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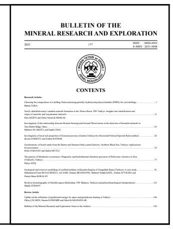

Update on the utilisation of geothermal energy for space and greenhouse heating in Türkiye

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ABSTRACT

As one of the sustainable, domestic and renewable resource, geothermal energy has a high potential and range of application in Türkiye and it is widely used especially in space and greenhouse heating. In this study, to overcome the challenges experienced in accessing data regarding geothermal energy utilisation in Türkiye (not being available in a single source, database irregularity/inadequacy, etc.) and to form a basis for future studies, current data were collected from various institutions and compiled by focusing on space and greenhouse heating. As of 2024, 170481 Residences Equivalence (1704.8 MWt) of space is heated with geothermal energy through 25 fields in 13 provinces. Additionally, 6970158 m^2 (1394 MWt) of greenhouses are heated through 62 fields in 27 provinces. 94% of space and 81% of greenhouse heating are carried out in Western Anatolia and Afyonkarahisar is the province with the most space and greenhouse heating. Most areas including 20 geothermal fields and numerous facilities (hotels, schools, etc.) are also heated with domestic heating. Space and greenhouse heating have increased by 210% and 850%, respetively, between 2007 and 2024. Considering Türkiye's geothermal potential, it is expected that this development will be even greater, especially in Eastern Anatolia.

1. Introduction

Energy requirements in Türkiye continuously increase due to the rapid growth in population, economy and industry. Projections of Turkish Statistical Institute (Türkiye İstatistik Kurumu, TÜİK) indicate that Turkish population will reach up to 93 million in 2050 (TÜİK, 2013), which as a result increases the individual energy consumption. Geothermal energy, being a domestic, environmentally friendly, sustainable and renewable resource, has the potential to cover a significant portion of the energy demand in Türkiye that is characterized by widespread thermal activity (Figure 1). Furthermore, the utilisation of this resource is critical to ensure energy security, diversify energy sources and reduce foreign dependency. In this regard, Türkiye's focus on geothermal energy will not only decrease the dependence on imported fossil fuels but will also contribute to reducing greenhouse gas emissions.

In Türkiye, geothermal energy exploration and research studies, which started in 1962, were carried out under the leadership of General Directorate of Mineral Research and Exploration of Türkiye (MTA) and continued progressively with the newly discovered fields. Subsequently, with the legal regulation enacted in 2007, the private sector also started to take part intensively in exploration and operation activities. This regulation is the Geothermal Resources and Natural

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Mineral Waters Law No. 5686 and the implementing regulation of the same law, which regulate operations for the exploration and exploitation of geothermal resources. In accordance with the provisions of this law, exploration, control and operation activities of geothermal energy are carried out under the coordination of the relevant governorates. In addition, Municipalities, General Directorate of Mining and Petroleum Affairs, MTA, Ministry of Culture and Tourism, Ministry of Environment, Urbanisation and Climate Change, Ministry of Agriculture and Forestry and other relevant institutions and organizations can take part in opinion and permit processes due to the prevailing legislations. Under these circumstances, the activities regarding the exploration and operation of geothermal energy cannot be carried out from a single, centralized authority, which causes various difficulties in accessing the required and up-to-date data, especially in space and greenhouse heating using geothermal resources.

In this study, 2024 (as of July) data of space heating and greenhouse heating were obtained in an attempt to i) eliminate the potential disorder that may occur in accessing data related to geothermal energy, ii) fill the data gap regarding geothermal energy utilisation, iii) update the data in reliable methods for public use, iv) compare and evaluate the updated data with the previous records, and v) construct a comprehensive database for future studies. In this context, literature survey was conducted on the official reports and database of MTA, covering all 81 provinces, followed by the data collection from every governorate with available data. Finally, collected data were matched with the MTA database and compiled to establish the most up-to-date database on Türkiye's geothermal energy-based space and greenhouse heating.

2. Overview of Geothermal Energy Explorations in Türkiye

The preliminary studies in geothermal resource exploration in Türkiye were initiated by MTA in İzmir - Balçova in 1962, and with the drillings carried out by MTA, many important high-temperature geothermal resources reaching up to 287.5 °C (Manisa - Kavaklıdere) were discovered over the years. As a result of geothermal resource exploration and research studies of MTA, so far, 669 exploration drillings with a total depth of 468337 meters were carried out, 4534 MWt of geothermal power capacity was revealed, and a total of 400 fields were discovered. Some of the discovered fields were transferred to investors through tendering processes in accordance with Law No. 5686. These studies have led to the growth and diversification of the use of geothermal energy resources by the

