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Alper Baba

# LECTURES ON GEOTHERMAL DEVELOPMENT IN TURKEY AND ENVIRONMENTAL ASPECTS OF GEOTHERMAL DEVELOPMENT AND ASSOCIATED PROBLEMS

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# LECTURES ON GEOTHERMAL DEVELOPMENT IN TURKEY AND ENVIRONMENTAL ASPECTS OF GEOTHERMAL DEVELOPMENT AND ASSOCIATED PROBLEMS

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# PREFACE

The UNU Visiting Lecturer in 2019 was the Turkish hydrogeologist and environmental scientist Prof. Dr. Alper Baba. Dr. Baba holds a degree in geology and a doctorate in the field of hydrogeology from the Dokuz Eylül University, Izmir, since the year 2000. He worked in the Department of Geological Engineering at the Dokuz Eylül University and Çanakkale Onsekiz Mart University from 1996 to 2009. In 2003, Dr. Baba attended UNU Geothermal Training Programme in Iceland, where he focused on environmental aspects associated with utilization of geothermal energy. He was a visiting professor at the Department of Civil Engineering at Wayne State University (USA) in 2005, and in 2012 in Environmental Science at the University of Toronto (Canada).

Since 2009, Dr. Baba has been a professor at the Izmir Institute of Technology in hydrogeology and director of its Geothermal Energy Research and Application Center. He has 25 years' experience working with geothermal energy, as well as in hydrogeology and environmental geology in different parts of the world. He has had collaborative research engagements with universities and research organizations in Canada, Georgia, Germany, Greece, Poland, UK, and USA. Dr. Baba received the "Successful Young Scientists Award" from the Turkish Academy of Science and has been awarded the "Gold Medal" from the Turkish Geological Engineering Association. Dr. Baba is the editor of the books "Groundwater and ecosystems", "Climate change and its effects on water resources: issues of national and global security" (NATO Science Series, Springer), and "Geothermal systems and energy: Turkey and Greece" (CRC Press).

Since the foundation of the UNU-GTP in 1979, it has been customary to invite annually one internationally renowned geothermal expert to come to Iceland as the UNU Visiting Lecturer. This has been in addition to various foreign lecturers who have given lectures at the Training Programme from year to year. It has been of great benefit to the UNU Geothermal Training Programme that so many distinguished geothermal specialists have made themselves available to visit us. Following is a list of the UNU Visiting Lecturers from 1979 to 2019:

| | |
|---|---|
| 1979 Donald E. White | United States |
| 1980 Christopher Armstead | United Kingdom |
| 1981 Derek H. Freeston | New Zealand |
| 1982 Stanley H. Ward | United States |
| 1983 Patrick Browne | New Zealand |
| 1984 Enrico Barbier | Italy |
| 1985 Bernardo Tolentino | Philippines |
| 1986 C. Russel James | New Zealand |
| 1987 Robert Harrison | United Kingdom |
| 1988 Robert O. Fournier | United States |
| 1989 Peter Ottlik | Hungary |
| 1990 Andre Menjoz | France |
| 1991 Wang Ji-yang | China |
| 1992 Patrick Muffler | United States |
| 1993 Zosimo F. Sarmiento | Philippines |
| 1994 Ladislaus Rybach | Switzerland |
| 1995 Gudmundur Bödvarsson | United States |
| 1996 John Lund | United States |
| 1997 Toshihiro Uchida | Japan |
| 1998 Agnes G. Reyes | Philippines/N.Z. |
| 1999 Philip M. Wright | United States |
| 2000 Trevor M. Hunt | New Zealand |
| 2001 Hilel Legmann | Israel |
| 2002 Karsten Pruess | United States |
| 2003 Beata Kepinska | Poland |
| 2004 Peter Seibt | Germany |
| 2005 Martin N. Mwangi | Kenya |
| 2006 Hagen M. Hole | New Zealand |
| 2007 José Antonio Rodríguez | El Salvador |
| 2008 Wang Kun | China |
| 2009 Wilfred A. Elders | United States |
| 2010 Roland N. Horne | United States |
| 2011 Ernst Huenges | Germany |
| 2012 Cornel Ofwona | Kenya |
| 2013 Kevin Brown | New Zealand |
| 2014 Malcolm Grant | New Zealand |
| 2015 Meseret Teklemariam Z. | Ethiopia |
| 2016 James Koenig | USA |
| 2017 Juliet Newson | New Zealand |
| 2018 William Cumming | USA |
| 2019 Alper Baba | Turkey |

With warmest greetings from Iceland

Lúdvík S. Georgsson, director, UNU-GTP

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**LECTURE 1**

# PRESENT AND FUTURE SITUATION OF GEOTHERMAL ENERGY IN TURKEY


## 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 Anatolia. The Aegean region is favoured with a large number of thermal springs known since ancient times. However, it was in the 20$^{th}$ century that geothermal energy was first used on a large scale for direct use and electricity generation. Population, migration and industrialization in Turkey have increased as the country develops, which has also resulted an increase in energy demand. According to the information provided by the Ministry of Energy and Natural Resources, a highly probable scenario of an increase of 4.8% to 385 TWh in the base, electricity consumption in the year 2023 is expected to rise by 5.5% to 357.4 TWh.

Currently, nearly 60% of the energy supply comes from fossil fuels in Turkey. Geothermal energy is a renewable heat energy with fluid production temperatures varying from 50 to 295°C. It occurs mainly in the form of water and water-steam mixture. Geothermal exploration studies in Turkey started at the beginning of the 1960s in Balçova, İzmir (1963), and in Kızıdere, Denizli (1968). Kızıldere geothermal field was the first geothermal field discovered at high enthalpy. The Kızıldere geothermal power plant, which was the first geothermal power plant of Turkey, was installed in 1984. With increasing capacity of nearly 1 GW, between 2013 and 2018, Turkey ranks top four globally for installed geothermal power capacity, after the U.S., Indonesia and the Philippines. Turkey managed to add 219 MW of new geothermal capacity last year (increase by 21%). Together with Indonesia, Turkey shared about two-thirds of the new capacity installed around the world. The issue of the Law for the Use the Renewable Energy Resources for Electricity Production has started the acceleration in utilization of renewable energies in Turkey. The law gives the prices of electricity as incentives for different renewable energy resources. Geothermal activities in Turkey is regulated by Law on Geothermal Resources and Natural Mineral Waters (No: 5686, Date: June 3, 2007) and its Implementation Regulation (No: 26727, Date: December 2007). The geothermal law and its regulations provide solutions to the problems concerning legislative matters and obligations of the exploration and production concession rights, technical responsibility, control and protection of the geothermal areas. These laws and supports mechanism accelerated the geothermal energy in Turkey. This support mechanism can be a good example in other geothermal countries.


## 1. INTRODUCTION

Energy resources and their efficient use is one of the most prominent and controversial issues today. World population is increasing and industrialization in parallel with urbanization is starting to create serious problems on limited energy resources of the world. Accelerating industrial activity along with global warming and climate change are also growing pressures on the policy makers of the global nations. Legal regulations and public sensitivities on environmental issues are also factors shaping the new energy outlook. These issues can directly affect citizens as well as fauna and flora. To fulfill the needs of increasing population, the energy demand will surely increase but the rise of demand towards energy is presumably more rapid than the rise of the population. Therefore, the world has to make use of its resources more efficiently and countries are increasingly prone to use their immediate resources. Energy demand increases with increasing technological development. With today's technological developments, energy can be produced with less carbon emissions than before, causing less damage to nature. One of the sources of sustainable and renewable energy production is geothermal energy (Røksland et al., 2017). Approximately 44 TW of heat power is thought to spread from the centre of the earth to its surface. With the gradual depletion of fossil fuels in the near future, geothermal energy will become an important alternative energy source in the future (Cheng et al., 2014). Geothermal energy can provide direct-use and electricity generation from hydrothermal resources and aquifer systems with different temperatures, and hot-dry rocks. Flash steam, dry steam, binary and enhanced geothermal systems (EGS) are the important geothermal plant technologies for electricity production. Another advantage of geothermal energy is that it can be produced actively during the year and 24 hours, regardless of weather conditions, unlike solar, wind and wave energy (Kharseh et al., 2019). Despite drilling costs, the installed capacity of global geothermal energy increased from 1,300 MW in 1975 to 11,715 MW in 2015 and is expected to reach 40 GW by 2035 (Gharibi et al., 2018; Bertani, 2016).

Turkey is turning to renewable sources such as wind, geothermal, solar. The reason for this is to increase the use of domestic and renewable resources and to control economic independence of the country. The current situation is in the majority of Turkey's electricity production from coal and natural gas which are also called as fossil fuels. The existing fossil fuels reserves and the production amount of the country is not sufficient to meet this need. Therefore, it has to close this gap by importing from other countries. Within Turkey's 2023 vision, energy security, and sustainable development, such as environmental pollution and climate change, renewable energy is crucial for combating problems involving natural resources. The Turkish government initiated various incentives to encourage national power generation. This situation gives motivation to the energy market to use geothermal resources. Turkey needs clean and sustainable energy, independent from imports and price fluctuations. For this reason, geothermal energy is important for today and the future of the country.

At the end of 2018, a total of 59 geothermal power plants were in operation in Turkey. In terms of installed capacity, Turkey is in fourth place in the world. According to the Turkish General Directorate of Mineral Research and Exploration (MTA), numbers of exploration wells drilled are now 600 and the total depth is 356,000 m. The total proven geothermal capacity of the wells which are conducted by MTA is 5000 MWt and together with the private sectors drillings, approximately 14,000 MWt proven capacity has been reached. Sixteen geothermal fields which are located in western Turkey and discovered by MTA are suitable for geothermal power production and need to be developed.

In this study, importance of geothermal energy in Turkey and the success of geothermal use in power generation is summarized. Also, the emphasis is placed on the practices behind this success.

## 2. ENERGY PRODUCTION

### 2.1 Global energy production

In 2017, World Total Primary Energy Supply (TPES) was 13972 Mtoe, of which 13.5%, or 1894 Mtoe (from 1845 Mtoe in 2016), was produced from renewable energy sources. Renewables are the second largest contributor to global electricity production. They accounted for 24.5% of world generation in 2017, after coal (38.5%) and ahead of gas (23.0%), nuclear (10.3%) and oil (3.3%). After surpassing natural gas in 2016, renewables further increased their share by 0.7% in 2017. Historically, the relative positions of renewables and natural gas have been influenced by various factors, amongst which weather conditions have played a key role. Policies which favour renewables over fossil fuels have also contributed to the increasing importance of renewables in world electricity production (IEA, 2019).

Rising shares of renewable energy continue to transform energy systems around the world. In recent years, many countries have seen significant growth in installed capacity and generation from sources of variable renewable energy. In 2018, at least nine countries supplied more than 20% of their electricity generation from variable renewable energy, while some countries have seen rapid annual growth of variable renewable energy penetration (Figure 1).

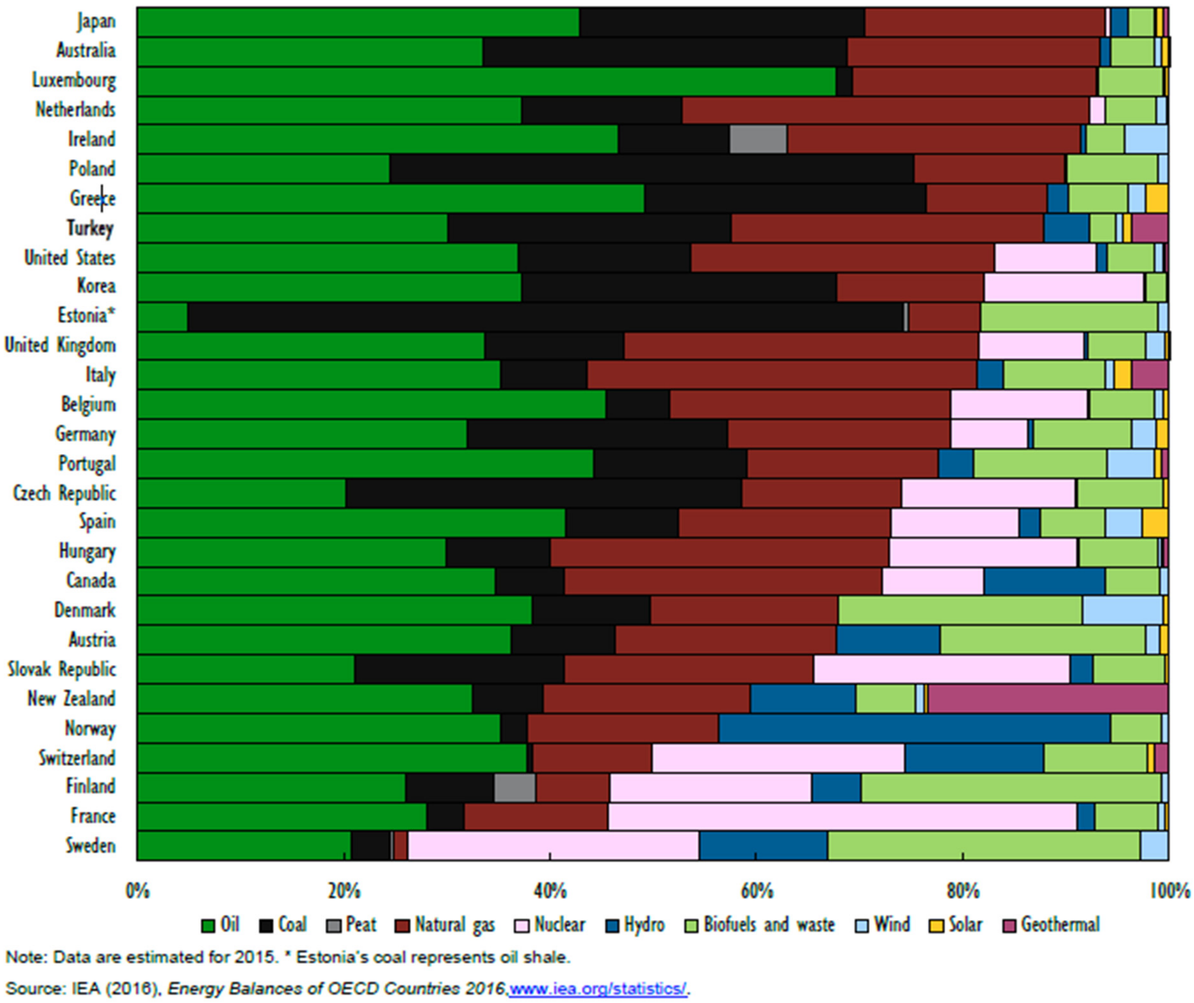


FIGURE 1: Energy balance of OECD countries (IEA, 2016)

As of 2017, renewable energy accounted for an estimated 18.1% of total final global energy consumption. Renewables supplied 10.6% of total consumption, with an estimated 4.4% growth in demand compared to 2016. Traditional use of biomass for cooking and heating in developing countries accounted for the remaining share. The greatest portion formed by renewable thermal energy (an estimated 4.2% share), followed by hydropower (3.6%), other renewable power sources (REN21, 2019).

Renewable energy in power generation continued its sprint in 2018. An estimated 181 GW was installed worldwide, and total installed capacity grew more than 8%. Additions from solar PV accounted for 55% of new renewable capacity, followed by wind power (28%) and hydropower (11%). Each year, more electricity is generated from renewable energy than in the previous year. Hydropower still accounted for some 60% of renewable electricity production in 2018, followed by wind power (21%), solar PV (9%) and bio-power (8%). Estimated share of the non-renewables such as coal and natural gas is 73.8% and share of renewables in global electricity generation was more than 26% by the end of 2018 (REN21, 2019). Non-renewables include coal and coal, oil, natural gas, biofuels, gas/liquids from biomass, industrial waste and municipal waste (Figure 2).

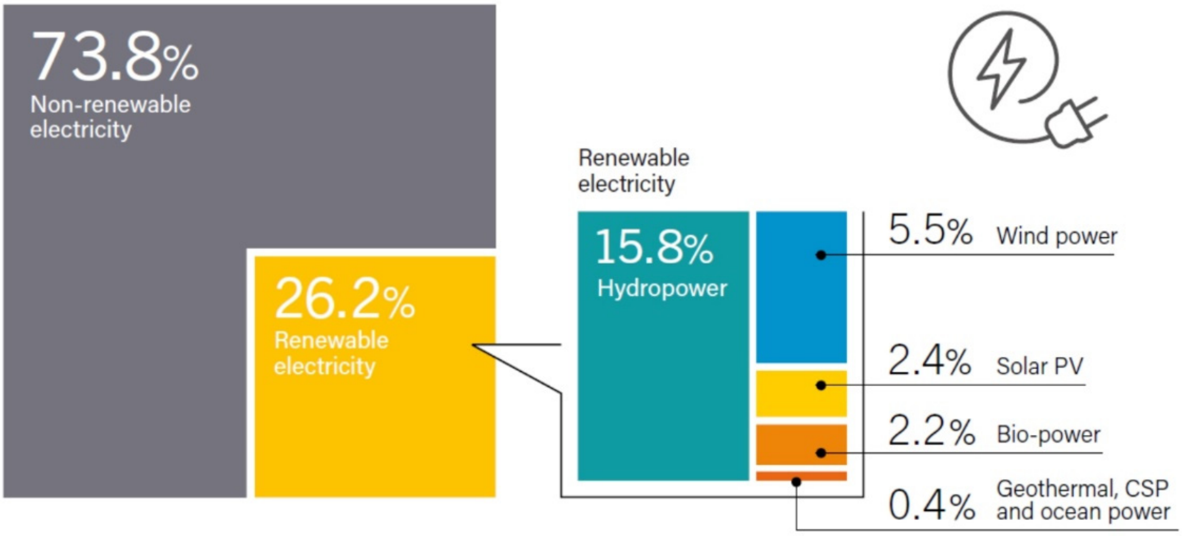


FIGURE 2: Estimated renewable energy share of global electricity production, end-2018 (REN21, 2019)

### 2.2. Energy production in Turkey

As the primary products used in electricity production are natural gas and coal in Turkey. In total, there are 320 natural gas and 42 coal power plants. Turning to natural gas to reduce $CO_2$ emissions and air pollution in Turkey, then it began to evaluate renewable energy sources. Hydraulic energy has a large share in the country's existing infrastructure. However, especially in recent years, the share of electricity generation in wind, solar and geothermal energy has increased considerably (Table 1).

TABLE 1: Distribution of licensed electricity installed power by source as of the end of May 2019 and comparison with May 2018 value (MW-%) (EPDK, 2019 – N.B.: uses decimal comma))

| Type | 2018 MAY | | 2019 MAY | | Difference (%) |
|---|---|---|---|---|---|
| | Installed Capacity (MW) | Ratio (%) | Installed Capacity (MW) | Ratio (%) | |
| **Natural Gas** | 26.352,02 | 32,04 | 25.940,07 | 30,90 | -1,56 |
| **Hydraulic (Dam)** | 20.127,10 | 24,47 | 20.582,40 | 24,52 | 2,26 |
| **Lignite** | 9.267,12 | 11,27 | 9.853,08 | 11,74 | 6,32 |
| **Imported Coal** | 8.938,85 | 10,87 | 8.938,85 | 10,65 | 0,00 |
| **Hydraulic (River)** | 7.578,19 | 9,21 | 7.815,92 | 9,31 | 3,14 |
| **Wind** | 6.617,03 | 8,05 | 7.086,55 | 8,44 | 7,10 |
| **Geothermal** | 1.129,24 | 1,37 | 1.335,52 | 1,59 | 18,27 |
| **Hard Coal** | 820,57 | 1,00 | 810,77 | 0,97 | -1,19 |
| **Biomass** | 480,04 | 0,58 | 594,90 | 0,71 | 23,93 |
| **Fuel Oil** | 496,77 | 0,60 | 487,17 | 0,58 | -1,93 |
| **Asphaltite** | 405,00 | 0,49 | 405,00 | 0,48 | 0,00 |
| **Solar** | 22,90 | 0,03 | 81,66 | 0,10 | 256,59 |
| **Naphtha** | 4,74 | 0,01 | 4,74 | 0,01 | 0,00 |
| **Lng** | 1,95 | 0,00 | 1,95 | 0,00 | 0,00 |
| **Diesel** | 1,04 | 0,00 | 1,04 | 0,00 | 0,00 |
| **Total** | **82.242,57** | **100,00** | **83.939,61** | **100,00** | **2,06** |

In terms of geological location and technology background, Turkey is a country that can easily benefit from renewable energy sources. The duration of sunlight, the potential to use water resources, the number and high temperatures of geothermal resources and wind potential is an important resource in reducing the country's dependence on energy imports. For this purpose, the state has implemented a mechanism called "Renewable Energy Resources Support Mechanism (YEKDEM)". YEKDEM is a support mechanism for electricity manufacturers from renewable energy resources, which has been regulated in the Regulation on Documentation and Support of Electricity Manufacturing from Renewable Energy Resources ("Regulation") which has entered into force in 2013. The support mechanism consists of feed-in tariffs for electricity manufacturing license holders and unlicensed electricity manufacturers producing electricity from renewables and other opportunities for renewable energy. However, YEKDEM will be valid until 2020, and investors and the private sector are waiting for new support and monetary incentives.

The issue of the Law for the Use the Renewable Energy Resources for Electricity Production (No: 5346, Date: May 10, 2005) has started the acceleration in utilization of renewable energies (geothermal, hydro, wind, biomass and sun). The law gives the prices of electricity as incentives for different renewable energy resources. The produced geothermal electricity received a price of 10.5 USDcent/kWh. Geothermal activities in Turkey is regulated by Law on Geothermal Resources and Natural Mineral Waters (No: 5686, Date: June 3, 2007) and its Implementation Regulation (No: 26727, Date: December 2007). The geothermal law and its regulations provide solutions to the problems concerning legislative matters and obligations of the exploration and production concession rights, technical responsibility, control and protection of the geothermal areas

As a result of all the support and investment, large-scale renewable energy investments in Turkey took place. By the end of 2018, power plants containing 4,025.5 MW additional capacities were added to the system, and at the end of 2018, capacity has risen to around 88,551 MW. As the end of 2018, EUAS (State Electricity Generating Company) had a share of 20.9% in installed capacity of Turkey, 64.7% of the private sector, 6.9% of build-operate plants, 1.5% of build-operate-transfer plants and 6.0% of unlicensed power plants. In March 2019, natural gas share of installed capacity reduced to 30.90%, hydraulic (river+dam) share increased to 33.83 and share of the all renewables also increased (Figure 3; EPDK, 2019).

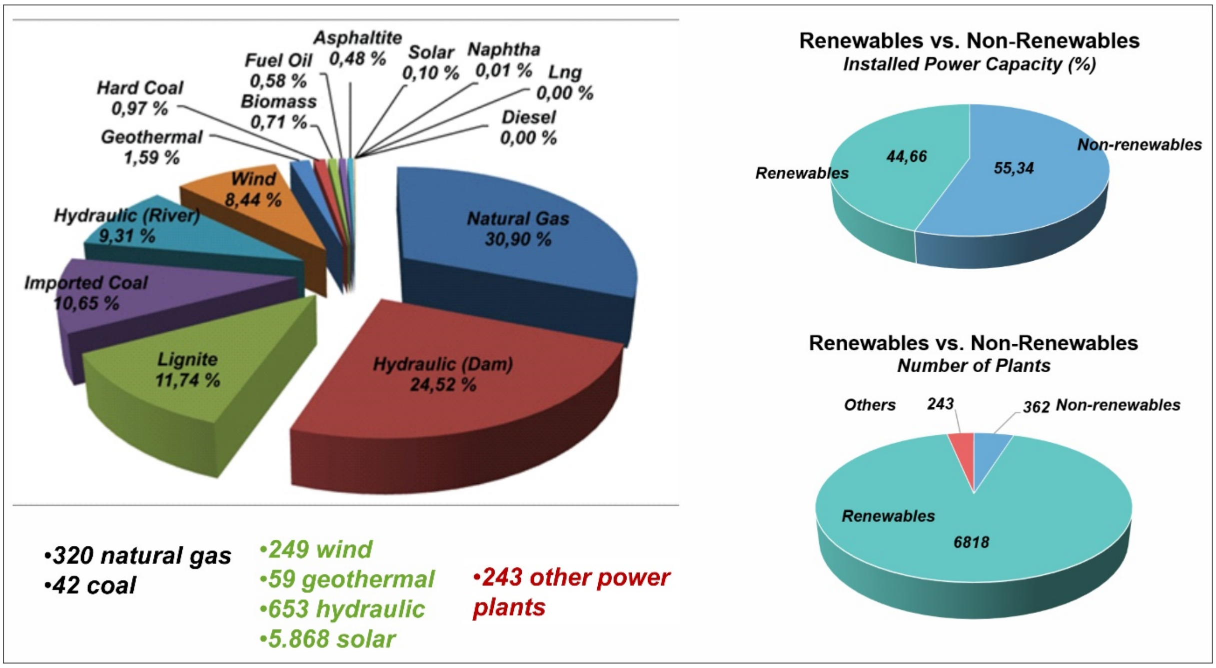


FIGURE 3: Distribution of licensed electricity installed power by source as of the end of May 2019 (%) (EPDK, 2019)

Looking at the overall situation in the amount of installed power, while power plants that use fossil fuels at the rate of 55.34%, 44.66% of the installed power is consisting of renewable energy sources in Turkey. The number of renewable energy plants has increased considerably in recent years. With considering all data of the Turkish energy market, nearly 24% of electricity production was obtained from coal, 30.9% from natural gas, 34% from hydropower, 8.44% from wind, 0.1% from solar energy, 1.59% from geothermal energy.

## 3. GEOTHERMAL ENERGY PRODUCTION

Geothermal energy output in 2018 was estimated at 630 pJ, with around half of this in the form of electricity (89.3 TWh) and half as heat. An estimated 0.5 GW of new geothermal power generating capacity came online in 2018, bringing the global total to around 13.3 GW. Turkey and Indonesia accounted for about two-thirds of the new capacity installed. Other projects have occurred in Iceland, Kenya, New Zealand, the Philippines, Croatia and the United States (REN21, 2019). The top five countries with the largest installed capacity in year-end 2018 were U.S., Indonesia, the Philippines, Turkey and New Zealand (Figure 4). The installed capacity values and current situations reached by countries in 2018 are summarized in Table 2.

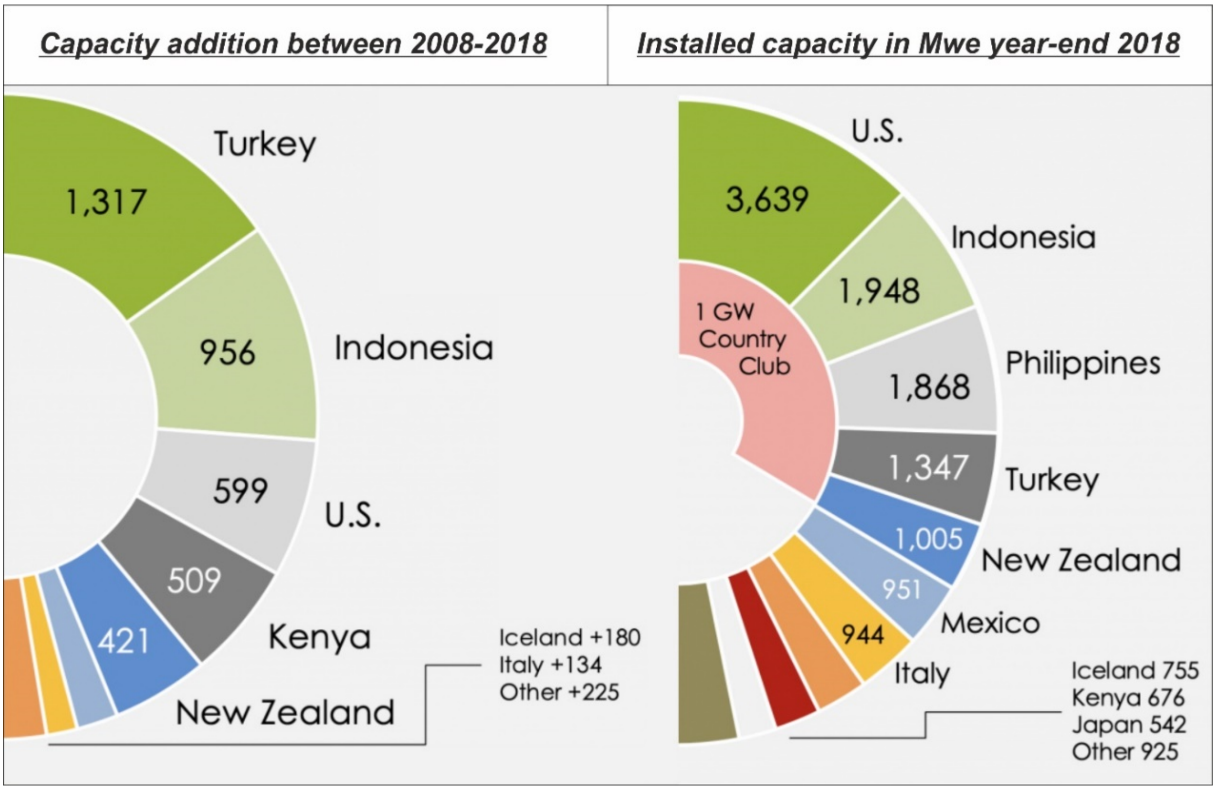


FIGURE 4: Information about global geothermal installed capacity
(Source: ThinkGeoEnergy, 2019)

According to the Republic of Turkey Ministry of Energy and Natural Resources, 78% of geothermal fields are situated in Western Anatolia, 9% in Central Anatolia, 7% in the Marmara Region, 5% in Eastern Anatolia and 1% in the other regions. 90% of Turkish geothermal resources are low and medium enthalpy geothermal areas, which are suitable for direct applications, while 10%, are suitable for the generation of electricity. Since the 1960s, the General Directorate of Mineral Research Application (MTA) has identified more than 200 geothermal fields in Turkey. Geothermal systems have water-dominated reservoirs and different reservoir temperatures.

