Energy for Sustainable Development 79 (2024) 101417

Contents lists available at ScienceDirect

Energy for Sustainable Development

journal homepage: www.journals.elsevier.com/energy-for-sustainable-development

Opportunities and challenges of geothermal energy in Turkiye[1]

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A R T I C L E I N F O

Keywords:
Geothermal energy
Turkiye
Challenges
Barriers
Opportunities

A B S T R A C T

As a domestic and non-intermittent resource, geothermal energy offers countries a clean and sustainable energy option while setting their energy mix strategies. Turkiye, endowed with rich energy fields, stands out as one of the fastest-growing countries in geothermal energy. The dramatic installed power capacity increase and significant expansion in the geothermal energy market, particularly after 2010 following the initiation of the incentive scheme, are pretty remarkable. Nonetheless, it is also evident that geothermal energy investments in the country have shown a decreasing trend in recent years. At this point, this paper aims to reveal the opportunities and challenges in the development of geothermal energy as the first comprehensive qualitative analysis for Turkiye. Furthermore, it evaluates the diffusion of geothermal energy in Turkiye based on the Technological Innovation Systems (TIS) framework to gain insight into the Turkish geothermal sector. According to the interviewees, financial and political barriers such as high investor costs, insufficient incentives for power generation, and the lack of incentives for direct utilization, along with lengthy and exhausting permitting processes, still hinder the prevalence of geothermal energy utilization in the country. Respondents find that Geothermal suggests a huge opportunity for the Green Energy transition in Turkiye and aids economic development through increases in employment opportunities and household welfare using combined uses in district heating, electricity, and greenhouse usage.

Introduction

In line with the Paris Agreement, which urges reducing carbon emissions and reaching net zero by 2050, energy transition constitutes one of the essential items on countries' agendas today. Along with the scenarios of abandoning fossil fuels, countries race to develop new technologies that will ensure the integration of renewable energy sources into the grid and increase the flexibility of energy systems. Among other renewable sources, geothermal energy is essential in providing a stable energy supply, allowing continuous electricity generation regardless of the weather conditions (Kubota et al., 2013). It has a less ecological effect as a source requiring less land (Li et al., 2015). Geothermal has a higher capacity factor of up to 96 % than other renewable systems (Lund, 2003) and lower emissions than coal and natural gas, making it a critical tool for nations' zero carbon targets.

As a part of the Agreement since 2021, Turkiye has prioritized long-term strategy and action plans to accelerate emissions mitigation. The energy sector, accounting for the largest share of national CO_2 emissions, has required special attention. As having a clean and sustainable energy strategy to increase the percentage of domestic and renewable energy in electricity production, Turkiye generated 42 % of its electricity from renewable energy sources in 2022, and its renewable capacity constituted 54 % of its total installed capacity (EMRA, 2023).[2] In the recent National Energy Plan (2022–2035) of Turkiye, it has been declared that the share of wind and solar energy plants in electricity generation, which was 11.7 % in 2020, will gradually increase to 34.3 % by 2035 while decreasing share of fossil fuels, commissioning of nuclear plants, and accelerating investments in storage technologies. All these scenarios suggest that Turkiye will not entirely phase out its fossil plants in the medium term and will continue to rely on intermittent energy

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[1] This paper constitutes a chapter of Aysun Korucan's Ph.D. dissertation studies at the Department of Economics of Middle East Technical University (Ankara, Turkiye) under the supervision of Pinar Derin-Gure.

[2] Licensed and unlicensed power plants are included.

https://doi.org/10.1016/j.esd.2024.101417
Received 2 January 2024; Received in revised form 7 February 2024; Accepted 16 February 2024
Available online 16 March 2024

sources in its power generation, which underscores the importance of geothermal energy in the successful energy transition of the country.

After commissioning the first geothermal plant in 1984, the installed power capacity in Turkiye has expanded rapidly over time. As the first in Europe and the fourth globally today, it has a vast potential for geothermal energy. In 2020, Turkiye was the country with the highest capacity increase since 2015 (Huttrer, 2021). Energy strategy documents frequently stressed its commitment to further developing geothermal energy. In the Tenth Development Plan (2014–2018) of the country, there was the goal of "Consistent with the target of reducing foreign dependency on energy production, exploration activities aiming at identifying the potential of domestic resources, such as lignite and geothermal, will be increased to the maximum extent." Similarly, in the National Energy Plan 2022 of Turkiye, the target is that "The installed capacity of geothermal and biomass power plants will reach 5.1 GW in total by 2035."

Today, geothermal energy constitutes 2 % of the total installed capacity in the country and gets a share of 3 % in electricity generation. While the share of geothermal energy may seem insignificant initially, a different perspective emerges when comparing its electricity generation performance with solar and wind. According to EMRA (2023) data, wind and solar energy constituted 11 % and 9 % of the total installed capacity in 2022, generating only 11 % and 4 % of Turkiye's total electricity. In light of these figures indicating that geothermal energy outcompetes its renewable rivals in capacity-based electricity generation, the increasing geothermal capacity can present an opportunity for more efficient electricity generation in the country. It is also important to mention that Turkiye is Europe's biggest Geothermal energy producer and 4th in the world, following the US, Indonesia, and the Philippines.

Besides electricity generation, geothermal energy proposes other direct utilization applications. Compared to power generation, Turkiye has much greater potential in direct utilization, which can remarkably contribute to its economic growth.

Nonetheless, investments in the geothermal energy market, with remarkable capacity growth after 2010, have declined dramatically recently. Furthermore, geothermal investments have lagged far behind the ones in solar and wind. Therefore, it is vital to reveal the barriers affecting the growth of the Turkish geothermal energy market while highlighting the opportunities. At this point, applying a qualitative analysis will allow us to deal with the issue holistically. This way, different opinions, needs, and demands in the geothermal energy sector will be revealed. As far as we know, this is the first study using semi-structured interviews on the opportunities and challenges of geothermal energy for Turkiye.[3] Furthermore, as a theoretical framework, this paper adopts Technological Innovation Systems (TIS) to focus on the specific functions that can influence the development and diffusion of geothermal energy in Turkiye.

The paper is composed of six sections. Following the introduction, the geothermal energy outlook in Turkiye is provided in Section 2, and the literature on challenges and opportunities in geothermal energy development is introduced in Section 3. After presenting the frame of the qualitative interview study and methodology in Section 4, the challenges and opportunities specific to the Turkish geothermal energy sector in stakeholders' views and European policy perspective are discussed in Section 5. Finally, Section 6 concludes the paper.

Geothermal energy in Turkiye

Turkiye's location on the Alpine-Himalaya orogenic belt, with young faults and active volcanism, accounts for its great potential in geothermal energy (Kaya, 2012). While geothermal resources are spread over many parts of the country, those for power generation exist in Büyük Menderes and Gediz Grabens, in Western Anatolia, where the exploration and drilling activities were mainly concentrated. According to the General Directorate of Mineral Research and Exploration of Turkiye (MTA), 90 % of geothermal resources in the country are with low to medium enthalpy, suitable for direct utilization applications (district heating, thermal tourism, various industrial applications, etc.), while only 10 % is for power generation.

Geothermal research and investigations in Turkiye have been carried out since the 1960s and accelerated mainly after the 1970s. Following a pilot power plant with a capacity of 0.5 MWe installed in the Denizli-Kizildere geothermal field in 1974, a plant with a 17.4 MWe was commissioned at the exact location in 1984 (Akpınar et al., 2008; Serpen & DiPippo, 2022) as Europe's second biggest geothermal power plant after Italy. Nonetheless, after this promising development, geothermal power generation activities in the country progressed very slowly for over 20 years (Tut Haklidir, 2015). Indeed, the adoption of the Law on Geothermal Resources and Natural Mineral Waters in 2007 setting the rules for the exploration and exploitation of geothermal resources, and the amendment in 2010 to Renewable Energy Law offering a feed-in tariff mechanism (YEKDEM) that was 10.5 USD/MWh and for ten years from the commissioning date, were two critical milestones for the geothermal energy sector. Additional incentives were also provided to the plants for their locally produced equipment. Following these developments, geothermal energy investments for power generation in the country increased significantly along with the great interest of the private sector. With the amendment in the YEKDEM mechanism in 2021, it was decided to give incentives in Turkish Lira for the power plants that will be put into operation until the end of 2025.

Other than feed-in tariffs and European Bank for Reconstruction and Development (EBRD) funds, the Geothermal Development Plan funded by the World Bank was realized in Turkiye by 2018. This project executed by the Development Bank of Turkiye has two components: a loan facility for resource development and Risk Sharing Mechanism (RSM). The RSM aims to cover 40 % to 60 % of the cost of failed wells and facilitate exploration drilling in new areas (TÜBA, 2020) as an early-stage risk-mitigating scheme for investors.

The geothermal energy market for power generation has grown tremendously over the past 20 years. As of 2024, there are 67 geothermal energy licenses for electricity generation, and the total operational installed capacity reached 1691 MWe, which was 14.801 MWe in 2003. The country aims to reach 4000 MWe by 2030 (Lise & Uyar, 2022), given that its potential is estimated at 4500 MWe (Mertoglu et al., 2021).

As seen in Fig. 1, geothermal energy investments in the country were on the rise, particularly in 2012, 2016, and 2018. To illustrate, in 2018, ten power plants received electricity generation licenses for a total capacity of 283.96 MWe. One of the main reasons for these capacity expansions was the existence of incentives offered to the plants under the mechanism of YEKDEM after 2010. As of 2015, production, injection wells, and accelerating exploration and drilling activities have increased remarkably. Investments in research and development, funded mainly by the private sector from 2015 to 2019, totaled $US 2.3 billion. For field development and drilling, they were $US 1.2 billion (Huttrer, 2021), which can be another factor accounting for the capacity jump in the country between 2016 and 2019.