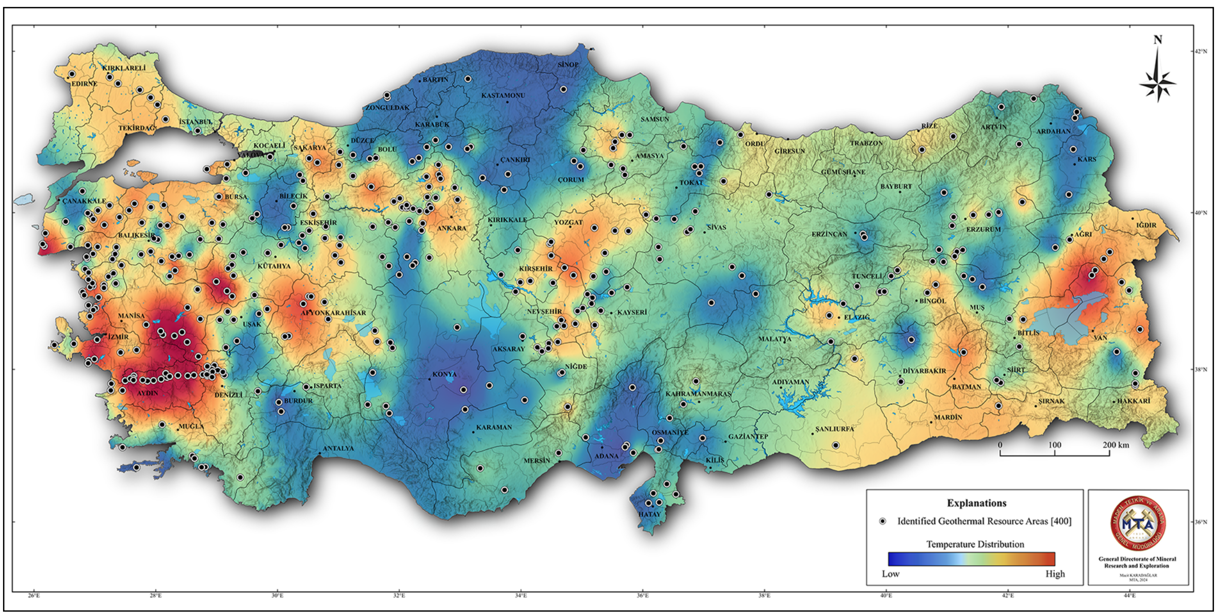

Figure 1- Geothermal resource distribution map of Türkiye (based on the bottom-hole temperature values measured from wells drilled at various depths by MTA).

private sector, both with new resource discoveries and investments as well as with field development studies in the geothermal fields transferred by MTA.

Geothermal energy resources in Türkiye are utilised directly and indirectly in activities such as electricity production, heating (space and greenhouse), balneological use (bathing, spas, hot springs, etc.), dry ice production, industrial mineral extraction, drying (e.g., fruit, wool), and fish farming. A significant part of these uses consists of space and greenhouse heating. Especially in the Western and Central Anatolia regions, many buildings and greenhouses are heated with geothermal energy in an environmentally friendly and economical way.

The first space heating using geothermal resources in Türkiye was implemented in Dokuz Eylül University in İzmir 1983, and the first district heating was done in 1987 with Gönen (Balıkesir) geothermal field. Over the years, it has become widespread throughout the country, being used for space heating in many provinces (especially in İzmir, Afyon, Kütahya and Manisa). Greenhouse heating started in 1987 by heating two greenhouses on an area of 1000 m^2 in Simav – Eynal (Kütahya) geothermal field. The increasing use of geothermal energy in greenhouse heating has made great contributions to the agricultural sector and related government incentives have been brought to the agenda. One of these incentives is Agriculture-Based Specialized Organized Industrial Zones (TDİOSB), which have been established within the framework of the “Supporting Rural Development Investments” project by the Ministry of Agriculture and Forestry in order to support greenhouse projects that use alternative energy sources (geothermal, solar energy, etc.).

As a result of all the exploration, research and development studies in geothermal energy led by MTA, the identified geothermal power capacity of Türkiye has exceeded 40000 MWt. In terms of the utilisation of geothermal resources, Türkiye has ranked third in Europe, fifth in the world in direct use and first in Europe, fourth in the world in indirect use (Table 1).

Table 1- World ranking on direct and indirect uses of geothermal resources (Lund and Toth, 2021; IRENA, 2024).

Direct Use			**Indirect Use**		
Rank	**Country**	**MWt**	**Rank**	**Country**	**MWe**
1	China	40610	1	USA	2674
2	USA	20713	2	Indonesia	2598
3	Sweden	6680	3	Philippines	1952
4	Germany	4806	4	Türkiye	1691
5	Türkiye	3488	5	New Zealand	1050

3. Space Heating in Türkiye: 2024 Status

Data collected from all provinces where space heating is provided by geothermal resources are presented in Table 2. In the table, districts that utilise geothermal energy for domestic heating, the number of heated facilities, and installed power values in MWt (megawatts thermal, which is the most commonly used unit) and Residences Equivalence are given. The value of “Residences Equivalence” is calculated from the required energy for heating a flat of 70 m^2 taken as the average living space of a family of four in France (équivalent logement) (AFPG, 2021, 2023), while in Türkiye, a flat of 100 m^2 with a height of 2.8 meters (Mertoğlu et al., 1997) is considered for this calculation. In this study, following the second approach, MWt conversions were made based on the assumption that approximately 1 MWt of power is needed to heat 100 areas of 100 m^2 (which equals to 100 Residences Equivalence).