TABLE 2: The installed capacity values and current situations reached by countries in 2018

| Countries | Installed capacity (MWe) | Planned |
|---|---|---|
| United States | 3,639 | 48 MWe addition |
| Indonesia | 1,948 | 95 MWe planned |
| Philippines | 1,868 | |
| Turkey | 1,347 | A significant amount of capacity increase planned |
| New Zealand | 1,005 | 25 MWe planned |
| Mexico | 951 | |
| Italy | 944 | |
| Iceland | 755 | 45 MWe addition |
| Kenya | 676 | |
| Japan | 542 | |

Western Anatolia has extensional tectonic systems while other regions have strike-slip and compressional tectonic setting (Figure 5). Extension in the west of the Anatolia formed more suitable tectonic settings and geothermal systems for geothermal power production. Büyük Menderes Graben and the Gediz Graben are the important regions for the geothermal activity and most of the power plants are located in that graben (Figure 6 and Figure 7). In addition, Çanakkale (Tuzla), Afyon, Cappadocia and regions around the major fault zones have significant potential and have many important geothermal fields with high temperatures. Niğde (Çiftlik-Bozköy) has the highest temperature value with 295°C. Manisa district has temperatures range from 117 to 287°C, while temperatures of other fields such as Denizli 242-103°C, İzmir 153-130°C, Aydın 239-160°C (Akkuş, 2018).

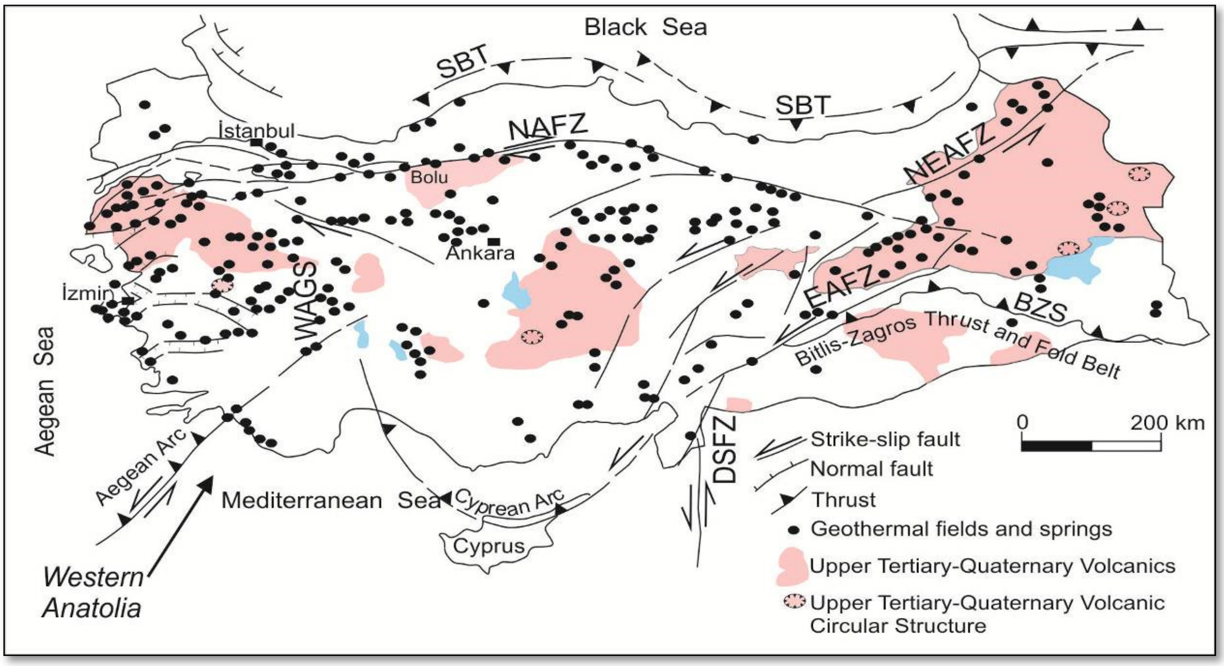


FIGURE 5: Tectonic map of the Anatolian plate showing major faults and distribution of geothermal areas in Turkey (Şimşek et al., 2002; Yiğitbaş et al., 2004; Baba and Ármannsson, 2006). (SBT, Southern Black Sea Thrust; NAFZ, North Anatolian Fault Zone; NEAFZ, Northeast Anatolian Fault Zone; EAFZ, Eastern Anatolian Fault Zone; WAGS, Western Anatolian Graben System; DSF, Dead Sea Fault Zone; BZS, Bitlis-Zagros Suture)

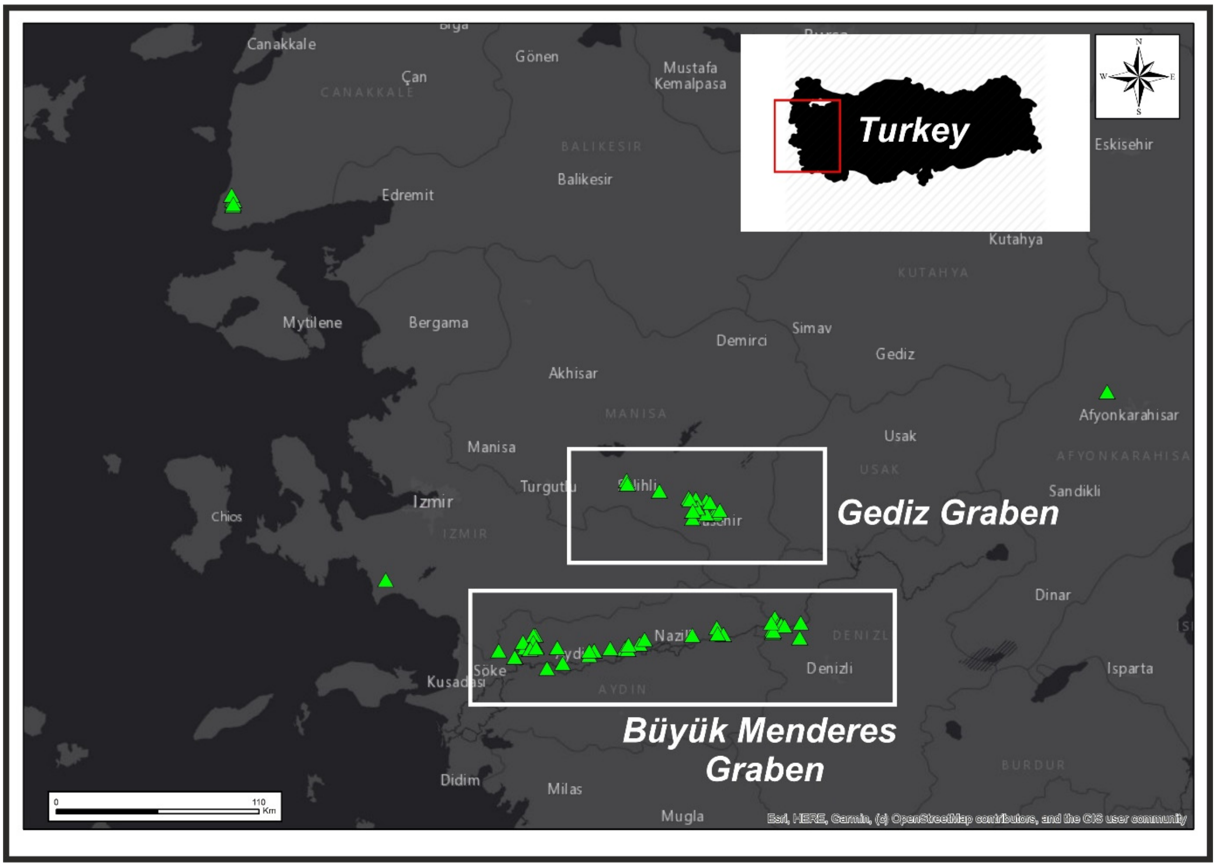


FIGURE 6: Geothermal power plants in Turkey showing Büyük Menderes and Gediz Grabens (Source of the power plant locations: JESDER)


FIGURE 7: Geothermal power plants in Turkey; A) Çanakkale (Inanli and Atilla, 2011); B) Kızıldere-III triple flash+binary geothermal power plant (Haklıdır Tut and Balaban, 2018, Photo credit: Zorlu Energy); C) Germencik geothermal power plant (Photo credit: Ormat company); D) Aydın Dora-1 geothermal power plant (Karadaş, 2012)

In the beginning, the country focused on high-temperature systems for power production and Kızıldere field was discovered in 1968, then Balçova and Seferihisar, two medium temperature fields, were located and analyzed in the 1960s and 1970s. The first geothermal electricity generation held in 1975, was initiated by Kızıldere power plant with 0.5 MWe power. Today, the majority of Turkey's geothermal power plants use binary-cycle technology. In the Germencik region, and in the Alaşehir region, there are double flash systems. In the Kızıldere region has one single flash and two triple flash+binary systems (Figure 8). Overall, four advanced geothermal power systems are located along the with graben systems (Haklıdır Tut and Balaban, 2019). The largest single unit completed in 2018 was the 65.5 MW Unit 2 at the Kizildere III plant, which became Turkey's largest geothermal power plant (165 MW). Other completed projects were 19.4 MW Baklaci, the 13.8 MW Buharkent, the 25 MW 3S Kale, and the 32 MW Pamukören Unit 4.9 A final addition, the 30 MW Alasehir Unit 3 (REN21, 2019).

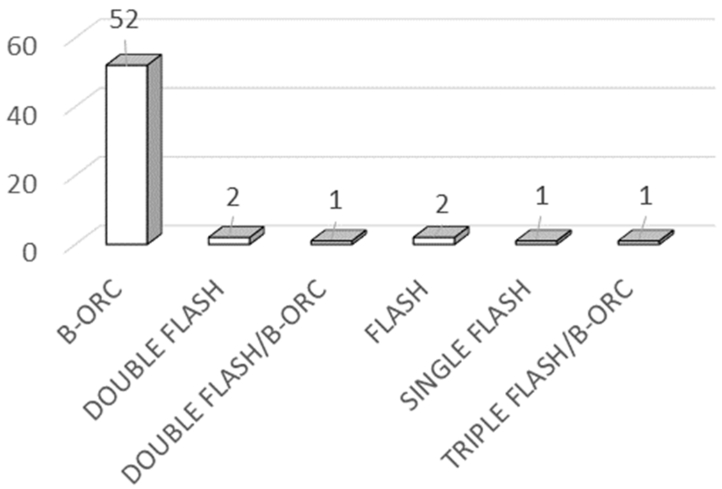


FIGURE 8: Number of geothermal electricity turbines by types of plants in Turkey

Turkish Geothermal Association has calculated the total geothermal theoretical heat potential of Turkey (hydrothermal 0–3 km) as 60,000 MWt. The total geothermal electricity technical potential of Turkey (hydrothermal) (0–3 km) is 4,500 MWe (Mertoğlu et al., 2019). In Turkey's 2023 vision targets, there is a target of installing 1,000 MW of geothermal power plants. However, this goal has already been achieved and exceeded. Therefore, Turkey aims to reach 2,600 MW by 2025, which is the target value. Figure 9 show that geothermal power generation capacity and its planned percent.

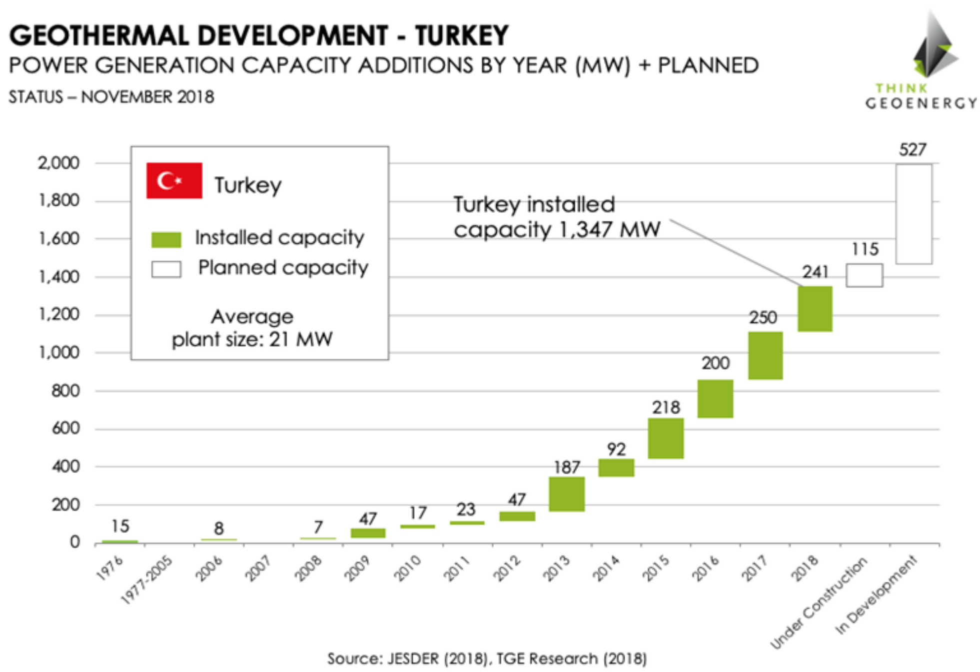


FIGURE 9: Installed and planned geothermal power plant capacity in Turkey (Source: ThinkGeoEnergy, 2019)

To achieve those targets, Turkey has a few critical challenges in the construction and operating phases of geothermal power plants. Environmental problems, changeable reservoir temperatures, corrosion, and scaling problems are caused by rock and water chemistry. These problems reduce the efficiency of the plants during operation and cause economic losses. Solving such problems with developing technology and new methods will not be difficult to achieve these goals.

## 3. CONCLUSION

Turkey has 347 geothermal areas and about 600 natural hot springs, which have surface temperatures above 30°C degrees. Electricity is produced in 12% of these areas, while heating is used in 43% and thermal use in 45%. Approximately 153 sites have 18 districts heating and two facilities have drying. In direct use, the installed capacity is 3,322.3 MWth. About 450 geothermal fields have been discovered in Turkey. Rapid development at geothermal electricity installed capacity reached up 1,347 MWe as of May 2019. The capacity has increased twice since 2016. The main direct geothermal applications are district heating, greenhouse heating, thermal facilities and hotels, balneological, drying, cooling and heat pump applications. Constantly evolving technology, with research and projects, electricity production and number of power plants in Turkey will increase in the near future.

TSI-TÜİK's annual data for 2018 showed that the country paid $42.99 billion for its energy imports last year compared to $37.2 billion in 2017. Energy accounted for 19.2 percent of the total import. Therefore, its means that, Turkey's energy import bill is still a problem for the current budget deficit. Today, geothermal studies are carried out mainly in Western Anatolia. However, data obtained in almost every region of Turkey shows that the presence of significant geothermal energy. Detailed geological, hydrogeological, geochemical, hydrogeochemical, geophysical and reservoir models should be made to develop existing resources. In addition, taking into account the following issues, geothermal resources will have a significant contribution to both the sustainability and the national economy.

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## LECTURE 2

# APPLICATION OF GEOTHERMAL ENERGY IN TURKEY


## ABSTRACT

Geothermal energy is an environmental friendly, sustainable, and global energy source. The most important feature is that it is available 24 hours and independent of seasonal and weather effects. Apart from electricity generation, geothermal energy has many important uses. It can be used in hybrid form in accordance with other energy systems or it can be effective in direct use. Geothermal energy has lower heating costs, reduces greenhouse gas emissions and domestic and renewable energy source for the whole earth. There are several ways to use geothermal sources except from geothermal electricity production. Many countries used these renewable sources in direct applications such as; geothermal heating, agribusiness applications, thermal and pools, drying and many other uses. Turkey is the fourth biggest country in terms of geothermal direct use applications with having 347 geothermal areas and about 600 natural hot springs, which have surface temperatures above 30°C degrees. Electricity is produced in 12% of these areas, while heating is used in 43% and thermal use in 45%. Approximately 153 sites have 18 districts heating and two facilities have drying. In direct use, the installed capacity is 3,322.3 MWth.


## 1. INTRODUCTION

Geothermal is the internal heat of the earth, which combination of two words “Geo” (earth) and “thermal” (heat). The geothermal heat continuously flows outward from the core and from hotter to cooler regions, increases gradually with depth and reaches mantle and crust. A rock unit melts with increasing temperature and form molten magma. The main heat sources of the earth are relict formation heat of planet about 4.5 billion years ago and decaying process of the radioactive isotopes in the core. Geothermal gradient, which is the rate of increasing temperature with respect to depth increase, generally controls the temperature ranges of geothermal systems with fluid and vapour circulation. In addition, plate tectonics, volcanism and magmatism processes have formed geothermal systems in the areas where the continental crust is thinner. Geysers, mud-pots, fumaroles and hot springs are typical surface manifestations of the geothermal activity.

Human beings have used geothermal resources in their daily life since ancient times. Geothermal resources, which are used for many purposes such as cooking, bathing and therapy, are emerging in different areas of daily life with the development of modern techniques. In our daily life, geothermal resources are now being evaluated together with the concept of energy. Geothermal resources, formerly considered only hot water, have now gained the status of the Earth's long-term energy source as a renewable resource. Geothermal resources have started to be used in many different fields such as electricity production from power plants, pool and spa applications in thermal hotels, district-greenhouse heating and drying.

The definition of direct use of geothermal resources is the use of the heat energy or the fluid from geothermal resources without energy production. Most direct use applications can be applied for fluids with temperature ranges from 20 to 120°C. Geothermal energy resources are grouped by several conditions pertaining to the resource such as temperature, depth and usage. The geothermal gradient-depth relationship is shown in Figure 10A. Geothermal resource classifications are generally based on this depth-temperature plot. Baldur Lindal (Lindal, 1973) indicates the temperature range suitable for various direct use activities and creates a scale for direct-use applications for geothermal resources.

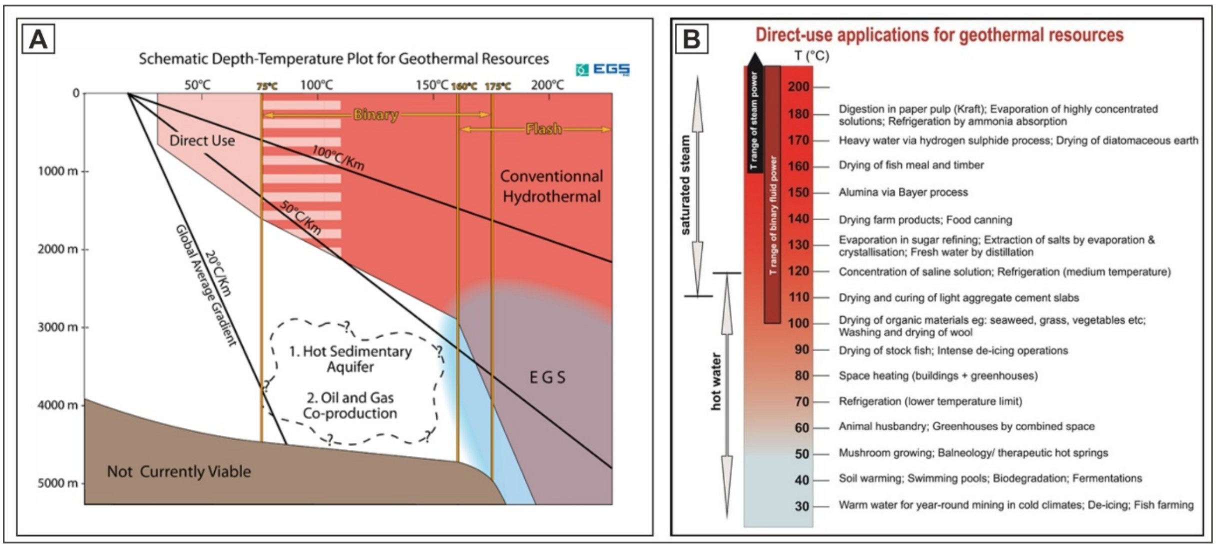



FIGURE.10: A) Schematic depth-temperature plot for geothermal resources (EGS, 2018);
B) Modified Lindal diagram for direct-use applications for geothermal resources
(Australian Academy of Science, 2018)

Later, the studies related to electricity generation were added to the diagram (Gudmundsson et al., 1985; Figure 10B). Determining with the Lindal diagram, the applications that can be made in response to the temperatures of geothermal sources are better understood so that it is realized how important even low temperature sources can be. Many countries have begun to make appropriate investments in regional terms, taking into consideration these diagrams directly in applications other than electricity generation from geothermal fields.

In direct applications, low-temperature geothermal reservoirs are suitable for heat pumps, residential heating, pools and spas, greenhouses, aquaculture and industrial processes. The output hot water from binary power plants can be used for direct applications such as agribusiness, drying and other industrial indirect applications such as mineral recovery. The top five countries of geothermal direct-use applications are USA, China, Sweden, Turkey and Germany, respectively. Except for electricity production in Turkey, the amount of capacity is the direct use of geothermal energy in the past the amount of 3,222.3 MW (Table 3). The largest share of direct use is district heating, while the second is thermal pool and spa treatments. Although different applications and improvements related to industrial applications and cooling have accelerated in recent years, there is no clear data on the amount of usage.

TABLE 3: General applications of geothermal direct-use in the Turkey and World
with national direct-use rankings in 2018 (modified after Akkuş, 2018 – uses decimal comma)

| | World | Turkey | Direct-use Ranking (2018) | |
|---|---|---|---|---|
| **Application Type** | **Capacity (MWt)** | | | |
| Geothermal Heat Pump | 49898 | 42,8 | 1 | USA |
| District Heating | 7556 | 1453 | 2 | China |
| Greenhouse Heating | 1830 | 820 | | |
| Aquaculture | 695 | ? | 3 | Sweden |
| Agricultural Drying | 161 | 1,5 | | |
| Industrial Use | 610 | ? | 4 | Turkey |
| Thermal Pool-Spa | 9140 | 1005 | | |
| Cooling | 360 | - | 5 | Germany |
| Others | 79 | - | | |
| Total | 70329 | 3322,3 | | |

## 2. GEOTHERMAL DIRECT-USE APPLICATIONS IN TURKEY

### 2.1. Thermal pool and balneological usage

Our ancestors have used geothermal resources for different purposes. Romans and ancient Greeks used baths as health centres and therapy centres. Roman baths are one of the important places where politics is discussed. Our ancestors discovered the therapeutic cures of hot springs and mineral waters and integrate these natural sources to their daily life. Ancient city of Hierapolis (Denizli-Pamukkale), Agamemnon springs, Roman and Byzantine baths in Anatolia are unique examples for historical use of the geothermal resources by humanity (Figure 11). Similarly, in the China, geothermal water has been used for medical treatments for nearly 600 years. Geothermal water with temperature of 50°C is used for blood pressure, rheumatism, nervous and skin disease treatments in some countries such as China, Japan and New Zealand (Lund, 1996).


FIGURE 11: Ruins of old spas in Turkey; A) Hierapolis (foto from Kader Reyhan); B) Allianoi (Hamamcioglu – Turan et al., 2013); C) Gulbahce (Urla); D) Ruins in Çanakkale

Typical temperature for a swimming pool is 27°C, therefore in a geothermal heated pool, the hot water must often be cooled by mixing with cooler water. Geothermally heated swimming pools have alternative energy sources if the geothermal water is not used directly in the pool. In all around Turkey, more than 260 thermal facilities established over an area of more than 1,500 thermal resources and it can get thermal cures for almost 300 days in a year.

Hot springs are important tourist attractions in Turkey. Along with the restoration of these areas in Anatolia and newly discovered resources, hotel management activities developed around geothermal wells have led to the development of spa and balneology practices in many cities today. In recent years, as in the case of Afyon, geothermal applications have been a new hope for local people in developing


FIGURE 12: Thermal hotel in Afyon Region

cities (Figure 12). The hotels are integrated with the geothermal and new concept of business-conventional centres, which host large-scale organizations and have started to attract the attention of local and foreign tourists especially in winter. This type of application has informed the local people who have not been acquainted with geothermal energy before and directed them to very efficient applications in terms of promotion, economy and future of their cities. Thermal pool and hotel management is an application that can be easily applied in many regions in Anatolia. The local people easily adopt the hot water and hot spring applications in our culture and our past. These applications, which have a great impact on the economy and the promotion of the region, can be developed together with other integrated applications to create new centres of attraction.

Balneotherapy is a treatment made by using natural elements such as mineral and thermal waters (healing waters), muds and gases with bath, drinking and inhalation methods. Balneotherapy is used as a unique treatment modality in hot springs and cure centres. Spa treatment or spa cure, with other treatment methods of balneotherapy, within the framework of a complex cure program refers to the use (Karagülle, 2008).

Turkey is making efforts in a push for its geothermal tourism sector for playing a leading role in tourism sector in the region, aiming to attract 1 million tourists. Newly added hospitals and health centres that are welcoming foreign patients for treatments and main target is to rank second place in the global health tourism sector by 2023. For this purpose, Turkey plans to host 1.5 million tourists with the support of thermal tourism by using geothermal resources and natural outlets. In addition to foreign tourists, thermal tourism, which is an alternative to coastal tourism especially in winter, attracts the attention of domestic tourists, even in harsh winter conditions. For example, Diyadin (Ağrı) hot springs host foreign tourists and local people who are trying to find a cure for diseases, many illnesses, such as skin diseases and rheumatism. Figure 13 and Figure 14 show some thermal centres in Turkey.

