Exploring the Past, Present, and Future: Geothermal Energy on the 100th Anniversary of the Turkish Republic

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ABSTRACT

This paper provides a comprehensive overview of the geothermal energy landscape in Türkiye on the occasion of the 100th anniversary of the Turkish Republic. The study examines the country's progress and internationally recognized applications in geothermal energy, highlighting key milestones and the impact of the founding vision that underscores the central role of geosciences in economic development. The use of legislation and feed-in tariff mechanisms to promote the use of indigenous energy resources is discussed in the context of cause-and-effect relationships, highlighting the dynamics of geothermal development.

MTA (The Institute of Mineral Research and Exploration) started geothermal exploration in Türkiyein the 1960s. From the drilling of the first geothermal well in 1963 to the centenary celebration in 2023, Türkiye has made its name in the global rankings and secured a pioneering position in the field. There are currently over 2000 thermal springs and wells, with drilling depths of up to 5 km, and direct use applications have resulted in 6300 MWt. This includes district heating (1422 MWt), greenhouse heating (2417 MWt), heating for thermal facilities, hotels, etc. (680 MWt), balneological use (1763 MWt), agricultural drying (9.5 MWt), cooling (0.35 MWt) and geothermal heat pump applications (8.5 MWt). The total installed capacity has reached 1710 MWe and the carbondioxide that is produced is used in the production of 400,000 tonnes of dry ice per year.

In 1982, the first Turkish-Italian seminar on geothermal energy was held. The first geothermal electricity was produced in 1984. In 1999, the Izmir-Balçova geothermal heating system was

selected as a best practice by the European Geothermal Energy Council (EGEC). The World Geothermal Congress (IGA-TGA) was held in 2005 and the European Geothermal PhD Days were held in Türkiye for the first time in February 2020. In April 2023, with the inauguration of the first geothermal-solar hybrid power plant, Türkiye has reached another significant milestone, demonstrating its commitment to innovative and sustainable energy solutions as it looks to the future.

1. **Introduction**

Geothermal is a domestic, renewable, environmentally friendly, base-load resource with multiple integrated uses such as electricity generation, district heating, greenhouse heating, spa and thermal tourism, liquid CO_2 and dry ice production, fruit and vegetable drying, production of various minerals, and aqua fishing. It is technically and economically attractive. If appropriate technology is used and reinjection is carried out, there is no discharge of uncondensed gas.

In Türkiye geothermal areas are mainly located along the main grabens in Western Anatolia, along the North Anatolian Fault Zone, and in volcanic regions in Central and Eastern Anatolia (Figure 1).

The utilization of geothermal potential in Türkiye extends far beyond the foundation of the Republic. For example, the ancient city of Hierapolis, recognized as a UNESCO World Heritage Site, was spa town and the use of geothermal resources here dates to the Roman Empire. In these lands, geothermal resources were used by Hittites, Romans, Seljuks, Ottomans and Turks for health and cooking purposes in BC and AD, and some of them were built spas, some of which are still in use. This study focuses on the utilization of geothermal resources in the first hundred years of Turkish Republic starting from 1923 to 2023.