From the collected data, it is revealed that geothermal space heating is carried out in 13 provinces and 25 fields in Türkiye, in a total area of 170481 Residences Equivalence with 1704.8 MWt of installed power capacity. The largest heated area in a province is in Afyonkarahisar (68883 Residences Equivalence in total). In terms of geothermal fields, the largest area is heated by Balçova field in İzmir (40630 Residences Equivalence), followed by Ömer - Gecek (33013 Residences Equivalence) and Hüdai (32000 Residences Equivalence) fields in Afyonkarahisar. Domestic heating is reported to be implemented in most of the fields, except for Heybeli (Afyonkarahisar), Büyük Kaynarca (Bursa), Şifne (İzmir), Kuzuluk (Sakarya) and Taraklı (Sakarya).

Table 2- Geothermal space heating data of Türkiye – July 2024.

Province	District	Geothermal Field	Total Heated Area (Residences Equivalence)	Total MWt	Domestic Heating	Types and Numbers of Heated Facilities	
						Municipal sector (Public utility, school, gym, mosque etc.)	Balneological purposes (hotel, thermal facility, pool, spa etc.)
Afyonkarahisar	Çobanlar	Heybeli	110	1.1		7	102
	İhsaniye	Gazlıgöl	3760	37.6	✓	5	44
	Merkez	Ömer-Gecek	33013	330.1	✓	35	17
	Sandıklı	Hüdai	32000	320	✓	30	245
Ağrı	Diyadin	Diyadin	800	8	✓	-	-
Ankara	Kızılcahamam	Kızılcahamam	1530	15.3	✓	5	-
Balıkesir	Bigadiç	Hisarköy	1300	13	✓	*	*
	Edremit	Derman	4930	49.3	✓	*	*
		Güre	1450	14.5	✓	2	3
	Gönen	Gönen	2000	20	✓	10	7
	Sındırgı	Hisaralan	4710	47.1	✓	23	9
Bursa	Osmangazi	B.Kaynarca	30	0.3		-	2
Denizli	Sarayköy	Demirtaş	2500	25	✓	-	-
İzmir	Balçova	Balçova	40630	406.3	✓	*	-
	Bergama	Dübek	400	4	✓	*	-
	Çeşme	Şifne	100	1		-	12
	Dikili	Kaynarca	1200	12	✓	*	-
Kırşehir	Merkez	Terme	1800	18	✓	*	-
Kütahya	Simav	Çitgöl	1200	12	✓	-	-
		Eynal	19440	194.4	✓	40	5
Manisa	Salihli	Kurşunlu	12000	120	✓	*	-
Nevşehir	Kozaklı	Kozaklı	3376	33.8	✓	36	16
Sakarya	Akyazı	Kuzuluk	573	5.7		-	-
	Taraklı	Taraklı	129	1.3		-	-
Yozgat	Sorgun	Sorgun	1500	15	✓	1	-
Total			**170481**	**1704.8**		**194**	**462**

* : numerical data not available
- : no heated facilities

The facilities heated with geothermal energy throughout Türkiye are examined in two main categories according to their areas of usage (Table 2, Figure 2). In this regard, public utilities including schools and gyms are considered as municipal sector and the buildings with thermal amenities are taken as facilities used for balneological purposes. Notable geothermal fields which are used for the heating of facilities in municipal sector are Eynal (Kütahya) and Kozaklı (Nevşehir) fields with 40 and 36 heated public areas, respectively. Two geothermal fields especially stand out for heating with balneological purposes; a total of 245 facilities in Hüdai (Afyonkarahisar) field and 102 facilities in Heybeli (Afyonkarahisar) field are heated with geothermal.

The distribution of heated facilities in Türkiye (Figure 2) displays that geothermal space heating is predominantly carried out in Western Anatolia which constitutes 94% of the total heated area. Space heating

Figure 2- Residences and facilities heated by geothermal in Türkiye.

is also utilised in certain fields in Central Anatolia (Kızılcahamam, Kozaklı, Sorgun, Terme) and in the Diyadin field in Eastern Anatolia.

4. Greenhouse Heating in Türkiye: 2024 Status

Data collected from all provinces where greenhouse heating is provided by geothermal resources are presented in Table 3 in terms of total heated area and related energy values. The MWt values are calculated following the assumption that 1 MWt of power is required to heat approximately 5000 m^2 of greenhouse area.

Geothermal greenhouse heating activities are carried out in 27 provinces and 62 fields in Türkiye on a total of 6970158 m^2 area with 1394 MWt of installed power. The largest heated greenhouse area is in Afyonkarahisar province (total of 2242455 m^2), and in Hüdai geothermal field (1825000 m^2). Hüdai geothermal field is followed by Dikili field (890000 m^2) in İzmir and Kurşunlu geothermal field (470000 m^2) in Manisa. It should also be noted here that greenhouse heating in Adıyaman is performed with the hot water obtained from oil production.

