# Evaluation of Geothermal District Heating Systems of Turkey

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## ABSTRACT

Turkey is one of the few countries that has almost all possible applications of geothermal energy. Geothermal district heating has a relatively short history (since 1987) compared to other direct utilization but plays important economic, social and environmental roles in some towns. There are 18 geothermal district heating systems (GDHS), mainly in the Aegean region with resource temperatures between 57–145°C. Current heating capacities of those systems are in the range of 570 to 37500 Residence Equivalent (RE, 1 RE= 100 m$^2$ heated area). This paper evaluates each GDHS on their technical characteristics, then gives details about three GDHS and compares the economics of district heating applications based on alternative fuel prices.

## 1. INTRODUCTION

Turkey is located on the seismically active Mediterranean Earthquake Belt. The active tectonics of Turkey results from the continental collision of the African and Eurasian plates, as expressed by collisional intra-continental convergence and tectonic escape-related deformation (Bozkurt, 2001). Owing to its setting in this tectonically active Alpine-Mediterranean Belt, Turkey has considerable geothermal potential. Exploration studies have identified about 250 geothermal fields and more than 2000 natural springs in Turkey. These manifestations are located mainly along the major grabens (such as Büyük Menderes, Gediz, Dikili-Bergama, Küçük Menderes and Edremit Grabens) along the Northern Anatolian Fault Zone and in the Central and Eastern Anatolia volcanic regions (Figure 1). More than 1500 geothermal wells have been drilled in those fields as exploration, production or injection wells. While the temperatures of natural springs vary between 20–100°C, wellbore temperature showed higher temperatures, as high as 295°C. This wide range of geothermal fluid temperatures enabled the utilization of geothermal energy at several applications, such as space heating (residential and greenhouse), bathing–swimming–balneology, electricity production, and $CO_2$ production. Statistics from 2015 indicate that "*Geothermal direct-use applications have reached 2886.3 MW$_t$ geothermal heating including district heating (805 MW$_t$), nearly 3 million m$^2$ greenhouse heating (612 MW$_t$), thermal facilities, hotels etc heating 420 MW$_t$, balneological use (1,005 MW$_t$) and heat pump applications (42,8 MW$_t$). Geothermal electricity production has reached 400 MW$_e$ (total of 17 geothermal power plants). Liquid carbon dioxide and dry ice production factories are integrated to the Kizildere and Salavatli geothermal power plants*" (Mertoğlu et al, 2015). Recent numbers for district heating and electricty production became 872 MW$_t$ and 1315 MW$_e$, recpectively, making Turkey the leading country in electricity production and second in district heating after Iceland, in Europe (EGEC, 2019). This paper is about the district heating applications of geothermal energy in Turkey.