On the other hand, capacity increases have recently remained less limited than in previous years. Indeed, the geothermal power sector will become less attractive for investors by 2022, which raises some important research questions: Why did the sector, which grew drastically with incentives after 2010, enter a period of stagnation again? Was this only due to the changes in the incentive scheme in 2021, or were there other structural problems triggering this slowdown?

The geothermal resources in Turkiye are the best suited to direct utilization applications such as district heating, greenhouse heating, use in thermal facilities and hotels heating, agricultural drying, geothermal cooling, and ground source heat pump applications. In 2020, Turkiye

[3] Same semi-structured interviews had been performed in Iceland, Belgium and Italy within the Geosmart Project.

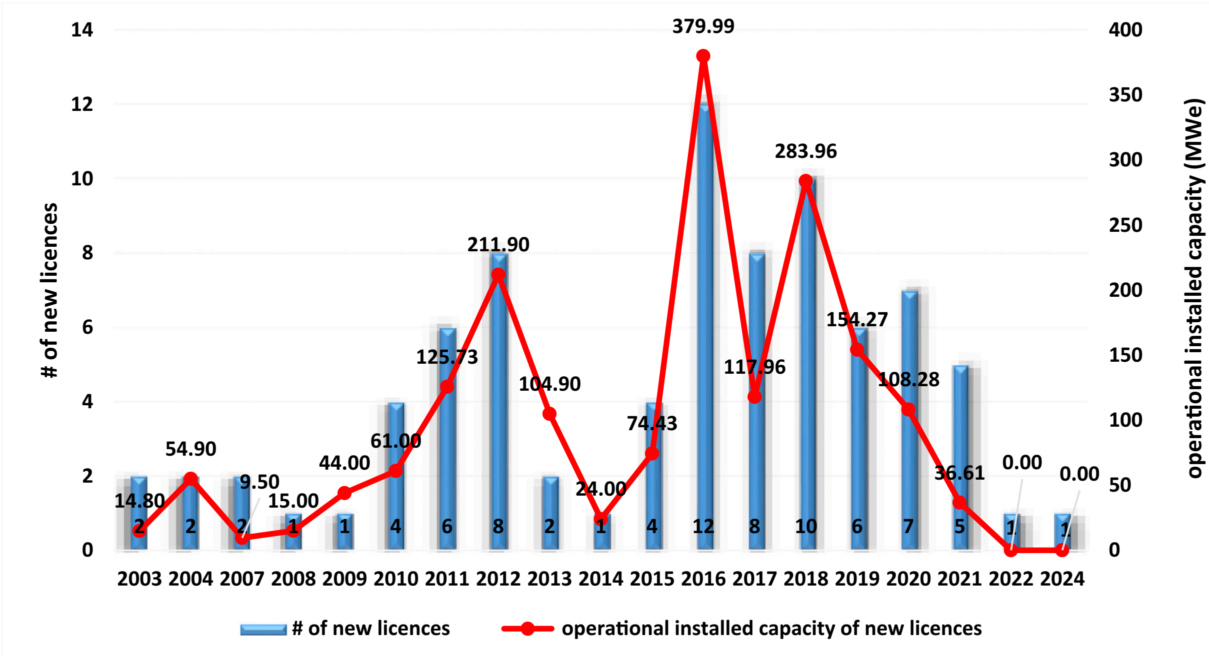

Fig. 1. Number of new licensed geothermal plants and their contribution to total operational installed capacity in 2003–2024[a]. **Source:** Authors' illustration based on EMRA (n.d.).

[a]Note that 16 licenses corresponding to the installed capacity of 129.889 MWe have been terminated or canceled by the authorities over time.

ranked second globally regarding its installed capacity for direct utilization of geothermal energy without heat pumps after China (Lund & Toth, 2021). The country's installed capacity for direct utilization was 5113 MWt in 2022, and its target is to reach 11,150 MWt, given that its potential is estimated at approximately 15,000 MWt. The distribution of direct utilization areas of geothermal energy in 2022 has been realized as 47.8 %, 27.8 %, 24.1 %, and 0.4 % for thermal tourism, district heating, greenhouse heating, heat pumps, and geothermal drying, and cooling applications, respectively (Şener et al., 2022). Indeed, according to the Turkish Geothermal Association data,[4] Turkiye can heat 158,000 dwellings with geothermal energy today, thus significantly saving natural gas consumption. Mesin and Karakaya (2023) indicate that geothermal district heating systems in Turkiye will provide a substantial economic advantage when heating with coal, gas, or electricity is given up.

Different institutions are responsible for geothermal energy resources in Turkiye. While continuing its geothermal exploration, development, and drilling activities, MTA provides the appropriate fields to investors through tenders. After license applications for geothermal resource exploration and operation are evaluated by the General Director of Mining Affairs (MAPEG), Invest and Coordination Agencies (YIKOB), subordinate to governorates in the provinces, issue the related licenses. The Energy Market Regulatory Authority (EMRA) examines the license applications for electricity generation and gives a license if it deems it appropriate. Furthermore, it examines and accomplishes the applications of plant operators for the YEKDEM mechanism.

Literature review on challenges and opportunities of geothermal energy development

Geothermal energy offers many advantages to resource-rich countries, such as allowing energy diversification, leading to stable electricity prices, offering a clean energy option, and contributing to regional development (Noorollahi et al., 2019). It helps countries alleviate their reliance on fossil fuels and intermittent renewable sources, given that climate change poses severe uncertainty on energy generation for countries (Guangul & Chala, 2021). On the other hand, there are some barriers to geothermal energy development, mainly centering on specific subgroups such as technical, political/legal, economic/financial, social/educational, and environmental. Although many items exist in each subgroup, some are the common problems experienced in most countries.

As discussed in many studies, high risks of failure while exploiting, high geothermal well cost, higher CAPEX, more extended construction, and longer payback time are the common features of geothermal energy investments (Bai & Patil, 2014; Li et al., 2015). Indeed, these structural problems account for geothermal projects' lagging behind other renewables with their rapidly increasing competitiveness, such as wind and solar. When considering the levelized cost of electricity between 2010 and 2020, it increased by 45 % for geothermal, decreased by 85 % for solar PV, and 56 % for onshore wind (IRENA, 2021). At this point, supporting geothermal projects that struggle with technical and financial problems becomes vital. Taleb (2009) indicates that the lack of government-led incentives in Saudi Arabia is an essential political barrier to progressing geothermal energy in the country, considering the high upfront capital costs. Providing financial incentives such as capital-investment subsidies or rebates can be critical for increasing the utilization of geothermal in the country. Furthermore, meeting the cost of failed wells in the exploration stage, offering feed-in tariffs for electricity generation, and providing tax benefits can support the development of geothermal projects (Sanchez-Alfaro et al., 2015).

In many countries, geothermal energy falls under the mandate of different institutions. Nonetheless, the lack of institutional coordination on geothermal issues makes the processes from exploration to exploitation difficult for investors, along with uncertainty in procedures. In addition, the absence of clear and comprehensive regulations regarding land use and exploration rights makes negotiating between investors, landowners, and local communities more challenging (Sanchez-Alfaro et al., 2015). Lengthy approval and permit procedures before drilling

[4] Retrieved August 20, 2023, from http://www.jeotermaldernegi.org.tr/sayfalar-Turkiye-de-Jeotermal

operations are other obstacles to geothermal projects (Bai & Patil, 2014). Indeed, the fact that there are many institutions that investors can apply to and that there is not enough information about the permit and legal processes causes many projects to be delayed or not realized (Shah et al., 2019). Hence, an integrated and centralized management agency seems critical for implementing geothermal projects (Pan et al., 2019).

Inadequate technology and R&D studies, lack of skilled professionals, and non-availability of industrial standards are some technical barriers to the implementation of geothermal projects. At this point, the new technologies that will reduce drilling costs can play an essential role, given that the drilling costs account for approximately 40–60 % of total project costs (Bai & Patil, 2014). Nonetheless, geothermal projects require more sophisticated machinery by nature, and most of the technology is imported from other countries, which makes the operation and maintenance of these types of equipment with current human resources more challenging (Puppala et al., 2022). Moreover, inadequate R&D studies and investments prevent domestic manufacturing of these technologies (Shah et al., 2019). As another point, it takes many years to specialize a staff generally from geothermal sciences and engineering in geothermal concepts. The operation of complex processes in the field necessitates skilled professionals, so deliberate human resource management (Noorollahi et al., 2019). The lack of industry standards specific to geothermal and generally applying those regarding conventional generation plants also puts a strain on providing energy conservation and emission reduction requirements for geothermal plants (Bai & Patil, 2014).

Another critical barrier to geothermal development is low social acceptance. The literature on this specific theme has flourished rapidly in recent years. There are many studies indicating the low social acceptance of geothermal energy, such as Rosso-Cerón and Kafarov (2015) for Colombia, Pellizzone et al. (2015) for Italy, Liu et al. (2018) for China, Payera (2018) for Chile, Im et al. (2021) for Korea and, Tunçbilek and Yılmaz (2022) for Turkiye. Limited public knowledge, environmental awareness of geothermal energy, and resistance to change are some factors determining the social acceptability of geothermal, as in the example of Saudi Arabia (Taleb, 2009). In the study evaluating the barriers to harnessing geothermal energy in India, Puppala et al. (2022) regard the fear of consumer acceptance and lack of knowledge on benefits and drawbacks as social challenges for developing geothermal projects. Indeed, the significance of social acceptance becomes more evident when large-scale projects are realized, as in Pakistan (Shah et al., 2019), and social resistance increases as these projects progress and cause some environmental problems (Yasukawa et al., 2021). Furthermore, the perception of induced seismicity by geothermal drilling, negative impacts on limited water resources, and lack of communication between the stakeholders in consultation processes and project development can be other drivers triggering the local resistance to geothermal (Dowd et al., 2011). Given that social acceptance is one of the critical elements to initiate a geothermal project, focusing on reducing unfavorable impacts of geothermal on the locals, providing additional benefits to them, and stimulating community engagement can be effective strategies to increase social acceptance (Karytsas & Polyzou, 2021).

