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Telescopic drilling view for future: A geothermal foresight study in Turkey

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ABSTRACT

This paper analyzes Turkey's geothermal energy future perspective and power generation strategy with a view to explaining Delphi approach to geothermal energy development. In this study, the two round Delphi survey was conducted to experts to determine and measure the expectations of the sector representatives through online surveys where a total of 32 experts responded from 14 different locations. The majority of the Delphi survey respondents were from different universities (59.4%), industries (25%) and governmental organizations (15.6%). The article discusses expert sights on geothermal energy technologies and also includes bibliometrical approaches in order to assess the potentials of emerging and existing technologies. The results indicated that Turkey's geothermal power installed capacity is expected to reach 500 MW by around 2021 subsequent to the implementation of "Renovation of Standards and Regulations" and "Fiscal Approaches".

1. Introduction

For centuries geothermal springs have been used for bathing, healing and cooking. Only in the early 20th century did people start to consider the heat from inside the Earth as a practical source of energy with huge potential. Geothermal energy is used to produce electricity on a significant scale, as well as for direct use applications like space heating, greenhouses and aquaculture. The exploitable geothermal resources are found throughout the world and are being utilized in at least 78 countries. Electricity is produced from geothermal in 24 countries spread over all continents. Six countries obtain 10–30% of their electricity from geothermal [1].

Although geothermal energy is well positioned within the renewables current growth is only steady but rather slow. While wind and solar PV show exponential growth, geothermal power develops rather linearly, so far provided by hydrothermal resources, located in special geological settings [2].

The thermal energy used is 121,696 GW h/year, about a 60% increase over 2005, growing at a compound rate of 9.9% annually. The distribution of thermal energy used by category is approximately 49% for ground-source heat pumps, 24.9% for bathing and swimming, 14.4% for space heating, 5.3% for greenhouses and open ground heating, 2.7% for industrial process heating, 2.6% for aquaculture pond and raceway heating, 0.4% for agricultural drying, 0.5% for snow melting and cooling, and 0.2% for other uses. Energy savings amounted to 46.2 million tonnes of equivalent oil annually, preventing 46.6 million tonnes of carbon and 148.2 million tonnes of CO_2 being release to the atmosphere which includes savings in geothermal heat pump cooling [3].

According to International Geothermal Association [1], the growth of geothermal utilization for power generation has averaged roughly 5.5% per year over the last 30 years, and the geothermal installed capacity in the world has been increased by about 1000 MWe every 5 years. The geothermal power plant installed capacity in the world is expected to reach 10,715 MW at the end of year 2010. Another expectation is the total installed capacity of geothermal power plants to increase from the value of 10.7 GW in 2010 to about 160 GW by 2050.

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Geothermal energy can play a significant role in developing countries [4]. The El Salvador 25% of electricity comes from geothermal steam [5] in the Philippines 17% [6], 14% in Costa Rica, 11% in Nicaragua [7], and 8% in Kenya [8].

Turkey is located on the Alpine–Himalayan orogenic belt, which has high geothermal potential. The first geothermal research and investigations in Turkey were started by The Mineral Research & Exploration Institute of Turkey (MTA) in the 1960s.

From this time, 186 geothermal fields have been discovered by MTA, where 95% of them are low-medium enthalpy fields, which are suitable mostly for direct-use applications. With the existing geothermal wells and spring discharge water, the proven geothermal capacity calculated by MTA is approximately 4000 MWt. Geothermal resources of the country are wide spread but the favorable reserve for heating and generating electricity is limited and even this limited reserve has not yet been used [9]. The geothermal potential is estimated at 31,500 MWt (5,000,000 residences equivalence). This figure means also that 30% of the total residences in Turkey could be heated by geothermal energy. Turkey is the 7th richest country in the world in geothermal potential [10].

Based on these data regarding the potential of geothermal energy in Turkey, a necessity has arisen for systematical evaluation of the field and Delphi approach was the most appropriate tool due to not just its benefits to aggregate group opinion of selected experts [11–14] but also a structural procedure for anonymous group discussion [15–17] in order to deal with various aspects of the geothermal energy and technology demand.

Therefore, the aim of this study was to identify the most important geothermal technologies and research priorities likely to be demanded by the Turkish energy industry and contribute to the achievement of strategic goals in the geothermal energy sub sectors vital for the national wealth creation, environmental effect and improvement of the quality and security of life. The specific geothermal energy technology statements and the features of societal expectations are synthesized by respondents. Furthermore, the intention of the study was to describe trends in the development of geothermal energy technologies and to bring out research and development needs in order to reach the priorities identified in the geothermal energy technologies. The ultimate objective was to provide advice on geothermal energy R&D priorities, based on sound expert knowledge with a time horizon of 2050.

In the scope of this study, bibliometric study was conducted in order to investigate the literature, one-to-one meetings were organized with the experts yielding the data for SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis and finally the two-rounded Delphi questionnaire was designed for eliciting the geothermal energy technologies in Turkey projected for the year 2050.

2. Methodology

Qualitative (e.g. expert interviews, literature reviews, expert workshops) and quantitative methods (e.g. standardized surveys, patent analysis) are nowadays to be regarded as complementary rather than competing methods for gaining insights after years of debate [18]. Integrating research methods has proven to be useful in other studies as well [19–22].

In this study, a bibliometric analysis [23] was conducted to find out the development trends of the scientific studies in the field of geothermal energies in Turkey. Additionally, a constructive SWOT analysis [24] has been carried out with the data gathered via face to face interviews by eliciting the opinions of previously identified academicians, policy makers and politicians, industrialists and representatives of civil society organizations, operating on renewable energies. The core of this study was a Turkey-wide Delphi geothermal energy technology survey with two rounds of expert consultations. The rationale of the Delphi method is based on expert judgment, reflection and iteration in order to produce consensus and accurate forecast when direct information for trend analysis and prediction is not available. The Delphi method is an appropriate approach not only to gain a consensual-based technological foresight, but also to integrate technological, social and economic perspectives of sustainable development [25–28]. The method is used for gathering data from respondents within their domain of expertise (Fig. 1). The technique is designed as a group communication process which aims to achieve a convergence of opinion on a specific real-world issue [29]. The Delphi methodology belongs to the subjective and intuitive methods of foresight. Issues are assessed, on which only uncertain and incomplete knowledge exists. It is based on a structured survey of expert groups and makes use of the implicit knowledge of participants. Hence, the Delphi method has both quantitative and qualitative dimensions. There is not a single method, but all agree [30–32] that a Delphi study requires an expert survey in at least two or more rounds. Starting from the second round, a feedback is given about the results of previous rounds: the same experts assess the same matters once more, influenced by the opinions of the other experts. The methodology facilitates a relatively strongly structured group communication process, revealing conflicting as well as consensus areas. Delphi-based foresight exercises, therefore, were used repeatedly and increasingly in the context of policymaking, building on their capacity to facilitate an alignment of actors' expectations through interactions [33].

