Evaluation of Production Capacity of Geothermal Power Plants in Turkey

Hakki Aydin[1], Serhat Akin[1] and Erdinc Senturk[2]

[1]Middle East Technical University, Ankara, Turkey

[2]Zorlu Energy

Keywords

geothermal, power plant, Gediz Graben, Büyük Menderes Graben, NCG, Turkey

ABSTRACT

The average working capacity (the ratio of produced power to gross installed power plant capacity) of active geothermal power plants in Turkey as of the end of 2019 is 64.5 %. The main reasons of the low utilization are the proximity of the licensed areas and high interference between geothermal wells. Lack of unitized reservoir management and aggressive geothermal production without exchanging resource information among the producers are other triggering reasons behind the low usage capacity. In this study, the production capacity of the major geothermal fields in Turkey is evaluated. The characteristics of the major fields located in Büyük Menderes and Gediz Grabens and their corresponding production history are analyzed for a better understanding of low production capacity of geothermal power plants in Turkey. It is found that as the number of production wells increased, the production capacity of the plants decreased continuously. It has been observed that drilling make up wells and using downhole pumps are commonly applied to increase the working capacity instead of having a unitized reservoir management.

1. Introduction

First geothermal electricity generation in Turkey started with an installed capacity of 0.5 MWe power in Kızıldere power plant in 1975. Having built up more than 1 GW of capability in only six years, between 2013 and 2018, the current installed capacity as of the end of 2019 is 1526 MWe, obtained from 54 geothermal power plants in operation, placing Turkey within the top four countries after only USA, the Philippines and Indonesia (ThinkGeoEnergy, 2019). Turkey completed several geothermal power projects in 2019, raising its installed capacity by 12.44% (167.7 MW), to 1.526 GW (Figure 1). The reason for this unprecedented increase is the

Renewable Energy Promotion Mechanism (YEKDEM) that was introduced in September 2005 (No: 5346, Issued Date: May 10, 2005) and which will run until September 2020 (legal sources on renewable energy, 2019). Based on this legislation, the incentives for the use of renewables in power generation include feed-in tariffs, purchase guarantees, connection priorities, lowered license fees, license exemptions in exceptional circumstances and various practical conveniences in project preparation and land acquisition. The legislation includes a differentiated feed-in tariff scheme that eventually provide the investors with predictable returns on their investment. The guaranteed prices are applicable for ten years after commissioning of the power plant. Due to the favorable feed-in-tariff, geothermal drilling increased from 2,000 meters/year in 2004 to 28,000 meters/year in 2018. Besides an enhanced supporting regulatory framework, the exploration activities conducted by the General Directorate of Mineral Research and Exploration of Turkey (MTA) have been a critical driver behind geothermal development in the country. As a result, a total of 632 geothermal wells with a total of 410.000 meters of depth were drilled by MTA between 2004 and 2018. The growth of the geothermal power sector in Turkey is expected to continue at a robust rate provided that favorable feed-in-tariffs will continue after 2020. By the end of 2020, the power plant capacities are expected to increase to 2,000 MW according to the Turkish Association of Geothermal Investors (JESDER).

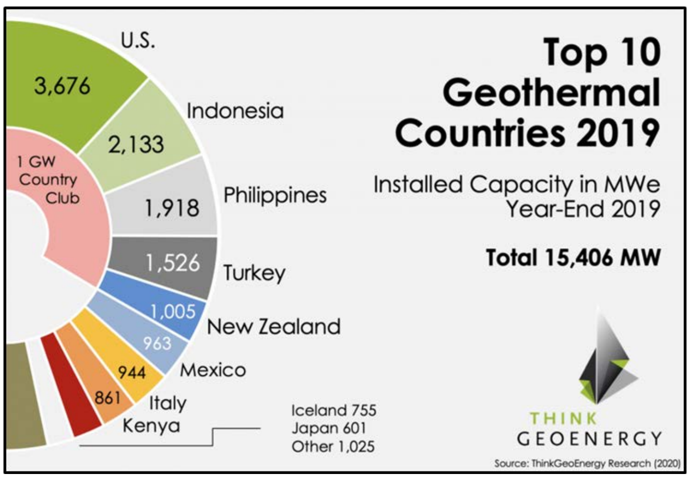

Figure 1: Top 10 geothermal countries by installed power generation capacity (ThinkGeoEnergy, 2020)

