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# SWOT analysis of a liquid-dominated active geothermal system for non-electrical uses of geothermal energy: A case study, Seferihisar-İzmir

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**Abstract**
There are numerous natural outflows, 3 thermal baths, 9 disused geothermal wells, and 3 private companies operating in the Seferihisar geothermal system, including a power plant generating electricity. The potential of these resources is suitable for non-electrical use of geothermal energy, such as greenhouse heating and thermal tourism. SWOT analysis method has been used to assess the pros and cons of the geothermal resource in Seferihisar, aiding the identification of suitable applications and investments for both present and future projects. The region is rich in terms of geothermal resources and has convenient access to both public and ware transport, which are described as strengths of the resource. However, poor management and an excess of licensed geothermal fields weaken the effective consumption of the system. A huge number of projects have led to opposition from environmentalist groups. The proven technology of geothermal energy has resulted in an increase in incentives and investment consolidations with governmental support. In the light of SWOT analysis, considering SO, ST, WO, and WT strategies, the untapped geothermal resources present in the Seferihisar geothermal system, combined with the natural attractions and cultural richness of the county, will contribute significantly to non-electrical/direct uses of the geothermal energy in the near future.

**Keywords**
Geothermal, direct use, greenhouse, thermal tourism, SWOT analysis

## 1. Introduction

Energy and its types emerge as a great power for energy-dominating countries. A great portion of the countries' energy consumption relies on fossil fuels. As the world's most widely used fossil fuels are evaluated with respect to both their reserves and environmental effects, developed countries have turned face to alternative energy sources due to concerns about climate change depending on the increasing greenhouse gas (GHG) emissions (Cassia et al. 2018). According to the United States Environmental Protection Agency's report records, fossil fuel use is the primary source of $CO_2$. Countries set global goals to limit and reduce greenhouse gas emissions, which are mostly known as Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($NO_2$), and Fluorinated gases (F-gases). In 1997, the Kyoto Protocol was committed to reducing greenhouse gas and carbon dioxide emissions (UN). Consequently, in 2019, by publishing the Paris Climate Agreement, aiming to tackle climate change, the European Union (EU) showed its seriousness about the "European Green Consensus", the focus of which is a clean and sustainable world (UN). European Green Consensus is important not only for EU member states but also for all countries with political, commercial, and geographical relations (Gürsan and De Gooyert, 2021). The agreement aims to reduce greenhouse gas emissions to net zero by 2050 and includes important issues such as "Border Carbon Regulation". In this challenging period the whole world is experiencing in terms of health and energy, with this agreement, also called the "twin cycle", the implementation of more creative and environmentally friendly regulations in the relevant legislation of the countries will be inevitable. At this stage, renewable energy sources have gained importance. The utilization and advantages of renewable energy sources, such as wind, solar, wave, biomass, and geothermal energy, vary depending on their types. While wind, solar, and tidal energy depend on atmospheric conditions, biomass, and geothermal energy, unlike the first three, are independent of climates or atmospheric conditions. Countries endowed with geothermal resources shift their energy investments to geothermal energy rather than fossil fuels. Geothermal energy has various applications, including electricity generation, district heating, greenhouse heating, aquaculture, thermal tourism, and healing purposes. Türkiye has made solid progress in securing supply through renewables within the last 15 years, especially in the geothermal energy sector. In the direct-use category of geothermal energy, Türkiye, with 3488 MWt, is in the first rank among the European countries (Çelmen, 2022). The installed capacity of geothermal power plants for generating electricity in Türkiye is 1682 MWe which places the country in the fourth rank and in the "1 GW country club", after the United States of America, Indonesia, and the Philippines (Tab. 1). In agricultural applications, 4000000 m² (4000 dunam) greenhouse heating and 130.000 HE (House Equivalent) district heating is being operated at present, additionally more than 400 geothermal resource is being consumed in respect of thermal facilities and baths, placing Türkiye in the 4th rank in worldwide direct use of geothermal energy, one house equivalent is being accepted as the energy needed to heat a closed area of 100 m² (Lund and Toth, 2021; Çelmen, 2022).

*Tab 1. Top 10 countries in the world generating electricity with geothermal energy*

| Rank | Country | Installed capacity* (MWe) |
|---|---|---|
| 1 | America | 3794 |
| 2 | Indonesia | 2356 |
| 3 | Philippines | 1935 |
| **4** | **Türkiye** | **1682** |
| 5 | New Zealand | 1037 |
| 6 | Mexico | 962.7 |
| 7 | Italy | 944 |
| 8 | Kenya | 944 |
| 9 | Iceland | 754 |
| 10 | Japan | 621 |
| 11 | Other | 1097 |

*: Installed capacity Year-End 2022 (www.thinkgeoenergy)

Geothermal energy is a very important renewable energy source in the western part of Türkiye, particularly in terms of electricity generation. The tectonic structure and geological features of the Aegean region are very favorable for the formation of geothermal resources, resulting in numerous geothermal fields and potential geothermal fields which have been studied by many researchers (Şimşek, 2003; Karamanderesi and Helvacı, 2003; Mertoğlu et al. 2005; Garg et al. 2015). There are 8 cities, İzmir, Manisa, Aydın, Denizli, Muğla, Afyonkarahisar, Kütahya and Uşak in the region. Regarding the studies carried out by MTA since 1962, all of these cities have geothermal resources within their boundaries (Akkuş et al. 2005). Geothermal fields bearing geothermal fluid at different temperatures are utilized in various applications. Since the geothermal fields located in Menderes and Gediz grabens in western Türkiye have moderate-high temperature geothermal fluids (Gemici and Tarcan, 2002;

Haklıdır, 2017), geothermal power plants (GPP), district heating, thermal facilities, and greenhouse heating applications are intensely implemented in these regions (Tab. 2).

