GEOTHERMAL ENERGY FROM BASIC SCIENCES PERSPECTIVE: TÜRKİYE'S POTENTIAL AND CONTRIBUTION TO THE ECONOMY

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Geothermal Energy From Basic Sciences Perspective: Türkiye's Potential and Contribution to the Economy

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Abstract

Science begins with physics from the moment of the Big Bang, and then with chemistry and geology. Geology science is closely interested in the tectonic and volcanic activities that occur on the planet Earth and its products. In the process that started with the big bang, geology science is extremely important in the formation and understanding of the earth. However, population growth on a global scale, rising living standards with modernization, and ongoing industrialization directly increases the energy demand and triggers the search for alternative energy sources. Fossil fuels meet the majority of energy needs worldwide. The fact that fossil fuels pose a risk to the environment and will run out soon has shown that renewable energy sources should replace fossil fuels in the future. In addition, as stated in the Paris Agreement, we need to avoid carbon-based energy sources to keep the global temperature rise below 2°C. If it is evaluated in terms of both regional and national development, one of the most important products of tectonism and volcanism is geothermal. Geothermal energy is one of the renewable energy sources and is a natural resource that can be utilized directly or by converting to other types of energy. The use of geothermal energy for different purposes such as electricity, home heating, greenhouse cultivation, thermal tourism, fishing, and road heating has become common in many countries, as of 2022, the direct contribution of geothermal applications to the Turkish economy is around 4 billion USD annually. the economic size can reach 15 billion USD annually if the potential is used after new geothermal applications and investments. In addition, the direct and indirect employment to be created by geothermal energy will be approximately 450,000 people. In summary, this study embodies the relationship between basic sciences and geothermal energy and reveals how to benefit from basic sciences in order to reach geothermal energy resources and make them sustainable.

Keywords
Basic science, Geology, Geothermal, Türkiye, Economy

Introduction

Science is a widely used and highly esteemed concept in modern times. It serves as the most influential reference point in contemporary life. Science has always been present as an endeavor to uncover the truth about humanity, the universe, and the societies in which we live. In this regard, science is an activity that exists in all societies. Both the scientific understanding of the historical process and modern science cannot be separated from their social context. When analyzing the development of modern scientific understanding, the 16th century appears to be a significant turning point. Following the Enlightenment, reason, and observation gained prominence, and induction was accepted as a valid method of acquiring knowledge (Köroğlu and Köroğlu, 2016). Basic science, often referred to as "pure" or "fundamental" science, plays a crucial role in helping researchers understand living systems and life processes. Given the vastness of fields such as physics, chemistry, geology, biology, etc., pure scientists must choose to specialize in order to excel in their chosen scientific disciplines (Karcher, 1938).

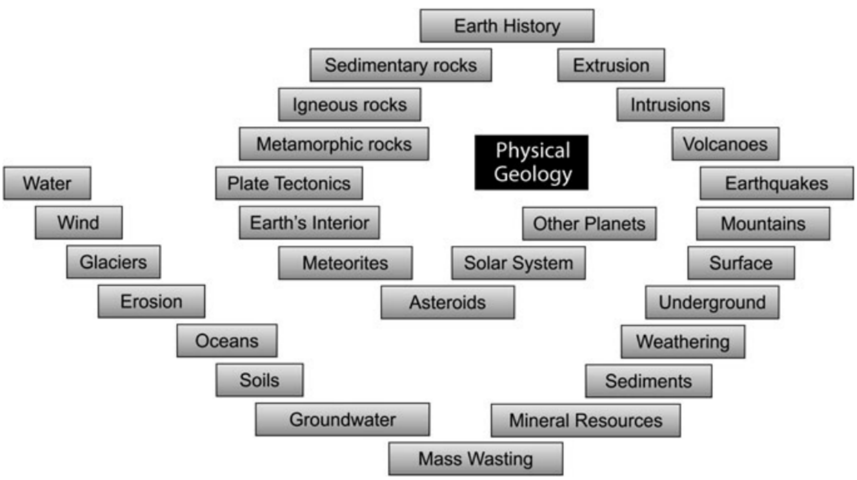
Geology encompasses the comprehensive study of the Earth, including its materials, the processes that influence them, the resulting products, and the Earth's history dating back to its birth approximately 4.54 billion years ago (±0.5 billion years). This estimation is inferred from the impact of the Canyon Diablo iron meteorite on the Barringer Crater in Arizona, USA (Warwick et al., 2007; Dalrymple 2001). Geology not only encompasses the investigation of processes that have shaped the Earth's surface but also includes the study of the ocean floor and the Earth's interior. To gain a profound understanding of the Earth and its mechanisms, it is essential to examine contemporary processes and structures and interpret them in relation to past occurrences. This objective is accomplished through the discipline of Geology. Geology is the scientific field dedicated to the comprehensive study of the Earth, focusing on its composition, structure, and geological history. It involves the examination of the origins, properties, and compositions of rocks and minerals. Describing the Earth's geological development and processes necessitates an interdisciplinary approach, incorporating fundamental sciences such as physics, chemistry, biology, and mathematics.

