Environmental and Social Impacts of the Increasing Number of Geothermal Power Plants (Büyük Menderes Graben - Turkey)

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Research Article

Keywords: Geothermal Power Plant, Geothermal Energy, Environmental Impact, Social Impact, Büyük Menderes Graben

Posted Date: May 16th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-427548/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on October 9th, 2021. See the published version at https://doi.org/10.1007/s11356-021-16941-5.

Abstract

The use of renewable energy is critical to the long-term development of global energy. Geothermal Power Plants (GPP) differ in the technology they use to convert the source to electricity (dual, single flash, double flash, back pressure, and dry steam) as well as the cooling technology they use (water-cooled and air-cooled). The environmental consequences vary depending on the conversion and cooling technology used. Environmental consequences of geothermal exploration, development, and energy generation includes land use and visual impacts, microclimatic impacts, impacts on flora-fauna and biodiversity, air emissions, water quality, soil pollution, noise, micro-earthquakes, induced seismicity, and subsidence. It can also have an impact on social and economic communities. As geothermal activity progresses from exploration to development and production, these effects become more significant. Before beginning geothermal energy activity, the positive and negative aspects of these effects should be considered. The number of GPPs in the Büyük Menderes Graben (BMG) geothermal area is increasing rapidly. According to the findings, in order to reduce the environmental and social impacts of the GPPs in the BMG, resource conservation and development, production sustainability, and operational problems should be continuously monitored.

Introduction

GPPs are classified into five types: binary, single flash, double flash, back pressure, and dry steam. Traditional steam turbines (single or double flash plants) and binary plants are used to generate utility-scale electricity, with the final technology choice based primarily on geothermal fluid temperature and reservoir conditions. A thorough examination of test well data is thus required for power plant design, including process technology, production and reinjection well locations, and pipeline routes. Due to the rapid increase in electrical energy consumption in the world after 1970, the use of geothermal resources has been accelerated. With this beginning, the effects of geothermal production on the environment have been examined, evaluated and compared with the effects of other energy types. The first Environmental Impact Assessment was published in 1970 in the USA. Later, many countries established their own rules, frequently citing the World Commission on Environment and Development's 1987 report and the United Nations Environment Conference in 1992. The potential negative environmental impacts of geothermal energy production are being thoroughly researched all over the world (Weissberg and Zobel 1973; Siegel and Siegel 1975; Dall'Aglio and Ferrara 1986; Bacci 1998; Kristmannsdottir and Armannsson 2003; Frick et al. 2010; Lacirignola and Blanc 2013; Ferrara et al. 2019; Pratiwi and Juerges 2020). Because all energy generation causes environmental changes, it necessitates engineering and construction activities that can have a variety of environmental consequences. Despite the fact that geothermal energy is considered a clean energy source, its development will result in the release of non-condensable gases that must be disposed of (Bacci et al. 2000; Kristmannsdottir and Armannsson 2003; Bravi and Basosi 2014; Paulillo et al. 2019; Bustaffa et al. 2020). It is made up of non-condensable gases and dissolved solid particles, the amount of which increases with temperature. Non-condensable gases, primarily carbon dioxide (CO_2), with trace amounts of hydrogen sulfide (H_2S), ammonia (NH_3), nitrogen (N_2), hydrogen (H_2), mercury (Hg), boron (B), radon (Rn), and methane (CH_4). Geothermal plants may contain heavy metals (Hg, Pb, Cd, Fe, Zn, and Mn) as well as harmful concentrations of Li, al, and NH, depending on the local geological conditions (Kristmannsdottir and Armannsson 2003; Bravi and Basosi 2014; Bustaffa et al. 2020; Lattanzi et al. 2020). Thermal pollution can also be caused by discharged hot water. In general, geothermal waters from power plants are re-injected into the geological units from which they were extracted to prevent environmental problems and to re-feed the reservoir (Baba and Sözbilir 2012; Shortall et al. 2015; Bosnjakovıc et al. 2019). Furthermore, GPPs have been using H_2S reduction systems for the emitted steam since 1976 (Matek 2013).