*Tab. 2. Geothermal power plants operating in the Aegean region and thermal facilities* (www.enerjiatlasi.com+ https://kaplica.saglik.gov.tr/)*

| City | Number of GPP | Installed capacity (MWe) | Thermal facility |
|---|---|---|---|
| İzmir | 1 | 12 | 16 |
| Aydın | 32 | 885.45 | 5 |
| Manisa | 15 | 380 | 6 |
| Denizli | 10 | 380.16 | 9 |
| Afyonkarahisar | 1 | 2.76 | 18 |
| **Total** | **59** | **1660.37** | **54** |

94% of the GPP is located in the Aegean region, with a total installed capacity of 1660.37 MWe, the rest 6% of the GPP is located in Çanakkale with a total installed capacity of 30.7 MWe (Fig. 1). According to the Republic of Türkiye Ministry of Health's website, 286 thermal facilities in Türkiye, 91 of them, 32%, located in Aegean region, serve in balneological purposes.

In order to use an energy source correctly, effectively, reliably, and in terms of sustainability of renewable energy, analyzing the features of the resource, the surroundings, and the specific needs of the region in which it is located is important.

In the case of the Seferihisar geothermal field, for utilization of the geothermal resource in a correct way, effectively, reliably, and in terms of sustainability, the features of the resource and surroundings and the needs of the region in which it is located have been described and analyzed. The micro and macro environmental (internal and external) factors of the Seferihisar geothermal system are determined, and feasible strategies are generated to shed light on possible future geothermal projects in the region.

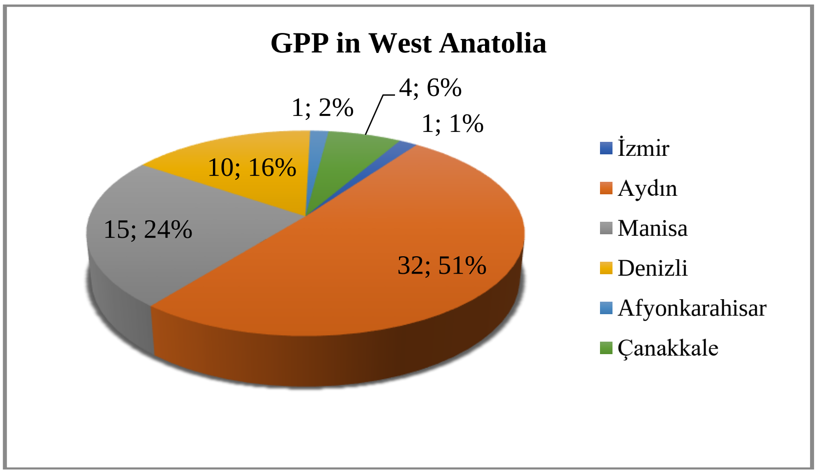


*Fig. 1. GPP located in West Anatolia*

## 2. Material and Methods

The SWOT analysis technique is useful in assessing different types of research and has been subject to various studies and theses (Fig. 2). Numerous researchers used the SWOT analysis method to assess energy strategies, applications, developments, state of the renewable energies, comparison of the energy sources (Ming et al. 2014; Shi, 2015; Abdul 2021; Igliński et al. 2021, Hastuti et al. 2021; Rahman et al, 2022; Romanov and Leiss, 2022). In many studies, internal issues are accepted as "controlled factors" whereas external issues are accepted as "uncontrolled factors" (Sarsby, 2012). SWOT (Strengths Weakness Opportunities Threats) analysis method was explained by Albert S Humphrey in the 1960s in a project at Standford University (Nistor, 2009). The SWOT analysis method is described as taking the information from an environmental analysis to divide it into two groups: strengths and weakness (internal issues) and opportunities and threats (external issues) (Sammut-Bonnici and Galea, 2015). If possible, SO, WO, ST, and WT strategies are assessed following the SWOT analysis. SO strategies make use of the strengths to take advantage of external opportunities; WO strategies focus on the improvement of weaknesses by taking advantage of opportunities; ST strategies aim to use strengths in reducing the impacts of threats; and WT strategies target to reduce weaknesses and avoid threats (David, 2006).