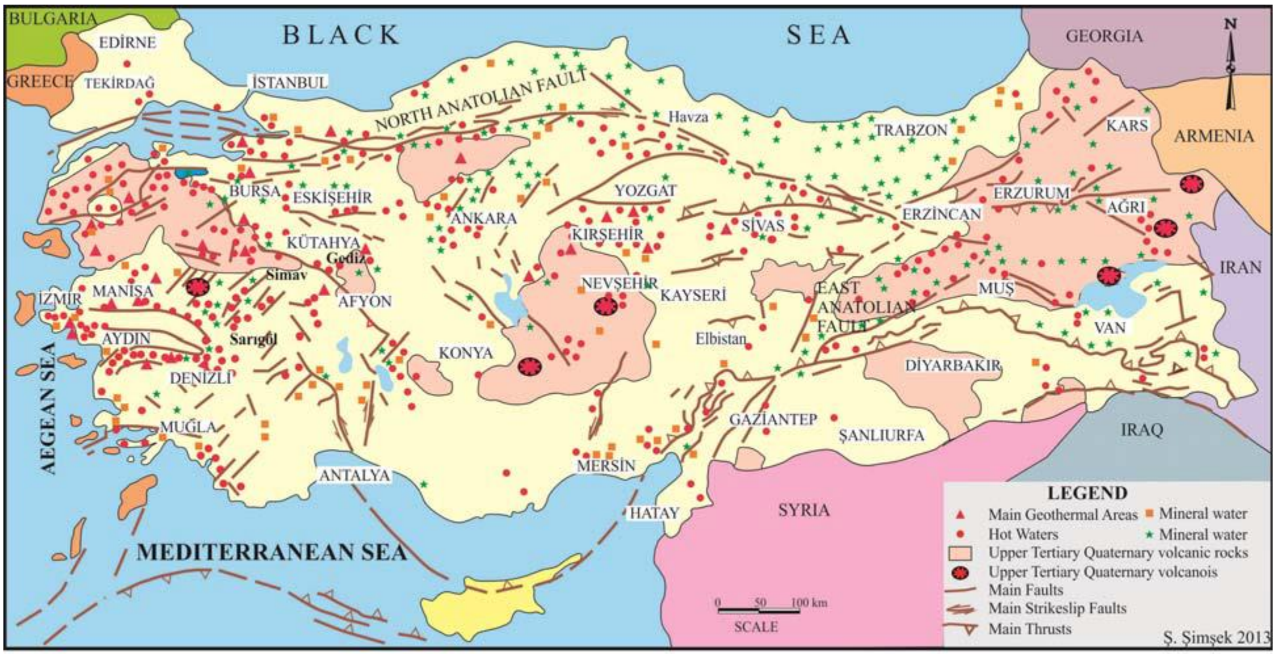


**Figure 1: Main neo-tectonic lines and hot spring distribution in Turkey (modified after Şimşek, 2009).**

## 2. GEOTHEMAL DISTRICT HEATING SYSTEMS IN TURKEY

Although Turkey has a long tradition of utilizing geothermal energy for bathing, swimming and balneology since the Roman and Ottoman eras, residential district heating applications are comparatively new. There are 18 geothermal district heating systems (GDHS) in operation, which are listed in Table 1 in alphabetical order of their provinces. Figure 2 shows the locations (provinces) of those GDHS on a map of Turkey. Among 18 GDHS, 13 of them are in the major graben systems of the Aegean region and four of them are in Central Anatolia. The first GDHS, Balıkesir–Gönen, was put in operation in 1987 followed by eight GDHS in the 90's and more after 2000.

Tables 2 and 3 present some properties of those GDHS in Turkey. The third column of Table 2 gives the heated area of each district heating system as Residence Equivalent (RE). Since one RE equals 100 $m^2$ heated area, the total area heated by GDHS in Turkey becomes 13,300,000 $m^2$. The next column of Table 2 shows the method of pricing and price of each GDHS for the heating season of 2018–2019 in Turkish Lira (1 Euro = 6.3 TL). There are two methods of pricing, based on heated area or energy consumed. Pricing based on heated area is applied initially in all GDHS but the inauguration of the Energy Efficiency Law after 2007 introduced the use of calorimeters for the measurement of consumed energy. This change in pricing methodology changed the attitude of consumers towards energy saving, heat insulation, reducing the comfort temperature of living areas which resulted with a considerable decrease in required flow rate for heating. The fifth column of Table 2 indicates that many of the GDHS are owned by municipalities although governorships of provinces, private sectors and some chambers have shares in certain percentages.

**Table 1: List of geothermal district heating systems (GDHS) in Turkey.**

| Number | Province–Town | Year of Commissioning |
|---|---|---|
| 1 | Afyonkarahisar | 1996 |
| 2 | Afyonkarahisar–Sandıklı | 1998 |
| 3 | Ağrı–Diyadin | 1999 |
| 4 | Ankara–Kızılcahamam | 1995 |
| 5 | Balıkesir–Bigadiç | 2005 |
| 6 | Balıkesir–Edremit | 2003 |
| 7 | Balıkesir–Gönen | 1987 |
| 8 | Balıkesir–Güre | 2006 |
| 9 | Balıkesir–Sındırgı | 2014 |
| 10 | Denizli–Sarayköy | 2002 |
| 11 | İzmir–Balçova | 1996 |
| 12 | İzmir–Bergama | 2009 |
| 13 | İzmir–Dikili | 2009 |
| 14 | Kırşehir | 1994 |
| 15 | Kütahya–Simav | 1991 |
| 16 | Manisa–Salihli | 2002 |
| 17 | Nevşehir–Kozaklı | 1996 |
| 18 | Yozgat–Sorgun | 2008 |

