Bull. Min. Res. Exp. (2023) 171: 69-90

Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr

The potential, utilization and development of geothermal energy in Türkiye

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Research Article

Keywords:
Geothermal Energy, Türkiye, Strategy Report, HDR/EDGS, Future Policy.

Received Date: 10.08.2022
Accepted Date: 03.01.2023

ABSTRACT

Geothermal energy is a natural resource that can be utilized directly or by converting to other types of energy. Considering the diversity of the geological structure of Türkiye, the geothermal systems have developed depending on young tectonic and volcanic active rock. Western and Central Anatolia are especially rich in geothermal resources. The geothermal well with the hottest well-bottom temperature was drilled in Central Anatolia, and the well-bottom temperature was measured as 341°C at a depth of 3845 meters. In 2022, Türkiye's electricity generation capacity and the total installed direct heat use reached 1663 MWe and 5113 MWt, respectively. Considering Anatolia's Curie depth and heat flux, the probable thickness of the batholith can be regarded as 10 km. For example, the total granitoid area of Western Anatolia is 4221 km^2 and at least 2% of this granitoid can provide approximately $8x10^7$ MWh of electricity by Enhanced Deep Geothermal Systems (EDGS). When all granites in Türkiye are considered, it is expected that the future capacity of Türkiye will be much higher with drilling research and development studies and the discovery of new fields. This capacity will exceed 100.000 MWt levels in the medium term, especially with the addition of EDGSs.

1. Introduction

The ever-increasing population density, industrialization and rising living standards increase the energy demand. Fossil fuels meet a large part of the energy requirement worldwide. The fact that fossil fuels pose risks to the environment and will run out in the future has shown that renewable energy sources should replace them. Problems that concern all humanity, especially global warming and climate change, are increasing. As emphasized in the Paris Agreement, it has become necessary to move away from traditional carbon-based energy sources as primary energy resources worldwide to keep the global temperature increase below 2°C. Therefore, in recent years, all countries have focused on developing new, renewable, and sustainable energy sources. Geothermal energy is one of the renewable energy sources. Geothermal energy is a natural resource that can be utilized directly or by converting it to other types of energy. It can also be transported through fractures and cracks in the rock by the water, steam, and gas energy created by the heat accumulated in various depths of the Earth's crust.

Using geothermal energy for different purposes such as electricity, residential heating, greenhouses,

Citation Info: Şener, M. F., Uzelli, T., Akkuş, İ., Mertoğlu, O., Baba, A. 2023. The potential, utilization, and development of geothermal energy in Türkiye. Bulletin of the Mineral Research and Exploration 171, 69-90. https://doi.org/10.19111/bulletinofmre.1229381

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thermal tourism, fishing, and heating roads has become widespread in many countries (Figure 1). According to the change in renewable-sourced, domestic installed power in Türkiye over the years, significant increases were achieved in power capacity between 2006 and 2022 thanks to the effective incentive mechanisms. Geothermal installed power, calculated at 23 MWe in 2006, increased to 1663 MWe as of 2022 (EPDK, 2022).

Türkiye is among the leading countries in terms of existing geothermal energy resources and the use of these resources, ranking 4th globally in energy production and 2nd in the world for direct use (Şener et al., 2022). In addition, according to the 2020 data from the General Directorate of Mineral Research and Exploration (MTA), the usable capacity of Türkiye is approximately 38.000 MWt. Due to the wells whose production data is not documented in the official records, the total current capacity is not known precisely. Nevertheless, according to the data obtained, the total possible theoretical heat potential is 62.000 MWt. Considering the potential of geothermal energy, it creates an inter-sectoral synergy with the heat energy alternative regarding supply security. It offers implementation in urban heating, agriculture, thermal tourism, manufacturing, and urban infrastructure opportunities. In this context, scientific studies were carried out in various regions of Türkiye (Eşder and Şimşek, 1977; Filiz, 1982; Yılmazer, 1984; Şimşek, 1985; Mutlu and Güleç, 1998; Gemici and Filiz, 2001; Gemici and Tarcan, 2002; Özgür, 2002; Baba et al., 2003; Tarcan et al., 2005; Gültekin et al., 2007; Tayfur et al., 2008; Baba et al., 2010; Özkan et al., 2011; Karakuş and Şimşek, 2013; Aksoy, 2014; Tarcan et al., 2016; Uzelli et al., 2017; Şener et al., 2017; Hatipoğlu Temizel and Gültekin, 2018; Şener, 2019; Baba et al., 2019; Şener and Baba, 2019; Şener, 2019; Aydın et al., 2020; Pasvanoğlu, 2020; Uzelli et al., 2021; Şener et al., 2021; Uzelli et al., 2021; Baba and Chandrasekharam, 2022). Along with significant progress in geothermal electricity supply, Türkiye also has great potential to be used in heat energy supply. This study includes Türkiye's current geothermal potential, usage areas, projections, and suggestions for the future.

2. Current Situation of Energy Resources

The world's total energy supply (TES) increased approximately 2.6 times between 1971 and 2018 (REN21, 2021). Most of this energy consumption belongs to developed countries such as the United States of America (USA), China, and Russia. On the other hand, although oil, one of the fossil fuels, still maintains its stability, the consumption rate decreased from 44% to 32%, while natural gas increased from 16% to 23% and took third place. As of 2021, oil, coal, and natural gas are still the world's primary energy sources and correspond to approximately 80.2% of the

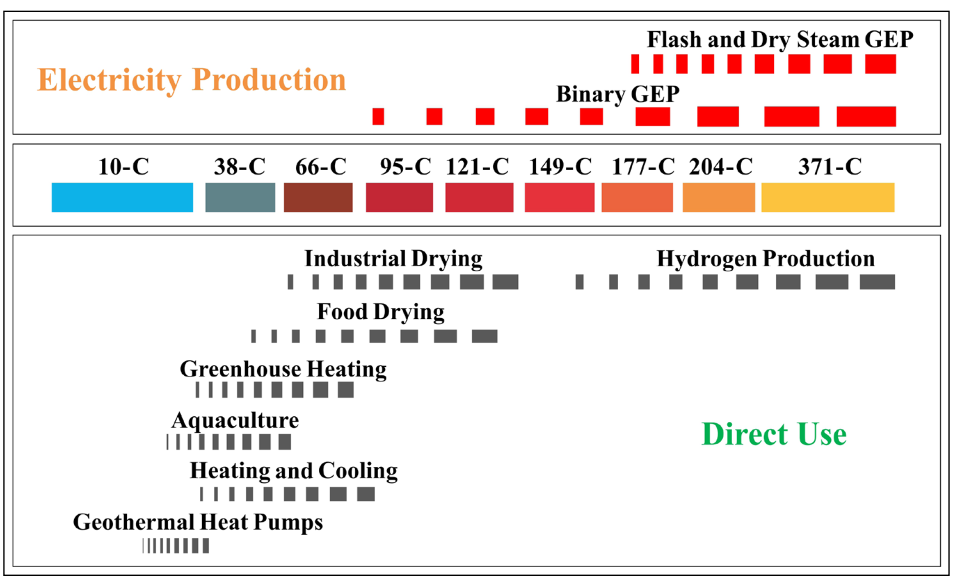

Figure 1- Direct and indirect usage of geothermal energy resources (modified from Lindal, 1973).

total energy consumption. According to the data, at the end of 2019, the rate of renewable energy sources is around 11.2% (REN21, 2021).

In 2020, electricity generation from geothermal sources, one of the renewable energy sources, reached a total of 97 TWh, and the direct use of geothermal heat reached approximately 128 TWh. In that year, geothermal power capacity grew slightly compared to recent years (partly due to disruptions caused by the Covid-19 pandemic), and almost all new facilities are located in Türkiye (REN21, 2021). Although the industry continues to face challenges owing to the pandemic, a total of 246 MW of additional capacity has been added worldwide with the inclusion of countries such as Colombia (small-scale ORC units from co-produced oil) and Taiwan (a 4.2 MW power plant) (Thinkgeoenergy, 2022).

$40 billion was invested in new geothermal energy developments worldwide from 2010 to 2020. By the end of 2021, the total installed geothermal power generation capacity was 15,854 MW, with an increase of 246 MW compared to 2020 (Thinkgeoenergy, 2022). Today's installed geothermal capacity is dominated by the USA with approximately 3722 MWe, followed by Indonesia, the Philippines, Türkiye, and New Zealand. Türkiye's share in electricity generation is around 11% (Şener et al., 2022). The top 10 geothermal producers contribute almost 90% of the world's total market, and many countries, especially Europe, plan to invest in geothermal energy soon.

Considering the direct use of geothermal energy for thermal heat applications, only four countries (China, Türkiye, Iceland, and Japan) account for three-quarters of the energy consumed. Direct use has grown by around 8% recently, with heating being the primary driver (Lund and Tóth, 2020).

Geothermal power generation plants are essential for Türkiye. With global warming and pandemic conditions, fossil fuel power plants have faced emission and supply problems. In addition, solar, wind, and hydraulic power plants have also been affected by climatic and regional meteorological events and experienced differences in their production (EPDK, 2019; 2022). The capacity factor, expressed mathematically, is the division of the total energy produced by a power plant in each period by the total capacity energy produced. Considering the capacity factor of geothermal power plants (GPP), the highest capacity factor among renewable energy sources belongs to geothermal power plants, according to the August 2021 data of Energy Markets Management Inc. (EMMI) (EPİAŞ, 2021; Selenka, 2021).

According to the capacity factor data for plants in Türkiye, wind power is 35.1%, solar power is 26.8%, hydroelectric power is 20.6%, biomass is 49.7%, and the GPP is 60.1% (Figure 2). The fact that power plant types have variable capacity factors has been one of the most critical indicators that geothermal power plants should be seen as the base load for power plants in Türkiye.