FIGURE 13: Geothermal fluid for treatment in Dalyan region


| Thermal Hotel and Spa Centers | | |
|---|---|---|
| İzmir-Balçova | Balıkesir-Edremit-Güre | Ankara-Ayaş |
| Afyon-Merkez-Sandıklı | Balıkesir-Hisaralan | Ankara-Kızılcahamam |
| Yalova-Termal | Sivas-Sıcakçermik | Ankara-Haymana |
| Nevşehir-Kozaklı | Gaziantep-Durantaş | Sakarya-Akyazı-Kuzuluk |
| Denizli-Tekkehamam | Hatay | Kütahya-Harlek |
| Kütahya-Gediz | Kütahya-Emet | Kırşehir-Terme |

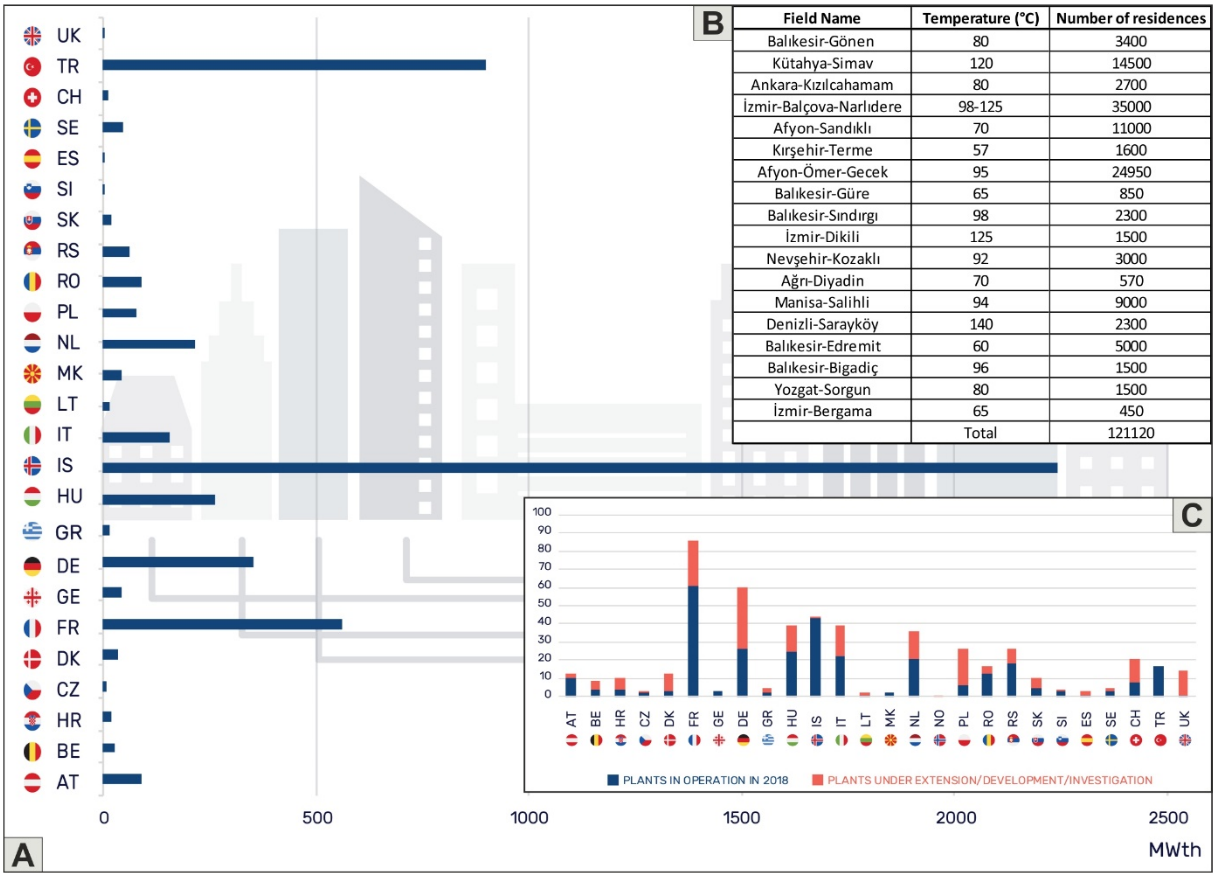

FIGURE 14: Thermal hotels, spa centres and pools around Turkey; A) Agamemnon springs (İzmir, Balçova); B) Kuzuluk hot-springs (Sakarya) C) Yalova thermal springs; D) Akrones thermal hotel (Afyon); E) İkbal thermal hotel (modified after Akkuş, 2018)

**2.2 Space conditioning and district heating**

Space conditioning has a two different type of application, cooling and heating processes. Heating and cooling are provided by means of geothermal fluid supported by heat pumps. It is known that the heating process is costlier as it requires a higher temperature fluid than the cooling process. For this reason, geothermal fluid is used predominantly in house and space heating in many countries. In addition, heat pumps have become widely used especially in Northern America and Europe.

Central district heating systems are based on the principle that the fluid in the geothermal system flows to the surface from production wells, collected in a heating centre, and then delivered to the buildings by distribution pipes. While district heating systems are widely used in Iceland, France, Turkey, U.S. and Japan, with the support of new projects and technologies, many countries are starting to use their geothermal resources in residential heating. Depending on the position of the wells, the status of reinjection and the supply, reservoir and other parameters in the system, the temperature of the fluid may vary periodically. With the development of efficiency, control and monitoring processes, unwanted problems such as temperature drops are eliminated in a short time and geothermal resources are protected.

Particularly in Europe, the trend towards geothermal heating systems has been increasing with the support of the investors and policy makers recently. In some regions of Europe, investments have started to be made with the support of local people and communities even in low temperature systems. The Netherlands, France, Germany, Serbia and Belgium have new additional projects in 2018 and improvements and investments will continue in the near future. Total installed capacity of geothermal heating and cooling use of Iceland is 2,172 MWth. Turkey follow Iceland with 872 MWth capacity and




| Field Name | Temperature (°C) | Number of residences |
|---|---|---|
| Balıkesir-Gönen | 80 | 3400 |
| Kütahya-Simav | 120 | 14500 |
| Ankara-Kızılcahamam | 80 | 2700 |
| İzmir-Balçova-Narlıdere | 98-125 | 35000 |
| Afyon-Sandıklı | 70 | 11000 |
| Kırşehir-Terme | 57 | 1600 |
| Afyon-Ömer-Gecek | 95 | 24950 |
| Balıkesir-Güre | 65 | 850 |
| Balıkesir-Sındırgı | 98 | 2300 |
| İzmir-Dikili | 125 | 1500 |
| Nevşehir-Kozaklı | 92 | 3000 |
| Ağrı-Diyadin | 70 | 570 |
| Manisa-Salihli | 94 | 9000 |
| Denizli-Sarayköy | 140 | 2300 |
| Balıkesir-Edremit | 60 | 5000 |
| Balıkesir-Bigadiç | 96 | 1500 |
| Yozgat-Sorgun | 80 | 1500 |
| İzmir-Bergama | 65 | 450 |
| | Total | 121120 |

FIGURE 15: A) Installed geothermal district heating capacity per country; B) Residential heating regions from Turkey (Akkuş, 2018); C) Number of geothermal heating plants in Europe: installed, planned, in development (EGEC, 2019)

France (544 MWth), Germany (343 MWth) and Hungary (253 MWth) are other important countries with higher capacities (Figure 15A and 15C; EGEC, 2019).

Many city centres (Figure 15) have been heated by geothermal applications as İzmir (Balçova-Bergama-Dikili-Narlıdere), Afyon (Ömer-Gecek-Sandıklı), Balıkesir (Gönen-Güre-Sındırgı-Edremit-Bigadiç) and Kütahya (Simav). Turkish people are living usually in building-blocks in cities and villages. The typical heating systems are using coal and natural gas. The economic problems, increasing amounts of fuel have started to cause people to use their demand in areas where geothermal heating systems can be applied in the direction of cheaper geothermal and demand has increased. In Balçova geothermal district heating system, the newest technologies are used and the operational costs are very low. Balçova geothermal is operating since 1996 and has reached 37,305 residences (Table 4 and Figure 16).

The cooling systems continue to become widespread in Turkey has focused on geothermal heating systems electric air conditioning systems. Both economic and applicability problems have not yet expanded the use of cooling systems. But, first geothermal cooling application has been operated in Izmir-Balçova by İzmir Jeotermal Inc. in 2018, for cooling of 1,900 $m^2$ 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 (Mertoğlu et al., 2019).

Ground source heat pump (GSHP) applications in Turkey started in 2000's for residential single family houses with a total installed capacity of 586 kWth. Today, with increasing interest in renewables number of HP systems has reached to 146 with a total installed capacity of 109 MWth (Mertoğlu, et al., 2019). Shallow geothermal resources assisted by heat pumps can be used everywhere in Europe, utilizing geothermal energy even at very low temperatures to supply heating and cooling to buildings of all sizes.

TABLE 4: Residential heating regions from Turkey

| City | Location | Production (m³/hour) | Temperat. (°C) | Total capacity | | Actual capacity | |
|---|---|---|---|---|---|---|---|
| | | | | Housing equivalent | % | Housing equivalent | % |
| Afyon | Merkez (Afjet) | 1500 | 95 | 30,000 | 18 | 25,256 | 21 |
| Afyon | Sandıklı (Sanjet) | 1440 | 80 | 18,000 | 11 | 15,700 | 13 |
| Ağrı | Diyadin | 180 | 78-82-85 | 2,000 | 1 | 540 | 0 |
| Ankara | Kızılcahamam | 63 | 75 | 3,000 | 2 | 2,400 | 2 |
| Balıkesir | Gönen | ? | 60-70 | 2,500 | 2 | 2,500 | 2 |
| Balıkesir | Edremit | 1440 | 58 | 7,500 | 5 | 5,200 | 4 |
| Balıkesir | Bigadiç | 54 | 98 | 3,000 | 2 | 3,000 | 2 |
| Bursa | Merkez | 1080 | 88 | 5,400 | 3 | 350 | 0 |
| Denizli | Sarayköy | 260 | 145 | 5,000 | 3 | 2,200 | 2 |
| İzmir | Balçova-Narlıdere | 2020 | 90-144 | 50,500 | 31 | 37,305 | 31 |
| İzmir | Bergama | 180 | 65 | 850 | 1 | 400 | 0 |
| İzmir | Dikili | 200 | 80 | 2,500 | 2 | 1,500 | 1 |
| İzmir | Çeşme | 49 | 57 | | | | |
| Kırşehir | | 983 | 55 | 1,800 | 1 | 1,800 | 1 |
| Kütahya | Simav | 828 | 130-150 | 15,000 | 9 | 14,000 | 12 |
| Manisa | Salihli | 540 | 88 | 12,000 | 7 | 8,000 | 7 |
| Nevşehir | Kozaklı | ? | 94 | 3,500 | 2 | 1,300 | 1 |
| Yozgat | Sarıkaya | 180 | 57 | 2000 | 1 | 0 | 0 |
| Yozgat | Yerköy | 648 | 65 | 1,000 | 1 | 250 | 0 |
| | | | **Total** | **165,550** | **100** | **121,701** | **100** |

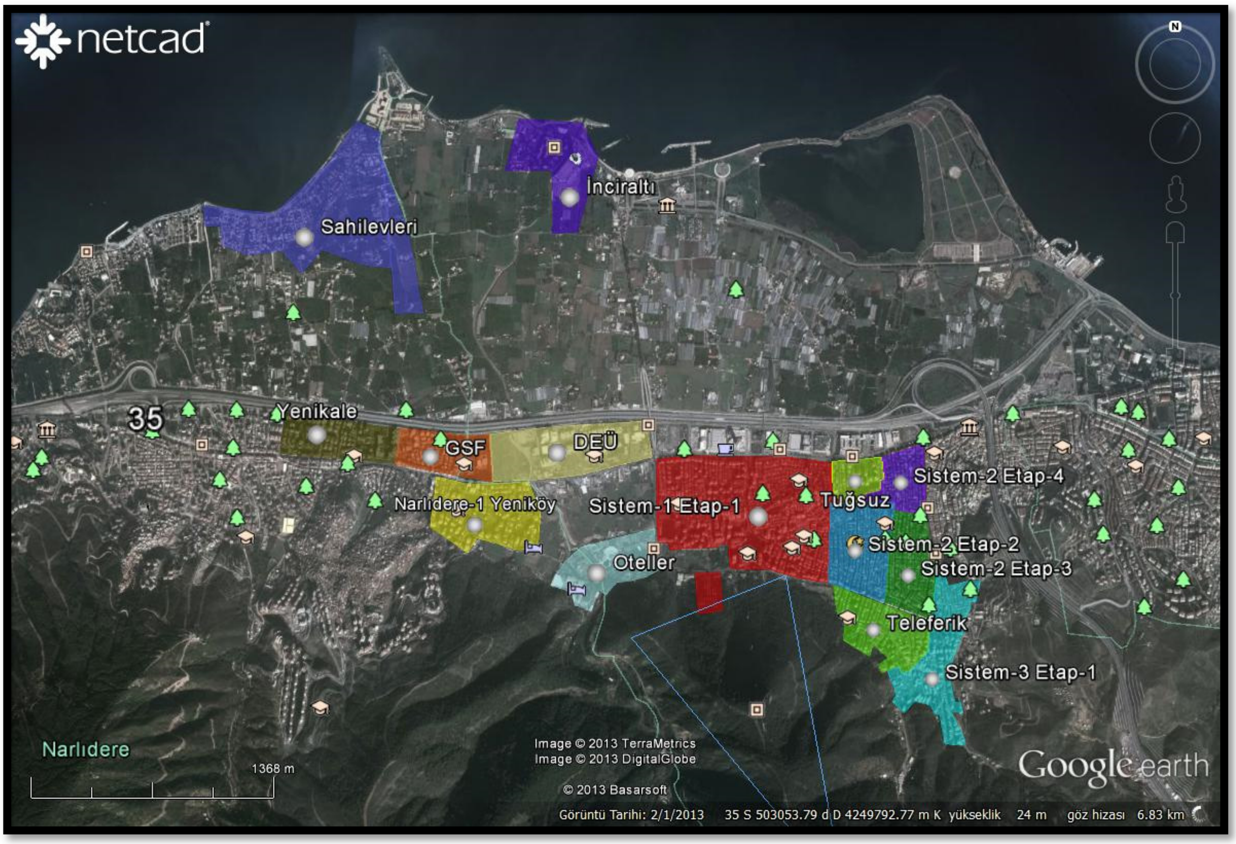



FIGURE 16: Picture from Balçova geothermal field; painted areas are heated by geothermal

For shallow geothermal energy overall installation growth is continuing on a steady pace. This brought installed capacity up to at least 23,000 MWth by 2018, distributed over more than 1.9 Mio GSHP installations. Annual GSHP sales in Europe in 2018 totalled around 92,000 units, approximately 45,000 of which (50%) were in just two leading countries: Sweden and Germany (EGEC, 2019).

### 2.3 Agribusiness applications

The definition of agribusiness is a general definition that includes greenhouse heating, aquaculture, animal husbandry facilities heating, soil warming-irrigation, and cooling, and bio-gas generation (Figure 17). While different applications exist in this field in the world, agribusiness applications are made only as cooling, fishing and greenhouse applications in Turkey.

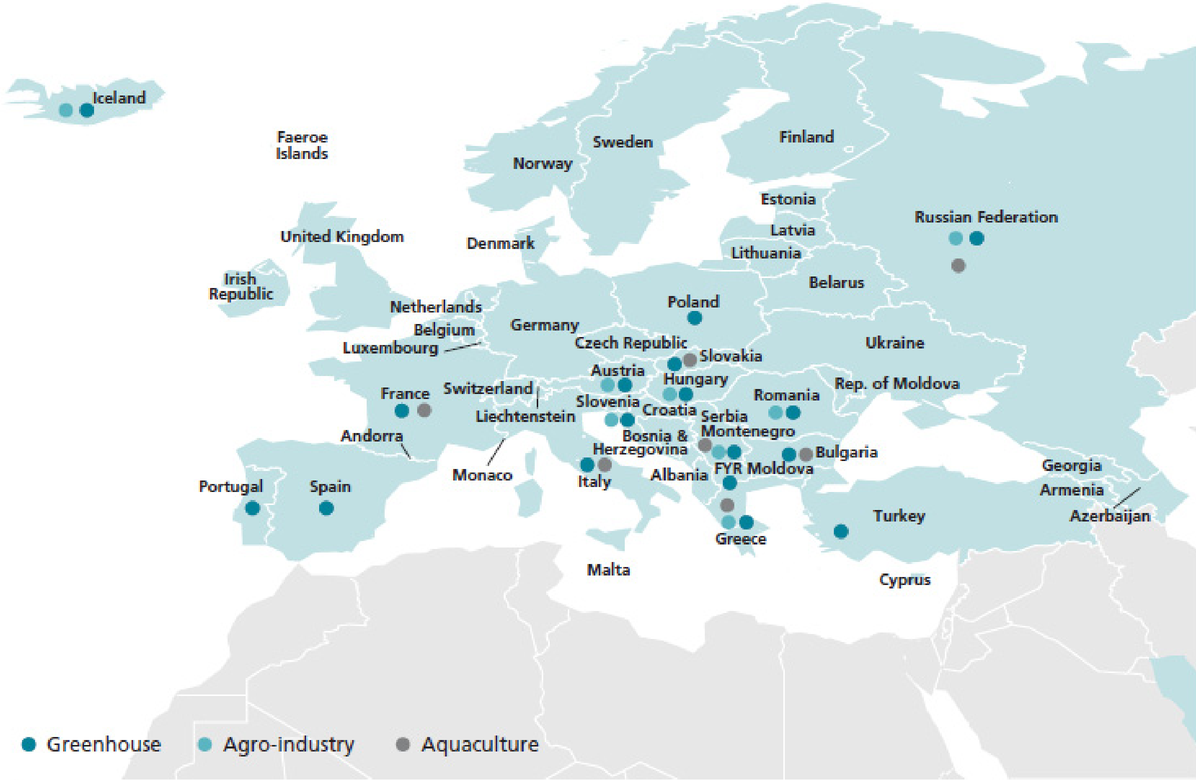



FIGURE 17: Different agribusiness applications from European countries (Van Nguyen et al.,

#### 2.3.1 Greenhouse heating

Agricultural products as vegetables, flowers and crops have been planted in greenhouses with geothermal system heating. Especially in cold climates with difficult geographies, greenhouse heating is favourable for vegetables such as; cucumber, tomato and lettuce which are growing best in the temperature range of 15-30°C (Lund, 1996).

Geothermal heating systems recover the geothermal energy, convert it to heat in greenhouses, and offer an economical future payback. Energy conservation, environmental heat controlling and other inside-building controlling systems effects this situation. Particularly by reducing heat loss to a minimum, it is possible to provide economic profit rates in a shorter time in geothermal supported greenhouses than in greenhouses heated by other energy sources. Heating systems in greenhouses are generally classified as two separate systems based on the principle of air and fluid circulation. The air flowing through the pipes buried in the soil first heats up with the heat of the ground, and then causes the greenhouse temperature to increase as it moves through the greenhouse. In the fluidized system, hot fluid will increase the greenhouse temperature while circulating through the pipes.

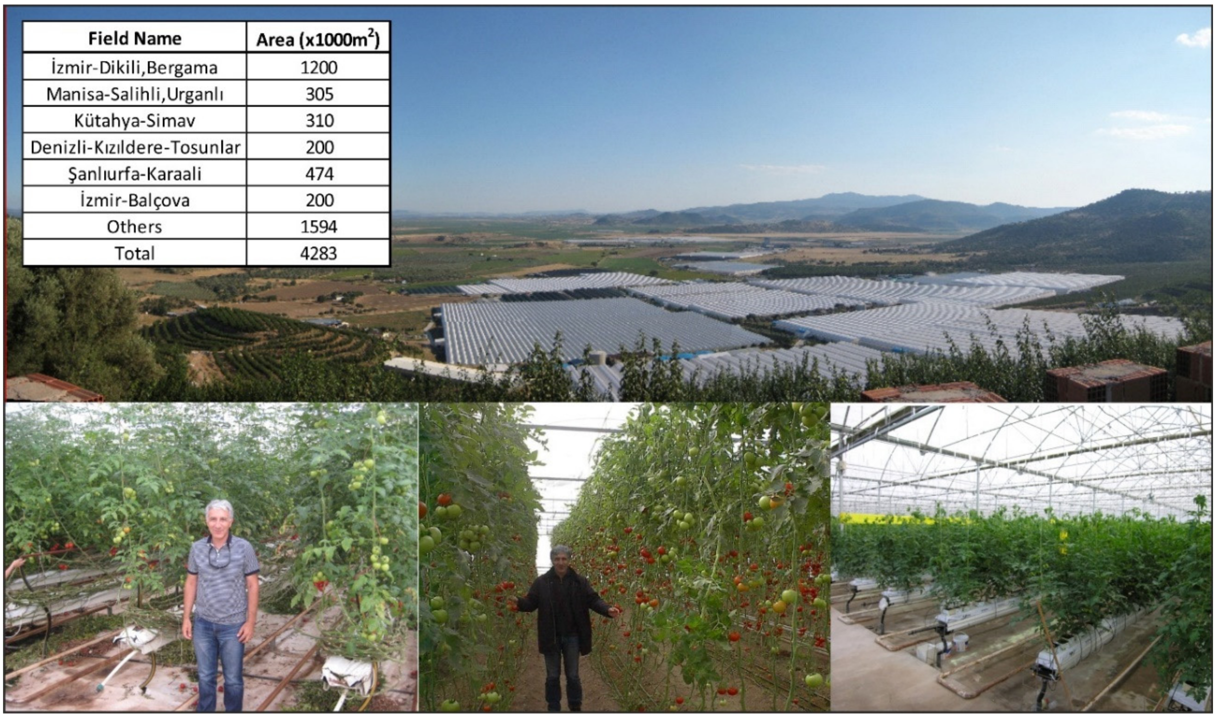
Fluid-containing systems have two different types called open and closed loop systems. The solution in closed loop systems never comes out of the pipes. During the circulation of the solution, it switches between the water tank and the heat pump. In some regions, the pipes come back to the system instead of heat pumps by heating deep inside the small natural lakes and ponds in the region. Such systems provide more economical solutions than heat pumps. In open loop systems, water from a well or power plant outlet is used to increase the temperature of the closed greenhouse environment by circulating through the pipelines in the greenhouse with its own temperature or underground heat. The water used in these systems is not returned to the system, either stored in a tank or pond or re-injected to the aquifer through the re-injection well.

Greenhouse construction may be considered to fall into one of the four categories which are glass, plastic film, fiberglass or similar rigid plastics and combinations. Glass greenhouses are the most expensive to construct. In many cases, fiberglass panels are employed on the side and end walls of the structure. Plastic film greenhouses are the newest variation in greenhouse construction techniques. All these types of greenhouses can be seen in different part of Turkey.

Nearly 34 countries use geothermal energy to heat agricultural greenhouses. Turkey, Hungary, Russia, China and Italy are among the countries that apply the most greenhouse heating. Geothermal resources decrease the fuel costs by about 80% and total operating costs by 5–8% (Duffield and Sass, 2003) and include better hygiene, air and water protection. While production around the world is concentrated on vegetables, flowers and fruit, in greenhouses of Turkey tomatoes and peppers are main crops while fruit species, strawberry (160,026 MT) and banana (172,006 MT) are the two species grown in plastic houses (Tüzel et al., 2015).

The greenhouse heating applications in Turkey mainly concentrated around the Western Anatolian region. İzmir (Dikili-Bergama-Balçova), Manisa (Salihli-Urganlı), Kütahya (Simav) and Denizli (Kızıldere-Tosunlar) are the most important regions for greenhouse applications with geothermal heating (Figure 18). Agrobay in Dikili region is one of the biggest greenhouses in world (Figure 19).

FIGURE 18: Geothermal greenhouse in Simav Region



| Field Name | Area (x1000m$^2$) |
|---|---|
| İzmir-Dikili,Bergama | 1200 |
| Manisa-Salihli,Urganlı | 305 |
| Kütahya-Simav | 310 |
| Denizli-Kızıldere-Tosunlar | 200 |
| Şanlıurfa-Karaali | 474 |
| İzmir-Balçova | 200 |
| Others | 1594 |
| Total | 4283 |

FIGURE 19: Geothermal greenhouse heating applications from Turkey (Dikili, İzmir)

Greenhouse heating applications are carried out in 4.3 million m$^2$ area today (820 MWt). Geothermal Power Plant Investors Association (JESDER) announced that 165 hectares of greenhouses will be built in Manisa, Aydin and Denizli. The overall investment is expected at EUR 132 million to build greenhouses. In addition, geothermal greenhouse development has started in Kirsehir province. The project is developing a greenhouse on 477 hectares of land in Karakurt village of Kirsehir.

### 2.3.2 Aquaculture

Geothermal fluid is used to heat freshwater in heat exchangers or is mixed with fresh water to obtain suitable temperatures in colder climates or close to markets where alternative heating sources are not economical (Boyd and Lund, 2003). The use of geothermal energy in fish farming protects the fish stock against cold weather and increases fish production (Gelegenis, Dalabakis and Ilias, 2006). Aquaculture is a form of isolated human-controlled environment where aquatic species (catfish, shrimp, lobster, oyster, fish etc.) can easily live and reproduce. Temperature of geothermal water offers these species to grow up and feed more optimal conditions and shorter time. By temperature controlling the growth rate of the fish can be increased by 50 to 100% and for this reason the number of yearly harvests are also increased with integrating geothermal energy. Nearly 25 countries have been integrated geothermal sources to the aquacultural activities. China, USA, Italy, Iceland, and Israel lead the direct use of geothermal energy in aquacultural applications such as Tilapia, salmon, trout, tropical fish, lobsters, shrimp, and prawns farming (Ragnarsson, 2014).

Aquaculture activities pave the 4.5% of whole direct usage of geothermal energy all over the world. However, in Turkey, although there are many geothermal resources, aquaculture and fish farming applications are limited and only freshwater fishing is widely available. By making use of geothermal resources for aquaculture activities in the regions where the water supply are not sufficient. Hisaralan (Sındırgı-Balıkesir) is an exemplary area for the use of hot water in the fish-farming. Hisaralan thermal springs are used in aquarium ornamental fish farming. In Hisaralan, thermal waters are used for heating the water supplied to the pools (Polat, 2018). Aquarium ornamental fish breeding started in 2007 by taking advantage of thermal resources in the field. The activity is carried out in four glass greenhouses with a size of 30 × 12 m$^2$ with a closed area of 1,500 m$^2$. Hot water is not supplied directly to the ponds because it contains harmful substances for aquarium fish and affects fish life negatively. Since the ideal

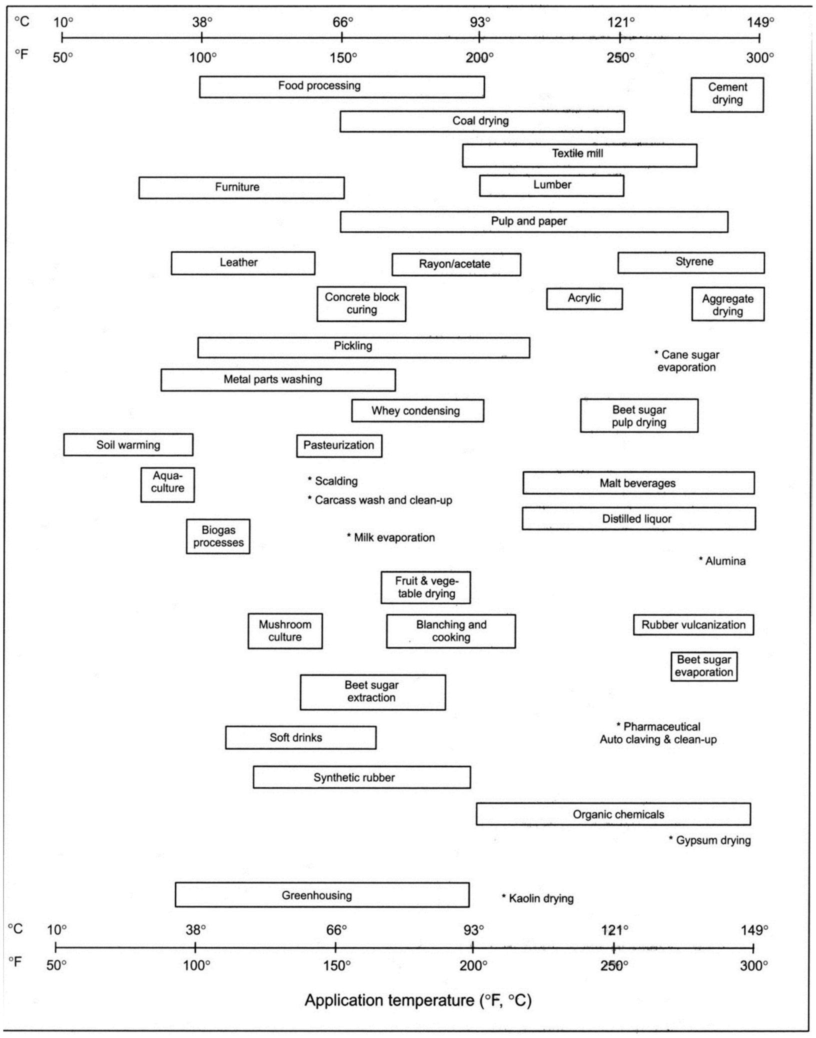



FIGURE 20: Temperature range for some industrial processes and agricultural applications (Jóhannesson and Chatenay, 2014)

water temperature for aquarium ornamental fish is around 24°C, ponds are kept constant at this temperature and fish production is carried out (Polat, 2018).