The BMG geothermal field examined in this study is significant in terms of its thermal water potential (Baba and Armannsson 2006; Yilmaz and Kaptan 2017). Many energy generation projects have been and are still being carried out in the BMG. However, the negative consequences of incomplete and faulty applications have resulted in some technical, environmental, and social issues. As a result, there is growing public opposition to certain projects. Many of these effects can be mitigated by existing technology, lowering the environmental impact of geothermal energy. As a result, it is critical to accurately define the processes from exploration to operation of geothermal resources in order to protect and develop the resource, ensure the sustainability of production, and continuously monitor the problems that arise during resource operation. This article is expected to contribute to ongoing and future projects aimed at better understanding the environmental impacts of geothermal energy generation.

Materials And Methods

Description of the study area

Turkey is a promising region in terms of the BMG energy production, with a high potential for geothermal energy. Geothermal water is currently produced from the BMG from geothermal reservoirs (1.1–3.5 km) with temperature between 35-242 °C. The BMG system is a region of tectonically active extension and is undergoing an extension of N-S leading to the formation of the graben geothermal fields (Fig. 1). Over the last decade, with the assigned "Geothermal Energy Act in Turkey," Geothermal Exploration, Research and Investment has increased rapidly. In May 2020, Turkey's geothermal electricity generation reached a total installed capacity of 59 MWe unit as of 1549. There are 42 of these in BMG. Denizli has 7 GPPs with a capacity of 321.8 MWe and Aydın has 35 GPPs with a capacity of 776.93 MWe. Land use and visual impact, microclimatic effects, impacts on flora-fauna and biodiversity, air emissions, water quality, soil pollution, noise, micro earthquakes, induced seismicity, and subsidence are all examples of environmental effects in geothermal energy applications.

Land use and visual impact

The amount of land needed for a geothermal power plant depends on the characteristics of the resource reservoir, the amount of power capacity, the type of energy conversion system, the type of cooling system, the layout of the wells and piping systems, and the substation and auxiliary building needs (NREL 2012) . Geysers, the world's largest geothermal power plant, has a capacity of about 1.517 megawatts and an area of about 78 km^2, which equates to about 13 acres per megawatt. Many geothermal areas, such as the Gaysers geothermal field, are located in ecologically sensitive areas. As a result, project developers should factor this into their planning processes. Furthermore, geothermal energy plants have visual effects on their surroundings (Fig. 2). Vapor emission, night lighting in the well area and power plant, and visibility of pipelines and transmission lines are some of the main visual quality impacts caused by geothermal development. The main factors that can reduce the visual impacts of geothermal energy facilities are detailed site planning, facility design, material selection, re-planting programs, and transmission line alignment. With proper operation and technology, water vapor emissions can be reduced. Furthermore, the visual impact can be reduced by taking appropriate measures (e.g. passing underground), particularly for fluid pipes passing close to settlements. Many investors are now using these mitigation techniques to reduce the visual impact of geothermal plants. However, due to the excessive concentration of fluid transmission lines and their proximity to settlements, negative visual effects have been observed in some areas.

Microclimate

Carbon dioxide accounts for approximately 10% of air emissions in open loop geothermal systems, with methane, a more potent global warming gas, accounting for the remainder. Open loop systems are estimated to emit 0.1 pound carbon dioxide equivalent per kilowatt-hour of global warming emissions. These gases are not released into the atmosphere in closed loop systems, but there are still some emissions associated with plant construction and surrounding infrastructure. The CO_2 produced during the geothermal resource production process can be used in integrated applications such as greenhouse or dry ice production, or it can be injected back into the reservoir. As a result, it should not be overlooked that CO_2 has a positive contribution when used in integrated facilities. However, because NCGs are released directly into the atmosphere without any controls, they have a microclimatic effect that contributes to climate change due to their status as a greenhouse gas emitter. It is a compensable effect if the necessary precautions are taken.