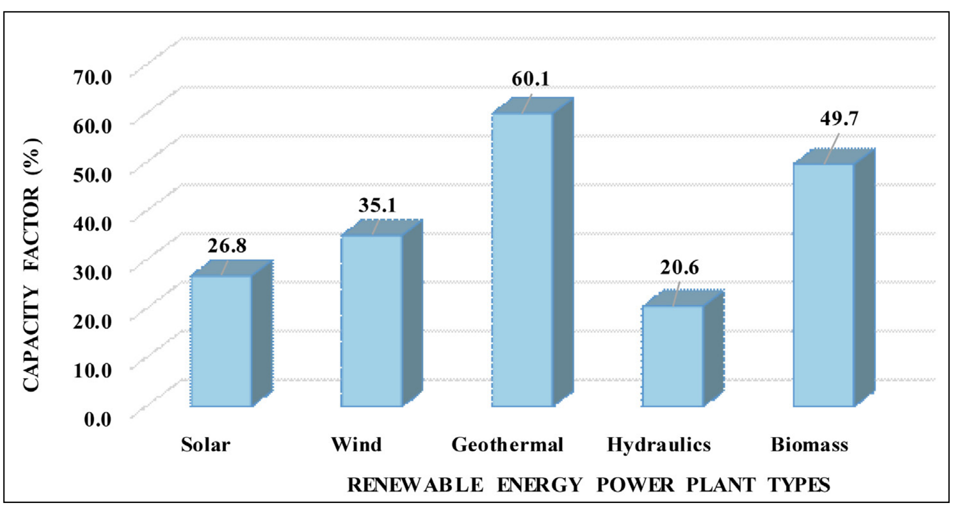

Figure 2- Renewable energy sources and capacity factors (Selenka, 2021).

2.1. Hydrothermal Geothermal Systems

The MTA research in 1960 is considered the beginning of Türkiye's geothermal energy research. Since than fields containing fluids suitable for different purposes, such as energy production and direct use, have been discovered. The period between 1970-2000 is primarily known for the reconnaissance of high-temperature reservoirs (Akkuş, 2017).

There are currently 415 geothermal fields with a temperature of 30°C and above. The number of geothermal fields includes both natural resources and drilled wells. According to their distribution, based on natural spring and well bottom temperature values, 84% consists of medium and low-temperature areas, and 16% consists of high-temperature areas.

The Western Anatolian Extensional Neotectonic Zone is well-known for its geothermal resources and numerous hot springs. The geothermal fields around Manisa, Denizli, Aydın, İzmir, and Muğla constitute the essential resources in this region (Figure 3).

The geothermal resources in İzmir Bay and its northern part were formed under the control of both the extensional tectonic regime and strike-slip faults (İZKA, 2022). In some regions, such as Manisa (Kula), Afyon, and Çanakkale, the geothermal system can also be seen to be affected by volcanism and magmatism. In addition, geothermal systems in Çanakkale, Balıkesir, Bursa, Bolu, and Yalova are located within a neotectonic region.

Geothermal areas are also located in the Central Anatolian Region, under the influence of the North Anatolian Fault Zone (NAFZ) to the north, the East Anatolian Fault Zone (EAFZ) to the east, and the Tuzgölü Fault Zone (TGFZ) to the west. Additionally, Tertiary granite intrusions, local and regional block faulting, and Pliocene volcanism form the geothermal systems (Şener et al., 2017). Ankara, Niğde, Yozgat, Nevşehir, Kırşehir, Aksaray, and Sivas geothermal fields are the most important geothermal resources in this region (Şener, 2019).

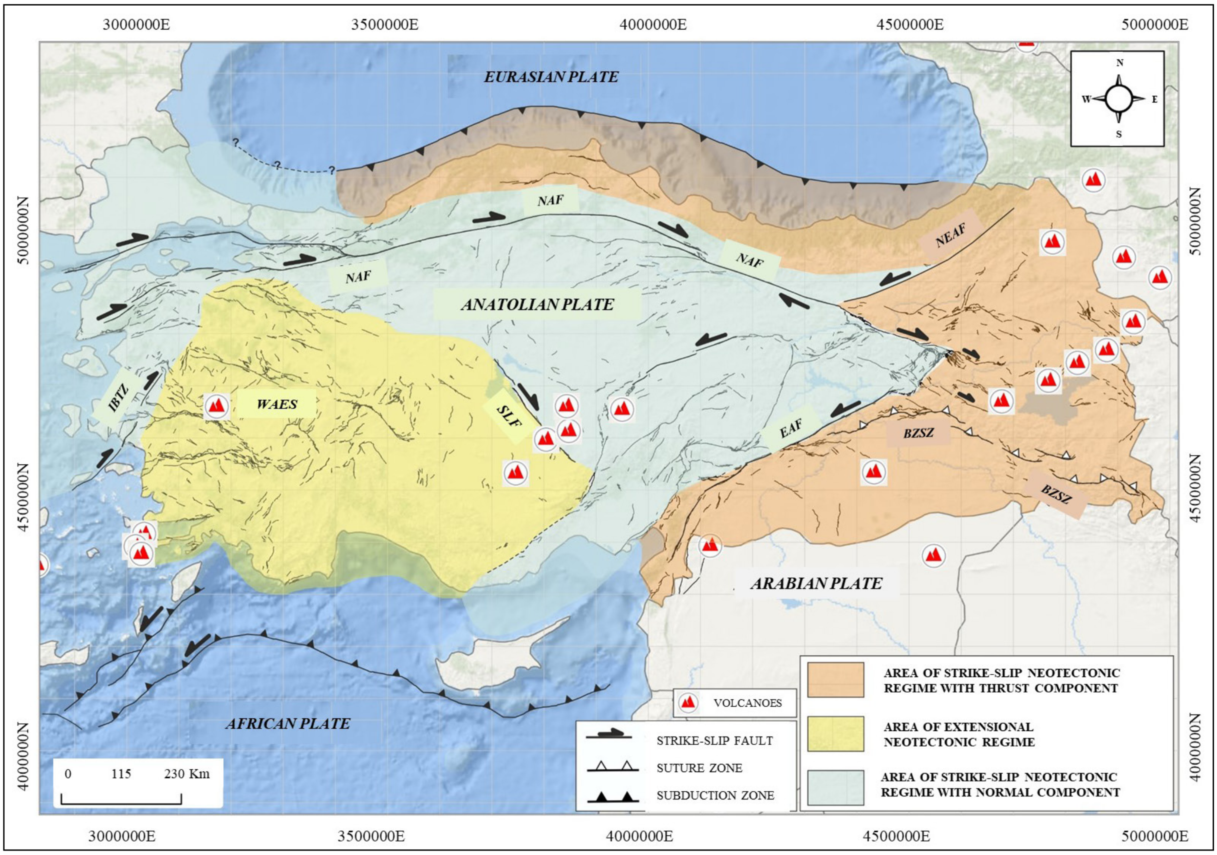

Figure 3- Neotectonic regions and structural features of the Anatolian Plate (modified from Baba et al., 2021, after Şengör and Dyer, 1979; Barka, 1992; Bozkurt, 2001; Koçyiğit and Özacar, 2003).

A dominant strike-slip neotectonic regime controls the geothermal systems along the NAFZ up to Bingöl-Karlıova and around the EAFZ. Geothermal fields in Hatay, Mersin, Kahramanmaraş, Osmaniye, Elazığ, Bingöl, and Muş were primarily formed under the control of EAFZ and its segments. In addition, the Bitlis-Zagros Suture Zone (BZSZ) and young volcanism areas have enriched the Southeast regarding geothermal resources and other geological events (Baba et al., 2021; Şener et al., 2021; Uzelli et al., 2021).

Many tectonic, volcanic, and magmatic factors such as caldera, domes, extension cracks, and magma chambers are located in the eastern part of the Anatolian Plate and are limited by the control of BZSZ and EAFZ. The essential areas formed under the compressional tectonic regime are Erzurum, Kars, Ağrı, Van, Bitlis, and Muş (Uzelli et al., 2021).

In the Southeastern Anatolia Region to the south of the BZSZ, the Karacadağ volcanism and compressional tectonics have led to the formation of critical geothermal fields in Gaziantep, Adıyaman, Diyarbakır, Şırnak, Batman, and Siirt. Since the Southeastern Anatolia Region is an oil region, it has been studied by many researchers. Medium-high temperature geothermal fluids have been found in many oil wells drilled around Adıyaman, Diyarbakır, and Batman. In this study, it has been determined that the wells that have not been discovered and are not currently in use are quite suitable and vital resources for geothermal applications in the region. It has been emphasized that they should be reintroduced to the region's economy in the future (Baba et al., 2019).

2.2. Hot Dry Rock (HDR) - Enhanced Deep Geothermal Systems (EDGS)

Hot dry rock can be defined as impermeable or semi-permeable rocks that reach a high temperature created by themself, such as granite-granodiorite. Using engineering methods, the utilization of unconventional geothermal resources to obtain an economical and appropriate amount of heat is called Enhanced Deep Geothermal Systems (EDGS).

The Anatolian Plate is in an important geological position for obtaining geothermal energy from hot and radiogenic granitoid using EDGS technology (Figure 4). EDGS is based on the principle of cracking the impermeable rocks at depth with pressure, creating an artificial reservoir, and then sending water to the fractured stones and using the energy of the heated water.