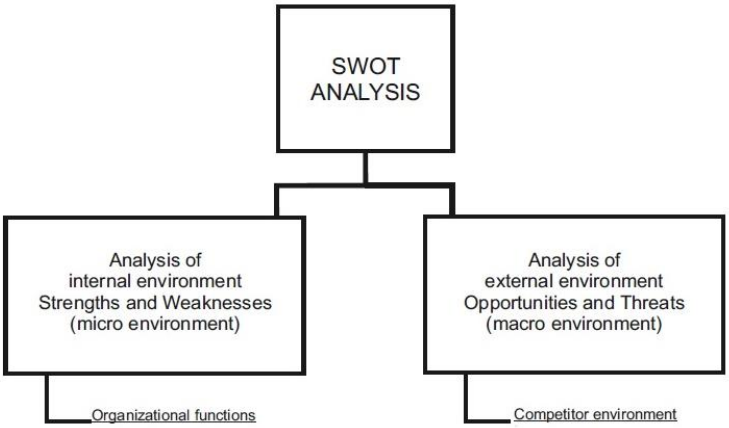


*Fig. 2. SWOT Analysis main components (Sammut-Bonnici and Galea, 2015)*

The SWOT Analysis technique was conducted to examine components and data related to the direct use of the geothermal energy potential of the Seferihisar geothermal system. Physical and geographical conditions, geological and tectonic structure, geothermal resources present within the boundary of the Seferihisar region together with their temperature, flow-rate values and up-to-date situations of the resources, management of the Seferihisar geothermal system, thermal tourism facilities and greenhouse applications in Seferihisar and public resistance constitute the components of the analysis. Following the SWOT analysis, SO, WO, ST, and WT strategies were assessed (Tab. 3).

*Tab. 3. SWOT Matrix (David, 2006)*

| | **Strengths-S** | **Weaknesses-W** |
|---|---|---|
| | Defining the strengths of the case | Defining the weaknesses of the case |
| **Opportunities-O** | **SO Strategy** | **WO Strategy** |
| Defining advantages of the case | Leveraging strengths to capitalize on opportunities | Overcoming weaknesses through the utilization of opportunities |
| **Threats-T** | **ST Strategy** | **WT Strategy** |
| Defining threats of the case | Using strengths in order to eliminate threats | Mitigating weaknesses to eliminate threats |

As the potential of the energy source is the major factor that affects the type and financial parameters of energy consumption, the second method applied to the case data is the calculation of heat capacity. There are several methods, such as stored heat potential calculation, apparent heat potential, planar heat, and magmatic heat budget (Muffler and Cataldi, 1978). The method of surface heat flux involves parameters such as temperature and flow rate of the geothermal fluid, and specific heat of the water at the measured temperature and is useful in calculating the potential energy of geothermal resources and being used by researchers in evaluating the energy consumption trend of geothermal fields and systems (Barylo, 2000; Satman et al. 2007; Boguniewicz-Zabłocka, 2019). The apparent potential energy of the system is assessed by the formula of "method of surface heat flux" (Muffler and Cataldi, 1978) where Q stands for flow rate, Cp specific heat of the water, T1 wellhead temperature, T2 reinjection temperature of the geothermal fluid (Çengel et al. 2019) (Eq. 1).

$$\text{Heat capacity: } Q*Cp*(T1-T2) \qquad (1)$$

## 3. Results and discussion

The strengths, weaknesses, opportunities, and threats of the Seferihisar geothermal system have been determined. SWOT Matrix of the Seferihisar geothermal system regarding the direct use/non-electrical use of geothermal energy with regards to the nature of the resource and social, cultural, and economic issues is constructed. The main components of the matrix are explained below.

### 3.1.Strengths of the Seferihisar geothermal system

- **Richness in source:** Seferihisar geothermal field is one of the significant geothermal fields of Türkiye, and geothermal research and studies were initiated by the General Directorate of Mineral Research and Exploration (MTA) in 1967. Most of the faults located in the region bear geothermal resources and geothermal wells. Two major faults mainly bound the region, the Seferihisar fault from the west and the Tuzla fault from the east, controlling the geothermal system (Fig. 3). Stratigraphically; the Paleozoic aged Menderes Massif metamorphites of crystalline schist and marbles, consist the basement of the region, overlaid by the Mesozoic İzmir flysch bearing limestone blocks and lenses, serpentine and volcanics. Lacustrine sediments of Miocene aged Yeniköy formation rest upon the İzmir flysch with disconformity. At the top of these units, alluvium of Quaternary and Holocene-aged travertine deposits, mostly around the geothermal resources, are observed (Eşder and Şimşek, 1975). İzmir flysch is accepted as the reservoir of the geothermal system, clayey zones of Neogene-Miocene sediments as the cap rock and high geothermal gradient, related to crustal thinning regarding the Curie-depth point map of Türkiye, as the heat source of the low temperature, single-phase liquid-dominated geothermal system (Eşder and Şimşek, 1975; Tarcan and Gemici, 2003; Akkuş et al. 2005, Aydın et al. 2005; Satman et al. 2005). There are numerous natural outflows, 3 thermal baths (in bad condition), 4 abandoned geothermal wells, 5 disused geothermal wells, 2 in-use wells, and 3 private companies operating in the Seferihisar geothermal system (Tab. 4).