Physics-Geology Relationship

The term "Physical Geology" was coined by William Hopkins, an English mathematician and geologist, in 1883. This field of study focuses on the physical forces and processes that result in changes in the Earth's crust or on its surface due to their prolonged existence and impact (Fig. 1). On the other hand, "Geophysics" refers to the scientific discipline that utilizes the methods and principles of physics to investigate various aspects of the Earth. The scope of geophysics encompasses a wide range of subjects within geology, including investigations into the conditions within the Earth's deep interior, characterized by temperatures reaching several thousand degrees Celsius and pressures in the millions of atmospheres. Geophysics also extends to the Earth's exterior, encompassing its atmosphere and hydrosphere.

Figure 1.

The relationship between physics and geology (Jain, 2014)

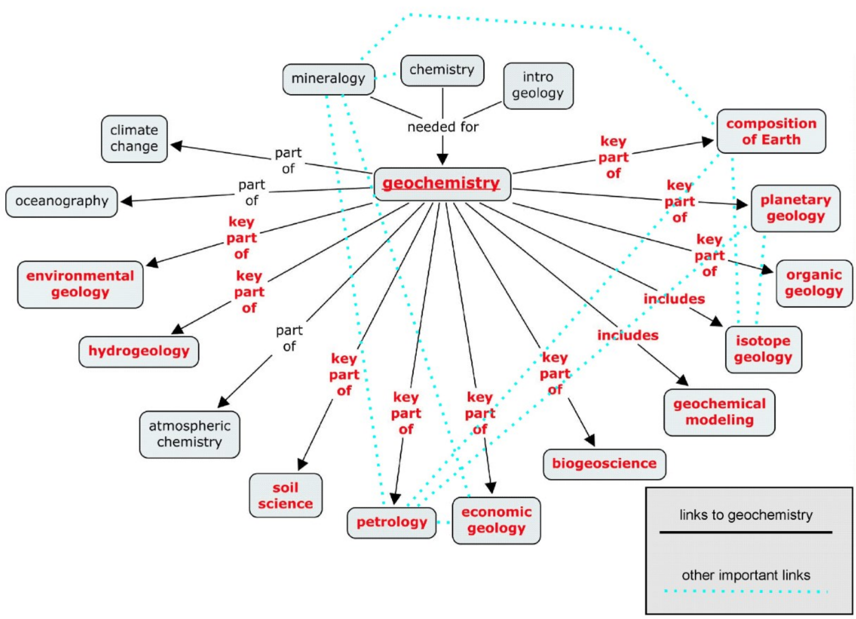


Chemistry-Geology Relationship

Geochemistry encompasses the broad application of chemistry to nearly all aspects of geology (Fig. 2). Since the Earth is composed of chemical elements, it is possible to consider all geological materials and processes from a chemical perspective. Geochemistry addresses various significant problems, including the origin and abundance of elements in the solar system, galaxy, and universe (known as cosmochemistry). It also investigates the distribution of elements in the major components of the Earth, such as the core, mantle, crust, hydrosphere, and atmosphere. Additionally, geochemistry explores the behavior of ions within crystal structures, the chemical reactions occurring during the cooling of magmas, and the origin and evolution of deeply buried intrusive igneous rocks. Furthermore, it investigates the chemistry of volcanic (extrusive) igneous rocks and phenomena closely associated with volcanic activity, including hot-spring activity, emission of volcanic gases, and the formation of ore deposits through hot waters derived from the late stages of igneous magma cooling. Geochemistry also explores the chemical reactions involved in rock weathering, which lead to the decay of previously formed minerals and the creation of new minerals. It examines the transportation of weathering products in solution by natural waters in groundwater, streams, lakes, and the ocean. Moreover, it investigates the chemical changes that occur during the compaction and cementation of unconsolidated sediments, leading to the formation of sedimentary rocks. Finally, geochemistry studies the progressive chemical and mineralogical transformations that occur during the process of rock metamorphism (Fig. 2).

Figure 2.

