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Geothermal Energy Use: Projections and Country Update for Turkey

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ABSTRACT

Turkey has achieved important geothermal developments since 2015. Since the 1960's, about 460 geothermal fields have been discovered in Turkey. Geothermal direct-use applications have reached 3828,5 MWt geothermal heating, including district heating (1120 MWt), 4.5 million m^2 greenhouse heating (855 MWt), thermal facilities, hotels, etc. heating 435 MWt, balneological use (1400 MWt), agricultural drying (9.5 MWt) and ground source heat pump applications (8.5 MWt).

Geothermal electricity production installed capacity is 1663 MWe (about 1263 MWe binary cycle and about 400 MWe flash steam geothermal power plants) as of December 2020. Liquid carbon dioxide and dry ice production factories, and greenhouse heating are integrated into the Kizildere and Salavatli geothermal power plants. Deep reservoir explorations are ongoing for electricity production purposes. For this reason, deep drilling targets have reached up to 4800 m. The increase of directional drilling and coil tubing operations are other important developments for the geothermal fields in Turkey.

The issued geothermal law and incentives contributed to the increase in geothermal electricity production investments within the Turkish private sector. Besides the hydrothermal system utilization, Turkey shall give emphasis to EGS systems for future projections. The Turkish Geothermal Association gave emphasis and advice on continuing the feed in tariff, which ended at the end of 2020 and the Turkish Government decided to be continued additional 10 years with same tarif value.

The total hydrothermal possible theoretical geothermal heat potential is 60,000 MWt, according to heat flow maps, measured well depth temperatures and calculations made for 4 km depth. Turkey's total geothermal electricity production potential (hydrothermal, 0-4 km) can be estimated as 4500 MWe with existing 10.5 US cents/kWh incentive, and 10 years purchase guarantee. The technical and economical EGS geothermal electricity production potential has been projected as 20,000 MWe if the 15 US cents/kWh incentive with minimum 15 year purchase guarantee would be possible.

It is known that CO_2 in the geothermal fields in Turkey is formed mostly by the marble and carbonate reservoir rocks due to the effect of the water and heat. CO_2 is emitting naturally towards the atmosphere at ground surface from the reservoir. It is a natural discharge of CO_2 and is independent to the existence of geothermal power plants. For this reason, 50-70 % decrease in the CO_2 amount in 10 years in the geothermal fields in Turkey has been obtained, and is ongoing The reasons of the decline are explained in the paper. As a natural result of CO_2 decrease in the geothermal fields, the downhole pump usage in the geothermal fields will be increased. Existing CO_2 in the geothermal fluid is the advantage for the artesian well flow, but it is a disadvantage for the power plant electricity generation.

1. INTRODUCTION

The first geothermal research and investigations in Turkey started by MTA (General Directorate of Mineral Research and Exploration) in the 1960's (MTA, 2005). Turkey has achieved important geothermal developments in the last 5 years. About 13 % of Turkey's geothermal potential is utilized so far in direct use and electricity production.

Today 17 cities are heated partly with geothermal in Turkey. These geothermal district heating systems have been constructed since 1987 and many developments have been achieved in technical and economical aspects. The first geothermal cooling application has been realized in Izmir - Balcova by Izmir Jeotermal Inc. In 2018, for cooling of 1900 m^2 indoor area by lithium bromide absorption and 90/85°C geothermal temperature regime by supplying 6/9 °C clean cold water to the coolers in the buildings. The 2025 target of Turkey for geothermal direct use, including mainly geothermal heating like district heating, greenhouse heating, thermal facilities heating and cooling and balneological use, has been estimated as 11.150 MWt.

2. GEOLOGY BACKGROUND

Turkey is geologically divided into three main tectonic units: the Pontides, the Anatolides-Taurides and the Arabian Platform (Ketin 1966). These terranes were amalgamated during the Alpine orogeny. The relics of the oceans, which once separated these terranes, are widespread through the Anatolia; they are represented by ophiolite and accretionary mixtures and complexes.

The three terranes, which make up the Pontides, namely the Strandja, Istanbul and Sakarya terranes, have Laurasian affinities. In contrast to the Pontic terranes, the Anatolide-Tauride terrane has not been affected by the Variscan and Cimmeride deformation and metamorphism but was strongly shaped by the Alpine orogeny. The Anatolide-Tauride terrane is subdivided into several zones, mainly on the basis of type and age of Alpine metamorphism. The Southeast Anatolia forms the northernmost extension of the Arabian Platform and shares many common stratigraphic features with the Anatolide-Tauride terrane. The final amalgamation of the terranes in the Oligo- Miocene ushered a new tectonic era characterized by continental sedimentation, calc-alkaline magmatism,

extension and strike-slip faulting. Most of the present active structures, such as the North Anatolian Fault, and most of the present landscape are a result of this neotectonic phase (Okay, 2008).