*Fig. 3. Location and geological map of Seferihisar geothermal* field through Google image (modified after Eşder and Şimşek, 1975; Sözbilir et al., 2008; Uzel & Sözbilir, 2008)

*Tab. 4. Geothermal resources in the Seferihisar geothermal system*

| Geothermal resource | Name | T (°C) | Q (l/s) | Hc (MWt) |
|---|---|---|---|---|
| **Natural Outflows and thermal baths** | Doğanbey Spa | 51,5 | 0,12 | 0,01 |
| | Doğanbey River-inside | 62 | 1 | 0.11 |
| | Doğanbey spring | 75 | 1 | 0.17 |
| | Karakoç Spa | 64.5 | 4 | 0.49 |
| | Tuzla Spa | 51 | 0,2 | 0,014 |
| **Abondened wells** | DI-1 | 78 | 12 | 2.16 |
| | SH-2 | 76.9 | 1 | 0.18 |
| | G-12A | 74 | 0,1 | 0.016 |
| | G-18A | 90.47 | 61,6 | 14.28 |
| **Disused wells** | DI-1A | 76.26 | 74 | 12.8 |
| | ISD-2013/6 | 54 | 36 | 2.86 |
| | ISD-1 | 68,1 | 15 | 2.1 |
| | SY-1 | 48 | 15 | 0.82 |

| | | | | |
|---|---|---|---|---|
| **In-use wells** | TAÇ-1 | 63,7 | 0,6 | 0.6 |
| | NATADB1 | 41 | 15 | 0.38 |
| **Geothermal investments** | Private company-1 | | | 48 |
| | Private company-2 | | | 112,5 |
| | Private company-3 | | | 60 |
| | | **Total** | | **256.86** |

- **Independent of atmospheric conditions:** In most renewable energy sources, such as solar, hydropower, and wind, outside conditions affect the consumption of the generated energy and its utilization (Rybach, 2014). Geothermal energy is located beneath the earth's crust. Outside conditions do not disturb the harvesting of the geothermal energy. Economically, oil price fluctuations have a minor effect on geothermal energy applications, especially in non-electrical consumptions such as direct use, balneology, and greenhouse heating.
- **Proven technology:** There are numerous projects ongoing around the world and in Türkiye (Georgsson and Fridleifsson, 2008; Hepbaşlı and Özgener, 2004; Aydın and Merey, 2021). Many projects and experience consequently gained in developing technologies in the geothermal sector have led geothermal energy to be considered "proven technology" by investors/entrepreneurs and banks. Examples include Türkiye Çanakkale-Tuzla GPP, Aydın-Gümüşköy GPP, Aydın-Germencik GPP and Denizli-KızıldereIII GPP (Herrera-Martínez, 2017).
- **Convenient access:** The Seferihisar geothermal field is in Seferihisar County, 70 km to the southwest of İzmir city, located in the Aegean region. The county is located 54 km SSW of the İzmir Adnan Menderes International Airport (ADB) and 45 km in the distance to the İzmir city center, as an ease of transportation. Public transport is also available from İzmir city center to Seferihisar and neighboring villages of Seferihisar as well. There are 2 bus lines from İzmir city center to Seferihisar, 2 lines to neighboring villages, and 4 lines from Seferihisar to villages carrying the public.
- **Antique sites**: The geology and tectonic features of the region also contribute to the cultural and archaeological wealth of Seferihisar County. Teos antique site is the only ancient excavation area active in Seferihisar, but there are numerous ancient ruins of the Roman period in Doğanbey and Karakoç geothermal fields as well (Hamilton, 1842). An ancient bath in Ürkmez ancient marble quarries in Sığacık, Turgut, and Kesikkaya villages are the other attractive spots. Karagöl marble quarry is located in the west of Sığacık Bay, 3 km northeast of Teos, 3.5 km to the Seferihisar county center. The Kayadibi locality, in the southeast of Karagöl, was also used as a marble quarry in ancient times as well.

### 3.2.Weaknesses of the Seferihisar geothermal system

- **Non-use of cascaded or integrated consumption of geothermal energy:** As the Seferihisar region is declared a "Tourism Centre and Culture and Tourism Conservation and Development Zone", the Government's priority is to ensure the integrated use of geothermal energy. The geothermal fluid returning from the geothermal power plant is still suitable for non-electrical uses (Dickson and Fanelli, 1996; Mink et al., 2015), but none of the active entrepreneurs in the Seferihisar geothermal system currently implement this cascaded/integrated use presently.
- **Unprofessional management of the system:** The license owners in the field authorize areas where geothermal water freely flows and is not being used for any purpose.
- **Too many licensed geothermal fields:** There are 8 different private companies owning research and operating licenses in the Seferihisar geothermal system by Act no 5686, Law on Geothermal Resources and Natural Mineral Water, dated 2007.
- **The minor interest of the investors:** Bureaucratic distress in the exploration and operation phase of geothermal energy, coupled with the reaction of local people, causes investors to act hesitantly. The current geothermal law in Türkiye employs a two-staged license system. The first stage involves exploration, and the second pertains to geothermal resource exploitation.
- **High investment costs:** Investing in geothermal energy offers a long-term return on investment (Soltani et al., 2021). Preliminary studies, research, and exploration stages incur higher costs than other renewable energy sources.