The consensus view of a geochemistry-centric world by workshop participants.



Math-Geology Relationship

Science inherently relies on numerical data and measurements. In the field of geology, various aspects can be quantified using numerical values. For instance, minerals can be quantified based on specific gravity, hardness, Miller index, and abundance. Geologic structures can be quantified using parameters such as strike and dip, and even abundance when assessing the integrity of rock masses. Economic geologists and geochemists construct intricate databases consisting of samples, each associated with multiple elements. Analyzing these elements provides valuable insights into ore genesis, the origin of water, environmental stresses, and rock classification, among other applications. Geophysics and remote sensing generate vast datasets represented as digital images, comprising large sets of numerical values. Mathematical geology encompasses the application of theoretical and applied mathematics to assess geologic data, aiding in the interpretation of the Earth's evolution (Carr, 2018). Consequently, this study employs a comprehensive approach that incorporates all fundamental sciences to evaluate and interpret geothermal phenomena, which falls within the realm of geology.

Basic Sciences and Geothermal Energy Exploration

Geothermal energy refers to the heat energy contained within the Earth's interior. The origin of this heat is associated with the internal structure of our planet and the physical processes occurring therein. While the Earth's crust and deeper regions contain vast and practically limitless quantities of heat, its distribution is uneven, concentration is rare, and often it exists at depths too great for industrial exploitation (Barbier, 2002). A geothermal system comprises several crucial components, as outlined below:

1. Heat Source: This refers to the source that provides heat to the geothermal system (Fig. 3). There are two primary heat sources.

- Geothermal Gradient: The geothermal gradient represents the rate at which the ground temperature increases with depth. Under normal crustal conditions, the temperature rises by approximately 1°C for every 33 meters. The geothermal gradient tends to be low in regions with a thick Earth's crust (compression-orogeny) and high in areas exhibiting an extensional regime (graben basins).

- Igneous Activity: This involves the cooling of underground magma (not necessarily volcanic in nature at the surface). The cooling of magma underground occurs over a period ranging from tens of thousands of years to several million years. High-temperature minerals cool earlier, while those formed during the late stages of magma crystallization cool at lower temperatures.