Flora-Fauna and Biodiversity

It is possible that geothermal resource use activities will have a negative impact on the region's flora, fauna, and biodiversity (Fig. 3). Especially during the planning stages. Measures can be taken to reduce the overall impact. The effects of the facilities on the flora and fauna, as well as the measures to be taken, are evaluated specifically in the EIA process within the scope of national legislation. GPP facilities in the project area, such as nature conservation areas, national parks, protected areas, wetlands. Although they are not included in the protected areas and their immediate surroundings, the authorized administrations handle these issues during the EIA process. Because GPP facilities are a resource that should be assessed at the location of the geothermal resource, they are likely to have an impact on the flora and fauna. Its impact on location selection, flora, fauna, and biodiversity can be avoided to some extent, particularly during the planning stages.

Air emissions

Air emissions from geothermal activities are most noticeable during the drilling, construction, and production stages. In terms of air emissions, the distinction between open and closed loop systems at the manufacturing stage is critical. Gases extracted from wells in closed circuit systems are not exposed to the atmosphere and are injected back into the ground after releasing their heat, resulting in low air emissions (Fig. 4). Open loop systems, on the other hand, emit hydrogen sulfide, carbon dioxide, ammonia, methane, and boron. The most common emission is hydrogen sulfide, which has a distinct "rotten egg" odor (Kagel 2007). When hydrogen sulfide enters the atmosphere, it converts to sulfur dioxide (SO_2). This contributes to the formation of small acidic particles in the bloodstream, which can lead to heart and lung disease (NRC 2010). Sulfur dioxide also contributes to acid rain, which harms crops, forests, and soil while acidifying lakes and streams. However, SO_2 emissions from GPPs are roughly 30 times lower per megawatt-hour than those from coal power plants, which are the country's largest SO_2 source. GPPs emit trace amounts of mercury, which must be reduced using mercury filter technology. Scrubbers can reduce air emissions, but they also generate a slurry of captured materials such as sulfur, vanadium, silica compounds, chlorides, arsenic, mercury, nickel, and other heavy metals. This toxic sludge is typically disposed of at hazardous waste sites (Kagel 2007). It is critical to continuously monitor air quality measurements and facility contribution values in order to detect particulate matter measurements in the region. Monitoring and measurements should be carried out, and necessary measures should be taken, to eliminate the cumulative effect of geothermal resource use activities.

Thermal waters originating from the region's fault lines caused boron element condensation by dissolving boron-containing minerals along the flow paths they followed (Aslan 2010). It is believed that the lack of quality in fruits, particularly the untimely leaf 5 casts seen in plants during the vegetation period, contributes to an increase in the relative humidity of the air in the activities of the plants, and thus the quality of the figs is negatively affected by the unwanted high humidity during the drying period, and the yield gradually decreases (Fig. 5-6).

The two main parameters most frequently examined in air pollution measurement are Particulate Matter 10 (PM10) and Sulfur dioxide (SO_2). PM10 affects human health and the environment. PM10 emissions are observed during the drilling / construction phases of the GPP facilities, during the operation phase of the water-cooled GPPs. The change of PM10 and SO_2 emission concentrations by years has been evaluated in Aydın, where GPPs are the most common (MoEU 2020). Air quality measurements were made by the MoEU between July and November 2019 in the city of Aydın and its vicinity. Atmospheric PM10 levels were determined as 50 μg/m^3 per day in air measurements. PM10 concentrations, on the other hand, have consistently exceeded the annual average limit value of 40 μg/m3 specified in the regulation, except for 2017. In the Air Quality Assessment and Management Regulation, annual SO_2 limit values are specified as 20 μg/m^3. It was observed that it exceeded the value in the measurements made by the MoEU between 2008-2012. In 2016 and after, SO_2 values were determined below the limit value (MoEU 2020). Odor measurements were carried out by the MoEU between July and November 2019 in the city of Aydın and its vicinity. In all the measurements made, the average H_2S values were measured as 7.10 μg/m^3. WHO recommends that the concentration of H_2S in the air should not exceed 7 μg/m^3 in 30 minutes in order to prevent odor disturbance. Boron values have an average of 0.32 mg/L in the analysis performed in 7 surface samples in Denizli city and its vicinity. Average boron value was measured as 0.92 mg/L in 13 samples analyzed in Aydın city and its vicinity. Boron levels in surface waters are not very high. In the measurements made in the fluid taken from the geothermal power plant in Aydın and its vicinity, the boron value was measured as 24.5 and 90.18 mg/L (MoEU 2020).