The distribution of fields that are utilised for greenhouse heating and the related TDİOSB areas are visualized in Figure 3. The results show that greenhouse heating takes place mostly in Western Anatolia, partly in Central Anatolia and Eastern Anatolia. These regions comprise 81%, 12% and 7% of the total heated greenhouse area, respectively.

Status regarding the investments in greenhouses has also been investigated in this study (Table 4). Among early-stage investments, it has been reported that in Tuzlukçu (Konya) field, a 48000 m^2 section of 300000 m^2 total investment area is about to be completed, while in Kula - Emir (Manisa) field, a 50000 m^2 investment is under construction. Additional investment planning is in process for Urganlı - Cambazlı (Manisa, 170000 m^2) and Yukarıyıldızlı (Sivas, 41000 m^2) fields. TDİOSB has been established in some provinces (Figure 3, Table 4). Moreover, the infrastructure works of TDİOSB located in Sarayköy district of Denizli province have been completed and 80000 m^2 section of the greenhouse area has become operational.

Table 3- Geothermal greenhouse heating data of Türkiye – July 2024.

Province	District	Geothermal Field	Heated Greenhouse Area (m^2)	Total MWt
Adıyaman	Kahta	Karakuş (Oil field)	32000	6.4
Afyonkarahisar	Bolvadin	Heybeli	50000	10
	Merkez	Ömer-Gecek	367455	73.5
	Sandıklı	Hüdai	1825000	365
Ağrı	Diyadin	Diyadin	40000	8
Aksaray	Sarıyahşi	Bekdik	40000	8
Ankara	Etimesgut	Eryaman	600	0.12
	Sincan	Mülk	1000	0.2
Aydın	Didim	Didim	1000	0.2
	Germencik	Germencik	41000	8.2
		Gümüşköy	74000	14.8
	İncirliova	İncirliova	8000	1.6
	Karacasu	Karacasu	4000	0.8
	Koçarlı	Koçarlı	5000	1
	Kuşadası	Davutlar	1000	0.2
	Kuyucak	Horsunlu-Ortakçı	1000	0.2
	Söke	Sazlıköy	2000	0.4
		Söke	1200	0.2
	Sultanhisar	Salavatlı	80000	16
Balıkesir	Edremit	Edremit	5700	1.1
	Sındırgı	Hisaralan	1000	0.2
Bolu	Merkez	Karacasu	3327	0.7
Çanakkale	Ayvacık	Babadere-Tuzla	5000	1
Denizli	Buldan	Yenicekent	55000	11
	Pamukkale	Gölemezli	70000	14
	Sarayköy	Babacık	11000	2.2
		Gerali	120000	24
		Kızıldere	130000	26
		Tosunlar	260000	52
Elazığ	Merkez	Cipköy	10000	2
Erzurum	Aziziye	Ilıca	10000	2
Eskişehir	Çifteler	Çifteler	25000	5
	Mahmudiye	İsmetpaşa	80207	16
		Şerefiye	55104	11
İzmir	Aliağa	Samurlu	25000	5
	Dikili	Dikili	890000	178
		Nebiler	1000	0.2
	Foça	Foça	2000	0.4
	Seferihisar	Seferihisar	5000	1
	Torbalı	Torbalı	10000	2
Kayseri	Kocasinan	Düver	31000	6.2
Kırklareli	Merkez	Asilbeyli	55000	11
Kırşehir	Çiçekdağı	Mahmutlu	120000	24
	Merkez	Karakurt	130000	26
	Mucur	Mucur	50000	10

Table 3- Geothermal greenhouse heating data of Türkiye – July 2024. (continue)

Province	District	Geothermal Field	Heated Greenhouse Area (m²)	Total MWt
Konya	Cihanbeyli	Ilıcapınar	107552	21.5
	Karapınar	Karapınar	200	0.1
	Tuzlukçu	Tuzlukçu	2040	0.4
Kütahya	Hisarcık	Hamamköy	1000	0.2
	Simav	Çitgöl	130000	26
		Eynal	287857	57.6
Manisa	Salihli	Caferbeyli	70000	14
		Kurşunlu	470000	94
	Turgutlu	Urganlı-Cambazlı	245000	49
Nevşehir	Kozaklı	Kozaklı	193000	38.6
Sakarya	Akyazı	Kuzuluk	74000	14.8
Şanlıurfa	Merkez	Karaali	350000	70
Sivas	Yıldızeli	Sıcakçermik	60000	12
Uşak	Banaz	Hamamboğazı	100000	20
Van	Çaldıran	Ayrancılar	34000	6.8
Yozgat	Boğazlıyan	Cavlak	56916	11.4
	Sorgun	Sorgun	54000	10.8
Total			**6970158**	**1394**