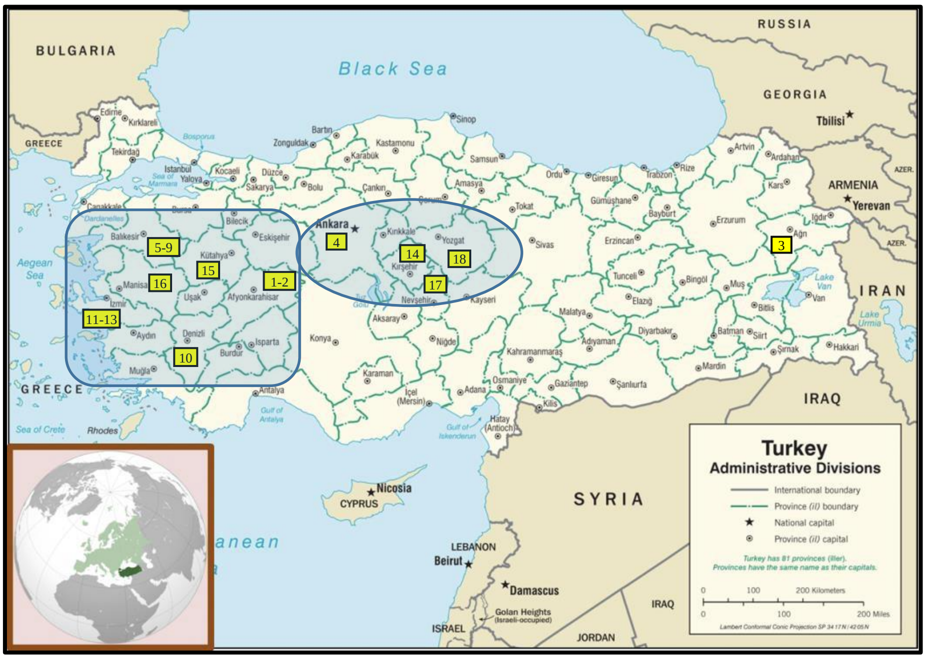


**Figure 2: Map of Turkey showing the provinces with geothermal district heating systems (GDHS).**

**Table 2: Properties of geothermal district heating systems (GDHS) in Turkey.**

| No | Province - Town | Residence Equivalent - Subscription | Method of Pricing and Price | Ownership | Wellhead temperatures (°C) | Maxiumun Flow rate (l/s) | Comments |
|---|---|---|---|---|---|---|---|
| 1 | Afyonkarahisar | 25610 – 10096 | Calorimeter – 0.093 TL/kWh Hot water: 2.19 TL/$m^3$ | 60% Afyon Governorship, 35% Municipality and 5% Chamber of Commerce | 100 – 125 | 360 | - |
| 2 | Afyonkarahisar - Sandıklı | 17226 – No information | Area based – 208.33 TL/month/100 $m^2$ Calorimeter – 0.070 TL/kWh | 99% Municipality, 1% Trade Unions | 70 | 450 | - |
| 3 | Ağrı - Diyadin | 570 – No information | No information | Ağrı Governorship | 70 | No information | - |
| 4 | Ankara - Kızılcahamam | 2100 – 1900 | Calorimeter – 0.133 TL/kWh | Municipality | 76 | 90 | Return water of heating system with temperature of 45 – 54 °C is used in hotels for heating, bathing, swimming |
| 5 | Balıkesir - Bigadiç | 1500 – 1200 | Calorimeter – 0.085 TL/kWh | Municipality | 57 – 98 | 32 | Two wellbores of the system have temperatures 57 and 98 °C. Hot water is pumped via 18 km pipeline to the heating center. Inlet and outlet temperatures of heating center is 75 °C and 52 °C, respectively. 42 °C hot water after residential use is given to a private hotel. |
| 6 | Balıkesir - Edremit | 5150 – 4015 | Area based – 155.73 TL/month/100 $m^2$ Hot water included | 10% Municipality, 90% Private Sector | 48 – 60 | 450 | - |
| 7 | Balıkesir - Gönen | 3400 – 2300 | No information | 90% Municipality, 10% Private Sector | 65 | 160 | - |
| 8 | Balıkesir - Güre | 1400 – 750 | Area based – 100 TL/month/100 $m^2$ | Municipality | 98 | 78 | - |
| 9 | Balıkesir - Sındırgı | 2500 – 1402 | Area based – 114.50 TL/month/100 $m^2$ Hot water: 20 TL/month | Municipality | 98 | | Geothermal fluid from natural springs and a well with artesian flow (55 l/s) is pumped via 25 km pipeline to the heating center. |
| 10 | Denizli - Sarayköy | 5000 – No information | Calorimeter – 0.1035 TL/kWh | Private Sector | 145 (outlet temperature of power plant) | 220 | Effluent of old power plant of Kızıldere geothermal field is transferred via 8 km pipeline into the town. Inlet and outlet temperatures of the heating center are 90 and 70 °C, respectively. |
| 11 | İzmir - Balçova | 37500 – 24000 | Calorimeter – 0.097 TL/kWh Area based: 937 TL/year/100 $m^2$ | 50% Municipality, 50% İzmir Governorship | 98 – 140 | 580 | - |
| 12 | İzmir - Bergama | 450 – 405 | No information | Private Sector | 65 | 50 | - |
| 13 | İzmir - Dikili | 1500 – 1382 | No information | Municipality | 74 – 83 | 60 | - |
| 14 | Kırşehir | 1800 – 1200 | Area based – 120 TL/month/100 $m^2$ | Municipality, Kırşehir Governorship, Chambers of Commerce and Agriculture | 50 – 57 | 80 | - |
| 15 | Kütahya - Simav | 17495 – 13560 | No information | Municipality | 120 – 140 | 340 | - |
| 16 | Manisa - Salihli | 9000 – 7500 | No information | Municipality | | | |
| 17 | Nevşehir - Kozaklı | 3000 – No information | Area based – 97.91 TL/month/100 $m^2$ | Municipality | | | |
| 18 | Yozgat – Sorgun | 2100 - 720 | Area based – 93.75 TL/month/100 $m^2$ | Municipality | | | |

Wellhead temperatures vary between 48 – 140°C and flowrates reach as high as 450 l/s. Details of selected GDHS will be discussed in the following subsections.