MTA has discovered nearly 300 geothermal resource areas in Turkey and has held several geothermal license auctions as part of an effort to engage private companies (Tureyen and Satman, 2013). MTA has offered 85 geothermal licenses since 2008. The majority of licenses are located in Western Anatolia. Geothermal power plants in Turkey are concentrated in Büyük Menderes Graben (Aydın-Germencik, Denizli-Sarayköy, Aydın-Salavatlı, Aydın-Hıdırbeyli) and Gediz Graben (Manisa-Alaşehir, Manisa-Salihli) (Figure 2). There are a few power plants with relatively lower installed capacity in other areas (i.e. Tuzla field in Çanakkale and Afyonkarahisar). The majority of the fields are medium enthalpy (675 kj/kg-1000 kj/kg) liquid dominated geothermal systems. The reservoir rock is Menderes metamorphics, which mainly consists of Paleozoic aged schist, quartzite and marble. Liquid dominated reservoir fluids include significant amounts of non-condensable gas (NCG) content, which is higher than that observed in other geothermal reservoirs located elsewhere. For example, initial NCG content of Alaşehir field, located in Gediz Graben is in the range of 2 % to 4 % (Haizlip et al., 2016; Aydin et al. 2018; Aydin and Akin 2019). In Kızıldere Field, which is located in Büyük Menderes Graben, the intermediate depth Iğdecik reservoir formation contains 1.5 % to 2.0 % of NCG content by weight and while the deep metamorphic reservoir contains 3 % to 4 % NCG (Haizlip et al. 2012; Satman et al. 2017; Kucuk, 2018; Senturk et al. 2020). The NCG content of Germencik field is between 1% and 2.1 % (Aksoy et al. 2015). The NCG content of Tuzla, Yilmazköy and Salavatli fields are 0.5 %, 2%, and 1.75 % respectively (Di Pippo, 2012; Aksoy et al. 2015). Carbon dioxide (CO_2) constitutes more than 99 % of NCG in geothermal fields located in Büyük Menderes and Gediz grabens in Turkey. It is important to note that the NCG content of geothermal reservoirs in Western Turkey has showed a sharp decline in most of the reservoirs. To illustrate, Layman, (2017) stated that Alaşehir field has the highest CO_2 emissions rate of all geothermal projects in Turkey as 1660 g/kWh. It is important to note that a very recent (May 2020) gas emission measurement at the Alaşehir plant, operated by Zorlu Energy (45MWe) was recorded as 0.3 % by weight, which corresponds to 190 g/Kwh. The decline of NCG is possibly due to dilution of gas-free reinjection fluid, which is a result of strong hydraulic connectivity of injectors with producers in the field.

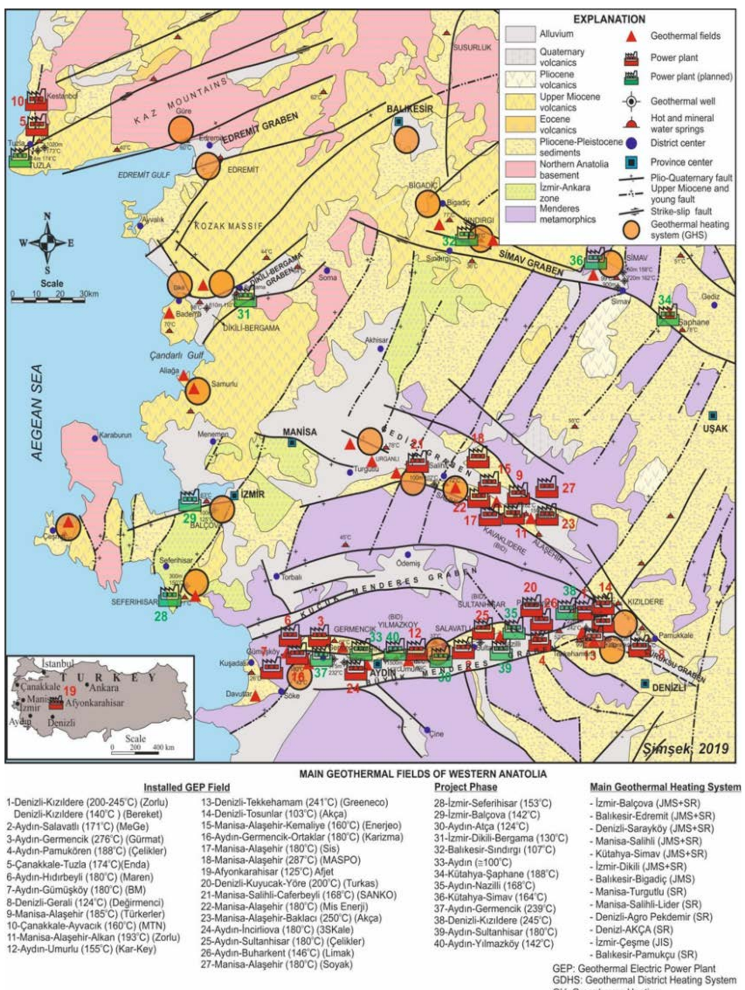

Figure 2: Geothermal fields and power plants in Western Anatolia (Şimşek, 2019)

In this study, the production capacity of geothermal power plants in Turkey is evaluated by a categorizing scheme based on field characteristics such as proximity of wells, configuration of licensed areas, different reservoir characteristics, type of power plants and production strategies. The production history of each geothermal developer is retrieved from Turkish Energy Transparency Platform (EPIAS, 2020). The gross energy production of geothermal power plants is calculated by estimating their internal consumption. The aim of this study is to determine the reasons for the low production capacity of geothermal power plants in Turkey.