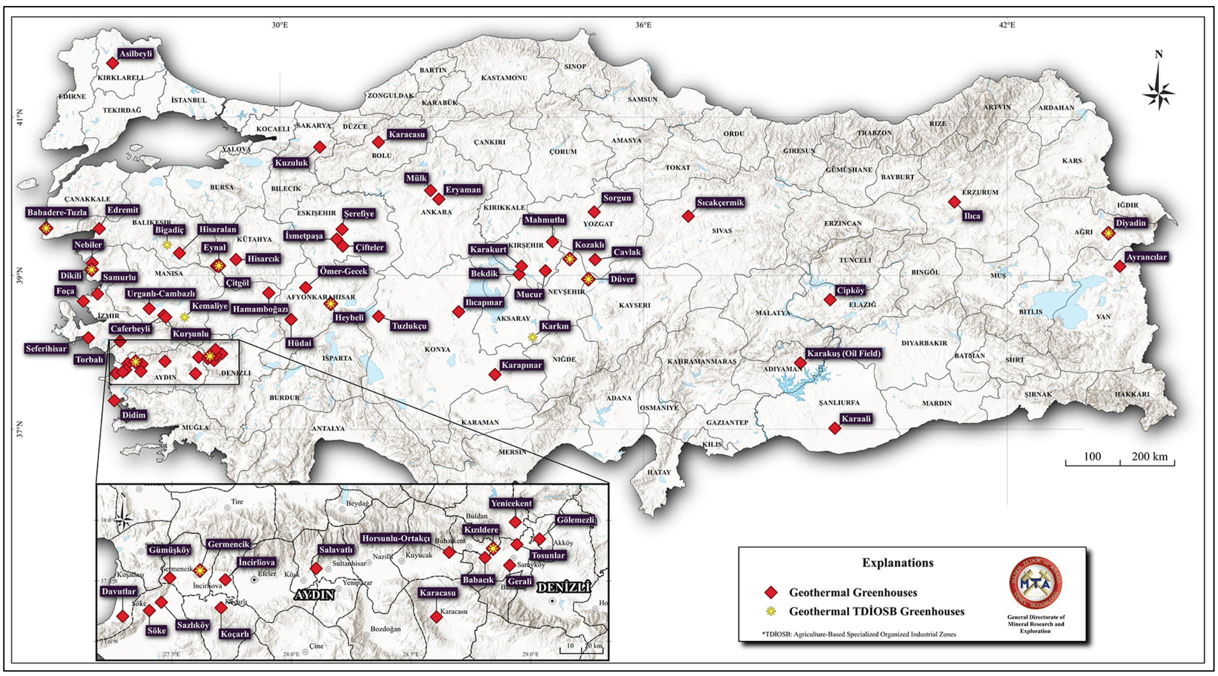

Figure 3- Greenhouses heated by geothermal and the related fields in Türkiye.

Table 4- Early-stage and TDİOSB investments in greenhouses heated by geothermal energy.

		Province	District	Geothermal Field
Geothermal Investments	Early-Stage	Ankara	Kızılcahamam	Kızılcahamam
			Sincan	İlyakut
				Türkobası
				Yenikayı
		Konya	Tuzlukçu	Tuzlukçu
		Manisa	Kula	Şehitli
			Turgutlu	Urganlı - Cambazlı
		Sivas	Merkez	Gaziköy
			Yukarıyıldızlı	Kalın
	TDİOSB	Afyonkarahisar	Bolvadin	Heybeli
		Ağrı	Diyadin	Diyadin
		Aksaray	Karkın	-
		Aydın	Germencik	Germencik
		Balıkesir	Bigadiç	-
		Çanakkale	Ayvacık	Babadere - Tuzla
		Denizli	Sarayköy	Kızıldere
		İzmir	Dikili	Dikili
		Kayseri	Kocasinan	Düver
		Kütahya	Simav	Çitgöl
		Manisa	Alaşehir	Kemaliye
		Nevşehir	Kozaklı	Kozaklı

5. Development of Space Heating and Greenhouse Heating in Türkiye over the Years

Current space and greenhouse heating data compiled in this study are evaluated using the previous datasets composed by MTA from 2007 to 2024 (Figures 4, 5, 6 and 7). 2007 constitutes a critical year for geothermal in Türkiye in terms of the increase in investments and the initiation of regular data collection in related institutes because of the Law No. 5686 that was enacted in 2007.