Concentrating on the opportunities and challenges of geothermal energy for Turkiye, it is evident that even though some studies address this specific issue, there is no comprehensive qualitative analysis for Turkiye. Among these studies, Aksoy (2014) points out resource risks, increasing investment costs, environmental problems caused by emissions, and improper reinjection operations in the Turkish geothermal energy sector. Halaçoğlu et al. (2017) highlight the importance of accurate resource data to make reliable assessments in the exploration areas, cooperation between the private sector and academia, offering different incentive mechanisms to investors (feed-in tariff, local manufacturing incentives, tax exemptions, etc.), and funding geothermal projects. Teke and Yaşar (2018) address the urgent need for efficient resource management, effective monitoring and control mechanisms, reduced bureaucracy, and measures to prevent environmental pollution. To evaluate the country's potential, Zaim and Çavşi (2018) emphasized providing a national plan for geothermal development, establishing a governmental organization directly responsible for geothermal projects, the existence of government-supported geothermal plant investments, and foundation of R&D centers in the neighborhood of resource-rich regions. Serpen and DiPippo (2022) attribute the slowdown in geothermal energy investments in Turkiye as of 2021 to the changes in the YEKDEM mechanism and the country's reaching its limit in finding new areas for electricity generation.

Furthermore, they stress the importance of increasing public involvement and awareness in realizing a new geothermal project. While insisting on financing the direct utilization of geothermal resources, Şener et al. (2023) stress that regional heating networks should be established in coordination with local authorities to benefit from the country's geothermal potential. On the other hand, there are some studies indicating low social acceptance of geothermal in Turkiye such as Çetiner et al. (2016), Ekşi et al. (2019), Tolunay and Erden (2021), Tunçbilek and Yılmaz (2022), Serpen and DiPippo (2022), Öztürk and Çobanoğlu (2023).

As seen in Table 1, conducting semi-structured interviews or surveys with stakeholders to encompass different parties' perspectives is one of the most applied methods. This study also addresses the challenges and opportunities of geothermal energy development and aims to contribute to the literature by adding the experience of Turkiye, one of the fastest-growing countries since 2015. Based on a theoretical framework, it evaluates the diffusion of geothermal energy in the country. As the first comprehensive qualitative analysis for Turkiye, it reveals the current problems faced by the energy sector and offers some suggestions for their solutions. Furthermore, it provides current and future opportunities for geothermal energy in a developing country that still heavily relies on fossil fuels but has ambitious aspirations for decarbonization.

Methodology: Semi-structured interviews

Applying semi-structured interviews is a standard method in qualitative data analysis. The overall purpose of this method is to gather information from individuals with enough knowledge and personal experience on the topic of interest. It allows the researchers to gain an insight into how much their prior information on a specific issue coincides with the behavior and perceptions of significant actors in the research area (Horton et al., 2004). In this research design, the interviewees face a pre-determined set of open-ended questions. Still, the interview is not restricted to these questions; it can be expanded through further discussion. At any moment, the participants can offer new research questions to enthusiastic researchers. On the other hand, snowball sampling is a method in which participants are asked to propose other potential interviewees, enabling the researcher to exert minimum time, money, and effort (Cohen & Arieli, 2011). Also, this method allows for a more diverse and inclusive participant pool to interview, which is crucial for obtaining the view of the whole.

To identify opportunities and challenges for geothermal energy development in Turkiye, semi-structured interviews with 21 respondents were conducted between December 2021 and January 2022.

Before identifying possible interviewees, key groups for the geothermal sector with their different roles, interests, and powers were searched initially based on the literature review. These groups that can affect or be affected by the success of a geothermal project mainly centered on financial institutions, manufacturers, plant operators, municipals, local/central government, land owners, local people (residents, farmers, etc.), customers (heat users, hot springs managers, etc.), academicians/collaborative groups, non-governmental organizations relying on some prominent studies such as Shortall et al. (2015), Climo et al. (2016), Yasukawa et al. (2018).

To gain insight into the Turkish geothermal energy sector, the

Table 1
Studies focusing on the challenges and opportunities of geothermal energy.

Study	Country	Main focus	Method	Data source
Taleb (2009)	Saudi Arabia	Barriers hindering the utilization of geothermal resources Potential enablers to overcome the barriers	Semi-structured interview analysis	**Interview with stakeholders:** Academics, engineers, geologists, senior managers, and energy consultants **(*n* = 19)**
Kubota et al. (2013)	Japan	Significant barriers to the development of geothermal power generation with an emphasis on social acceptance	Semi-structured interview analysis	**Interview with stakeholders:** Developers, hot spring inn managers, and local government officials **(n = 26)**
Sanchez-Alfaro et al. (2015)	Chile	Perceived advantages, barriers and incentives for geothermal development	Survey analysis	**Interview with stakeholders:** Participants from government institutions, industry, and academia **(*n* = 30)**
Winters and Cawvey (2015).	Indonesia	Governance obstacles to geothermal energy development	Interview analysis	**Interview with stakeholders:** Central government officials, international business consultants, domestic industry insiders, foreign aid agency staff involved with renewable energy development, provincial officials, and representatives of the local PLN office **(*n* = 26)**
Shortall and Kharrazi (2017)	Iceland and Japan	Influence of cultural characteristics on geothermal energy development	Structured and semi-structured interview analysis	**Interview with stakeholders:** decision-makers and experts from two countries **(*n* = 8)**
Yasukawa et al. (2021)	Eastern and South-Eastern Asian countries	Environmental barriers to geothermal development	Survey analysis	**Interview with stakeholders:** Geothermal experts, including academia, industry, and government
Shah et al. (2019).	Pakistan	Barriers to the adoption of cleaner energy technologies also including geothermal energy	Modified Fuzzy Delphi method Fuzzy Analytical Hierarchy Process	**Interview with experts:** University professors, senior research fellows, board members of the RE institute in Pakistan, and investors **(*n* = 14)**
Puppala et al. (2022)	India	Identification and analysis of barriers to harnessing geothermal energy	Fuzzy Delphi Method Fuzzy Analytical Hierarchy Process	**Interview with experts:** Researchers working in the domain of geothermal energy in India and scientists **(*n* = 8)**
Taghizadeh-Hesary et al. (2020)	Japan	Analysis of the various barriers to geothermal energy deployment	Vector Error Correction model	Variables proxy for barriers obtained from different data sources
Bai and Patil (2014)	China	Identification of growth barriers to the exploitation of geothermal energy	An overview study	
Setiawan (2014)	Indonesia	Progress, challenges, and the prospect of geothermal energy development	Qualitative-descriptive method focused on the literature review.	
Noorollahi et al. (2019)	Iran	Geothermal energy development, benefits, challenges, and future policy	An overview study	
Guangul and Chala (2021)	Ethiopia	Opportunities and challenges of developing geothermal energy	An overview study	

researchers first determined 56 stakeholders from six different groups by applying purposeful sampling followed by snowball sampling. The purposeful sampling method focuses on identifying and selecting individuals who are particularly well-informed about or experienced with the issue being addressed (Cresswell & Plano Clark, 2011). This selection can be made by contacting people in touch with the key individuals in the specific area (Suri, 2011). In this research, the key individuals are obtained by contacting project partners and previous contacts related to this field. The main advantage of this method is that it obtains the major view in the research area supplied by leading individuals (Suri, 2011) since it is assumed that they represent the view of the majority of the market. Furthermore, there is no specific restriction on the sample size as long as the intended information is acquired (Tongco, 2007). However, a bias could occur, such as not getting the view from less represented stakeholders. At this point, snowball sampling can be helpful. The snowballing method is used after contacting the leading stakeholders by purposeful sampling, and other stakeholders are obtained from the initial list. With the snowballing technique, at first, there will be many new names; however, as the interviews progress, this list converges to a final one (Suri, 2011). This method can help reduce the bias and gather the views of the underrepresented stakeholders.