The most important project planned for the near future is the facility to be established in İzmir. For the first time, shrimp, lobster and fish will be grown in geothermal fields of Balcova thermal facilities. The shrimp, lobster and fish cultivation are planned within the scope of this project which will be the first example of the implementation.

## 2.4 Industrial applications

Industrial applications encompass a rather wide range of industrial activities requiring fluid at low to medium temperature for instance to preheat, wash, evaporate, distillate or dry. Typical applications are presented in Figure 20 (Jóhannesson and Chatenay, 2014). There is a broad range of industrial applications that may use geothermal resources. Conventional industrial processes that utilize heat can in many cases be used with minor adaptation in a technically efficient and economically feasible way.

### 2.4.1 Drying

Agricultural industries are using geothermal drying applications to preserve a growing range of foods (Senadeera et al. 2005). The main idea is to reduce energy consumption by using renewable energy resources for agricultural drying, and low- to medium-enthalpy geothermal resources are the best option (Ogola, 2013). Drying can benefit from the water and steam of geothermal wells or outlet water of plants by using heat exchanger. The air is heated by the hot water or steam and is then blown into the drying chamber for the drying process. Geothermal drying products such as fig, water-melon, pear, date, and peach from Turkey are increased each year (Figure 21).

Kirsehir Municipality and the Special Provincial Administration cooperation, with the support of Ahiler Development Agency established in the town of Karakurt with the support of the first geothermal vegetable and fruit drying facility began to operate.

Geothermal power plants located in the Aegean region of Turkey. This region, where grapes, figs and many important agricultural products are grown, is actually a very important region for the direct use of geothermal resources. Fresh fruit production outside of Turkey is an important country in the dried fruit sector. For example, in dried figs field it is the world leader in Turkey. By 2014 dried fig exports (to EU, Russia, Far East and Arab countries) had risen to 76,000 t, worth 253 million US$ (Arpacı, Konak and Çiçek, 2018). The integrated and cascade systems to be installed with geothermal power plants located in the nearby areas during the drying process have the potential to increase the cost and efficiency. At the same time, such investments will change the perspective of the local people towards geothermal. In addition, vegetable production in Turkey has reached serious proportions. However, there is not much investment in drying. As it can be seen from the table of vegetables that can be dried for the months shown in the Figure 22 with important moisture and temperature levels, it would be very beneficial to develop different applications related to vegetables and low temperature geothermal resources in Turkey.


FIGURE 21: Geothermal drying products from Turkey

### 2.4.2 Other applications

Most geothermal plants are relatively clean, but the limestone-rich reservoirs in Turkey lead to high carbon emissions. It is therefore careful to check $CO_2$ emissions for all power generation and if necessary to include capture of geothermal $CO_2$ in the project design. It has already four GPPs have capture and sold $CO_2$ for food and beverage industries (Table 5). Also, $CO_2$ can be usefully applied to increase urea production or in greenhouse. If $CO_2$ is used from GPPs for these purposes, it is possible to improve greenhouse gas balance of the whole value chain:

- Reducing the industrial waste;
- Powder material;
- Salt production.

TABLE 5: Liquid $CO_2$ and dry ice production factories are integrated to the GGPs in western Turkey

| No. | Company | Power plant | Location | Prod. capacity (ton/day) | Production |
|---|---|---|---|---|---|
| 1 | BM | Gümüşköy GPP | Aydın-Germencik | 25 | Liquid $CO_2$ |
| 2 | Linde | Kızıldere GPP | Aydın-Germencik | 360 | Liquid $CO_2$ |
| 3 | Linde | Dora I GPP | Aydın-Köşk | 100 | Liquid $CO_2$ |
| 4 | HABAŞ | Dora II GPP | Aydın-Köşk | 300 | Liquid $CO_2$ |

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| cabbage<br>cauliflower<br>mushroom<br>radish<br>zucchini | broccoli<br>cabbage<br>cauliflower<br>mushroom<br>zucchini | artichoke<br>asparagus<br>broccoli<br>lettuce<br>mushroo<br>m<br>radish<br>spinach | asparagus<br>cabbage<br>endive<br>radish<br>rhubarb<br>root<br>spinach | asparagus<br>celery<br>tomato<br>cress | melon<br>sweet<br>corn<br>onion<br>cucumb<br>er<br>haricot<br>vert<br>peas<br>pepper<br>marrow<br>s | cabbage<br>melon<br>sweet<br>corn<br>cucumber<br>dill<br>eggplant<br>haricot<br>vert<br>okra<br>pepper<br>watermelon | tomato<br>beet<br>cabbage<br>carrot<br>sweet<br>corn<br>cucumbe<br>r<br>dill<br>eggplant<br>melon<br>pepper<br>marrows<br>tomato | broccoli<br>carrot<br>cauliflower<br>sweet corn<br>cucumber<br>dill<br>greens<br>melon<br>okra<br>onion<br>pepper<br>squash<br>tomato | broccoli<br>pepper<br>squash | broccoli<br>cabbage<br>cauliflower<br>eggplant<br>mushroom<br>squash | mushroom |

| Vegetable name | Drying the moisture level at the start | After drying, the moisture level | Highest allowable drying temperature(˚C) |
|---|---|---|---|
| pea | 80 | 5 | 65 |
| cauliflower | 80 | 6 | 65 |
| carrot | 70 | 5 | 75 |
| green beans | 70 | 5 | 75 |
| onion | 80 | 4 | 55 |
| garlic | 80 | 4 | 55 |
| cabbage | 80 | 4 | 55 |
| pepper | 80 | 5 | 65 |
| okra | 80 | 20 | 65 |
| tomato | 96 | 10 | 60 |

FIGURE 22: Varieties of vegetables that can be dried per months and important levels of moisture and temperatures for drying (Başak, Madakbaş and Gürdal, 2014)

## 3. CONCLUSION

Turkey has 347 geothermal areas and about 600 natural hot springs which have surface temperatures above 30°C degrees. Electricity is produced in 12% of these areas, while heating is used in 43% and thermal use in 45%. Approximately 153 sites have 18 districts heating and two facilities have drying. In direct use, the installed capacity is 3,322.3 MWth. About 450 geothermal fields have been discovered in Turkey. The main direct geothermal applications are district heating, greenhouse heating, thermal facilities and hotels, balneological, drying, cooling and heat pump applications. Constantly evolving technology, along with research and projects, it is estimated with increasing geothermal power plant in Turkey will increase the number of direct geothermal utilization.

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## LECTURE 3

# ENVIRONMENTAL PROBLEMS OF GEOTHERMAL RESOURCES


### ABSTRACT

Geothermal is an environmentally friendly energy source. Geothermal development over the last fifty years in the world has shown that it is not completely free of impacts on the environment. The environmental impacts are projected to limit the use of this needed energy resource. Environmental impacts of geothermal sources are projected for the low demand. Generally, the chemical composition of each geothermal field is quite different from the others because of the complex lithology, tectonics and volcanic activity. Geothermal fluid is highly mineralized with high concentrations of arsenic (As), boron (B), cadmium (Cd), and lead (Pb), resulting in scaling and corrosion. In areas where no reinjection is performed, the discharges of geothermal resources are causes soil and water contamination. Therefore, the implementation of standards-compliant re-injections will ensure the elimination of significant environmental impacts. In parallel to developing geothermal energy applications in many countries such as Turkey, many sites experience problems associated with waste geothermal fluid disposal. Particularly, the uncontrolled discharge of geothermal fluid that is rich in arsenic, boron, lithium and other toxic elements into water resources of the area influences other potential uses of these resources.

As the primary products used in electricity production are natural gas and coal in Turkey. In total, there are 320 natural gas and 42 coal power plants. Turkey began to evaluate renewable energy sources because of energy independence of country, climate change and environmental problems of fossil fuels. Turkey has 347 geothermal areas and about 600 natural hot springs, which have surface temperatures above 30°C degrees. Electricity is produced in 12% of these areas, while heating is used in 43% and thermal use in 45%.


## 1. INTRODUCTION

Energy is seen as an indispensable factor in creating a rich, peaceful and independent country in the world. The importance of energy in economic development has been universally accepted. Besides, the historical data points to a big relationship between energy availability and economic improvements. Industrialization and technological development are causing the consumption of energy to rally in the world (Kaygusuz, 2003). In the light of potential benefits of improving energy efficiency, the world has seen the diffusion of new techniques and know how among countries, which is expedient, because consumption of energy is still foreseen to increase significantly in the incoming years. The world's population is expected to grow by nearly two billion people, therefore to amount to about 9.2 billion by the year 2040 (UN-DESA, 2017**)**. While the global middle class is expected to almost double in the same period (Kharas, 2017). A larger population, combined with global GDP growth, forecast to grow on average by 3.4% annually (IMF, 2015). Therefore, energy resources and their efficient use is one of the most disputable issues today. These prospects can directly affect countries and their policies as well as larger-scale issues such as global warming and climate change. Increasing population and accelerating industrial activity are known to cause climate change due to global warming. Greenhouse gas emission is purported to be a prominent factor contributing to changes in the global climate (Özçağ, 2004). With increasing energy efficiency policies, there are many research and development projects in which countries can rapidly increase the demand for energy and electricity and reduce associated carbon emissions.

Energy sources exist in various forms and reserves around the world. Some resources are limited, while others are considered renewable. The energy obtained from fossil fuels known to have limited reserves (oil, natural gas and coal) accounts for approximately 70-80% of the total amount of energy. In the current market structure, a direct transition to renewable energy will be costlier. If renewable technologies continue to increase their market share, they need to consider the sustainability of existing fossil fuels for some time (Blazquez et al. 2018).

Fossil fuel's global climate change contributions lead the world to want to replace them with renewable energy sources to reduce the amount of global $CO_2$ emissions. Since approximately 1850, the global use of fossil fuels has increased to dominate energy supply, leading to rapid growth in carbon dioxide ($CO_2$) emissions (SIO, 2019; Figure 23). $CO_2$ concentration is reached 410.38 ppm in the world. Current data confirm that the consumption of fossil fuels accounts for the majority of global anthropogenic greenhouse gas emissions. The high concentrations of $CO_2$ have been measured in China and the USA (Figure 24). As well as having a large potential to mitigate climate change, renewable energy can provide wider benefits. Deployment of renewable energy such as geothermal energy has been increasing rapidly in recent years. Numerous types of government policies, the declining cost of many renewable energy technologies, changes in the prices of fossil fuels, an increase in energy demand and other factors have encouraged the continuing increase in the use of renewable energy.

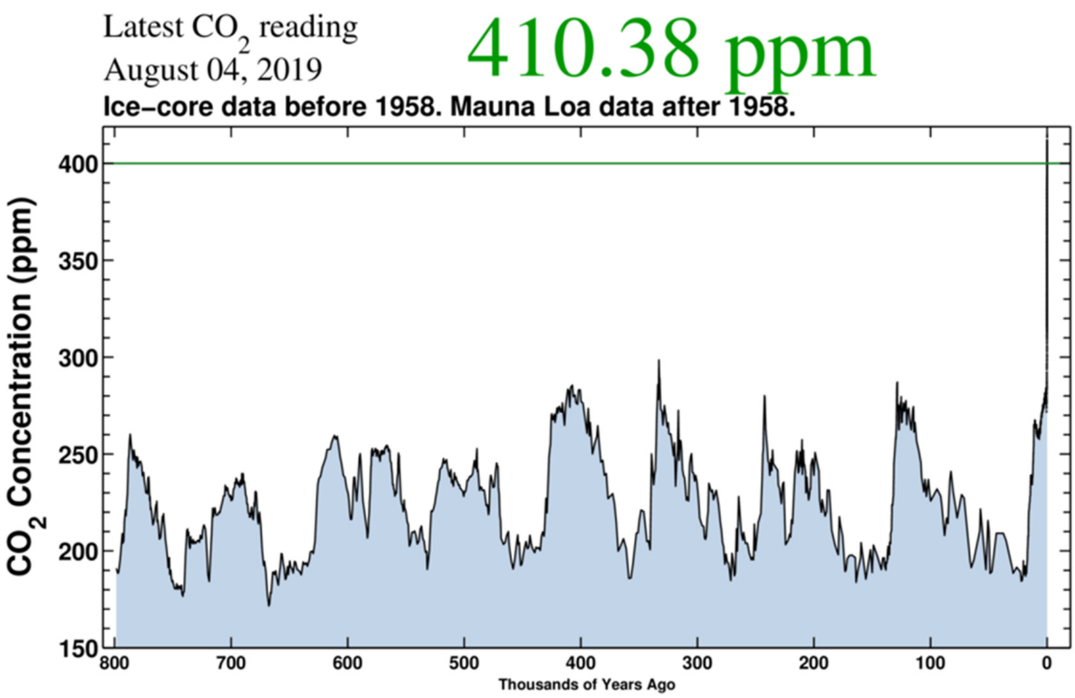


FIGURE 23: The latest reading value and concentration of $CO_2$ change (SIO, 2019)

Geothermal systems are mostly fluid containing systems with a meteoric origin while rainwater drains deeply and heats up to the surface. The heat source, reservoir, cover rock and fluid circulation are the main components of the system. The heat source which provides the heating of the fluid circulating in the underground geothermal system and located in the depths of the earth's crust; may occur due to a young volcanic and/or tectonic activity. Another important factor in the formation of geothermal systems is the reservoir rock, which is composed of porous and permeable rocks where underground water can be stored. The porosity of the reservoir rock indicates how much fluid it contains, while the permeability determines the velocity of the produced fluid. According to the studies conducted to date,

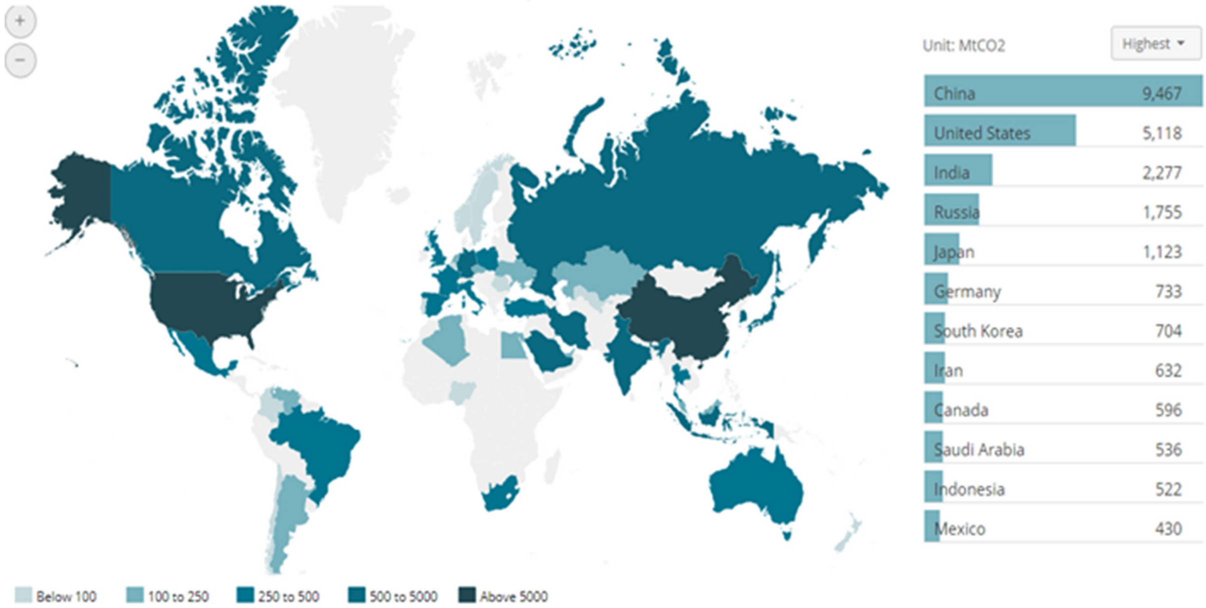


FIGURE 24: Change of concentration of $CO_2$ in top twelve counties (Enerdata, 2019)

most of the hot and mineral waters on the earth are meteoric origin waters. Juvenile waters rising from the depths of the earth mix with water leaking from the surface in different environments and regions in different proportions and form the third kind of hot and mineral waters. These are called mixed waters. Since the waters that make up the geothermal fluid are formed by meteoric and juvenile origin or a mixture of both, the reservoirs in the crust of the earth are continuously fed and the source can be renewed.

The potential of a geothermal field is directly related to a water supply. Precipitation and the waters participating in geothermal systems are in constant interaction with surface waters, groundwater and circulating water. This shows that geothermal resources, which are clean and renewable, should be used with caution. Otherwise, it will be inevitable that geothermal fluids will mix into drinking and utility water. In this case, Reinjection is the most important process of geothermal power production and defining as; not sending them back to the environment and sending them back to the underground after use to feed the reservoir. Therefore, reinjection is a procedure to be performed. Reinjection has been made compulsory by law in many countries.

Geothermal energy has many advantages over other types of energy, making it more important in the future. Geothermal is a more environmentally friendly and clean resource compared to other energy sources. Most of the countries want to develop clean and environmentally friendly combustion technologies to create a near-zero emission for use in residential, in agriculture, in industry, in greenhouses and similar areas are suitable for multipurpose heating applications. Geothermal energy is a renewable resource and more independent upon weather fluctuations and climate changes. Geothermal resources are available 24 hours a day, 7 days a week. However, the evaluation of the applications during the construction and operation phases in terms of environmental impacts should be done.

## 2. ENVIRONMENTAL EFFECTS

Environmental effects can be roughly classified as physical and chemical effects. All these effects can be directly effective, but in some geothermal systems, cumulative effects arising from geothermal and other environmental factors can be observed. Therefore, when evaluating each effect, all components that affect the system should be considered and the effects and results should be examined in detail.

### 2.1 Physical effects

Such impacts are more pronounced especially before the project starts. The most important of these impacts are the impacts during the preparation of drilling, construction of road accesses, platforms and pipelines. Besides, subsidence, seismicity and noise are the most important environmental effects during the operation of the plant.

#### 2.1.1 Land use and scene pollution

The visual pollution during the construction phase consists of earthmoving tools and materials and other materials stored at this stage. In the processing stage, scene pollution is composed of the pipelines and operating building of the power plant. It is quite small in terms of usage area and operation building compared to coal, nuclear, solar and hydraulic power plants. However, pre-operation errors prevent this situation. Plant buildings have to be built nearby the geothermal reservoir and well because fluid transport and circulation are distance-dependent. Cooling towers, electrical switchyard, and pools are other buildings in the geothermal power plant area. During operation, facilities such as training areas, national parks and technology research centres and geothermal power plants can be easily integrated. It is known that in some plants, where we can see some examples, pipes and other plant components are painted or camouflaged in harmony with the natural background. Such improvements reduce visual pollution. They are also small but effective improvements that prevent people from being at the forefront of geothermal power plants and attracting reactions.

#### 2.1.2 Subsidence

Subsidence is most commonly thought of like the slow, downward sinking of the land surface. Fluid withdrawal from the geothermal reservoir results in a fluid volume and pressure drop in underground strata and reservoir. Fluid withdrawal can damage facilities such as roads, buildings and irrigation systems, pipelines, well casings and plants. Subsidence can occur as a result of the extraction of natural gas, petroleum, geothermal fluids and also natural processes. In these cases, a reduction in reservoir pore pressure dangerous for the reservoir and the cover rocks and buildings in the populated areas.

Sedimentary units where the porosity and permeability are controlled by rock grains, re-injection can successfully solve the problem of subsidence. Natural subsidence most frequently takes place in volcanic and tectonic regions. Secondary fractures affect the subsidence in these areas and also in areas where sedimentary basin cover unit are composed of unconsolidated material. Subsidence occurs in areas where the reservoir rocks are porous sedimentary or pyroclastic formations. Although, it is too difficult to differentiate the natural and human-made subsidence from each other in such geological environments. Also, another undetermined problem is whether the subsidence is caused by the removal of the geothermal fluid to the surface or the change in pore pressure during re-injection.

Subsidence evidence has been seen all around the world and especially for high-temperature fields. Wairakei-New Zealand, Cerro-Prieto-Mexico, Larderello-Italy and The Geysers-USA are important examples of subsidence events (Hunt, 2001). Most of the situations experienced in these regions are due to groundwater level changes and collapses due to the fluid occurring underground due to lack of reinjection.

#### 2.1.3 Seismicity

Earthquake activity, or seismicity, is a result of the activity of faults in tectonically active zones. An earthquake occurs when ground ruptured and forms seismic waves that shake the ground. Seismicity has at times been induced by human activity, including the development of geothermal fields and natural activities. These low-magnitude seismic activities named “micro-earthquakes” which are earthquakes with Richter magnitudes below 3.

Human activities can cause induced seismicity in many different ways such as geothermal energy production, hydrological engineering applications, mining, injections, petroleum and natural gas extraction processes and hydraulic fracturing processes in enhanced geothermal systems. The fluid pressure in discontinuities reaches a critical value above which the friction preventing fault slip exceeds and this situation results in activity along with rock bodies. But slow movements generally unnoticed unless sensitive seismometers are located in the geothermal field.

Some recent studies conducted around the geothermal plants in Turkey regarding micro-earthquakes are available. Uytun et al. (2019), evaluated production and re-injection data and seismic data by considering geological and tectonic characteristics (Table 6). In this analysis, seismic activity around the geothermal wells drilled for re-injection was followed and it was concluded that earthquakes 1-3 magnitude may be related to geothermal activities. However, no direct relationship was found between pressure, flow rate and earthquake magnitude of injected fluids. In addition to the re-injection process, micro-earthquakes were observed during the hydraulic fracture process that may occur due to the re-activation of existing faults. According to AFAD (Republic of Turkey Ministry of Interior Disaster and Emergency Management Presidency) data, the epicentre depth of earthquakes varies between 2-10 km. Most of the earthquake epicentre depth is between 2-7 km at the intersection of the Holocene and Quaternary fault zones and reservoir levels, and more activity is estimated in the regions where the Quaternary faults are dense (Figures 25 and 26).

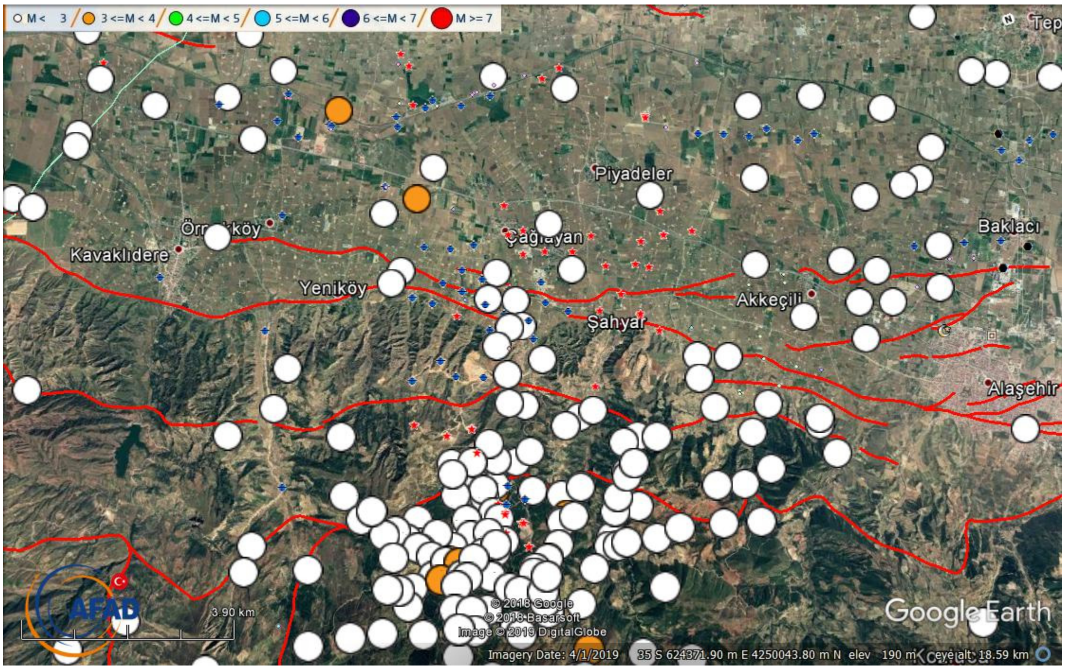


FIGURE 25: Earthquake epicentres (circles), geothermal wells (stars) and active faults (red curves) in Turkey (Uytun et al., 2019)

TABLE 6: Geothermal sites and maximum observed magnitudes of earthquakes (Uytun et al., 2019 – uses decimal comma)

| Geothermal Site & Power Plant | Capacity (MW) | Date of Operation Starting | Injection Depth [m] | Daily Average Injection ($m^3$ / day) | Seismicity | Largest Earthquake [ ML ] | Reinjection Site |
|---|---|---|---|---|---|---|---|
| **Soğukyurt** | 23,52 | 2017 March | 1500-3700 | 15000 | Large | 3,4 | Gediz Graben Detachment Fault |
| **Alkan-Piyadeler** | 48 | 2015 September - 2016 October | 1300-2700 | 50000 | Minor | 2,1 | Alaşehir Segment |
| **Çeşneli-Şahyar** | 45 | 2015 October | 1000-1900 | 45000 | Moderate | 2,2 | Alaşehir Segment |
| **Kemaliye** | 24,9 | 2016 May | 700 - 3400 | 35000 | Minor | 1,4 | Northern Graben Fault |
| **Örnekköy** | 10 | 2017 June | 2000-2500 | 12000 | Minor | 1,6 | Alaşehir Segment |

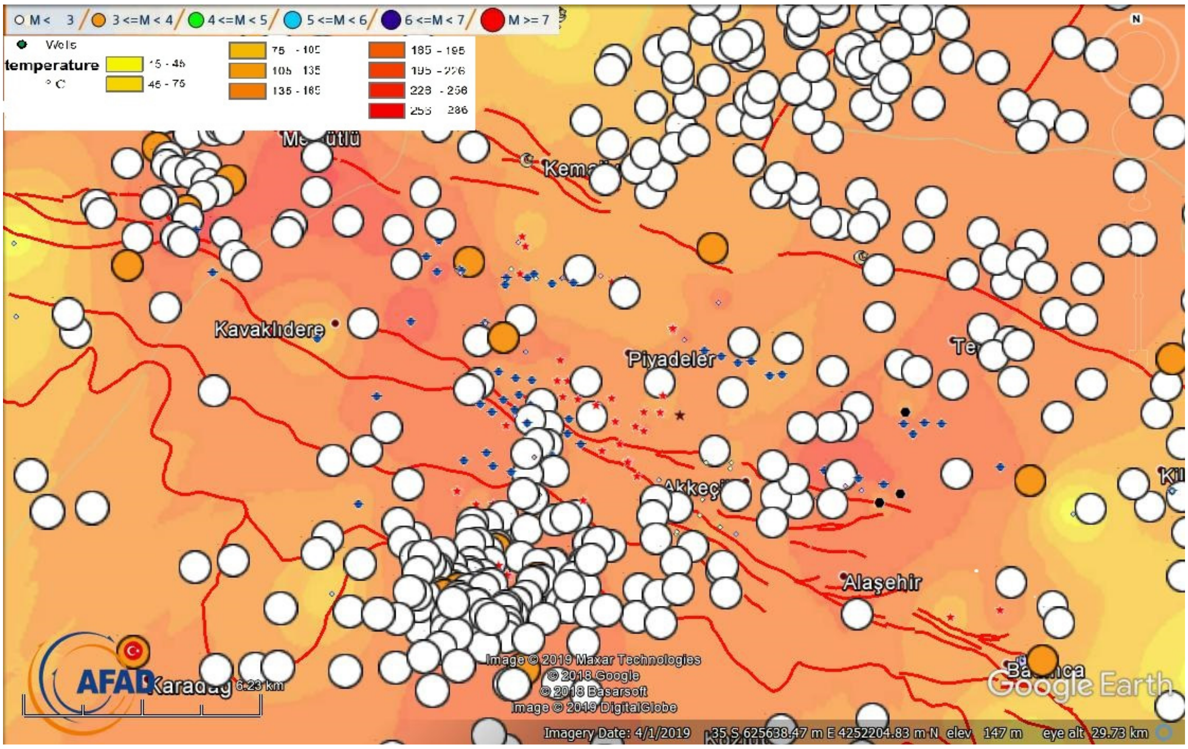

FIGURE 26: Earthquake epicentres, geothermal wells and bottomhole temperature (Uytun et al., 2019)

Production and re-injections of geothermal fluids are generally concentrated in five different regions and all of the sites except the Kemaliye area have high-temperature values. Seismic activity is higher in faults in these important areas and most of them are active (Figure 26).