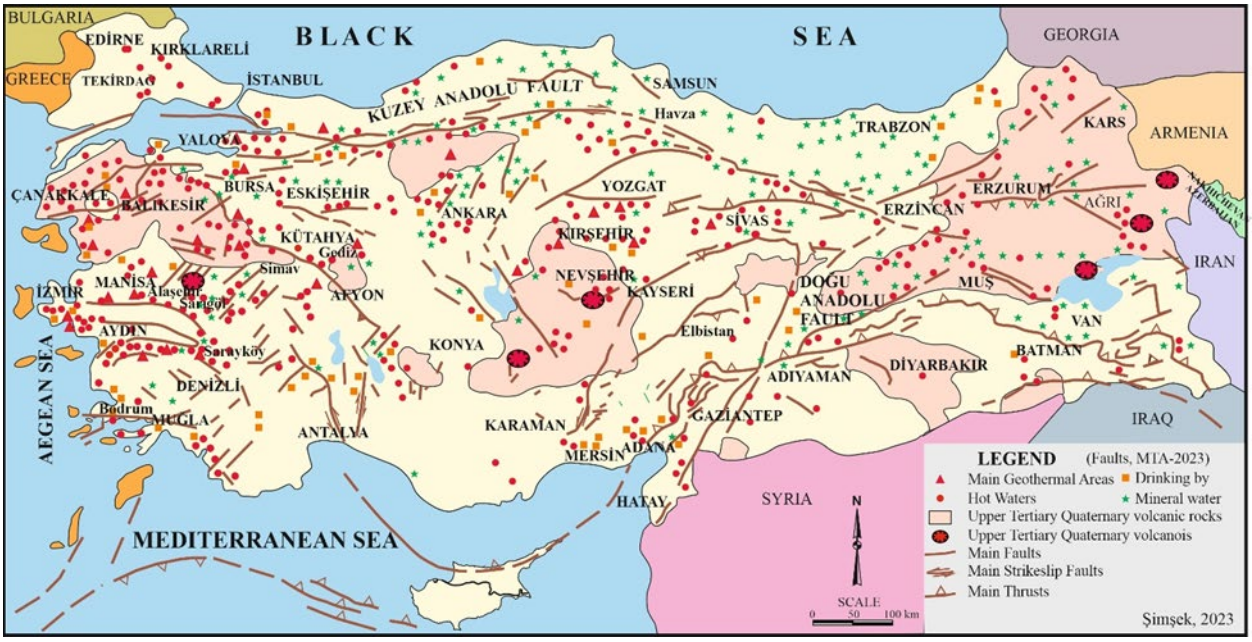

Figure: Türkiye map showing the main geothermal sites with main neotectonic lines, hot spring distribution, and volcanic areas (Şimşek, 2023).

2. Past

In the early years of the Republic, geothermal hot springs were used for spa, treatment and health purposes. The first law on the exploitation of hot springs was passed in 1926, just three years after the foundation of the Turkish Republic, reflecting the founder's vision of the vital role of earth sciences. This foresight led to the establishment of the Institute of Mineral Research and Exploration (MTA) in 1935, when the Republic was only 12 years old. The vision also included sending the country's youth abroad for higher education and training cadres with a strong belief in science (Law No. 1416). The MTA, as one of the institutions employing these cadres, carried out surveys and inventory studies throughout the country.

In some regions, natural springs continued to be used in traditional spas, and in the 1970s they were also used for simple greenhouse heating. The first geothermal borehole was drilled by MTA in 1963 in Izmir-Balcova. The well-bottom temperature of the 40-meter deep well was measured at 124°C. The well was in production for a few days but was closed due to scaling and then abandoned as it was considered unviable.

In 1968, with the financial and technical support of the United Nations, drilling was started in the Denizli Sarayköy-Kızıldere geothermal field as part of the geothermal exploration for electricity generation under the United Nations - UNDP project of MTA. A 200ºC reservoir was discovered and 2-decare geothermal greenhouse was heated as a pilot application. A 0.5 MWe pilot geothermal power plant was designed, built and commissioned using MTA facilities. Fundamental information and experience on geothermal scaling, corrosion, non-condensable gases (NCG), etc. were gained from this power plant. This power plant provided free electricity to the villages of Kızıldere, Karatas and Savcılı for 7 years. The work carried out at these stages are all exploration investments and geothermal services of MTA.

In the following years, exploration and drilling continued and in the light of these developments, the first commercial power plant with a gross capacity of 20 MWe was established by the Turkish Electricity Authority (TEK in Turkish initials) in 1986. Subsequently, an integrated liquid carbon dioxide-dry ice (CO_2) factory was established by the private sector. This factory cleaned and liquefied the carbon dioxide released into the air by the geothermal power plant and distributed it all over Türkiye. In those years, this factory was a first in the world. Today, its total capacity is 400.000 tonnes/year.

Subsequently, MTA carried out geothermal survey and exploration drillings in hundreds of places such as Afyonkarahisar, Gönen, Simav. In 1983, the downhole heat exchanger was applied in Izmir-Balcova and the heating of Dokuz Eylül University hospitals, campus and thermal facilities was provided. It paved the way for the heating of Afyonkarahisar city centre by conducting heat exchanger tests. In 1974, a 1000m deep well was drilled in Afyonkarahisar. Under the conditions of the time, 1000m was an important depth for geothermal energy.

In addition to electricity generation, district heating, central heating, CO_2 production, the use in spas and thermal facilities has gained momentum and the first 5-star thermal touristic facility of the private sector was established in Afyonkarahisar. Gönen became the first town geothermally heated in 1986 and it was followed by Simav, Kırsehir, Balcova, Narlıdere, Edremit, Kızılcahamam, Kozaklı, Sarayköy, Sandıklı and Bigadic. District heating has been achieved using 55-60°C geothermal fluids and this has had a global effect. In 1999, İzmir-Balcova geothermal

heating system was selected as the best practice by the European Geothermal Energy Council (EGEC). District heating has been an investment that has made great contributions to the benefit of the people, the environment and raising the standard of living. However, it has slowed down after the 2000s.