After determining the related sample for the Turkish geothermal sector, the stakeholders were ranked based on their power level and interest. They were valued on a scale of 0–2, with 0 meaning low level and 2 meaning the highest level. Then, they were mapped on the Power-Interest matrix illustrated in Fig. 2 to identify which ones are more relevant and essential for the purpose of the study. While the term "power" is defined in this study as the "power of a stakeholder to

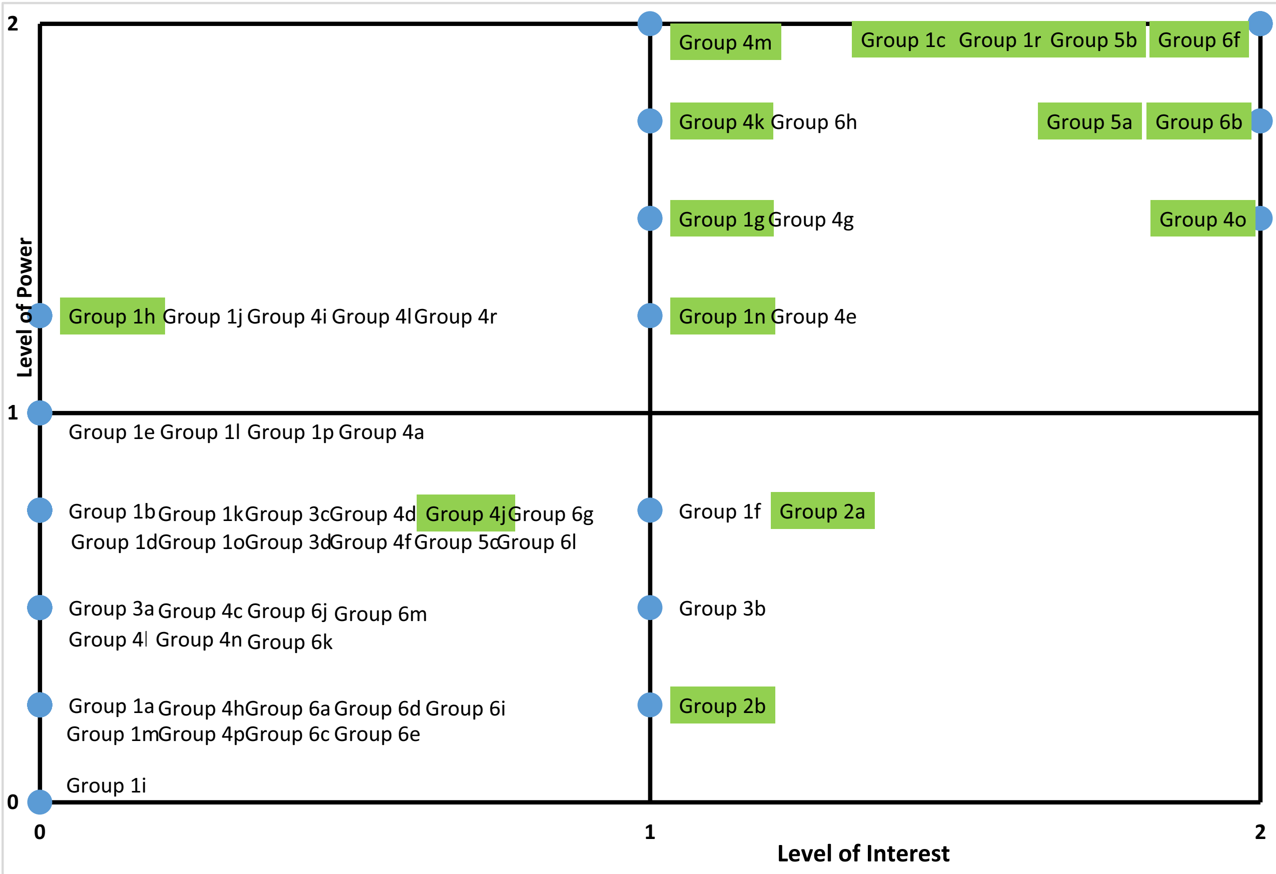

Fig. 2. Power and Interest stakeholder matrix for the Turkish geothermal sector. **Group 1:**Ultimate end users; **Group 2:**Optional end users; **Group 3:**Manufacturers; **Group 4:**Primary influential bodies; **Group 5:**Investors; **Group 6:**Academia and Policymakers.

Table 2
Interviewee groups.

Interviewee groups	# of respondents
Group 1: Ultimate end users and beneficiaries, including plant operators	4
Group 2: Optional end users, mainly R&D companies	4
Group 3: Influential primary bodies: public mineral research and exploration institutions, geothermal energy associations, or governorships	5
Group 4: Investment enterprises, banks, or regional development agencies	3
Group 5: Academia and public policymakers	5
Total # of respondents	**21**

influence the development of the Turkish geothermal sector," the term "interest" refers to the impact of the development of the sector on the stakeholder." The individuals with a high level of interest and influence were the target interviewees of this study. Indeed, those marked by green in Fig. 2 were also in the final interviewee list. Thus, many key stakeholders determined by purposeful sampling and stakeholder mapping were interviewed at the end.

Primary respondents of the interview were picked using this stakeholder mapping and the others by snowball sampling technique. The snowball sampling method was particularly appropriate for this research since people in the sector knew each other quite well, so their suggestions for the next person could be to the point. Their background, involvement, and experience in the renewable energy sector were vital in determining the target respondents to interview.

Finally, five stakeholder groups and their participants were interviewed, as presented in Table 2 and Table 3. Even though the unavailability of some groups, such as manufacturers or local people, seems to offer a certain amount of selection bias to the research, a participant from a leading NGO was interviewed as the representative of local people, and those from R&D companies as those of manufacturers.

The interviews were conducted with participants from five groups representing Turkiye's geothermal energy sector, as provided in Table 2. All participants had solid educational and technical backgrounds and experience, with mainly over ten years in the energy sector, as seen in Table 3. Some of them had past field experience or were still working, which proposes valuable inferences for this study.

The interview, composed of 15 questions on technical questions, was mainly intended to reveal the interviewee's opinion on Turkiye's geothermal energy market, the role of geothermal resources in the energy mix policies, opportunities, and challenges hindering geothermal energy development in the country and policy recommendations. Furthermore, social acceptance of geothermal energy was one of the issues frequently addressed during the interviews. The document encompassing the interview questions was sent to the participants in advance by e-mail to familiarize them with the questions. Interviews arranged according to the date of availability of the participants lasted between 60 and 90 min. The transcriptions were taken after the interviews were conducted and recorded with the interviewee's consent. Utilizing the coding tool proposed by MAXQDA, the most cited issues on geothermal energy during the interviews were identified as

Table 3
Information on interviewees.

ID	Gender	Background	Years of experience	Current status	Group ID
1	Male	Social Science	19	Manager in the energy company	Group 1
2	Male	Engineering	26	Manager in the geothermal energy company	Group 1
3	Male	Social Science	34	Manager in the geothermal energy company	Group 1
4	Male	Engineering	7	Manager in the geothermal energy company	Group 1
5	Male	Engineering	10	R&D manager in the geothermal energy company	Group 2
6	Male	Engineering	35	Founder of the R&D energy company	Group 2
7	Male	Engineering	36	Engineer in the R&D company	Group 2
8	Female	Engineering	15	Founder of the energy consulting company	Group 2
9	Female	Social Science	17	Manager of the non-governmental energy organization	Group 3
10	Male	Engineering	27	Manager in the energy sector	Group 3
11	Male	Engineering	11	Expert in the energy sector	Group 3
12	Male	Economics	32	Manager in the Geothermal Energy Association	Group 3
13	Male	Engineering	15	Manager in the governorship	Group 3
14	Female	Engineering	16	Expert in the bank	Group 4
15	Female	Social Science	21	Manager in the bank	Group 4
16	Female	Social Science	8	Expert in the regional development agency	Group 4
17	Male	Engineering	13	Manager in the energy sector	Group 5
18	Male	Engineering	30	Academician	Group 5
19	Female	Engineering	19	Academician	Group 5
20	Female	Engineering	16	Manager in the energy sector	Group 5
21	Male	Engineering	40	Mayor at present	Group 5

opportunities and challenges. The interviews had been implemented as a part of a policy work package in a technical geothermal project; therefore, the other half of the project included technical questions on projects (Geosmart innovations).[5]

Table 3 shows the background information on interviewees, as mentioned in different groups in Table 2. Rather than an NGO manager, the interviewees do not cover the societal players. Therefore, a more detailed study could be implemented, especially focusing on social acceptability at the community level, but it is missing in this study.

[5] As there were also technical questions in the interview, the questions and the protocol are not added to the text but are available upon request. Ethical approval for the questions was taken from the Applied Ethics Research Center of METU on the 29th of September 2021 with the 366-ODTU-2021 protocol number.

Table 4
Challenges hindering the development of geothermal energy in Turkiye.[a]

Codes	Frequency	Percentage (%)
Challenges	**478**	**49,6**
Political/Regulatory/Institutional	**135**	**28,2**
Lack of institutional coordination/lengthy approval process, etc.	18	13,3
Competition to natural gas, regional lobby activities	6	4,4
Poorly development of direct utilization areas	26	19,3
Legislative gaps	21	15,6
Desegregated sector (small, non-institutional, domestic firms)	27	20
Conflicts between investors, land owners, or municipality	14	10,4
Inadequate monitoring and auditing	23	17
Financial/Economic	**145**	**30,3**
Lack of direct utilization incentives	25	17,2
Current economic conjuncture	14	9,7
Current incentive scheme (for a particular time, in TL)	34	23,4
Foreign dependency on technology	10	6,9
Investor costs (drilling, risks, long payback period, etc.)	62	42,8
Technical	**71**	**14,9**
Same reservoir use/reservoir management problems	14	19,7
Demand for further information/R&D/technology	19	26,8
Plant installation above resource capacity by ignoring efficiency	14	19,7
Technical deficiencies (fluid quality, silica, cooling problems)	17	23,9
Inadequate geothermal standards	7	9,9
Environmental/ Social	**127**	**26,6**
Profit-oriented investor attitude	30	23,6
Poor social acceptance/local resistance	53	41,7
Misperception/insufficient information among the public	21	16,5
Smell/improper reinjection practices	23	18,1

[a] "Frequency" corresponds to how many times the respondents mentioned the related item during the interviews as a challenge to geothermal projects, and "Percentage" indicates the share of this item in the corresponding challenge subgroup. Similar comments can be made for the opportunity part.

Challenges and opportunities for the development of geothermal energy in Turkiye

As listed in Table 4 and Table 5, the interviewees addressed many opportunities and challenges while evaluating the Turkish geothermal energy sector. They emphasized the current advantages of having geothermal resources and the future ones for Turkiye. On the other hand, they mostly pointed out the financial problems encountered by plant operators. They stressed the political and regulatory barriers to overcome while expressing their social and environmental concerns due to improper practices. As illustrated in Appendix 1, even though the interviewees gave mainly negative feedback on the issues in the geothermal energy sector today, they stated they were hopeful for the future in general.