2. Production Capacity of Geothermal Power Plants in Turkey

In Turkey, binary type power plants are more suitable for generating electricity since reservoir temperatures are in the range of 150 °C and 240 °C. There are six flash type power plants (two 47.4 MWe dual flash plants in Germencik Field; 165 MWe combine plant (triple flash plus binary plant), 80 MWe combine plant (triple flash plus binary) and 15 MWe a single flash plant in Kızıldere Field; 45 MWe combine plant (double flash plus binary) in Alaşehir Field) in resource temperature higher than 190 °C. In medium enthalpy resources, binary type power plants produce at a relatively higher efficiency (10% -12%) comparing to flash type plants. However, having a combined system (flash + binary system) can increase the efficiency of geothermal power plants to higher levels (14 % -16 %). In a typical flash type power plant, a wet cooling system is usually applicable. In such a system, based on resource temperature, 15 % to 30 % of produced fluid is used for cooling condenser, pumps and compressors. However, in a dry cooling system, which is a commonly used technology for binary type plants, all of the produced fluid is re-injected back to the reservoir (except for NCG, which is released to atmosphere), which may provide better pressure maintenance. Instead of using steam condensate, a dry cooling system uses air for cooling the aforementioned equipment. During summer, the production capacity of binary power plants usually decreases by 30 % to 40 % because of the efficiency reduction caused by the dry cooling system. However, during winter, there is no significant efficiency difference between dry and wet cooling systems. Thus, one can say that binary type plants are more effective from reservoir management point of view.

Reservoir management is critical for operating geothermal plants at their maximum capacity for a given period of production. The reasons of low usage capacity of geothermal plants in Turkey can be addressed with the following two common applications:

- Each geothermal developer evaluates the resource that is located in its license area instead of considering the whole system. This causes construction of oversized plants, which cannot be supported by the actual resource performance.

- Resource assessment for power plants are in a good agreement with actual reservoir performance. However, reservoir performance decreases substantially because of poor reservoir management, which may arise from inadequate production strategy due to presence of multiple developers in the same resource area.

Increasing the amount of produced fluid from a given geothermal reservoir, poses some problems such as pressure depletion, temperature reduction and NCG decline. In Turkey, geothermal licenses are issued without considering the reservoir as a whole, resulting in licenses dividing the reservoir. As a consequence, there are a number of licenses that are developed by different geothermal developers sharing the same reservoir. For example, there are seven (7) geothermal developers within the Alaşehir Field with total installed power capacity of 310 MWe. Akin, (2017) assessed the geothermal capacity of Alaşehir field as 270.9 MWe using the heat in place method. This means that construction of new power plant in Alaşehir field may not be supported by the resource since the installed power plant capacity is already higher than the calculated one. In Kizildere geothermal area, there are three producers sharing the same reservoir. There is a huge competition among the developers resulting in aggressive production for maximizing profit from the limited resource area.

Proximity of production areas and high reservoir hydraulic connectivity create unfavorable pressure interference between wells. Multiple geothermal developers in the same resource area is a common problem of the Turkish geothermal industry. Distribution of license areas of two current production fields, Alaşehir and Kizildere are shown in Figure 3 and Figure 4.