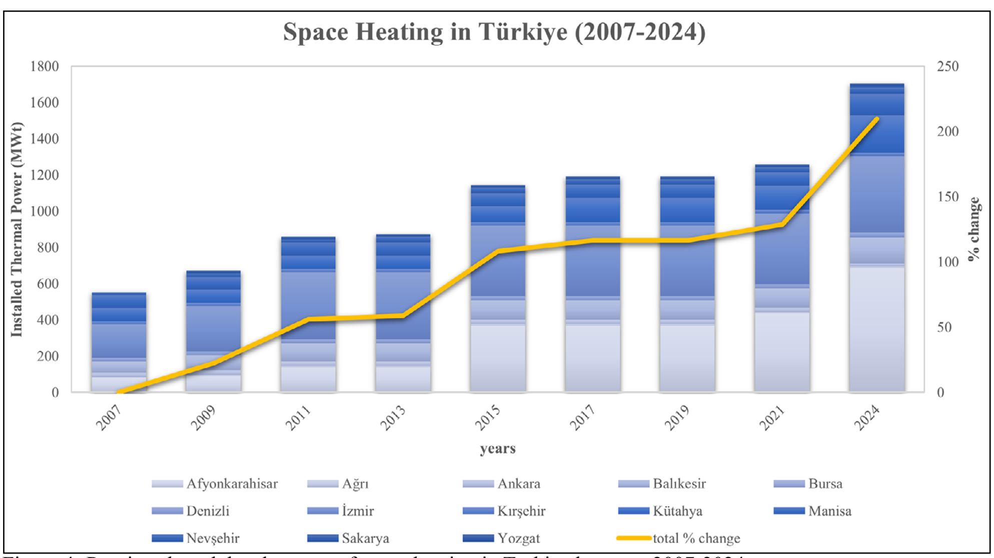

Figure 4- Province based development of space heating in Türkiye between 2007-2024.

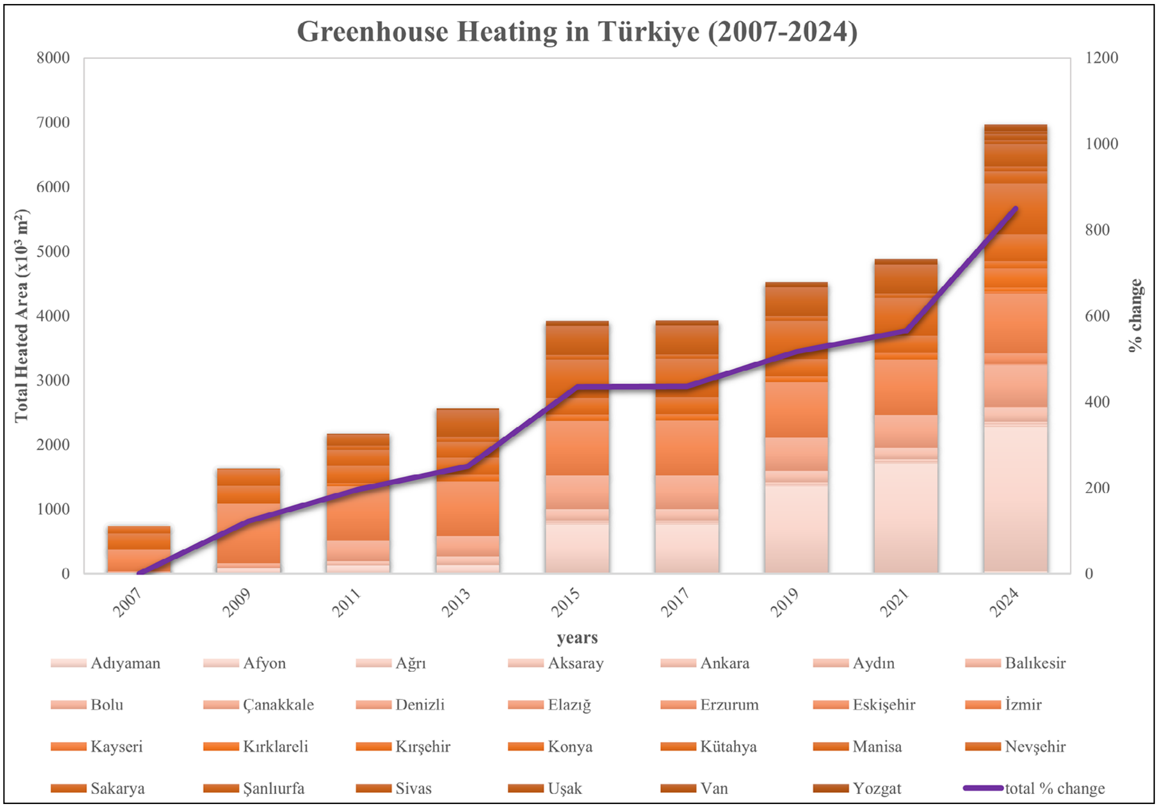

Figure 5- Province based development of greenhouse heating in Türkiye between 2007-2024.