In this study, Delphi statements were developed by using the results obtained from the bibliometric and SWOT analyses. The survey was thus able to give a comprehensive view of the future of geothermal energy from basic research to social impact and from subjective and normative points of view to objective and extrapolative perspectives. The results of the impacts were subsequently weighted using the weights attributed to a particular level. The particular expertise categories and corresponding weight are calculated as (High (expert) responses $*(2)+$ Knowledgeable responses $*(1)+$ Familiar responses $*(0)+$ Unfamiliar responses $*(-1))/$ total responses on impacts (non-responses not included). Finally, overall impact was calculated as overall impact index $1/4[(\text{index of wealth creation impacts})^2+(\text{index of environmental impacts})^2+(\text{index of life quality impacts})^2+(\text{index of energy supply safety impacts})^2]^{0.5}$.

This work is a part of a holistic foresight analysis of renewable energies in Turkey and Delphi studies. In bibliometric study [23], a total of 12,197 publications were processed article by article and as a result 1555 papers were found to focus on renewable energies between the years 1980 and 2008. For each paper, the distributions of publications over years, the authors, the authors'

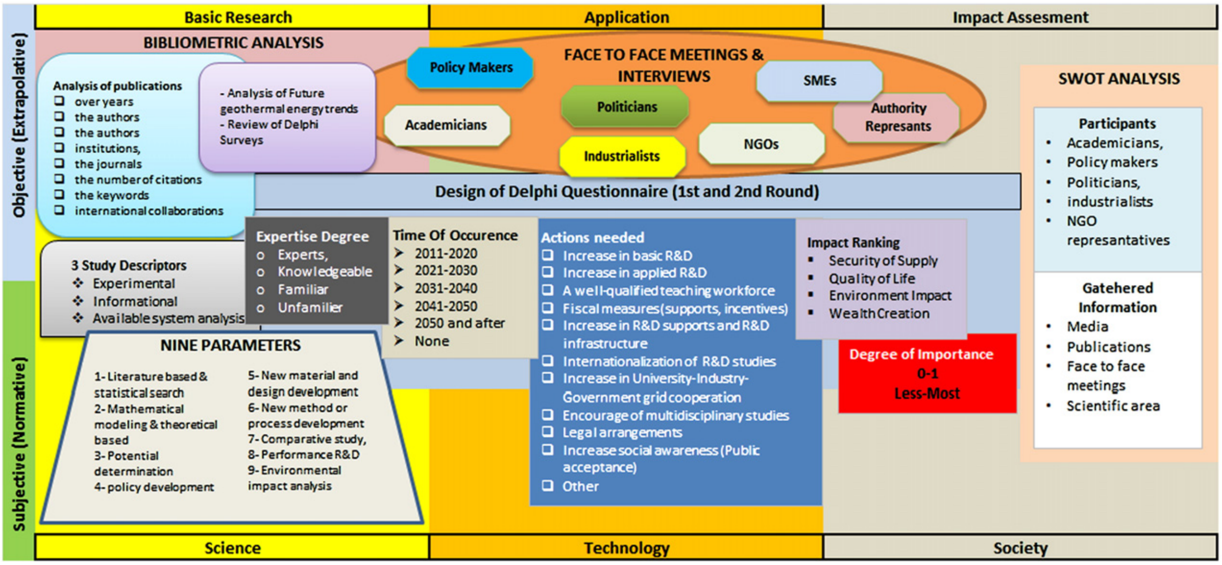


Fig. 1. Structural design of foresight workflow.

institutions, the journals, the number of citations, the keywords, and international collaborations were identified. Subsequently, these records were analyzed using Access, Microsoft Excel and macros for gathering further scientometric indicators in order to identify various properties of publication clusters and were categorized under 11 sub-fields. After that, all publications in these sub-fields were classified according to three descriptors, namely, experimental study, informational study and available system analysis. Additionally, nine parameters were defined to delineate the sub-fields identified in renewable energies by screening and classifying a cluster of 1555 publications. Subsequently, sub-fields were also analyzed according to these nine parameters, listed as follows, literature based and statistical search, mathematical modeling and theoretical based, potential determination, policy development, new material and design development, new method or process development, comparative study, performance R&D, and environmental impact analysis.

In the SWOT analysis, various sources of information have been used for the analysis of Turkish renewable energy technologies, market and policies [24]. A different technique has been developed for analyzing all segment applications, named as quadratic helix approach formed by eliciting the opinions of previously identified academicians, policy makers and politicians, industrialists and representatives of civil society organizations, operating in the field of renewable energies. First, all statements and press releases published in the newspapers by all Turkish renewable energy parties starting from the launch of renewable energy process of law till today (May 2005–February 2009) were gathered and screened. Second, all articles presented in the events between 2000 and 2008 were collected and evaluated. Finally, face to face interviews were conducted with all the parties determined within the quadratic helix. A number of trigger questions were used during face to face interviews and for formulation of the output elicited from the screening studies.

The Delphi poll was created by the outcomes of bibliometric analysis [23] by which researchers working in this field were elicited. Moreover, experts and various actors in geothermal energies were identified by screening the people working in governmental, non-governmental organizations and industry which was reflected in the quadratic helix approach [24].

Respondents were asked to assess the time occurrence of Delphi statements for seven time intervals from today to 2050 and never. Regarding times of technological realization, the earliest and latest quarters of the answers were discarded and the half in between was used to obtain a value. The quartile including the top statistically ranked members is called the first quartile and denoted Q1. The center half (Q1–Q3) is used as the range of answers and the median (Q2) is used as the representative value for achievement. An average time of occurrence of the statements was evaluated after the second round of Delphi. First and third quartiles were used respectively for the evaluation of the time of occurrence.

Four groups of people are invited to participate in this Delphi survey:

- according to bibliometric results, academics in relevant areas of geothermal
- related NGOs, administrator or representatives from its energy specialized board
- industry (all supply or value chain represents from manufacturing to sales)
- related politicians and governmental authorities (from Ministry of Energy and government agencies like Energy Market Regulatory Authority).

In the process of the construction an evaluation model, the opinion of stakeholders of the system under investigation has been considered. Academics are also included because it is believed that they understand scientific principles in areas that are related to geothermal energy and so their expertise will be relevant to the construction an evaluation model.

Delphi survey participation criteria were identified by authors as follows:

1. Any person who has published any article on the topic of geothermal energy in an academic publication.
2. Any person who has worked on the topic of geothermal energy in industry, authority or NGOs.
3. Any person who satisfies the condition above is eligible to be invited.

The Delphi survey was comprised of two sections, where the first section was designed to cover participants' demographic properties and the second section was dedicated to questioning of ten Delphi statements. The foresight period was ascertained as 40 years from today to 2050. Because a similar horizon was used in other studies [7,24], therefore cross-comparison of data was available.

The web-based questionnaire was developed and designed using Hypertext Preprocessor (PHP) and Structured Query Language (MySQL) databases. The survey was structured and functionally designed as a web-based, flexible, scalable, analogical and analyzable format which had a user-friendly interface. The user friendliness and accuracy of the web based survey system was pre-tested with some expert participants from Ege University. These experts were elicited from bibliometric study [23]. According to this study, a total of 19 different institutions contributed to the papers published in geothermal systems.