### 3.3.Opportunities of the Seferihisar geothermal system

- **Sustainability:** Geothermal energy is a renewable energy source by definition, as the energy extracted from the resource is continuously replenished over time scales similar to those required for energy removal in typical/societal systems. However, the system needs to sustain the needed energy for an extended period (Rybach, 2003; Rybach and Mongillo, 2006). The sustainability of geothermal systems is crucial as it encompasses aspects such as reservoir management, operations, related facilities, and economic considerations. Geothermal sites require multidisciplinary studies involving both engineering and geological aspects (Franco and Vaccaro, 2012; Axelsson et al., 2005). Therefore, effective management is necessary to ensure this resource's long-term sustainability. Over-exploiting of the geothermal resources located in the Seferihisar geothermal system, along with the use of inefficient techniques and non-environmentally friendly approaches in geothermal projects, will affect the sustainability of the geothermal system (Hähnlein et al., 2013).

- **Heating/Cooling and industrial applications:** Geothermal energy has been used for various purposes in both ancient and modern times and has been attractive for human beings; even the expression of "well-dressing" was inspired by the decorations of divine springs and wells (Albu et al. 1997). The use of geothermal for healing purposes dates back to the 5$^{th}$ century BC in places historically known as "Asklepios" such as Bergama-Pergamon and İstanköy-Kos Island in Türkiye, Calistoga in California, Teplice in Czech Republic-Bohemia, Bath in England (Albu et al. 1997). Additionally, cooking, bathing, and space-heating were among the other utilizations of geothermal resources. In the early 1800s, the first industrial scale and direct use of geothermal energy was implemented in Larderello, Italy, and a chemical factory was set up in order to extract minerals from the geothermal liquid (Dickson and Fanelli, 1996). Apart from electricity generation, today, many countries take advantage of geothermal energy and consume in non-electrical applications such as mineral extracting, geothermal desalination, space heating and cooling, industrial processes (utilizing cascaded use, such as milk pasteurization and honey processing using geothermal fluid before reinjection), aquaculture, agriculture, balneology and thermal facilities (Yanagase et al. 1983; Lund, 1997; Saevarsdottir et al. 2014; Stringfellow and Dobson, 2021; Bourouni et al. 1999; Goosen et al. 2010; Steins and Zarrouk, 2012; Yadav and Sircar, 2019). It would be misleading to estimate the capacity of thermal facilities operated using this apparent potential, as the heat and volume of hot water required vary depending on the business size. However, it is possible to provide greenhouse heating for a total area of 1767196,8 m² (approximately 1767,2 dunam). The assumed heat demand for heating 1 m² of a greenhouse for 1 hour is 125 kcal, based on outdoor-indoor temperatures of -1°C and +15°C, respectively (Havuz, 2012).
- **No drilling costs:** There are numerous geothermal wells in the region, and utilizing these existing wells in the geothermal region would be an economically beneficial addition to future projects. There are 4 abandoned geothermal wells, 5 disused geothermal wells, and 2 in-use wells, which colllectively reduce the cost of new drills.
- **Incentives regarding direct use of geothermal energy:** In addition to the Government incentives, financial institutions such as the World Bank and the European Bank of Reconstruction and Development also provide loans and grants to investors, supporting numerous geothermal projects of various applications and contributing to local development. In Türkiye Çanakkale-Tuzla GPP, Aydın-Gümüşköy GPP, Aydın-Germencik GPP, Denizli-KızıldereIII GPP have benefitted from these financial supports (Herrera-Martínez, 2017). Also, within the framework of the Tourism Incentive Law No: 2634, the investors are encouraged by the Government through tax discounts, interest support, convenience in investment place allocation, VAT exemption, and customs tax exemption. The amount and rates of these incentives vary according to the region where the investment is located.
- **Developing technology:** In the first years of geothermal energy research, some hydrogeochemical problems have been faced, such as scaling and corrosion (Gunnarsson and Arnórsson, 2005; Tomarov et al., 2015). With the development of new technologies over time, various inhibitors have solved these problems (Soltani et al., 2019).

### 3.4.Threats of the Seferihisar geothermal system

- **Uncontrolled harvesting of the geothermal energy:** In geothermal systems with high temperatures and significant potential, especially in long-term applications, issues may arise, particularly in systems with high $CO_2$ contents, as seen in the Aegean region, including the Seferihisar region as well, due to the wild harvesting of the geothermal fluid (Satman et al. 2017; Şentürk et al., 2020). The geothermal water in the region freely flows and is not being consumed presently. The temperatures of these springs vary between 51°C and 75°C. Some of the licensed wells in the region are not being used either. The geothermal resources located in the Seferihisar are harvested by a few geothermal energy applications, including one geothermal power plant and primitive spa usage.
- **Location-dependent use:** The nature of the geothermal system allows for in-situ consumption. Although it may be transferred via specially designed pipelines to prevent temperature loss, it is typically used in or close to the geothermal field where the geothermal wells/resources are located (Reyes et al., 2002; Miranda and López, 2014; Mahmoud et al., 2021). In certain urban regions, the geography may not be

suitable for the transportation of geothermal fluid (Molar-Cruz et al., 2022). However, in the Seferihisar geothermal system, the terrestrial structure, exhibiting a gentle slope, enables the transportation of the geothermal fluid or the construction of facilities close to it.