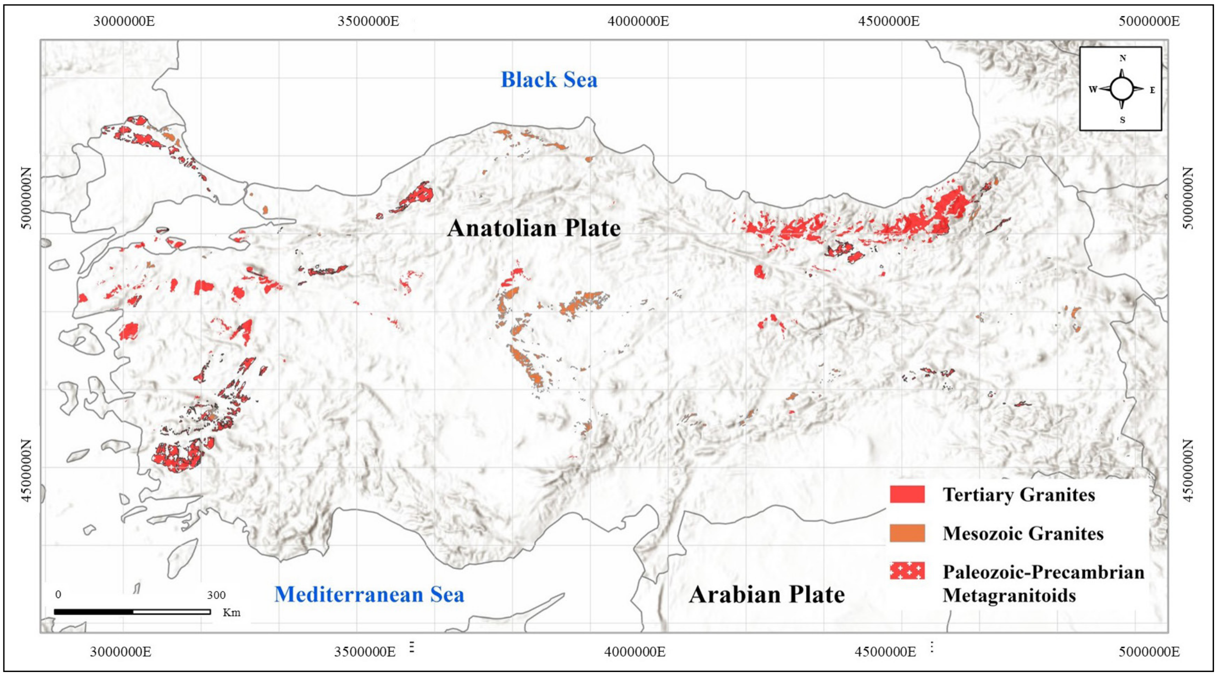

Figure 4- Granitoid distribution of Anatolian Plate (Chandrasekharam and Baba, 2021).

The following criteria must be carried out for successful EDGS;

- The underground crack network is sufficient for high temperatures.
- The permeable area should be large enough to provide an adequate amount of fluid flow between the wells and the contact surface of the fluid, and the hot rock should be large enough to allow the rock to heat the fluid without cooling.
- Geothermal energy can be brought to the surface and used in electricity generation and/or heating.

Since granites in Türkiye contain high concentrations of U, Th, and K, they have above-average calorific values and generate significant heat. The heat generation value (A) is obtained based on the Rybach Equation:

$$A(\mu W/m^3) = 10^{-2} * \rho * (9.52C_U + 2.56C_{Th} + 3.48C_K) \quad (1)$$

($\rho(g/cm^3)$: density of the rock; C_U, C_{Th} and C_K: uranium (ppm); thorium (ppm) and potassium (%) concentrations).

Surface heat flux values are calculated using the Lachenbruch (1968) Equation:

$$Q = Q_0 + D * A \quad (2)$$

(Q: heat flux at the surface; Q_0: the initial value of a heat flux; D: rock thickness; A: radioactive heat generation).

Considering the Curie depth and heat flux of Western Anatolia, the probable thickness of the batholith can be regarded as 10 km. Considering that the total granitoid area of Western Anatolia is 4221 km^2, at least 2% of these granitoid rocks can provide electricity by EDGS, then EDGS. Electricity generation potential in Western Anatolia is approximately $8x10^7$ MWh. When all granites in Türkiye are considered, it is clear that the latent energy which could be obtained is very high (Chandrasekharam and Baba, 2021, 2022).

In the Bozköy district of Niğde, a 3845-meter-deep well was drilled by a private company in 2016, and the highest well-bottom temperature (341°C) was measured. Hence the highest well-bottom temperature indicates that the EDGS energy potential of Central Anatolia is high and it is predicted that the geothermal system in Central Anatolia can be developed using EDGS Technologies (Şener et al., 2017).

2.3. Distribution, Utilization, and Potential of Geothermal Energy Resources in Türkiye

Türkiye has more than 2000 wells and 415 geothermal fields, in which the lower temperature limit is accepted as 30°C. In 2022, Türkiye's electricity generation capacity reached 1663 MWe, and the total direct heat use (installed thermal power) reached 5113 MWt. Considering the diversity of the geological structure of Türkiye, the geothermal systems have developed depending on young tectonic and volcanic active rock. Western and Central Anatolia are especially rich in geothermal resources (Figure 5). The geothermal well with the hottest well-bottom temperature was drilled in Niğde (located in Central Anatolia), and the well-bottom temperature was measured as 341°C at a depth of 3845 meters. Different parts of the country, such as Nevşehir, Sivas, Yozgat, Erzurum, Ankara, Batman, Van, and Şırnak, also have medium-high temperature springs.

In this study, the fluid temperature and flow rate in 2089 wells with accessible data were taken as the basis. According to the obtained data, the capacity is around 36025.81 MWt. However, because of the differences in the first measurement values required for the license in the well data, values may have changed later in the production process. The well data not being shared for commercial reasons as well as unsaved well data, the capacity will be above the registered value.

According to the distribution of the number of wells by region, the Aegean Region ranks first with 1635 wells, followed by Central Anatolia and Marmara (Figure 6). In terms of capacity, the Aegean Region ranks first by far with 34.920 MWt. The 673 wells in Aydın, 384 in Manisa, 228 in Denizli, and 209 in İzmir indicate the high potential in the Aegean Region (Table 1).

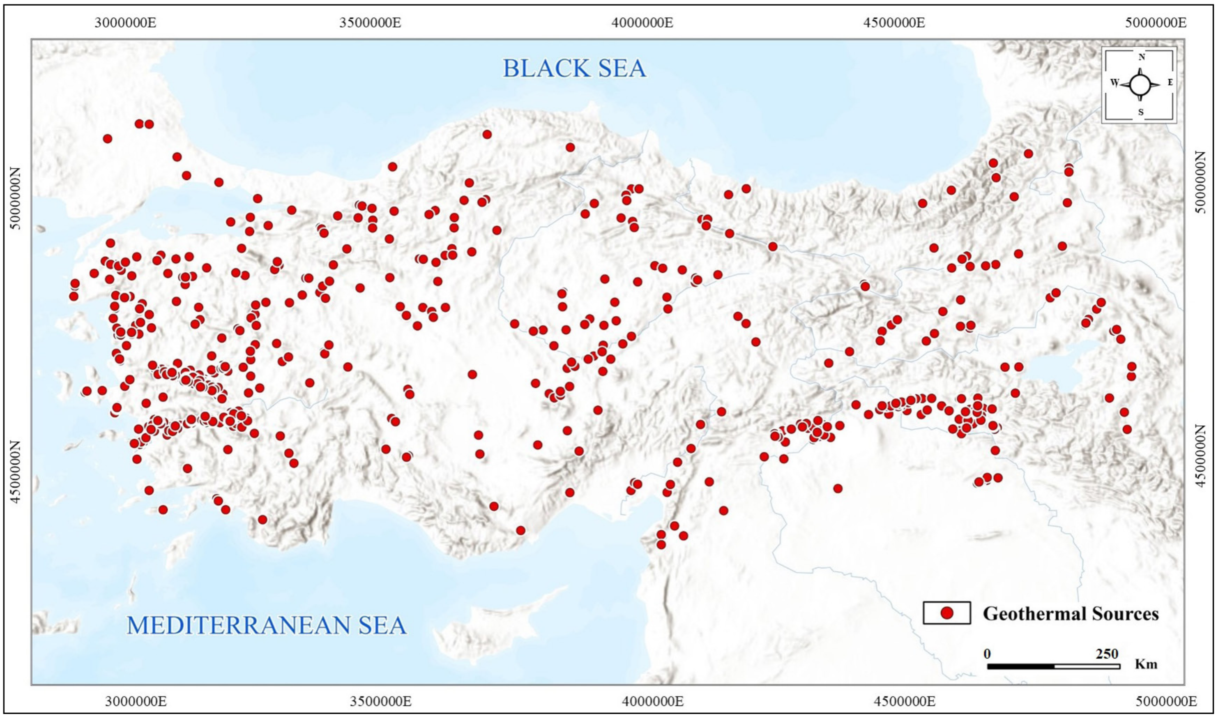

Figure 5- Geothermal sources of the Türkiye (Updated from Akkuş et al., 2005; Baba et al., 2019; EBRD, 2020*a*).

Table 1- Geothermal well capacity values of provinces in Türkiye (Baba et al., 2019; EBRD, 2020*a*).

Province	Number of Wells	Capacity (MWt)	Province	Number of Wells	Capacity (MWt)	Province	Number of Wells	Capacity (MWt)
Afyon	52	334.1	Erzincan	1	0.00	Muğla	5	11.38
Ağrı	6	87.04	Erzurum	11	21.82	Nevşehir	13	90.26
Aksaray	5	1.12	Eskişehir	14	20.83	Niğde	14	15.38
Amasya	7	4.79	Gaziantep	1	0.00	Ordu	1	0.00
Ankara	62	108.65	Hatay	8	0.22	Osmaniye	1	0.00
Aydın	673	19143.53	İstanbul	9	0.79	Rize	4	4.84
Balıkesir	33	90.25	İzmir	209	874.10	Sakarya	5	56.52
Batman	1	3.21	Kahramanmaraş	7	8.61	Samsun	12	12.92
Bilecik	1	0.22	Karabük	1	0.33	Siirt	1	0.29
Bingöl	4	6.00	Kayseri	6	2.62	Sivas	16	58.38
Bolu	23	20.84	Kırklareli	2	2.76	Şanlıurfa	25	57.21
Bursa	5	17.43	Kırşehir	21	66.46	Tokat	7	5.82
Çanakkale	21	180.44	Kilis	1	0.00	Tunceli	2	0.81
Çankırı	5	5.91	Kocaeli	2	0.00	Uşak	5	15.64
Çorum	10	0.80	Konya	18	20.92	Van	7	26.85
Denizli	228	4906.63	Kütahya	84	392.36	Yalova	6	19.75
Diyarbakır	7	6.30	Manisa	384	9242.40	Yozgat	40	74.83
Elazığ	1	0.63	Mersin	2	2.82			
TOTAL NUMBER OF WELLS								2089
TOTAL CAPACITY (MWt)								36025.81

In recent years, the potential of the Central Anatolia Region (especially in Nevşehir, Aksaray, and Niğde) has been increasing, while other regions are still waiting for investment (Figure 7).