Due to its complex geology and active tectonic properties, Turkey has high geothermal (hydrothermal and EGS) potential distributed in whole Turkey with different temperature intervals (Figure 1). Due to the effect of extensional tectonism, the western part of Turkey has the most abundant geothermal activity with highest temperatures (up to 287 °C in Manisa -Alasehir in Gediz Graben) (Figure 2). Faults accommodating the deep circulation of hydrothermal fluids of mostly meteoric origin are the primary means by which of geothermal systems are controlled in this region.

In Büyük Menderes Graben located in Aydin - Denizli province, around 1000 MWe geothermal electricity installed capacity exist which constitutes the majority of total geothermal electricity production of Turkey (Figure 3).

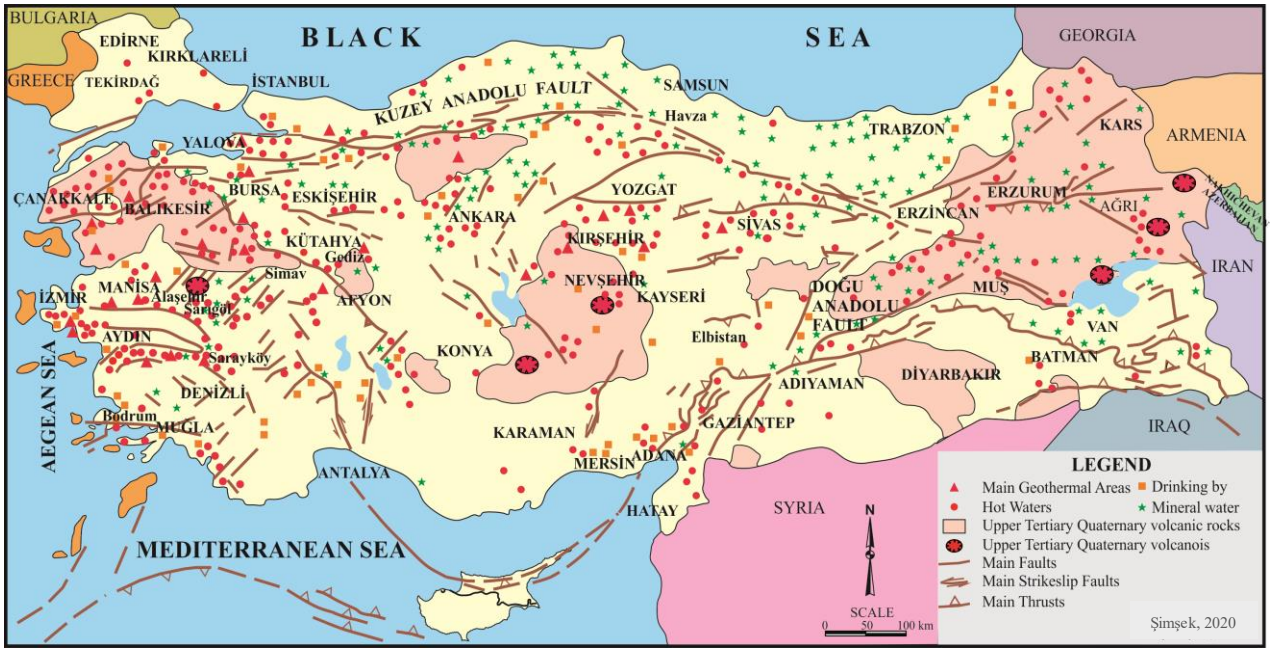


Figure 1: Distribution of geothermal resources and the active faults of Turkey (Simsek, 2020).