### 2.1 The Afyonkarahisar GDHS

The Afyonkarahisar GDHS has been operated by AFJET Inc. since 1996. The Ömer–Gecek geothermal field is situated about 15 km northwest of Afyon city in the Central Aegean Region of Turkey (Figure 3). Thermal waters from the Ömer–Gecek field are used to feed the Afyonkarahisar GDHS and for greenhouse heating, thermal tourism and physiotherapy. The field was developed in two stages. In the first stage (earlier than 2010), more than 30 wells were drilled with depths of 56.8 m to 902 m with a maximum temperature of 111.6 °C (Satman et al., 2007). Those studies enabled the establishment of a GDHS with 4500 RE. Further geophysical studies in the field during the second development stage identified new horizons to be drilled which resulted in wellbores having 125°C (Başaran et al., 2015). New wellbores made it possible to enlarge the Afyonkarahisar GDHS for the current capacity.

The daily average temperature graph of the region indicates that there is a need for heating for about 8 months based on a reference temperature of 18°C (Figure 4). A schematic diagram of the heating facility is mainly divided into two subsections, namely the GDHS and hot water for thermal facilities. The geothermal waters produced from production wells are firstly directed into the storage tanks to mix the geothermal fluid from different wells with different temperatures. Mixed geothermal fluid is then used in the main heating center to heat up the circulation water for the GDHS network. The circulation water inlet and outlet temperatures are 45°C and 90°C, respectively. On the other hand, geothermal fluid leaves the main heating center at 55°C and is directed to re-injection wells. Circulation water leaving the main heating center at 90°C is pumped to the city center where intermediate heating centers are located at each apartment and are used to heat the water in the network of each apartment (Figure 5). In addition, the Ömer-Gecek geothermal field supplies heating and utilization waters along a 18-kilometer line from a single authority to the thermal facilities with a capacity of 10.000 beds.

Wellbores drilled during the second development stage ended up with higher temperatures (125°C) which made it possible to construct a 3 $MW_e$ binary cycle power plant. Effluent from the power plant is directed to a greenhouse complex (90000 $m^2$) where the inlet and outlet temperatures are 70°C and 50°C, respectively (Figure 6). In all these applications, more than 95% of the produced geothermal fluid is re-injected.