On the other hand, the participants who regarded financial barriers as the most crucial today were also hopeless about the future situation. Concentrating on group-based opinions presented in Appendix 2, it is evident that plant operators and participants from R&D companies were the most pessimistic parties about the sector's development today. On the other hand, academicians and policymakers were the most optimistic about the future development of the geothermal energy sector.

Challenges

The respondents, pointing out the geothermal energy potential in the country during the interviews, concentrated on the challenges of its exploitation and development. Among these challenges, financial and economic ones were the most stressed. Furthermore, while indicating

Table 5
Current and future opportunities for the development of geothermal energy in Turkiye.

Codes	Frequency	Percentage (%)
Opportunities	**486**	**50,4**
Current	**297**	**61,1**
Environmentally friendly/sustainable energy source	12	4
More efficient than other REs	11	3,7
Benefits offered by direct utilization	34	11,4
Suitability for direct utilization	38	12,8
Suitability for hybrid energy systems	15	5,1
Increased employment opportunities for locals	16	5,4
The non-intermittent energy source (base load)	13	4,4
Existing human resources and know-how	15	5,1
Paris Climate Agreement requirements/emission reduction	29	9,8
Technological advances	34	11,4
Resource potential in the country	38	12,8
Advantages offered to investors (financing/technical support)	12	4
Being a domestic energy source	11	3,7
High imported energy prices/geothermal use for heating	19	6,4
Future	**189**	**38,9**
Conducting/supporting R&D	32	16,9
Increasing social acceptance with awareness	36	19
Increasing social acceptance with social benefits	37	19,6
Making legal arrangements (suggestions etc.)	38	20,1
Establishing geothermal standards	26	13,8
Offering plant-based incentives (rewards, drilling costs, etc.)	12	6,3
Promoting domestic equipment production/use	8	4,2

the political, regulatory, and institutional barriers, they highlighted the environmental and social problems. Compared to the group-based opinions in Appendix 3, the plant operators centered on all challenge categories. On the other hand, the participants from R&D companies, academicians, and policymakers were concerned primarily about financial and economic challenges, while primary bodies and investment enterprises were about environmental and social ones. More details on the sub-categories of each challenge based on the different groups are represented in Appendix 4.

Most barriers underlined by stakeholders to obstruct the widespread diffusion of geothermal energy in Turkiye are similar to those encountered in many other countries. Nonetheless, it is interesting that Turkish interviewees linked geothermal-related environmental and social problems to the market's desegregated structure. Furthermore, while criticizing the recent changes in the YEKDEM mechanism, they also acknowledged that these incentives acted as a driving force for making investments with a profit motive above resource capacity. The participants, who frequently emphasized the country's potential, were insistent on formulating policies to promote direct utilization of geothermal energy and provide incentives to investors.

Political, regulatory, and institutional challenges

As many interviewees stated, the Turkish geothermal energy market evolved as a segregated sector, accounting for many problems today. The geothermal energy investments in the country were remarkably on the rise after 2010, along with increasing financial incentives offered to the electricity generating plants under the YEKDEM mechanism. As a result, the geothermal energy market became very attractive for investors at that time, even those from non-energy sectors such as construction, textile, and real estate. While the geothermal power sector experienced significant momentum with the entry of each new player, the penetration of these small, non-institutional, and primarily domestic firms into the market also brought about some structural problems. The improper practices of these firms with only profit-oriented attitudes fired up the local resistance, which also caused dissatisfaction among the large and institutional companies in the sector over time. Ultimately, these displeased companies resorted to establishing another geothermal energy association by departing from the national one. At this point, the comment of one of the interviewees (#1) was quite striking: "*The most complicated renewable energy sector was left in the hands of small and non-cooperate firms. It is the most important problem in the country's geothermal energy story*."

Offering incentives to the plants only to generate electricity was also another issue strongly criticized by the interviewees. The lack of another mechanism for incentivizing direct utilization practices was frequently stressed as the most crucial obstacle to developing the country's real potential. Besides an interviewee (#8) advocating that every geothermal energy project should be integrated with a direct utilization application, one of the participants (#9), as a plant operator, also stated: "*If additional incentives were offered, I would be willing to undertake such integrated geothermal energy projects as many firms in the sector*."

Interviewees also complained that the country needs centralized management of geothermal energy. From exploration to operation, lengthy permission and approval processes wait for the investors, and they should always apply to different institutions to complete all these bureaucratic procedures. One of the interviewees (#18) stated, "*There is no only one owner of geothermal energy. Many institutions are interested in the resource. There is a multi-headed system*." the other (#2) complained that "*We are going through such long and exhaustive processes, and we are left alone as investors at the end of the day*." At this point, Italy's geothermal story, from being the pioneer in installing the world's first geothermal plant to facing a slowdown in geothermal energy development in time, parallels the challenges encountered by Turkiye. Lengthy and unpredictable authorization processes, coupled with limited support schemes for power generation and the absence of such support for direct utilization, stand out as the main factors hindering geothermal energy development in Italy (Manzella et al., 2019).

Lastly, the participants primarily associated inadequate monitoring and auditing with the plant operators' improper practices. They justified that the legislative gaps in the monitoring system resulted in environmental and social problems over time, and they continue.

Financial and economic challenges

During the interviews, the most addressed issue was the investors' costs. The respondents, particularly experienced in field studies, indicated that drilling is still a technically complex and expensive part of geothermal projects, even with the current technologies. They stated that the risk investors have to bear was relatively high, considering the possibility of not reaching a resource with the expected enthalpy or even a resource at the end of the drilling. However, Serpen and DiPippo (2022) point out that the robust drilling industry in Turkiye is characterized by competition between private and public companies, with drilling prices generally remaining stable. On the other hand, there are successful examples of countries, such as France and the Netherlands, that offer national risk mitigation schemes primarily for geothermal heating. Since the 1980s, France has established short- and long-term funds to promote the country's expansion of geothermal energy usage.[6] At this point, interviewees from the investment enterprises argued that there is partial drilling subsidization of geothermal projects in Turkiye through international funds. These subsidies alter 40 % to 60 % of well costs in case of unsuccessful drilling.

The interviewees underlined that geothermal is still less cost-effective than solar and wind energy. The geothermal energy projects with high initial capital costs have more extended payback periods than the other REs, urging investors to consider less expensive alternatives.

Another issue strongly criticized during the interviews was the new YEKDEM scheme that presumes that the plants to be commissioned after

[6] Retrieved January 20, 2024, from https://eurogeologists.eu/european-geologist-journal-43-boissavy-the-successful-geothermal-risk-mitigation-system-in-france-from-1980-to-2015/

2021 will be entitled to incentives in terms of Turkish Lira rather than USD. Some interviewees advocated that supporting the plants this way would be a significant obstacle to new investments, considering the depreciation of the domestic currency against the foreign and the relatively higher costs of investing in the geothermal energy market. Indeed, one of the participants (#12) commented on this issue: "*The energy sector, which gained momentum with the first YEKDEM setup, entered into a period of stagnation with the new TL-based mechanism, and the investments declined remarkably after 2021. YEKDEM is a prerequisite for investing. Thus, the mechanism must be revised urgently considering the international financial conditions.*" Contrarily, there were also some comments from policymakers that the electricity market clearing prices are so high that the function of YEKDEM, so the necessity of incentivizing certain plants in this way, is questionable nowadays.

As another issue, providing financial incentives in direct utilization applications was frequently offered to reveal the country's real potential. Some countries stand out as compelling examples of effectively utilizing their geothermal endowments. Notably, Iceland meets 90 % of its space heating through geothermal energy, while in Sweden, 40 % of buildings are heated using geothermal heat pumps (Lund & Toth, 2021). One of the interviewees (#10) stressing Turkiye's potential said, "*You can benefit from a geothermal resource differently until you send it back under the ground. You can generate electricity, heat a house or a greenhouse, operate a thermal facility, and then reinject it based on the temperature. The value of these practices has not been widely appreciated in the country. Incentivizing investors for direct utilization seems important to better understand geothermal energy and benefit more from the resource.*"

Technical challenges

Among the technical barriers hindering geothermal energy development in Turkiye, the participants mainly focused on the need for further information and technology. While indicating some problems affecting the power plant efficiency, such as silica precipitation and cooling in summer, they emphasized the importance of collaboration between scientific disciplines and the private sector to deal with technical deficiencies and conduct R&D projects. At this point, interviewee (#16) stated: "*A bridge is required to connect technology producers with technology users. The project's sustainability is compromised when the technology providers that offered support during its development phase withdraw once the project is implemented.*"

The interviewees strongly criticized that the investors racing for the incentives in the early days of YEKDEM established their plants above resource capacity regardless of considering efficiency, and social and environmental impacts were mostly ignored. Furthermore, they complained that the over-exploitation of geothermal resources resulted in decreased power output due to temperature and pressure drops in time. One of the interviewees (#8) remarked: "*Land license areas in Turkiye were not determined based on the reservoir; on the contrary, all divisions were made over the land. In this case, neighboring power plants had to use the same reservoir. Considering the profit maximization motivation of the investors, the aggressive use of the reservoirs threatens the resource sustainability today.*"

Lastly, they expressed that the technical standards for drilling or the types of equipment utilized in the plants were inadequate. They also disapproved of using some environmental standards specific to conventional energy resources for geothermal energy.