3. GEOTHERMAL RESOURCES AND POTENTIAL

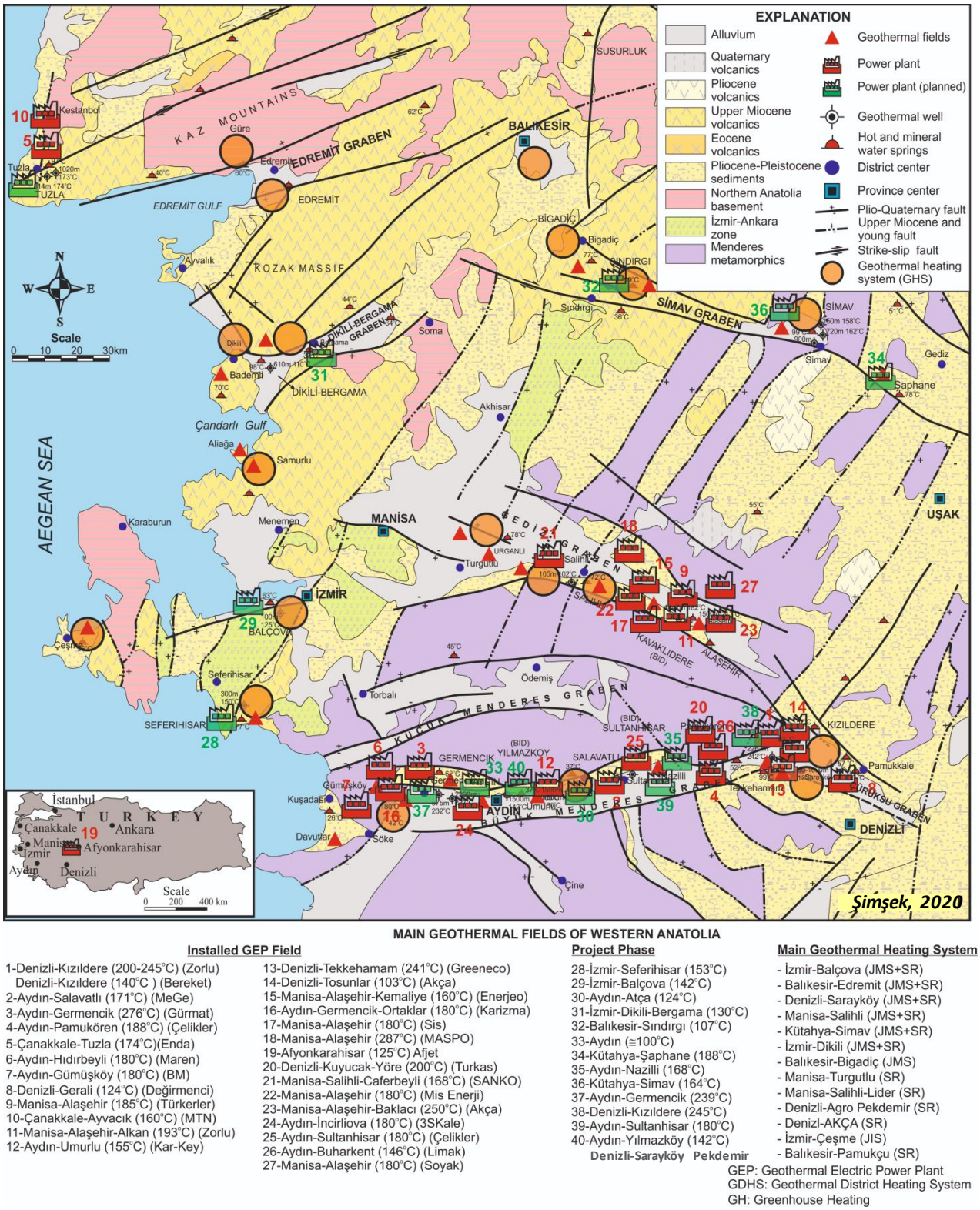
3.1. Geothermal Potential of Hydrothermal Systems

The total geothermal theoretical heat potential of Turkey (hydrothermal 0–4 km depth) has been calculated by Turkish Geothermal Association as 60,000 MWt. The total geothermal electricity technical potential of Turkey (hydrothermal 0–4 km depth) is 4500 MWe. The 2025 target of Turkey is 2500 MWe with incentive (10.5 US cents/kWh feed in tariff, durations of the FIT effectiveness in 10 years).

3.2. EGS Potential and Projections

We estimated the EGS-Enhanced Geothermal System electricity production technical potential of Turkey (3–5 km depth) as 400,000 MWe. The EGS-Enhanced Geothermal System target of Turkey (3-5 km depth) is 20,000 MWe. This production potential is expected to be realized with the feed in tariff of 15 US cents/kWh for 15 years purchase guarantee.

The highest reservoir temperature of 287 °C has been measured at 2750 m depth at Manisa-Alasehir geothermal field in Gediz Graben. A high temperature geothermal field (295°C) at a depth of about 3000 m was also discovered at Nigde province in Central Anatolia.