Some definitions used in structuring the Delphi questionnaire and calculation methodologies were given in our previous study [29].

Over 1900 experts in the field of all Turkish renewable energy sectors were directly invited to participate in the two-round Delphi questionnaire. Projections were structured according to the SWOT analysis where technological, economical, political and social aspects were considered [34].

Experts who accepted the invitation to participate were asked to complete two questionnaires. The link of the questionnaires was sent to respondents consecutively between March and May of 2009. The second questionnaire included the results of the first one and was identical to the first questionnaire. The overall response rate for the first round of the Delphi process was (382/1900) 20.1%; this improved to (325/382) 84.9% in the second round questionnaire. The majority of the Delphi survey respondents were from universities (63%) and industries (18%). The respondents came from governmental organizations (11%), research institutions (4%) and others (4%) [29].

The list of experts was composed of representatives from science and technology institutes, industry, academia, governmental authorities and as well as non-governmental organizations corresponding to all Turkish renewable energy actors. First and second rounds of Delphi study were carried out by using online survey. Among 382 respondents, totally 32 experts from 14 different locations participated in the whole Delphi questionnaire process which shaped out the future of geothermal energies in Turkey. In terms of institutional background the respondents show a very good distribution within the various fields.

Impact analysis is usually applied to take account of interactions among different events and future developments. The respondents were also invited to assess each statement in terms of its impact on the four following elements: wealth creation, environment, quality of life and security of supply.

The respondents were asked simultaneously with other questions to assess which of the following actions could promote an early occurrence of the statement; respectively, “Increase in basic R&D”, “Increase in applied R&D”, “A well-qualified teaching workforce”, “Fiscal measures (supports, incentives)”, “Increase in R&D supports and R&D infrastructure”, “Internationalization of R&D studies”, “Increase in University-Industry-Government grid cooperation”, “Encourage of multidisciplinary studies”, “Legal arrangements”, “Increase social awareness (Public acceptance)” and “Other”.

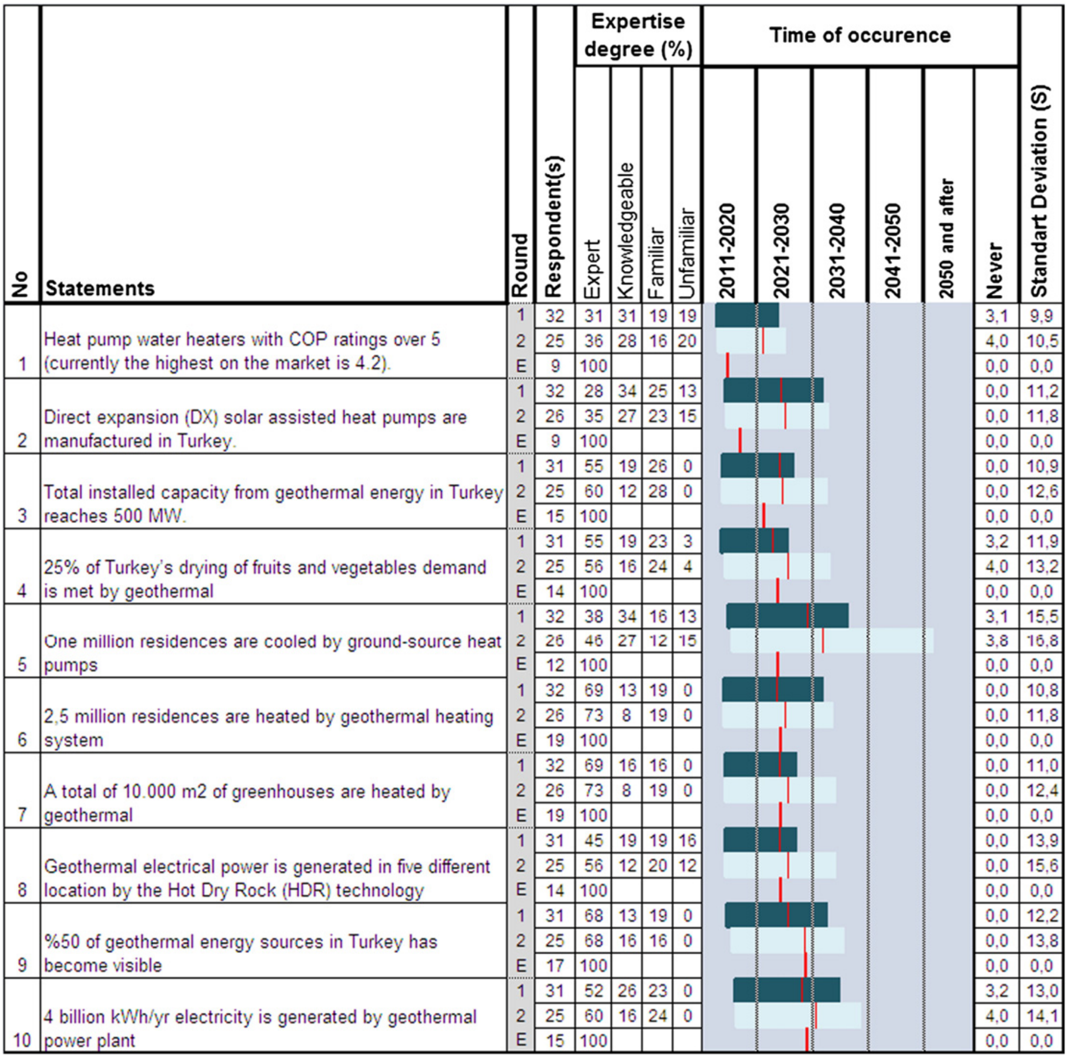
Finally, all the outcomes of the Delphi survey were evaluated using Access, Microsoft Excel and macros software tools.

3. Results and discussion

This paper analyzes Turkey's geothermal energy future perspective and sector development strategy with a view to explaining Delphi approach to in the time horizon up to 2050 and identifies key geothermal energy technologies of strategic importance. In this study, a two round Delphi research study was undertaken to determine and measure the expectations of the technology representatives regarding foresight of geothermal energies. In other words, the two round Delphi survey was conducted to experts to determine and measure the expectations of the sector representatives through online surveys.

The majority of the respondents were from 13 different universities (59%), industries (16%), governmental organizations (16%) and other institutions (9%). The respondents come from different age groups who were classified into 5 different groups: 21–30; 31–40; 41–50; 51–60; and >60. The distributions by the age groups of the respondents were, 9%, 44%, 19%, 16% and 12% respectively. The gender distribution was 71.9% male and 28.1% female. The respondents show a perfect mix of technological (50%) and non-technological (50%) experts. The non-technological experts have their expertise primarily expertise public policy (9.4%).

