. Despite having great potential for geothermal energy, One of Türkiye's most polluted provinces is Afyon. To take advantage of this potential and reduce air pollution problems, Mustafa [32].While Harun et al [33] studied an exergy and energy evaluation and demonstrating of GTPP and to determine ideal performance and operating conditions, evaluate the impact of changing departed-state features on the exergy efficiencies of the Kizildere KGPP.

Zuhal et al [34] provided an overview of the Gonen Geothermal Region, including its geology, geothermal resources, heating system in the Gonen Geothermal Region, and its potential as a cleaner and cheaper alternative to fossil fuels in Türkiye. Ramadan [35] focused on the GTPE for power generation at Türkiye, specifically in the Cemav region, for electricity generation and evaluated its potential and applications. proposed a dual cycle power plant using HCFC-124 as the working fluid and concluded that the project was feasible and economically viable.

Füsun et al [36] investigated Türkiye's first geothermal field, the Kizildra geothermal field. The field is in Western Anatolia's Buyuk Menderes Graben (BMG). The findings of the water and gas analyses presented that the geothermal fluids in all generating portions are of meteoric origin. Additionally, it has been discovered that when reservoir temperature rises, more violent water-rock interactions take place. In between the reservoir units, impermeable deposits like mica schist and chlorite schist function as a seal because of the distinct geochemical properties of each production segment. The Kyzyldera geothermal tank is not very homogenous due to the vertical split of tank parts, which necessitate a unique injection production design for a sustainable productive life, according to the study's findings. In contrast, the BNGF in Türkiye is a geothermal system of the extensional domain type that may be used for both cooling and heating. Alper et al [37] studied the field has been extensively for over 50 years, and using information from hydrogeology and geology, A novel conceptual model has been developed in the field. The findings demonstrated that the fault's porous fracture zone serves as flow channel for the warm water from the tank as it rises to a surface. The field can be further developed, and the installation of a district cooling system is planned.

Ali et al [38] studied and examined the effect of urban heat islands, and regarding their effects on the temperature of the groundwater in narrow aquifers in heart of Kutahya city, as well as to evaluate the geothermal system's temperature readings and determine the alluvial aquifer's thermal potential. While Dornadola et al. [39] focused on the potential of enhanced geothermal systems (EGS) in Türkiye to reduce CO_2 emissions, sustain 32% economic growth by 2030 and increase renewables in the primary energy mix. Mehmet [40] also studied the ecological and community impacts of GPPs in Buyuk Menderes Graben (BMG) geothermal area in Türkiye. It includes technical analyses and assessments done over long period for scientific objectives to track the influence of GPPs on the environment and nature in the BMG geothermal arena, which is Türkiye's first GTF.

Since geothermal energy development faces problems due to some hazardous chemicals, such as boron, which are highly concentrated in geothermal fluids, Mott et al. [41] stated on the removal of boron from geothermal fluids using different types and configurations of membranes. The study analyzed the initial boron concentration; permeate flow rate, and permeation recovery for different membrane systems. The results presented that boron elimination efficiency varied depending on type of membrane and composition used.

Research that reported geothermal energy applications in some areas in Türkiye was summarized as shown in Table 3.

2.2 Numerical investigation geothermal energy

Haqqi et al. [42] Study of the Dodan field in Türkiye, one of the depleted gas fields for GTE production. The study used a Monte Carlo imitation method to evaluate the GTP of each producing formation in the field. Various factors, such as reservoir properties, input parameters in Monte Carlo imitation, and recovery factors, are taken into consideration to determine the geothermal potential. It is concluded that the probabilistic technique delivers a good impression of the probabilities of incidence in relation to reserve evaluation. The reservoir characteristics of the formations and the GTP of each creating formation are discussed. The study emphasized the importance of the probabilistic approach in determining whether to grow the tank or capitalize in it.

Özgür [43] revealed the source of heat for Afyon's geothermal system, together with the temperature and deepness of the magma tank located under the Afyon area. To tackle these problems, a series of two-dimensional numerical models were developed in order to address the co-thermal evolution problem in a crustal lava cavity. Heat dispersion produced by the numerical simulations is contrasted by the published temperature statistics of thermal wells and warm springs. Then, it is likely to determine which imitation results correspond with geothermal fine data.

Akar et al. [44] studied the fluid flow and heat transfer numerical modeling in Salihli, Manisa, Türkiye's Kurşunlu geothermal field (KGF). The researchers used the FEFLOW software to create a two-dimensional vertical model of the region, which included impermeable rocks, cap rocks, aquifers, and fault zones. The objective of the study had to be to comprehend the geothermal system's fluid circulation mechanism and the circumstances that lead to the heating of leaking water. The findings demonstrated that convective flows originated in fault zones and the geothermal aquifer below a height of -1000 m, while heated fluids reached the Kurşunlu region and formed springs. Two additional high-temperature regions were found by the study, which suggests that the flow vectors point toward the surface.

Alperen et al [45] research indicates that thermal energy storage incurs additional expenses, however near-surface geothermal sources could potentially reduce the cost of energy derived from renewable sources. It is discovered that (PTC-HYB, PTC-CGN, and PTC-ORC) have electricity generation costs of, 0.448 $/kWh, 0.257 $/kWh, and 0.401 $/kWh, respectively. A goal of the project is to determine the financial advantages of combining close-surface, low-temperature GTE support—is accessible over much of Türkiye—with solar power producing technology. The study includes detailed system descriptions, thermodynamic analyses, and economic analyses for the three systems.