The current usage areas and capacities of geothermal energy in Türkiye are presented in the Türkiye Geothermal Strategy Report, prepared in 2022. According to the report, the total installed heat power in direct use is 5113 MWt (Table 2).

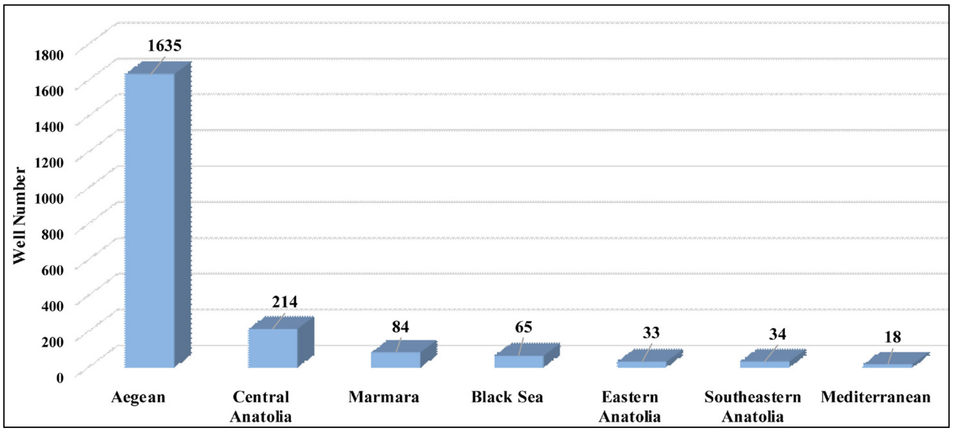

Figure 6- Distribution of the number of wells by region (Akkuş et al., 2005; Şener et al., 2017; Baba et al., 2019; EBRD, 2020*a*).

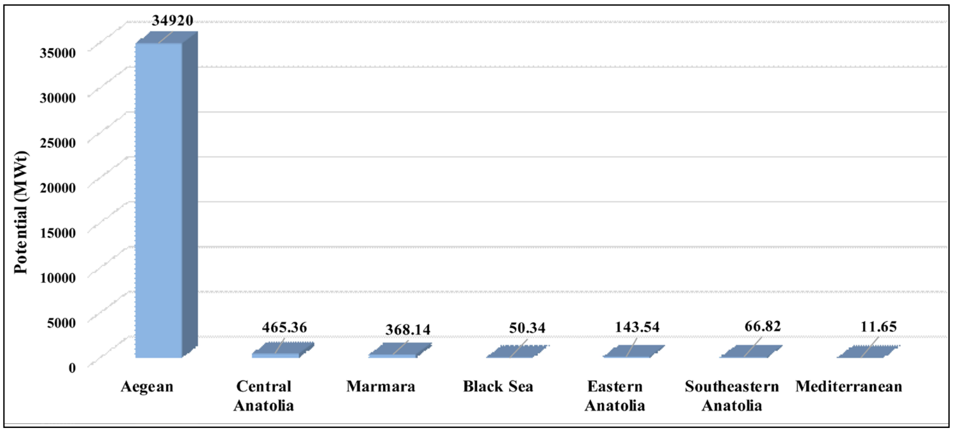

Figure 7- Regional capacity distribution from existing well data (Akkuş et al., 2005; Şener et al., 2017; Baba et al., 2019; EBRD, 2020*b*).

Table 2- The current situation of geothermal evaluations in Türkiye.

Evaluation	**Capacity**
Geothermal District Heating (city, residential)	158.000 Housing Equivalent (1422 MWt)
Greenhouse Heating	5293 Acres (1230 MWt) 146.600 Housing Equivalents
Spa Facilities, Thermal Hotels and Timeshare Facilities Heating	68.000 Housing Equivalents (680 MWt)
Thermal Energy of Thermal Water used in Hotels, Spas, Timeshares	520 Spas(1763 MWt) (23 million People Per Year)
Fruit and Vegetable Drying	9.5 MWt
Cooling	0.35 MWt
Geothermal Heat Pump (ground source)	8.5 MWt
Total Heat Usage (installed thermal power)	5113 MWt
Total Electricity Production (installed power)	1663 MWe
Industrial Liquid CO_2, Dry Ice Production	400.000 Tons/Year

2.4. Electricity Generation

Türkiye has been dependent on fossil fuels for more than 60% of electricity generation until recent years. Since oil and natural gas production is too low to serve the purpose, this deficit is resolved through imports. Increasing global prices and policies to reduce foreign dependency have increased investment and incentives to exploit Türkiye's natural resources. For this reason, in addition to using domestic sources from fossil fuels, the trend toward new technologies has accelerated, and investments in solar, wind, hydraulic and geothermal energy have increased. Electricity production from geothermal energy has grown rapidly, especially with the Türkiye Renewable Energy Resources Support Mechanism (YEKDEM) (Figure 8).

The sector has recorded significant growth by including the private sector in energy production from geothermal resources. As of 2022, the number of geothermal power plants in Türkiye is 65, and the installed geothermal power capacity is 1663 MWe (EPDK, 2022). Today, all geothermal power plants are located in the western part of Türkiye. While most of the power plants are situated in Aydın, Denizli, and Manisa, new power plants have started to be established in developing areas of İzmir, Afyon, and Çanakkale (Figure 9).

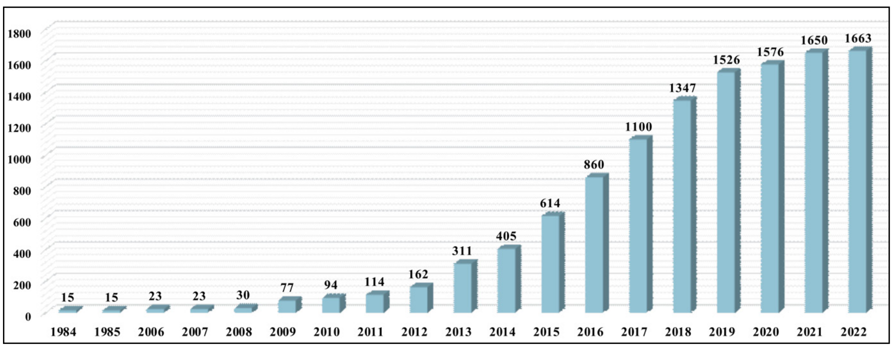

Figure 8- Capacity development of geothermal power plants in Türkiye (MWe; EPDK, 2022).

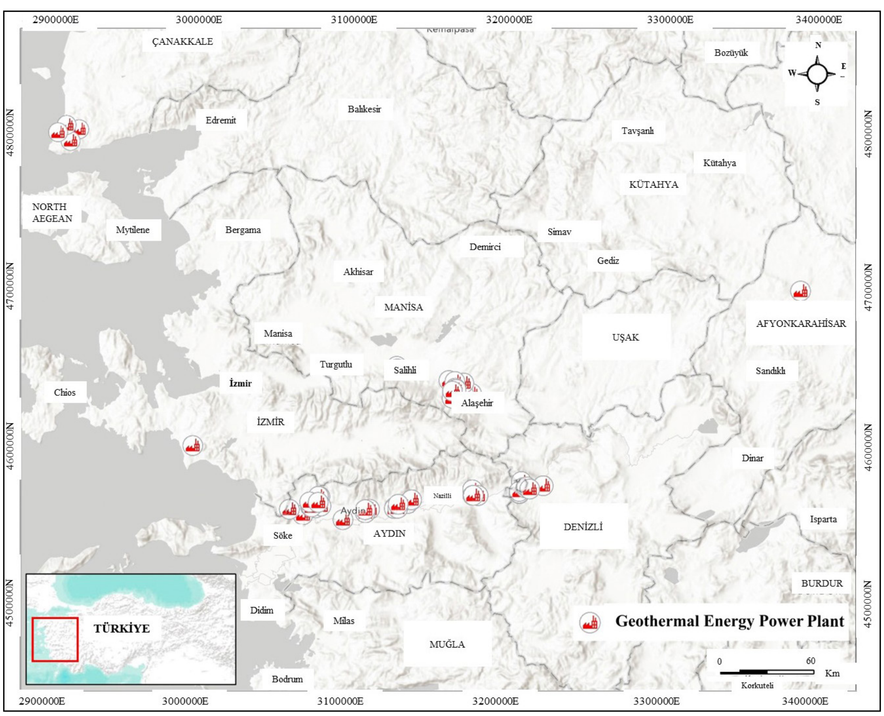

Figure 9- Location map of existing geothermal power plants in Türkiye.

Geothermal power plants in Türkiye and their operating capacities are presented in Table 3. Table 3 also shows that 98% of the existing power plants are in Western Anatolia. According to Energy Market Regulatory Authority (EMRA) data, apart from the existing power plants, there are 12 projects which have received a pre-license, with a total capacity of 310 MWe at the beginning of 2022. In addition, two projects are under construction, and the total capacity of geothermal power plants is approximately 62 MWe.