Environmental and social challenges

The interviewees associated the environmental and social problems regarding geothermal energy with the improper applications of the small and non-institutional firms that entered the market quickly after the initiation of YEKDEM. With their only profit-oriented attitudes, these firms demonstrated little or no environmental awareness and did not care about social acceptance or local resistance. Improper reinjection practices damaging farmers' fields and disturbing smell problems are some factors accounting for low social acceptance of geothermal. Indeed, before Law in 2007, and in the early times when only a limited number of projects were implemented, the remaining geothermal fluids after the power generation process were partially released to nearby streams or agricultural lands (Serpen & DiPippo, 2022). This past misapplication has not been erased from the memory of the local people, which still triggers local resistance to geothermal today. Indeed, Doğdu and Çelmen (2023) highlight that a well-conducted reinjection process brings several advantages. These include ensuring long-term resource sustainability by maintaining reservoir pressure and temperature, facilitating continuous and reliable geothermal power production, and improving groundwater quality.

One of the interviewees (#10) stated that the smell problem resulting from the release of hydrogen sulfide disturbed the local people and emphasized: "*The rotten egg smell caused by hydrogen sulfide is a big problem for the local people. Investors trying to convince the public about their projects need to focus more on somehow eliminating or reducing this smell problem that profoundly affects the daily lives of the locals.*"

Many participants noted a need for more public knowledge or a common misperception about geothermal energy. At this point, the interviewee (#10) gave a striking example: "*Water vapor comes out of the geothermal plant. People see it whenever they drive through there, and they say, "You see, geothermal energy is spreading the poison out.*" interviewee (#7): "*Even there are the people in the local strongly advocating that the geothermal energy causes cancer.*" Some also indicated that the lobbyists intentionally constituted this prejudice against geothermal energy. Thus, the participants argued that local resistance and low social acceptance problems could only be overcome if the public benefited more from geothermal along with increasing local employment and social responsibility projects, and their resource awareness increased starting from schools, thus from family members to the community. While highlighting regional differences in social acceptance, one of the interviewees (#20) remarked: "*For instance, in the Afyon Sandıklı region with its enhanced geothermal district heating system and many thermal tourism facilities, we observe high satisfaction among the community regarding geothermal energy. However, the situation is the opposite in the Aydın Efeler region, where the interaction of firms with the public is very low. We believe that this difference is fundamentally related to the level of benefits geothermal resources provide to the public. Integrated systems such as district heating, greenhouse heating, and agricultural drying play a crucial role in social acceptance. We have directly experienced that when the public perceives a benefit for themselves, they do not oppose geothermal energy.*"

Opportunities

Through the interviews, the participants often called attention to the country's resource potential. They also focused on future opportunities while primarily mentioning the current advantages of geothermal resources, as in Table 5. As illustrated in Appendix 3, academicians and policymakers were the ones who most concentrated on the present benefits of geothermal energy. In this group, policymakers emphasized the importance of geothermal energy in the country's energy mix and energy supply security policies. On the other hand, plant operators, primary influential bodies, academicians, and policymakers were the primary ones centered on the future opportunities geothermal resources would offer.

Current opportunities

The interviewees pointed out the country's potential for electricity generation, first in Europe and fourth in the world regarding the installed capacity. Even one of the participants from an energy consultancy agency claimed that this potential of 1600 MWe today could reach 4500 MWe. They expressed that focusing only on the fact that geothermal energy has a tiny share in electricity generation could be misleading. Instead, they insisted that geothermal energy was more efficient than other REs, with its high capacity factor reaching over 90 % as a base load.

Many participants advocated that the country concentrate on its potential for direct utilization rather than only electricity generation. They underlined that Turkiye's 63 cities already had geothermal resources, and their usage areas, from heating to cooling, thermal tourism to drying fruits and vegetables, were quite broad. One of the interviewees (#19) stated: "*Turkiye possesses substantial geothermal potential. Our primary focus has been on Western Anatolia due to its economic feasibility. Moving eastward, we must drill deeper into reservoir rocks to reach hot rocks, leading to higher drilling costs. While there is a gradual shift towards Central Anatolia, various regions in Turkiye hold significant potential for electricity production. However, the thicker crust in Eastern Anatolia presents a more challenging task requiring additional effort and financial resources. Despite these challenges, geothermal heating can be effectively utilized in a significant part of Turkiye.*"

They drew attention to the fact that geothermal resources could bring considerable advantages to the locals regarding district heating and reduce their heating costs, considering high imported energy prices. One of the interviewees (#20) insisted: "*Heating 80% of Turkiye with geothermal energy is feasible. Even with natural gas, geothermal energy would still result in significant savings, approximately 30%, in these regions. When evaluating the payback period for investments in regional heating, it is crucial to consider the reduced costs associated with using geothermal energy instead of natural gas, along with the impact on employment and the social benefits it would provide. For instance, transitioning to geothermal-based regional heating in areas where central heating systems are already in place could be much easier. Promoting regional heating with geothermal energy sources instead of individual heating would be both a more economical and environmentally friendly approach.*" Besides offering a reasonable solution to the heating problem, geothermal would contribute to the regional development of rural areas where natural gas has not yet been reached.

Geothermal-powered greenhouse projects could increase employment opportunities for locals, particularly women. In addition to these economic benefits, direct utilization practices could be quite effective in increasing social acceptance and changing the attitude of the locals against geothermal.

The respondents stated that the energy sector increased its human resources, know-how, and experience in geothermal energy along with technological advances. One of the interviewees (#8) suggested: "*There are thousands of oil wells in Turkiye that have the potential to produce not only oil and natural gas but also geothermal energy. The seismic structure and rock pressures of all oil fields are well-known. The existing knowledge about the underground conditions in oil wells is a significant advantage that can substantially reduce the initial investment costs for geothermal projects.*" The participants appreciated the existence of financial support mechanisms to cover the costs of drilling risks, such as RSM and technical assistance offered to investors today. Thus, it is time for Turkiye to focus on new geothermal technologies, such as hot and dry rock, offering 400,000 MWe power generation potential. The country should also accelerate its effort to hybridize geothermal energy with other technologies. Hybridizing geothermal power with solar or wind energy to enhance power generation or supply the plant's self-consumption was frequently stated as a promising development.

The interviewees emphasized the importance of geothermal energy in reaching emission reduction targets envisaged by the Paris Climate Agreement as a domestic, non-intermittent, and environmentally friendly energy resource. They stressed that its high geothermal potential was an essential tool for Turkiye in the accelerating energy transformation race of countries.

Future opportunities

The interviewees, regarding low social acceptance and local resistance to the geothermal projects as one of the most critical challenges, underlined that these problems could be overcome by increasing public awareness and offering benefits to the locals. One of the interviewees (#12) commented: "A *geothermal project can no longer be carried out despite the public. In this context, pondering on social acceptance is critical. People should first be sufficiently knowledgeable about the resource. This can be achieved through the education system. This is one of the reasons why post-acknowledgment struggles become insufficient. A person naturally fears what he does not know. For this reason, the government, other relevant institutions, NGOs, and local administrations should work together and answer the questions of the local people.*" the other (#9) stated: "*By not only generating electricity but also heating the houses and building greenhouses, providing local employment, the more people you touch in this way, the more you will make these people adopt the geothermal.*

Furthermore, the participants noted that Turkiye should support its know-how on geothermal energy with new technologies and focus on the academia-industry collaboration while accelerating R&D activities and project incentives.

Establishing new geothermal standards, rather than relying on the ones for oil or other conventional resources, was also seen as an opportunity among the interviewees.

Besides other suggestions, such as offering incentives to efficient and properly operated plants or promoting domestic equipment production and use, the respondents offered some proposals for making legal arrangements. These offers centered on constituting a governmental institution directly focusing on geothermal energy, prioritizing geothermal energy development while preparing the country's strategic plans, revising the current incentive scheme, and making direct utilization practices obligatory for electricity generation projects.

A European policy perspective

Some significant developments in EU policy could be replicated in Turkiye to aid the more considerable geothermal energy deployment. Firstly, France, Germany, Ireland, and Poland published national roadmaps with growth targets and financial support. They proposed changes to national legislation to aid geothermal energy investments and capture the industry value chain of its key technologies.

EU legislation was also updated to address critical barriers to geothermal energy deployment. Firstly, the European Commission outlined an indicative target to triple geothermal energy capacity by 2030.[7] The Renewable Energy Directive, the primary legal instrument, was revised to establish standard rules around the permitting of geothermal systems, identifying areas where permits for geothermal are required, digitalizing the permitting process, and providing a clear timetable for the approval of projects.

A binding sub-target was established for renewable heating and cooling, significantly favoring geothermal energy. The Energy Efficiency Directive introduced an imperative mandate on local authorities with populations of 45,000 and more extraordinary inhabitants to zone areas suitable for renewable heating and cooling district systems. This will significantly drive growth in the geothermal district heating and cooling market. A plan to accelerate the deployment of 30,000 hydronic heat pumps and low-to-medium temperatures as outlined in the REPowerEU Plan in May 2022. An Action Plan for delivering this is expected to be launched in 2023. However, emergency rules were introduced in December 2022 to streamline permitting air-source and geothermal heat pumps with a capacity of up to 50 MWth. There has also been increased inclusion of geothermal in EU research funding in Horizon Europe and Life-funded projects focused on research and innovation of geothermal-related technologies and raising social awareness.

The diffusion of geothermal energy in Turkiye based on the Technological Innovation Systems Function approach

Besides revealing the opportunities and barriers for the diffusion of geothermal energy based on semi-structured interviews, the

[7] Retrieved January 20, 2024, from https://eurogeologists.eu/european-geologist-journal-43-boissavy-the-successful-g

Technological Innovation Systems (TIS) framework is applied in this paper to evaluate the structural components and functional dynamics of geothermal development in Turkiye.