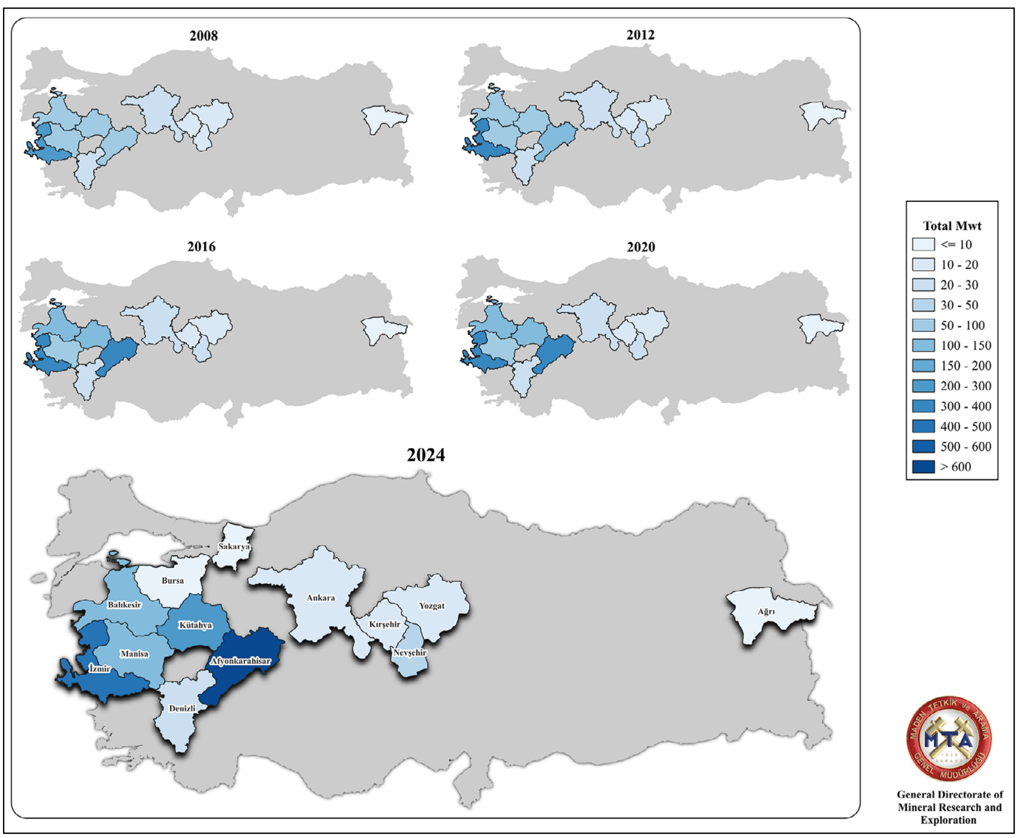

Figure 6- Geographical distribution of geothermal space heating in Türkiye in the years 2008, 2012, 2016, 2020, 2024.

