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ORIGINAL ARTICLE

Use of abandoned oil wells in geothermal systems in Turkey

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Abstract Human beings have been benefiting from geothermal energy for different uses since the dawn of civilization in many parts of the world. One of the earliest uses of geothermal energy was for heating and it was used extensively by Romans in Turkey. The Aegean region is favored with a large number of thermal springs known since ancient times. However, it was in the twentieth century that geothermal energy was first used on a large scale for direct use applications and electricity generation. The country's installed heat capacity is 3322.3 MW_t for direct use and 1347 MW_e for power production. Also, many drilled wells to extract oil or natural gas were abandoned for various reasons in the southeast of Turkey. Some of the oil fields have heat content that can be used for geothermal energy. Some even have hot fluid in the reservoir. This paper presents an investigation into how to use geothermal energy in abandoned oil and natural gas wells. Methods used to generate geothermal energy from abandoned oil fields other than conventional geothermal energy production are examined. Downhole heat exchangers can be used to extract heat without producing geothermal fluid which decrease gas emissions to the atmosphere and energy need for reinjection, from the abandoned oil wells to generate electricity or direct use applications. Using this method, it is possible to use abandoned wells in southeastern Turkey where this energy improves the economy of the region.

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1 Introduction

The requirement for energy increases with increasing technological development. With today's developments, energy can be produced with less carbon emissions than before, so it is less damaging to nature. One of the sustainable and renewable energy production sources is geothermal energy (Røksland et al. 2017). It is thought that approximately 44 TW of heat power spreads over the earth surface. Geothermal energy will become an important energy source in the future with gradual depletion of fossil fuels such as coal and oil (Cheng et al. 2014a; Cheng et al. 2016). Another advantage of geothermal energy is that it can be produced throughout the year irrespective of weather conditions, unlike solar, wind and wave energy (Kharseh et al. 2019). High drilling cost is one of the biggest financial problems of geothermal exploitation. In spite of this, the installed capacity of global geothermal energy increased from 1300 MW in 1975 to $>$ 11,715 MW in 2015 and is expected to exceed 40 GW by 2035 (Gharibi et al. 2018; Bertani 2016).

Several abandoned oil wells registered bottom hole temperature of the order of 150–250 °C. The amount of abandoned oil wells worldwide is approximately 20–30 million (Cheng et al. 2014b). Given high drilling cost of geothermal wells, abandoned oil or natural gas wells can be used to reduce geothermal production costs. Reusing abandoned oil wells improves the economic feasibility of geothermal energy production since drilling costs, which generally correspond to 50% of total costs of a power plant project, are avoided (Alimonti and Soldo 2016). These wells could be converted into geothermal wells using downhole heat exchangers (DHEXs), which are closed loop systems such as U-tube or double-pipe heat exchangers (see Fig. 1). In closed loops, a single well is used, as opposed to open loop systems which use two wells (one for production and another one for re-injection). Closed loop systems are similar to conventional geothermal production and require less pump power due to natural convection (Templeton et al. 2014). The U-tube heat exchanger consists of thin pipes or bundles of pipes extending along a single line. The double pipe heat exchanger consists of two concentric pipes. The outer wall of the inner pipe is wrapped with insulation material such as polystyrene. The annular channel between the inner pipe and outer pipe, where the fluid is injected into the well, is called the injection well, and the inner pipe where a heated fluid is extracted to the surface is called the recovery well. The formation and the well are sealed with cement and casing in order to avoid any contamination between the formation and the well. The fluid is injected into the well through the outer tube and the heated fluid is extracted from the inner pipe. The double-pipe heat exchangers are more advantageous than the U-tubes in terms of having a higher surface area for heat exchange, higher fluid circulation, and lower speed due to the larger cross-sectional area, which means less hydraulic pressure and less pumping power to ensure the circulation of the fluid (Templeton et al. 2014).

The main purpose of this study is to investigate geothermal energy production methods from abandoned oil wells and their usage areas. We also aim to promote the use of geothermal energy, which is more sustainable and less damaging to nature than traditional methods of electricity generation, as well as the use of abandoned oil wells that are not being used.

2 Methods of harnessing geothermal energy in oilfields

Geothermal energy obtained from abandoned oil wells can be used for power generation and direct use applications such as district heating, greenhouse heating, spa, leisure and balneo-therapy applications, industrial processing (fruit drying and fishing), etc. Direct use of geothermal resources is the oldest method of use as it is widely utilized in more than 82 countries worldwide (Wang et al. 2018a).

There are two types of geothermal power production methods. One of these methods is the thermal cycle. Since geothermal resources in the oilfield are classified as medium to low enthalpy geothermal energy, Binary Cycle using Organic Rankine Cycle (ORC) is used for geothermal energy production in oilfields (Wang et al. 2018a). Geothermal fluid