The TIS approach is based on the "technological systems" introduced by Carlsson and Stankiewicz (1991). It is defined as a '*network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology*.' In this definition, the technological system is mainly identified by three structural components: *agents, networks, and institutions* (Bergek et al., 2008; Jacobsson & Bergek, 2004). Actors include firms and organizations such as governmental bodies, financial institutions, universities, and NGOs. The networks can be in the form of learning or political networks. While learning networks aim to develop and diffuse technical knowledge between suppliers, users, firms, and researchers, political networks seek the power to influence government decisions. Institutions include regulations, laws, and some norms on culture and tradition. The technological system framework was further developed as TIS by some studies such as Jacobsson and Bergek (2004), Hekkert et al. (2007), Negro et al. (2007), Bergek et al. (2008), Markard and Truffer (2008), etc. Besides structural components, these studies focus on the functions that must be fulfilled for the successful diffusion of new technology. Indeed, the performance of an innovation system can be analyzed by a set of specific functions such as knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, resource mobilization, legitimation, and development of positive externalities. If some of the functions are not fulfilled, this will adversely affect the performance of TIS. Hence, identifying malfunctioning functions is crucial to developing policies to accelerate technology diffusion (Vasseur et al., 2013).

Considering that General Directorate of Mineral Research and Exploration of Turkiye (MTA) conducted its first geothermal exploration in Balçova-İzmir in 1962, the first geothermal heating system was established in Gönen-Balıkesir in 1964, and geothermal power generation projects started in Kızıldere-Denizli in 1974 (Herrera-Martínez, 2017), Turkiye has been one of the leading countries in making efforts to utilize its geothermal potential. Nonetheless, all these developments were public-sector-driven at that time. The first private geothermal energy power plant was established in 2006, and the technology diffusion was realized very slowly until 2008. In terms of the *institutions,* the enactment of the Renewable Energy Law in 2005, the Geothermal Resources and Natural Mineral Waters Law in 2007, and the introduction of an incentive scheme in 2011 were the main drivers for attracting private sector investments, so the rise of geothermal power generation in the country. Furthermore, the goals specific to geothermal energy development have been included in many governmental documents and national energy plans, which kept this interest alive.

Considering the *actors*, the geothermal energy sector in Turkiye evolved as a desegregated one. ZORLU, GURMAT, KIPAS, CELIKLER, and SARAY&ACARSAN (GREENECO) are leading companies. They also invested in other renewable energy sources, including coal, hydropower, and wind. Nonetheless, some small and non-institutional firms are also operating in the market. Regarding the political *networks* or advocacy coalitions, there are two geothermal associations in Turkiye: the Geothermal Power Plant Investors Association (JESDER), established in 2014, and the Geothermal Energy Association (JED) in 2020. JED mainly consists of large and institutional firms that parted later from JESDER, indicating again the sector's desegregated development.

Regarding technological equipment, the Turkish geothermal energy sector continues to be foreign-dependent. Even if the local manufacturing incentive scheme for specific components, such as turbines, generators, power electronics, etc., led several binary equipment retailers to manufacture, its success has remained limited (Halaçoğlu et al., 2017). Nonetheless, the country's *knowledge development and diffusion* efforts have increased. Specialization in the oil and gas sectors provided an advantage for geothermal drilling activities. Firms have significantly accumulated their human resources, experience, and know-how. Although the R&D activities in geothermal have not yet been at the desired levels compared to other REs, Turkiye has also intensified its geothermal efforts in recent years. The first geothermal R&D center for aiming localization of machinery and equipment was established in 2020. TUBITAK (Scientific and Technological Research Council of Turkiye) has promoted R&D studies for geothermal energy technologies and direct utilization applications in the scope of the GEOTHERMICA project, consisting of 20 geothermal energy research and innovation program owners and managers from different countries, to strengthen the European geothermal sector. The partnerships between technology developers and academia have accelerated through the national research centers at universities and some international projects such as GECO (Geothermal Emission Control), GeoSmart, GEOPRO, SUCCEED (Synergetic Utilization of CO_2 Storage Coupled with Geothermal Energy Deployment) executed by the partnership of ZORLU as a pilot plant operator from Turkiye and other national and international researchers (TÜBA, 2020). Annual national or international meetings and conferences supported by the government and developers or associations have been effective in knowledge exchange, getting in touch with other researchers, and keeping track of the latest developments in the geothermal industry.

Concentrating on *entrepreneurial activities and market formation* for the Turkish geothermal power generation sector, it is remarkable that there have been only two new entrants after 2021, still not operational, which can be partly accounted for by market structure. The market has a desegregated structure of small and large firms. Fig. 3 shows ten prominent companies in the market in 2024. These companies are ambitious to conduct R&D studies and are open to further industrial cooperation with their national and international partners to develop geothermal energy. They are also keen on innovative and efficient plant design. To illustrate, the Kizildere-3 plant operated by ZORLU received the 2018 American Council of Engineering Companies Award for its engineering excellence. With 45 plants, these ten companies constitute 84 % of the installed capacity in 2024. In addition to the energy sector, these firms operate in many fields, such as construction, cement, textile, real estate, etc. Remarkably, the market share of ZORLU is even more than the total percentage of 19 companies, with 22 plants regarded as small ones in terms of their installed capacity (OTHERS). Unlike other REs, foreign direct investments in Turkiye remained relatively limited for geothermal energy. As a promising development, the Dutch company TRANSMARK and French company ALBIOMA entered the geothermal market only after 2021.

The government plans, and strategy documents concerning RE development have been practical tools for *influencing the direction of the search* for investors. Indeed, the absence of clear and long-term targets set by the governments that outline the desired percentage of the related energy source mix, along with a specified timeline for achieving this goal, can pose a significant barrier to the widespread adoption of the technology (Edsand, 2017). Turkiye included its geothermal-based goals in many governmental documents (Şahin, 2021), such as the National Climate Change Action Plan (2012), National Renewable Energy Action Plan (2014), Tenth Development Plan (2014–2018), National Energy Strategic Plan (2015–2019). As the most recent one, in the National Energy Plan 2022, the target is that "*The installed capacity of geothermal and biomass power plants will reach 5.1 GW in total by 2035*." This decisive attitude instilled confidence in the development of the geothermal sector and its profit opportunities, which promoted new entries to the market. Strong political commitment to the diffusion of geothermal energy guided the expectations of the entrepreneurs along with the offered incentive scheme. YEKDEM has been the most successful driver for the rapid growth of geothermal power generation. It offered guaranteed and long-term income for the investors. The small firms, which had not previously engaged in the energy sector but pursued incentives, quickly penetrated the market after 2010.

Nonetheless, after the changes in YEKDEM in 2021, offering incentives in Turkish Lira rather than foreign currency, the geothermal

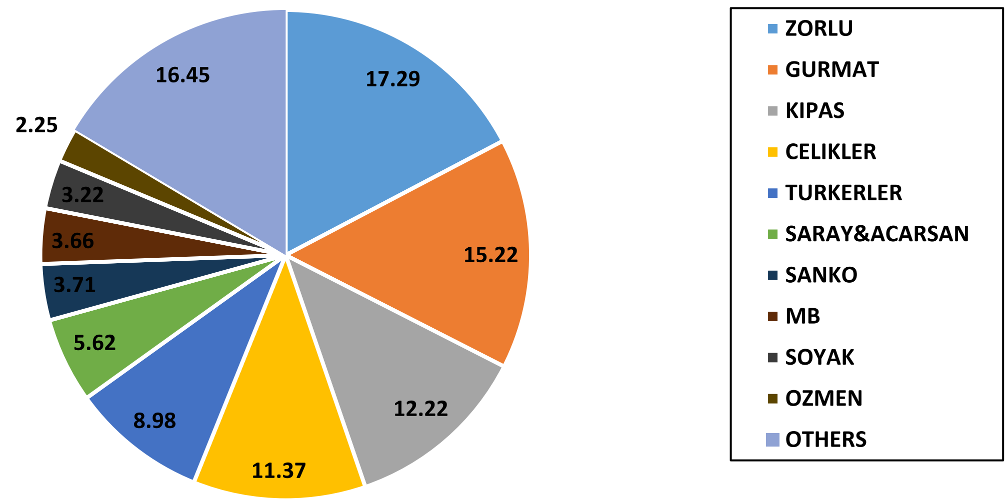

Fig. 3. Distribution of company-based installed capacity in 2024(%). **Source:** Authors' illustration based on EMRA electricity market generation license data.

power generation sector has lost its appeal to investors. Öznazik (2022) reveals that electricity generation prices of geothermal power plants decreased by over 60 % after this change, which accounts for why new plant investments in the market reached a standstill. As a recent development, a price floor in USD/MWh has been determined in the Turkish support scheme, and in this way, it has been aimed to protect the feed-in price in local currency against exchange rate fluctuations. Indeed, the changes in the YEKDEM mechanism in the last two years have been frequently criticized as creating uncertainty for the investors willing to build up their future business strategies under stable and long-term policy support. On the other hand, the lack of incentives for direct utilization has been a significant obstacle to revealing the country's real potential in geothermal energy. Despite some international co-operations, such as the Turkiye-Denmark Strategic Sector Cooperation Program initiated in 2017, the Turkish heating law discussed for many years has not yet been enacted.