2.5. Direct Use

The installed direct-use geothermal capacity in Türkiye has been calculated as 5113 MWt within the scope of the Türkiye Geothermal Resources Strategy Report. Approximately 47.8% is thermal tourism applications, 27.8% is central heating applications, 24.1% is greenhouse heating applications, and 0.4% is heat pumps, drying, and cooling applications (Figure 10).

Table 3- Geothermal power plants and their operating capacities (EPDK, 2022).

Province / District		**Field Name**	**Company**	**Operating Capacity (MWe)**
Denizli	Sarayköy	Kızıldere-Karataş	Zorlu Elek.	260
			Bereket Enerji	6.85
		Tekkeköy	Greeneco Enerji	77.2
		Tosunlar	Akça	3.804
Manisa	Alaşehir	Kurudere-Alkan	Zorlu Elek.	45
			Türkerler Jeot.	78
		Kemaliye	Enerjeo	24.9
		Alaşehir-Soğukyurt	Sis Enerji	47.52
		Alaşehir-Kavaklıdere	Maspo Enerji	44
		Alaşehir-Baklacı	Akça Enerji	19.4
		Piyadeler	Soyak Enerji	60.3
Manisa	Salihli	Caferbey-Hasalan-Sart	Sanko	64
Aydın	Germencik	Ömerbeyli	Gürmat Elek.	259.9
		Hıdırbeyli/ Bozköy	Kipaş Holding	218.6
		İncirliova	3 S Kale	25
		Turanlar	Beştepeler Enj.	24
		Gümüşköy	Gümüşköy Jeot.	13.2
	Nazilli	Güzelköy-Durasıllı	Kipaş Holding	10
Aydın	Kuyucak	Yöre	Turcas	18
		Pamukören	Çelikler Jeot.	176.55
Aydın	Sultanhisar	Sultanhisar		36.31
			Menderes Geot.	7.951
Aydın	Köşk	Salavatlı		60.5
Aydın		Umurlu	Karkey	24
Aydın	Buharkent	Buharkent	Limgaz	13.77
İzmir	Seferihisar	Kavakdere	RSC Elektrik	12
Çanakkale/Ayvacık Tuzla Babadere		Tuzla	Yerka	11.75
		Tuzla Jeot.	7.5	
		MTN Enj.	7.95	
Afyon		Ömer-Gecek	AFJET	2.755
Denizli	Sarayköy	Gerali	Jeoden	2.52
Total Production				1663.23

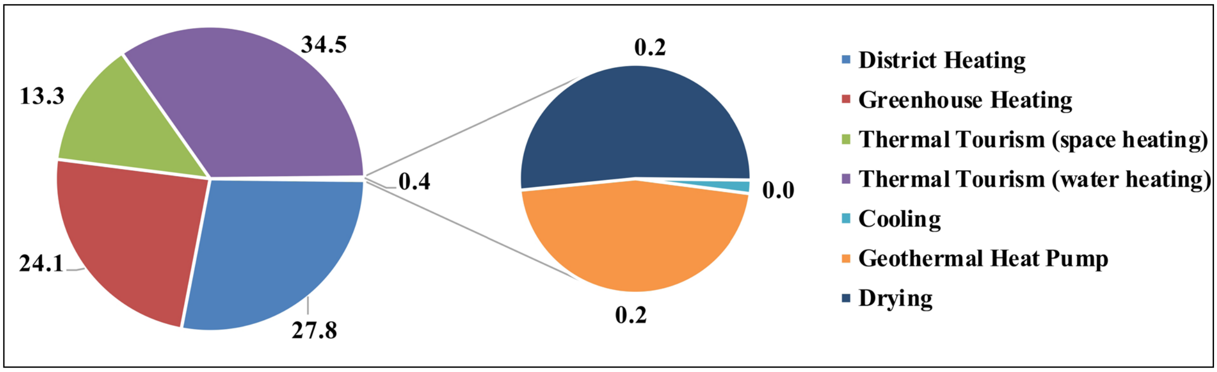

Figure 10- Percentage of current direct use applications (MWt) in Türkiye.

The capacities of direct-use applications in MWt determined in this study are shown in Figure 11. Considering the general distribution of usage, heating applications come to the fore. The thermal energy capacity of the thermal water used in thermal spas and pools is 1763 MWt, and the heat energy capacity used for geothermal heating of the thermal facility and related spaces is 680 MWt. The heat energy capacity of central heating systems in cities and districts has reached 1422 MWt. In agricultural applications, the heat energy capacity for greenhouse heating is 1230 MWt, while the heat energy capacity for drying agricultural products is 9.5 MWt. The heat energy capacity of the heat pumps is 8.5 MWt, and the cooling application capacity with the geothermal fluid is 0.35 MWt.

2.6. Urban Heating and Cooling

According to the Energy Cities Association (EKB, 2022) data, heating systems for cities and commercial buildings/facilities are Türkiye’s most common direct use of geothermal energy today (Figure 12 and Table 4). The total capacity of central geothermal heating and thermal facility space heating applications is 2102 MWt.

2.7. Thermal and Health Tourism

As of today, more than 520 active spa facilities use geothermal resources. These facilities host approximately 20-23 million people per year. This contributes to the rise of Türkiye to 3rd place in the world in thermal facility applications of geothermal

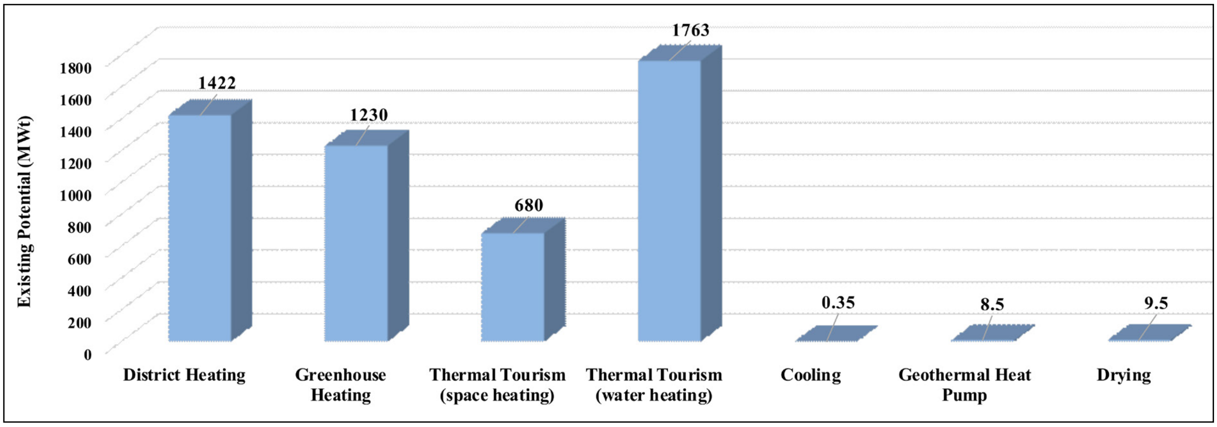

Figure 11- Current capacities of geothermal direct use applications in 2022.

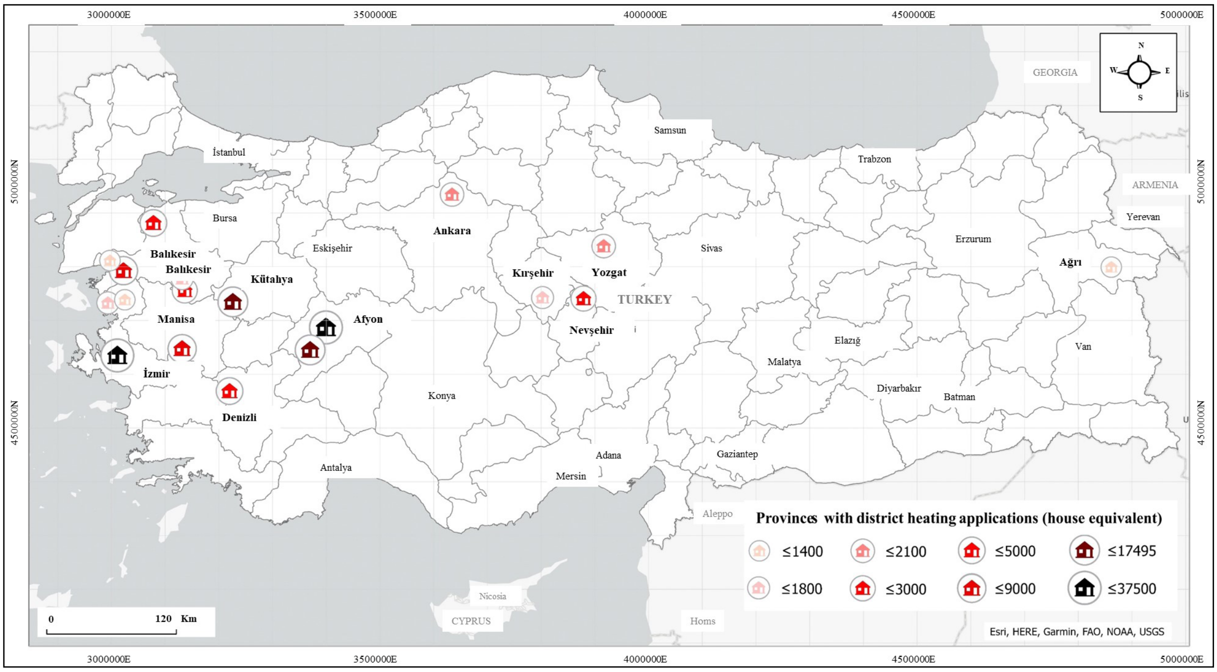

Figure 12- Provinces with district heating in Türkiye and housing equivalents (created from EKB, 2022 data).

Table 4- District heating applications.