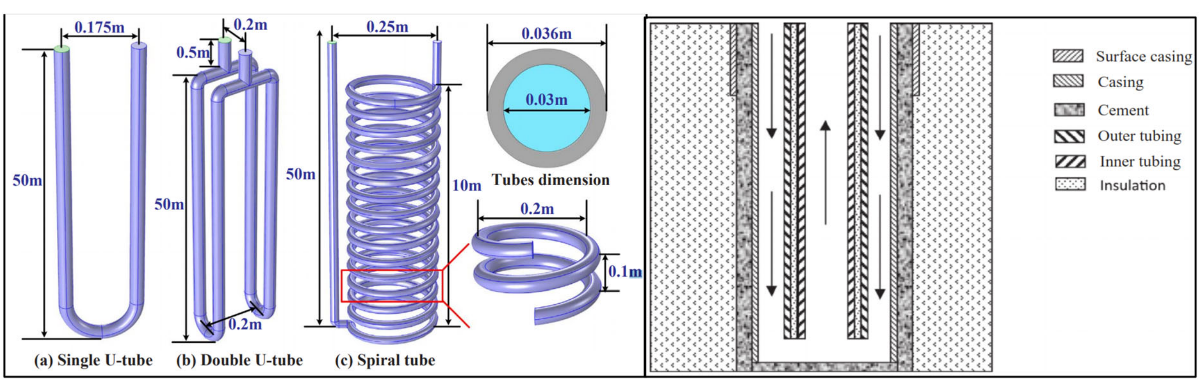


Fig. 1 U-tube heat exchanger types (left) (Shi et al. 2018), wellbore structure with double-pipe heat exchanger (right) (Nian and Cheng 2018a)

extracted from the geothermal well is used as working fluid in conventional geothermal systems. However, organic fluids are used to get more heat because of geothermal energy of low and medium quality obtained from abandoned wells with temperatures of less than 150 °C (Cheng et al. 2014b). Secondary fluids such as isobutane, isopentane, freon and ammonia which evaporate at a lower temperature than water are used to improve the cycle efficiency of the system. In binary cycle, the heat of the fluid within the first cycle occurring in the well is absorbed by the secondary fluid, and the cooled fluid is returned to the well through the injection well (see Fig. 2). The secondary fluid's steam drives the turbine to generate electricity and then flows back to the evaporator for transferring heat. Another method that is thought to be able to accelerate geothermal energy growth is thermoelectric production technology. Thermoelectric power generation is a way of energy harvesting based on the Seebeck effect (Ismail and Ahmed 2009). Thermoelectric modules are capable of converting thermal energy required to rotate the turbines directly into electricity without turbine work. Briefly, the Seebeck effect demonstrates that electricity can be generated from the temperature difference that may occur between the two sides of the module (Wang et al. 2018b). These modules currently operate at quite low efficiency as 4–5% in comparison to the highest conversion efficiency of approximately 21% at the Darajat vapor-dominated geothermal system. The average efficiency is encountered as 12% worldwide (Wang et al. 2018b; Zarrouk and Moon 2014). It may be more suitable to use in field applications with advances in technology and materials science. Figure 3 shows the structure of thermoelectric generators, and Fig. 4 shows thermoelectric generators installed in a well that is already in production.

3 Usage of abandoned oil wells

Many modelling and simulation studies exist in the literature on harnessing abandoned oil wells but actual applications are quite limited. Nian and Cheng (2018a, b) investigated the methods to use abandoned oil and natural gas wells reviewing 143 articles which are on theoretical technical and economical analysis of existing wells without any implementation. Some applications are reported by researchers from Europe, the USA and China. According to Wang et al. (2018a), Austria has been heating water in spas for a long time using abandoned oil wells. Similarly, fluid (below 65 °C) obtained from abandoned oil wells are used for greenhouse heating. Another interesting application is the heating of the oil transport pipes in Hungary to transport oil with lower viscosity.

An example of electric power production from abandoned oil wells using ORC is from the USA. The

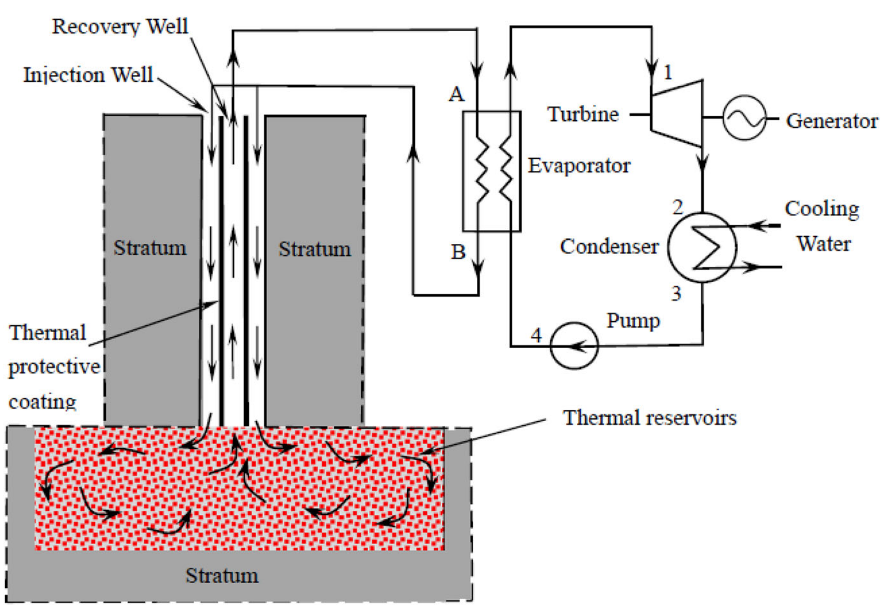


Fig. 2 Structure of geothermal power system with binary cycle (Cheng et al. 2016)