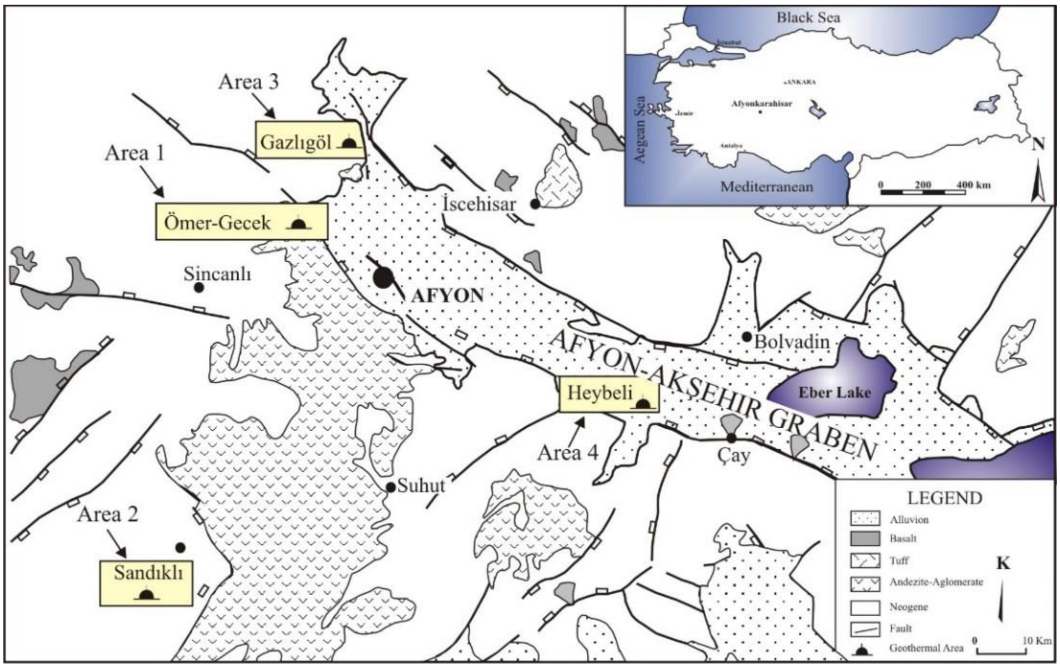


**Figure 3: Geothermal areas in the Afyon-Akşehir graben system (modified from Gürsoy at al. 2003).**

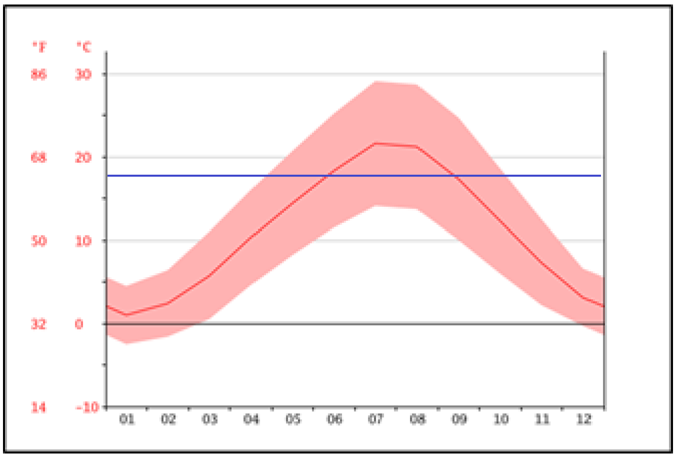


**Figure 4: Daily temperature variability in Afyonkarahisar province.**

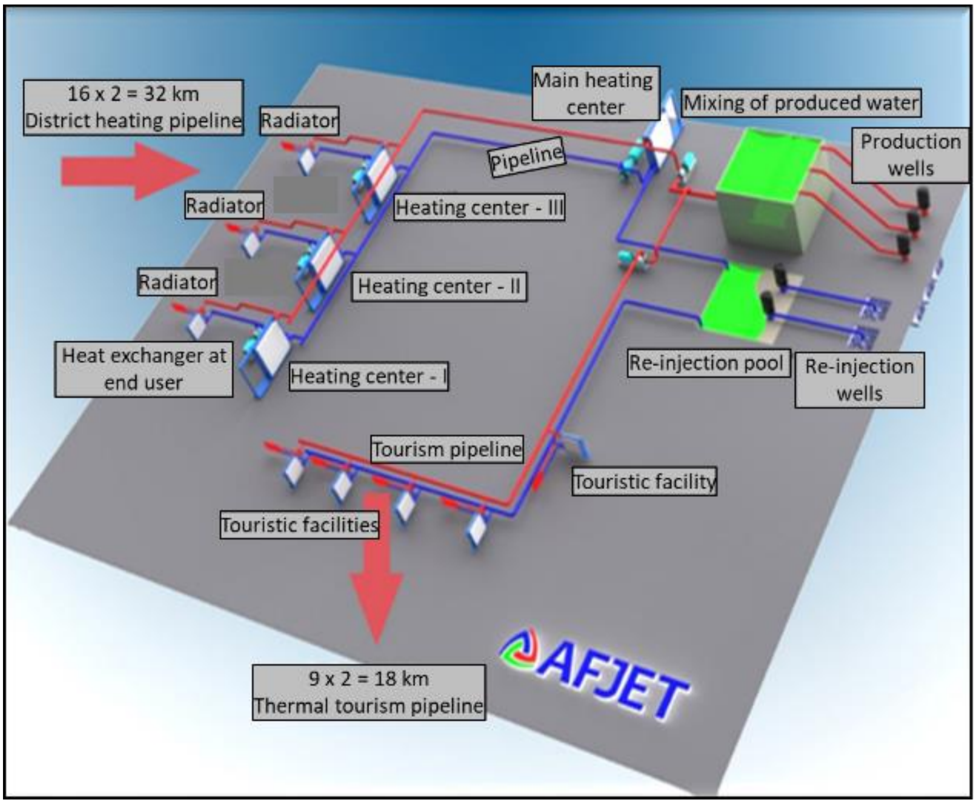


**Figure 5: Schematic diagram of the Afyonkarahisar geothermal district heating system (GDHS).**

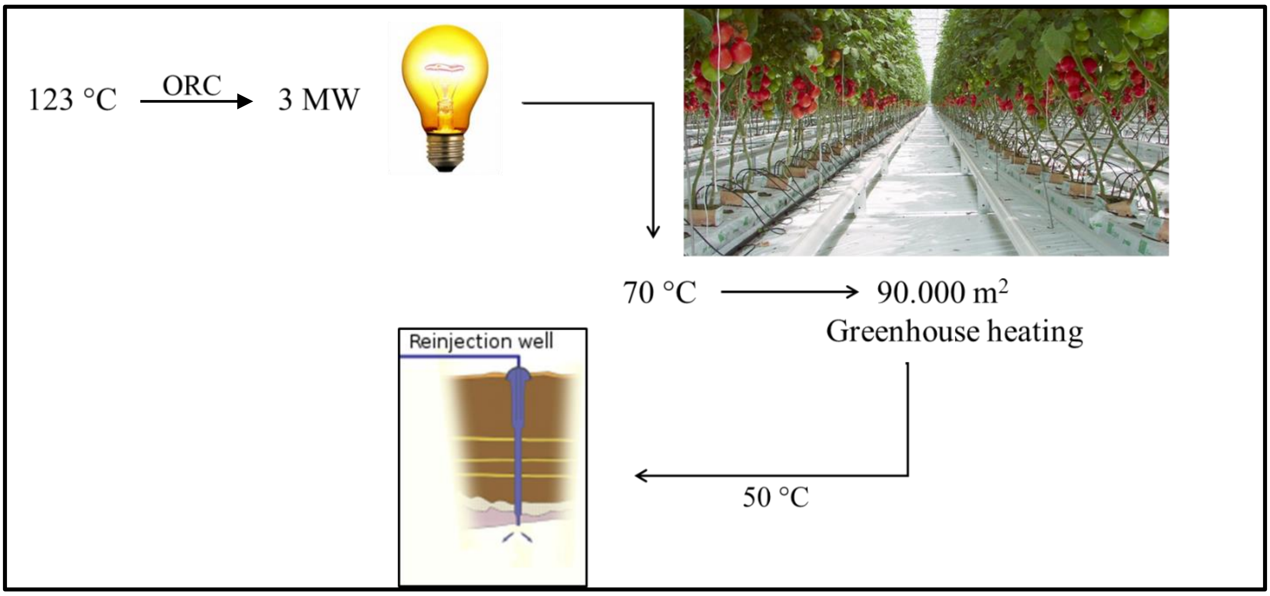


**Figure 6: Schematic diagram of an electricity generation application by AFJET.**

### 2.2 The İzmir–Balçova GDHS

The Balçova geothermal field is located in the Izmir Bay area of the Aegean coast, 11 km southwest of the city of Izmir (Figure 7). The field is located in a densely populated area which makes direct heat applications very efficient and economical (Figure 8). Heat produced from the Balçova geothermal field is utilized for three main purposes: greenhouse heating, balneology and residential heating. Among these three applications, the latter one is the main application throughout the Balçova GDHS. Izmir has a relatively mild climte compared to Afyonkarahisar which makes the heating season shorter (about 6 months) based on a reference temperature of 18°C (Figure 9).

There are three main flow loops within the Balcova GDHS system (Figure 10):

- *Geothermal water loop* in which produced geothermal fluid at an average temperature of 120°C is sent to heating centers to transfer its thermal energy, using heat exchangers, to the closed city water loop. Geothermal fluid from the heating centers is re-injected into the ground at an average temperature of 60°C.