The Turkish Geothermal Association (TGA), which was established in 1992, has organized congress and conference trips to various countries of the world such as Germany, France, Italy, Japan, Japan, USA, Iceland for the promotion of geothermal, ensured the participation of ministers, members of parliament, governors, mayors, bureaucrats and engineers in these countries, organized technical trips and carried out promotional activities. All these expenses were covered by TGA and its sponsors.

MTA continued exploration, discovered geothermal fields by taking risks and started the preparation of geothermal law through the commissions established. However, the biggest development came after the World Geothermal Congress (WGC2005), organized by the International Geothermal Association (IGA) and the Turkish Geothermal Association (TGA) in Antalya in 2005. 2000 people from Türkiye and the world attended this congress. In addition, the participation of ministers, member of parliaments, scientists and bureaucrats was ensured and the importance of geothermal was understood. Thereupon, the Law No. 5686 on Geothermal Resources and Natural Mineral Waters was enacted as a stimulus law. In addition, the model of leasing the geothermal sites, explored and discovered by MTA, to the private sector for 30 (+10) years with 1 or 2 wells drilled was accepted and appreciated by the Turkish private sector. As a result, MTA has leased the fields for very large amounts (up to $109 million). Additionally, MTA has conducted hundreds of tenders and leased low temperature fields to the private sector.

The Turkish private sector has acted swiftly, drilled additional production and reinjection wells, prepared feasibility studies and projects, started investment, and constructed and commissioned a power plant in record time. Congratulations and thanks are due to the State and Government of the Republic of Türkiye, the Ministry of Energy and Natural Resources, the universities, the private sector and, of course, MTA.

The milestones in Turkey's geothermal history are presented in chronological order in Table 1.

3. Present

After the Law No. 5686 on "Geothermal Resources and Natural Mineral Waters" entered into force in 2007, significant developments have been achieved and investments have started as mentioned in the previous chapter. Power plants have started to be established rapidly and the adventure that started with 0.5 MWe pilot power plant and 20 MWe commercial power plant has reached 1710 MWe of installed capacity today, ranking 1st in Europe and 4th in the world. 3-4% of country's electricity production is met from geothermal resources. Table 2 presents the full list of geothermal power plats active in Türkiye.

Geothermally heated greenhouses have gained momentum and importance in the last 10 years due to the importance of food security, economic use of geothermal heat, export and employment. Today it has exceeded 10400 acres and ranks 1st in the world.

Table 1: Year-based development in Turkish geothermal sector.

Year	Development
1926	A law was enacted regarding hot springs.
1935	The General Directorate of Mineral Research and Exploration (MTA) was established.
1947	'Türkiye Mineral Waters' book was prepared (Çağlar, 1947).
1948	'Tectonics of Aegean Region, Hot Springs, Mineral Water Sources' was published (Pınar,1948).
1960s	MTA General Director Dr. Sadrettin Alpan emphasized geothermal research.
1962	The first geological surveys were conducted in Balçova.
1963	The first geothermal drilling was carried out in Balçova.
1966	Several studies including thermal mineral resources were published (Erentöz and Ternek, 1966).
1967	The Western Anatolia and Kızıldere geothermal exploration project was initiated by MTA-UNDP.
1968	The first high-T reservoir was discovered at 198°C at a depth of 540 meters in Kızıldere.
1974	The first geothermal power test plant with a capacity of 0.5 MWe was established in Kızıldere.
1975	The book 'Türkiye Mineral Waters' was published by Istanbul University Faculty of Medicine.
1979	The first draft geothermal law was prepared by MTA.
1982	The Germencik (232°C) and Tuzla (174°C) fields were discovered through drilling.
1982	The first Turkish-Italian seminar on geothermal energy took place.
1982	The first geothermal regulation was included in the Mining Law.
1983	The first geothermal heating system with an in-well heat exchanger was established in Balçova.
1984	The first GEPP with single flash steam technology was commissioned in Kızıldere (15 MWe) by TEK.
1986	The first CO_2 factory was established in Kızıldere.
1987	The first centralized geothermal district heating system was initiated in Gönen.
1990	The scaling problem was resolved, leading to increased investments in heating applications.
1990s	Heating became widespread, started in Afyon, Kırşehir, Balçova, Narlıdere, Edremit, Bigadiç, Salihli.
1999	Balçova geothermal heating system was selected as a best practice by EGEC.
2000	After earthquakes in 1999, TÜBİTAK, universities, MTA monitored field (Simsek&Yildirim, 2000).
2002	The first reinjection studies were carried out in the Kızıldere.
2003	The Bank of Provinces (İller Bankası) began research and credit support for geothermal projects.
2005	The World Geothermal Congress (WGC-2005) was held in Antalya. MTA inventory was published.
2006	The first private sector plant (Mege) and binary system power plant were established in Salavatlı.
2007	The Geothermal Resources and Natural Mineral Waters Law was published, and the related regulation
2008	Kızıldere was privatized.
2009	The first double flash steam power plant was established in Germencik (47.4 MWe).
2011	MTA auctioned off the fields it had discovered to allow private sector exploration and operation.
2013	A new 80 MWe power plant was commissioned in the Kızıldere.
2014	The total installed capacity of geothermal power plants reached 400 MWe by the end of 2014.
2015	The installed capacity in Ömerbeyli reached 162 MWe.
2016	Türkiye's heat flow data were added to IRENA Atlas.
2017	Türkiye joined 1 GW country club. OrmaTürk started domestic manufacturing.
2020	11th European Geothermal PhD Days was hosted for the first time in Türkiye.
2022	awarding of WING Türkiye with the WING Global Operations role.
2023	inauguration of the first geothermal-solar hybrid power plant by Zorlu Energy