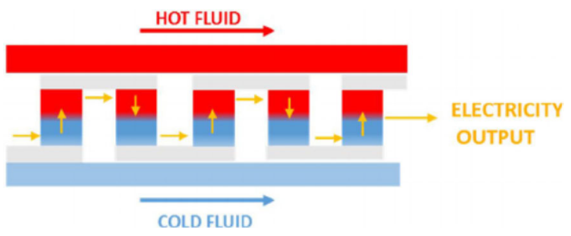


Fig. 3 Schematic of thermoelectric generator (TEG) (Wang et al. 2018b)

plant produces 180 kW electric power from a fluid at 90–99 °C. This project is also the first commercial project to produce geothermal energy in an oilfield (Wang et al. 2018a). There is a co-produced well where water also is extracted from actively producing oil wells in the Huabei oil field in China (Liu et al. 2018). This well has an installed capacity of 400 kW and a wellhead temperature of approximately 110 °C. In addition, the Naval Petroleum Reserve No. 3 (NPR-3) in Wyoming region of the USA also has a co-produced well with 250 kW installed capacity using fluid at a temperature of 95 °C (Liu et al. 2018). The Villafortuna-Trecate oilfield which is one of the largest oil fields in Europe, has been active since 1984. Eight of the 50 drilled wells currently are in production at depths between 5800 and 6100 m. The wells can be classified as high enthalpy geothermal resources with their temperature range from 160 to 170 °C. Alimonti and Soldo (2016) indicated that using a single well, 1.5 MW thermal power and 134 kW maximum net electrical power are obtained by a downhole heat exchanger with ORC binary cycle for a flowrate of 15 m^3/h.

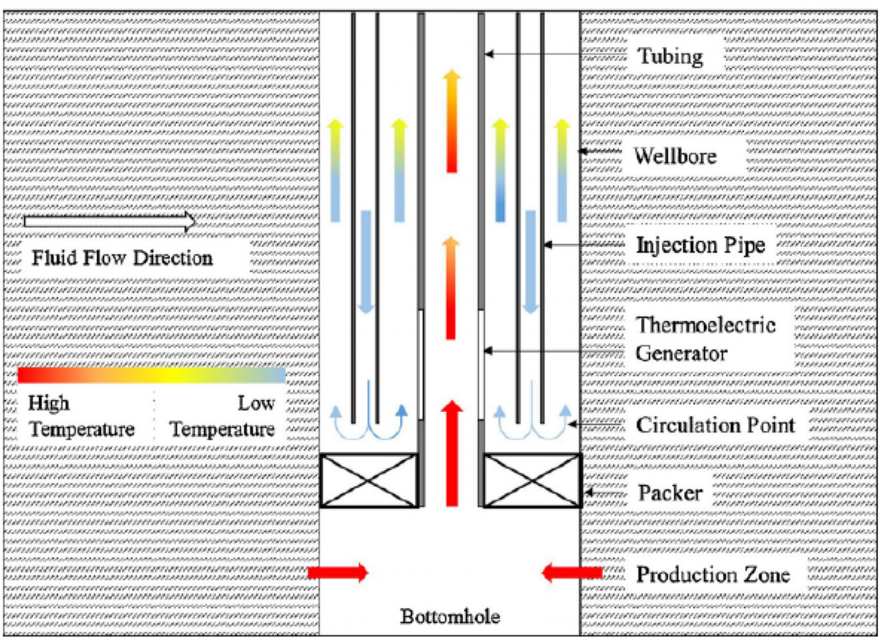
4 Geothermal energy in Turkey

4.1 Status of geothermal energy in Turkey

Turkey's western region, in particular, is one of the most seismically active regions of the world due to passive volcanoes in the region. Therefore, Turkey is a rich country in terms of the underground heat source (see Fig. 5). Geothermal energy in Turkey is utilized in various ways. Geothermal resources in Turkey are generally used in greenhouse heating, drying of fruits and spas, and electricity production. About 1.5% of Turkey's annual electricity production is obtained from 48 geothermal power plants in the Aegean region.

Turkey wants to make better use of its geothermal energy potential and aims to achieve a geothermal based-power generation capacity of 2000 MW by 2020 (Fig. 6). The country has a current installed capacity of 1347 MW (Fig. 7). Based on 2019 data, Turkey ranked fourth in world installed energy

Fig. 4 Thermoelectric generator placement in an active production well (Wang et al. 2018b)