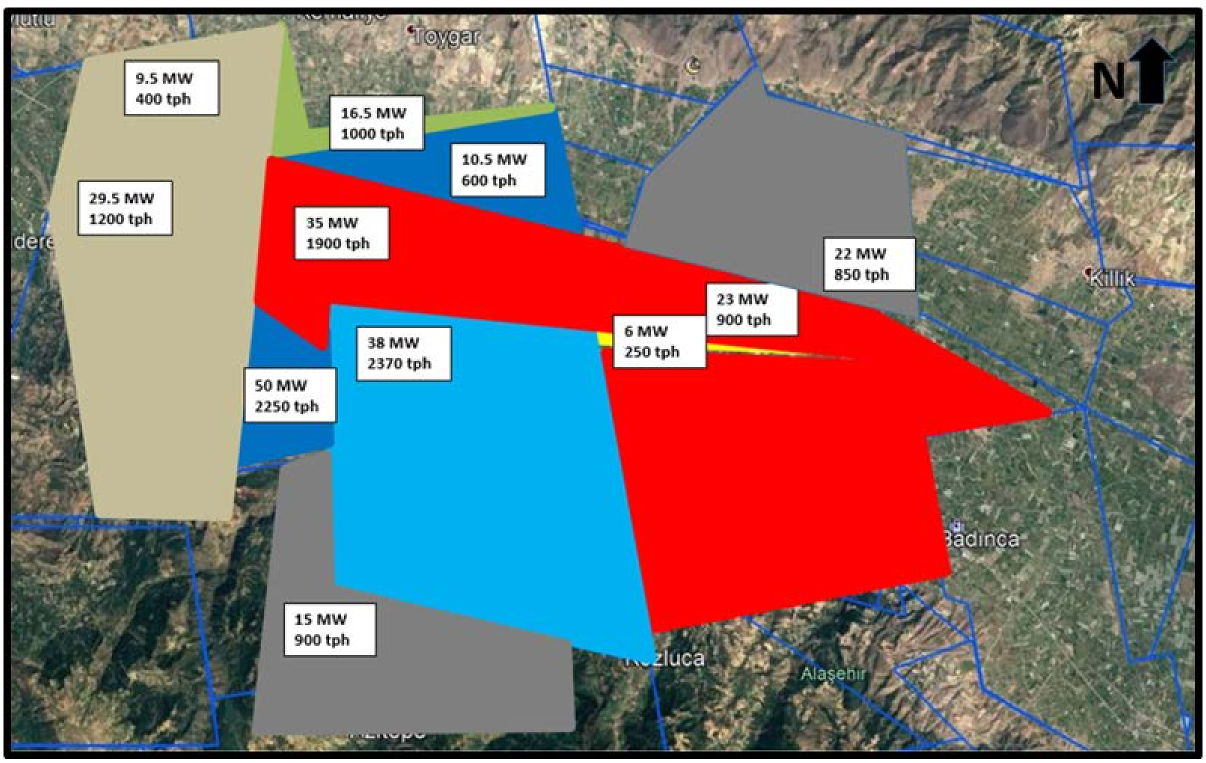

Figure 3: Distribution of license areas in Alaşehir field and current installed capacity and production of geothermal power plants.

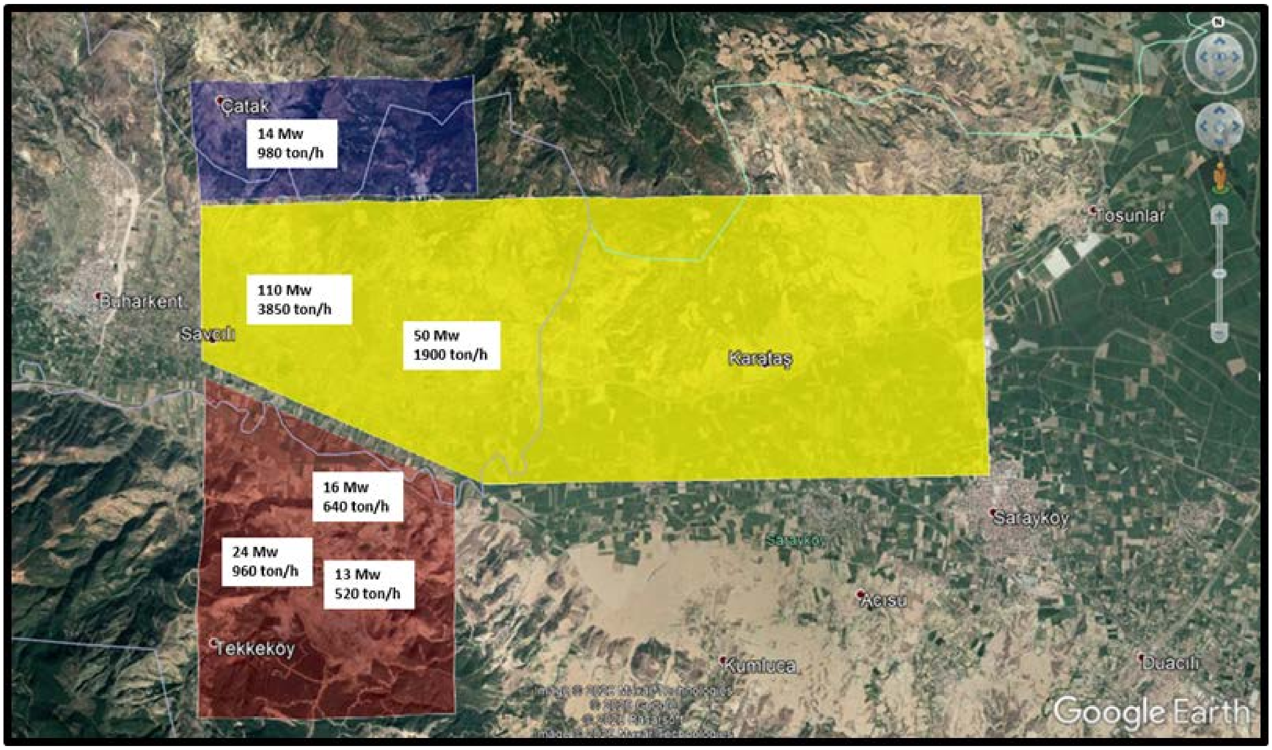

Figure 4: Distribution of license areas in Kızıldere field and current installed capacity and production of geothermal power plants.