The Delphi statements and their time of occurrence were assessed by all respondents. The time of occurrence was evaluated on the data from the first and second rounds of the Delphi results which is presented in Fig. 2 which displays the answers obtained in all rounds for all respondents who considered themselves to be either experts, knowledgeable or familiar with the geothermal energy. The first column shows the Delphi statements. The number of the respondents and the expertise degree distribution (%) were displayed on the left side of the figure. The answers obtained in the second round and experts for all those participants claiming to be either experts, knowledgeable or at least familiar with the topic were displayed on the right hand side of the figure. The bars indicate the statistical distribution of the responses.



No	Statements	Round	Respondent(s)	Expertise degree (%) Expert	Knowledgeable	Familiar	Unfamiliar	Time of occurence 2011-2020	2021-2030	2031-2040	2041-2050	2050 and after	Never	Standart Deviation (S)
1	Heat pump water heaters with COP ratings over 5 (currently the highest on the market is 4.2).	1	32	31	31	19	19						3,1	9,9
		2	25	36	28	16	20						4,0	10,5
		E	9	100									0,0	0,0
2	Direct expansion (DX) solar assisted heat pumps are manufactured in Turkey.	1	32	28	34	25	13						0,0	11,2
		2	26	35	27	23	15						0,0	11,8
		E	9	100									0,0	0,0
3	Total installed capacity from geothermal energy in Turkey reaches 500 MW.	1	31	55	19	26	0						0,0	10,9
		2	25	60	12	28	0						0,0	12,6
		E	15	100									0,0	0,0
4	25% of Turkey's drying of fruits and vegetables demand is met by geothermal	1	31	55	19	23	3						3,2	11,9
		2	25	56	16	24	4						4,0	13,2
		E	14	100									0,0	0,0
5	One million residences are cooled by ground-source heat pumps	1	32	38	34	16	13						3,1	15,5
		2	26	46	27	12	15						3,8	16,8
		E	12	100									0,0	0,0
6	2,5 million residences are heated by geothermal heating system	1	32	69	13	19	0						0,0	10,8
		2	26	73	8	19	0						0,0	11,8
		E	19	100									0,0	0,0
7	A total of 10.000 m2 of greenhouses are heated by geothermal	1	32	69	16	16	0						0,0	11,0
		2	26	73	8	19	0						0,0	12,4
		E	19	100									0,0	0,0
8	Geothermal electrical power is generated in five different location by the Hot Dry Rock (HDR) technology	1	31	45	19	19	16						0,0	13,9
		2	25	56	12	20	12						0,0	15,6
		E	14	100									0,0	0,0
9	%50 of geothermal energy sources in Turkey has become visible	1	31	68	13	19	0						0,0	12,2
		2	25	68	16	16	0						0,0	13,8
		E	17	100									0,0	0,0
10	4 billion kWh/yr electricity is generated by geothermal power plant	1	31	52	26	23	0						3,2	13,0
		2	25	60	16	24	0						4,0	14,1
		E	15	100									0,0	0,0

Fig. 2. The Delphi statements and their time of occurrence.

The mean value of the time of occurrence for the most statements lies between 2015 and 2030. This corresponds well with the intended 20 years time horizon of the geothermal energy applications. According to the participants, approximately 4 billion kW h of electricity has been expected to generate annually in Turkey by around 2029. On the other hand, electricity generation from geothermal was projected to reach 177 TW h by 2030, an average rate of growth of 4.7% per year in the reference scenario prepared by International Energy Agency [35].

Electricity generation from geothermal steam is an emerging industry, dating back to the beginning of the last century. In fact, commercial generation of electricity from geothermal steam began in Larderello, Tuscany, Italy, in 1913, with an installed capacity of 250 kWe. Since 1950, other countries have followed the Italian example, and at present, electricity is generated from geothermal energy in 24 countries all over the world [4]. Geothermal-based electricity generation is expected to continue to increase in the next years all over the world because of the privatization of construction and operation of geothermal power plants in many countries [36]. On the other hand, there are 50,583 MWt of installed direct use capacity in 78 countries, producing 121,693 GW h of geothermal energy per year about a 60% increase over 2005, growing at a compound rate of 9.9% annually [1,3].

By the end of 2010, the total installed capacity in Turkey was 49.562 MW; and when the breakdown of the installed capacity in operation is examined by enterprises, it can be seen the public has a dominant concentration in the market. Capacity under the public control, namely, EUAS, and subsidiaries of EUAS such as, IHD, BO, and BOT, account for about two thirds of the total installed capacity [37].

The geothermal electricity generation capacity potential of Turkey is estimated at 2000 MW (16 TW h/year) and a generation capacity of 300 MW that utilizes geothermal sources is expected by the year 2015 [38,39]. Turkey's installed capacity from geothermal power has been expected to reach 500 MW among the respondents by around 2021 or even later as a result of "Renovation of Standards and Regulations" and "Fiscal Approaches" studies (Fig. 3).

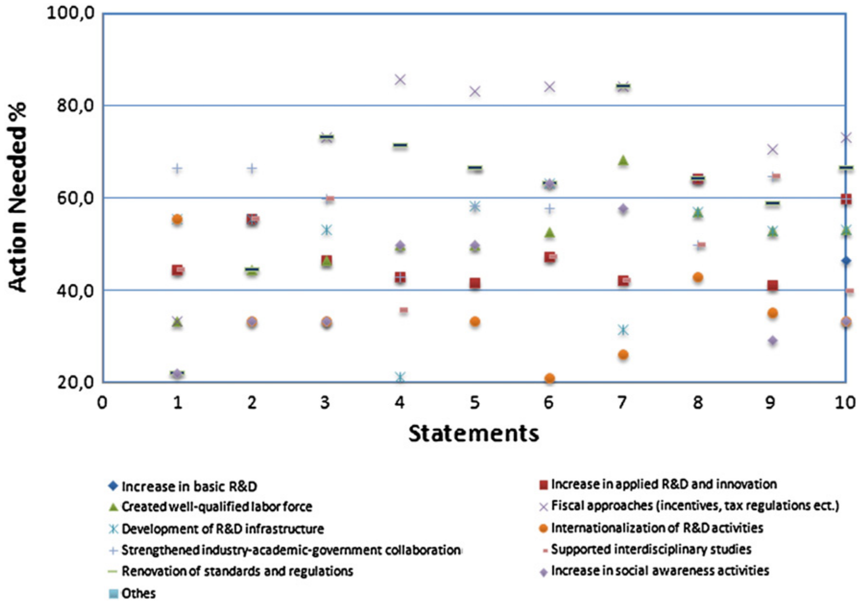


Fig. 3. Comparison of actions needed to enhance the Delphi statements.

This installation process is foresighted to be completed by 2021. On the other hand, within the framework of the strategy paper [40], by the year 2023 at the 100th anniversary of the foundation of Turkish Republic, the geothermal energy installed capacity has been aimed to reach up to 600 MW after the integration of entire potential into economy.