Resource mobilization is vital for geothermal energy investments with extended payback periods, construction costs, and risks. Offering incentives or financial tools to reduce exploration risks can attract investments in new projects. In the Turkish geothermal market, there is no government-supported risk mitigation scheme, but international institutions offer some funds to investors. Besides the European Bank for Reconstruction and Development funds, the Geothermal Development Plan funded by the World Bank flows capital in the form of a loan facility for resource development and a Risk Sharing Mechanism to cover 40 % to 60 % of the cost of failed wells. Regarding tax incentives for physical capital, geothermal power generation plants holding an investment incentive certificate can purchase new machinery and equipment without paying VAT, and they are also exempt from customs duties when importing equipment. Some other incentives and exemptions currently applicable for oil exploration and drilling, such as exemption from fuel-related VAT, special consumption tax, etc., can also be provided for geothermal drilling (Akkuş & Alan, 2016). Regarding human capital accumulation in the geothermal energy sector, the number of qualified engineers and technical personnel to install and maintain a plant remains inadequate but continues to increase.

Along with the climate change objectives, legitimizing geothermal energy as an energy mix option has been more apparent in many governmental documents. Furthermore, geothermal associations and developers accelerated lobbying activities to incentivize further geothermal energy development. They have exerted their political power to influence government decisions, as observed in the recent change in the YEKDEM while emphasizing that the incentive scheme is a prerequisite for increasing geothermal power generation capacity. They also continue to stress the necessity of incentives in direct utilization on every political platform. Nonetheless, low social acceptance among the locals has continued to be a significant hindrance in initiating a new project, and it is pretty common to come across the news of public protests against geothermal energy almost every day. Indeed, there were no public complaints during earlier periods, and the geothermal projects were executed without local resistance (Serpen & DiPippo, 2022). The rapid penetration of many companies into the market to receive a share from incentives and the attitudes of these developers, mainly from non-energy sectors and demonstrating little or no environmental awareness, have sparked anti-geothermal movements over time. Most locals still insist that geothermal energy damages the environment and agricultural production, as indicated in the recent studies of Tolunay and Erden (2021) and Öztürk and Çobanoğlu (2023). On the other hand, long negotiation or lawsuit processes with landowners or local communities prevent developers from making geothermal investments.

As a *positive externality*, each new entrant to the geothermal market has benefited from the opportunities, accumulated experience, and technology knowledge offered by the incumbent firms.

Conclusion and policy implications

This study aims to identify challenges and opportunities in developing geothermal energy in Turkiye, a country abundant with geothermal resources. Furthermore, it is the first comprehensive qualitative analysis of Turkiye. The findings from the interviews indicated that Turkiye has a vast potential in geothermal energy that can be developed along with the new technologies and its current know-how. Nonetheless, some political, financial, technical, and social barriers restrain geothermal energy development in the country. Direct utilization of geothermal energy is feasible in many parts of Turkiye, and it can offer significant advantages such as reducing the dependency on natural gas for heating, contributing to regional development, creating local employment, and increasing the social acceptance of geothermal. At this point, new financial incentives or legal obligations to the plant operators can be an effective tool for the prevalence of direct utilization practices in the country. The country can alleviate its foreign dependency on technology by conducting and supporting R&D studies, which can disseminate information between investors and researchers and develop further cooperation among the parties. To minimize bureaucratic processes and conflicts between investors and landowners/local communities, a principal institution's centralized management of geothermal energy seems critical. This can also enable the investors to realize their current projects rapidly and be willing to pursue further ones. More stringent and systematic monitoring mechanisms can play an essential role in preventing the environmental damages resulting from the improper practices of profit-oriented plant operators and maintaining reservoir sustainability. In line with all the projected developments, the attitude of local people, whose economic and social benefits increase and who do not suffer from environmental damage, towards geothermal may change, and the social resistance to new geothermal projects might remarkably decrease in time. Moreover, stimulating community engagement and continuous dialogue with the locals before realizing a geothermal project and including geothermal energy in the school curriculums can effectively increase awareness and, thus, social acceptance of geothermal energy.

This study suggests that Turkiye should prioritize the sustainable development of geothermal energy, particularly after gaining considerable momentum over time. The slowdown observed in the Turkish geothermal power sector, following changes in the supporting scheme in 2021 and resulting in decreased returns for plant operators, underscores the critical importance of incentives in attracting investors to the market. Despite its potential, geothermal energy still requires more incentives due to its high upfront capital costs compared to other renewable energies. Additionally, implementing direct utilization practices or making them obligatory for electricity generation projects, coupled with specific incentive schemes and more investment in geothermal R&D studies, can expedite geothermal energy development in the country. Notably, increasing the benefits of the locals from geothermal investments in geothermal R&D studies can play a vital role in enhancing social acceptance of the resource.

As stressed by the interviewees, the social acceptance of geothermal energy varies remarkably between the different parts of Turkiye. Interestingly, the locals in some regions are content with geothermal energy, while others are firmly against it. These two different attitudes towards the same resource also raise many questions. At this point, some factors can be determinants of social acceptance, such as public benefit from the direct utilization of geothermal energy, the characteristics of the companies operating in these regions, etc. Thus, further studies on this specific issue can be conducted, and in this way, social acceptance of geothermal energy can be put forward from a different perspective.

Funding

This research is funded by EU H2020 Project GeoSmart: Technologies for geothermal to enhance competitiveness in smart and flexible operation under Grant Agreement number 818576 website: geosmartproject.eu.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank Alper Baba, Erkan Erdil, Philipe Dumas, and Geosmart consortium partners for their valuable comments and suggestions.

Appendices

Code System	Positive(today)	Negative(today)	Hopeful(future)	Hopeless(future)	SUM
Opportunities					0
Current	57	14	59	1	131
Future	22	27	31	3	83
Challenges					0
Political/Regulatory/Institutional	4	34	10	6	54
Financial/Economic	13	48	15	25	101
Technical	3	20	5	2	30
Environmental/ Social	13	24	10	2	49
Σ SUM	112	167	130	39	448

Appendix 1. MAXQDA output_opinions on opportunities and challenges.

Code System	Group 1	Group 2	Group 3	Group 4	Group 5	SUM
Opinions						0
Positive(today)	15	13	8	8	16	60
Negative(today)	26	24	19	9	17	95
Hopeful(future)	13	12	13	6	22	66
Hopeless(future)	10	7	1		2	20
Σ SUM	64	56	41	23	57	241

Appendix 2. MAXQDA output_group-based general opinions on geothermal energy.

Code System	Group 1	Group 2	Group 3	Group 4	Group 5	SUM
Opportunities						0
Current	61	57	44	41	94	297
Future	52	25	51	17	44	189
Challenges						0
Political/Regulatory/Institutional	60	14	23	17	21	135
Financial/Economic	50	27	26	16	26	145
Technical	25	10	11	8	17	71
Environmental/ Social	46	9	34	22	16	127
Σ SUM	294	142	189	121	218	964

Appendix 3. MAXQDA output_group-based opinions on opportunities and challenges.

Code System	Group 1	Group 2	Group 3	Group 4	Group 5	SUM
Opportunities						0
Current						0
Environmentally friendly/sustainable energy source	2	1	4	3	2	12
More efficient than other REs	2	2	1	2	4	11
Benefits offered by direct utilization	8	8	4	6	8	34
Suitability for direct utilization	4	6	4	8	16	38
Suitability for hybrid energy systems	4	4	2	2	3	15
Increased employment opportunities for locals	6	1	2	4	3	16
Non-intermittent energy source (base load)	5		2	1	5	13
Existing human resources and know-how	4	6	3	1	1	15
Paris Climate Agreement requirements/emission reduction	6	5	3	3	12	29
Technological advances	3	11	6	1	13	34
Resource potential in the country	7	9	5	3	14	38
Advantages offered to investors (financing/technical support)	2	1	2	5	2	12
Being a domestic energy source	3	1	3	1	3	11
High imported energy prices/geothermal use for heating	5	2	3	1	8	19
Future						0
Conducting/supporting R&D	4	3	10	4	11	32
Increasing in social acceptance with awareness	8	9	7	2	10	36
Increasing in social acceptance with social benefits	12	2	11	5	7	37
Making legal arrangements (suggestions etc.)	17	6	7	2	6	38
Establishing geothermal standards	5	5	7	4	5	26
Offering plant-based incentives (rewards, drilling costs, etc.)	5		5		2	12
Promoting domestic equipment production/use	1		4		3	8
Challenges						0
Political/Regulatory/Institutional						0
Lack of institutional coordination/lengthy approval process etc	9		3	3	3	18
Competition to natural gas, regional lobby activities	1	2			3	6
Poorly development of direct utilization areas	7	7	2	3	7	26
Legislative gaps	6	1	8	5	1	21
Desegregated sector(small, non-institutional, domestic firms)	23	1	2		1	27
Conflicts between investors, land owners or municipality	7	2	2	2	1	14
Inadequate monitoring and auditing	7	1	6	4	5	23
Financial/Economic						0
Lack of direct utilization incentives	5	6	6	2	6	25
Current economic conjuncture	5	4			5	14
Current incentive scheme(for a particular time, in TL)	16	8	4		6	34
Foreign dependency on technology	1	4	2		3	10
Investor costs(drilling, risks, long payback period etc.)	23	5	14	14	6	62
Technical						0
Same reservoir use/reservoir management problems	4	1	1	4	4	14
Demand for further information/R&D/technology	9	2	2	1	5	19
Plant installation above resource capacity ignoring efficiency	3	3	2	3	3	14
Technical deficiencies(fluid quality, silica, cooling problems)	6	4	3		4	17
Inadequate geothermal standards	3		3		1	7
Environmental/ Social						0
Profit-oriented investor attitude	12	2	9	7		30
Poor social acceptance/local resistance	22	3	13	11	4	53
Misperception/insufficient information among the public	4	3	6	2	6	21
Smell/improper reinjection practices	8	1	6	2	6	23
Σ SUM	294	142	189	121	218	964

Appendix 4. MAXQDA output_group-based detailed opinions on opportunities and challenges.

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