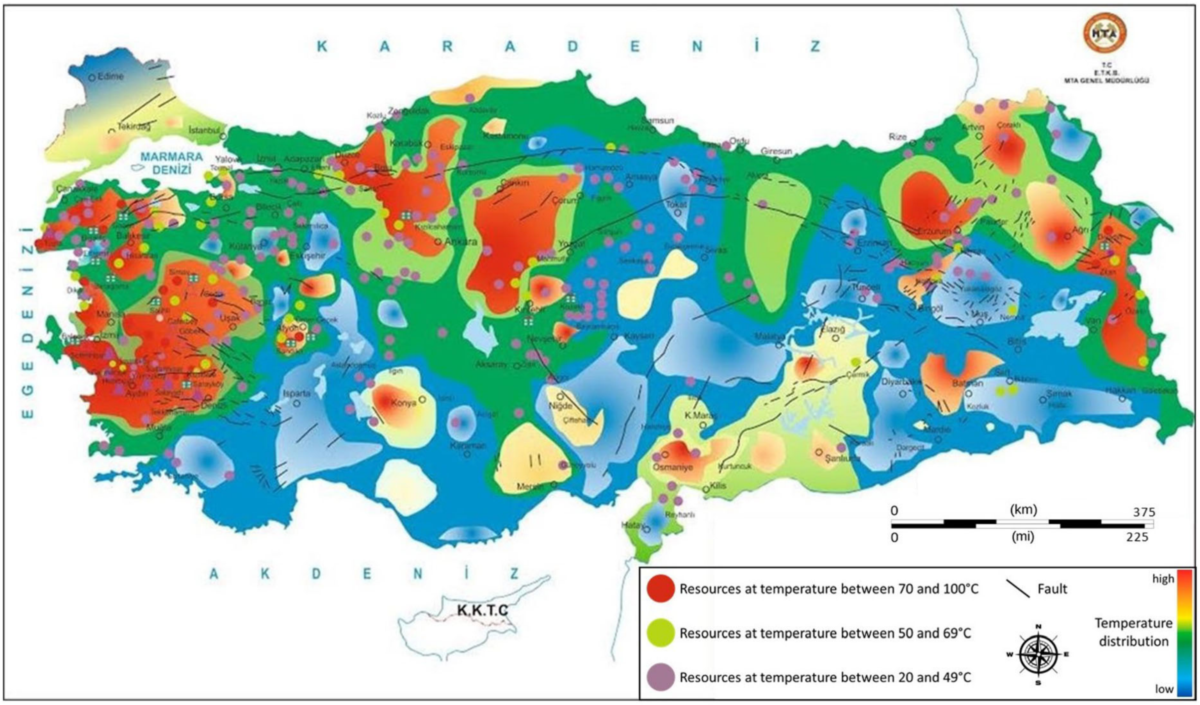
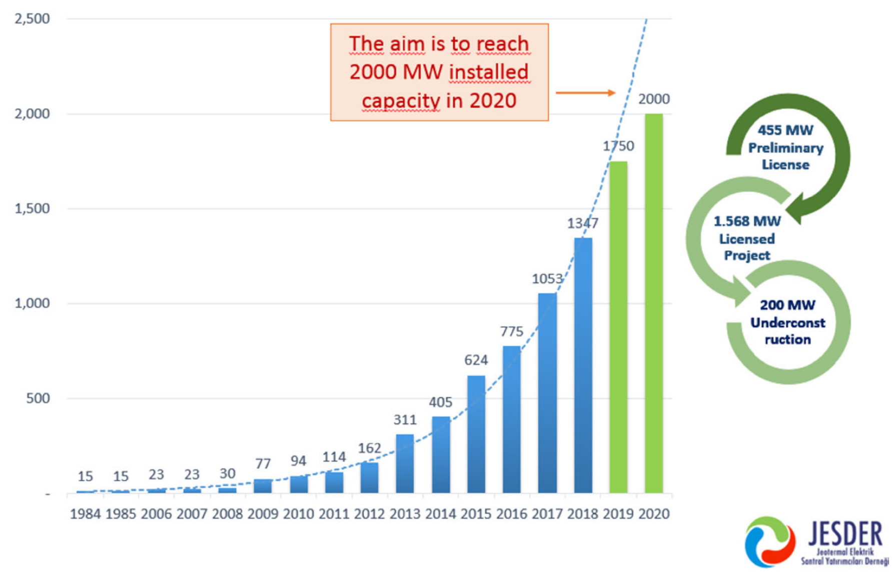


Fig. 5 Geothermal resources and applications map of Turkey (MTA 2019)

Fig. 6 Installed capacity of geothermal energy for power generation



capacity, behind the USA, Indonesia, and the Philippines (Fig. 8).

The Turkish energy policy relies on the expansion of renewable energies. Its aim is to reduce dependence on imported fossil fuels and curb the chronic trade deficit. Geothermal energy for power and heat generation is becoming increasingly important (Richter 2019a).

Besides power production, Turkey exploits geothermal energy for district and greenhouse heating. Based on 2018 data, Turkey ranked second within

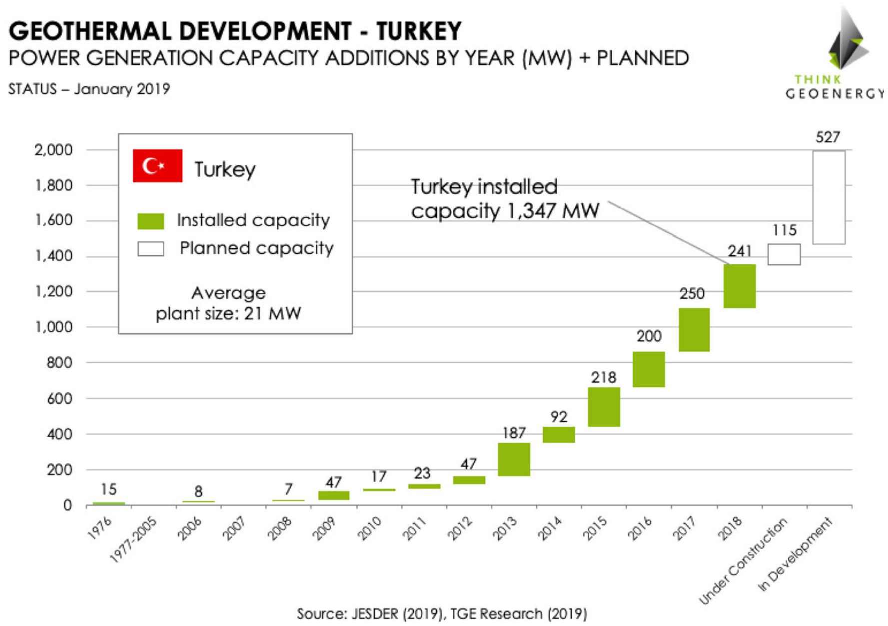


Fig. 7 Geothermal development in Turkey from 1976 to 2019 (Richter 2019a)

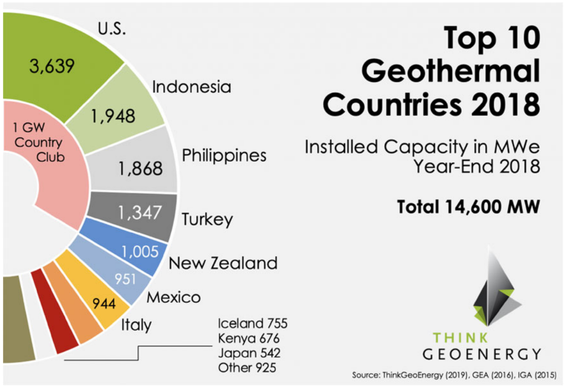


Fig. 8 Top 10 geothermal countries—by installed power generation capacity (MW) (Richter 2019b)

Europe with 872 MW_t installed capacity, following Iceland (Fig. 9).