However, the utilization of geothermal energy in Turkey has increased since 1984 when the first geothermal power plant with a total capacity of 20.4 MWe was installed. Up to date, Turkey has about 94.2 MWe geothermal power installed capacity in operation and about 69.5 MW under construction. Also, license applications for a total capacity of 129.5 MW have been submitted to the Energy Market Regulatory Authority of Turkey (EMRA) by private sectors as of March 2010. As of today, Turkey has almost 50,004.2 MW of installed capacity and the geothermal power is only 0.2% of the country's total energy capacity [41,42].

On the other hand, there has been a huge potential in the United States, Indonesia, the Philippines, parts of Africa and also in Central Europe. The geothermal industry in the United States, which is the world leader in online capacity [1], currently enjoys an unprecedented level of support from Congress and President Obama's Administration. The American Reinvestment and Recovery Act of 2009 allocated $400 million to the Department of Energy's Geothermal Technologies Program [43].

Indonesia also known as the world largest geothermal potential resources has given rise to large concentration of high temperature geothermal system. The total potential estimated by National Geological Agency of Indonesia is about 27,000 MW. In term of geothermal development and its utilizations, the Government of Indonesia is planning to utilize those big energy resources as a leading alternative energy to substitute fossils that may be fulfilling Indonesia's growing demand for electric power in the next 20 years [44].

Geothermal energy in the Philippines is used primarily for electric power generation. In 2010, the installed capacity for electric power generation reached 1907.32 MWe with approximately energy generation total of 10,311 GW h for the year representing about 17% of the country's total energy generation. The country envisions being the world's largest producer of geothermal energy. Additional capacity of 800 MWe intends to be commissioned between 2010 and 2014. The Philippines is also actively promoting the development of geothermal. Although, the global financial crisis has affected plans and programs on geothermal development, the Philippines's Expansion program has continued [6,45].

In Europe just over 1 GW geothermal electric power (of which 0.95 GW operational) is installed and producing roughly 7000 GW h of electricity per year. The geothermal market is currently concentrated in a number of countries across Europe, with Italy, France, Portugal, Iceland and Turkey leading the electricity sector. In the power sector, the installed capacities of geothermal energy for the EU-27, with respect to the baseline, are 1 GW in 2020 and 1.3 GW in 2030. The estimated maximum potential for geothermal power in the EU-27 is up to 6 GW by 2020 and 8 GW by 2030. This represents about 1% and 1.3% of projected EU gross electricity consumption by 2020 and 2030 respectively [46].

Majority of the respondents stated that “50% of geothermal energy sources in Turkey have become visible”. Indeed, Turkey has extended its involvement in geothermal energy projects, supported by loans from the Ministry of Environment, and geothermal energy is expected to increase substantially in the coming years [47]. Research in this field has almost diminished in 1990 as sufficient emphasis was not given to geothermal energy in Turkey. But, in recent years, in an attempt to reduce its dependence on petroleum and natural gas, a search has begun among basic resources to close the energy gap. In other words, works have been accelerated after some laws and regulations (Appendix A) were published in Official Gazette.

In terms of geothermal resources, Turkey is Europe's number one, and the world's number seven country [1,10]. According to the Ministry of Energy and Natural Resources, geothermal energy will dominate the coming period just like wind energy [48]. Recently, many research studies [49–54] have been conducted and reported on assessment of Turkey's geothermal resources. These research studies show that the total apparent geothermal capacity of identified fields is 4800 MWt and 4500 MWt based on reference temperatures of 15 °C and 20 °C, respectively. On the other hand, there are 276 geothermal occurrences including nearly 110 fields having at least one drilled well known to exist in Turkey with surface temperatures ranging from 22.5 °C to 220 °C according to both Mineral Research & Exploration General Directorate of Turkey (MTA) [52].

Geothermal energy from hot rocks differs from the conventional hydrothermal energy process that produces power commercially in geologically active areas. HDR energy is clean, abundant and reliable and if properly developed, it can offer a renewable, sustainable, CO_2-free and independent of time of day, of weather or season full base-load energy sources [55].

Starting as early as 1970, experiments were conducted in hot dry rock (HDR) in the USA, UK, France, Australia, Germany, Switzerland and Japan. The HDR concept has been to extract heat from rocks that are not naturally fractured and where permeability is generally low [56]. In fact, the use of hydro-geothermal energy is only a fraction of the total potential of geothermal energy, which mainly associated with the much deep-seated HDRs generally at depths ranging around 4–6 km. Based on some presumed parameters, the geothermal energy potential in the uppermost 10 km of the Earth's crust was tentatively estimated to 50,000 times the energy of all known oil and gas resources in the world. Early on, HDR was not considered technologically or economically accessible, but technological advances in recent years have pushed the concept toward commerciality [55–57]. When this technology becomes commercial, the resource base of geothermal energy will increase dramatically worldwide [58].

According to the Delphi survey respondents, “Geothermal electrical power will be generated in five different locations by the HDR technology in 2024”. More R&D activities are required to implement HDR technology. On the other hand, the renovation of standards and regulations on support for electricity generated from the HDR technology needs to be regulated or adopted and entered into force. Some preliminary studies have been planned for the exploration of the HDR sources in Turkey [59,60], which have been integrated and reviewed [61]. The HDR researches and investigation in Turkey started by Turkish Mineral Research and Exploration Institute (MTA) in 2009s. This investigation has been continued in Çanakkale–Balıkesir–Kütahya regions [60]. But so far, MTA has not explored any HDR yet.

Greenhouse heating is one of the popular applications of low-to moderated-temperature geothermal resources. Using geothermal energy is both an economical and efficient way to heat greenhouses. Greenhouse heating systems can be designed to utilize low-temperature resources, which make the greenhouse an attractive application. These resources are widespread throughout the western states providing a significant potential for expansion of the geothermal greenhouse industry [62]. Greenhouse heating area has increased from year to year. The countries which have made maximum use of geothermal energy for heating greenhouses and covered ground include China, Georgia, Hungary, Iceland, Italy, Russia and the United States [63]. According to Lund et al. [64], greenhouse heating energy use increased only 9.8% or 1.9% annually down from the 1995–2000 period. A total of 30 countries reported geothermal greenhouse heating: the leading countries being Georgia, Russia, Turkey, Hungary, China and Italy. Most countries did not distinguish between covered (greenhouses) versus uncovered ground heating, and also did not report the area heated. Several countries, such as Macedonia, reported a decrease in geothermal greenhouse use, due to economic problems. United States greenhouse growers are experiencing increased competition from import of plants from Latin America, such as roses, undermining the market.

According to Turkey's Geothermal Country Update Report [65], Turkey is the fifth country in the World in operating geothermal direct use applications. Most of the development has been achieved in geothermal direct-use applications by 201,000 residences equivalence geothermal heating (1494 MWt) including district heating, thermal facilities and 2,300,000 m^2 geothermal greenhouse heating. A total of 260 spas in Turkey are used for balneological purposes (552 MWt). By summing up all these geothermal utilizations in Turkey, the installed capacity is 2084 MWt for direct-use and 81.61 MWe for power production in Turkey, where a liquid carbon dioxide and dry ice production factory is integrated to this power plant. About 7% of our total geothermal potential has been utilized so far [10,65].