MAIN GEOTHERMAL FIELDS OF WESTERN ANATOLIA

Installed GEP Field

1-Denizli-Kızıldere (200-245°C) (Zorlu)
Denizli-Kızıldere (140°C) (Bereket)
2-Aydın-Salavatlı (171°C) (MeGe)
3-Aydın-Germencik (276°C) (Gürmat)
4-Aydın-Pamukören (188°C) (Çelikler)
5-Çanakkale-Tuzla (174°C)(Enda)
6-Aydın-Hıdırbeyli (180°C) (Maren)
7-Aydın-Gümüşköy (180°C) (BM)
8-Denizli-Gerali (124°C) (Değirmenci)
9-Manisa-Alaşehir (185°C) (Türkerler)
10-Çanakkale-Ayvacık (160°C) (MTN)
11-Manisa-Alaşehir-Alkan (193°C) (Zorlu)
12-Aydın-Umurlu (155°C) (Kar-Key)
13-Denizli-Tekkehamam (241°C) (Greeneco)
14-Denizli-Tosunlar (103°C) (Akça)
15-Manisa-Alaşehir-Kemaliye (160°C) (Enerjeo)
16-Aydın-Germencik-Ortaklar (180°C) (Karizma)
17-Manisa-Alaşehir (180°C) (Sis)
18-Manisa-Alaşehir (287°C) (MASPO)
19-Afyonkarahisar (125°C) Afjet
20-Denizli-Kuyucak-Yöre (200°C) (Turkas)
21-Manisa-Salihli-Caferbeyli (168°C) (SANKO)
22-Manisa-Alaşehir (180°C) (Mis Enerji)
23-Manisa-Alaşehir-Baklacı (250°C) (Akça)
24-Aydın-İncirlliova (180°C) (3SKale)
25-Aydın-Sultanhisar (180°C) (Çelikler)
26-Aydın-Buharkent (146°C) (Limak)
27-Manisa-Alaşehir (180°C) (Soyak)

Project Phase

28-İzmir-Seferihisar (153°C)
29-İzmir-Balçova (142°C)
30-Aydın-Atça (124°C)
31-İzmir-Dikili-Bergama (130°C)
32-Balıkesir-Sındırgı (107°C)
33-Aydın (≅100°C)
34-Kütahya-Şaphane (188°C)
35-Aydın-Nazilli (168°C)
36-Kütahya-Simav (164°C)
37-Aydın-Germencik (239°C)
38-Denizli-Kızıldere (245°C)
39-Aydın-Sultanhisar (180°C)
40-Aydın-Yılmazköy (142°C)
Denizli-Sarayköy Pekdemir

Main Geothermal Heating System

- İzmir-Balçova (JMS+SR)
- Balıkesir-Edremit (JMS+SR)
- Denizli-Sarayköy (JMS+SR)
- Manisa-Salihli (JMS+SR)
- Kütahya-Simav (JMS+SR)
- İzmir-Dikili (JMS+SR)
- Balıkesir-Bigadiç (JMS)
- Manisa-Turgutlu (SR)
- Manisa-Salihli-Lider (SR)
- Denizli-Agro Pekdemir (SR)
- Denizl-AKÇA (SR)
- İzmir-Çeşme (JIS)
- Balıkesir-Pamukçu (SR)

GEP: Geothermal Electric Power Plant
GDHS: Geothermal District Heating System
GH: Greenhouse Heating

Figure 2: Main geothermal fields of Western Anatolia (Simsek, 2020).