As presented in the 2014 National Renewable Energy Action Plan of Turkey, the forecasted installed capacity of geothermal resources for electricity production was 1000 MW for the year 2023. Today with 1347 MW_e installed capacity Turkey is now one of the five-country that have more than 1 GW installed capacity. With the 2023 target already reached today, Turkey has set itself a new target of 4000 MW of capacity to be reached by 2030.

The main geothermal fields of Turkey are located in the central Aegean region, stretching inland from İzmir to Uşak, the north Aegean region around Balıkesir, as well as further sites in north-central Anatolia around the capital Ankara and smaller reserves in the east and north-east of the country.

The geothermal potential was known as 31,500 MW_t up to 2010. However, according to recent calculations, Turkey's geothermal heat potential is estimated as 60,000 MW_t. According to data in 2016, geothermal direct use applications' total installed capacity, in 230 geothermal regions identified by MTA since the 1960's, has reached 3262.3 MW_t geothermal heat, including district heating (1033 MW_t), 3.93 million m^2 greenhouse heating (760 MW_t), thermal facilities, space heating (420 MW_t), balneological use (1.005 MW_t), agricultural drying (1.5 MW_t) and geothermal heat pumps (42.8 MW_t). The geothermal heat capacity that can be obtained according to the outlet temperature of 35 °C with the existing wells is calculated as 8000 MW_t by MTA (Mertoglu et al. 2016).

As seen in Fig. 10, there are many places, especially in Western Anatolia of Turkey, where geothermal heat is used in district heating. Geothermal heating systems used for district heating in Turkey with the commissioned year, the number of residences benefiting and fluid temperature, respectively, is as follows. Gönen (commissioned: 1987, residences: 3400, geothermal water temperature: ~ 80 °C),

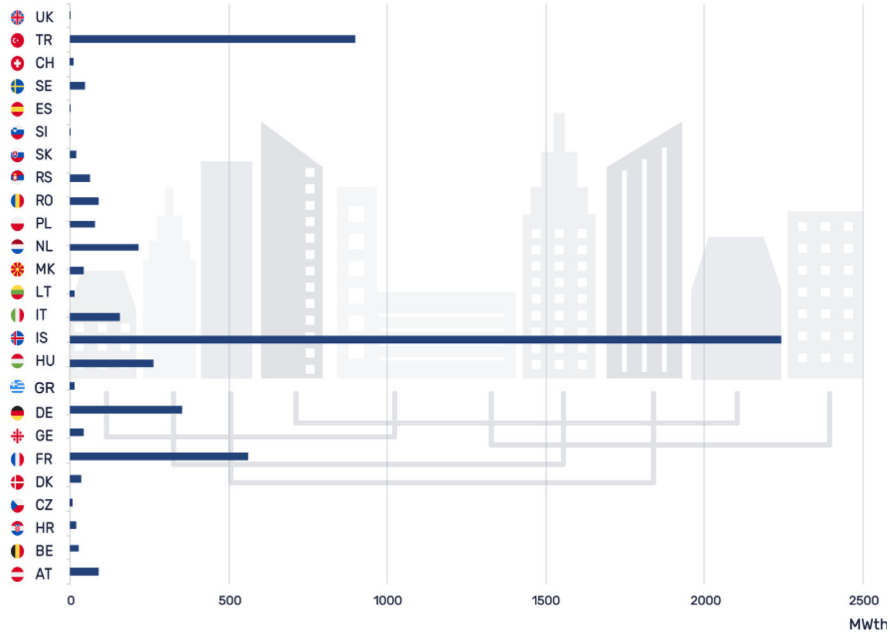


Fig. 9 The installed capacity for heating in world (EGEC 2019)

Simav (1991, 12,000, ~ 120 °C), Kirsehir (1994, 1900, ~ 57 °C), Kizilcahamam (1995, 2500, ~ 80 °C), Izmir (1996, 35.000, ~ 115–142 °C), Sandikli (1998, 11,000, ~ 70 °C), Afyon (1996, 14,000, ~ 95 °C), Kozakli (1996, 3000, ~ 90 °C), Diyadin (1999, 570, 70 °C), Salihli (2002, 8500, 94 °C), Edremit (2003, 6000, 60 °C), Balikesir-Bigadic (2005, 1500, 96 °C), Yozgat-Sorgun (2008, 1500, 80 °C), Izmir-Bergama (450 residences), Izmir-Dikili (2000 residences) and Denizli-Saraykoy (2500 residences) (Mertoglu et al. 2016).