Approximately 40000 houses in İzmir-Balcova, 30000 houses in Afyonkarahisar, hotels, greenhouses and university campuses have started to be heated with geothermal energy. The total residential heating capacity has increased to 158000 housing equivalents.

According to the type of evaluation of geothermal resources in direct applications (non-electricity), it is in the 2nd - 4th position in the world. This success of Türkiye has been the subject of all conferences, aroused curiosity and appreciation.

Türkiye started to be a part of international projects such as GEOCOND, GECO, GEOENVİ, GEORISK, GEOSMART, REFLECT Horizon 2020 projects. For Horizon Europe projects, Türkiye signed an agreement to participate with same conditions as EU members (Directorate for EU Affairs, 2021).

Therefore, the biggest driving forces in the development of geothermal in the country can be listed as the organization of the World Geothermal Congress in 2005, followed by the introduction of a geothermal law and incentive system, scientific and technical monitoring of geothermal developments in the world by scientists in Türkiye, and organizing seminars, summer schools, national symposia and training courses. In addition, the fact that MTA took the risk of exploring and discovering the fields and opening them up to the Turkish private sector through competitive bidding has ensured progress and development.

The economic activity contribution of geothermal to the Turkish National Economy through electricity generation, geothermal district heating, greenhouse heating, carbon dioxide production, thermal tourism and others has been calculated as approximately 172 billion TL per year by 2023 (October 2023 in US$). Total (direct/indirect) employment in the sector is 240.000 people.

In addition, according to the separate calculation of all existing geothermal assessments according to the electricity tariff and state-supported heating tariff, it is approximately 78 billion TL natural gas equivalent (October 2023). In addition, if all existing assessments are made with natural gas, it will be approximately 5 billion m^3/year natural gas equivalent. (Note: October 2023 average US dollar value is taken as 28 TL.)

In Türkiye, as of 2023, a depth of 5000m has been reached. The number of thermal resource outputs and wells has exceeded 2000. As a result, as of 2023, 100th anniversary of Turkish Republic, Türkiye has reached an important position in the world with the studies carried out by the government, technical staff, engineers, employees and investors for the development of geothermal resources in the country. However, due to the size of the geothermal potential, it is of great importance to accelerate and support continuous exploration and development activities in order to meet the energy needs of the country and to benefit from these domestic resources socially and economically.

Here is the Türkiye's geothermal technical potential according to various estimations:

- The geothermal technical heat potential is 107000 MWt. This potential is equivalent to approximately 13 million house heating or 400 thousand acres of greenhouse heating or approximately 90 billion m^3/year natural gas equivalent.
- Technical economic electricity potential is 9000 MWe.

- EGS/HDR (Enhanced Geothermal System/Hot Dry Rock) technical economic potential is 40000 MWe.

Now, a new geothermal law regulating exploration, operations and increasing non-electricity geothermal incentives has been initiated by MENR (ETKB in Turkish initials) and is expected to be finalized.

Table 2: Full list of geothermal power plants active in Türkiye and their characteristics.