- **Public resistance:** Similar to other energy sources, geothermal projects have encountered opposition from local residents living around the source who resist development in certain areas. Local resistance against socially beneficial facilities, described as "Not in my back yard-NIMBY" syndrome pronounced by Rıchman and Boerner in 2006, is an expression that is adaptable for the opposition against geothermal energy projects. From 1985 to 1986, a pilot power plant with an installed capacity of 2Mwe was established on Milos Island, Greece, to generate electricity from geothermal energy. It operated intermittently until 1989. Due to the protests and misinformation of the people living in the vicinity, this power plant is not currently in use. Nevertheless, current efforts are underway to revive plans for establishing a geothermal power plant on Milos Island (Popovski, 2002; Papachristou et al., 2016; 2019). A situation akin to a standstill in geothermal projects due to political circumstances in Kochani Valley, Macedonia, was brought under control by the Government (Dimitrov et al. 2000). The surge in geothermal investigations and investments consolidated by the governmental support led to opposition from environmentalist, including in Türkiye. After two decades of rapid scale-up in renewable energy studies, local people are now not as receptive to these energy investments as they once were.
- **Loopholes in the legal regulations:** Türkiye has specific legal regulations governing geothermal energy. One of Turkey's key laws related to geothermal energy is the "Geothermal Resources and Natural Mineral Waters Law" (Law No. 5686), enacted in 2007. This law provides the legal framework for the country's exploration, development, and utilization of geothermal resources. It delineates the rights and obligations of stakeholders, outlines licensing procedures, addresses environmental considerations, and offers fiscal incentives for geothermal energy projects. Geothermal energy studies, require two distinct licenses: an exploration license and an exploitation/operation license. The legal obligations within the license application process for geothermal fields often cause entrepreneurs to hesitate. It is noteworthy that exploration and exploitation licenses have identical conditions, regardless of the type of geothermal resource utilization. Additionally, there is no obligation for cascaded use within the requirements of these licenses.
- **Environmental issues:** Geothermal fields may cause environmental impacts. These can be listed as gas emissions, noise caused by either drilling or exploitation of the geothermal resource, triggered seismic events, subsidence resulting from a disturbed geothermal reservoir, water pollution, disturbance of surface manifestations, and protection of natural features (Hunt, 2000; Kristmannsdóttir and Ármannsson, 2003; Shortall et al., 2015; Soltani et al., 2021).

## 4. SWOT Analysis: SO, ST, WO and WT strategies

The results of the SWOT Matrix are summarised in Tab. 5. From the analysis of the Strengths (S), Weaknesses (W) , Opportunites (O), and Threats (T) components of the matrix, strategic combinations known as SO (Strengths-Opportunites), ST (Strengths-Threats), WO (Weaknesses-Opportunites) and WT (Weaknesses-Threats) have been identified.

*Tab. 5. The SWOT Matrix of the Seferihisar geothermal system*

| | ***Strength-S*** | ***Weakness-S*** |
|---|---|---|
| | 1. Richness in source | 1. Non-use of cascaded or integrated consumption of geothermal energy |
| | 2. Independent of atmospheric conditions | 2. Unprofessional management of the system |
| | 3. Proven technology | 3. Too many licensed geothermal fields |
| | 4. Convenient access | 4. Minor interest of the investors |
| | 5. Antique sites | 5. High investment costs |
| ***Opportunities-O*** | ***SO- Strategies*** | ***WO- Strategies*** |
| 1. Sustainability | SO1.Ensuring the sustainability of rich resources | WO1. Reinjection of geothermal energy after use |
| 2.Heating/Cooling and industrial applications | **SO2.Greenhouse applications, balneology, and thermal tourism** | WO2.The use of hot fluid returning from thermal tourism in greenhouse and aquaculture applications |
| 3.No drilling cost | SO3.Rehabilitation of the previously drilled geothermal wells | WO3.Existing previously drilled well in the field will reduce the cost |
| 4.Incentives regarding the direct use of geothermal energy | SO4.Proven technologies and experiences in the sector enable the government to encourage geothermal investors | WO4.Incentives may encourage investors in geothermal energy application projects |

| | | |
|---|---|---|
| 5.Developing technology | SO5.Encouraging geotourism in the region, including antique sites | WO5.By using the new technologies, obtaining by-products of geothermal energy |
| ***Threats-T*** | ***ST- Strategies*** | ***WT- Strategies*** |
| 1. Uncontrolled harvesting of the geothermal energy | ST1.Controlled use of the resources and wells | WT1.Organized cascaded use will bring control to the geothermal system |
| 2.Location-depended use | ST2.Geographically suitable climate for greenhouse, thermal, and balneological purposes | WT2.Easy access to the region facilitates control and inspection mechanism |
| 3.Public resistance | ST3.Rehabilitation of the pre-existing wells will not cause additional environmental concern | WT3.Accurate information for the public regarding the exploitation purpose of the geothermal system |
| 4.Loopholes in the legal regulations | ST4.Conservation of the antique sites and projects, including these sites | WT4.Eliminating the deficiencies of the current law |
| 5. Environmental issues | ST5.Preventing entrance to protected areas by organizing cultural tours to preserved antique sites | WT5. Detailed preliminary studies before carrying out the project |

## 4.1.SO Strategies for the Seferihisar geothermal system

Among the identified qualifications of geothermal utilization, the "greenhouse applications, balneology and thermal tourism in Seferihisar (SO2)" strategy has been thoroughly assessed and chosen as the primary focus among other strategies for the Seferihisar geothermal system.