Re-injection data were obtained from geothermal investment companies and Manisa Governorate Investment, Monitoring and Coordination Directorates. In the region known to have existed in the past, 233 out of 500 earthquakes between 1990 and 2018 occurred between 2016 and 2018 (Figure 27). Most of the geothermal wells were drilled between 2011 and 2015, and injection tests and shots may have triggered seismicity. Before geothermal fluid production and re-injection, the reservoir pressure which was locally at 5 MPa levels decreased to 1-2 MPa with production. This also affected the flow rate and re-injection pressure, and changes in partial carbon dioxide pressure were determined. Since 2017, the decline in re-injection pressure has led to a decrease in seismicity (Figure 27).

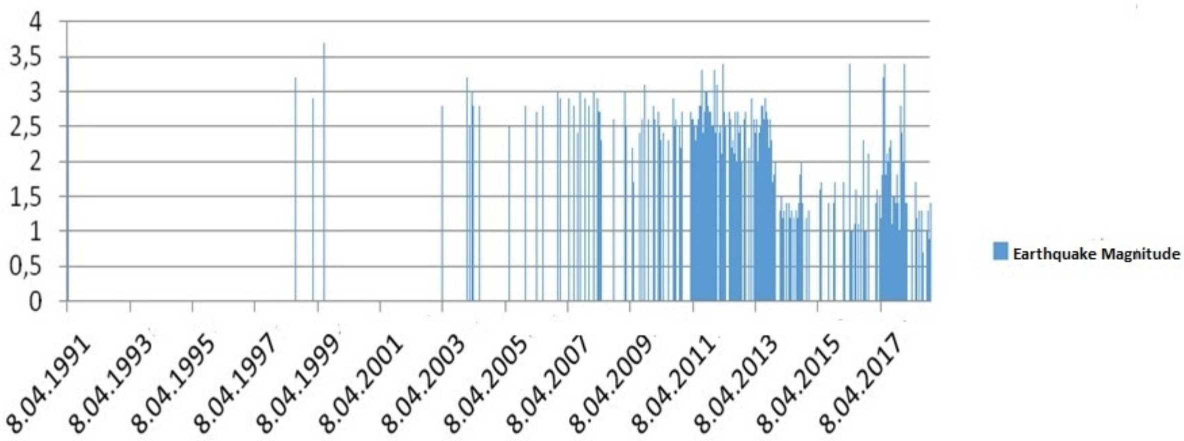


FIGURE 27: Observed earthquakes magnitudes in the Gediz Graben between 1990 and 2017 (Uytun et al., 2019)

### 2.1.4 Noise pollution

Decibels (dB) are a measurement of sound and environmental studies are usually measured in decibels A-weighted (dBA). Common sound levels weighted A-weighting refers to an electronic technique that simulates the relative response of the human auditory system to the various frequencies comprising all sounds. People react according to the nature of the sounds they can hear. While stimuli such as sounds of nature do not cause overreaction, sounds such as mechanical-machine work sounds can cause sudden or long-term reactions, psychological effects and restlessness. Such situations are often seen in the vicinity of heavy construction sites, industries, production plants and explosion operations.

TABLE 7: Major noise sources of geothermal power plants with other reference sounds (modified from Hunt, 2001)

| Noise sources | Sound level (dBA) |
|---|---|
| Geothermal standard operation | 15-28 |
| Whisper | 35 |
| Residential noise | 40 |
| Geothermal construction | 55 |
| Geothermal well drilling | 54 |
| Human voice | 60 |
| **Vacuum cleaner** | **70** |
| Mud drilling | 80 |
| Well bleeding | 85 |
| Earth moving-construction site | 90 |
| Car horn sound | 100 |
| Well testing with silencers | 7-110 |
| Discharging well | 100-120 |
| Air drilling | 120 |
| Well testing without silencers | 140 |

The construction phase is one of the noisiest phases of geothermal energy production, but even construction noise generally remains below the 65 dBA and that is accepted as a temporary noise impact until the construction ends. The well-drilling and testing phase of geothermal development generally does not exceed the noise regulations but they continue for 24 hours per day and all week. However, well-drilling operations typically take place 24 hr./day, seven days a week. In Table 7, the general noise scale was given with geothermal activities. As seen from the sound level scale, the most important phase is well testing, drilling and discharging applications. Sound silencers are more important for such operations because they reach levels that are critical for both the environment and human health. Noise during discharge can be reduced to about 85 dB using a traditional silencer and to 65-70 dB with a rock muffler (Landsvirkjun, 2001).

### 2.1.5 Thermal pollution

Some changes occur in natural processes with discharge to the streams. When high-temperature fluids meet cold surface waters, more active vapour formation occurs (Figure 28). In some cases, precipitations may occur due to fluid content. The easiest way to identify such pollution in the vicinity of power plants is steam in streams. If excess heat enters the environment via geothermal steam it may affect cloud-weather conditions, the health of animals and aquatic species.

For example; Nesjavellir Plant (Iceland) is located near Lake Thingvallavatn, warm water of the power plant is discharged into parts of Lake Thingvallavatn. The water temperature in the lake is about 4-5°C. But after the start of electricity generation temperatures in the lake at the discharge were raised to 13-26°C (Wetang´ula and Snorrason, 2003). This situation causes sudden changes in the receiving ambient temperature, especially after uncontrolled discharge and the destruction of aquatic life. As a result of the thermal load created by the discharge exceeding the carrying capacity of the system, the complete disappearance of the aquatic life or the change of form is the most common effect.

In river beds, especially in the ecosystems associated with freshwater lakes, when the fluids containing heavy metals and elements that may show toxic properties are released, environmental adverse effects on fauna and flora may occur. Apart from hot water plants such as thermal mash, bacteria and some algae species, many species are adversely affected by hot water input. Sudden and continuous temperature differences are critical in freshwater environments because the time interval of the fishing seasons, the wildlife cycle, the presence of creatures that prefer a certain temperature range (eg trout,

FIGURE 28: Effect of geothermal fluid on soil and water resources

frog, crustaceans, shrimps), oxygen-nutritional support are shaped directly in the control of temperature change. The uncontrolled release of geothermal wastewater not only affects living organisms, but also negatively affects freshwater and transitional plants, the most important link in the food chain.

**2.2 Chemical effects**

Turkey has geologically complex lithologies, volcanic and tectonic properties. This situation creates different compositions of the chemistry of the fluids in geothermal areas (Figure 29). For example, in high-temperature fluids in Gümüşköy area (Aydın), higher mineralization is observed because the dominant ions are $Na^+$, $K^+$ and $Cl^-$ and $HCO_3^-$. On the other hand, mineralization of low-temperature Argavlı and Sazlıköy springs (Aydın) is lower due to the predominance of $Ca^{2+}$, $Mg^{2+}$ and $HCO_3^-$ (Baba and Sözbilir, 2012). Although the thermal waters have $Na^+$-$Ca^{2+}$-$HCO_3^-$ type in Turkey, $Na^+$-$Cl^-$ water type has emerged as a result of marine initiatives in more coastal environments in Western Anatolia (Mutlu and Güleç, 1998; Baba and Sözbilir, 2012).

In Paleozoic marbles, Mesozoic recrystallized limestones and Tertiary carbonates, as a result of the water-rock interactions of groundwaters, geothermal fluid chemistry has significant concentrations in terms of $HCO_3$ (Mutlu et al., 2014; Mutlu and Güleç, 1998). Salts in Turkey (Çanakkale), Seferihisar (Izmir), Gülbahçe (Izmir) and fountain (Izmir) geothermal fluid in the areas can be classified chemically as 95% encrusting. In three of the 140 geothermal areas, the total dissolved solids (TDS) concentration in the geothermal fluid is above 5,000 ppm. This can lead to serious usage problems, corrosion and environmental effects (Baba and Ármannsson, 2006; Gemici and Filiz, 2001; Mützenberg, 1997).

In essence, uncontrolled discharge of geothermal fluid with high dissolved element and gas components and thermal differences is known to have a significant impact on the environment. Today, with the developing geothermal industry in Turkey, and not only the waste disposal as well as geothermal fluid

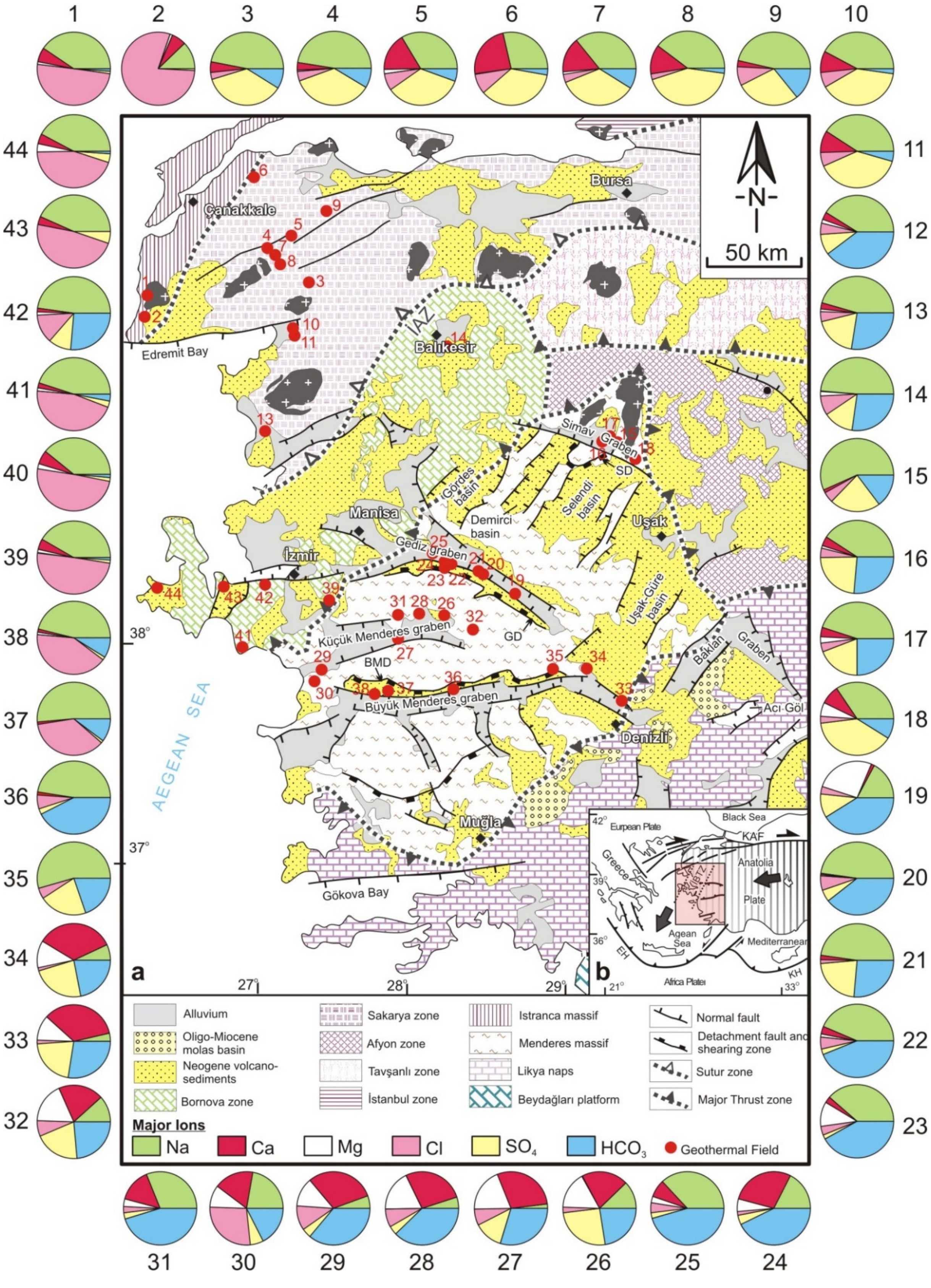


FIGURE 29: Map of western Turkey and location of geothermal areas (Baba and Sözbilir, 2012)

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contamination in an explosion during a drilling in the Gediz Graben in Western Anatolia. Geothermal fluids produced as a result of the accident show that water resources affect grape fields and groundwater resources where agricultural irrigation is frequently used (Baba and Murathan, 2013). Although not in the short term, the concentration of some heavy metals such as boron and lead has increased in the groundwater resources in the region in the long term (Baba, 2015).

Geothermal fluids include non-condensable gases and dissolved solid particles, the amount of which increases with temperature. Non-condensing gases are mostly carbon dioxide ($CO_2$) and varying amounts of hydrogen sulphide ($H_2S$), ammonia ($NH_3$), nitrogen ($N_2$), hydrogen ($H_2$), mercury (Hg), boron vapour (B), radon (Rn) and methane ($CH_4$). Although $CO_2$ gas has a global effect due to the greenhouse effect, the effect of $H_2S$ discharge is local and depends on topography, wind direction and land use (Gökçen, 2001). Although gas emissions are very important environmental factors, there are no problematic emissions in geothermal power plants other than water vapour (in the case of controlled and correct operation). In the field observations, it is determined that the main problem for geothermal power plants is the release of waste geothermal fluid to the environment when information and monitoring data are obtained from the inhabitants and the public. In fact, the most important chemical effects occur with a discharge of well and cooling water wastes to nature without taking precautions. Therefore, this hot fluid has a significant effect on the soil, the flora and fauna and the cold water resources of the region.

### 2.2.1 Air pollution

From an environmental perspective, the most important pollutant gases are Carbon dioxide ($CO_2$), Hydrogen sulphide ($H_2S$), Ammonia ($NH_3$), Mercury (Hg) and Boric Acid ($H_3BO_3$). Geothermal energy is considered a “climate-friendly” technology due to the low emission rates of carbon dioxide ($CO_2$) and other greenhouse gases and geothermal power plants emit $CO_2$ lower than fossil-fuel combustion power plants. Additionally, closed-cycle binary geothermal plants produce zero greenhouse gas emissions. Carbon dioxide harms human health and it has also a greenhouse effect for global warming and climate change. In power plant system $CO_2$ can be released in the water and vapour phase as $H_2S$.

Geothermal power plants in Turkey are concentrated in grabens in western Anatolia. The Büyük Menderes and Gediz Grabens are the most important structure for geothermal systems in Turkey. These grabens and basins are fault-controlled. High-temperature (150-240ºC) resources located on grabens and region has important geological properties. The alteration and water-rock interactions between fluids and carbonates are a major source for the $CO_2$ content in western Anatolia (Table 8). Paleozoic metamorphics, together with gneisses and schists, form the geological basis in the form of massifs in Western Anatolia. Ophiolitic units and clastic-carbonates covering the geothermal systems are located on these units. Limestones in the basement and cover units are generally considered as geothermal reservoirs (Şimşek, 1985). The younger Neogene and Quaternary basin fillings also serve as a cover rock that creates pressure in the system. This situation is similar in general terms for Anatolia. In addition, dense volcanism is another important controller on the system around Eastern Anatolia. Hot water outlets, as well as $CO_2$ and $H_2S$ outlets, can be observed along with the caldera, volcano and dyke systems.

TABLE 8: Non-condensable gas compositions of selected geothermal systems in Western Anatolia (Haizlip Robinson et al., 2013)

| *Geothermal Field* | *Reservoir gas/steam (kg/kg)* | *$CO_2$ %* | *$H_2S$ %* | *Ar %* | *$N_2$ %* | *$CH_4$ %* | *$H_2$ %* |
|---|---|---|---|---|---|---|---|
| Kızıldere Deep Reservoir | 0.030 | 98.7 | 0.021 | 0.01 | 0.67 | 0.56 | 0.025 |
| Germencik | 0.021 | 98.5 | 0.21 | 0.001 | 0.44 | 0.70 | 0.035 |
| Alaşehir | 0.034 | 98.5 | 0.20 | 0.004 | 0.40 | 0.80 | 0.07 |

$CO_2$, which is dissolved in water under reservoir conditions, is a gas that should not be neglected due to the problems and benefits it creates during the operation of the field. The most important problem it creates is the calcite deposition in wells and surface equipment during fluid production from the reservoir. Despite the calcite problem it creates, it is also beneficial to have $CO_2$ in the reservoir with pressure changes during the production phase.

$H_2S$ is the other important pollutant in the geothermal systems. Some plants adapted to convert geothermal based $H_2S$ to elemental sulphur. But $H_2S$ is still an important problem for geothermal non-condensable gases. Steam and flash type power plants have $H_2S$ production but binary type plants produce nearly zero $H_2S$. Fossil combusted power plants are a major source of the $H_2S$ and $SO_2$. When plants emit $SO_2$, breathing is a big problem for asthmatic people and it has also temporary effects on health such as illness and wheezing. There is no direct $SO_2$ release from the geothermal power plants, but the released $H_2S$ then converts to $SO_2$, causing air pollution. At one plant in Kizildere, Turkey, the non-condensable gases are scrubbed of $H_2S$, and the $CO_2$ recovered to provide around 80% of the $CO_2$ used by the country's soft drinks industry (Baba and Ármannsson, 2006).

### 2.2.2 Water pollution

Geothermal fluids contain large quantities of carbonates, silica, sulphates and chlorides, as well as chemical contaminants such as lithium, boron, arsenic, fluorine, hydrogen sulphide, mercury, lead, zinc and ammonia. As the fluid exits to the surface, dissolved $CO_2$ in the well passes into the gas phase and leaves the liquid phase. During this time, calcium carbonate ($CaCO_3$) precipitation occurs in the production well. This is an important problem in areas with high non-condensable gas. The problem seen during reinjection is the precipitation of silica ($SiO_2$) due to the decrease in fluid temperature. Where the geothermal fluid is discharged into a river or lake, these pollutants have the potential to harm water organisms, plants and/or human health. Discharge of high salt waters also has a negative effect on water quality (Baba, 2004; Baba and Ármannsson, 2006; Gökçen, 2001; Baba and Sözbilir, 2012). The vapour condensing in the post-turbine condenser typically contains a high concentration of $H_2S$, Hg, $NH_3$, and less B. As a result, these pollutants are found extensively in the cooling water discharge (Gökçen, 2001).

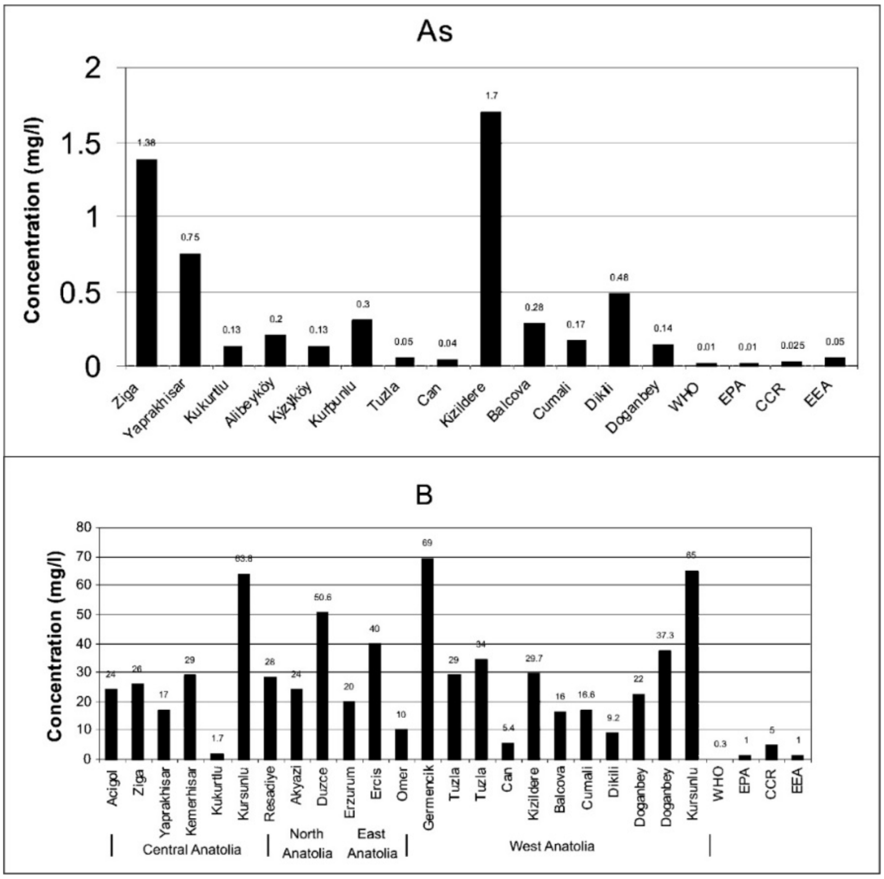


FIGURE 30: Concentrations of As and B in geothermal waters from different parts of Turkey and comparison of these with the maximum permissible drinking water concentration (Baba and Ármannsson, 2006)

One of the most important issues in Turkey is geothermal fluid with a high concentration of arsenic and boron (Figure 30). In geothermal steam systems, boron occurs as boric acid. It has high solubility easily dissolve in the steam condensate around the cooling tower. There are new studies about boron emission-reducing from geothermal fluids. The geothermal fluids in western Anatolia especially in Kızıldere-Denizli have high boron concentrations. The thermal wastewater from the Kizildere geothermal area contaminates the Büyük Menderes River too. The supply of produced wastewater to the rivers near the site creates agricultural problems. Such environmental problems can also be solved by reinjection. Generally, B concentrations are high in thermal fluids in Anatolia and it has a relation with volcano-sedimentary units and degassing of magma intrusive.

Other trace metals such as As, Hg, Cd, Cu, Cr, Pb, and Zn have not generally been determined in geothermal fluids in Turkey, although As was determined in water from Alibeyköy (Canakkale), Kızılkoy (Balıkesir), Kukurtlu (Bursa), Cumali-Seferihisar (Izmir), Doganbey-Seferihisar (Izmir), and Balcova (Izmir). Arsenic is a gray, crystalline solid, but can be form compounds with other elements. Arsenic comes from the volcanic and magmatic processes. It affects human health (sore throat, irritated lungs, abnormal heart rhythm) and defined as a carcinogen.

Most harmful chemicals are generally found in solution in the fluid outside the plant. Apart from re-injection processes, these chemicals may produce high concentrations in certain areas in cases such as a discharge to the creek, blow-out accidents. It mixes with streams, lakes, drinking-water basins and starts to affect the natural life. Life in the river and lake basins is badly affected. The chemicals accumulated in the basin sediments are then mixed into the groundwater through processes such as natural or well drilling, and gradually begin to affect human life. Blow-out events are an accelerated version of this process. Fluid emitted by blow-outs can be evaluated as a catastrophic event due to excess pressure. For example, in a blow-out event in Alaşehir-Manisa, local people and their grape farms were affected in a way that could not be repaired (Figure 31).

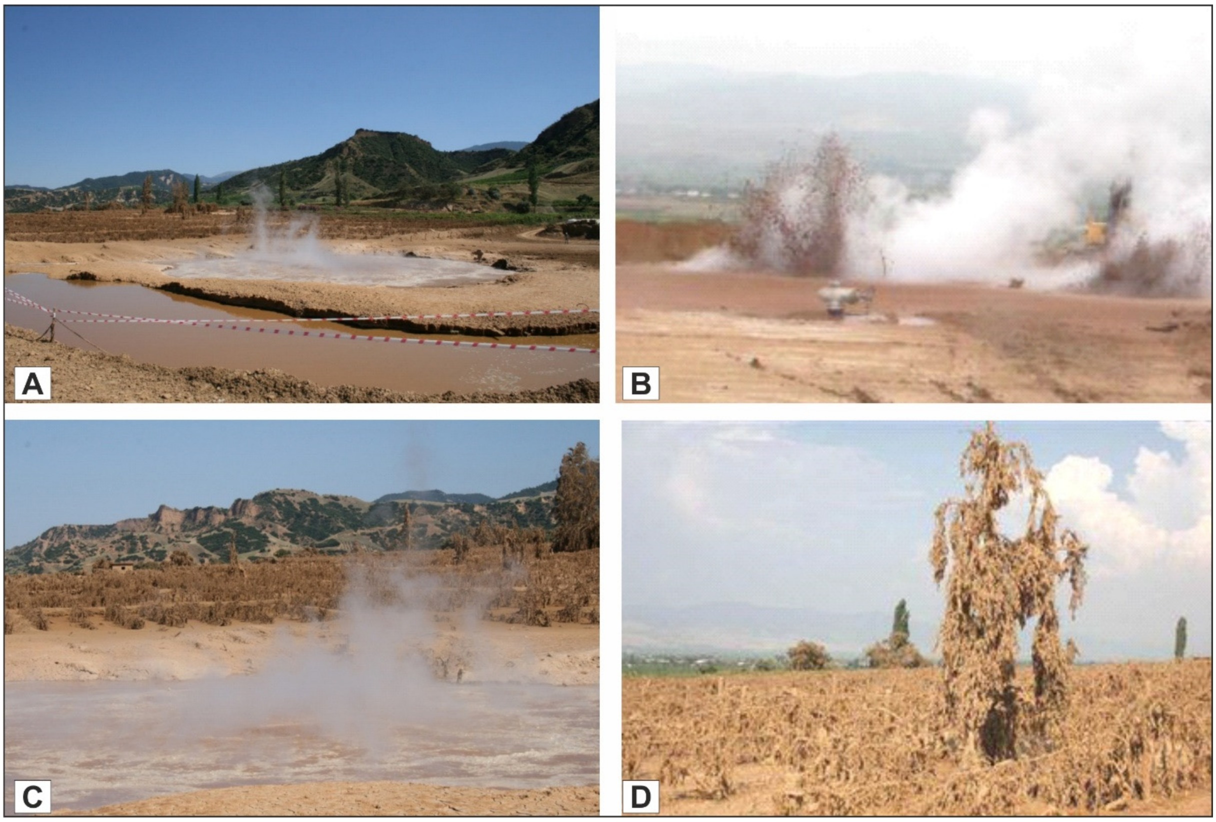


FIGURE 31: Blow-out event in Alaşehir; A) Blow-out site; B) Blow-out event; C) After scene of blow-out; and D) damage on grapes on agricultural site

### 2.2.3 Corrosion and scaling

One of the most important problems in our country is that geothermal boreholes are not designed correctly according to the engineering properties (Figure 32). Therefore, such material decay and collapse in a short time. In this case, the hot fluid is transported to the cold water sources and deteriorates the chemical properties of the cold water sources. Nearly all geothermal waters of Turkey have significant scaling and corrosion potential (Battocletti, 1999; Mutlu and Güleç, 1998). Geothermal fluids are saturated with silica and are typically close to saturation with calcite, carbonates, silicates and metal sulphides. The reduction of temperature and pressure during production lowers the solubility and causes prodigious precipitation known as scaling (Demir et al., 2014). The production of thermal fluids causes several problems in western Anatolia. Scaling appears especially at depths between 550 and 70 m in wells with mainly calcite scaling, but in the upper part of the well aragonite dominates (Giese, 1997; Giese et al., 1998). Carbonate scaling caused problems in the beginning of the operation phase, and the production wells have had to be cleaned.