- *City water loop:* In this loop, the city water is circulated in a distribution network between the heating centers and residences. The city water is heated to a temperature of 90°C at the heating centers and sent to residences in which each residence has its own heat exchanger to heat its radiator water.
- *Residential loop:* This is the loop within a single residence through which the thermal energy of the city water is transferred to the residential radiator system.

Although more than 40 wells have been drilled in the Balçova geothermal field, 13 of them are used as producer and 7 of them are utilized to re-inject the geothermal fluid (Figure 8). There are thirteen heating centers within the system to cover the residential area of the Balçova–Narlıdere districts. Each heating center serves the residences in their nearest vicinity. Heating centers do not operate at their full installed capacities since some of the residences do not subscribe to the GDHS. On average 70% of the installed capacity is used by subscribers (Figure 11). As seen in Figure 11, both installed capacity as well as subscription has increased with time. In addition to heating centers, the GDHS has two pumping stations and more than 450 km long pipeline network. Individual houses, governmental institutes and private firms such as the Dokuz Eylül University Hospital, University Dormitories, Izmir Economy University Campus, one shopping center and a hotel are the subscribers of GDHS. In addition to the GDHS, the Balçova geothermal field supplies geothermal water to two health center-hotels for balneological purposes, namely the Balçova Thermal Hotel and the Kaya Hotel (Figure 8).