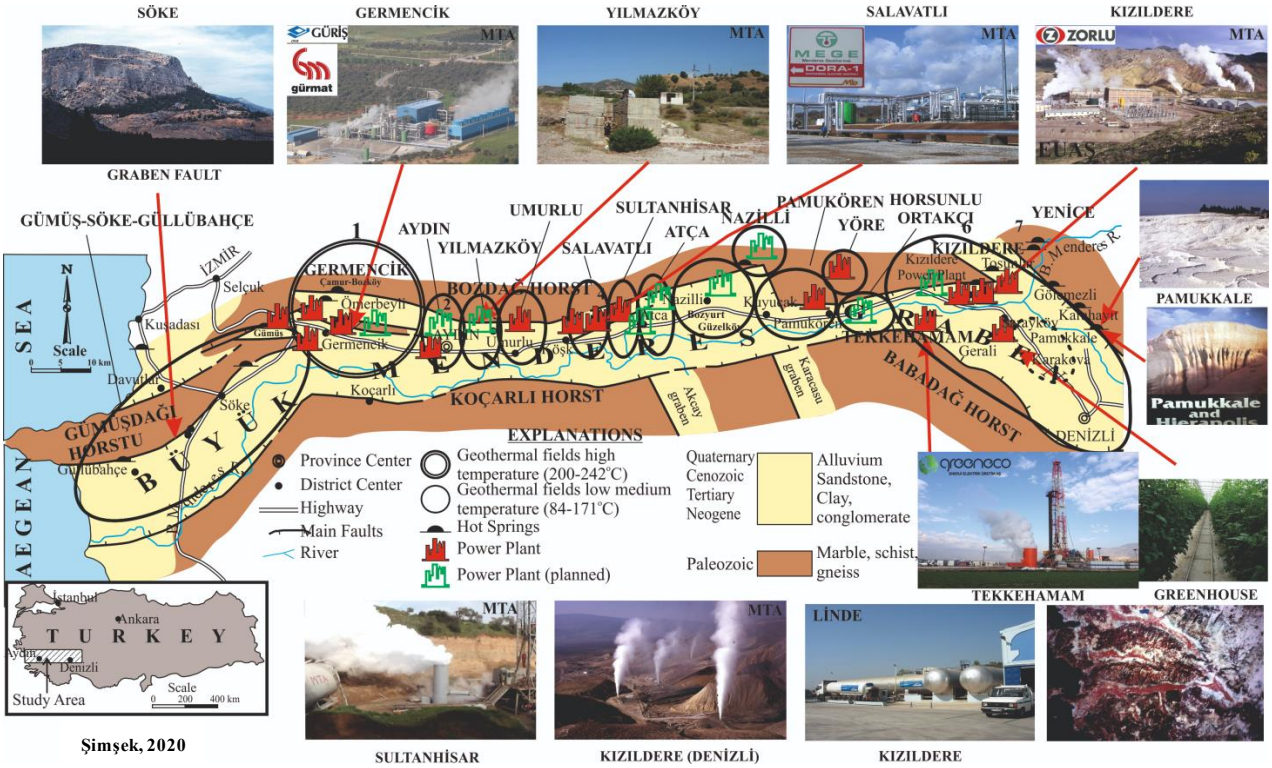


Figure 3: Geothermal fields of the Büyük Menderes Graben (Simsek, 2020).

4. GEOTHERMAL UTILIZATION

As at the end of December 2020, there exist 62 operating geothermal power plants at 27 geothermal fields in Turkey which have a total installed capacity of 1663 MWe (Figure 4). Deep reservoir explorations are going on for electricity production purposes. The increase of directional drillings and coil tubing operation applications are very important for developments of geothermal reservoirs in Turkey. Deep drilling targets have reached up to 4800 m depth. The successful results have been obtained in deep marble reservoirs (about 250°C) at Kizildere and Tekkehamam geothermal fields (Simsek, 2017, 2020).