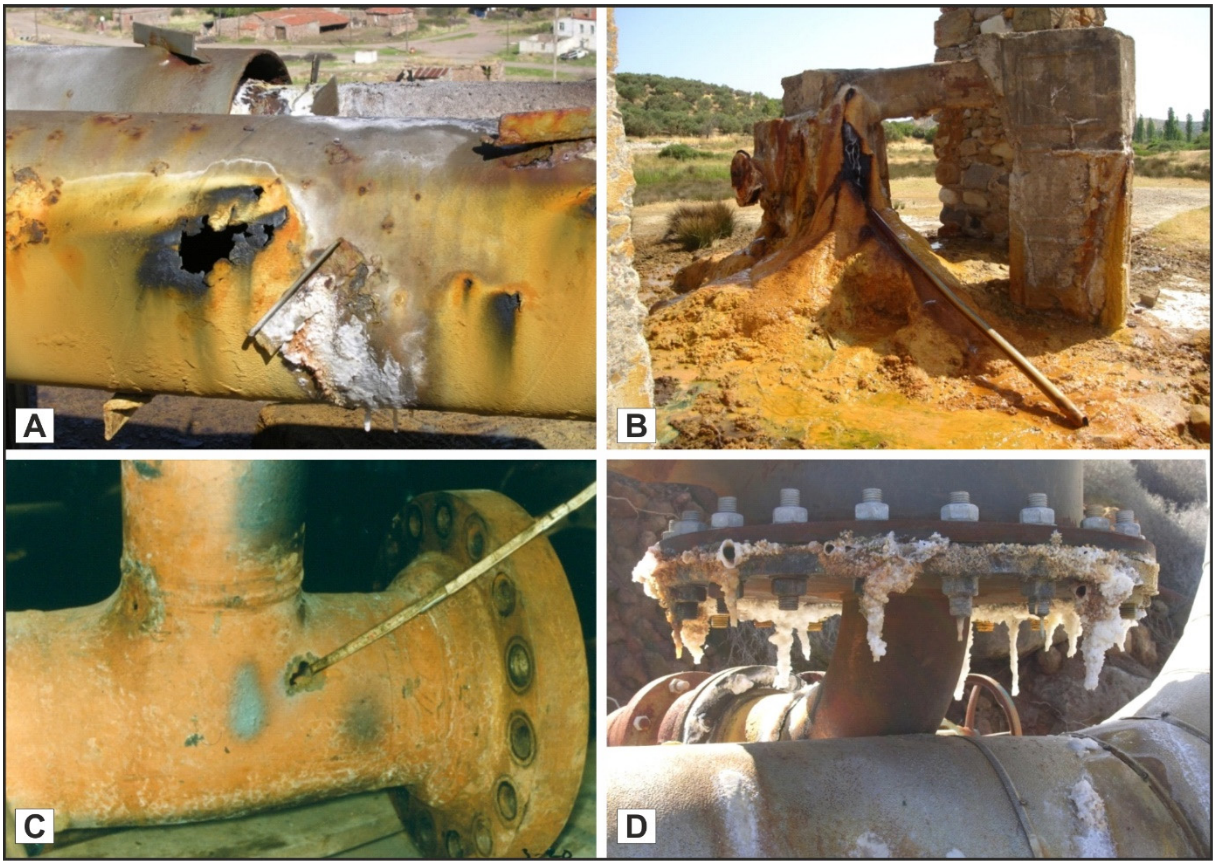


FIGURE 32: Examples of scaling (B and D) and corrosion (A and C) from geothermal fields

Geothermal fluids contain chloride ($Cl^-$), hydrogen sulphide ($H_2S$), carbon dioxide ($CO_2$), iron ($Fe^{3+}$), copper ($Cu^{2+}$), and ammonia ($NH_3$) that cause significant corrosion in metallic construction materials. For example, geothermal fluid from Kızıldere geothermal field is corrosive due to the pressure of free $CO_2$. The precipitation of calcium carbonate and iron sulphide is favoured in places where corrosion spots have formed. Geothermal fluid from Tuzla and Seferihisar geothermal fields is also corrosive due to the high $Cl^-$ concentration (Baba, 2003). Greenhouses have not been constructed in Kestanbol (Çanakkale) because of the danger of corrosion.

In general, the dissolution process of elements and minerals at increasing temperature values causes geothermal fluid and gas components to cause scaling and corrosion. This situation causes disruptions in production in power plants. Different types of situations regarding scaling in power plants in Turkey are observed. Calcium, aragonite-controlled silica and sulphur are the most common scaling in Turkey (Doğan et al., 2014; Baba et al., 2015). Demir et al. (2014) observed scales in Tuzla geothermal system around the down hole and the surface pipeline. PbS and $CaCO_3$ were detected in the downhole and the surface pipeline. In contrast, sulphide based-scaling was encountered only in the downhole, not along the surface pipeline.

### 2.3 Biological effects

Geothermal development poses only minimal impact on wildlife and vegetation in the surrounding area when compared with fossil fuel plants. However, problems such as wrong-site selection for the power plant increase the effect of geothermal resources on a small amount. Biological effects of geothermal projects; human and animal health and vegetation. Control of these effects can be achieved by setting an upper limit for the level of pollutants that can be discharged into the environment. Negative effects on biological life may be determined above the recommended limit values, with no long or short term effects below these limits. Different criteria are determined for different purposes such as air, drinking water, protection of water organisms, product irrigation, water stock and protection of the aesthetic quality of the environment (IGA, 2000; Gökçen, 2001). Insulating pipelines, not recharging, building fences and protecting nature should be within the scope of operation of the plants.

### 2.4 Socio-economic impacts

Socio-economic parameters may vary depending on the size of the project. Common socio-cultural and economic impacts observed in geothermal projects are listed below (Brown, 2005; Dickson and Fanelli, 1990; Barbier, 1997; Gökçen, 2001).

*Physico-social changes*
- Degradation of landforms, hydraulic balance, aesthetics, cultural/historical sites and impacts on public health.

*Economic changes*
- Increased job opportunities and increased income in return;
- Funds for the benefit of the community through taxes and other agreements;
- Development of lifestyle from rural to industrial/economic location.

*Institutional changes*
- Cultural adaptation;
- Risk of cultural erosion if cultural-economic developments are not well managed;
- Changes in composition and number of population that will apply pressure on a resource basis;
- Aesthetics and effects on people's interests.

## 3. CONCLUSION

Geothermal energy has been widely used in Anatolia since ancient times and the Roman period for different purposes. As a result of volcanic and tectonic activities, more than 1,500 natural geothermal springs have emerged in Anatolia. Their importance was recognized decades ago and geothermal fluids were used for district heating, industrial processes, domestic water supply, balneology and electric power generation. Turkey's installed heat capacity is approximately 322.39 MWe to 2,705 MWt for energy production and direct use, respectively. Although most of the thermal waters are of the $Na^+$-$Ca^{2+}$-$HCO_3^-$ type, the $Na^+$-$Cl^-$ type waters characterize the coastal regions of western Anatolia and show a mixture of seawater and aquifers. Geothermal fluids contain high concentrations of elements and quantities of gas and therefore can be extremely difficult to use in geothermal operations. This situation can cause pollution in surface and groundwater during and after an operation, and monitoring of such environmental problems in soil and water during the production process is very important.

Turkey has 347 geothermal areas and about 600 natural hot springs which have surface temperatures above 30°C degrees. Electricity is produced in 12% of these areas, while heating is used in 43% and thermal use in 45%. In direct use, the installed capacity is 3,322.3 MWth. Especially in Turkey, geothermal research and production some problems that arise during the negativity have begun to experience. This situation leads to a decrease in interest in geothermal but it can be changed with technological ideas and investments, supports and solutions.

Reinjection should be considered an integral part of any modern, sustainable, and environmentally friendly geothermal utilization, both as a method of wastewater disposal and to counteract pressure drawdown by providing continued water recharge. Therefore, reinjection should be used in geothermal fields in Turkey, where heavy metal concentrations of the fluids may be high.

Another technical problem in Turkey is that geothermal boreholes are not designed correctly according to the engineering properties. Therefore, such borings decay and collapse in a short time. In this case, the hot fluid is transported to the cold water sources and deteriorates the chemical properties of the cold water sources. This includes processes such as scaling and corrosion.

Geographical information systems are important for identifying problems spatially. Overlay maps are easy to use and understand and are popular in practice. They are a very important way of showing the spatial distribution of impacts. They also lead intrinsically to a low-impact decision. Therefore, overlay maps should be used in all geothermal fields in Turkey.

Also, the implementation of an environmental impact analysis provides a practical and interesting approach to the understanding and appreciation of the many complexities and uncertainties involved with natural energy sources, health and environmental problems. By this way, all possible environmental effects should be identified, and mitigation measures should be devised and adopted to avoid or minimize their impact. With continued technological development and understanding of current problems, geothermal can be expanded all over the world, environmental geothermal impacts can be reduced. Geothermal energy can provide a clean, reliable, and renewable energy resource for the world.

Today, the benefits of geothermal energy production continue to increase with increasing technology and investments. The most important effect of the developing technology on geothermal is to reduce environmental pollution with new methods to be applied in geothermal fluid and to increase economic gains by obtaining different elements and minerals. As technological developments continue, geothermal resources can be expanded and their environmental impacts can be reduced to almost zero all over the world. Geothermal energy can provide a clean, reliable, domestic and renewable energy source for the world.

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**LECTURE 4**

# IMPORTANCE OF CUMULATIVE ENVIRONMENTAL IMPACT ASSESSMENT FOR GEOTHERMAL RESOURCES

**ABSTRACT**

Geothermal energy is generally accepted as being an environmentally benign energy source, particularly when compared to fossil fuel energy sources. Geothermal developments in the last 60 years, however, have shown that it is not completely free of impacts on the environment. These impacts are becoming of increasing concern, and to an extent which may now be limiting development. History shows that hiding or ignoring such problems can be counterproductive to the development of an industry because it may lead to a loss of confidence in that industry by the public as well as by regulatory and financial sectors. Therefore, The Environmental Impact Assessment (EIA) is used worldwide as an instrument for development planning and control these problems. Before starting, energy application each company should prepare EIA which is set for a single company. But cumulative impacts are the successive, incremental and combined impacts of one, or more, activities on society, the economy and the environment which are a result of the aggregation and interaction of impacts on a receptor and may be the product of past, present or future activities. The Cumulative Environmental Impact Assessment (CEIA), an improved version of the EIA, is an application that covers and covers other similar, existing and planned actions and projects. There are several tools to consider environmental and social risk assessment and management. Therefore, many countries are preparing the CEIA.

## 1. INTRODUCTION

Environmental Impact Assessment (EIA) is the tool most widely used in environmental management. The first EIA process was established in the USA in 1969. EIA has been established in various forms throughout the world, beginning with Canada in 1973, Australia in 1974, Germany in 1975, and France in 1976 and later in other countries too (Thors and Thóroddsson, 2003; Baba, 2003). Many countries have adopted their own EIA procedures. Every country that has developed a process for making Environmental Impact Assessments has given it a different name and some slightly different meaning (Roberts, 1991). EIA is an assessment of the natural, social and economic aspects of the project and possible impacts on the environment. It aims to enable decision-makers to systematically consider, evaluate and mitigate the environmental impacts. There are also types of environmental impact assessment studies with different names and scopes. The most important of these are The Strategic Environmental Assessment (SEA) and Cumulative Environmental Impact Assessment and Management (CEIA).

Strategic Environmental Assessment (SEA) is implemented at an earlier stage than the EIA and on a country-by-country basis, taking into account national impacts (Cooper, 2004). While the EIA assesses project-based environmental issues, the Strategic Environmental Assessment (SEA) includes private and governmental institutions, taking into account the interests of the state, the public and the public. Therefore, all stakeholders and decision-makers are strategically involved in the impact assessment and implementation of decisions from the beginning of the projects. The SEA is used to coordinate sectors, protect interests and formulate national policies that cannot be represented by a single EIA.

Today's biggest environmental challenges are global warming, climate change effects, biodiversity problems, water and food security problems and many similar problems. Human beings can create an impact on nature with all kinds of activities and studies on earth. While these effects will be positive or negative, some results may occur in the long term or short term. Cumulative impacts are the successive, incremental and combined impacts of one, or more, activities on society, the economy and the environment which are a result from the aggregation and interaction of impacts on a receptor and may be the product of past, present or future activities (Franks et al., 2010). The Cumulative Environmental Impact Assessment (CEIA), an improved version of the EIA, is an application that covers and covers other similar, existing and planned actions and projects. Potential environmental and social interactions of the project's impacts should be assessed together with potential impacts from other future projects or activities that are reasonably identified and planned in a geographic area to create a more / less significant overall impact with the project. There are several tools to consider environmental and social risk assessment and management (IFC, 2007).

There are various definitions of CEIA that appear in guidelines, assessment and approval requirements and legal findings. Globally or nationally, no methodology for quantifying cumulative impacts has been established that has gained wide acceptance and methodologies determined according to the scenarios based on scale, context and timing. There are generally 4 different situations for cumulative effects (MCA, 2015);

- The cumulative impact of combined elements of a single project/activity;
- The contributing impacts of a single project/activity on an existing baseline or current health of the system;
- The cumulative impact of multiple projects/activities on a single environmental value or asset;
- The cumulative impact of multiple projects/activities on multiple/all environmental values/assets (with each value/asset assessed separately or by the system).

According to the World Bank and ESMAP (2012), the Cumulative Environmental Impact Assessment (CEIA) is an assessment of these impacts and/or effects. Cumulative impacts occur as interactions--between actions, between actions and the environment, and between components of the environment. These pathways between a source and an effect are often the focus of an assessment of indirect or cumulative impacts. Indirect Impacts or secondary impacts are not directly caused by the activity or project, but the project has a raising effect on the impact and occurs in complex pathways. Cumulative impacts are incremental effects of all activities related to all times combine with the proposed activity. Impact Interactions are the results of reactions between the impacts of proposed projects or other actions (World Bank and ESMAP, 2012).

## 2. BASIC CONCEPTS OF CEIA

The basic concepts of importance in a CEIA are the valued ecosystem components (VECs), area of influence, and limits of acceptable change. All these constitute the main issues in defining the study area, the cumulative impacts, and their significance. Some important definitions are given below:

*Action:* Any project or activity of humanity.
*Assessment framework:* A description of a process that organizes actions and ideas, usually in a step-by-step fashion. Frameworks are an important part of an assessment.
*Effect:* Any response by an environmental or social component to an action's impact.
*Environmental components:* Fundamental elements of the natural environment. Components usually include air, water, soil, biodiversity and natural resources.
*Region:* Any area is under the effects due to the action where may interact with effects from other actions. The initial size of the area related to impact extension.
*Threshold:* A limit of tolerance of Valued Ecosystem Components which include air, water and soil, etc. to an effect, that if exceeded, results in an adverse response by the Valued Ecosystem Components.

### 2.1 Valued Ecosystem Components (VECs)

VECs are the main objects of the cumulative impact assessment process. VECs are defined as any part of the environment that is considered important by the proponent, public, scientists, and government involved in the assessment process (World Bank and ESMAP, 2012). VEC selection should include the following issues: abundance and spreading, species, health, socioeconomic, availability of the database, importance to society in terms of cultural heritage, ecological and natural environment. In several countries such as Turkey, VECs are generally specified as sensitive and protected areas in the national EIA regulations. Water resources, natural habitats, forests, lakes, groundwater and river protection zones, agricultural and ecological areas are some examples of protection zones in Turkey. Cumulative Environmental Impact Assessment for Hydropower Projects in Turkey was done in 2012. In this project terrestrial environment, water resources, flora species, fish species, agriculture, forest, etc. are evaluated (Figure 33).

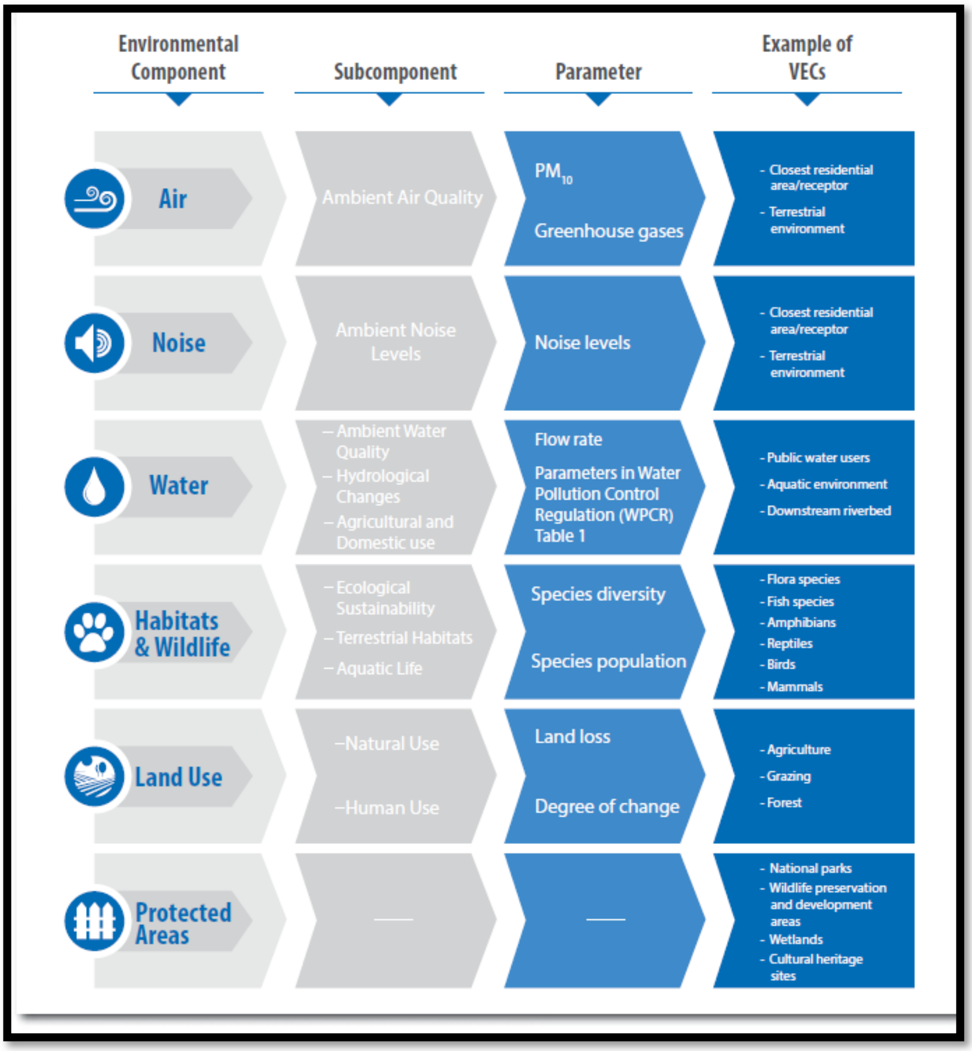


FIGURE 33: VECs for a hydropower project in Turkey (World Bank and ESMAP, 2012)

### 2.2 Area of Influence

Area of Influence (AOI) is the spatial impact area for which the study or assessment would be conducted and considered. Study time, available budget, and data directly affect the boundaries of AOI. Area of Influence is possibly affected by the project and the project owner's activities and facilities; impacts from unplanned, but predictable developments caused by the project, indirect project impacts on biodiversity or ecosystem services (World Bank and ESMAP, 2012).

Boundaries of AOI reflect the potential impacts and potentials of the projects. For example, watersheds are AOI for aquatic VECs while forests are important for ecological VECs. For VEC's with widely distributed impacts, spatial AOI can be selected in terms of population distribution. Another important criterion for selecting AOI is the environmental and geological structures. While investigating environmental effects on water pollution, hydrogeological basin boundaries are a critical element. When working on studies about seismicity, major tectonic structures and fault zones should be taken into account and time-dependent effect and impact changes over these areas should also be considered.

### 2.3 Limits of Acceptable Change (LAC)

Limits of Acceptable Change (LAC) which is also known as a threshold (target, standard, limiting capacity, etc.), are limits beyond which cumulative change become a problem for situation, environment and society. A threshold can be the definition of effect area of the pollutant, its concentration, or buffer zone of a fault segment, the drainage area of the river, a basin, etc. If a total of cumulative effects of studies do not exceed LAC's, that situation, effects and impacts seen to be acceptable and not harmful. But limits and thresholds should clearly define. Regulations and laws are important examples of threshold identification which are very useful for cumulative impact assessment studies (World Bank and ESMAP, 2012).

## 3. MAIN STEPS OF CEIA

CEIA steps are consisting of understanding, defining and responding to the environmental, socio-cultural and economic issues. It should be approached as an iterative process, rather than a one-off activity, and be focused on how to identify, avoid, and mitigate negative outcomes and enhance positive outcomes. Impact Assessments can be predictive or evaluative. They can be focused on assessing impacts at the scale of a project, plan or region (Franks et al., 2010). Besides, laws, permits and country bans are important factors in the study of the CEIA. Drilling, Exploration and Construction phases are the first steps of geothermal energy production. The production phase covers the period in which the power plant operates. In these processes, expropriation, land use, discharge/reinjection zones and well drilling areas are important to project steps that should be planned under current legal requirements.
Geothermal projects are dynamic studies that different from most other projects that have to comply with the EIA act (Albertsson et al., 2010). This project includes some problems such as difficulties in a projection of the reservoir behaviour, reinjection schemes and unknown variables about the geothermal system, facility locations, number of drilling pads, physical and natural effects and changes in geothermal fluid properties.

According to the Albertsson et al (2010) schedule of preparation, exploration, research and engineering design of geothermal power plants are longer than for most other EIA projects and today it is common in Iceland that it takes 10 to 13 years to develop a geothermal greenfield project. Also, along with understanding the geothermal source, project designers have to be prepared plans for the short and long term effects of the project. CEIA studies mainly consisting of five different steps which are scoping, impact assessment, mitigation, evaluation of significance and monitoring, respectively (Table 9).

### 3.1 Scoping

In general, at this stage, taking into account the social and environmental conditions prevailing in the regions affected by the project and the characteristics of the project, it is defined which VECs should be included in the Cumulative Impact Assessment. The completion of the engagement activities of the relevant stakeholders and the determination of the temporal and spatial boundaries of the assessment are examined at this stage. It takes part in this stage in the determination of other projects or human activities

TABLE 9: Generalized main CEIA steps and definitions

| Main CEIA Steps | Definition |
|---|---|
| Scoping | Definition of project activities, identification of area of influence, selection of Valued Ecosystem Components, identification of standards and activities |
| Impact assessment | Baseline of project area and impact assessment of activities |
| Mitigation | Identification of mitigation measures |
| Evaluation of significance | Identification of residual effects and significance |
| Monitoring | Monitoring and management |

that have the potential to have cumulative impacts on the identified Environmental and Social Aspects. The scoping step involves the identification of possible problems, effects, concerns and VECs to supply effective focusing and manageable and practical study for cumulative impacts. Identification and final decisions about VECs and also other studies as methodology, standards and related activities have to be decided. Generally scoping is a process for identifying and selecting the most important factors and items to be examined for detailed assessment. This step should involve an open, participatory, transparent, and meaningful consultation with affected parties (IFC, 2007).

The scoping phase aims to prepare the database for the next steps of the study. The first objective is to determine the scale, timing and focus of the assessment. The second main objective is to determine the factors that will be affected and the actions that will create these effects (Franks et al., 2010). During the determination of cumulative effects, the aim of the study should be determined in detail and clearly. Small and insignificant impacts identified in the scope of the objective may lead to critical situations in the later stages of the study. Therefore, the effects that seem harmless are likely to accumulate over time, causing a larger cumulative problem. The priority sequence of the impacts identified at this stage should be determined. With this sequencing, it is important to develop different alternative options for further study.

Determination of the area of influence is included in the scope determination section. Spatial and temporal boundaries are determined and it is aimed to predict the extent of the cumulative effect. When making estimates, the cumulative impacts of all steps of the project should be taken into account. Future events, similar studies and impacts, long-term project development and planning, developing technology, and different situations that may be related to changing external environmental conditions should be considered within the scope of the estimates.

### 3.2 Impact assessment

Impact assessment progress is starting with scoping analysis but the major concern for the study is the working schedule, budget and size of the investigation area and also affects an area. All of these factors connecting to each other with one major concern the database. Data collecting, processing and reaching all the needed is the major problem in the assessment process. Collected data have to consider all of the effects and VECs so this step has important detailed studies in CEIA. Also, collected data should be determined scientifically and carefully with considering the environmental effects.

Environmental effects can be seen around much larger areas in cumulative environmental impact analysis. Scoping and impact assessment studies should cover this larger area. Although the expansion of the study area raises some problems, such as budget and time, there are some effective and useful applications (GIS studies, spatial information databases, satellite imagery, etc.) to accelerate the work. The methodology and methods used at this stage are quite important and suggested methodologies in the scoping phase should be identified in detail.

### 3.2.1 Assessment methods and tools

While experts carry out the impact assessment study, they can benefit from different methods. However, these methods should apply to all selected VECs. One of the most preferred methods in such studies is the interaction matrix. An interaction matrix is a tabulation of the relationship between two quantities which are often used to identify the likelihood of whether an action will affect a certain environmental component or to present the ranking of various effect attributes (e.g., duration, magnitude) for various VECs (World Bank and ESMAP, 2012). Matrices that provide a results-based representation of observation, analysis, measurement, research, prediction and other studies in the scoping stage are simplified presentation tools that show the cause-and-effect relationship and the importance ranking for possible effects. The action-impact interactions can be qualitatively determined and point ranked (e.g., very low: 1 to very high: 10). And project steps also can be grouped separately with different steps of actions, such as the construction phase and production phase:

*Expert opinions* are based on persons who are persons with scientific and technical experience. Experts can anticipate different problems that may arise in different areas with their existing knowledge and enable them to prevent impacts during the CEIA phase. For example, when examining the impact of geothermal power plants on the environment, geological, environmental and agricultural engineers can make very useful approaches in determining the potential damages of the plants on nature and agriculture.

*Questionnaires-surveys* are another way to identify problems that may be encountered at different stages of the project. Questionnaires to be asked to stakeholders and information to be taken directly in the surveys are very useful in determining the environmental impact. The surveys can be directed to different stakeholders at different stages of the project, as well as providing detailed results regionally and locally. They can be made face-to-face with direct contacts or easily implemented through online portals, e-mails and sites.

*Checklists,* which can be easily applied to ensure that all issues are taken into account, to simplify action-effect based complex issues, to set priorities and to assist in site selection, are practical methods that can be used in CEIA studies.

*Network* association can be used to link action and effect. With indirect and secondary effects, it is possible to see all processes during impact formation in flow charts.

*Models* (conceptual, numerical) are analytical tools that model environmental conditions as if they are real and cause cause-effect relationships to be seen. Models should include detailed data on the action being evaluated. It may include spatial and temporal relations.

*GIS applications* are geographic-based analysis methods used to determine the spatial distribution and interaction of the cumulative effects of different actions. By overlapping the areas where the impact areas, action areas and VECs are located, they can show the effects that may occur with the actions spatially and zoning of data distribution can be made.

## 3.3 Mitigation

The mitigation step of the CEIA process aims to minimize the effects that may occur as a result of actions. This step should include all direct, indirect and cumulative effects of the action. To reach this, mitigation firstly based on local effects and then more regional. Collaboration and cooperation with regional factors, administrations, institutions, stakeholders, and non-governmental organizations are very important for solving and detecting regional impacts and monitoring. In this way, a wide-scale application will reveal hidden effects and different concerns.

## 3.4 Evaluation of significance

It is the evaluation part of the other planned or reasonably defined development activities with the project to determine the interaction power to have a cumulative effect on the relevant VECs. It should be noted that the assessment presented in this section only examines the effects of the project after mitigation. The main purpose of this stage is to identify the problems that may be encountered in advance and categorize them according to their importance and prevent or minimize the damage.

In the evaluation of significance, some limit-threshold values can be very important for the study. In particular, health-related criteria such as the amount and presence of harmful substances that will affect the ecosystem and human life are already limited to certain thresholds in air, water and in most environments. In most countries, harmful substances are controlled by laws and regulations. If no predetermined limit-threshold is available during the assessment, the project consultants are required to determine reasonable and consistent thresholds. Therefore, when making impact-response assessments, the relationships between threshold values and impacts should be carefully determined.

### 3.5 Monitoring

It is important to consider environmental issues in the early stages of the development of geothermal resources and to consider these issues in the design of a power plant. It is very important to start collecting basic environmental information as soon as possible, conduct pre-production analyses and develop scenarios for geothermal fluid properties and composition and usage. A well-designed and well-managed geothermal power plant in terms of environment has little environmental impact. Management weaknesses and accidents cause environmental problems. The monitoring phase is basically how and how natural factors, interactions and how it is performed on the map. The stage at which measurement and monitoring methods are applied can be selected in accordance with the cumulative impact study and purpose. Monitoring should have a specific program for CEIA identification. The responsibilities of project employees and consultants should be based on measures and actions to prevent cumulative impacts.

Monitoring should include situations where the current conditions apply (World Bank and ESMAP, 2012) such as uncertainty about impacts, the effectiveness of the mitigation measures and assessment of the impacts is based on a new method or approach. Some direct and indirect methods can be applied while observing the environmental impact of geothermal power plants. For example, leakage discharge applications from power plants to river beds can be determined by direct measurements on the drainage network of the creek and observation of groundwater interference can be realized with long term tracers. Likewise, sound pollution and image pollution can be achieved through instant measurements and detections (Table 10). However, long-term environment-damaging actions and impacts can only be detected as a result of monitoring over time.