Application Field	Temperature °C	House Equivalent	Application Field	Temperature °C	House Equivalent
Balıkesir-Gönen	80	3.400	İzmir-Dikili	125	1.530
Kütahya-Simav	120	18.612	Nevşehir-Kozaklı	92	3.800
Ankara-Kızılcahamam	80	2100	Ağrı-Diyadin	70	970
İzmir-Balçova-Narlıdere	98-125	38.899	Manisa-Salihli	94	10067
Afyon-Sandıklı	70	30.000	Denizli-Sarayköy	140	5000
Kırşehir-Terme	57	1.800	Balıkesir-Edremit	60	5.100
Afyon-Ömer-Gecek	95	25.610	Balıkesir-Bigadiç	96	1.500
Balıkesir-Güre	65	1400	Yozgat-Sorgun	80	2100
Balıkesir-Sındırgı	98	4.000	İzmir-Bergama	65	866
TOTAL					156.754

* Considering the current growth, the total value is approximately 158.000. Energy Cities Association data has been updated and used.

energy. The countries most known for health tourism operating under medical supervision are the USA, Germany, Thailand, India, and Türkiye. The geothermal fluid was examined that heats the thermal pools, health and cure centers, natural outlets-spas, and historical and renovated thermal pools. The thermal applications and facilities of the provinces in Türkiye are shown in Figure 13.

Thermal tourism is the oldest sector of geothermal application in Türkiye. Thermal facilities use geothermal fluid for baths, pools, and spas. As 520 hot springs use approximately 1763 MWt of capacity and serve 20 million people annually, the estimated future thermal requirements are also in line with the current condition and geothermal resource potential (WB, 2021).

Figure 13- Provinces with thermal tourism facilities or spas in Türkiye and the approximate number of facilities (Ministry of Health, 2021).

2.8. Greenhouse Heating and Agricultural Drying

Türkiye has made rapid progress in the greenhouse sector since 1970. In recent years, greenhouse cultivation has adopted geothermal direct-use applications for developing technology, innovative approaches, and inexpensive economic heating. Currently, the Turkish greenhouse sector ranks 4th in Europe in total production. According to the data compiled in this study, geothermal use (greenhouse heating and drying) is being applied in 17 provinces of Türkiye (Figure 14).

Most of the existing greenhouses are located in the southern provinces, where the climatic conditions are more favorable. The lack of improvement in colder climates is due to the cost of conventional energy sources. However, in recent years, a growing geothermal greenhouse sector has started to develop in cold climate regions (such as Sivas, Afyon, Kırşehir, and Ağrı-Diyadin) due to the widespread use of geothermal energy in greenhouses.

Annual energy use rates for greenhouse heating with geothermal resources worldwide almost tripled from 1995 to 2020. In line with the global trend, Türkiye increased its geothermal greenhouse heating capacity to 1230 MWt and the total greenhouse area to 5293 decares in 2022. However, high-tech greenhouse cultivation (by all kinds of heat sources) accounts for less than 2% of the total. As of 2022, geothermally-heated greenhouses have a significant share of 30% of the total heated greenhouse area.

In addition to geothermal greenhouses, geothermal energy is also used for drying the products. The use of geothermal sources in the food drying process aims to reduce food loss all over the world. According to the 2021 UN Food Waste Index Report, a total of 931 million tons of food is wasted worldwide yearly (UNEP, 2021). According to the same report, more than 7.7 million tons of food are wasted in Türkiye annually. Traditional drying methods, such as sun drying in an open area, are still the most common

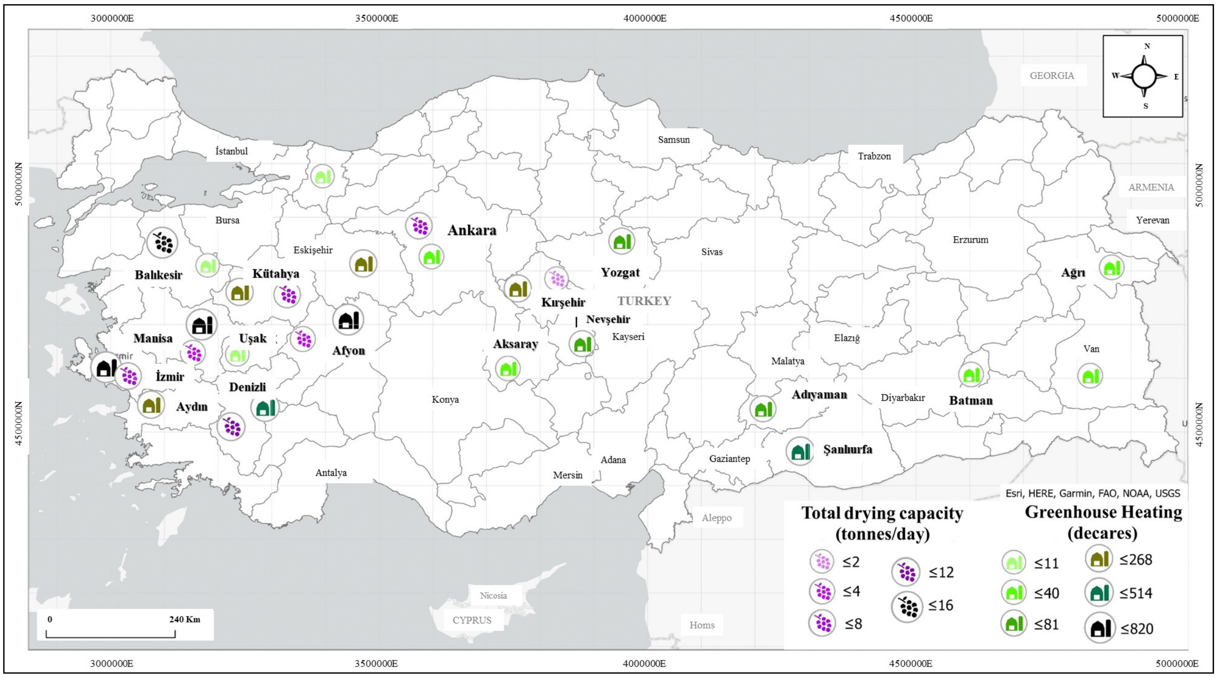

Figure 14- Current geothermal greenhouse heating and drying applications in Türkiye.

drying methods in Türkiye. However, contamination by dust, soil, and insects and unmanageable drying parameters such as temperature and wind speed can cause excessive drying and decrease the quality of the dried product. Therefore, renewable energy sources such as geothermal energy play an essential role in controlled drying methods. In the current situation, as in the examples of İzmir, Balıkesir, and Kırşehir, agricultural drying practices have increased in recent years, and the 2022 capacity has reached the level of 9.5 MWt.

2.9. Integrated Systems

Integrated (gradual) use of geothermal resources is defined as electricity generation, distribution and use of thermal energy, drying and dehydration processes, recreational uses, and sequential use of geothermal heat in applications by integrating different technologies (Rubio-Maya et al., 2015).

Some of Türkiye's existing geothermal power plants provide good investments and fluid support for integrated use. For instance, in Çanakkale-Babadere, Aydın-Ortaklar, Germencik, Salavatlı, and Denizli-Sarayköy, the geothermal fluid from the geothermal power plant is used in a cascade manner in greenhouse heating and urban heating before being sent for re-injection (Figure 15).

3. Contribution of Geothermal Energy to National Economies, Support Mechanisms, and Investment Costs

One of the most important economic aspects of geothermal energy is that it reduces the dependency on imported energy by using domestic resources. Thus, domestic investments will reduce trade deficits and keep capital in the country.

No matter how high a country's technical potential for geothermal electricity generation is, technology and incentives for the market and production are the primary determining role. For instance, although electricity generation from a 180°C geothermal well in the Kızıldere Geothermal Field in the 1980s was not considered economically and technically appropriate, today, it is regarded as desirable and economical. Therefore, the critical factors are an incentive, purchase price, purchase period, and financial opportunities.

In addition to environmentalism and security of supply, the cost of geothermal heating is at least 60% cheaper than fossil fuels. Today, geothermal heat is 70% cheaper than natural gas in many places (local house tariff). Considering the state's subsidy to natural gas for residential heating, it becomes clear how much geothermal energy contributes to the country's economy. Compared to the actual natural gas cost