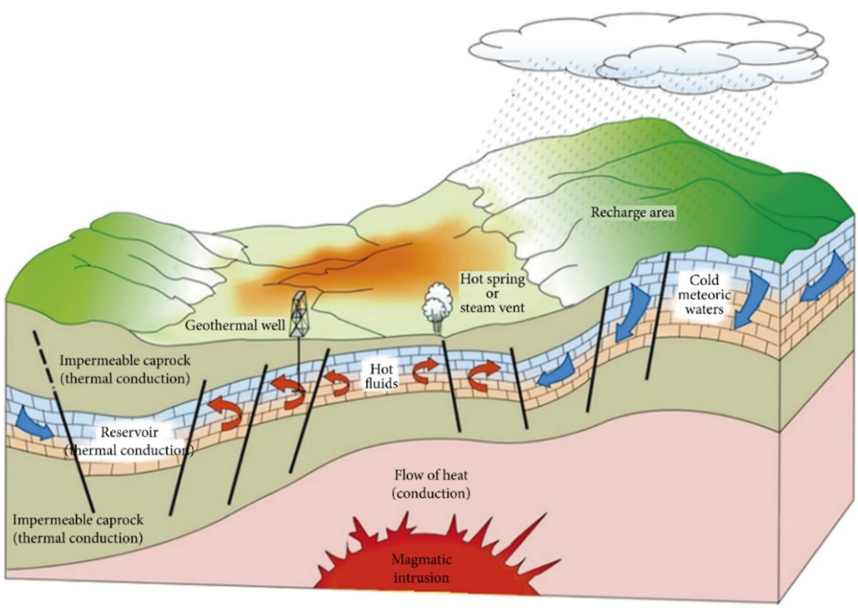
2. Reservoir Rock: This refers to a type of rock that possesses sufficient permeability to store or accumulate heated fluid. Reservoir rocks can be of various types, including sedimentary, igneous, or metamorphic rocks (Fig. 3).

3. Fluid: The fluid within the geothermal system can consist of liquid, steam (gas), or a mixture of both. It facilitates the transfer of underground heat to the surface (Fig. 3).

4. Cap Rock: The cap rock is a lithological unit comprised of impermeable materials located above the reservoir rock. It serves as insulation, preventing the escape of heat stored underground within the reservoir rock (Fig. 3).

Figure 3.

Schematic diagram of an ideal geothermal system (Huenges, 2016).



Results and Discussions

The Contribution of Geothermal Energy Discovered with Basic Sciences to The Country's Economy

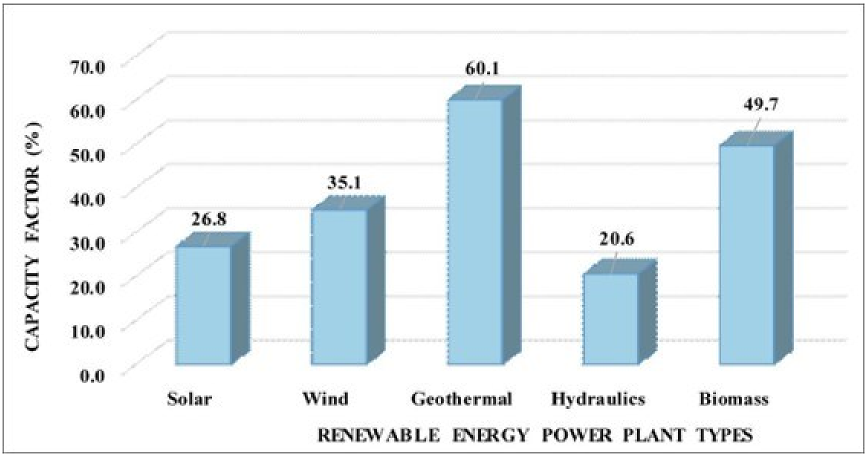
In the last century, industries have experienced rapid development, populations have witnessed significant growth, and standards of living have improved considerably. As a consequence, there has been an ever-increasing demand for energy and mineral resources. Geologists, geochemists, and geophysicists have played a pivotal role in the exploration of fossil fuels such as coal, oil, and natural gas, as well as the identification of geothermal energy reservoirs. In recent years, the applications of geothermal energy have expanded, further driving the interest and research in this field.