Water quality

The most significant factors that can affect surface water resources are geothermal fluid leaks, drilling mud, and uncontrolled fluid discharge. These activities, which can cause both physical and chemical changes that can be detected through surface water monitoring, are the result of poor practices (Fig. 7-11).

GPPs have the potential to impact both water quality and consumption. Sulfur, salt, and other minerals are frequently found in hot water pumped from underground reservoirs (Fig. 13). The extracted water is pumped directly back to the geothermal reservoir after being used for heat or electricity generation in most geothermal plants' closed circuit water systems. Water is kept in steel well casings cemented to the surrounding rock in such systems (Kagel 2008). There have been no reported water pollution cases from geothermal fields in the United States as a result of stringent inspections (NREL 2012). The BMG is a location where many important cultural and tourism factors interact with important residential, agricultural, and industrial areas. As a result, holistic basin management studies that take into account population density, sensitive areas, and agricultural activities, as well as water resource planning, management, and use while considering natural life and ecosystems, have recently become very important (MoEU 2020). These effects can be reduced through mitigation measures and good practices, as well as training activities, tighter inspections, and the development of new technologies.

It has been determined that the pH limit values in the water sources contaminated by geothermal waters are generally between 7.3-8.6 and are basic in character. In some samples, the pH values showing values between 6.1 and 6.85 (acidic) are due to the mixing of these waters with the acidic geothermal waters. Due to the high concentration of Na^+ ions in thermal waters, the alkalinity of irrigation waters increases. This causes alkalinity in agricultural lands irrigated with water. EC values in the samples taken from the water resources in the research area and negatively affected by the thermal resources were found to be quite higher than normal values. While EC values increase in some years, it decreases with the effect of rain water without salt content in the spring period. EC is important as it is an important criterion for irrigation water quality. As a result of the determination of boron element in thermal springs and the waters where they mix, values far above normal limits have been obtained. Especially the concentration of thermal springs in the water resources in the immediate vicinity varies between 24.5-48.38 ppm. It is the ideal boron concentration of 0.35-1 ppm in irrigation waters. As a result of the analysis performed on water samples that are heavily contaminated with thermal sources in the research area, we see that the Cl concentration is carried to the agricultural lands in remote areas through the wide irrigation system. According to the data of the research area, more than 20 ppm Cl concentration was found.

Soil pollution

When geothermal resources, which are important in terms of flow and temperature, enter the earth, they reach the nearest stream bed based on the topographic structure of the location and contaminate the basins' groundwater and surface water resources. After being used for its intended purpose, water with significant flow and temperature levels is injected underground. But a significant portion of it is mixed with the water system with natural waterways and uses for irrigation (Bolca et al. 2010). Thermal waters have higher levels of radionuclides and heavy metals than drinking water. Because they are hot and have a high salt concentration, they help all elements dissolve in the soil (Kılınç and Yokaş 1987) (Fig. 12-13). There is no doubt that radionuclides and heavy metals carried by thermal waters have an impact on the soils and water accumulation basins (dams, lakes, wells, and streams) along the flow path. Irrigation from these sources may also contaminate plants (Bolca et al. 2010). Leaks from underground storage tanks are among the most common sources of soil pollution, as are the conversion of gases such as carbon dioxide, nitrogen dioxide, and sulfur dioxide resulting from various combustion processes into acid droplets by combining with water vapor in the air, and acid rain, which occurs as a result of acid droplets falling to the earth with rainfall. Acid rain causes pH changes in both water resources and soil. When the pH of the soil changes, some components (heavy metals) become free and the natural structure of the soil deteriorates. All types of wastewater should not be discharged to the soil unless the proper procedures are followed. Contaminated water should not be used in agriculture as irrigation water.