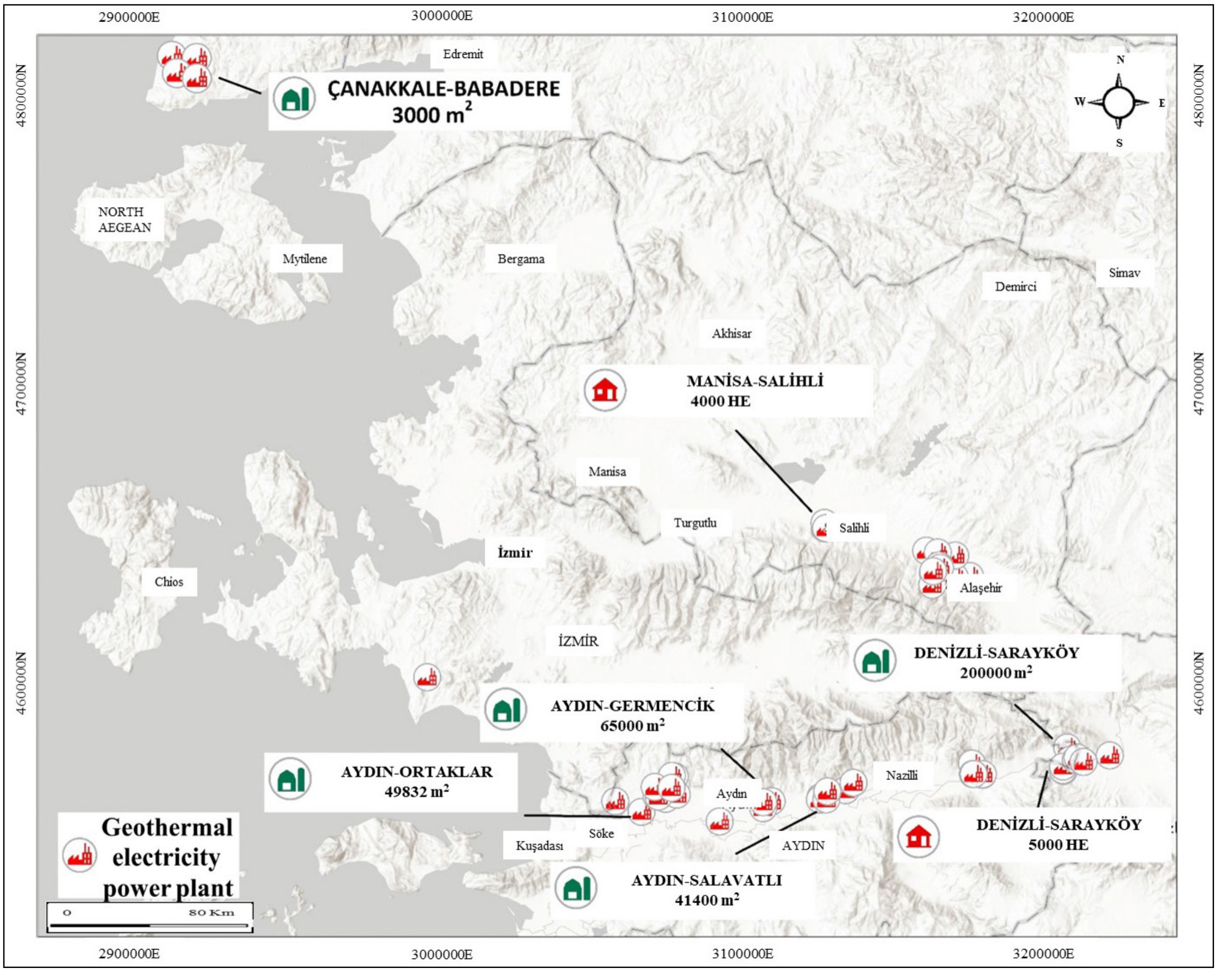

Figure 15- Examples of existing geothermal integrated applications in Türkiye (WB, 2021). HE: House Equivalent.

of 9.135 TL/m^3 (6.3 TL/m^3 x 1.45 (45% BOTAŞ increase as of 01.04.2022)), a very economical price of approximately 1/8 is in favor of the state and population. Data on the contribution of geothermal energy to the annual economy regarding electricity and direct use are presented in Table 5 and Figure 16.

The direct contribution of geothermal applications calculated above to the economy is 54,857,760,000 TL in total (excluding contribution to employment, natural gas savings, and CO_2 emission reduction). Also, when 5% is added for the unknown and unregistered, the direct contribution of the geothermal applications to the economy can be considered as approximately 58 billion TL/year.

3.1. Current Incentive System

The Ministry of Industry and Technology has an incentive system for investments of a specific size. Customs duty exemption, Value Added Tax (VAT) exemption, permission for loan allocation, etc., are applied within this incentive system; these parameters change annually according to the circumstances.

3.2. Investment Costs of Geothermal Energy Applications

The approximate amount invested in some basic geothermal energy applications were calculated in this study.

3.3. Geothermal District Heating System General Investment

Since the late 1980s, geothermal central city heating applications have been ongoing and significantly contributed to the Turkish economy. Geothermal central heating investments are made under the leadership of provincial governors, development

Table 5- The annual contribution of electricity generation and direct use of geothermal energy to the economy.

Geothermal Energy Application	Calculation Details	Economic Contribution (TL/ Year)
Electricity Generation	1663 MWe x 103 x 0.8 (domestic consumption factor) x 0.95 (production reduction factor and others in summer) x 8500 hours/year x 2.5 TL/kWh (average sales to the end consumer)	26.857.400.000
House, Hotel, Spa, Thermal Facility, Central Heating	Equivalent to 216.000 residences x 330 TL/month x 12 months	855.360.000
Greenhouse Heating and Production	5293 acres x 103 x 50 kg/m^2 season x 20 TL/kg	5.293.000.000
Liquid CO_2 and Dry Ice Production	400.000 tons/year x 300 dollars/ton x 14 TL/US$	1.680.000.000
Mineral Water Production and Sales	MASUDER, 2022	6.500.000.000
Thermal Tourism (Ministry and Municipality certified Hotels and Spas)	~ 80.000 beds x 0.7 occupancy rate x 400 TL/day person (room + meal + treatment) x 365 days/year	8.176.000.000
Thermal Tourism (Spa, Cure Center, Physiotherapy, Daily Spa Facilities)	320 spa facilities x 500 people/day x 130 TL/day person (including treatment, etc.) x 365 days/year x 0.7 occupancy rate	5.314.400.000
Thermal Tourism (Thermal Timeshare Facilities)	Facilities Using Geothermal Heating and Thermal Water (Except for the amount paid for the purchase of time-share property (for investment)) 10.000 rooms x 2500 TL/year (Operation and maintenance expenses) x 23 terms (350/15 days)	575.000.000

agencies, YIKOB (Department of Investment Monitoring and Coordination), and municipalities in Türkiye. Two examples of the cost of geothermal heating applications are presented below.

The first is an investment made by the governorship, municipality, and partially the private sector with the public's participation. The approximate amount includes the main investment, wells, and distribution, thus:

158.000 residences (equivalent to 100 square meters per residence) x 35.000 TL/house = 5,530,000,000 TL.

Second is the calculation of global investment by citizens for indoor installations in geothermal central heating. This is calculated according to the internal installation of at least 158.000 residential equivalents in geothermal central heating (low-temperature system). The 158.000 residences are considered new indoor installations. According to the figures of January 2022, this installation, including under-building pumps, piping, calorimeters, room radiators, hot water boilers, etc. for a 100 m^2 house, is accepted as 17.000 TL, as below:

158.000 x 17.000 TL = 2,686,000,000 TL invested.

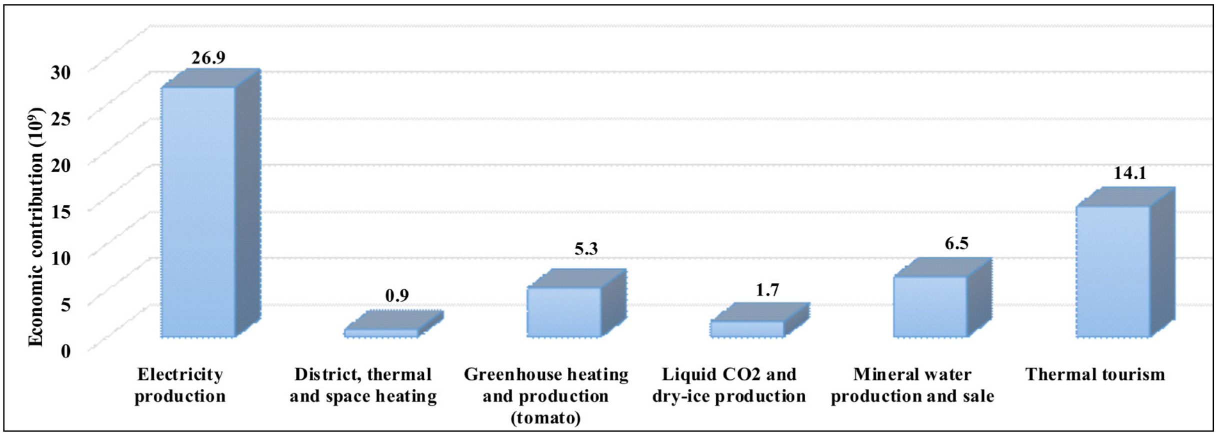

Figure 16- The annual contribution of geothermal energy to the Turkish economy in terms of electricity and direct use (TL/year).

3.4. Geothermal Power Plants Investment

All the existing geothermal power plants in Türkiye, except the Kızıldere-Denizli power plant, were built by the private sector. If we assume the total electricity generation capacity as 1663 MWe and calculate an average investment cost of 4 million dollars per MWe, the result is:

1663 MWe x 4 million USD/MWe x 14 TL/USD = 93,128,000,000 TL.

3.5. Investment in Thermal Tourism, Thermal Hotels, Cure Centers, Spas, etc.

Today, it is difficult to calculate the total investment cost for these sectors because the investments were made in different years, and new investments are still being made. Furthermore, since these investments are not in a certain classification and standard, making a standard calculation is impossible.

3.6. Geothermal Greenhouse Investment

Currently, the total of geothermal heated greenhouses is 5293 decares. Türkiye is the world leader in terms of geothermal-heated greenhouses. The cost of a 1 m^2 greenhouse investment is between 80-120 dollars. This cost varies according to the region where the greenhouse is installed in terms of the type, size, and condition of the land, the characteristics of the geothermal field, and the type of heat used. However, if the average is calculated as 100 dollars per m^2:

5293 acres x 10^3 (m^2) x 100 USD/m^2 x 14 TL/USD = 7,410,200,000 TL.

4. Recommendations and Strategies for the Sustainability of Geothermal Resources

Geothermal resources are an important renewable energy source for Türkiye's economy if they are systematically and technically explored, operated, and inspected within legal regulations. Today, the geothermal resource is widely used directly and indirectly in Türkiye. Electricity produced in geothermal power plants from a geothermal fluid is termed indirect use, while urban heating and cooling, greenhouse heating, agricultural drying, thermal and health tourism, CO_2, and dry ice production applications are used directly (Figure 17).