- **Ensuring the sustainability of rich resources (SO1):** Minimizing intervention in the internal dynamics of the geothermal reservoir, such as pressure and temperature, is crucial for ensuring the sustainability of the resource. Hence, as emphasized by current law, the reinjection of the geothermal fluid must be implemented in future projects. Also, an increase in the distance between the reinjection and production wells, a requirement for future projects, will also affect the sustainability of resources in the Seferihisar geothermal system (Hähnlein et al., 2013).
- **Greenhouse applications, balneology, and thermal tourism in Seferihisar (SO2):** Most of the greenhouse cultivation areas in the world are found in countries around the Mediterranean basin. Türkiye ranks fourth globally in terms of greenhouse area and second among Mediterranean countries, following Spain (Öztekin and Örs, 2022). Türkiye is a leader in geothermal greenhouse heating both in Europe and worldwide (Lund and Toth, 2021). The Government in Türkiye declared some regions as organized industrial zones through legal regulations to foster a more organized economic structure, industrialization, and production process. There are 15 zones designated as "Agricultural Specialized Organized Zone-ASOZ" in Türkiye, established with the support of government policies, including interest-bearing long-term loans. Among these, 4 zones are dedicated to the greenhouse industry, comprising a total of 140 greenhouses (Ülgen, 2020). These zones are similar to Special Economic Zones-SEZ's widely popular industrial development tool, but ASOIZ is based on agro-industry. Various kinds and forms of SEZs have been used as policy instruments for ages. Gibraltar (1704), Singapore (1819), Hong Kong (1848), Hamburg (1888), and Copenhagen (1891) are some of the examples to underline the history of SEZ (FIAS, 2008). ASOIZ, an agro-industry-based zone, is officially defined in the Official Gazette dated 06.02.2019 as "Agricultural Specialized Organized Industrial Zone-(ASOIZ)." It refers to an area established by public legal entities or persons, serving as a production area for goods and services. This includes vegetal and animal production as well as industrial facilities for processing these, thereby integrating the agriculture and industry sectors. In regions with a geothermal energy resource, the establishment of ASOIZ is a priority, and the mandatory reinjection of the geothermal fluid is also required. Amendments to the regulation on ASOIZ in Türkiye have facilitated the establishment of these zones. This is further supported by the priority given to the "Supporting Rural Development Investments Project" of the Türkiye Republic of the Ministry of Agriculture and Forestry, emphasizing the use of alternative energy sources. The first ASOIZ in Türkiye has been announced and established in Denizli Sarayköy. In the greenhouse industry, the most significant expense items are space heating and maintaining optimum plant moisture levels (Özgener and Koçer, 2004). The use of geothermal fluid for heating greenhouses in Saraköy ASOIZ will significantly reduce the heating costs, providing an advantage for greenhouse cultivation. The planned regions and their properties are given below (Tab. 6), and infrastructure works for these announced ASOIZ are still ongoing. Seferihisar geothermal system is extremely suitable for the establishment of ASOIZ, considering both the terrain and the features of the geothermal fluid.

Tab. 6. ASOIZ in Türkiye*

| City-county | Area (m²) |
|---|---|
| Denizli-Sarayköy | 712000 |
| Aydın-Kadıköy | 717300 |
| Ağrı-Diyadin | 1297000 |
| İzmir-Dikili | 3038834,97 |
| Kütahya-Simav | 1185000 |
| Nevşehir-Kozaklı | 1352000 |
| **Total** | **5575834,97** |

*: Türkiye Republic of Ministry of Agriculture and Forestry website (access date 20.12.2022)

As the pandemic affected the entire world and altered societal routines, travel, and holiday habits have consequently changed. People are more inclined to visit places where they can both heal and rest simultaneously. The traditional concept of vacation, centered around the trio of sea, sun, and coast, has evolved into journeys in which nature and cultural tours take precedence. As a result, destinations abundant in natural and archaeological sites are currently one step ahead, and Türkiye is among the leading countries in this regard. There are 233 zones classified as Tourism Centres and Culture and Tourism Conservation and Development Zones in Türkiye and 286 recorded thermal facilities as per information obtained from the website of the "Republic of Türkiye Ministry of Health, General Directorate of Public Health". Most of these facilities are located in the Aegean region. According to the official and current data from the Ministry of Culture and Tourism of the Republic of Turkey, Seferihisar has 261 facilities with operating licenses and 59 facilities with investment certificates. The number of simple accommodation facilities is 1386 (Tab. 7). Currently, only one facility uses thermal water with a transport system. The transportation method should be approached cautiously, as even the use of pipelines presents challenges that are currently being addressed earnestly (Montegrossi et al., 2013; Boch et al., 2017). Considering the geothermal potential and features of the system, thermal tourism and balneological facilities are extremely suitable for future projects in the region.