TABLE 10: Sample monitoring programme for one parameter of CEIA for geothermal power plants

| Definition of phase | Monitoring parameters | Monitoring location | Type of monitoring | Monitoring schedule |
|---|---|---|---|---|
| Construction | Noise pollution | Excavation and construction sites | Direct measurement on site | Construction times |
| Production | Noise pollution | Geothermal borehole | Direct measurement on site | All day long |

According to Hunt (2000), the monitoring process in geothermal projects primarily aims to create a detailed database for use by the developer and regulatory authorities. Other important objectives of the monitoring phase are to question the accuracy of the decisions to be taken, to ensure public confidence in environmental, social and health issues and to provide information about geothermal systems with environmental sensitivity.

## 4. ENVIRONMENTAL IMPACTS OF GEOTHERMAL PROJECTS

Due to increasing energy consumption, air, water, and soil pollution will become an important environmental concern for Turkey. Especially in the Aegean region, geothermal power plants, which are concentrated in a certain area, have started to cause some damages to the environment with the increasing number and wrong applications. Many of the known physical and chemical effects of geothermal power plants are the result of incorrect applications. These effects vary in the installation and production stages of the plants. For example, air pollution factors such as dust and particulate matter occur during the construction phase of the power plant, while sound pollution is one of the effects that may be encountered during construction and production phases.

Cumulative impacts are defined as successive, incremental, and/or combined effects of a project or activity, accumulated with other projects or activities. The cumulative impact may be influenced by existing projects, as well as by similar projects already initiated or other projects in the region and other future activities. Therefore, other factors should be taken into consideration when evaluating cumulative effects. There are some identified effects in geothermal power plant applications. Some problems that may affect the environment, social life and health after the construction of the power plant are as follows (Hunt, 2000; Landsvirkjun, 2001; Wetang'ula and Snorrason, 2003; Baba, 2003; Baba and Ármannsson, 2006):

*Cultural and natural heritage*
Cultural and natural heritage are the elements that are at risk in all kinds of human work and projects. However, laws and regulations set many criteria for the protection of cultural assets and natural wonders. Studies related to geothermal energy are also obliged to comply with these laws. Geothermal power plant applications are also intertwined with cultural and natural assets. What is important in such studies is to minimize risk and impact and to be able to determine in advance. Determining the distances of power plants and wells is the most important step at this stage.

*Land acquisition, involuntary resettlement and economic displacement*
During land acquisition procedures, landowners must mutually agree and make agreements. Expropriation-like problems may also occur at different stages. If the research and operation licenses to be obtained for the power plant may be the source of agricultural and economic livelihoods in the region or coincide with the natural protected areas, it is necessary to make detailed negotiations and agreements with the local people. At this stage, it is necessary to cooperate with regional administrations in the interest of the public.

*Community health and safety*
As it is known, geothermal power plants have less health impact compared to fossil fuel power plants. Only incorrect applications and gas emissions such as $H_2S$ are a risk factor for the environment. Undesirable events can be prevented by security measures to be taken in the vicinity of the well and hot fluid central components. Therefore, the interaction between the plant components and the living spaces used by the local people should be minimized.

In terms of safety, the most important areas before operation are drilling wells and the surrounding area. Safety measures should be taken by the enterprise as there may be equipment or pits and wells that may pose a danger in these areas. Incorrect practices that may pose a risk factor should be avoided and necessary precautions should be taken by both employees and the local community. Walking and crossing roads should be arranged, warning signs should be prepared and fence-like measures should be taken to prevent any living creatures from entering the working area (Figure 34). During operation, there may be problems with power plant components. Preventing problems such as corrosion and scaling problems is very important to prevent problems such as unwanted leakage in plant components. Long-term problems such as collapse and seismic activity due to excessive water withdrawal should be monitored and monitored.

*Unemployment*
Local changes in unemployment may occur during geothermal power plant installation and operation phases, depending on company policies. The first job opportunity for the local people in the region where the power plant will be established is found during the construction phase. However, most energy companies have professional teams. Therefore, short-term recruitment outside the construction phase is not observed much. Also, after the installation of the plant, it may be possible to hire workers for

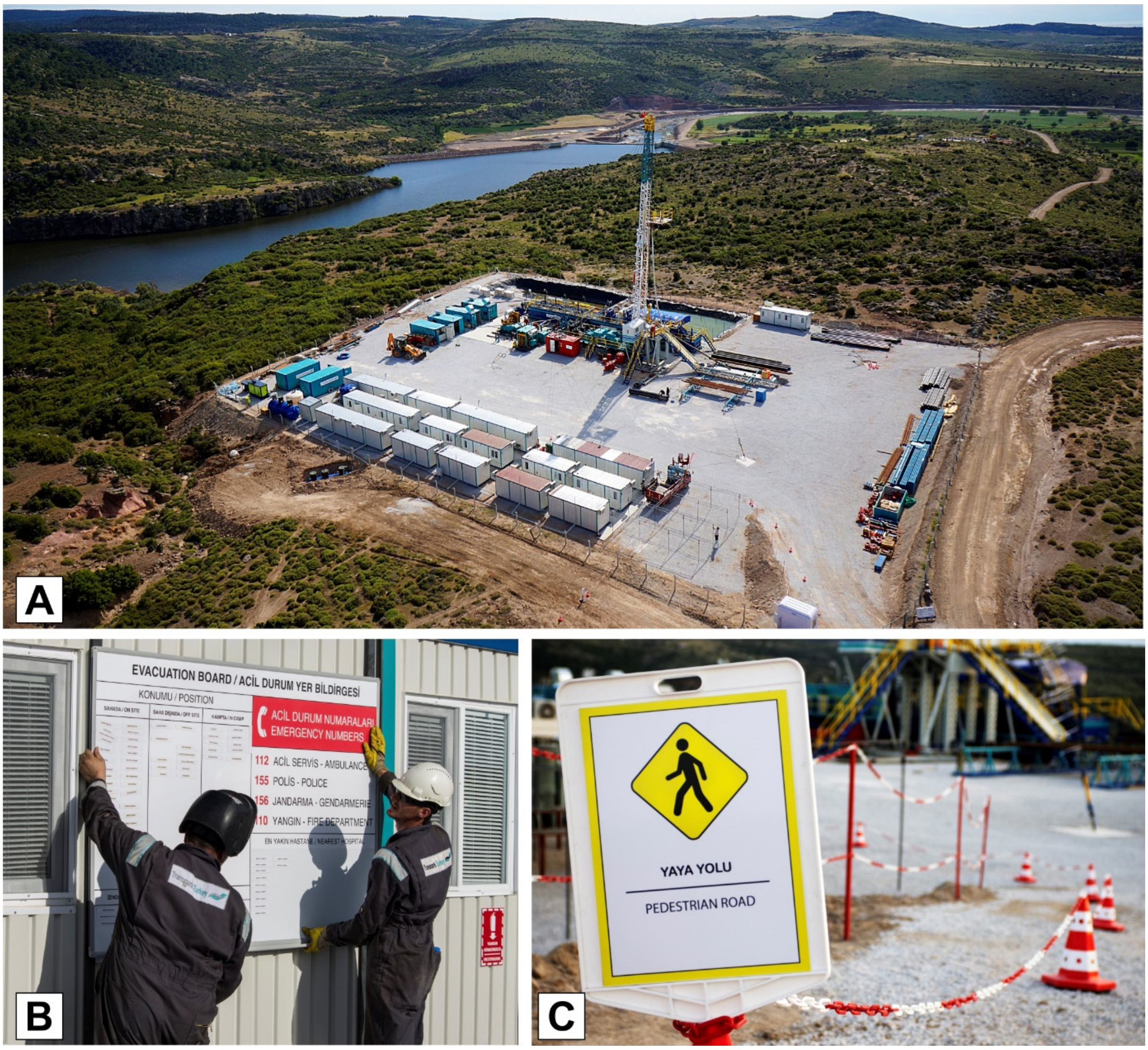


FIGURE 34: Security precautions in a geothermal drilling site; A) Air-view of a typical drilling site; B) Evacuation and warning signs; C) Pedestrian road example (source:Fotokopter-Transmark)

security-like services within the plant. As a result, creating employment is actually at the discretion of power plant companies. Long-term and functional employment can be created by direct applications such as greenhouse production that can be performed outside the power generation after the plant. Thus, an economic and social impact can be created for the region in the long term.

*Waste management*

Waste management in geothermal power plant projects is a task that needs to be planned at different stages. Excavation wastes generated during an excavation in the construction phase cause environmental pollution. Besides detailed plans for reuse and recycling should be made for other wastes that may arise during the drilling sludge operation phase.

*Noise pollution*

During the operation phase, wellhead equipment and generators are expected to be the main noise-generating sources. As the equipment will all be housed in closed spaces, the Project operation activities are not expected to have any noise impact on local communities. Noise pollution would occur during the construction and production phases. One of the most important problems encountered in geothermal power plants is noise pollution. In the construction phase, as in all construction activities, noise from workers and equipment may occur in power plant construction. Noise pollution from the geothermal borehole can be quite high (up to 140 dB as much as the take-off sound of the passenger plane). To cope with this problem, noise reduction measures such as silencer and rock mufflers are available.

*Biodiversity and living natural resources*
In the geothermal well and power plant construction phase, the use of mud and water at the head of the well and the impact on the environment should be minimized and not damaged. Discharges and other wrong practices during operation should not pollute the water and nutrient resources that other living things can use in the environment. In addition, it is necessary to pay attention that the plant areas are not located in the protected areas, designated sites and transition zones of natural life.

*Water resources*
The most important factors of the water issue are supply, quality and contamination-pollution. Some activities that may cause environmental pollution in geothermal power plants. Water pollution can be observed in groundwater or surface water as a result of incorrect applications. Environmental pollution can be experienced in such situations as discharging of geothermal fluid to creeks, lakes or surface waters without leakage, leakage in transmission pipes and wells, insufficient storage and emergency ponds.

Drilling mud and wastewater used during well drilling are discharged to stream beds and surface water resources for a while if there is no reinjection well drilled in the field. Generally, the most important problem is the lack of ponds to collect these wastewaters. With sufficient-volume ponds to be made, the contamination of water resources will be prevented until the time of re-injection wells will be opened. Geothermal fluids accumulated in ponds will not mix with surface water and groundwater, thus avoiding many problems. In addition, emergency pools will prevent similar impacts during operation.

*Air quality*
Gas emissions from geothermal power plants should be within certain limits that are important for the environment and human health as in other power plants. The most harmful gases associated with geothermal systems are $CO_2$ and $H_2S$, while $CH_4$, Hg, Rn, $NH_3$ and B are other gas components with particulate matters that can cause air pollution. Gas emission values of geothermal power plants with lower carbon dioxide emissions than those using fossil fuel power plants vary according to the location, geology and fluid properties of the power plant. Especially in the areas where limestone and carbonate lithology is dominant, $CO_2$ values may be higher. $SO_2$ values have higher concentrations in the plants where geothermal fluids circulating in geological environments generally associated with different mineralization types and volcanic processes are used. In binary geothermal power plant systems, these values are close to zero. Other power plants do not emit $SO_2$ directly, spreading in the air of $H_2S$ causes the formation of $SO_2$.

Particulate matter is used for substances such as smoke, dust and ash which may have different chemical properties. In geothermal power plants, the release of these substances into the air is considerably less than in other power plants. Most of the particulate matter formed during the drilling and construction phase with the release of the dust from the heavy trucks and excavation works. Water vapour, which is not harmful but may affect air quality, is also an element. Water vapour has the potential to affect product quality negatively, especially in critical agricultural areas where fig, grape, etc. production is carried out. It is possible to increase the water vapour effect from cooling towers, especially in cool and cold weather.

*Geology and soil quality*
Road construction works, excavation and cleaning operations during the construction phase are the first activities causing soil degradation. Incorrect applications at this stage may cause problems such as erosion, landslide and collapse in the long term. Heavy metals and other undesirable components in the geothermal fluid that is not reinjected during the well drilling phase pass to the soil. In this case, the chemical can cause soil pollution. The same situation can also occur in the case of direct discharge during operation.

*Visual pollution*
Geothermal power plants have a smaller size and fewer component plants compared to other power plants. High steam chimneys and similar structures are not very common. However, it makes a visual difference according to the environment. In particular, power transmission lines and pipe networks can cause image pollution around the power plant. In some plants, colouring works are performed on the pipes in compliance with the background. Another factor that causes visual pollution is the intense water vapour outflow from the cooling towers. This problem can also be avoided by using condensation techniques.

*Transportation and traffics*
Development and operations would result in additional vehicle trips during the construction phase. During the construction and drilling phase, there will be intensity in transportation in and around the work area in proportion to the number of personnel and construction equipment, but only the number of personnel in operation will affect the traffic problem. Another factor that will affect the traffic and transportation problem is the buildings and pipelines in the power plant facility. Although the power plant building does not create a huge problem, the pipes passing through the fields cause local transportation problems for the local people, especially in areas where there is agricultural activity. Planning the pipeline network considering the needs of the region will eliminate the effects in the long term.

*Land use*
Geothermal power plants have less surface area than the other power plants. The main power plant building, pipe network, well-pads and transportation routes are the basic structures in a facility. The wells can spread in different regions in the license area. The shorter the connections between the wells and the power plant, the less heat loss in the fluid. At the same time, the extension of the plant depends on this. Electrical switchyards and power transmission lines must be present in geothermal power plants as in other power plants.

## 5. CUMULATIVE ENVIRONMENTAL IMPACT ASSESSMENT IN TURKEY

The method and content of the CEIA study have not yet been clearly defined in Turkish laws and regulations. Cumulative impact assessment is a phenomenon mentioned only in Turkish environmental legislation. It is used in the General Format of Environmental Impact Assessment, which forms the Annex 3 of the Environmental Impact Assessment (EIA) Regulation published in the Official Gazette (Official Gazette no. 28784 of 3 October 2013). In 2012, with the support of the World Bank, the Cumulative Environmental Impact Assessment (CEIA) Guide was prepared in Turkey. The Ministry of Environment and Urban Development (MoEU) and the Ministry of Water Affairs and Forestry (MoFWA) have conducted a study in coordination and cooperation with the international format with the relevant departments to determine the cumulative impacts of hydropower projects in Turkey

The 2013 Turkish Regulation only refers to the CEIA; However, there is uncertainty about the definition, content and applicability of this concept. Even in EIA planning and decisions, considering the problems experienced in today's conditions, the CEIA phenomenon needs to be developed. Today, the Turkish public, non-governmental organizations and the general public have started to develop a more sensitive environment perception than before. The emphasis on a liveable environment, a safe and healthy future is increasing day by day. In particular, studies and findings related to climate change, deforestation and global warming are at the forefront of social responsibility. To this end, the relevant government agencies and ministries are developing joint projects with internationally experienced institutions such as the World Bank and the European Development Bank.

Turkey, at the end of 2020, aims to reach 2 GW of installed power and has become a focal point for investments in new projects. Turkey, with the contribution of the private sector and incentives, has become currently the world's 4th largest producer of geothermal energy. There are also studies on many projects, including new units in existing facilities. The government of Turkey has applied the Renewable Energy Incentive Mechanism-YEKDEM to subsidize geothermal energy investment. The program enables companies to gain tax benefits and guarantees a 10-year energy intake between 2005 and 2020. Therefore, there has been a recession and uncertainty in renewable energy investments. In addition, geothermal power plants, which are concentrated in a limited area, have started to cause some problems both in production and environmental aspects.

European Development Bank (EBRD), is conducting a study to determine the environmental and social impacts of geothermal plants in Turkey. The project report to be prepared is planned to be a very comprehensive report in the cumulative impact area. The World Bank also supports geothermal energy research. Also, the World Bank is conducting a detailed study on carbon dioxide gas emissions from geothermal power plants.

## 6. CONCLUSION

When investigating the cumulative effects of geothermal power plants associated with an existing, approved, proposed and reasonably predictable development, CEIA should focus the assessment and management strategies on VECs such as physical features, ecosystem-habitats, natural processes, Social-Cultural aspects and conditions. Cumulative impact assessment is a study to identify and evaluate the importance of impacts from multiple activities. The analysis of the consequences of the causes of these effects is an important part of the process. Identifying the sources and processes and identifying their effects define the complex cause-effect relationship in the cumulative impact assessment.

Project managers have to prepare the road plans to monitor the environmental resources and impacts of the project in pre-operation and during the operation process of the geothermal power plants. Cumulative impact assessments are the most important studies conducted for this purpose. In addition to project impacts, other environmental impacts should be assessed within the scope of the assessment. Thus, processes such as which effect causes, the size of damage, minimization of damage will be processed faster. At the same time, this kind of work can provide the basis for laws and directives, long-term plans and comprehensive projects. The analysis can be improved by continuous monitoring and updated depending on the developing technologies. Problems that may occur in the long term can be predicted through such studies. For this reason, cumulative impact analysis is an important assessment method with short, medium and long term developments, problems and benefits.

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## LECTURE 5

# INNOVATIVE APPLICATIONS OF GEOTHERMAL ENERGY FOR ENVIRONMENT


## ABSTRACT

Geothermal energy is widely used for many applications such as power generation, district heating, chemical production, greenhouse application, snow melting, fish production, industry and thermal tourism. However, geothermal brine can be extremely difficult to handle. Geothermal fluid display high contents of elements and gases. Therefore, they can severely affect the environment such as air, soil and water resources. In essence, with its high dissolved constituents and thermal content, geothermal fluid is known to have significant impacts on environment when disposed in an uncontrolled manner. In parallel to developing geothermal energy applications, many countries start to find innovative solution for minimize environmental problem and use waste from geothermal fluid for economy. The recovery of valuable elements and minerals from geothermal fluid has been studied for years and new methods have been developed recently. Mineral recovery such as lithium, boron and gold, mineral extraction from geothermal fluid and return water is an advanced method of mining and in some way reducing environmental impact.


## 1. INTRODUCTION

Geothermal fluids originating from the Earth's crust and heated by the internal heat of the world have been used for different purposes for thousands of years. While ancient civilizations have been used in different direct applications such as bathing, heating, cooking and pond, geothermal is seen as an important renewable energy source today. Brine in petroleum and geothermal systems have recently gained economic importance with its element concentration potential.

The recovery of valuable elements and minerals from geothermal fluid has been studied for years and new methods have been developed recently. Geothermal fluid may contain high concentrations of rare earth and other elements and minerals, depending on regional geological and hydrogeochemical properties. This has led to the formation of a different sector where geothermal fluids can be used economically other than energy production, regardless of the temperature range. Today, although some geothermal sources have started to provide mineral recovery, most studies in this area are in feasibility and research stage. Low temperature geothermal resources can be used in mineral and element recovery along with the developing technology in addition to the known direct use areas. This situation will enable the re-evaluation of the unused geothermal resources and fields and increase their potential. Since geothermal brines can pass through different formation and geological environments and contain significant amounts of mineral and metal concentrations, they can create an extra economic resource for geothermal energy companies.

## 2. MINERAL RECOVERY

Mineral recovery, mineral extraction from geothermal fluid and return water is an advanced method of mining and in some way reducing environmental impact. In the control of geological and hydrogeological effects in geothermal fluids, minerals that may be present in significant concentrations are: silica, strontium, zinc, rubidium, lithium, potassium, magnesium, lead, manganese, copper, boron, silver, tungsten, gold, caesium and barium.

These elements are used as raw materials in many fields in the renewable energy sector, which gained prominence in recent years. These elements and minerals are needed in solar panels, wind turbine components, all kinds of tools and materials that use electricity. Human beings, who try to give up fossil fuels, should use all the means available for both energy efficiency and sustainability. In this context, it is necessary to search for new resources, to find alternative methods and, if not, to recycle existing resources.

The extraction of minerals from geothermal fluid first started in Italy with the applications in the Larderello geothermal field. In 1818, applications started with boric acid extraction from thermal pools improved the scope with other methods developed in 1920. Sodium perborate, ammonium carbonate, carbonic acid and talcum powder were other products obtained from Larderello. In the 1960s, the process of mineral extraction continued in the United States, especially in the Imperial Valley (CA) and in the 1970s with the production of potassium chloride in Mexico continued to accelerate in the 1990s. Reykjanes sodium chloride plant and zinc production continued after 2000s with the production of different minerals such as Li, Mg, and Zn from geothermal fluids. Geothermal fluids contain dissolved and undissolved substances from different ion types and rock lithology. During energy production from geothermal fluid, changes in temperature and pH values are observed during power plant production process. Decreases in temperature also affect solubility equilibria in the geothermal fluid and may cause precipitations. This process can form the basis for the process of mineral extraction from fluid, as well as undesirable problems such as scaling and fouling in plant equipment and components. This situation, which may cause problems during production and re-injection stages, is predominantly controlled by geological controls. Therefore, defining the lithological characteristics and geochemistry of the fluid in the region is a step that will accelerate the efficient use of geothermal resources and the orientation towards renewable energy.

### 2.1 Solid geothermal residues

Acid leaching: It contains solid waste material, silica, salts and heavy metal concentrators that come out of the filter after treatment in geothermal power plants. Hydrochloric acid is used to separate iron-like metals and silica, and silica can be separated in the process for use as additives in cement (Bourcier et al., 2003).

Biochemical leaching: This method, which is used in ore extraction in copper, uranium and gold mines, has made it possible to obtain minerals from solid wastes thanks to the adaptations made in some geothermal power plants (Bourcier et al., 2003).

### 2.2 Recovery of metals and salts from geothermal fluids

As Bourcier et al. (2003) mentioned in their study, there are three basic steps in the extraction of metals and salts from geothermal fluid. These are sorption, precipitation and evaporation. Resins used in synthetic ion exchange, as well as bacteria, are used to remove certain ions from solutions which is called as a sorption process. This process may vary depending on pH, temperature and ionic forces. There are studies to recover U, Co, Zn, Mn and Li ions in the solution (Premuzic et al., 1995). Geothermal fluids could be used to produce some inexpensive salts such as NaCl, $Na_2SO_4.H_2O$, $CaCl_2$. Evaporation is a process used in the Imperial Valley-CA and similar regions to obtain minerals from salts, as in solar evaporation ponds, when energy costs and re-injection water are not needed. The addition of hydrogen sulphide to geothermal fluids to precipitate most heavy metals into insoluble metal sulphides is called the precipitation process (Schultze and Bauer, 1985).

### 2.2.1 Silica

Obtaining minerals from geothermal systems is a process that starts to gain importance with the problems encountered during production (problems in plants, pipes, heat exchangers and fluids). Decreases in production capacities are usually due to differences in temperature, pH and other fluid parameters. In addition, scaling problems occur due to the acidic environment. Silicon dioxide is the most important factor that can reveal yield loss-decreases in production and scaling problems in geothermal fluid (Demir et al., 2014). If the calcium, iron and other metal contents in the geothermal fluid are at low concentrations and the salinity values are suitable, silica can be very efficient, economical and high purity.

Silica is a common component in geothermal fluids. Hydrothermal systems are predominantly in equilibrium with quartz ($SiO_2$). In this case, the silica concentration indirectly reflects the temperature of the geothermal reservoir. In geothermal power plants, when the geothermal fluid cools, the saturation of silica in the fluid begins to increase. With the removal of water vapour, this process is further accelerated and begins to precipitate in plant components and well walls. The deposition of silica adversely affects the plant yield and the production of minerals that can be obtained from the same fluid in the long run. With the production of silica from fluids, it is possible to get rid of all these problems and the silica in the system and to obtain an economical commercial material. The purity and physical properties of silica directly affect its value in the market. Economical silica is precipitated silica, predominantly produced by the interaction of alkaline solutions and quartz sands. Colloidal silica generally refers to silica precipitated from the acidic solution with pH changes (Bourcier et al., 2003).

Although there are many studies related to scaling in geothermal systems, there are very few studies explaining the formation of scaling clearly. Demadis (2010) in his study stated that pH increases and reactions between amorphous silicas and metal-hydrooxides cause scale formation, and in addition, it is shown that $CO_2$ in the system is important in the separation process. $CO_2$, which is an acidic gas originating from $H_2CO_3$, is dissolved in the geothermal reservoir, while $CO_2$ in the plant system decreases its solubility in the fluid by evaporation and the pH in the fluid begins to rise rapidly. The new fluid with basic properties begins to promote the formation of hydroxide and silicic acid. Generally, the scales are a result of the reaction between metal hydroxides and colloidal silica (Demir et al., 2014).

Geothermal fluids are saturated with silica and are typically close to saturation with magnesium silicate, aluminium silicates, opaline silicate, iron-magnesium silicates and metal sulphides. Scaling is one of the problems encountered in both oil and geothermal systems. As a precaution, acid dosage and ionic interactions should be considered when acid and scale inhibitors can be administered. In recent years, there are studies on (Fe, Mg) silicate scaling (Topçu et al., 2017). The reduction of pH by organic acids whose structure is close to $CO_2$ for instance formic acid has been an effective solution for the minimization of scaling. Herein, the effect of $CO_2$ injection on the formation of scaling particularly metal-silicates was investigated for the model case of Tuzla Geothermal Field (TGF) located in the northwest of Turkey (Topçu et al., 2019).

### 2.2.2 Lithium

Lithium, the first member of the alkali metal family, was discovered by Johan August Arfvedson in the $19^{th}$ century, and then lithium synthesis was first performed by Robert Bunsen and Augustus Matthienson as a result of electrolysis of LiCl mineral. After the Second World War, research on the use of lithium has increased and its usage area has become an increasing element day by day. It has a wide range of applications as metal, mineral or compound. Lithium is one of the most important sources in the $21^{st}$ century because it is a strategic energy material.

Lithium is a very important element in electric vehicles and energy storage-battery applications. Lithium, which can reach significant concentrations in geothermal fluid, has a large and continuously developing market with sectors such as aluminium and glass. Chile, Australia, China, Argentina, Russia

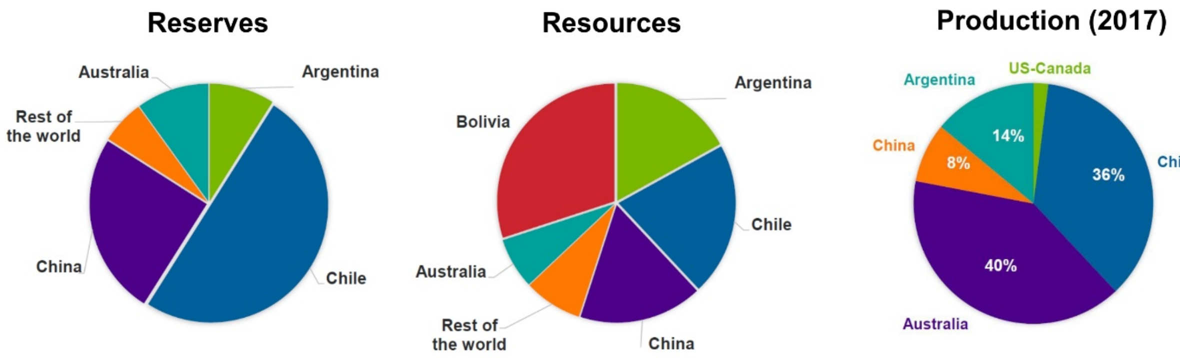


FIGURE 35: Lithium reserves and resources (2016) with production by country (2017) data (Source: SQM)

and the United States are the leading manufacturers of lithium in the world. In terms of reserve, Chile, China, Argentina and Australia constitute the top four countries, while Bolivia, Argentina, Chile and China are in the top four in terms of resources (Figure 35). Today the most important high compositions of Lithium brines located in USA (Clayton Valley, Salton Sea, Great Salt Lake), Chile (Salar de Atacama), Bolivia (Salar de Uyuni) and China (Zabuye, Taijinaier).

According to the Li et al. (2018) 35% of lithium market share is composed of batteries, 32% is ceramic and 9% is lubricants (Table 11). However, lithium demand is expected to increase significantly due to the development of today's technology. Electric vehicles are expected to replace fossil fuel-powered vehicles and demand for developing storage and battery-to-battery systems will double in every 5-10 years. The cost of lithium hydroxide and lithium carbonate is expected to increase, and in the 2020s, prices are expected to double today's prices.