3. Results and Discussions

The net electricity generation of power plants are retrieved from Turkish Energy Transparency Platform (EPIAS, 2020). The gross electricity generation of the plants is obtained by considering power consumption of equipment such as injection pumps, cooling tower fans, compressors, feed pumps and vacuum pumps. In Turkey, the internal consumption of geothermal plants is in the range of 12 % to 20 % of the gross production, which is based on the type of geothermal power plant technology and injection capacity of wells. The distribution of net geothermal power production in Turkey is such that 72% of it is from Büyük Menderes graben and 27 % is produced from Gediz graben (Figure 5). The remaining 1% of production is in Afyonkarahisar and Çanakkale regions.

As the net electricity production is converted to gross production (Figure 6), it has been observed that only 64.5% of the installed capacity is produced. This means that 381 MWe of the installed capacity remain untapped. As it is stated in the previous section, the main reason of low usage capacity can be addressed as oversized plants and poor reservoir management. At this point, it is required to individually evaluate the fields for a better understanding.

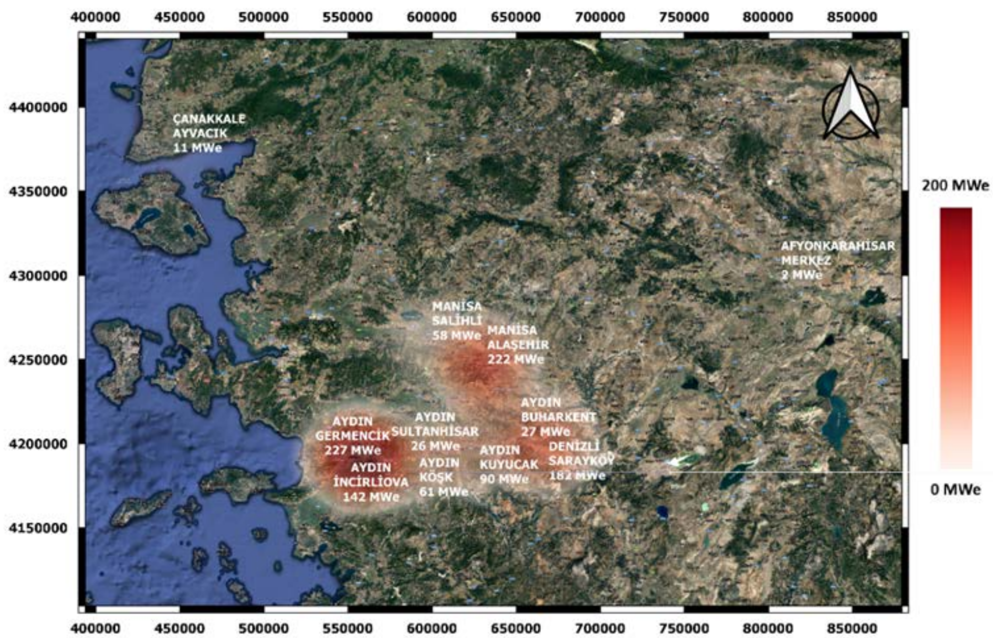

Figure 5: Net Production capacity of plants in Turkey

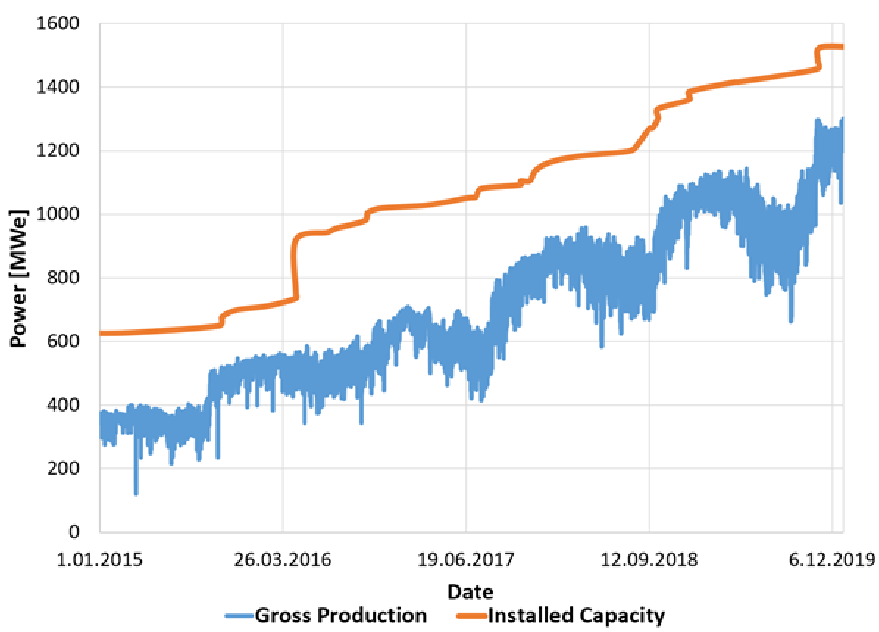

Figure 6: Gross production capacity versus installed power capacity of geothermal power plants in Turkey

The total installed capacities of power plants and production capacities of three (3) different geothermal power plants located in Kizildere and Alaşehir fields are given in Figure 7. It is clear that production capacity of these power plants continuously decreases as new plants are put on production (Table 1 and Table 2). With new production wells in the same resource area the total production increases, however production capacity of the plants shows declining behavior, which is an indication of well interference. The number of make-up wells to maintain the production capacity of the plants in Alaşehir field is higher than those in Kizildere field. In Kizildere field, downhole electrical submersible pumps (ESPs) are now tested as of May 2020, after 40 years of production from shallow Kizildere-I production wells.