Noise pollution

The noise significance level that may occur as a result of geothermal resource use activities in the project area is rated as "medium." Other industries' and activities' contributions to noise levels are also rated as "medium." However, there is little chance of a cumulative effect in terms of the noise component. Because the distances between the noise sources prevent a cumulative effect from occurring, these sources are considered to be independent noise sources. However, a cumulative effect can be mentioned, especially during the drilling phase when there is a lot of noise and you're close to other noise sources. Although it is not practical or economically feasible to completely eliminate noise generation, it is considered an environmental component that can be taken into account when necessary mitigation measures are implemented, and thus a cumulative effect can be avoided (Fig. 14-15).

Micro earthquakes, induced seismicity and subsidence

Low-intensity seismic activity can be observed depending on the production, re-injection of geothermal fluid for geothermal resource utilization, as well as the temperature and flow rates of these processes. It has been observed in the literature that the induced seismicity values are too low to be felt by humans. Geothermal systems in Western Anatolia's grabens are located in active fault zones, and it has been observed that the microseismic activity corresponding to seismic movements in the region has increased as a result of geothermal fluid withdrawal and re-injection activities. When we examine the magnitude of these earthquakes and the efficiency of the cumulative distributions of the seismic energy they emit over time, it is understood that the number of earthquakes smaller than 4.5 in the region after 2000 increased rapidly. Two different explanations for this change can be made. The first reason may be that small earthquakes remain unrecorded due to the low number of nearby earthquake stations in the region and insufficient azimuthal distribution, and the second reason may be the small earthquake activity triggered by the GPPs that started to be established in the 1975 and increased in number. The production and re-injection values should be determined correctly based on the reservoir's physical and chemical parameters, as well as the rock strength of the forming formations. Otherwise, micro-seismic activities in the rocks may occur as a result of the reservoir pressure decreasing over time during geothermal fluid extraction and the different temperature-pressure changes caused by fluids pushed back into the reservoir through the fault during re-injection. Changes in pore pressure, particularly in rocks, can cause collapse. The effect type is negative because it causes permanent surface deformation. It is a scenario that could occur in uncontrolled production areas. It occurs as the physical properties of the underground change over time and over a long period of time. Permanent damage is caused by deformation that may occur in the production area. This collapse has a negative impact on structures located on the surface, such as residential, road, and other structures. Continuous and long-term micro-seismicity data must be recorded in both exploration and production areas, and measures must be taken when an anomaly is discovered.

Social and economic impact

In the current situation, the negative effects of GPP investment implementations, which have increased in intensity in recent years, have had a negative impact on social acceptance (Fig. 16). Specifically, the negative effects felt in agricultural lands and production processes, as well as the odor felt in urban living areas. In terms of the region's geothermal investment potential, the effects caused concern among residents. The formation of social acceptance, whether negative or positive, occurs over a long period of time. Media analysis conducted as part of the social acceptance project shows that the social acceptance of geothermal energy applications has become a national agenda item and a source of opposition since 2009. As a result, if investors and the general public become more sensitive to stakeholder engagement and mechanisms for benefit sharing are not developed, the possibility of social acceptance will arise, with significant consequences.

Conclusion

Geothermal resources contribute significantly to the production of sustainable energy. However, as with other energy generation activities, it may have environmental consequences. It has been determined that the high concentration of boron element, which geothermal waters contain due to their high temperature and solvent structure, has a toxic effect on plants as a result of condensation in the soil with irrigation. The mixing of hot geothermal waters with high boron concentration into groundwater or surface waters creates a great danger for agricultural areas. Especially in agricultural lands around thermal springs, the concentration of boron is well above the toxicity limit. For this purpose, in order to minimize the harmful effects of geothermal resources on the environment, it is absolutely necessary to return the geothermal waters that come to the earth underground (reinjection). Thus, by giving the geothermal waters coming to the soil surface underground, the possible boron, salinity, heavy metal. In addition to preventing pollution, it will be suitable for feeding the underground geothermal reserve. It necessitates consistent monitoring of activity in order to assess its environmental impacts as part of long-term development planning. GEP facilities and other practices can have an impact on seismicity. Renewable energy sources, which contribute significantly to the fight against climate change while emitting little carbon, should be encouraged. Although there is no luxury of location, it is recommended that wells and production facilities be established away from agricultural production areas and people's living areas. According to scientific evidence, environmentally friendly production is feasible. Thanks to strict supervision practices and systematic evaluations, it appears that existing problems can be minimized. Finally, there is a need to strike a balance between energy-related development and environmental protection.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Consent for participation Not applicable.