He et al [46] provided a study using numerical modeling to assess how a high-permeability geothermal reservoir is affected by natural breakage networks. A GTR model with extensive natural fracture networks in Türkiye is examined using the combined thermal discrete fracture model (EDFM). Evaluations are conducted on the temperature conduct of fracture field and matrix, wellhead temperature, bottom- perforation temperature, and electricity production. Additionally, the impact of well placement and the density of naturally occurring fracture networks was examined.

Kubilay [47] investigated the possibility of geothermal energy in different Turkish locations. The current study is innovative since Türkiye can use geothermal energy to manufacture green hydrogen. In addition, additional hydrogen production is demonstrated, and calculations are designed for high-temperature electrolysis systems to produce hydrogen from geothermal resources that have temperatures above 170°C. The government and local-level policy makers can leverage the potential of green hydrogen produced in different regions to better align their energy trends with the country's green energy resources. This would eventually position the country as a global energy hub.

Haqqi et al. [48] A model was created to simulate the use of electric submersible pumps (ESP) in a geothermal well. The Alaşehir geothermal field well is in western Türkiye. The ESP design was implemented using codes generated in PYTHON and the sensitivity of the well production profiles was simulated utilizing WELBOR, a wellbore imitation program. Compassion studies were lead for changed sizes of manufacture pipes (5, 6, 8, inches), installation depths 500, 600, 700 m and discharge 85, 150, 180, 250, 275 t/h. The ideal conditions for designing an electrostatic precipitator are determined by taking into account pump ingesting, flash depth, wellhead flow pressure, and production rate. Ultimately, it had discovered the well in the situation study would produce 165 tons more per hour if electrostatic precipitator was designed properly. Additionally, the suggested ESP will turn a profit for a minimum of eight months. Table 4 shows a brief description of some research that used numerical analysis in the field of GTE.

2.3 Experimental investigation geothermal energy

Mehmet et al. [49] conducted an experimental study in which they analyzed the properties of geothermal fluids, membrane test results, and the need for water treatment strategies for agricultural irrigation. It is concluded that different methods and water treatment strategies are necessary to make treated geothermal fluids suitable for agricultural irrigation. Misirkhan et al [50] two usual geothermal fluids from East Türkiye GTF (Keklik Mağarasi \ and Afyon GT wells) have had their thermodynamic and transport properties experimentally studied. There in height temperature and in height pressure densities and vapor pressures have been measured done a temperature variety of 274 to 413 K and at pressures of awake to 100 MPa. Using a VTD, DMA HPM (Anton Paar, Austria), and the PVT properties were slow. The complete static method was utilized to measure the vapor-pressure. The estimated standard uncertainties for the, pressure, temperature, and density measurements are 10 mK, 0.001, and 0.0001 to 0.0003 contingent on the T and P ranges. The Tait's parameters C and B and their temperature dependency were estimated using the slow values of the high-temperature and high-pressure density (PVT data). Other derived key thermodynamic possessions (β_S , β_T , α_P , γ_V , H, S, U, u , C_P , C_V) of the GT waters at tall temperatures and tall pressures have been calculated using the industrialized Tait-type equation of national. These properties are crucial for demonstrating the GT reservoirs and optimizing the processes involved in producing geothermal energy. The accuracy and dependability of the high temperature and high pressure forecast approach for GTFs using just concentrations at room temperature and atmospheric pressure were further examined and confirmed using the unhurried values of the PVT stuff of GT water examples. Table 5 shows a brief description of some research that used experimental methods in the field of GTE.

3. Türkiye's potential for geothermal energy

Since 1984, a 20.4 MW geothermal power station has been operating in the Denizli-K$_1$ z$_1$ ldere district. Since 1998, Residential buildings have used GT heat pumps in both cooling and heating and greenhouse initiatives have made substantial headway. The total zone of the conservatories using GT heat was around 35 hectares, and they could heat about 70 megawatts, KAMİL [51]. Orhan [52] stated that Türkiye used only 3% of its geothermal energy potential. Using an approximate potential of 31,500 MW for greenhouse, residential, spa, balneotherapy, resource recovery, and air conditioning, several studies have examined the existence of 11 geothermal district heating systems (GDHS) in Türkiye, with the first system installed in 1987, a great deal of technical and economic experience has been gained over the years. The significant growth in geothermal heating systems in Türkiye can be attributed primarily to several factors, the most important of which is the adaptation of system designs to suit Turkish conditions. In addition, consumers played a pivotal role by contributing approximately 50% of the investments required for geothermal district heating despite not receiving any direct financial recovery. Furthermore, geothermal heating has proven to be approximately 50-70% more cost effective than natural gas. Arif [53] gives a summary of Türkiye's usage of geothermal energy. Discussed the past growth, GTE uses, and the potential for electricity generation and direct uses. The main findings included Türkiye had a significant geothermal energy potential, with only around 2-3% for its estimated potential being utilized. used for space heating, conservatory heating, balneology, CO_2 and thirsty-ice manufacture, heat pumps, and electricity generation. With a connected capacity of 20.4 MWe, the Kizildere GT plant is the only one in operation in Türkiye.

Etemoglu et al [54] studied The geothermal resources in Turkey have been categorised according to specific exergy rates (SER). Exergy analysis provides a means of assessing resource characteristics and can be used to determine the optimal utilisation of geothermal resources.

Orkun et al [55] studied is to manage geothermal energy resources well planned and systematically. Within this standpoint, called "integrated reserve organization" in the literature, it goals to use geothermal resources in countries that are more efficient and sustainable. literature review and well-examined application stories involving integrated resource management steps were conducted. While Niyazi [56] an analysis demonstrates Türkiye's geothermal resources' potential for producing power. and the country's efforts to develop and expand its geothermal energy sector. Table 6 indicates statistics from some research that presents Türkiye's potential within the geothermal energy area.