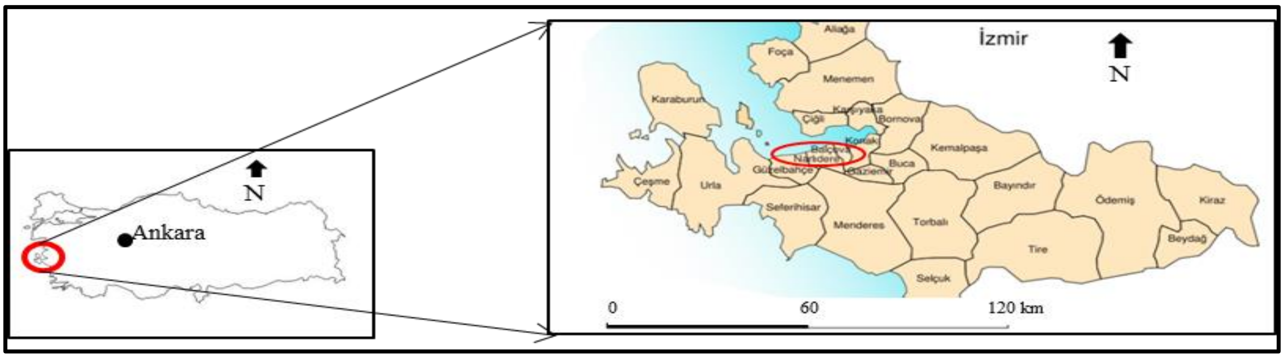


**Figure 7: Location of the Balçova geothermal field in the Izmir Bay area of the Aegean coast.**

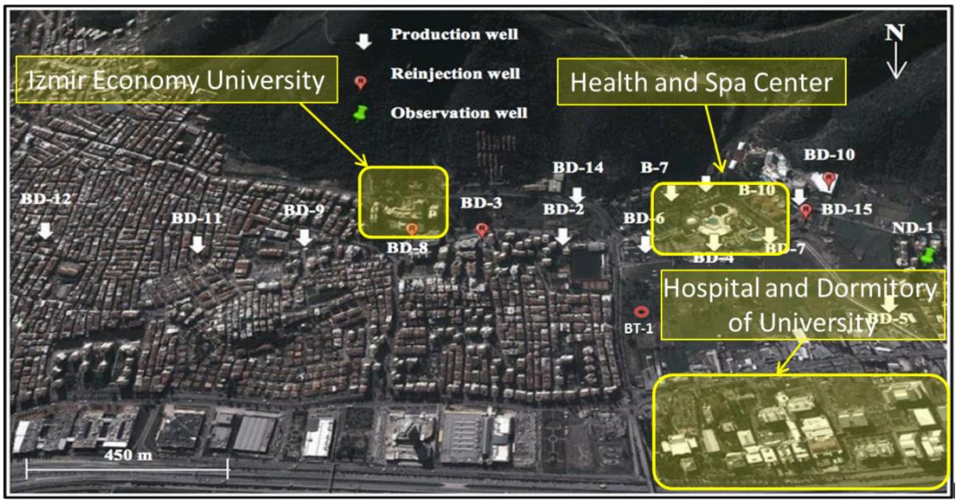


**Figure 8: Residential view of Balçova District with well locations.**

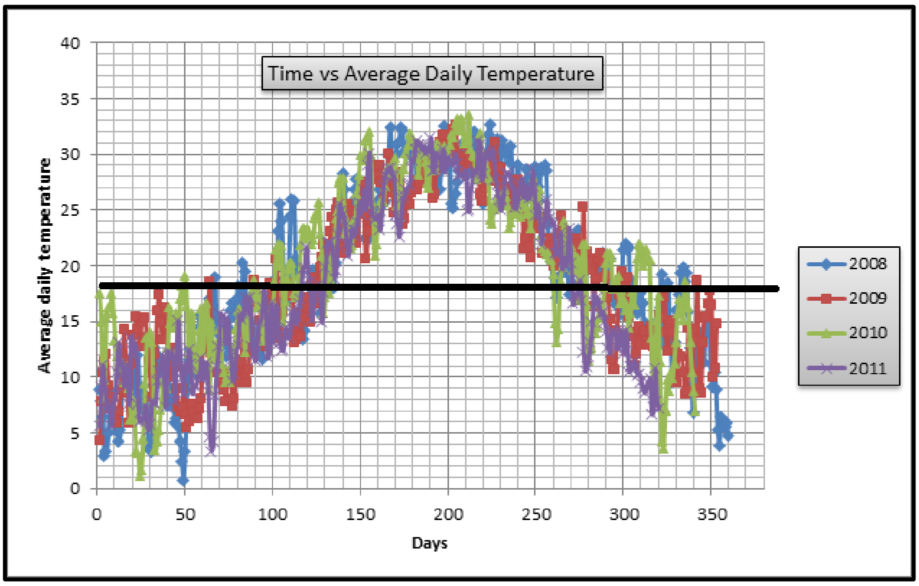


**Figure 9: Variability in the average daily temperature in Izmir.**

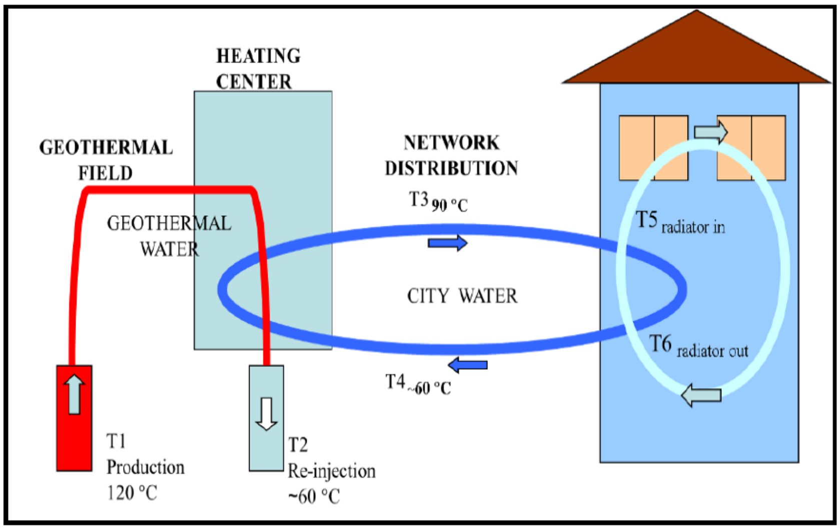


**Figure 10: Schematic diagram of the İzmir–Balçova geothermal district heating system (GDHS).**

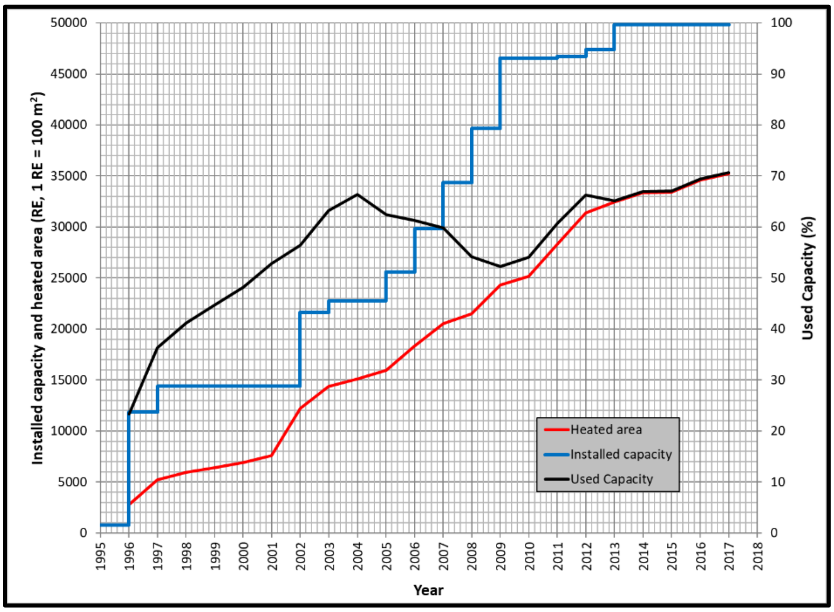


**Figure 9: Development of the İzmir–Balçova geothermal district heating system (GDHS).**

Table 3 compares the economics of GDHS with alternative fuels for heating a 100 $m^2$ closed area in which 14,007,285 kcal/year of energy is consumed. It is seen that the most economical alternative is a GDHS using calorimeters use followed by a GDHS using area-based pricing. The closest alternative to GDHS is natural gas with 1.74 times compared to GSHS using calorimeters. On the other hand, the cost of using diesel fuel can be as high as 6.83 times the expensive of using GDHS with calorimeters.

**Table 3: Cost comparison of heating by alternative fuels.**

| Energy Type | TL/year | Difference |
|---|---|---|
| GDHS (calorimeter) | 866 | 1.00 |
| GDHS (area based) | 973 | 1.12 |