Geothermal greenhouse heating has gained speed particularly in the last 3 years in Turkey [10]. Delphi respondents pointed out that a total of 2500 ha (10,000 m^2) greenhouses will be heated by geothermal and 2.5 million residences are expected to be included in geothermal heating system by around 2025. Additionally, 25% of Turkey's drying of fruits and vegetables demand is expected to be met by geothermal resources. It is worth to mention that approximately, 19,607 TJ energy is required to heat almost 1000 ha of greenhouse worldwide annually [64].

On the other hand, the Delphi second round results showed “One million residences are cooled by ground-source heat pumps” in Turkey in 2023. Experts' opinions on the times of occurrence also seem more optimistic than the other participants for this development. However, there are very limited applications (<1% of all geothermal applications) in this area with space cooling in the world [64]. This statement has the highest impact on wealth creation taking into account the time perspective. Correspondingly, only 3.8% of the experts find the technology entirely impossible.

Solar energy systems and heat pumps (HP) are two promising means of reducing the consumption of fossil energy resources and hopefully, the cost of delivered energy for residential use. An intelligent extension is to use refrigerant-filled solar collectors to replace the standard air-source evaporator in a heat pump system, which is called direct-expansion solar assisted heat pump (DX-SAHP) system. An advantage from the heat pump standpoint is that the collector/evaporator can operate at a temperature higher than ambient due to solar heating, which increases the heat pump coefficient of performance (COP) [66]. Recently, many research studies have been conducted on HP and DX-SAHP systems both in Turkey [66–70] and in the world [71–80]. These research studies showed the total apparent geothermal capacity of identified fields. According to the replies of the interviewed and surveyed people, DX-SAHP systems could be manufactured in Turkey in about 2017. Although currently the highest COP on the market is 4.2 [81], the heat pump COP ratings have been expected to improve over 5 in 2015, whereas some respondents thought that this statement will never succeed. On the other hand, experts seem more optimistic than the other participants on the times of occurrence for these statements.

Among key actors, all of these realized developments were foresighted from 2015 to 2030. Another generated result from the Delphi was that Turkey should be at the forefront of the world countries for utilizing the geothermal energy in next decades. Actions needed were evaluated on the basis of the Delphi results for all statements (Fig. 3). The three items with the highest degree of consensus among the respondents were "Fiscal approaches (incentives, tax regulations etc.)", "Renovation of standards and regulations" and "Strengthened industry–academic–government collaboration". On the other hand, "Internationalization of R&D activities" and "increase in social awareness activities" have been pointed out by few respondents. According to these results, R&D infrastructure and research efforts, incentives and fiscal approaches, national and international collaborations, standards and regulations must be increased at least on the world level in order to play a major role in the world by 2030, otherwise the time frame will not be realistic.

The recommended actions are a little bit different from each other. According to experts' opinions, recommended actions for developing the geothermal system technologies were quite similar. On the other hand according to the participants, heat pump and DX-SAHP system manufacturing were expected to strengthen industry–academic–government collaborations (Fig. 3). The following statements, "Increase in basic and applied R&D" and "Increase in social awareness activities" were backed by approximately 50% of the respondents and likewise "Increase in social awareness activities" and "Internationalization of R&D activities", were recommended by 33% and 39% respectively.

Impact analysis is usually applied to take account of interactions among different events and future developments. This technique can provide some supplementary information especially when shortcomings of a Delphi study occur [82]. The respondents were also invited to assess each statement in terms of its impact on the four following elements: wealth creation, environment, quality of life and security of supply.

The statements were ranked according to their impact on these four impact measures. According to experts' opinions, the geothermal energy technology statements impact rankings were shown in Fig. 4. The evaluation of the impact assessments of the ten Delphi statements was based on an overall impact index calculation. The overall impact index ranged from 1 for an adverse impact until 4 for a highly beneficial impact. According to overall impact index, the statements namely "Geothermal energy installed capacity reaches 500 MW" and "2.5 million residences are heated by geothermal" had a strong impact and the statements "DX-SAHP systems are manufactured in Turkey" and "one million residences are cooled by GSHP" had the most significant impact on the geothermal energy systems.

As can be seen in Fig. 4, the top three statements were generally rated similar across the four impact measures. Likewise the statement "hot dry rock (HDR) technology in 5 locations" received the minimum impact value as a result of both the first and the second round Delphi survey. The statement "DX-SAHP systems are manufactured in Turkey" had a strong impact on security of supply. On the other hand the statement "Heat pump water heaters with COP ratings over 5" had the minimum impact on security of supply area.

In terms of the impact, it should be noted that the statement "implementation of HDR technology" had a very low wealth creation, environmental impact and quality of life score compared to the statement "1 million residences are cooled by GSHP" which was ranked with the highest score. The lowest ranked is the same statement of the total impact ranked, but the top ranked was different.

The degree of importance of the statements to Turkey was reflected as a percentage breakdown of respondents who indicated "high," "medium," "low" or "unnecessary". The index was worked out from the following equation; the index was accepted as 100 when all respondents indicated "high" and 0 when all indicated "unnecessary". Degree of importance index was calculated as: degree of importance index 1/4(number of "high" responses $*$ 100 + number of "medium" responses $*$ 50 + number of "low" responses $*$ 25 + number of "unnecessary" responses $*$ 0) / total number of degree of importance responses.

Finally, the degree of importance of the statements to Turkey was reflected as a percentage breakdown of respondents who indicated "high," "medium," "low" or "unnecessary". The evaluation of the degree of importance of the ten Delphi statements to Turkey was based on an importance index calculation. The overall importance index ranged from 0 for less importance to 1 for the most important. According to experts' opinions, the degree of importance of the Delphi statements to Turkey was shown in Fig. 5. According to the degree of importance index, the top three statements were "*50% of geothermal energy sources in Turkey have become visible*" calculated as 0.94, "*2.5 million residences are heated by geothermal heating system*" calculated as 0.92 and "*One million residences are cooled by ground-source heat pumps*" calculated as 0.90. The top three statements are generally rated similar based on four impact measures. On the other hand, the statement at the bottom of the list was "*Heat pump water heaters with COP ratings over 5*" calculated as 0.67. There are little differences between the statements ranked at the top and bottom of the list.