4. Status and evaluation of geothermal energy in Türkiye

Ibrahim [57] reviewed Türkiye's expectations and future policies in rapports of the possibility using GTE and compared it to other energies from an environmental and economic standpoint. He made important suggestions and recommendations, including that geothermal energy is clean, renewable, reliable, available and cheap local energy.

Türkiye has inordinate untapped latent to enhance the competence of geothermal applications. The effectiveness of exergy analysis in evaluating the performance of geothermal applications has been proven. Enhancing and optimizing geothermal powered processes can be attained over the use of thermal power analysis, Gulden et al [58]. However, during the twentieth century, geothermal energy was initially widely used for both direct use purposes and electricity production, Etimoglu [59]. Melih et al [58] studied bibliometric scholarship was lead in order to study the literature, individual summits were prearranged with specialists producing SWOT strengths, weaknesses, opportunities and threats examination data and lastly a two-round Delphi. A survey was intended to elicit expected geothermal skills in Türkiye for a year 2050. Oner et al [60] Provided a summary of the drilling fluids now in use in the more than 250 deep geothermal wells that have been drilled. They talked about choosing drilling fluids according to three standards and six risk-reduction guidelines that emphasized the dangers associated with drilling fluids.

Umran et al [62] highlighted the potential of geothermal resources in Türkiye and the methodology used to estimate convertible energy. The results indicate that Türkiye has a significant amount of geothermal potential, especially in Class 2 resources, which are appropriate for direct industrial usage and the production of power. Furthermore, the study highlights the need for appropriate legislation to harness the potential of GTE in Türkiye and challenges faced by geothermal investors in dealing with multiple organizations to obtain permits for exploration and development.

Erkan [63] examined the potential and present state of geothermal energy in Türkiye and offered recommendations to decision-makers. In addition to discussing Türkiye's geothermal energy progress as of January 2009, this article offers recommendations for developing policy. As such, it constitutes a significant contribution to the existing corpus of literature. Table 7 presents an evaluation of some studies on geothermal energy in Türkiye.

5. Geothermal energy's role in sustainable development

Murat et al [64] gave a thorough summary of Türkiye's geothermal energy situation at the time, its economic aspects, and guidelines for policymakers. Discuss geothermal energy's potential and applications in Türkiye. Stressed that Türkiye has great potential in geothermal energy and can meet a big portion of its power requirements from geothermal bases. Also highlighted the environmental benefits of geothermal energy and its ability to reduce Türkiye's dependence on imported energy.

Agar et al [65] discussed the history of the growth of GTE, its applications, and the present situation in the domain and Türkiye during the ten years. Discussed their types, fields, direct and indirect uses, and the possibility of generating electricity from them. Provide detailed information about specific geothermal fields in Türkiye, such as Denizli-Kızıldır, Aydın-Germencık, and Çanakkale-Tuzla, including their estimated capacities and characteristics. He stressed the importance of GTE as a reliable, clean and safe resource of renewable power. They also addressed the contests and chances related with the use of GTE.

Adam et al [66] described several sources of modern energy: wood, plant and animal waste, hydroelectricity, geothermal energy, coal, firm coal, oil, normal gas, wind and solar energy. For Türkiye in the new century, made an economic and environmental contrast between GTE and these bases.

Mustafa [67] discussed the potential and use of GTE in Türkiye. Türkiye is the seventh unlikeliest country in a world in terms of GTP, with total GTP reaching around 38,000 megawatts, of which about 88% is suitable for thermal usage and a rest is suitable for electricity manufacture. Türkiye has expanded its participation in geothermal plans, reinforced by loans from the Ministry of Environment, and GTE is predictable to rise significantly in the pending years.

Mehmet [68] provided summary of GTE, its applications, and possibility of its development and use around the world and Türkiye, where he discovered that 30% of Türkiye's electricity needs will be met by renewable energy sources by 2023. According to the study, of the targets established at 600 MW by 2023, geothermal energy has the smallest share, accounting for only 0.5% of Türkiye's installed capacity. Nonetheless, Türkiye's installed geothermal capacity reached 623.9 MW at the end of 2015, which is essential to meeting Vision 2023's energy objectives. It was proposed to amend the targets to increase the composite capacity of GTE to 1,000 MW that would raise the share GTE in Türkiye's connected capacity for 2023 to approximately 0.8%.

Türkiye consumes a rapidly growing economic and population growth, leading to increased demand for energy. Just 12.8% of the nation's energy needs are satisfied by domestic resources, mostly fossil fuels, making it a large energy importer. Türkiye's geothermal potential is the sixth largest in the world, however just 1.2% of it is being used. Türkiye also has a rich base of geothermal resources, with the total potential of geothermal energy for electricity generation estimated at 3,100 MW and 4,500 MW, and for direct use 31,500 MW, which made Bahtiyar et al [69] highlight the importance of geothermal energy in Türkiye's energy strategy. Which is painstaking one of the renewable, maintainable, clean and safe sources of power. It contributes to reducing air emissions resulting from fossil fuels and helps create job opportunities in this sector.

Alper et al [70] discussed potential bases and levels of arsenic in GTS in several areas, including Gediz Graben, Büyük Menderes Graben, and the Semav Graben. With special importance on the sedimentary and tectonic characteristics of Western Anatolian Bowl.