4.2 Abandoned oil wells in Turkey

The GAP region located in the southeastern Anatolia of Turkey is an important area in terms of oil resources. In this region oil production and exploration are ongoing. In addition to many oil production wells opened by Turkish Petroleum (TPAO) in this region, there are many abandoned wells due to certain reasons. There are many convenient wells for these applications even if the geothermal energy from abandoned oil wells is not currently harnessed effectively in Turkey. Some of these wells contain geothermal fluid. Figure 11 shows the wells drilled and abandoned in the GAP region and their surface temperature distribution. When we look at the wells, there are wells ranging in depth between 1200 and 3200 m in the Batman region. The temperatures of abandoned wells used for greenhouse heating and thermal tourism are between 51 and 109 °C. In addition, TPAO has opened many wells for oil production in Diyarbakır and Şırnak regions. The depths of the wells in Diyarbakır range from 1400 to 4000 m, and the wellhead temperatures vary between 41 and 107 °C. The depths of the wells in Şırnak are between 1500 and 3900 m and the temperature range is from 56 to 137 °C, respectively (Baba et al. 2019).

As given in Fig. 12, geothermal resources are used in different ways because of different surface temperature distribution. Power production and district heating are more suitable in Diyarbakır and Batman due to higher enthalpy geothermal energy. Other areas in GAP region, which are Mardin, Siirt, Şırnak, Adıyaman, Şanlıurfa, Gaziantep and Kilis, are convenient for applications such as a greenhouse, thermal tourism, fruit drying and fishery. Different types of industrial branches to be established in these regions can benefit in different ways from the geothermal energy obtained.

5 Results and conclusions

Geothermal heat contained in the oil or natural gas wells that have been abandoned for various reasons

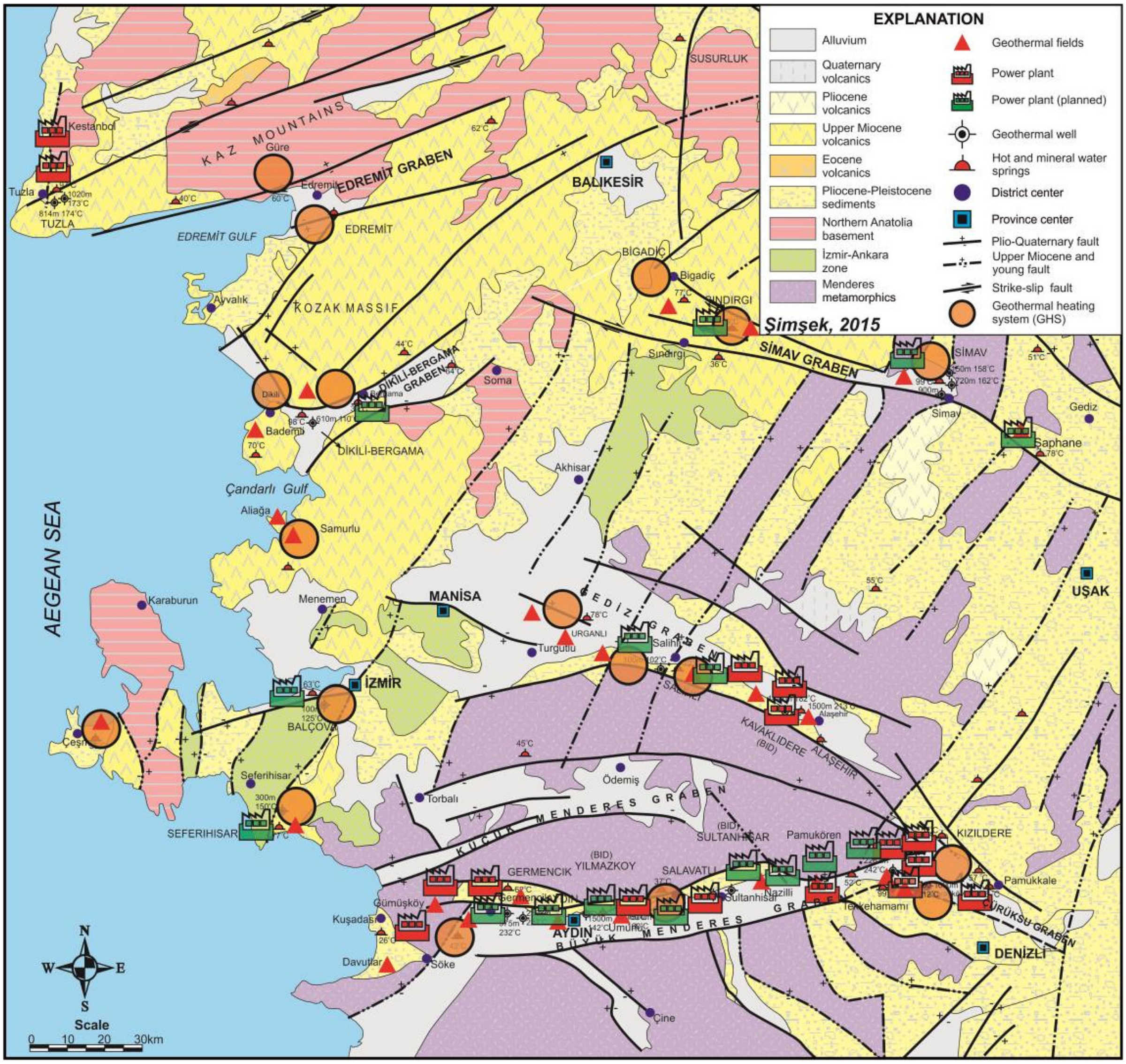


Fig. 10 Geothermal fields and geothermal applications in Western Anatolia of Turkey (Mertoglu et al. 2016)

around the world can be used in different ways. Literature survey indicated that since there are extensive studies on modelling and simulation of abandoned oil and natural gas wells since 2010s, applications are limited. The studies are fairly new and show an interest on utilisation of these wells for geothermal applications. Downhole Heat Exchangers (DHEXs) are used to extract heat without producing geothermal fluids. In this way, CO_2, other greenhouse gases and harmful gases emitted by conventional geothermal power plants are almost completely reduced. Thus, atmospheric conditions have been optimized for future living. Along with the reduced environmental impact, energy need for reinjection is also reduced. Corrosion and scaling problems are avoided since fluids are not in direct contact with the formation. The main disadvantage is the reduction in heat recovery efficiency. The available electric power is much lower than conventional geothermal power plants, and this constitutes a weakness of the DHEXs. Instead, the possible use of thermal power in heating applications can be favorably considered. A techno-economic analysis should be done before deciding the application. Also, it is possible to use abandoned wells