Geothermal energy has witnessed the development of a variety of applications, encompassing public buildings, residential heating, and greenhouses. The global total energy supply (TES) experienced an approximately 2.6-fold increase between 1971 and 2018, as reported by REN21 (2021). Despite the slight growth in geothermal power capacity in comparison to recent years (partly due to disruptions caused by the Covid-19 pandemic), most new facilities were established in Türkiye, as indicated by REN21 (2021). Despite challenges faced by the industry due to the pandemic, a total of 246 MW of additional capacity has been installed worldwide, including countries such as Colombia (with small-scale ORC units from co-produced oil) and Taiwan (with a 4.2 MW power plant) (Thinkgeoenergy, 2022).

Between 2010 and 2020, a total of $40 billion was invested in new geothermal energy developments worldwide. As of the end of 2021, the global installed geothermal power generation capacity reached 15,854 MW, reflecting an increase of 246 MW compared to the previous year (Thinkgeoenergy, 2022). Presently, the United States leads in installed geothermal capacity with approximately 3,722 MWe, followed by Indonesia, the Philippines, Türkiye, and New Zealand. Türkiye's share in electricity generation from geothermal sources amounts to around 11% (Şener et al., 2022). Geothermal power generation plants play a crucial role in Türkiye. Additionally, solar, wind, and hydroelectric power plants have also been impacted by climate-related events and regional meteorological variations, resulting in fluctuations in their production levels (EPDK, 2019; 2021). Capacity factor data for power plants in Türkiye reveals that wind power, solar power, hydroelectric power, biomass, and geothermal power plants (GPP) have capacity factors of 35.1%, 26.8%, 20.6%, 49.7%, and 60.1%, respectively. The significant variation in capacity factors among different power plant types emphasizes the crucial role of geothermal power plants as base load providers in Türkiye's power generation system (Fig. 4).

Figure 4.

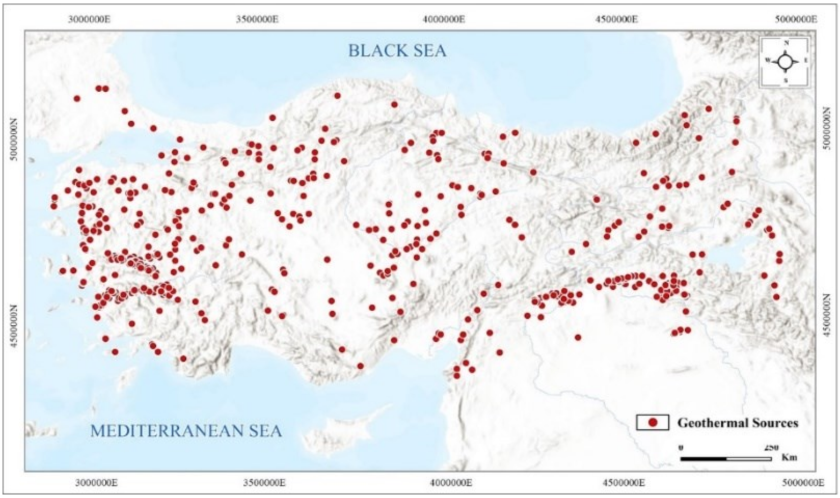
Renewable energy sources and capacity factors (Selenka, 2021).



Türkiye boasts over 2,000 wells and 415 geothermal fields, where the accepted lower temperature limit is 30°C. In 2022, the electricity generation capacity in Türkiye reached 1,663 MWe, while the total installed thermal power for direct heat use reached 5,113 MWt. Due to the diverse geological structure of the country, geothermal systems have flourished primarily in regions characterized by young tectonic and volcanic activity. Notably, Western and Central Anatolia stand out as particularly rich in geothermal resources (Fig. 5). The geothermal well with the highest recorded well-bottom temperature was drilled in Niğde, located in Central Anatolia, reaching a temperature of 341°C at a depth of 3,845 meters. Other regions in the country, such as Nevşehir, Sivas, Yozgat, Erzurum, Ankara, Batman, Van, and Şırnak, also possess medium-high temperature springs (Şener et al., 2023).