D. Yener et al. [71] examined data on soil temperature prediction, particularly for shallow geothermal applications. In addition to regular air and earth temperatures between 1960 and 2015, it includes 81 cities, almost 300,000 data points, and the forecast of soil temperatures at nadirs of 5, 10, 20, 50, and 100 cm. A link between soil temperatures at various depths and ambient air temperatures is assessed as the investigation ends. In order to forecast annual fluctuations in earth temperature as a meaning of time and complexity, the theoretical model uses a sinusoidal temperature equation.

Korkmaz et al [72] Türkiye's hydrothermal and EGS capacities are the subject of the study. The capacity of 290 geothermal sites that have been currently found and the GTS base in Türkiye among 0 and 3 km depth are calculated to be 3.96 10^{23} J and 10,576*10^6Wt, correspondingly. 38 mediums to tall temperature ≥100 ºC hydrothermal fields were imitation out of a total of 135 hydrothermal arenas that were separately examined in order to determine the power generation. To determine the direct usage potentials, the residual 97 arenas were imitation. P10 and P90 values correspond to bottom and top limits of power generating potential, respectively, of 1673 and 3140 MWe. Furthermore, 135 hydrothermal fields have inferior and higher thermal latent bounds of 38.2 and 68.4 GWt, respectively, equivalent to P10 and P90 equals. Table 8 indicates some research that discussed geothermal energy's role in sustainable development.

6. Summary and Conclusions

Given the remarkable development that geothermal energy has witnessed over the past years in Türkiye and the large number of studies on this type of renewable energy, some points can be summarized based on previous research, including:

1- Applications of geothermal energy in generating electricity: To decrease the usage on fossil fuels and reliance on them in generating electrical energy, GTE, which is regarded as one of types of renewable power, has contributed significantly to the field of electricity generation, as geothermal energy stations have a great ability to generate Electricity through the use of heat generated from tanks.

2- Applications of geothermal energy in heating and cooling: One of the requests of GTE is heating and cooling for various sectors in Türkiye, including industrial, commercial and residential, which makes it of effective and sustainable importance.

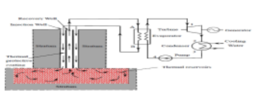
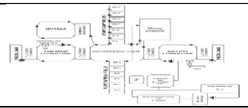
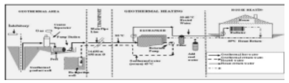
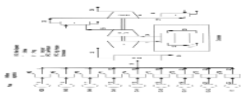
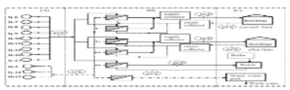
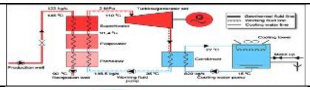
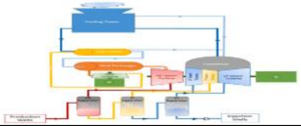
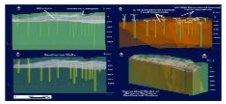
3- Geothermal energy potential: Due to Türkiye's geographical location on the tectonic plate border, which is considered a strategic location, it has rich resources of GTE and is regarded as one of the main rich sources of this power compared to the biosphere.

4- Exploration and Exploitation: As a result of the studies, research and efforts made in Türkiye to broadly explore the scope of geothermal energy and determine its commercial feasibility, Türkiye is ahead of the rest of the republics in world in the field of renewable power represented by GTE.

5- Environmental effects: GTE is regarded as a type of clean power, but here are some ecological concerns about the leakage and emission of conservatory gases from the ground, in addition to concerns about creation of a seismic activity, so the necessary precautionary measures must be taken to mitigate and monitor continuously to reduce these effects.
6- Controlling framework: To facilitate the growth process in GTE in Türkiye, Türkiye has developed an encouraging and supportive policy for this type of energy, as it has determined the tax limits and necessary permits for projects that use geothermal energy, which facilitates the investment process in this field.

In conclusion, Türkiye is considered one of countries which have exploited the potential of GTE as clean, renewable, cheap and environmentally friendly energy. It has planned to develop this energy and exploit its potential with the continued construction of geothermal energy plants. The Turkish government has launched a program that encourages the generation of energy using local sources for use in heating and cooling applications. Electricity generation, thermal and health tourism, extraction of industrial minerals, fishing, drying, and several other fields. Continuing research and progress in this field helps technological and environmental advancement, which enhances the growth of GTE resources in Türkiye, as it is heading to forefront of the world in generating GTE.

Table (3): Summary of some research on geothermal energy applications in different regions