| Natural Gas (90% burning efficiency) | 1507 | 1.74 |
| Coal (from Siberia) | 1986 | 2.30 |
| Fuel Oil No:4 | 3746 | 4.33 |
| Electricity (residential tariff) | 5244 | 6.06 |
| LPG (bulk) | 5257 | 6.08 |
| Diesel oil | 5911 | 6.83 |

### 2.3 The Balıkesir–Sındırgı GDHS

Balıkesir–Sındırgı is the last GDHS put in operation. It is a unique system as it supplies most of its geothermal fluid from natural springs in the Hisaralan geothermal field (Figure 12). The geothermal fluid from the field is transferred via a 24 km long pipeline along which the total temperature drop is about 4°C.

**Figure 10: Natural springs in the Hisaralan geothermal field.**

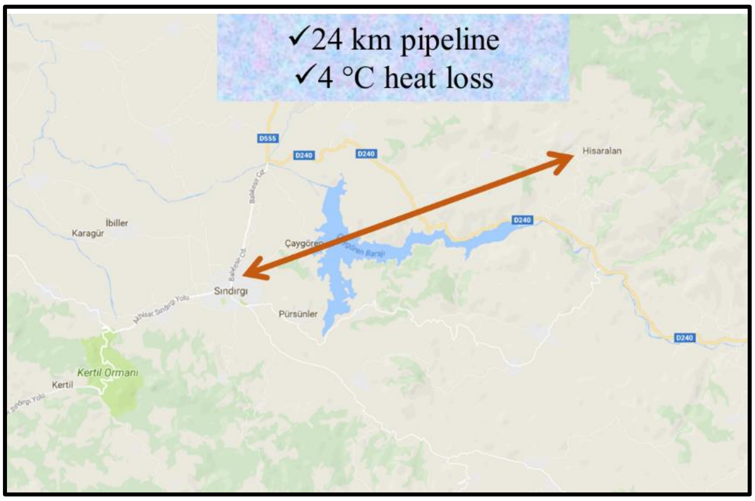


**Figure 11: The Balıkesir–Sındırgı geothermal district heating system (GDHS) water supply.**

## 3. CONCLUSIONS

Owing to its great potential for geothermal energy, Turkey put 18 geothermal district heating systems (GDHS) into operation since 1987. Cost comparison indicates that GDHS with the use of calorimeters for pricing the energy is the most economical option among several fuels for heating. Many projects have an integrated use approach, utilizing the geothermal fluid for greenhouse heating, bathing–swimming–balneology, even electricity production.

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