Competing interests The author declare no competing interests.

Author contribution Author read and approved the manuscript.

Funding Not applicable.

Availability of data and materials All data used to support the findings of this study are included within the article.

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Tables

Table 1 Chemical analysis results of different years in the geothermal waters of Aydın city and its vicinity (MoAF 2020)

		Y e a r s											
Parameter	**Unit**	**1971**	**1976**	**1988**	**1989**	**1992**	**1994**	**2000**	**2005**	**2007**	**2008**	**2012**	**2017**
Temperature	**ºC**	35	34.8	-	21.6	-	-	37	223.8	38	32	80	43.1
pH	**SU**	6.72	6.5	6.1	7.3	6.1	6.1	6.43	8.6	6.73	6.85	8.8	6.63
EC	µhos/cm	1008	6000	9200	770	11000	10380	1709	-	7320	8700	6280	9720
Na^+	(me/l)	20.7	82	84	14.5	76	60	23	1750	3023	75.13	1503	1690
K^+	(me/l)	5.77	8.8	3.3	11.5	1.6	3.6	33	105	53	4.01	196.64	91.1
Ca^{++}	(me/l)	112	119	20.1	80.2	17	28.9	164	4.8	57.3	7.10	11.63	422
Mg^{++}	(me/l)	90.2	56	8	60.2	7.9	14.1	143	1.2	15.2	4.0	0.793	105
Cl^-	(me/l)	25	24	75	35.4	74	77.4	20	1819	241	39.46	42.58	2687
HCO_3^-	(me/l)	488	696	37.5	52.5	25	16.6	1016	1376	5397	29.96		1647
SO_4=	(me/l)	252	116	2.7	22.8	2.2	16.6	228	133	2321	17.02	105.92	48.4
Aluminum (Al)	(me/l)	-	-	-	-	-	-	-	-	0.74	-	-	-
Si	(me/l)	-	-	-	-	-	-	-	-	31.41	-	-	-
Li	(me/l)	-	-	-	-	-	-	-	-	4.88	-	-	-
Boron (B)	ppm	-	-	-	-	-	-	-	45	48.38	24.5	2.32	2.3