Ref.	*Schematic*	Study case	Methodology	Results	Conclusion
[30]		Examine the techniques for harnessing GE from decommissioned oil wells and explore potential applications for this energy source.	Using downhole heat exchangers to remove heat without generating geothermal fluids	Downhole heat exchangers can remove heat without GT fluids, minimizing gas releases and the obligation to re-inject energy from unused oil wells for electricity or straight usage.	Abandoned wells in southeastern Türkiye can be utilized to harness electricity, thereby enhancing the region's economy.
[31]		Usages of GTE in Izmir - Balkova	Geothermal heating applications in Türkiye.	GTE holds significant potential to contribute to Türkiye's future energy production.	GTE is less expensive than alternative energy sources such as relic fuels, as it contributes to lowering carbon gas emissions.
[32]		Ömer-Gecek fields in Afyon	Reducing air pollution.	With 17.56% ash and 1.27% combustible sulfur, Tuncbelk-Kutahya coal would have emitted roughly (768 tons) of sulfur oxides, (78,740 tons) of carbon dioxide, and 4,083 tons of particulate matter into the environment during combustion.	Avoiding huge amounts of pollutants, providing a low-cost energy alternative with an environmentally acceptable heating source.
[33]		KGPP's energy efficiencies were analyzed	Using the plant data	The whole plant's energy destructions were originated to range from (17.2% - 24%) depending on the situation state values. It was discovered that the KGPP's exergy efficiencies ranged from 17.2% to 24% for different orientation state values.	Provides valuable insights into the presentation of GTPPs and the potential for improving their efficiency through exergy analysis. It is anticipated that the findings will be advantageous to GTE researchers, government officials, and engineers.
[34]		Gonen area, Türkiye	Analysis of geothermal resources, geothermal wells, and district heating scheme	Estimation of geothermal reservoir temperature, energy capacity, and usable thermal power	Geothermal district heating is a domestic and inexpensive option than using fossil fuels or other renewable energy resources in Türkiye
[35]		geothermal resources in Kutahya Simav area	Plan project for the energy plant in Simav-Inal field	AKutahya-Semav GTPP has a capacity to produce an installed capacity of 2.9 $*10^3$ W and at least 17,020 $*10^3$ Wh of electrical power	Preliminary feasibility study of the project of economic value and workability
[36]		Kızıldere geothermal field	Geochemical analysis, isotope analysis, geothermometric, reservoir simulation	Tracer tests indicate that impermeable layers separate the production sections. Reinjection has stabilized reservoir pressure.	The Kızıldere field is a complex, heterogeneous system that requires a unique injection-production setup for environmentally friendly manufacture .
[37]		Balçova-Narlıdere geothermal field (BNGF)	Development of a conceptual model Geological and hydrogeological studies	As a flow channel, warm water from the reservoir is elevated to the surface via the fault's permeable fracture area. .	The field can be further developed, and the installation of a district cooling system is planned.

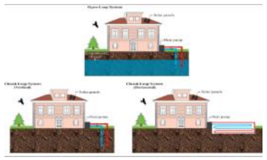
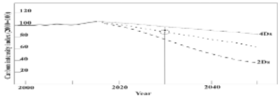
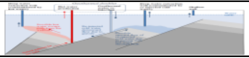
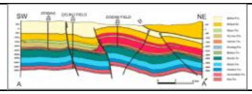
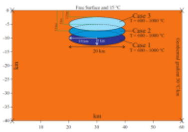
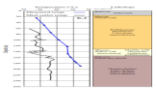
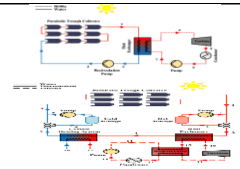
[38]		Kütahya city center	measuring the temperatures of the groundwater in a 53 square kilometer area for a year.	The temperature of the groundwater was 7.60°C in March at site L40, Dist., while the highest recorded temperature was 17.55°C in August at site L26. According to information gathered from every well under investigation, the yearly average temperature of the groundwater in Kütahya's downtown is 13.02 °C.	The urban heat island effect raises groundwater temperatures in addition to air temperatures. The increased thermal energy can be used to heat buildings through the use of systems called "shallow geothermal". The alluvial aquifer's thermal potential was computed.
[39]		Focus on ability of granite to generate heat in the Western Anatolia region	Use geological data, heat flux values, and geothermal gradients to evaluate EGS potential.	Turkish granite contains high concentrations of U, Th and K, generating a large quantity of heat overhead the normal heat generation value of (5 μW/m³) in granite. Heat flux values intended based on enthalpy of granite are alike to values slow from deep wells	The potential of environmental and social services to reduce carbon dioxide emissions and maintain economic growth. Implementing EGS technology can contribute significantly to Türkiye's efforts to mitigate CO_2 emissions and achieve its renewable energy goals
[40]		observing how GPPs affect the environment and nature at BMG	Evaluate the impacts of GPPs on land use and visual impact	Found that the ecological consequences differ depending on change and cooling technology secondhand.	Recommends that before start GTE activity, the optimistic and undesirable aspects of this effect should be reflected.
[41]		Boron in Geothermal Fluid	boron management at a GE production site.	Initial boron concentration, permeate flow rate concentration, and permeate recovery	Boron removal efficiency varies depending on membrane type and configuration

Table (4): Summary of some numerical research on geothermal energy applications

Ref.	Schematic	Study case	Methodology	Results	Conclusion
[42]		Dodan field, Türkiye	(Numerical) Monte Carlo simulation	Evaluate the geothermal potential of each product configuration	Probabilistic method provides insight into resource evaluation chances
[43]		numerical models	model the evolution of the magma chamber beneath the Afyon geothermal fields and its temperature distribution.	compared with the recorded temperatures of thermal wells and hot springs in the literature.	A magma chamber that is between those two temperatures of 600–800 °C at a depth of 5–7.5 kilometers is necessary to maintain the fluids' temperature at estimated tank temperature of 125 °C or recorded well-head temperature of 110 °C..
[44]		Numerical modelling of fluid flow and heat transfer	FEFLOW software	Equations for fluid flow and heat transmission on the two-dimensional vertical model solved	Convective flows originated in fault zones and geothermal aquifers below a height of -1000 meters.
[45]		(Numerical) Thermos economic investigation of the mixture cogeneration plant with usage of	Thermodynamic and thermos economic investigation of systems which provide electricity and heat by usage and save the solar power and near surface GTS	PTC-ORC, PTC-CGN, and PTC-HYB have different electricity production costs: 0.257 \$/kWh, 0.448 \$/kWh, and 0.401 \$/kWh, respectively.	While near-surface geothermal sources could potentially reduce the cost of energy from renewable sources, thermal energy storage comes with additional costs.