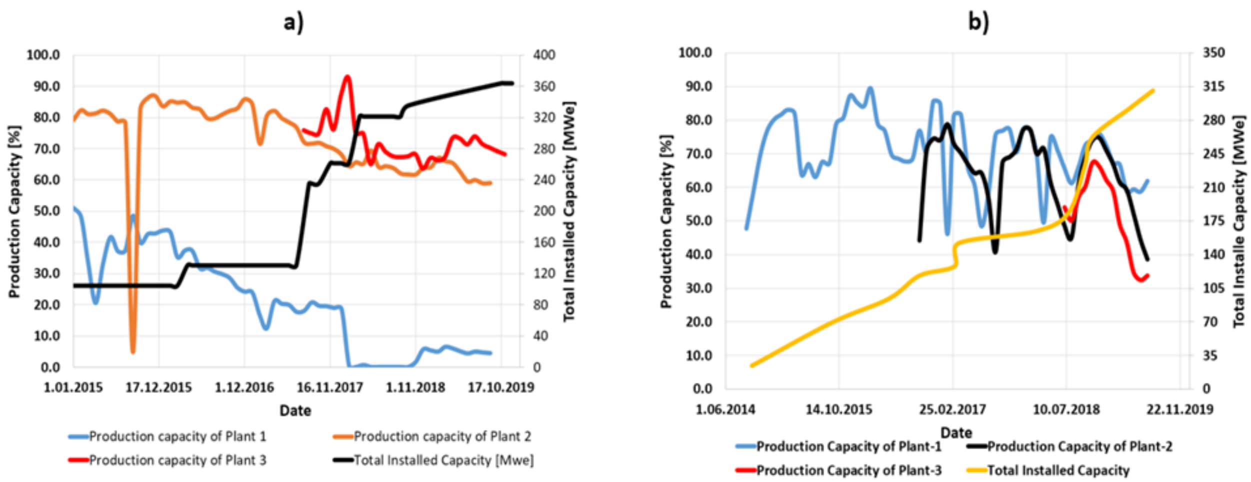

Figure 7: Total installed capacity and production capacity of power plants located in Kizildere (a) and Alaşehir (b) fields.

Table 1: Number of production wells and total installed capacity of power plants in Kizildere field

Date	Production Wells	Capacity [MWe]
1.01.2015	14	104.4
11.04.2016	21	130.4
22.08.2017	37	230.4
17.11.2017	44	256.4
18.2.2018	52	321.4
2.10.2018	57	335.4
17.10.2019	64	363.9

Table 2: Number of production wells and total installed capacity of power plants in Alaşehir field

Date	Production Wells	Capacity [MWe]
25.09.2014	5	24.0
12.09.2015	10	69.0
20.05.2016	25	93.9
1.9.2016	27	93.9
1.10.2016	33	117.9
6.03.2017	35	127.9
24.03.2017	40	151.9
1.6.2017	44	151.9
1.03.2018	46	164.4
1.6.2018	50	164.4
20.07.2018	52	183.8
28.09.2018	58	231.8
31.10.2018	63	261.8
11.04.2019	67	291.8
25.07.2019	68	310.8

As it is reported in aforementioned studies given in the introduction section, Turkish geothermal reservoirs have significant amount of NCG prior to commencement of field production. NCG constituting CO_2 increases emissions in geothermal power production. On the other hand, presence of NCG provides additional partial pressure in the wellbore by creating a pump effect, which is one of the primary mechanism of artesian production. Satman et al. (2017) studied the effect of carbon dioxide content on the well and reservoir performance in the Kizildere Geothermal field. It is important to note that the NCG content of geothermal reservoirs in Western Turkey has showed a sharp decline in most of the fields. Injection of gas-free brine into re-injection wells that have strong hydraulic connectivity with production wells are the main reason of high NCG decline. Aydin et al. (2018) reported more than 60 %NCG decline in Alaşehir field. The decline of NCG production in Alaşehir and Kızıldere fields is given in Figure 8 (a). Since, these reservoirs produce from fault associated intersected fractures, conductivity of the reservoirs is several orders of magnitude higher than that of a typical oil reservoir. To understand well connectivity and the effect of re-injection on production, tracer tests were conducted in the three major fields, Germencik, Alaşehir, and Kizildere by using naphthalene sulfonates (Akin, 2016; Akin, 2018 and Senturk 2020). Tracer breakthrough curves of the effluents are given in Figure 8 (b). The tracer breakthrough curves are best represented by multi-fracture models. Alaşehir field has the most conductive reservoir with relatively smaller mean travelling time. Germencik field has medium reservoir properties compared to other fields. In Kizildere field, the shallow and deep reservoir showed different characteristics. Senturk et al. (2020) reported that there is a vertical compartmentalization formed by interbedded mica-schists that seal the connection between shallow and deep metamorphic reservoirs.