Figures

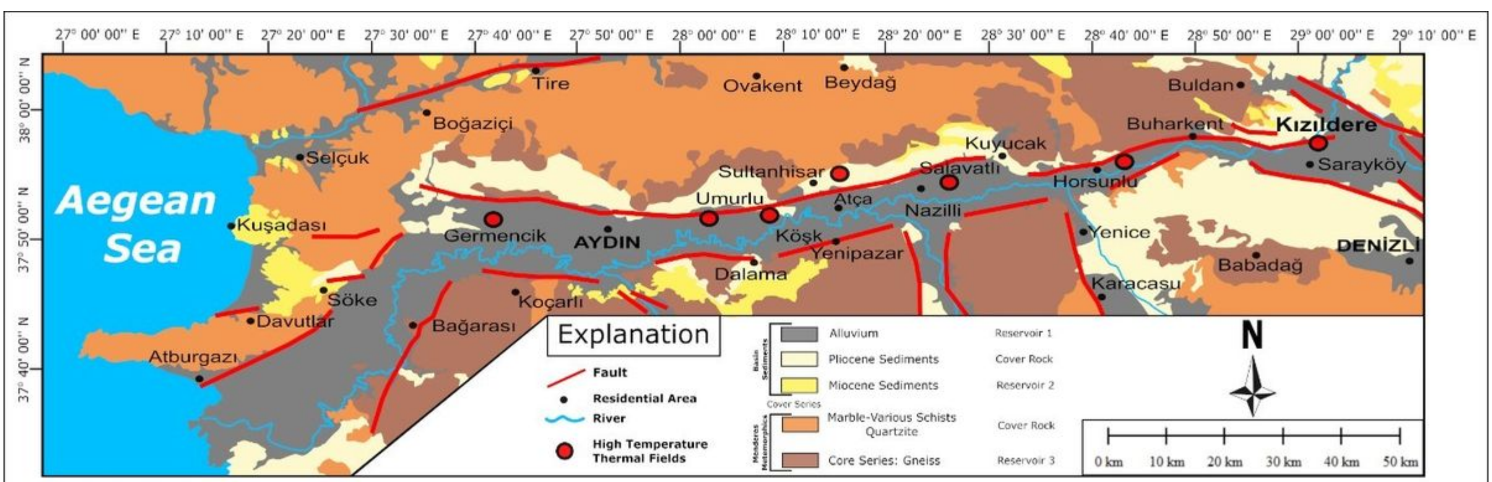


Figure 1

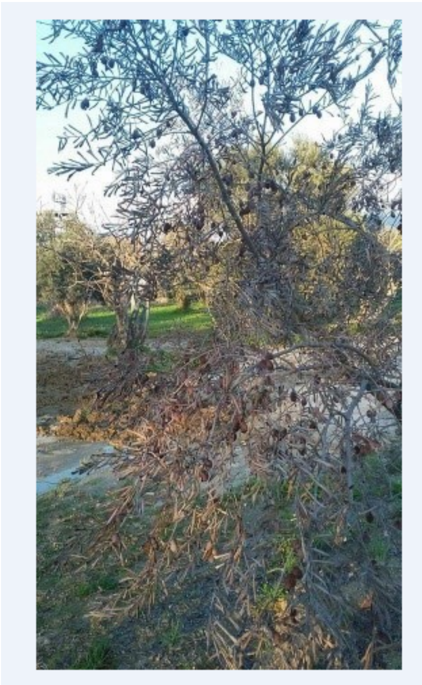
Geothermal fields and tectonic structure in BMG. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

A

B

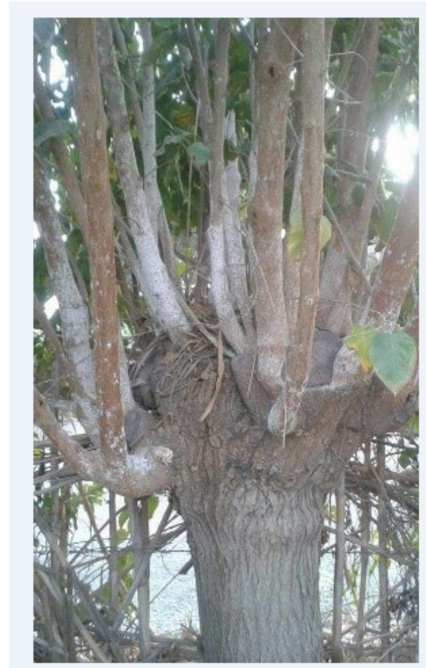
Figure 2

(a,b) Land use and visual impact of GPP



A

B



C

Figure 3

(a,b,c) Impact on flora, fauna and biodiversity

a

b

Figure 4

(a,b) GPP's cooling mechanism from the side

Figure 5

General view from the fig garden close to the facility

a

b

Figure 6

Natural fig (a) and Boron toxicity seen in figs with its geothermal effect (b)

a

b

Figure 7

(a,b) Laying pipes in agricultural areas

a

b

Figure 8

(a,b) Thermal water discharge to stream

a

b

Figure 9

(a,b) The discharge of bentonite used in drilling into the stream

Figure 10

Drilling mud near the greenhouse

Figure 11

Thermal water discharged into the stream

a b c

Figure 12

(a,b,c) Explosion of the borehole and its damage to the land

a b

Figure 13

Olives and mulberry trees drying out as a result of explosion (a) The effect of air emissions on fig (b)

a

b

Figure 14

(a,b) Transmission line studies

a

b

Figure 15

(a,b) View of reinjection wells in the field

a

b

Figure 16

(a,b) Social responses at the site