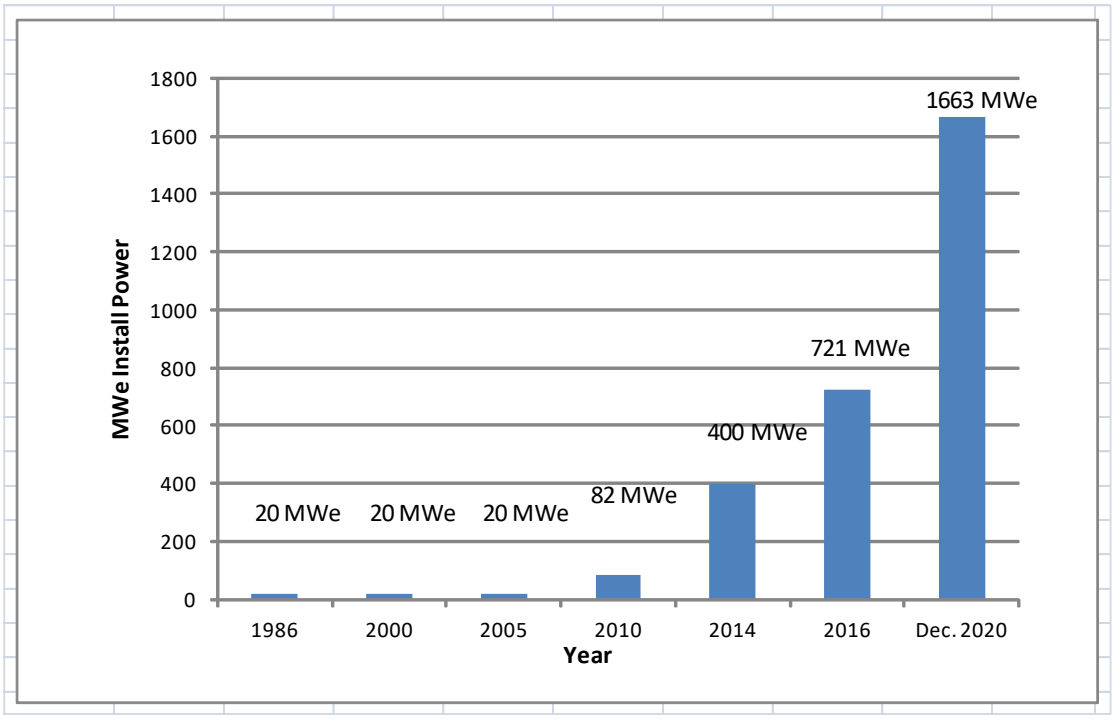


Figure 4: Geothermal electricity production increase in Turkey (Mertoglu et al, 2020).

The operational capacities of the city based geothermal district heating systems (GHDS) existing in Turkey are as follows: Gönen (Commissioned: 1987, 3,400 residences), Simav (1991, 14,500 residences), Kirsehir (1994, 1,900 residences), Kizilcahamam (1995, 2,500 residences), Izmir (1996, 37,000 residences), Sandikli (1998, 11,000 residences), Afyon (1996, 30,000 residences), Kozakli (1996, 3,000 residences), Diyadin (1999, 570 residences), Salihli (2002, 7,500 residences), Edremit (2003, 5,500 residences), Balikesir-Bigadic (2005, 1,500 residences), Yozgat-Sorgun (2008, 1,500 residences), Izmir-Bergama (450 residences), Izmir- Dikili (2000 residences), Denizli-Saraykoy (2,500 residences) and Balikesir-Sindirgi (2014, 300/3000 residences). Today, as low as 40-45°C temperature geothermal waters are also used for space heating in Turkey without heat pumps (Mertoglu et al, 2020).

Some of the existing cities heating have increased their heating capacities as it can be seen in Table 1. Geothermal greenhouse heating applications have reached 4,5 million m^2 during last five years. Ground source heat pump (GSHP) applications in Turkey started in 2000's for residential single family houses with a total installed capacity of 586 kWt. Today, 90 GSHP applications are closed systems with installed capacity of 8,5 MWt (Mertoglu et al. 2020). In recent years, as a new source waste heat from balneological use is recovered.

Table 1: Geothermal utilization capacities in Turkey

UTILIZATION	CAPACITY
GEOTHERMAL DISTRICT HEATING (CITY, RESIDENCES)	126.000 RESIDENCES EQUIVALENCE (1120 MWt)
GREENHOUSE HEATING	4,5 Million m^2 (855 MWt)
HEATING OF THERMAL FACILITIES, SPAS, THERMAL HOTELS AND TIME SHARE FACILITIES	48.600 residences equivalence (435 MWt)
HEAT ENERGY OF THERMAL WATER USE IN HOTELS, SPAS AND AND TIME SHARE FACILITIES	520 GEOTHERMAL SPA (1400 MWt) (about 23 Million guests/annual)
AGRICULTURAL DRYING	9,5 MWt
GEOTHERMAL COOLING	0,35 MWt
HEAT PUMPS; GSHP	120 MWt; 8,5 MWt
TOTAL HEAT USE	**3828,5 MWt (373.000 Residences Equivalence)**
TOTAL ELECTRICTY PRODUCTION	**1663 MWe** (Aydın, Denizli, Manisa, Çanakkale, Afyon)
CARBONDIOXITE PRODUCTION (Food grade Liquid CO_2)	400.000 Tons/year

4. DISCUSSION AND CONCLUSIONS

About 460 geothermal fields have been discovered in Turkey. Rapid development at geothermal electricity installed capacity reached up to 1663 MWe as of December 2020. The capacity has increased more than twice since 2016.

Geothermal direct-use applications have reached 3828,5 MWt geothermal heating, including district heating (1120 MWt), 4,5 million m^2 greenhouse heating (855 MWt), thermal facilities, hotels, etc. heating 435 MWt, balneological use (1400 MWt), agricultural drying (9,5 MWt), geothermal cooling (0,35 MWt) and Groundsource Heat Pump applications (8,5 MWt). Deep reservoir explorations are ongoing for electricity production purposes. For this reason, deep drilling targets have reached up to 4500m. Successful results have been obtained for the exploration of deep reservoirs. As natural result of CO_2 decrease in the geothermal fields; The downhole pump usage in the geothermal fields will be increased in coming years.