Figure 5.

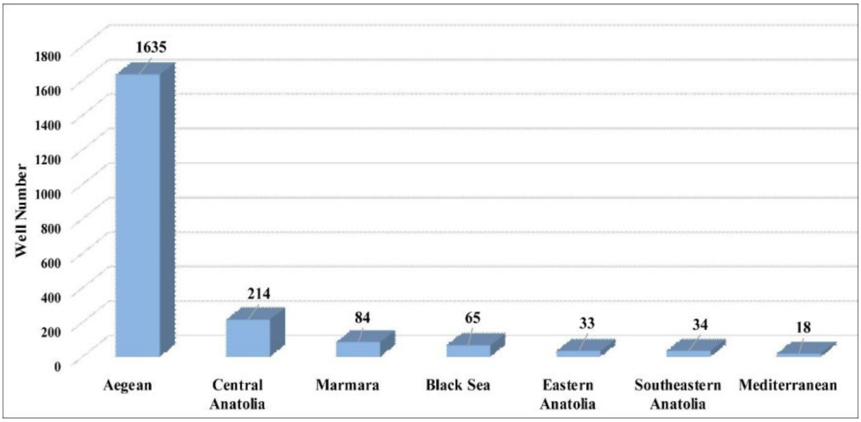
Geothermal sources of the Türkiye (Updated from Akkuş et al., 2005; Baba et al., 2019; Şener, 2019; Şener and Baba, 2019; EBRD, 2020a).



Regarding the distribution of wells by region, the Aegean Region takes the lead with 1,635 wells, followed by Central Anatolia and Marmara (Fig. 6). However, in terms of capacity, the Aegean Region significantly surpasses others, boasting a capacity of 34,920 MWt. The presence of 673 wells in Aydın, 384 in Manisa, 228 in Denizli, and 209 in İzmir underscores the high geothermal potential in the Aegean Region.

Figure 6.

Distribution of the number of wells by region (Akkuş et al., 2005; Şener et al., 2017; Baba et al., 2019; EBRD, 2020b; Şener et al., 2021).



In recent years, the Central Anatolia Region, particularly in Nevşehir, Aksaray, and Niğde, has witnessed a growing potential, whereas other regions are still awaiting investment. The current utilization areas and capacities of geothermal energy in Türkiye are outlined in the Türkiye Geothermal Strategy Report, which was prepared in 2022. According to the report, the total installed heat power for direct use amounts to 5,113 MWt (Lund and Torth, 2020).

Support Mechanisms and Investment Costs

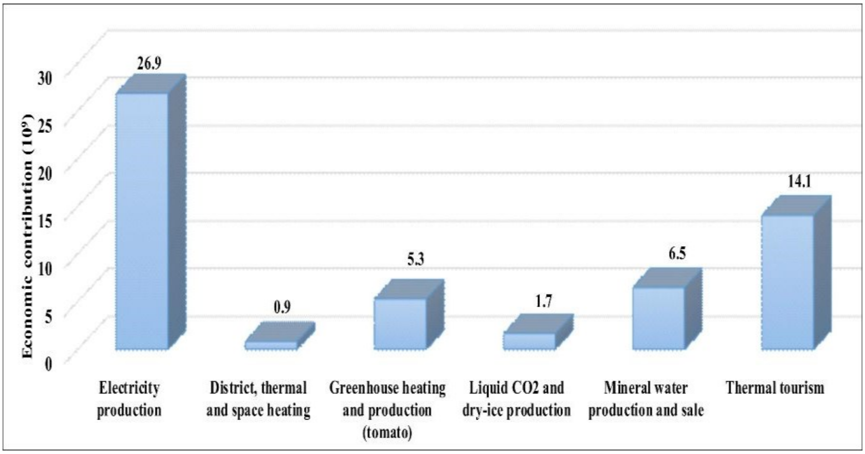
One of the key economic advantages of geothermal energy is its ability to reduce dependence on imported energy by utilizing domestic resources. As a result, domestic investments in geothermal energy can contribute to reducing trade deficits and retaining capital within the country.