4. Conclusion

This paper is the first attempt to provide a Delphi analysis of the Turkish geothermal energy and has explored the future geothermal technologies in Turkey using expert opinions elicited from the bilateral or face to face meetings and a web-based survey developed and designed using PHP and MySQL databases in order to gather information for the two-round Delphi

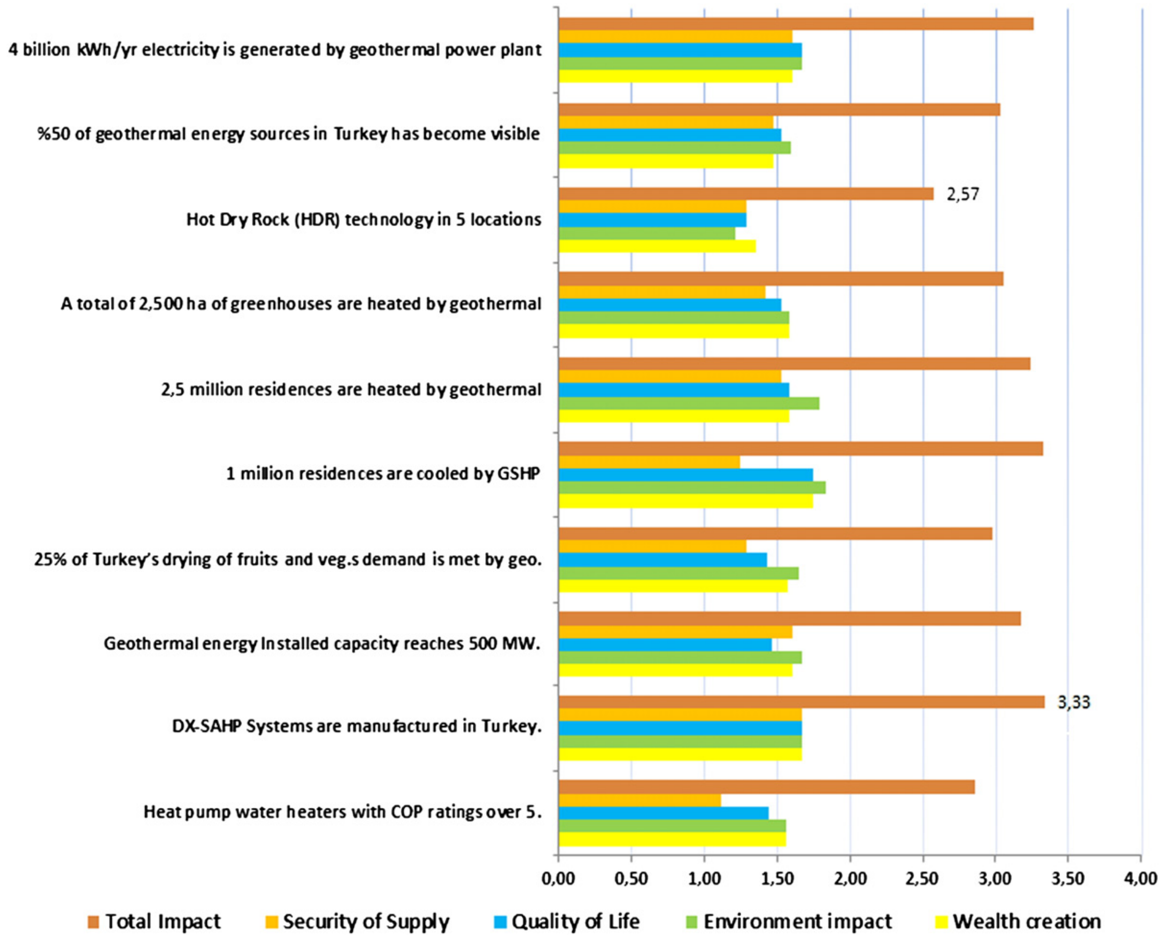


Fig. 4. Impact ranking of all statements.

method. Furthermore, web based survey was structured with a functional design in order to improve man–machine interfaces.

The participants chosen for the survey played key roles in the sector. The outcome was enriched with the inclusion of all the actors such as academicians, policy makers, politicians, industrialists and representatives of civil society organizations related to geothermal field.

In this paper, we looked for the most important geothermal technologies and research priorities likely to be demanded by the Turkish industry. In this context, we investigated Turkey's geothermal future and we believe that this foresight exercise may contribute to the policy objective of fostering the diversity of technological options especially through the development of alternative geothermal technology roadmaps that support participants in their R&D activities.

The mean value of the time of occurrence for most of the statements lies between 2015 and 2029. The other most important findings obtained from the Delphi survey can be summarized as follows:

- As consensus is achieved by 72% of the votes at the second round, the study was concluded in two rounds which is in accordance with the literature Green [83].
- The Delphi statements "50% of geothermal energy sources in Turkey have become visible," "2.5 million residences are heated by geothermal heating system" and "One million residences are cooled by ground-source heat pumps" were highly prioritized by the experts and there are great expectations for the development of these technologies.
- Statements 1, 4, 5 and 10 (Fig. 2) have a little share of respondents in the *Never* category.
- Geothermal electrical power will be generated in five different locations by the HDR technology and 25% of Turkey's dried fruits and vegetables demand will be expected to be met by geothermal in 2024.
- Turkey's geothermal power production will reach 4 billion kW h/year in about 2029.
- About 50% of geothermal energy sources will become visible by around 2029.
- Almost all statements peak in the period 2021–30.

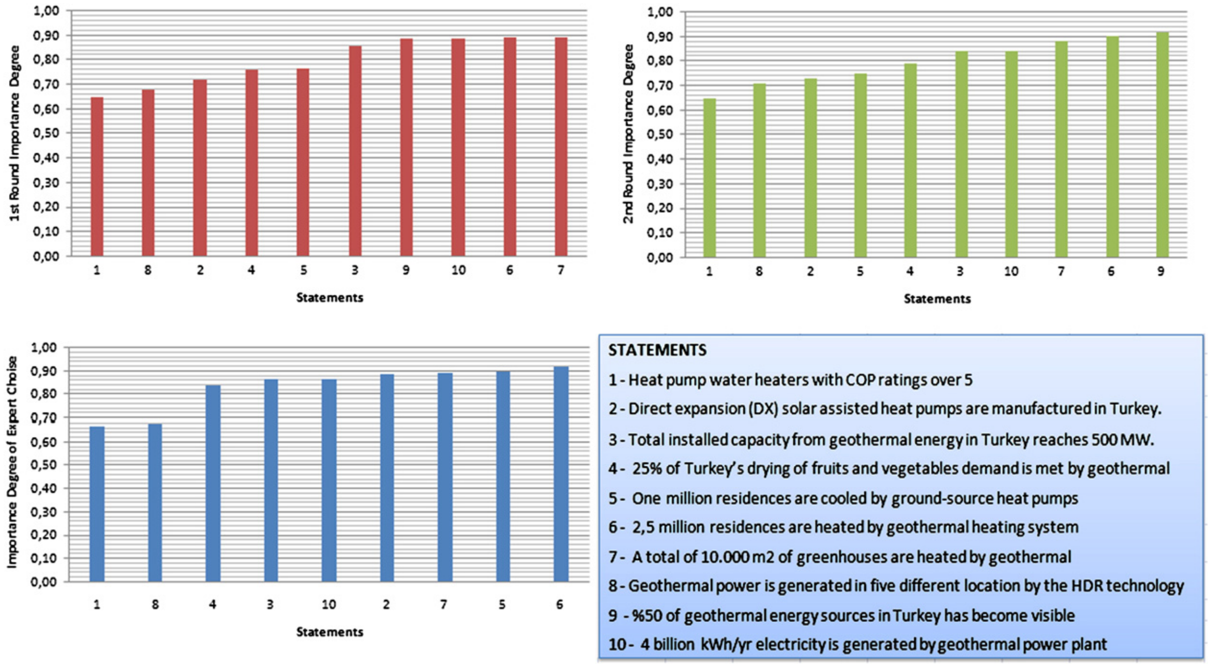


Fig. 5. The degree of importance of the Delphi statements to Turkey.