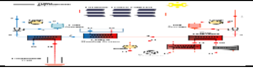
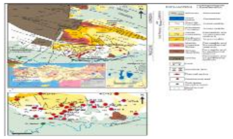
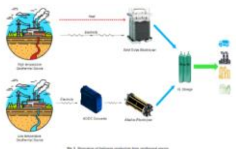
		near-surface GTS in Türkiye			
[46]		Kizildere Field, Türkiye	(Numerical) Thermal Embedded Discrete Fracture Model (thermal EDFM)	Cooling zone volume of horizontal wells aligned horizontally is larger; The generation of electricity from both horizontal and vertical wells aligned horizontally are similar, while horizontal wells aligned vertically have lower output	Natural cracks barely affect the effectiveness of the system. . The optimization of well placement is heavily reliant on reservoir dimensions; Horizontal well placement may be better for Kizildere field.
[47]		Study focuses of the potential of geothermal energy on green hydrogen production in Türkiye.	The study assesses Türkiye's potential for producing hydrogen overall using geothermal resources, estimates the potentials for hydrogen production for different Turkish cities, and discusses the feasibility of a hydrogen economy. It also explores the use of alkaline electrolysers and high-temperature solid-oxide electrolysers for hydrogen production, considering the geothermal energy sources available in different regions of Türkiye	The study assesses Türkiye's potential for producing hydrogen overall using geothermal resources, estimates the potentials for hydrogen production for different Turkish cities and discusses the feasibility of a hydrogen economy based on geothermal energy. It also presents the technical details of high-temperature, alkaline solid-oxide electrolysers being evaluated for the creation of green hydrogen.	GTE has the potential to make Türkiye a leader in green hydrogen production and can contribute to the development of new energy policies. It also emphasizes the importance of planning and strategizing based on available green power potentials on a country.
[48]		Geothermal well data analysis and performance evaluation of ESP systems in Western Anatolia, Türkiye	Use various technical and analytical methods to evaluate an ability of geothermal power plants to produce power and the functionality of ESP systems, including similarity analysis and correlation studies.	The importance of ESP systems in maximizing production in geothermal wells is revealed and highlights the need for optimal design and implementation.	The importance of ESP systems in geothermal energy production and the need for further research and development in this field were emphasized.

Table (5): Summary of some experimental research on geothermal energy applications

Ref.	Schematic	Study case	Methodology	Results	Conclusion
[49]		Experimental	Analysis of geothermal fluid characteristics, membrane testing, and discussion of water treatment methods	Geothermal fluid characteristics, membrane testing results, and the need for water treatment for agricultural irrigation	To use preserved spent geothermal fluid aimed at irrigation, several strategies are required., and water treatment strategies are necessary to tailor the produced water for agricultural use

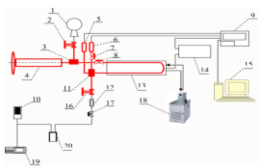
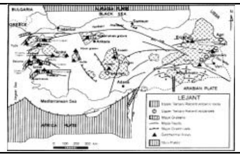
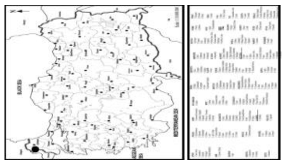
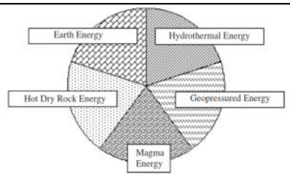
[50]		(experimental) Geothermal fluids from East Türkiye	High temperatures and high pressures PVT capacities using vibrating pipe densimeter (VTD) DMA HPM	The measured standards on density (ϱ) of the geothermal waters by way of function of temperature and pressure were obtained	The problem of environmental influence of producing GTE will be successfully resolved with the use of precise and trustworthy thermo physical possessions data of the geothermal waters from Türkiye's Geothermal Fields. Additionally, the effectiveness of the current technical processes connected to producing GTE in this area will be enhanced.

Table (6): Summary of Türkiye's potential for geothermal energy

Ref.	Schematic	Study case	Methodology	Results	Conclusion
[51]		analyses geothermal energy's capability and application	Several resource assessments have been passed out by Türkiye's Mineral Study and Exploration Executive (MTA).	According to data collected since 1962, There is an estimated 4500 MWe of geothermal power and 31500 MWt of direct consumption potential.	Based on existing usage in Türkiye, geothermal energy is clean and significantly less expensive than extra relic and renewable power sources.
[52]		studied GTE applications in 11 regions in Türkiye	The engineering project for the geothermal region boiler system that serves an estimated 300,000 residential units has been finished by ORME Geothermal Inc.	The construction of a 25 MW double-cycle power facility in Aydın/Germencik is imminent. The established geothermal capacity is 3,132 MW, as determined by data collected from geothermal resources and organic discharges.	Türkiye has used only 3% of its geothermal potential. Using the approximate 31,500 MWt potential for greenhouse, residential, spa, balneology, resource recovery, air-conditioning, and manufacturing would result in a net national benefit of $20 billion.
[53]		Türkiye's Present Situation with Geothermal Energy Applications	The study provides an indication of the historical development and position of GTE use in Türkiye. It includes data on installed capacity, growth of residence connections, and the main geothermal provinces in the country.	Türkiye has a significant GTP, with only about 2-3% of its estimated potential being utilized. - GTE is used for various applications in a Türkiye, including interplanetary heating, greenhouse heating, balneology, CO_2 and dry-ice manufacture, heat pumps, and electricity cohort. with an connected capacity of (20.4 MWe), the Kizildere geothermal plant is the only one in operation in Türkiye.	Study emphasizes the need for further development and utilization of GTE assist in improving Türkiye's power supply and lower air pollution.
[54]		Geothermal resources in Türkiye	Exergy analysis-based classification	Specific enthalpy-specific entropy (h-s) diagram Specific exergy specific entropy (C-s) diagram Temperature dependence of exact exergy and SER	Geothermal capitals in Türkiye categorized founded on exergy standards