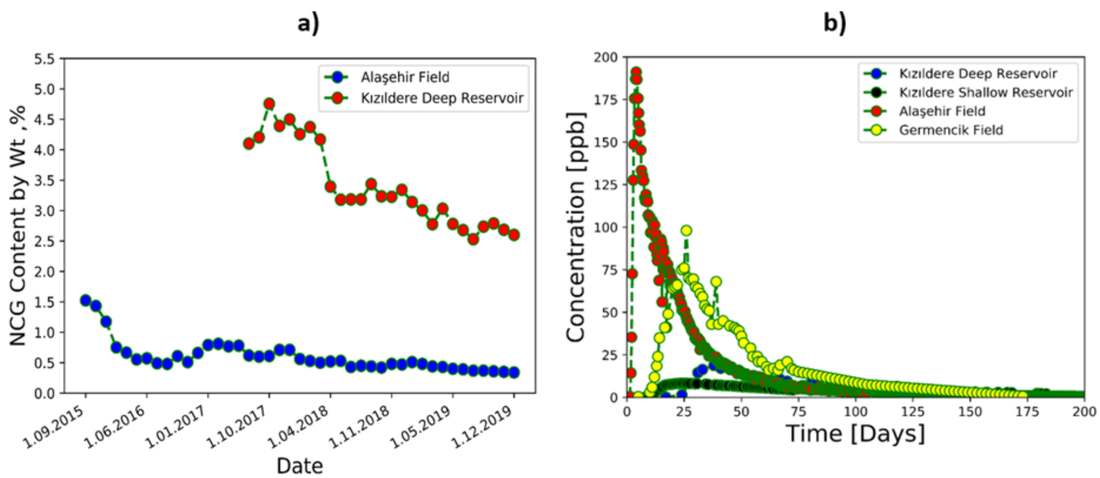

Figure 8: a) Decline of NCG in Gediz (Alaşehir field) and Büyük Menderes Graben (Kızıldere field) b) Tracer return curves observed in several fields that are located in Gediz and Büyük Menderes Grabens (revised from Akin, 2018)

The effects of new power plant activities within neighboring licenses on the performance of production wells in Alaşehir and Kizildere field are reported in Figure 9(a) and 9(b). It can be observed that there is a significant reduction of performance in both fields over a short time. Thus, it is important to make the right decision on the size of plants by considering the future production activities in neighboring licenses.

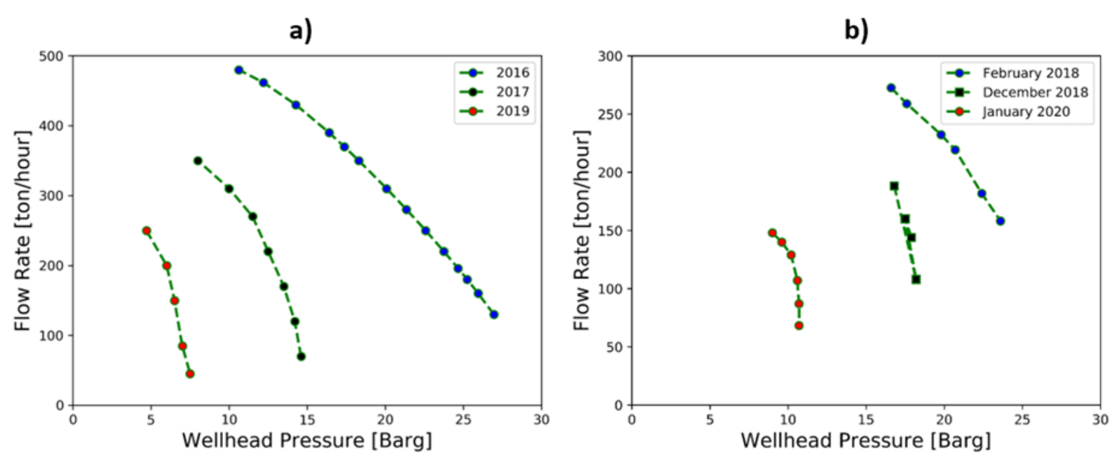

Figure 9: Typical performance reduction of a production well in (a) Gediz graben and (b) Büyük Menderes graben.