*Tab. 7. Tourism facilities in Seferihisar**

| | Operating license | Investment certificates | Simple accommodation |
|---|---|---|---|
| **Number of facilities** | 261 | 59 | 1386 |
| | | Total | 1706 |

*: Ministry of Culture and Tourism of the Republic of Turkey (access date: 14.12.2022)

- Utilizing previously drilled geothermal wells by rehabilitating them contributes economically to projects to be implemented in the region and saves time. Proven technologies and experiences in the sector encourage the government to support geothermal investors (SO3).
- The other opportunitive strength of the Seferihisar geothermal system is that the region was declared a "Tourism Centre" on 07.12.1985 according to the Official Gazette in issue numbered 18951. Although there are two little separate rooms, each 25 m² in area, in Doğanbey and one single room of approximately 6 m² in the area in Tuzla, serving in primitive conditions, these are only being used by either local people or outsiders learned in one way. Also, future projects involving geotourism in the region, including antique sites, will increase the region's contribution in terms of tourism (SO4-SO5).

### 4.2.WO Strategies

- As stipulated in the law regulating the exploration and exploitation of geothermal resources in the country, it is important to re-inject geothermal fluid after utilization (WO1).
- The use of hot fluids that return from thermal tourism before reinjection in greenhouse and aquaculture applications will contribute to the region economically and employ the local people (WO2).
- Using the existing previously drilled wells in the field will reduce the cost (WO3).
- Incentives encourage investors in geothermal energy application projects (WO4).
- Adopting new technologies and utilizing by-products from geothermal energy are among the other strategies (WO5).

**4.3.ST Strategies**

- The geothermal wells and resources should be used in a controlled manner (ST1).
- The region is geographically suitable and has a convenient climate for greenhouse, thermal, and balneological purposes. Rehabilitation of the pre-existing wells will not cause additional environmental concerns (ST2).
- It is suggested that a comprehensive approach to safeguarding historical sites while also acknowledging and incorporating related projects that contribute to the overall conservation and understanding of these valuable antiquities (ST3).
- Also, a controlled and intentional approach to managing access to protected areas ensures that visitors can still appreciate and learn from the historical significance of these sites through organized cultural tours while preventing unsupervised or potentially damaging entrances (ST4-ST5).

**4.4.WT Strategies**

- Implementing organized cascaded use will bring control to the geothermal system. Cumalı spa, located 250 m SSW of the GPP in Cumalı, is dried up after the GPP has started operation. A cascaded use would be revitalizing for this spa (WT1).
- Easy access to the region facilitates control and inspection mechanism (WT2).
- Providing accurate information to the public regarding the purpose of exploitation of the geothermal system is essential and will reduce public reaction (WT3).
- Eliminating the deficiencies of the current law. In order to encourage gradual utilization, secondary use of the returned hot water may be made mandatory during the operation license stage (WT4).
- Detailed preliminary studies should be conducted before carrying out a new project in the region (WT5).

## 5. Conclusion

Assessing the pros and cons of geothermal energy resources is crucial before determining their intended use. Therefore, the SWOT Analysis method has been conducted in the Seferihisar geothermal system. The performed SWOT Analysis Matrix identified the Strengths, Weaknesses, Opportunities, and Threats of the case, leading to the formulation of corresponding SO (Strengths-Opportunities), WO (Weaknesses-Opportunities), ST (Strengths-Threats), and WT (Weaknesses-Threats) strategies. The apparent potential of the Seferihisar geothermal system aligns well with greenhouse heating. Geothermal energy is independent of atmospheric conditions and has a proven technology. The region is geographically accessible and falls within the incentive zone for culture and tourism, featuring archaeological sites. These factors strengthen the region in terms of direct use. Despite the presence of numerous licensed geothermal areas in the region, the non-use of cascaded or integrated consumption of geothermal energy, together with unprofessional management of the system, weakens the geothermal system. Sustainability, fiscal ease, and technological developments present opportunities for the geothermal region. However, the uncontrolled harvesting of geothermal energy, which relies on location-dependent usage and faces opposition from the public and ecological groups, threatens the direct use of geothermal energy. The Seferihisar geothermal system is highly suitable for establishing an Agricultural Specialized Organized Industrial Zone (ASOIZ) due to the terrain and features of the geothermal fluid. The region offers a substantial untapped energy potential and convenient access for the transportation of goods, providing additional advantages for the direct use of geothermal energy in ASOIZ. Moreover, the availability of suitable incentives, grants, and opportunities for cost reduction through developing technology makes it an attractive prospect for investors and entrepreneurs. Despite the potential threats posed by the uncontrolled harvesting of geothermal energy and the opposition from the public and ecological groups, geothermal energy remains one step ahead of renewable energies. The declaration of Seferihisar as the "İzmir Seferihisar Thermal Culture and Tourism Conservation and Development Zone" in accordance with the Tourism Encouragement Law No. 2634 will facilitate the development of thermal tourism in the county. Considering the SWOT analysis, the untapped geothermal resources present in the Seferihisar geothermal system, combined with the county's natural attractions and cultural richness, will contribute significantly to non-electrical/direct uses of geothermal energy in the near future.

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