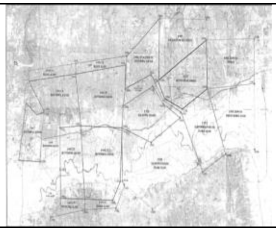
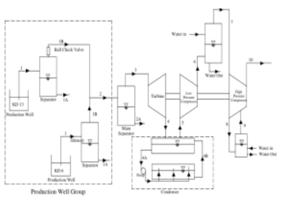
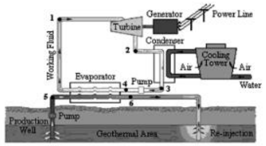
[55]		Integrated resource management approach, which aims to assess all processes that affect capitals and elements.	The approach strategical thinking	the importance of efficient resource use, recurrent audits and even application panels	Fewer bureaucracies in geothermal energy management.
[56]		Türkiye's geological features	Display information about geothermal power generation and link it with the private sector	Türkiye's geothermal fields generate large amounts of greenhouse gasses, which are thought to be a major contributing factor to global warming	The Turkish energy market was liberalized in 2001, with founding of power Market Controlling Authority (EMRA) to achieve the regulatory and guiding role in power market. The connected capacity of GTPPs is expected to reach 444.6 MW in 2014, 713 MW by 2015, and 1000 MW by 2020, presumptuous all schemes under contemplation are approved

Table (7): Summary of Status and evaluation of geothermal energy in Türkiye thermal energy applications

Ref.	Schematic	Study case	Methodology	Results	Conclusion
[57]		Comparing geothermal energy with other energies environmentally and economically	a review of the geothermal potential	GTE is a clean, stable, inexpensive, and sustainable source on household energy which is abundant in Türkiye.	Geothermal energy research and development initiatives need to be funded.
[58]		Give an overview of the geothermal power plant located at Denizli-Kizildere (DKGPP).		Türkiye's electricity generating plans include 500 MWe from Germencik, Kizildere, Tuzla, and other resources though 2010, and 1000 MWe by 2020. The anticipated capacity of the Denizli-Kizildere geothermal area is 200 MWe. The DKGPP was implemented in 1984 and has been in operation ever since. In 2001, it generated 89,597 MWh of electrical energy, which corresponds to an electric energy output of 10.6 MWe during the same year.	Current application has demonstrated that GTE is the promising alternative in Türkiye and can substantially contribute to lowering greenhouse gas emissions.
[59]		An examination of the thermodynamics of geothermal energy production systems .	Exergy is implemented to analyse the simplified organic Rankine cycle (ORC).	Examined are changes in the parameters—like working fluid condenser temperatures, and evaporation, mass-flow rates, and dead- state conditions—that impact the system's performance. Geothermal power generation systems are evaluated regarding their first and second - law efficiency, total irreversibility and economic profit on the basis of turbine network output.	The efficiencies on the first and second laws decline as the evaporation temperature decreases. Moreover, when the condenser temperature rises, there is a corresponding increase in total irreversibility, accompanied by a fall in both second-law efficiency and economic profit.

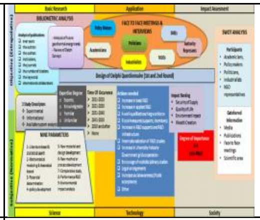
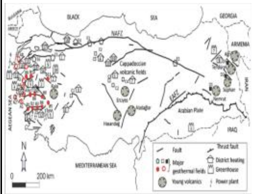
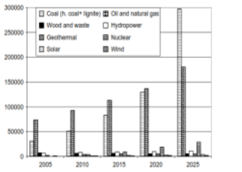
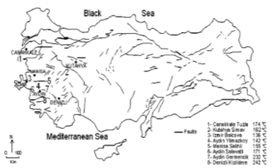
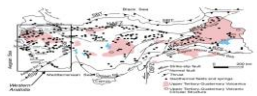
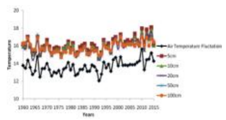
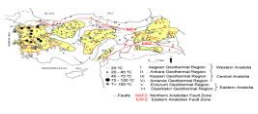
[60]		geothermal foresight study in Türkiye	analyze using statistical methods.	Includes the assessment of the impact of geothermal energy technology statements on wealth creation, quality of a life, environment and provision security.	provides a comprehensive analysis of the future outlook and sector growth strategy for geothermal energy in Türkiye, based on the input of many experts from different institutions and backgrounds.
[61]		250+ deep geothermal wells in Türkiye. 26”-, 17.5”-, 12.25”-, and 8.5”-hole sizes	Extensive laboratory studies based on three criteria: formation temperature, wellbore stability, and formation damage	Guidelines for mitigation have been shown effective for primary Six distinct types of drilling fluids and associated dangers were identified for Türkiye's geothermal wells.	For the drilling of a deep geothermal well to be successful, the choice of drilling fluid is crucial
[62]		The thermal energy stored in subsurface fluids and minerals between the surface and 3 kilometres deep in the crust beneath a particular region (datum: 15 °C)	Estimating convertible energy using the approach by a World Energy Council (1979)	According to the analysis, 84.2 GW of heat were emitted, and the average heat flux was: 1 The geothermal source base refers to the aggregate heat that is stored in subsurface minerals and fluids extending from the surface to a designated depth. (datum: 15 °C). 2 Heat stored in subterranean rocks and fluids between the surface and three kilometers below the surface of the crust beneath a certain area is known as accessible geothermal resources (datum: mean annual temperature). 3 The portion of the resource base that may be effectively harvested and used directly for consumption or electricity generation is known as convertible energy.	Class 2 resources have the greatest potential for geothermal energy in Türkiye; these resources are suitable for both direct industrial applications and the generation of electricity through binary cycle plants. Ample low-temperature resources (Class 1) are also available for direct use lke food drying, greenhouse and space heating, and aquaculture.
[63]		Examines the economics of GTE use and evaluates its advantages and disadvantages.	Examines the economics of geothermal energy use and evaluates its advantages and disadvantages.	Discusses the economics of GTE. Assesses the benefits and drawbacks of GTE use.	Provides recommendations for policymakers regarding geothermal energy.