The increase of directional drillings and coil tubing operation applications are other important environmental and economic developments for the geothermal fields in Turkey. The EGS-Enhanced Geothermal System target of Turkey (3-5 km) is 20.000 MWe. This production potential expected to be realized during the next 20 years. Heat pump (HP) applications in Turkey started in 2000's and with increasing interest in renewables, number of HP systems has reached to 149 with a total installed capacity of 120 MWt as of December 2019. The 2025 target of Turkey about geothermal direct use has been estimated as 11.150 MWt.

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APPENDIX A: Supplementary Tables

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2020	1.663	8.764	46.398		28.409				13.594		89.737	
Under construction in December 2020	50	264										
Funds committed, but not yet under construction in December 2020	413	2.178										
Estimated total projected use by 2021	1.850	9.755										

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019

[1] N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

[2] 1F = Single Flash; 2F = Double Flash; 3F = Triple Flash; D = Dry Steam; B = Binary (Rankine Cycle); H = Hybrid (explain); O = Other (please specify)

[3] Electrical installed capacity in 2019

Electrical capacity actually up and running in 2019

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1]	Type of Unit[2]	Total Installed Capacity MWe[3]	Total Running Capacity MWe[4]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Denizli (Zorlu)	Kızıldere	1984	1	O	2F	15			
Denizli (Zorlu)	Kızıldere 2	2013	3	O	B+2F	80			
Denizli (Zorlu)	Kızıldere 3	2015	5+1	O	B+2F	165			
Manisa (Zorlu)	Alaşehir	2015	2	O	B	45			
Aydın (Güriş)	Galip Hoca Germencik	2009	1	O	2F	47,4			
Aydın (Güriş)	Efeler	2014	4	O	B	115			
Aydın (Çelikler)	Pamukören	2013	1	O	B	68			
Aydın (Çelikler)	Pamukören 2	2013	1	O	B	23			
Aydın (Çelikler)	Pamukören 3	2013	1	O	B	23			
Aydın (Çelikler)	Pamukören 4	2018	1	O	B	32			
Aydın (Kipaş)	Mehmethan	2016	1	O	B	25			
Aydın (Kipaş)	Deniz	2012	1	O	B	24			
Aydın (Kipaş)	Ken Kipaş	2015	1	O	B	24			
Aydın (Kipaş)	Kerem	2014	1	O	B	24			
Aydın (Kipaş)	Maren	2012	1	O	B	44			
Aydın (Kipaş)	Melih	2018	1	O	B	33			
Aydın (Kipaş)	Ken-3	2015	1	O	B	24,8			
Aydın (MB)	Dora-1	2006	1	O	B	7,95			
Aydın (MB)	Dora-2	2010	1	O	B	9,5			
Aydın (MB)	Dora-3	2014	1	O	B	34			
Aydın (MB)	Dora-4	2016	1	O	B	17			
Denizli (Greeneco)	Greeneco 1-2	2016	2	O	B	26			
Denizli (Greeneco)	Greeneco 3-4	2016	2	O	B	26			
Denizli (Greeneco)	Greeneco 5	2019	1	O	B	28			
Denizli (Greeneco)	Greeneco 6	2019	1	O	B	26			
Manisa (Enerjeo)	Kemaliye	2016	1	O	B	25			
Aydın (Çevik)	Kubilay	2016	1	N	1F	24			
Manisa (Türkerler)	Alaşehir-1	2014	1	O	B	24			
Manisa (Türkerler)	Alaşehir-2	2017	1	O	B	24			
Manisa (Türkerler)	Alaşehir-3	2018	2	O	B	30			
Manisa (Akça)	Baklacı	2018	1	O	B	19,4			
Aydın (Turcas)	Kuyucak	2018	1	O	B	18			
Aydın (Karadeniz)	Karkey Umurlu	2016	2	O	B	12			
Aydın (Karadeniz)	Karkey Umurlu-2	2018	1	O	B	12			
Aydın (Çelikler)	Sultanhisar	2017	1	O	B	13,8			
Aydın (Çelikler)	Sultanhisar-2	2018	1	O	B	22,5			
Çanakkale (MTN)	Babadere	2016	1	O	B	8			
Çanakkale (Enda)	Tuzla	2010	1	O	B	7,5			
Denizli (Bereket)	Kızıldere	2007	1	O	B	6,85			
Denizli (Akça)	Tosunlar	2015	1	O	B	3,81			
Afyonkarahisar (Afjet)	Afjet	2018	1	O	B	2,76			
Aydın (3S Kale)	3S Kale	2018	1	N	B	25			
Denizli (Jeoden)	Sarayköy	2014	1	O	B	2,52			
Aydın (Limgaz)	Buharkent	2018	1	O	B	13,8			
Aydın (BM)	Gümüşköy	2014	1	O	B	13,5			
Manisa (Sanko)	Salihli 1	2017	1	O	B	15			
Manisa (Sanko)	Salihli 2	2019	1	N	B	24,5			
Manisa (Sanko)	Salihli 3	2019	1	O	B	30			
Manisa (Sis)	Özmen 1	2017	1	O	B	23,5			
Manisa (Sis)	Özmen 3	2019	1	O	B	19			
Manisa (Maspo)	ALA-1	2018	1	O	B	10			
Manisa (Maspo)	ALA-2	2019	1	O	B	30			
Manisa (Soyak)	Mis-1	2018	1	O	B	12,3			
Manisa (Soyak)	Mis-3	2019	1	O	B	48			
Manisa (Zorlu)	Alaşehir-2	2019	1	O	B	18,6			
Aydin (Gürmat)	Efe-8	2020	2	O	B	50			
Aydın (Kipaş)	Nezihe Beren	2020	1	O	B	20			
Aydın (Kipaş)	Kiper Nazilli JES	2020	1	O	B	10			
Seferihisar (RSC Elektrik)	Seferihisar JES	2020	1	O	B	15			
Çanakkale (Yerka)	JES	2020	1	O	B	10			
Aydın (Çelikler)	Pamukören-5	2020	1	O	B	32			
Total						**1.663**			