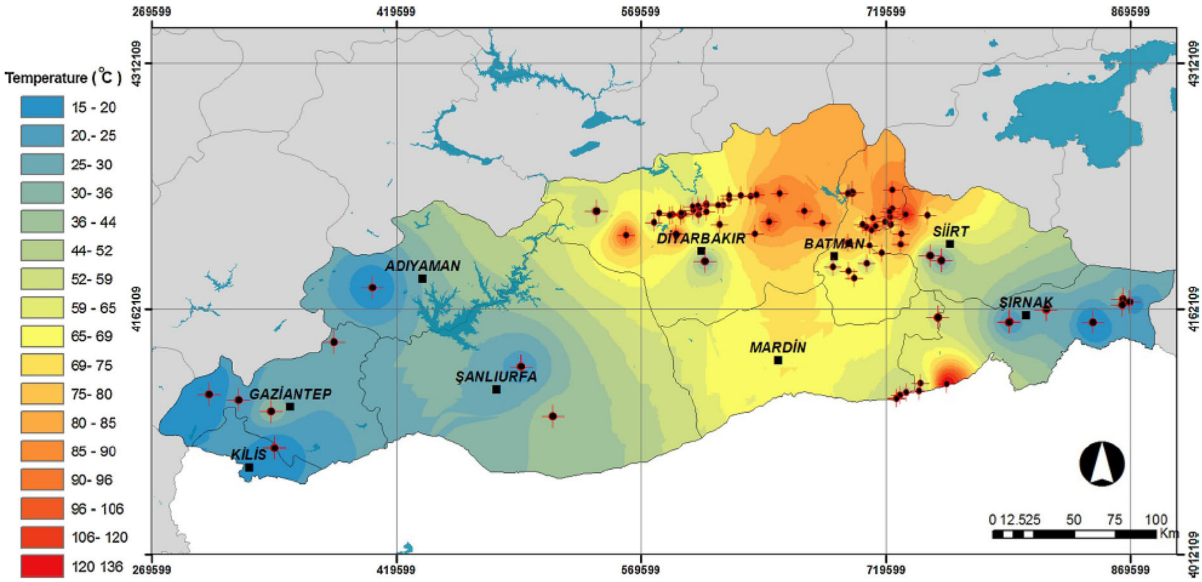


Fig. 11 Surface temperature distribution of geothermal fluid in the GAP region (Baba et al. 2019)

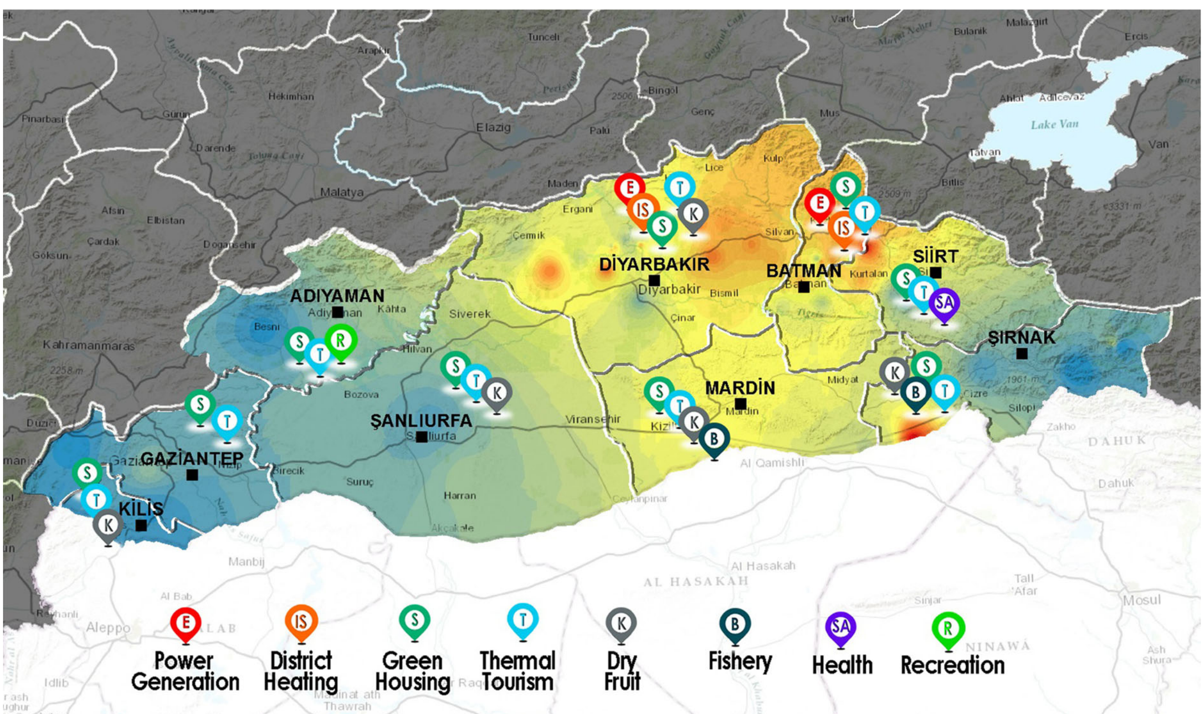


Fig. 12 Potential geothermal applications in the GAP region (Baba et al. 2019)

in southeastern Turkey where this energy improves the economy of the region.