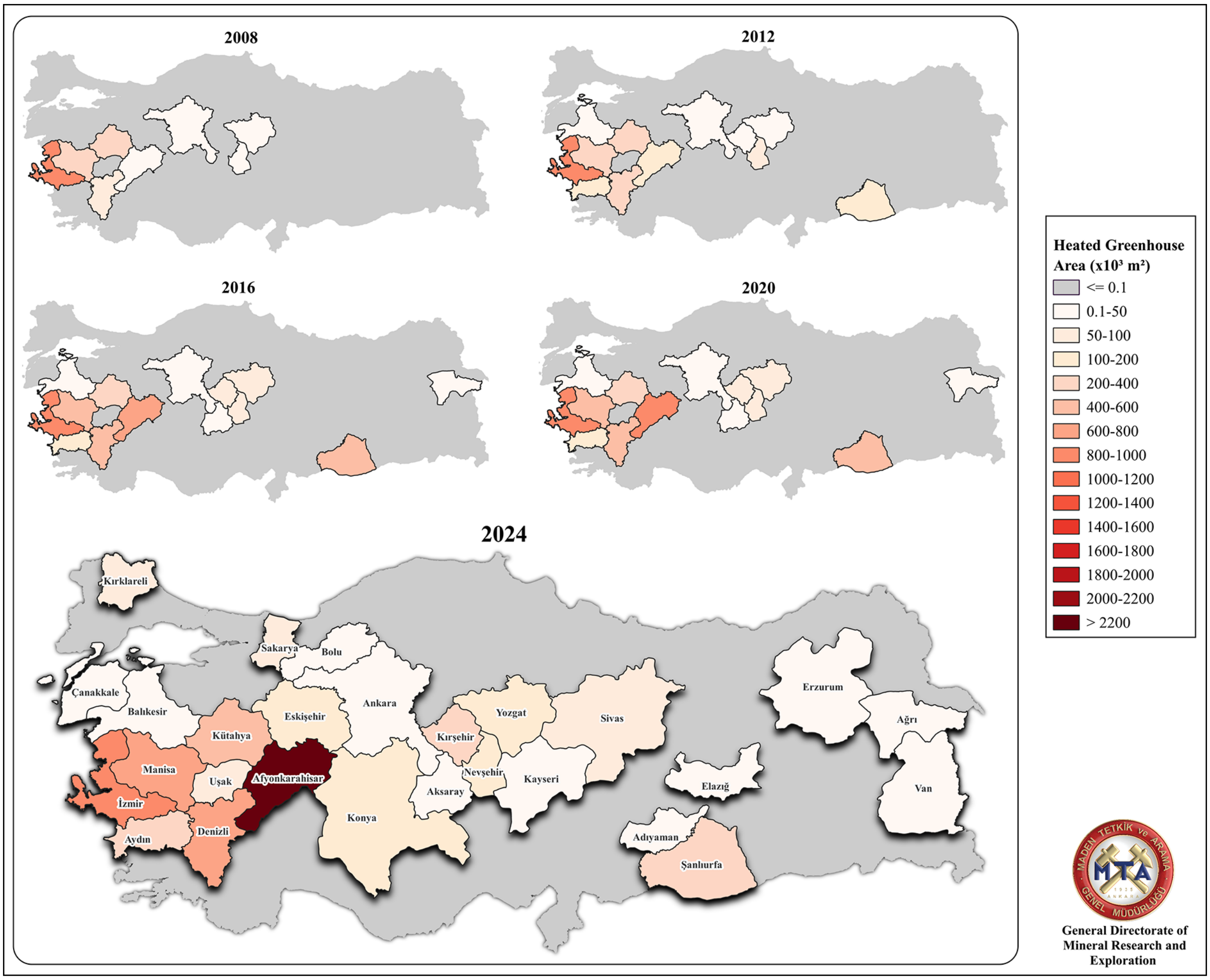

Figure 7- Geographical distribution of geothermal greenhouse heating in Türkiye in the years 2008, 2012, 2016, 2020, 2024.

Space and greenhouse heating activities have been continuously increasing in the past 17 years. The results point out that from 2007 to 2024, installed power of geothermal space heating has increased by 210% (550 MWt – 1704.8 MWt), and the values for greenhouse heating have risen by 850% (733630 m^2 – 6970158 m^2, Figures 4 and 5). The comparison of percentage increases reveals that the growth in greenhouse heating has been almost four times higher than space heating in this period. The development in Afyonkarahisar province especially stands out in both space heating and greenhouse heating, which is followed by İzmir and Manisa in space heating, İzmir and Denizli in greenhouse heating.

It is observed from the data that the growth for space heating in Türkiye is not as high as the heating in greenhouses and it has been almost stagnant after 2015 (especially when heating in Afyonkarahisar province is ignored). The reasons include, i) the incentives provided for geothermal greenhouse heating, ii) the low investment requirements for greenhouse construction, iii) the adequacy of lower temperatures for greenhouse heating compared to space heating, and iv) the widespread use of natural gas-based space heating instead of geothermal resources.

The changes in space and greenhouse heating have been examined province by province in every four years since 2008 (Figures 6 and 7). Maps show that both investments have started in the Western Anatolia and partly in the Central Anatolia region, and expanded in these regions following more resource discoveries and related investments. Although there are identified resources (Figure 1) and apparent potential in the

Eastern Anatolia (Koçyiğit, 2023), these areas are yet to be converted into investments and field development efforts have not reached a sufficient level.

6. Discussions and Conclusions

Geothermal space and greenhouse heating have a significant potential and importance as a renewable, sustainable, and environmentally friendly heat source for the direct use of geothermal energy in Türkiye. With technological progress, resource management and increased government support, the use of geothermal energy for space and greenhouse heating purposes could play a more important role compared to other applications. The economic and environmental advantages of geothermal energy utilisation have also been investigated in recent studies by comparing it with other energy types, which suggest that geothermal energy is indeed a highly cost-effective solution for heating purposes (Şahin et al., 2023; Di Nunzio et al., 2024). To maximize these advantages and to ensure more efficient utilisation of geothermal energy, consolidation of all activities (exploration, operation, inspection, regulation etc.) and related datasets under a single authority rather than multiple institutions would be critical. In this regard, geothermal heated space and greenhouse data were collected from governorates and other public institutions, matched with the MTA inventory and compiled to create the most up-to-date database in this study.

Nationwide gathered data reveal that the majority of space and greenhouse heating takes place in the Western Anatolia region (space heating: 94%, greenhouse heating: 81%) and in Afyonkarahisar province (space heating: 40%, greenhouse heating: 32%). Regarding the geothermal fields, Balçova (İzmir) field stands out for space heating, while Hüdai (Afyonkarahisar) field is prominent in greenhouse heating.

The evaluation of the geothermal space and greenhouse heating data from 2007 to 2024 display that greenhouse heating has increased approximately four times compared to space heating in 17 years. During this period, geothermal investments in the Western and Central Anatolia regions have increased significantly; however, the same increase has not occurred in Eastern Anatolia region. Geothermal utilisation in Eastern Anatolia would most likely to have a substantial growth with new resource discoveries, field development studies and related investments considering the geothermal potential and the discovered resources in the same region.

Another point to be emphasized is that the calculation of geothermal power in terms of MWt involves some uncertainties. In the calculation, the required parameters are thermal fluid flow rate and inlet - outlet temperature of the fluid that heat the facility. Since acquisition of continuous data from each and every heated area throughout the country is not practically possible, all calculations are either performed theoretically or based on certain assumptions. One way to eliminate these uncertainties is by using a calorimeter or an automation system in the facilities to record the necessary data. By regular monitoring, the installed power capacity of all geothermal energy investments could be accurately determined.

Maintaining a regularly updated database and ensuring a constant data flow on geothermal energy usage values would have significant importance as geothermal energy is one of the critical energy resources for Türkiye. With this study, the compiled geothermal space and greenhouse utilisation data have filled the existing data gap and provided a database for future studies. This database will also make a significant contribution in monitoring the further development of geothermal energy in Türkiye.

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