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

1) I = Industrial process heat; H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling); D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables); B = Bathing and swimming (including balneology)
F = Fish farming; G = Greenhouse and soil heating
K = Animal farming; O = Other (please specify by footnote)
S = Snow melting

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (^{o}C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Izmir (Balcova+Narlidere)	D, B, G						250			
Gonen	D, I						19			
Simav	D,G						120			
Kirsehir	D, A						20			
Kizilcahamam	D, B						28			
Afyon	D, B, G						200			
Kozakli	D, B						34			
Sandikli	D, B						119			
Diyadin	D						67			
Salihli	D, B						52			
Saraykoy	D						19			
Edremit	D, B						39			
Bigadic	D						7			
Dikili	D,B,G						19			
Bergama	D						3			
Sorgun	D						19			
Sindirgi	D						24			
Others	D,B,G						81			
TOTAL							1120			

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the rejected to the ground in the cooling mode as this reduces the effect of global warming.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate - typically 3 to 4

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

6) Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.

Locality	Ground or Water Temp. (^{o}C)[1)]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2)]	COP[3)]	Heating Equivalent Full Load Hr/Year[4)]	Thermal Energy Used[5)] (TJ/yr)	Cooling Energy[6)] (TJ/yr)
TOTAL								

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.131 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^{6} W
since projects do not operate at 100% capacity all year

4) Other than heat pumps

5) Includes drying or dehydration of grains, fruits and vegetables

6) Excludes agricultural drying and dehydration

7) Includes balneology

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	435	4800	0,35
District Heating [4]	1120	12362	0,35
Air Conditioning (Cooling)	0,35		
Greenhouse Heating	855	16178	0,6
Fish Farming			
Animal Farming			
Agricultural Drying[5]	9,5	317	0,3
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	1400	26490	0,6
Other Uses (specify)			
Subtotal	**3819,85**	**60147**	
Geothermal Heat Pumps	8,5	171	0,7
TOTAL	**3828,35**	**60318**	

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)					
Production	>150° C	240			30	535
	150-100° C			40	15	68
	<100° C		100		20	164
Injection	(all)	100	40			135
Total		340	140	40	65	902

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Prograr
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	150	250	90	30		100
2016	170	260	100	35		110
2017	190	280	110	40		115
2018	200	290	120	45		125
2019	220	300	130	50		130
Total	220	300	130	50		130

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling*	Field Development Including Production Drilling & Surface Equipment**	Utilization***		Funding Type	
			Direct***	Electrical****	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	6	18		40	80	20
2000-2004	13	40	64	120	80	20
2005-2009	245	80	190	245	70	30
2010-2014	1100	320	200	540	70	30
2015-2019	2330	1210	60	1760	90	10

* 1-2 exploration well and gradient wells included.
** Reinjection well included.
*** Heating Plant + distribution network
**** Surface Equipment + power plant