Presently, geothermal heat is approximately 70% cheaper than natural gas in many locations based on local household tariffs. When considering the subsidies provided by the government for natural gas used in residential heating, the substantial contribution of geothermal energy to the country's economy becomes evident. In comparison to the current actual cost of natural gas at 9.135 TL/m3 (6.3 TL/m3 x 1.45, accounting for the 45% increase by BOTAŞ as of 01.04.2022), the highly economical price of geothermal energy at approximately 1/8th of the cost is advantageous for both the state and the population. Data on the economic contribution of geothermal energy for electricity generation and direct use are presented in Figure 7 (Şener et al., 2023).

The total direct contribution of geothermal applications to the economy, as calculated above, amounts to 54,857,760,000 TL (excluding the contribution to employment, natural gas savings, and CO_2 emission reduction). Additionally, when accounting for an estimated 5% for unknown and unregistered factors, the direct contribution of geothermal applications to the economy can be considered to be approximately 58 billion TL per year.

Figure 7.

The annual contribution of geothermal energy to the Turkish economy in terms of electricity and direct use (TL/year).



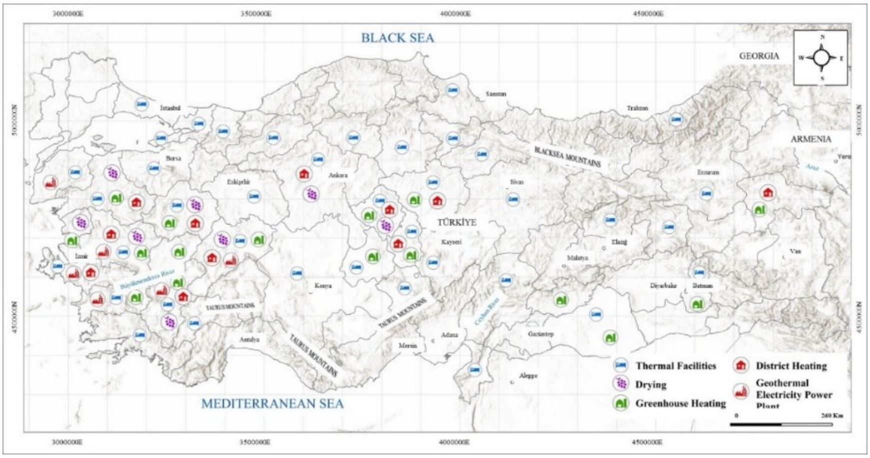
Recommendations and Strategies

If systematically and technically explored, operated, and regulated within legal frameworks, geothermal resources hold significant importance as a renewable energy source for Türkiye's economy. Presently, geothermal resources are extensively utilized both directly and indirectly in the country. Indirect utilization refers to the production of electricity in geothermal power plants from geothermal fluids, while direct utilization includes applications such as urban heating and cooling, greenhouse heating, agricultural drying, thermal and health tourism, CO_2 production, and dry ice production (Fig. 8).

In view of the geological data obtained, an evaluation of which applications can be made in which provinces in Türkiye is presented in Figure 8. Geothermal energy power plants and electricity production, as well as integrated production, can be implemented in numerous cities in Western Anatolia. Agricultural applications, thermal tourism, and heating are becoming increasingly prevalent in Western and Central Anatolia. Thermal tourism and integrated facilities, along with heating and cooling applications, can be observed in different regions across Türkiye. Furthermore, it is recommended to explore the geothermal potential in select provinces of the Mediterranean and Black Sea regions.

Figure 8.

Current direct and indirect use of geothermal energy sources in Türkiye (Şener et al., 2023).