Region	Plant - Company	Start Year	Number of Units	Unit Type	Total Installed Capacity (MWe)
Denizli	Kızıldere (Zorlu)	1984/2003	2	1F, 2F+B	80 + 15
Aydın	Salavatlı Dora 1,2,3 (MeGe)	2006/2013	3	B	50.86
Aydın	Germencik (Gürmat)	2009	1	2F	47.4
Çanakkale	Tuzla (Enda)	2010	1	B	7.5
Aydın	Hıdırbeyli (Maren)	2011/2013	3	B	92
Aydın	Pamukören (Çelikler)	2013	1	B	45
Denizli	Kızıldere (Bereket)	2007	1	B	6.85
Manisa	Alaşehir (Türkerler)	2014	1	B	24
Aydın	Gümüşköy (BM)	2014	1	B	6.6 + 6.6
Denizli	Gerali (Değirmenci)	2014	1	B	2.52
Aydın	Germencik (Gürmat)	2014	1	B	22.5
Denizli	Tosunlar (Akça)	2015	1	B	3.5
Aydın	Pamukören (Çelikler)	2015	1	B	22.5
Aydın	Germencik (Gürmat)	2015	3	2B + 2F	22.5 + 22.5 + 47.4
Manisa	Alaşehir (Zorlu)	2015	1	B	45
Aydın	Umurlu (Kar-Key)	2015	1	B	12
Denizli	Tekkehamam (Greeneco)	2015	1	B	12.8
Manisa	Alaşehir – Kemaliye (Enerjeo)	2015	1	B	25
Aydın	Germencik 2 (Gürmat)	2016	1	2F	25
Aydın	Sarayköy (Zorlu)	2016	1	2F	50
Denizli	Sarayköy 2 (Zorlu)	2017	1	2F	65
Manisa	Alaşehir 2 (Zorlu)	2018	1	B	40
Aydın	Efeler (Gürmat)	2018	1	2F	162
Manisa	Salihli (Zorlu)	2019	1	2F	60
Aydın	Kızıldere 3 (Zorlu)	2020	1	2F	165
Total					**1710.03**

Legend: 1F = Single flash, 2F = Double flash, B = Binary

4. Future

Table 3 represents the 2030 projections in the country.

Table 3: Türkiye's 2030 projection for geothermal applications and the additional investment required to reach this target

Geothermal Application	Estimated Targets for 2030	Additional Investment Required (USD) (2024 to 2030)
Electricity Production	3000 MWe (24 billion kWh)	5.4 billion
Heating (residential, hotel, etc.)	5000 MWt (Equivalent to 500000 Households)	1.2 billion
Greenhouse Heating	5600 MWt (Equivalent to 24,000 Acres)	2.5 billion
Drying, etc.	80 MWt (Equivalent to 300000 tons/year)	30 million
Thermal Tourism (Renovation and Development)	2000 MWt (520 Facilities including Thermal Springs, Health Tourism Facilities)	1.0 billion
Cooling	350 MWt (Equivalent to 20000 Households)	140 million
Fishing and Other Uses (Mineral Extraction, etc.)	400 MWt	100 million
Total Investment		10.37 billion

Natural Gas Equivalent of All Geothermal Uses (additional): 6.8 billion USD/Year

Economic Impact of Geothermal Electricity Production, Heating (residential, thermal facilities, etc.), Thermal Tourism (thermal springs), Greenhouses, Drying, Fishing, and Other Applications by 2030: 420 billion TL/Year (as of October 2023)

Direct and Indirect Employment Created by 2030: 420000 People

Further suggestions to pursue the development in the country can be listed as follows:

- Strengthen Public-Private Partnerships: Encouraging collaboration between government agencies, private companies, and research institutions can drive innovation and increase investment in geothermal projects. Public incentives and subsidies can be used to attract private sector participation.
- Invest in Research and Development: Supporting R&D initiatives focused on improving geothermal technologies, such as enhanced geothermal systems (EGS) and resource assessment methods, can help unlock new resources and increase efficiency.
- Expand Workforce Training: Developing specialized training programs and educational initiatives to build a skilled workforce will ensure that the sector has the expertise needed for advanced geothermal projects.

- Promote International Collaboration: Engaging in international partnerships and knowledge exchange with countries. Türkiye can be an international hub for geothermal energy as it enables in-situ learning, observation of different geological settings and different utilization ways and holds a geopolitical position between Europe and the rest of the world.
- Explore Hybrid Energy Solutions: Integrating geothermal with other renewable energy sources, such as solar or wind, can create more resilient and efficient energy systems, maximizing the potential of available resources.
- Establish a 'National Data Repository and Processing Center for Geothermal Resources' in Türkiye (Turan, 2019) while making subsurface data older than 10 years open to public (i.e. Germany).

5. Conclusion

The Turkish geothermal sector has evolved significantly from its early exploration phases in the 1970s to becoming a global leader in geothermal energy production by the 2020s. This growth has been driven by strategic regulatory changes, increased investment, and a strong emphasis on sustainable practices. Moving forward, Turkey's focus on innovation and efficiency will likely further enhance its position in the global geothermal market.

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