4. Conclusion

Installed geothermal power capacity of Turkey reached 1526 MW in 2019. Approximately a quarter of the total installed power capacity remains untapped due to operation of oversized plants and poor reservoir management. A better resource characterization and efficient management of geothermal reservoirs are crucial for optimal production of geothermal power plants. To prevent the construction of oversized geothermal power plants, it is extremely important to delineate resource assessment properly. The production performance of geothermal resources should be considered as a whole rather than taking into account only the licensed area. Otherwise, installed geothermal power plants may not be operated at optimal production capacity in a given geothermal reservoir. To maximize the production capacity of plants, a common reservoir management is essential. New production and injection scenarios can increase the productivity of the fields by contribution of all the geothermal developers in the same resource area via a unitized reservoir management scheme.

REFERENCES

Akin S. "Geothermal Resource Assessment of Alaşehir Geothermal Field". *42nd Workshop on Geothermal Reservoir Engineering,* Stanford, University, Stanford, CA USA (2017).

Akin S. "Geothermal Resource Assessment of Alaşehir Geothermal Field". *42nd Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2017).

Akin S. and Gulgor A. "Comprehensive Tracer Testing in the Germencik Field". *43rd Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2018).

Akin S., Guney A., Senturk E., Sengun R. and Kilincarslan S. "Tracer Testing at Kizildere Geothermal Field, Turkey, Using Napthalene Sulfonates". *41st Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2016).

Aksoy, N., Gok, O., Mutlu, H. and Kilinc, G. "CO_2 emissions from geothermal power plants in Turkey". *Proceedings*, World Geothermal Congress, Melbourne, Australia (2015).

Aydin H. Akin S. and Tezel, S. "Practical Experiences about reservoir monitoring in Alaşehir Field". *43rd Workshop on Geothermal Reservoir Engineering,* Stanford University., Stanford, CA USA (2018).

Aydin H. and Akin S. "Discrete Fracture Network Modeling of Alaşehir Geothermal Field". *44th Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, CA USA. (2019).

Aydin H. and Akin S. "Numerical Reservoir Simulation of Alaşehir Geothermal Field ".*45th Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2020).

DiPippo, R." Geothermal power plants-principles, applications, case studies and environmental impact". *3rd edition, Butterworth-Heinemann,* Elsevier publishers (2012).

EPIAS(Transparency Platform of Turkish Energy Exchange).2020: https://seffaflik.epias.com.tr/transparency/uretim/gerceklesenuretim/gercek-zamanli-uretim.xhtm

Haizlip J.R., Guney A., Tut Haklidir, F.S. Garg, S.K. "The Impact of High Non-condensible Gas on Well Performance". *37th Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2012).

Haizlip J.R., Stover M., Garg, S., Haklidir, F. and Prin N. "Origin and Impacts of High Concentrations of Carbon Dioxide in Geothermal Fluids of Western Turkey". *41st Workshop on Geothermal Reservoir Engineering* Stanford University, Stanford, CA USA (2016).

Kucuk, S. "Simulation of Geothermal Reservoirs with High Amount of Carbon Dioxide". *Master Thesis, Department of Petroleum and Natural Gas Engineering,* Middle East Technical University (2018).

Layman E.B. "Geothermal Projects in Turkey: Extreme Greenhouse Gas Emission Rates Comparable to or Exceeding Those from Coal-Fired Plants". *42nd Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2017).

Legal Sources on Renewable Energy, http://www.res-legal.eu/search-by-country/turkey/single/s/res-e/t/promotion/aid/feed-in-tariff-7/lastp/207/ accessed at 5.25.2020.

Mertoglu O., Simsek S. and Basarir, N. "Geothermal Energy Use: Projections and Country Update for Turkey". *Proceedings,* World Geothermal Congress, Reykjavik, Iceland (2020).

Richter A. (2019) "The top 10 geothermal countries 2019-based on installed generation capacity (MWe). In: Think geoenergy-geothermal energy new. https://www.thinkgeoenergy.com/the-top-10-geothermal-countries-2019-based-on-installed-generation-capacity-mwe/

Satman A., Tureyen O.I., Basel, E.D., Guney A., Senturk E. and Kındap A. "Effect of Carbon Dioxide Content on the Well and Reservoir Performances in the Kizildere Geothermal Field". *42nd Workshop on Geothermal Reservoir Engineering,* Stanford University (2017), Stanford, CA USA.

Senturk E., Aydin H. and Tuzen M.K. "Injection Rehabilitation at Kızıldere Geothermal Field: Use of Flow Rate Weighted Average Production Wellhead Pressure for Reservoir Management". *45th Workshop on Geothermal Reservoir Engineering* Stanford University, Stanford, CA USA (2020).

ThinkGeoEnergy, http://www.thinkgeoenergy.com/the-top-10-geothermal-countries-2018-based-on-installed-generation-capacity-mwe/ accessed at 25.5.2020.

Tureyen O.I. and Satman, A. "Multiple License Holders in the Same Area: An Expected Risk to Geothermal Development in Turkey ". *38th Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, CA USA (2013).