While not included in the short and medium-term projections, hot dry rock (HDR) and Enhanced Geothermal Systems (EDGS) hold significant potential in geothermal energy applications. In the calculations conducted in this study, when the value of EDGS is taken into account, Türkiye's total potential is predicted to reach at least 400,000 MWe. Furthermore, with the realization of potential targets and estimated investments, it is anticipated that geothermal energy will contribute approximately 210 billion TL per year to the economy, generating direct and indirect employment opportunities for approximately 450,000 individuals (Table 1).

Table 1.

Potential targets and estimated investment amounts for geothermal applications.

Geothermal Application	Estimated Goals for 2030	Additional Investment (USD) (from 2022 to 2030)
Electricity Generation (Hydrothermal)	3000 MWe (24 billion kWh)	5,4 billion USD
Heating (housing, hotel, thermal facilities, etc.)	5000 MWt (500,000 Housing equivalent)	1,2 billion USD
Greenhouse Heating	2800 MWt (12,000 Acres)	1,3 billion USD
Drying, etc.	80 MWt (300,000 tons/year)	30 billion USD
Thermal Tourism	2000 MWt Total of 520 thermal springs, Health Tourism Facilities, ect.	1 billion USD
Cooling	350 MWt (20,550 residences equivalent)	140 million USD
Fishing+Other Uses (Mineral extraction, etc.)	400 MWt	100 million USD
Total Investment		9,170,000,000 USD

The natural gas equivalent of all geothermal uses above	6 billion USD /Year
Amount of economic growth created by applications such as geothermal electricity production, heating (housing, thermal facilities, etc.), thermal tourism (spa), greenhouse cultivation, drying, fishing, etc. if goals in 2030 are reached	210 billion USD /Year
Direct and Indirect Employment	450,000 people

Geothermal energy implementation, both on the supply and demand sides, should be prioritized in the short and long term through collaboration between national and local authorities. The private sector, universities, institutes, and research centers needs to develop short-term, medium-term, and long-term strategies for the effective utilization and development of geothermal resources. In the geothermal sector, there are still areas where wells have not been drilled despite the studies conducted thus far. Therefore, it is anticipated that Türkiye's future capacity will significantly increase with the inclusion of drilling research and development studies, as well as the discovery of new fields. This capacity is expected to surpass 100,000 MWt levels in the medium term, particularly with the incorporation of Hot Dry Rock (HDR) technology.

Conclusion

Basic sciences form a fundamental element of a country's technological and economic development system. The proper utilization of basic sciences plays a crucial role in a country's progress, while their incorrect application can result in irreparable damage. Geology, as a scientific field, combines essential disciplines such as physics, chemistry, and mathematics. Geothermal energy represents one of the most prominent applications of basic sciences within the realm of geology. It is a natural resource that can be directly harnessed or converted into other forms of energy. Türkiye, with its diverse geological structure, has witnessed the development of geothermal systems associated with young tectonic and volcanic activity. Geothermal energy is now extensively employed for various purposes in Türkiye, including power generation, residential heating, thermal tourism, and greenhouse cultivation. Particularly, Western and Central Anatolia boast abundant geothermal resources. Notably, the hottest geothermal well was drilled in Central Anatolia, reaching a well-bottom temperature of 341°C at a depth of 3845 meters. As of 2022, Türkiye's electricity generation capacity and total installed direct heat use have reached 1663 MWe and 5113 MWt, respectively. Considering the Curie depth and heat flux in Anatolia, it is estimated that the batholith's probable thickness is approximately 10 km. Türkiye occupies a geologically strategic position to harness geothermal energy from hot and radiogenic granitoids using Hot Dry Rock (HDR) technology. With further drilling research, development studies, and the discovery of new fields, Türkiye's future geothermal capacity is expected to surpass 100,000 MWt in the medium term, particularly with the integration of HDRs. Effectively and appropriately utilizing geothermal resources can significantly mitigate Türkiye's energy challenges in a short timeframe. Therefore, increasing and supporting geothermal research in Türkiye is of utmost importance.

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