TABLE 11: List of estimated global lithium end-use applications (Li et al., 2018)

| Applications | Market share (%) | Products |
|---|---|---|
| Batteries, portable electronics, hybrid cars, electric vehicles, grid storage applications | 35 | $Li_2CO_3$; LiOH; Li metal; $LiPF_6$ electrolyte salts; LiCL; Li alloys, $LİCoO_2$ and other Li electrode compositions |
| Ceramics and glass | 32 | Spodumene - $LiAl(SiO_3)_2$; $Li_2CO_3$ |
| Lubricants and greases | 9 | LiOH |
| Air treatment; continuous casting mould flux powders; polymer production; primary Al production | 5-5-3-1 | Li organometallics; Li metal; LiCl; $LiAlH_4$; butyl lithium; lithium citrate |
| Other uses such as in medicine as antidepressants, bipolar disorder | 9 | Li compounds |

Lithium is naturally found in some clays and minerals as well as in sea water and salty groundwater. The average concentration of lithium in the earth's crust is 0.007%, approximately 20 ppm lithium is present in seawater or groundwater, and approximately 59% of global lithium reserves come from saltwater reservoirs. Lithium can be obtained from two different sources including lithium mineral ores and salt water and sea water. Due to its low cost and reserve potential, it is more preferable to recover lithium from water sources rather than lithium mineral ores (Xiang et al., 2016). Lithium can be captured from geothermal liquids in salt form or by ion exchange resin using direct precipitation methods. There are several methods for separating cations from aqueous systems such as ion exchange, chemical precipitation, reverse osmosis and coagulation. The adsorption method is more efficient, practical and economical than all, and the separation of other valuable ions such as lithium can be promising for mining (Nishihama et al., 2011; Çelik et al., 2018).

Some useful extraction methods include solvent extraction, molecular recognition technology, designed microbes and magnetic separation. However, the three most efficient methods for obtaining lithium from geothermal fluid are adsorption, ion exchange and electrodialysis.

*Adsorption*
This method includes using sorbents to adhere to the lithium for selective removal which can recover about 90% of the lithium present, including recently tested lithium aluminium layered double hydroxide chloride sorbent, or LDH.

*Ion exchange*
These systems are used in industries for water softening, purification, and different separation purposes that separate ionic contaminants from solution through a physical-chemical process where undesirable ions are replaced by other ions of the same electrical charge.

*Electrodialysis*
This method is a kind of ion exchange that can be used for recovery of lithium from geothermal brine. That membrane process uses charged ions to allow charged particles to flow through a semipermeable membrane.

There are many different methods used in the literature for the recovery of lithium from groundwater. It is difficult to determine a general method for the recovery of lithium from geothermal fluid. Each fluid has its own composition and requires different analyses and approaches. Lithium recovery with lithium aluminate precipitation method has been tried and achieved successful results by many researchers in the literature. Separation from other alkali metals by chromatography (An et al., 2012) Lithium recovery by liquid-liquid extraction from brine (Gabra and Torma, 1978; Gao et al., 2015) and the use of ion exchange resins are quite common (Bukowsky et al., 1991). Lithium recovery with membrane technology, ion-sieve oxides, reverse osmosis and nano-filtration methods are more modern and specific methods (Liu et al., 2015; Xu et al., 2016)

Lithium ion sieves (LIS) are only lithium ion materials, while oxidized ion sieves are used as an effective scavenger for specific metal ions. These sieves can separate lithium ions, which is the smallest radius of all metal ions, from aqueous solutions. In the synthesis of these materials, hydrogen-filled structures are obtained from the lithium crystal structures with lithium-hydrogen exchange. Selective adsorption of lithium ions is then achieved when the structures obtained are treated with solutions containing lithium ions. In general, this process is called the "LIS effect" (Figure 36).

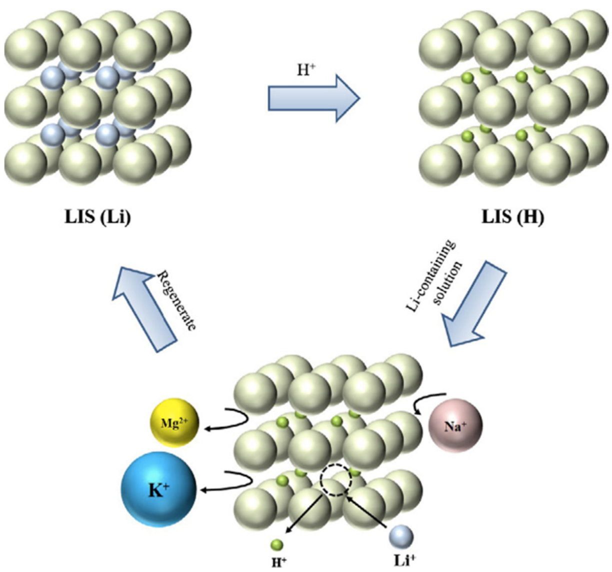

FIGURE 36: Schematic representation of LIS preparation steps (Xu et al., 2016)

Different methods have been used to removal lithium from geothermal brine (Figure 37). Çelik et al. (2017) have developed a membrane system that comprises a surface that is capable of holding metallic ions. It has been demonstrated that the chitosan fibre mats can efficiently adsorb various cations including lithium. Moreover, the fibres are stable under hypersaline brine as no fibre breakage or change was observed upon treatment. Thus, the fibre mats obtained via electrospinning are promising materials for the removal of metallic ions from geothermal brines.

The lithium concentration reach 325 ppm in Tuz Gölü (central Turkey) and 20 ppm lithium in the Tuzla geothermal field in the northwestern Turkey (Şahiner and Akgök, 2017; Demir et al.,

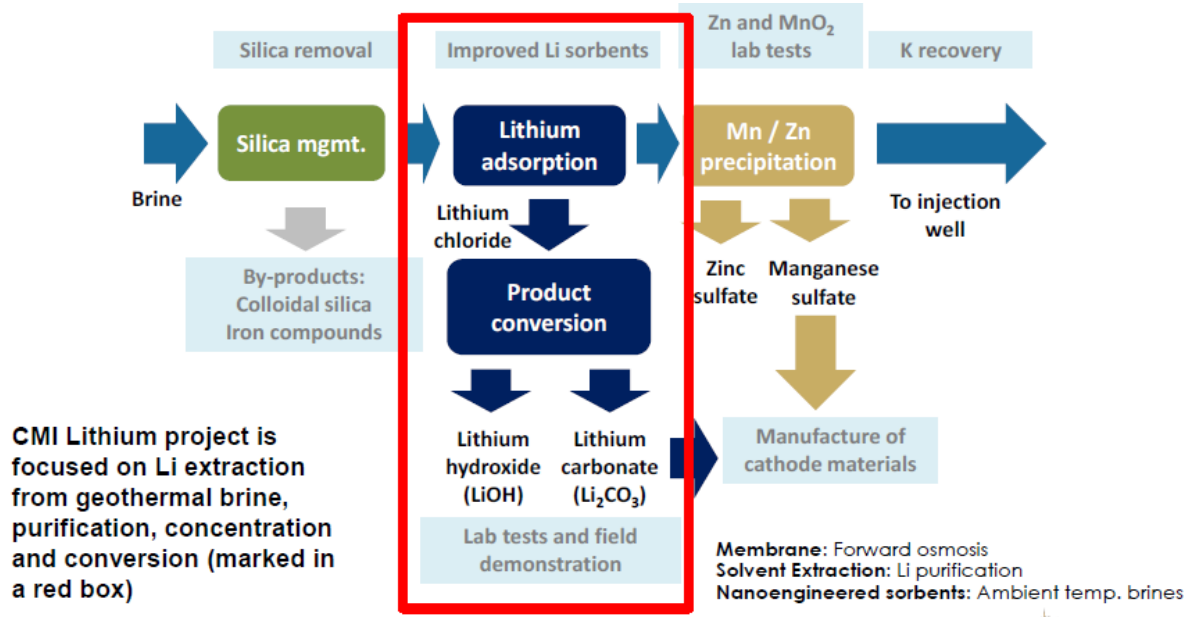


FIGURE 37: Lithium removal process flow from geothermal brine (Harrison, 2014)

2014). However, magnesium content in Tuz Gölü and sodium and chlorine in the Tuzla Geothermal field suppress lithium. In the production of lithium in salty geothermal fluid, pre-separation is necessary to remove lithium from other elements and this process is not an economical method in terms of both cost and time.

### 2.2.3 Boron

Boron is an essential element for the growth and development of plants. However, after certain limits on plants and humans, it starts to show toxic effects and symptoms. The boron element comes from the geological environment to the environment, surface and groundwater resources. Decomposition and degradation processes in boron-containing geological formations result from volcanic activity as well as sea water and geothermal power plant vapours.

Generally, boron is high in some geothermal fluid especially in geothermal system in Turkey. Boron concentration is related to volcanic and sedimentary rocks, but may also be controlled by degassing of magma intrusive (Baba and Ármannsson, 2006). The results of previous works showed that concentration of Boron in geothermal fluid were higher than that of groundwater. In addition, boron values have exceeded national and international limits. The boron concentrations reached to 67 mg/l (Baba et al., 2015). The thermal waters of Kizildere in the Buyuk Menderes Graben has boron concentrations of up to 32 mg/l. High boron contents possibly has a relation with boron-bearing minerals in the metamorphic rocks and a magmatism. Figure 38 shows the boron concentration of geothermal fluids in different geothermal system.

Geothermal waters may contain large amounts of boron and other species, depending on the geological environment. In most boron-rich geothermal systems, non-boron boric acid ($H_3BO_3$) and borate ions are in the form of $[B(OH)^-_4]$ (Yılmaz et al., 2007). It is possible to obtain boron from geothermal returned fluids with some methods which are tried-applied today. It is tried to obtain boric acid from water with high boron concentration by using ionic exchange resins. However, the chemical content of water, pH value, temperature and organic material content and the properties of the resin used directly affect the yield of boron production. There are several methods such as co-precipitation and adsorption of removal of boron from water that contains a high concentration of boron (Itakura et al., 2005; Yurdakoç et al., 2005; Polat et.al., 2004). In order to get some information about column performance of chelating resins on removal of boron from Balçova geothermal water (Turkey), chelating resins Dowex (XUS 43594.00) and Diaion CRB 02 were tested for column-mode sorption of boron. According to İpek et al. (2008) both ion exchange resins were found to be effective for boron removal from geothermal water. Also, it

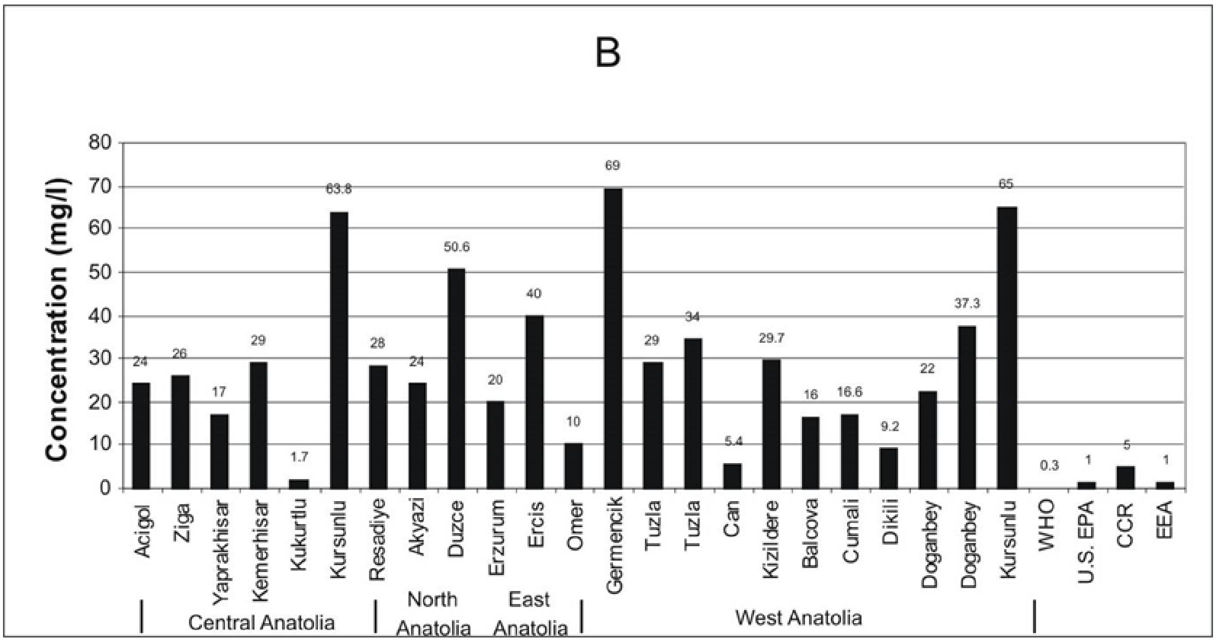


FIGURE 38: Boron concentrations of geothermal systems in Turkey (Baba and Ármannsson, 2006)

was obtained that the breakthrough capacity of Dowex (XUS 43594.00) resin decreased when the feed flow rate was increased due to the decrease in contact time.

**2.2.4 Carbondioxide ($CO_2$)**

Geothermal use for energy production can cause some greenhouse gas emissions compared to other power plants. Non-condensable gases (NCG) are naturally found in most geothermal fluids. In general, carbon dioxide ($CO_2$) that makes up more than 95 percent of the NCG content. These gases are called non-condensing because they do not condense under similar water vapour conditions and remain in the gas phase.

Geographically, there may be differences in emissions from the plants. The differences can be explained by the chemical composition of the main rocks of the geothermal system and the geothermal fluid. Turkey and many Mediterranean countries to be more of carbonate units, such as Iceland geothermal reservoir leads to more $CO_2$ emissions by country, consisting of igneous rocks.

In a backpressure power plant, after the flash in the separator, steam and NCG expand in the turbine and exhaust gases are released into the atmosphere. However, these types of power plants are not very common today. In the flash condensing plant, the expanded steam and NCG are condensed in a cooling system to increase the expansion rate in the turbine; roughly 84% of the global installed capacity is based on this second method. Two-phase and single-phase dual power plants use geothermal fluid to heat the working fluid and then expand into a turbine. In a two-phase power plant, the working fluid is heated in both steam and liquid phases with geothermal fluid. In the single-phase power plant, only geothermal water is present in the liquid phase. The binary power plant is more suitable for re-injection. In the case of a single-phase dual power plant, the gases remain dissolved in brine and can be re-injected into the reservoir.

Different applications and methods have been developed in different sectors to reduce $CO_2$ emissions. In geothermal systems, NCG and $CO_2$ reinjection was tried to be provided to the system with different applications in America, Japan and Germany. Today, with the developing technology, both the reduction of the effects of greenhouse gases on global warming is tried to be achieved and economic gains are also achieved through some applications. For example, $CO_2$ and NCG gas while being pressed back into


FIGURE 39: The CarbFix project at the Hellisheidi geothermal power plant, Iceland

the geothermal systems in Iceland, geothermal origin $CO_2$ in Turkey is used for the production of carbonated soft drinks industry.

The CarbFix project started in 2007 at the Hellisheidi (Iceland) geothermal power plant (Figure 39). Within the scope of the project, $CO_2$ injection could be made to volcanic basalt units and a very important step was taken in the emission problem of the plant. The $CO_2$ and $H_2S$ gases injected into the rocks formed carbonate minerals within the basalt units and are likely to be a method of controlling the release of NCG emissions in geothermal power plants in the long term. Reducing industrial $CO_2$ emissions is considered one of the biggest challenges of this century. For this reason, the carbon released from different sources by releasing $CO_2$ into the appropriate environment underground is returned to the place where it was extracted instead of releasing it into the atmosphere. For this reason, the two main objectives of the Carbfix project are to remove $CO_2$ from the emission points or atmosphere and inject $CO_2$-containing water into geological formations (Figure 40).

Geothermal activities in Western Anatolia (Turkey) are generally controlled not by magmatic heat sources but primarily by deep fault controlled convection. Mutlu et al. (2008) account for 70% to 97% of the carbon budget from crusty marine limestone, from 1.04% to 26.6% sediments and from 0.03% to 4.37% mantle rocks originating from. Geology around the geothermal springs in Büyük Menderes and

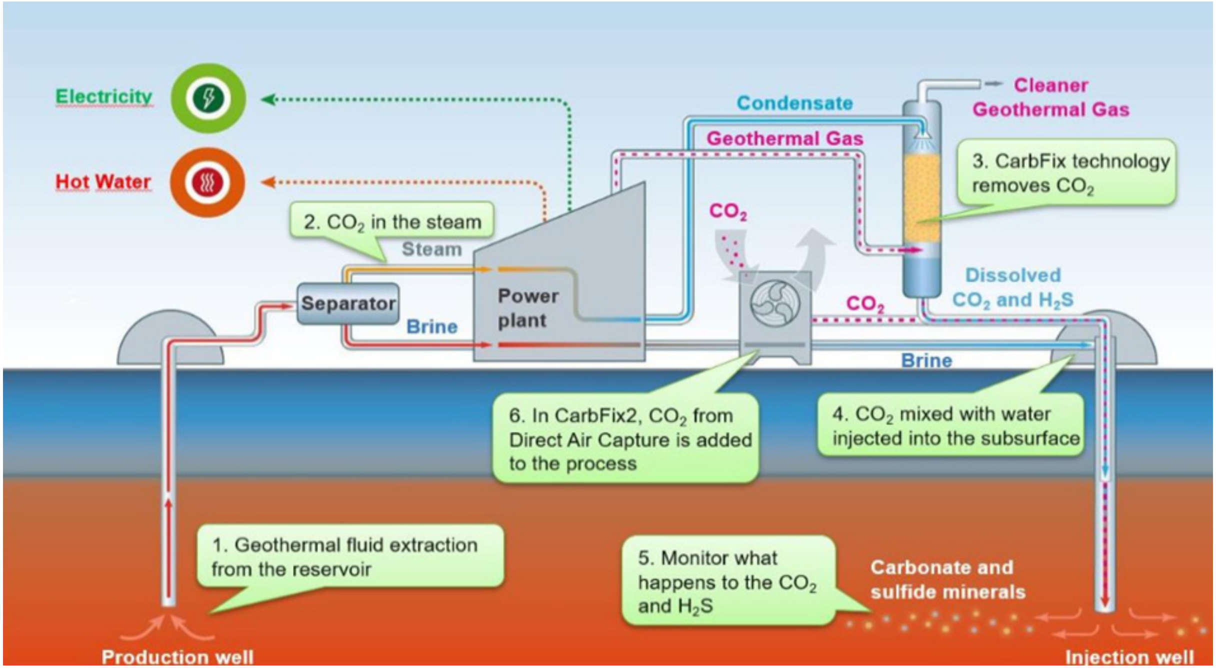


FIGURE 40: Carbfix project working principle diagram (Source: CarbFix, *www.carbfix.com/*)

Gediz Graben consists of carbonate rocks containing limestone and marble. If the calcite is formed in reservoir, then the geothermal brine is assumed to be in equilibrium with calcite. Then $CaCO_3$ precipitates during the generation, and $CO_2$ gas is released. The reported $CO_2$ contents range from 1.5 to 4.4 wt% (Tuzla and Buharkent are excluded) (Figure 41). These data clearly show the $CO_2$-rich nature of Turkey geothermal resources (Layman, 2017).

| Name of Power Plant / Project Site | Developer | Installed Capacity (MW) | Plant Technology Type | Planned / Under Const. (MW) | Resource temp, deg C | CO2 in reservoir fluid, wt % | CO2 emissions rate, g/kwh | *Sources for CO2 data* |
|---|---|---|---|---|---|---|---|---|
| *In Operation or Under Constructo n* | | | | | | | | |
| Kizildere | Zorlu | 95 | 1F, 2F, B | | 200-245 | 1.9 - 4.4 | 900-1300 | *Askoy et al (2015); Gokcen et al (2004)* |
| Kizildere | Bereket | 6.9 | B | | 140 | | | *no data available* |
| Salavatli (Dora 1, 2, 3a) | Mederes Geothermal | 50.9 | B | 37 | 171 | 1.0-2.2 | 900-1100 | *Askoy et al (2015); Di Pippo (2012); Kaplan & Serpen (2010)* |
| Germencik | Gurmat | 162.3 | 2F, B | | 230-276 | 1.5 - 2.1 | 813-1100 | *Atkins International Ltd (2014); Askoy et al (2015); Tureyan et al (2016)* |
| Germencik | no data | 22.5 | F | | | | | *no data available* |
| Tuzla | Enda | 7.5 | B | 7.5 | 174 | 0.5 | 400 | *Askoy et al (2015)* |
| Hidirbeyli | Maren | 92 | B | 96 | 180 | 1.5 - 2.0 | 1423 | *Kaypakoglu et al (2015); Askoy et al (2015)* |
| Pamukoren | Celikler | 45 | B | | 161-191 | 1.54 | 925 | *Karahan et al (2015); Askoy et al (2015)* |
| Alasehir | Turkeler | 24 | B | | 185 | 3.4 | ND | *Askoy et al (2015)* |
| Alasehir-Kavaklidere | Zorlu | 45 | 2F, B | | 287 | 3.4 | 1640 | *ENVY (2013); Askoy et al (2015); Veizades & Associates (2012)* |
| Gumuskoy | BM | 6.6 | B | 6.6 | 180 | 1.5 - 2.0 | 900-1100 | *Askoy et al (2015)* |
| Yilmazkoy | KenKipas Energy | 24 | B? | | 175 | 2.0 | ND | *Askoy et al (2015)* |
| Gerali-Sarakoy | Degirmenci / GreenEco Energy | 24 | B | | 124 | ND | ND | *no data available* |
| Umurlu | Karadeniz Elektrik | 12 | B | 12 | 155 | ND | ND | *no data available* |
| **TOTALS** | | **617.7** | | **147.1** | | | | |
| ***Planned Project*** | | | | | | | | |
| Buharkent | Limak Yatirim | 15 | BP | | 146 | 0.2 | 0 | *Mertogulu, Basarir & Saracoglu (2015)* |

1F= single flash; 2F = dual F ash; B = artesian binary; BP = pumped binary

FIGURE 41: Turkey geothermal plant capacity, technology and $CO_2$ emissions data (Layman, 2017); plant capacity and technology adapted from Mertoğlu et al., (2015)

Geothermal plants in Kızildere and Salavatlı are producing $CO_2$ for the beverage industry and other sectors. The 17.8 MW Kizildere Unit-I plant is a single flash facility that was commissioned in 1984 and produces approximately 193,460 tons per year (Layman, 2017). Between 1984 and 1999, 40,000 tonnes of $CO_2$ were sold annually, and then the amount increased to 120,000 tonnes /year (Gökçen et al., 2004). The 7.35 MW Dora-1 binary plants in the Salavatli geothermal field supplies 30,000 tons/year of $CO_2$ for commercial use (Baba et al., 2014). In recent years, these plants meet almost all $CO_2$ needs of the sparkling beverage sector.

Metal-silicate scaling is one of the major obstacles to geothermal power plants, particularly in volcanic system. Scaling reduces the efficiency of the plants due to clogging of the transfer lines and reduction of thermal conductance. pH modification is a fruitful approach to mitigate scaling, therefore $CO_2$ gas is injected to the geothermal system to prevent the formation of metal silicate scaling. This study was done in high hyper-saline geothermal system in Tuzla geothermal power plant in Turkey (Figure 42). This study is one of the most important applications in the geothermal sector today.

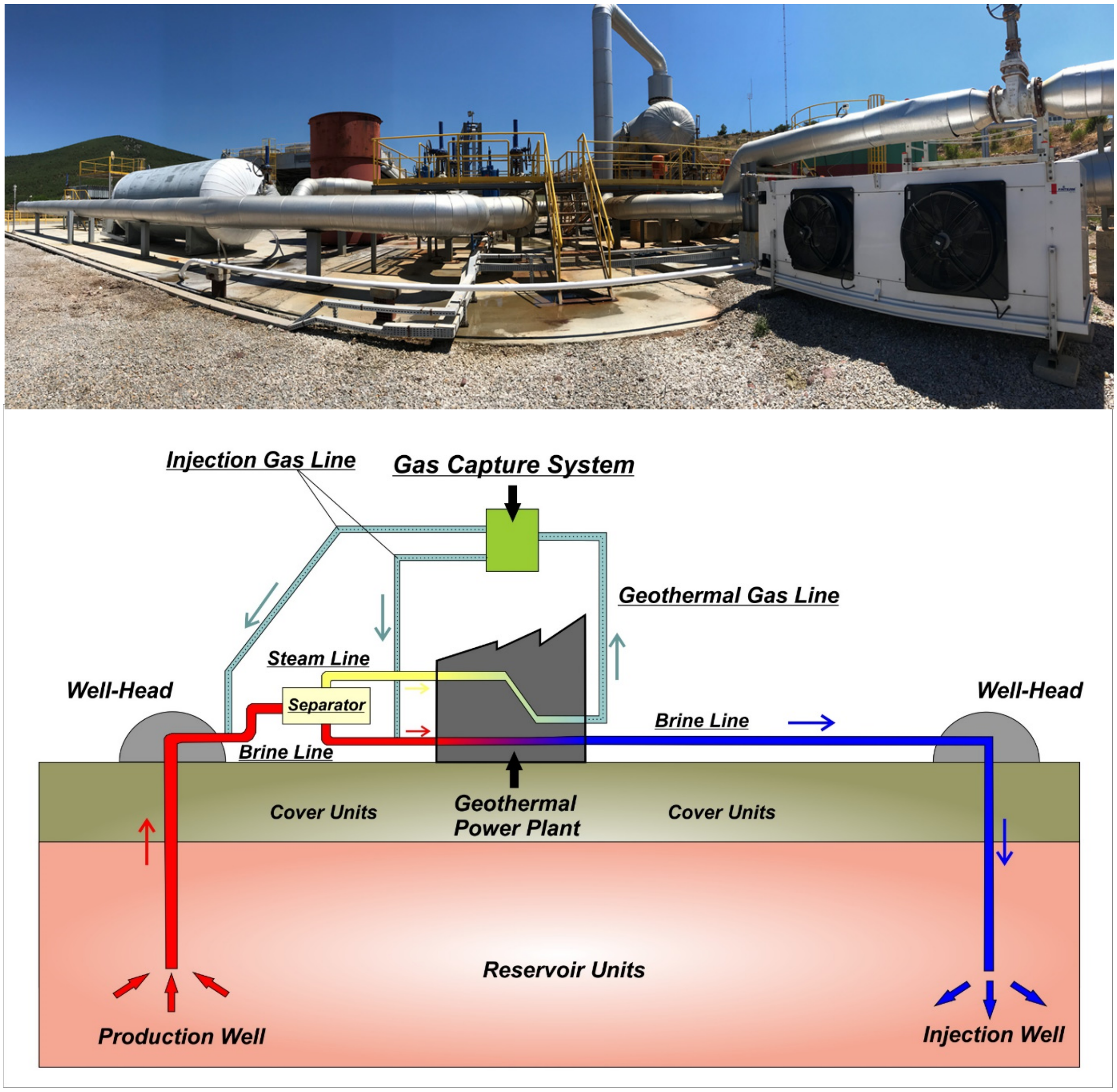


FIGURE 42: Injection $CO_2$ injection in geothermal system to minimize scaling

## 3. CONCLUSION

Today, environmental pollution, global warming and climate change problems have started to lead countries and companies to different energy sources. Geothermal energy is a renewable and clean natural energy source. It is easy to minimize environmental problems with the right methods and businesses. During the studies and studies aimed at preventing environmental problems, some alternative and economical methods have been found. With the modern methods such as mineral recovery, $CO_2$ and $H_2S$ capture systems, geothermal fluid used in geothermal power plants can serve different purposes with the processes that will be subjected to before or after the power plant. Silica recovery method can be used to prevent scaling, which negatively affects the plant efficiency and components, while reinjecting $CO_2$, which plays an important role in the balance of pressure and pH in the geothermal system, should be considered as a very useful process.

The removal of Zinc, Silica, Boron and Lithium from the geothermal fluid is considered as a highly economical alternative mining method in the long term. These methods can also help to reduce the environmental impacts of mining. Elements such as caesium and rubidium can also be enriched with geothermal fluids and profitable due to their high values (Bourcier et al., 2003). Geothermal fluids have the potential to be used in the production of NaCl, $Na_2SO_4.H_2O$, $CaCl_2$ and calcium carbonate. There are also different studies on scale based mineral production. In such applications, it is possible to obtain elements such as gold and silver on the scale formed by the geothermal fluid. Zinc, copper, lead, boron and arsenic are generally controlled by geography, geology and geothermal fluid chemistry.

A new idea, creative thoughts, new imaginations in geothermal system both help economy of country and minimize environmental problems.

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