- The two statements with the highest degree of consensus among the respondents on the necessity of basic research are: HDR technology statement and DX-SAHP systems statement. On the other hand, statement 7 and statement 3 have few respondents pointing towards a required action for realization.

The respondents were asked to rate the anticipated impact of the statements in the areas of Wealth Creation, Environment, Quality of Life and Security of Supply. An index based calculation of the impacts allowed comparison between the technology statements. According to the impact values, the top statements are "DX-SAHPs are manufactured in Turkey" with an average effect index score of 3.33 and "One million residences are cooled by ground-source heat pumps" with an average effect score of 3.32. In addition to the positive security of supply impact, the respondents highlighted the strong contribution to environmental impact, wealth creation and quality of life. DX-SAHPs and GSHP statements scored higher than the other technological statements. This may reflect R&D interest and relative priority given to social and economical wealth creation. On the other hand the bottom statement is "implementation of HDR Technology in 5 locations" with an average effect index score of 2.57.

The nature of support measures required to accelerate the diffusion of energy systems varies widely among technologies. Relatively mature technologies, such as geothermal for heating and electricity generation, need less R&D but rely heavily on fiscal and regulatory policies for their growth. Actions needed were evaluated on the basis of the Delphi results for all statements (Fig. 3). The "Fiscal measures" item received the highest degree of consensus among the respondents, whereas, "Internationalization of R&D studies" has been pointed out by few respondents.

Turkey has a substantial technically and economically exploitable geothermal resource. It is obvious that the advancements in the mentioned geothermal technologies in this publication are going to make an impact on wealth creation and quality of life, therefore bringing economic benefits and societal prosperity.

Finally, most participants believed in the power of strengthened and increased collaboration between industry–academic–government collaboration and renovation of standards and regulations.

It is recommended that this type of a study shall be repeated in certain time intervals in order to observe the developments and ascertain upcoming trends in this field for future research. Also, in this study we did not use correlational and associational analyses which would definitely distinguish our work from others by making a contribution to theory development. These analyses will be considered in our future studies.

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Appendix A. Laws and regulations regarding geothermal energy in Turkey

1*	2*	3*	4*
5346	Use of renewable energy resources for electricity generation	18.05.2005	25,819
Aim: Duration of the purchase guarantee offered to electricity energy to be generated from renewable energy resources was increased from 7 years to 10 years, and by introducing a price ceiling of 5 to 5.5 €cent/kW h, an impetus was given to investments in this area. Furthermore, certain incentives were introduced for facilities to be built on Forest or Treasury lands or on lands that are at the disposal of the State for producing electricity energy from renewable energy resources.			
5627	Energy efficiency law	02.05.2007	26,510
Aim: This law introduced measures for incentivizing efficient use of energy with the ultimate target of making best use of the significant potential in this area. In addition, thanks to additional articles introduced by this law to the Petroleum Market Law, biodiesel production will be reorganized in a way to support national agriculture. Again, with a paragraph added under this law to Article 3 of the Electricity Market Law, natural and legal persons who build renewable energy based production facilities and micro cogeneration facilities for personal use, whose production capacity shall not exceed 200 kW, will be exempted from the obligation to obtain a license and start a company.			
5576	The amendment of petroleum market law	13.02.2007	26,433
Aim: This law regulates direction, surveillance and supervision activities required in order to ensure transparent, equalitarian and stable market activities for offering petroleum of domestic or foreign origin, directly or after being processed, to users in a safe, economical and competitive manner.			
5669	The amendment of natural gas market law	12.06.2007	26,550
Aim: This law aims at creating a financially-strong, stable and transparent natural gas market by liberalizing it with a view to offer natural gas to consumers in a high-quality, uninterrupted, economical, competitive, and environment-friendly manner; and ensuring independent regulation and supervision in this market.			
5686	Geothermal resources and natural mineral waters	13.06.2007	26,551
Aim: This law regulates procedures and principles for effective prospecting, researching, developing, producing, protecting, owning and transferring ownership, environment-friendly use and abandonment of geothermal and natural mineral water resources.			
5710	Construction and operation of nuclear power plants and energy sale	21.11.2007	26,707
Aim: This law regulates procedures and principles for constructing and operating nuclear plants that will produce energy in accordance with energy plans and policies, and for energy sale.			
Regulations			
6094	The amendment of the use of renewable energy resources for electricity generation	08.01.2011	27,809
The New Law raises the guaranteed prices for the sale of electrical energy by renewable energy resources ("RER") certificate holders. Such guaranteed prices are in the range of 5–5.5 €cent/kW h under the Renewable Energy Law for all types of renewable energy sources. In addition to the above-stated guaranteed prices, the New Law envisages a further incentive for the projects to be commissioned by 31 December 2015 whose mechanical and/or electromechanical parts have been produced in Turkey.			
3213	The amendment of mining activities permit regulation issued by the council of ministers:	27.04.2007	26,500
Aim: While some of the intended implementation targets were achieved, there were delays in the granting of the Mine Operation Permit, particularly due to various problems arising from local governments, in areas that are of primary concern to the sector, especially in offering license assurance to investors and in procedures required for obtaining a Workplace Opening Permit (the GSM Permit), which is one of the permits listed under Article 7; and the "Regulation on the Amendment of Mining Activities Permit Regulation" took effect after being published in Official Gazette.			
3213–5177	The amendment of mining law implementation regulation	15.07.2007	26,583
With a view to eliminate problems arising from the mining sector and from implementation, the 26 "Regulation on the Amendment of Mining Law Implementation Regulation" took effect after being published in Official Gazette.			
3213	The amendment of implementation regulation pertaining to group 1(a) minerals of the mining law	15.07.2007	26,583
Aim: With a view to eliminate problems arising from the mining sector and from implementation, the "Regulation on the Amendment of Implementation Regulation Pertaining To Group 1(a) Minerals of the Mining Law" took effect after being published in Official Gazette.			
5686	Geothermal resources and natural mineral waters law implementation regulation	11.12.2007	26,727
Aim: This regulation defines procedures and principles for issuing licenses for prospecting and operation of discovered and potential geothermal resources, natural mineral waters and gases of geothermal origin; for transferring licenses; supervising activities, the resource and the environment; terminating the license; protecting the resource and catchment; and abandonment of the licensed area.			

1* Law & Regulations (or Official Gazette) No.
2* Name of Law and/or Regulation.
3* Published date in Official Gazette.
4* Number of Official Gazette.

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