References

Alimonti C, Soldo E (2016) Study of geothermal power generation from a very deep oil well with a wellbore heat exchanger. Renew Energy 86:292–301. https://doi.org/10.1016/j.renene.2015.08.031

Baba A, Şaroğlu F, Akkuş I et al (2019) Geological and hydrogeochemical properties of geothermal systems in the southeastern region of Turkey. Geothermics 78:255–271. https://doi.org/10.1016/j.geothermics.2018.12.010

Bertani R (2016) Geothermal power generation in the world 2010–2014 update report. Geothermics 60:31–43. https://doi.org/10.1016/j.geothermics.2015.11.003

Cheng W, Li T, Nian Y, Xie K (2014a) An analysis of insulation of abandoned oil wells reused for geothermal power generation. Energy Procedia 61:607–610. https://doi.org/10.1016/j.egypro.2014.11.1181

Cheng W, Li T, Nian Y, Xie K (2014b) An analysis of insulation of abandoned oil wells reused for geothermal power generation. Energy Procedia 61:607–610. https://doi.org/10.1016/j.egypro.2014.11.1181

Cheng W, Liu J, Nian Y, Wang C (2016) Enhancing geothermal power generation from abandoned oil wells with thermal reservoirs. Energy 109:537–545. https://doi.org/10.1016/j.energy.2016.05.009

EGEC (2019) EGEC geothermal market report 2018, 8th edn. European Geothermal Energy Council, Brussels

Gharibi S, Mortezazadeh E, Hashemi Aghcheh Bodi S, Vatani A (2018) Feasibility study of geothermal heat extraction from abandoned oil wells using a U-tube heat exchanger. Energy 153:554–567. https://doi.org/10.1016/j.energy.2018.04.003

Ismail B, Ahmed W (2009) Thermoelectric power generation using waste-heat energy as an alternative green technology. Recent Pat Electr Eng 2:27–39. https://doi.org/10.2174/1874476110902010027

Kharseh M, Al-Khawaja M, Hassani F (2019) Optimal utilization of geothermal heat from abandoned oil wells for power generation. Appl Therm Eng 153:536–542. https://doi.org/10.1016/j.applthermaleng.2019.03.047

Liu X, Falcone G, Alimonti C (2018) A systematic study of harnessing low-temperature geothermal energy from oil and gas reservoirs. Energy 142:346–355. https://doi.org/10.1016/j.energy.2017.10.058

Mertoglu O, Şimşek Ş, Basarir N (2016) Geothermal energy use, Country update for Turkey. In: European geothermal congress 2016, Strasbourg, France, 19–24 Sept 2016

MTA (2019) Mineral research and exploration (MTA). In: mta.gov.tr. https://www.mta.gov.tr/v3.0/arastirmalar/jeotermal-enerji-arastirmalari. Accessed 26 Aug 2019

Nian Y, Cheng W (2018a) Evaluation of geothermal heating from abandoned oil wells. Energy 142:592–607. https://doi.org/10.1016/j.energy.2017.10.062

Nian Y, Cheng W (2018b) Insights into geothermal utilization of abandoned oil and gas wells. Renew Sustain Energy Rev 87:44–60. https://doi.org/10.1016/j.rser.2018.02.004

Richter A (2019a) Turkey targets 2,000 MW geothermal power generation capacity by 2020. In: Think geoenergy-geothermal energy news. http://www.thinkgeoenergy.com/turkey-targets-2000-mw-geothermal-power-generation-capacity-by-2020/. Accessed 26 Aug 2019

Richter A (2019b) The top 10 geothermal countries 2018-based on installed generation capacity (MWe). In: Think geoenergy-geothermal energy news. http://www.thinkgeoenergy.com/the-top-10-geothermal-countries-2018-based-on-installed-generation-capacity-mwe. Accessed 26 Aug 2019

Røksland M, Basmoen T, Sui D (2017) Geothermal energy extraction from abandoned wells. Energy Procedia 105:244–249. https://doi.org/10.1016/j.egypro.2017.03.309

Shi Y, Song X, Li G et al (2018) Numerical investigation on the reservoir heat production capacity of a downhole heat exchanger geothermal system. Geothermics 72:163–169. https://doi.org/10.1016/j.geothermics.2017.11.007

Templeton J, Ghoreishi-Madiseh S, Hassani F, Al-Khawaja M (2014) Abandoned petroleum wells as sustainable sources of geothermal energy. Energy 70:366–373. https://doi.org/10.1016/j.energy.2014.04.006

Wang K, Liu J, Wu X (2018a) Downhole geothermal power generation in oil and gas wells. Geothermics 76:141–148. https://doi.org/10.1016/j.geothermics.2018.07.005

Wang K, Yuan B, Ji G, Wu X (2018b) A comprehensive review of geothermal energy extraction and utilization in oilfields. J Petrol Sci Eng 168:465–477. https://doi.org/10.1016/j.petrol.2018.05.012

Zarrouk S, Moon H (2014) Efficiency of geothermal power plants: a worldwide review. Geothermics 51:142–153. https://doi.org/10.1016/j.geothermics.2013.11.001