In view of the geological data obtained, an evaluation of which applications can be made in which provinces in Türkiye is presented in Figure 18. Geothermal energy power plants, electricity production, and integrated production can be implemented in many cities in Western Anatolia. Agricultural applications, thermal tourism, and heating are becoming common in Western and Central Anatolia. Thermal tourism and integrated facilities,

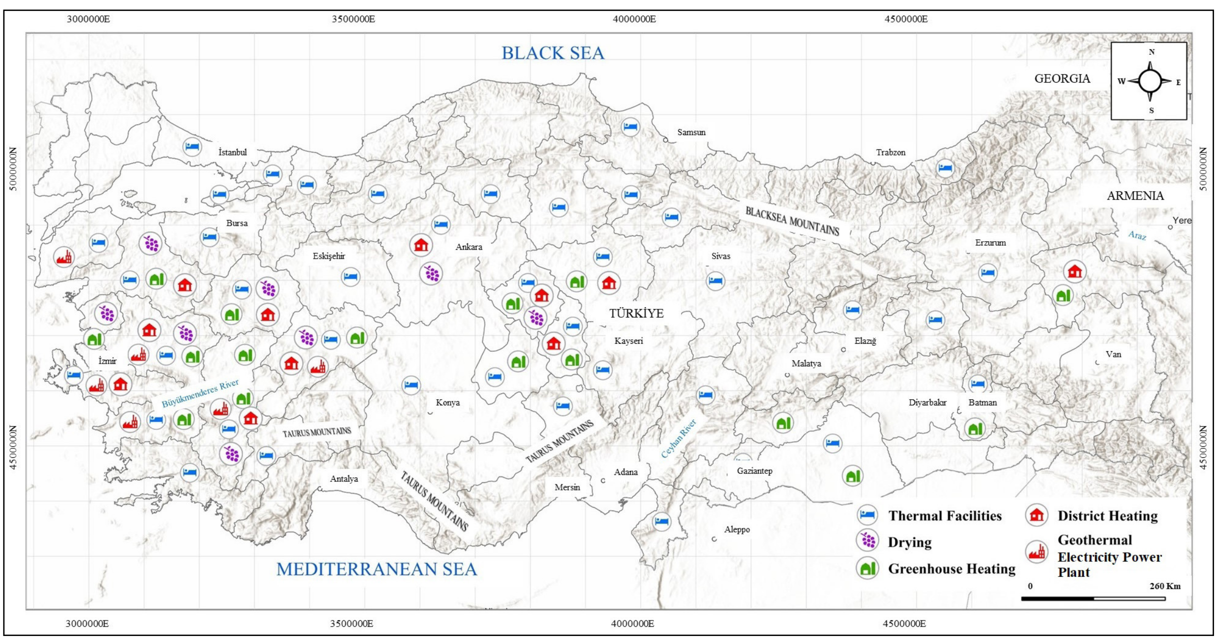

Figure 17- Current direct and indirect use of geothermal energy sources in Türkiye.

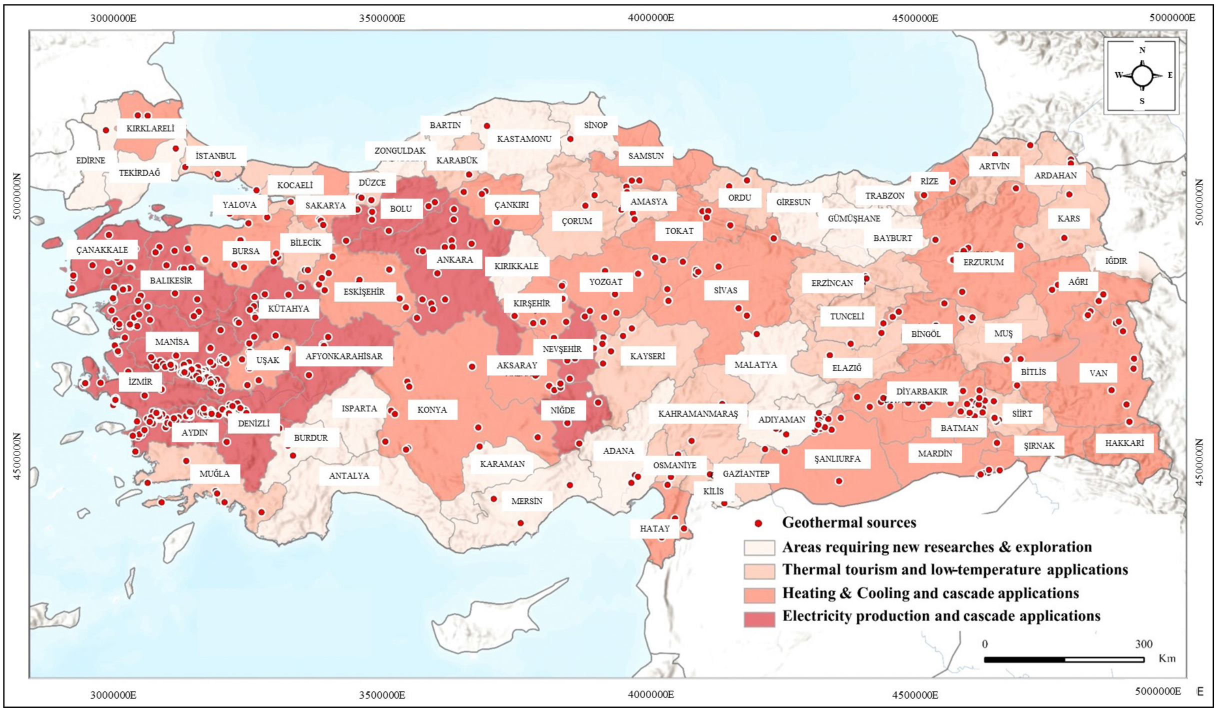

Figure 18- Projection of future fields using direct and indirect geothermal energy sources in Türkiye.

and heating and cooling applications can be seen in different regions of Türkiye. In addition to these, geothermal potential should be investigated in some provinces of the Mediterranean and the Black Sea regions.

Considering the total potential of 62.000 MW currently, a short- and medium-term approach can be made. These approaches have been calculated based on the present situation and the continuity of economic conditions in the world geothermal energy sector (assuming no pandemics, wars, or other catastrophic events). Accordingly, a total of 51.492 MWt usage is foreseen in the medium term (Table 6).

Although hot dry rock (HDR) and EDGS have not been considered in the short and medium term, the projections have a high potential in this application. In the calculations made in this study, when the EDGS value is added, it is predicted that Türkiye's total potential will be at least 400.000 MWe. In addition, when the potential targets and estimated investment are realized, it is thought that the contribution of geothermal energy to the economy will be 210 billion

Table 6- Short- and medium-term plans for the use of existing geothermal energy.

		Direct Use (MWt)	Current Status (2022)	Short Term (2030)	Medium Term (2040)	Long Term (2050)
Total geothermal energy capacity (62.000 MWt)	Total electricity generation capacity (MWe)		1663	3000	4500	6000
	14% MWt conversion efficiency		11878	21428	32142	42586
	Direct use capacity (MWt)	Residential Heating	2102	5000	9000	14000
		Greenhouse	1230	2800	4600	6600
		Thermal Tourism	1763	2000	4500	6000
		Drying	9.5	80	300	1000
		Cooling	0.35	350	800	2000
		Geothermal Heat Pump	8.5	40	150	1500
	Total	MWt	16991.35	31698	51492	73956

TL/year, with direct and indirect employment for approximately 450,000 people (Table 7).

Geothermal energy should be implemented in the short and long term on both the supply and demand sides with the national and local authorities. The private sector, universities, institutes, and research centers should prepare short-, medium- and long-term strategies for developing and effectively using geothermal resources.

In geothermal systems, wells have not yet been drilled in all areas determined by the studies carried out to date. Therefore, it is expected that the future capacity of Türkiye will be much higher when encompassing drilling research and development studies and discovering new fields. This capacity will exceed 100,000 MWt levels in the medium term, especially with the addition of EDGSs.

The following factors were deemed critical in the Science and Technology Commission's Policy Recommendations and Actions meeting held by the climate council in 2022 by the Ministry of Environment, Urbanization, and Climate Change:

- Development of materials resistant to high temperature and high pressure.
- Concentrating on deep and directional drilling technology studies.
- Measuring and monitoring geothermal seismic data.
- Developing models and technologies that will solve the problems of collapse and microseismicity in geothermal fields.
- Increasing and developing studies on obtaining minerals from geothermal fluids.
- Development of borehole designs.
- Developing innovative technologies to eliminate environmental impacts.
- Studies and development of technologies for the direct use of geothermal fluid.
- Dissemination and development of geothermal source heat pumps.
- Creating detailed heat maps of the earth's crust.
- Increasing studies on HDR/EDGS systems and developing technologies for using gases instead of fluids in these systems.

In addition to the Policy Recommendations and Actions of the Science and Technology Commission, it is essential to carry out the following strategies:

- Developing the geothermal energy sector in

Table 7- 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

cooperation with the private sector and local government.

- Expanding the sector and making research-development plans with the participation of the MTA, TÜBİTAK, universities, institutes, and the private sector.
- Promoting further development of the industry through the development of industry standards, information sharing, and transparency.
- Ensuring local and national consensus within the community on geothermal energy.
- Developing laws and regulations, an administrative structure, and incentive mechanisms.
- Ensuring that sufficient capacity is increased in central and local government to process permit applications in a fast, open, systematic, and transparent manner.
- Establishment of heating networks in a region-oriented manner in coordination with local governments.
- Determination of stable and predictable long-term finance-oriented energy policies to ensure sustainable direct-use practices and sectoral improvement.

5. Results

Geothermal energy is a natural resource that can be utilized directly or by converting to other types of energy. Using geothermal energy for different purposes, such as power, residential heating, thermal tourism, and greenhouses has become widespread in Türkiye. Türkiye is in a crucial geological position for obtaining geothermal energy from hot and radiogenic granitoid using EDGS technology. Türkiye energy problem can be minimized in a short time with the effective and correct use of geothermal resources. For this reason, it is extremely important to increase and support geothermal research in Türkiye.

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