Table (8): Summary of Geothermal energy's role in sustainable development

Ref.	Schematic	Study case	Methodology	Results	Conclusion
[64]		Focuses on how energy needs are currently being met, in addition to its potential, use, and significance of GTE.	Uses data on Production and utilization of energy in Türkiye, primary energy sources, electricity production, and geothermal energy potential	The total geothermal potential is estimated at 31,500 MW for immediate use and 4,500 MW for energy generation. Then, only 4% of these potentials has been exploited yet.	In comparison to other energy sources, geothermal energy is a comparatively safe source, and its use can reduce greenhouse gas emissions. The paper emphasizes the need to accelerate the use of GTE for electricity production and its immediate use in Türkiye.
[65]		GTE in Türkiye	Analyze and discuss the use of GTE	Türkiye's high potential and detailed information about specific areas of geothermal energy	The importance of GTE as a reliable, clean, and safe source of renewable power and opportunities and challenges associated with its application
[66]		discusses the energy sources	A review of Türkiye's primary energy sources	Türkiye has a significant GTP, However, only 2% to 3% of this potential has been exploited.	Türkiye's power request is expectedly to increase rapidly, with primary power production projected to be (66 Mtoe) by 2020 and primary power consumption to be (310 Mtoe) by the same year
[67]		GTP in Türkiye and its usage.	Summarizing Türkiye's geothermal potential and usage categories, and distributing geothermal wells drilled by MTA in accordance with years.	Türkiye's politics in the near future and the proposed Geothermal Law, which ought to establish the regulatory structure required for the harnessing of geothermal energy.	summarizing the utilization of GTE for electric energyr generation as of 1999 in Türkiye.
[68]		literature review and an examination grounded in Türkiye's energy plans for Vision 2023	Analyzing the role of GTE in Türkiye's energy goals for Vision 2023 and providing an overview of geothermal energy, its applications, and its potential for development and utilization around the world.	GTE has the smallest share in Türkiye's Vision 2023 power targets, set at 600 MW by 2023, which is only 0.5% of Türkiye's installed capacity. But, the installed capacity of GTE in Türkiye reached (623.9 MW) at end of 2015, which is decisive important for the realization of the Vision 2023 power targets. According to the study, the goals should be changed to expand the installed capacity of geothermal energy to 1000 MW, which would increase its proportion of Türkiye's installed capacity to over 0.8% by 2023.	Geothermal energy has the potential for development and utilization around the world, and its portion of the worldwide energy mix is in anticipation of increase in the future.
[69]		Highlights the importance of geothermal energy in Türkiye's	Literature review	Türkiye's geothermal energy market has been expanding gradually, and by 2020, it is expected to account for 2.22% of primary energy consumption.	Emphasizes the demand for further expenditure in geothermal energy research and evolution, exploration, and production to utilize the full potential of this sustainable energy source in Türkiye

[70]		The source of arsenic in GTSs in Western	Chemical analysis of water samples from GTSs and plotting the results on Piper and Schoeller diagrams.	The geothermal fluids in the study areas are dominated by Na-Cl, Na-HCO3, and Ca-Na-HCO3 types and found that the GTF from Gediz Graben is fed by waters are meteoric in nature.	The geological and hydro geochemical properties of GTSs in Western Türkiye are the source of arsenic in the region.
[71]		Theoretical investigation and prediction of soil temperatures in Türkiye's different regions	Utilizes a sinusoidal temperature model and makes various assumptions	Prediction of temperatures of the soil at various depths and evaluation of the connection between soil temperature and outside air temperature	Importance of soil temperature in different applications and its impact on ecological processes, agricultural practices, and other environmental factors
[72]		Geothermal energy in Türkiye	Estimation of the geothermal resource base, its specific capacity and potential using various methods including volumetric method and Monte Carlo simulation.	Within a depth of three kilometers, the estimated GTS base in Türkiye was 3.96 x 10^{23} J. Using a temperature references of 15°C, the total identified capacity of geothermal sites was calculated to be 10,576 MWt. Using the volumetric approach and Monte Carlo simulation, the potential of GTE in Türkiye for power generation and direct usage was assessed for 135 geothermal fields.	With a large variety of identified geothermal site capacities, Türkiye offers substantial geothermal potential for both direct consumption and power generation. The report suggests that Türkiye's geothermal resources be further explored and developed.

Abbreviations

GTE	Geothermal Energy
BMG	Buyuk Menderes Graben
GTF	Geothermal Energy
GTP	Geothermal Power
GTS	Geothermal System
GTPP	Geothermal Power Plant
EGS	Enhanced Geothermal Systems
ESP	Electric Submersible Pumps
SER	Specific Exergy Rates
ORC	Organic Rankine Cycle
VTD	Vibrating Pipe Densimeter

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