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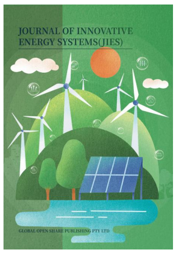

Article

Exploring the Challenges of Integrating Geothermal Energy in Sport Spots: A Multi Method Research Design

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Abstract

Recently, the global need for renewable and sustainable energy reservoirs has gained significant momentum. Among the multiple renewable energy options, geothermal energy stands a particularly advantageous and promising option. This research provides useful information to support sustainable development via clean energy use in sports facilities. A mixed-methods is used, including a qualitative section (interview with experts and reviewing the previous papers), and two survey sections to validate the challenges. 23 experts participated in the qualitative section and initial variables were identified. There were 123 participants in survey one, and the data were analyzed by exploratory factor analysis (EFA) and there were 137 participants in survey two, and the data were used for confirmatory factor analysis (CFA). to ensure adherence to subject-to-item ratio guidelines (5:1 for EFA, 10:1 for CFA) and statistical power for robust factor analysis. The results identified six main challenges and 18 sub-challenges. It was found that financial aspects pose a key challenge, as the upfront costs of installing geothermal systems can be higher compared to traditional energy sources. Another significant challenge is the scarcity of awareness and comprehension of geothermal technology. Technical complexities, as drilling and heat exchange system design, require specialized knowledge and expertise. Some practical options are presented for establishing geothermal energy use in sport facilities, including (1) financial incentives (e.g., government subsidies, public-private partnerships), (2) awareness campaigns targeting facility managers and policymakers, (3) technical training programs for geothermal system maintenance, and (4) streamlined permitting processes to reduce bureaucratic barriers.

Keywords

Energy, Sports, Geothermal energy, Renewable energy, Global warming

Article History

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1. Introduction

The development of human societies has increased the requirements for energy to meet human needs [1-3]. In the past, the main sources for meeting this energy need have been fossil fuels [4]. Such fuels are buried and are produced over millions of years [5]. Fossil fuels are widely used to generate electricity [6,7], power vehicles, and produce industrial products [8,9]. However, nonrenewable fuels are finite [10,11]. Moreover, burning fossil fuels emits carbon dioxide and other greenhouse gases that participate to global warming as well as other substances that contribute to air pollution [12-14].

Fossil fuels are the primary source of carbon dioxide (CO_2) emissions [15,16], which are the primary cause of global warming and consequently climate change [17-19]. Fossil fuels accounted for 79% of the world's primary energy utilization in 2019 [11,20], and 89% of the world CO_2 emissions from energy and industry [21]. Globally, coal was accountable for 40% of the CO_2 emissions, oil for 34% and gas for 20% [22], while the remaining CO_2 emissions came from different sources, like land use change, agriculture, and waste [23]. To limit the rise of global temperature and inhibit the worst causes of climate change, the world has to reduce its dependence on fossil fuels and reform to low-carbon reservoirs of energy, like renewable energy sources [24].

Renewable energy comes from natural reservoirs which can be replenished or reproduced in a short frame of time [25]. Renewable energy is solar, wind, geothermal, hydro, and biomass energy [26,27]. Renewable energy is considered to be cleaner than fossil fuels, as it produces little or no emissions and reduces the dependence on imported fuels [28]. The renewable energy source that forms the focus of this paper is geothermal energy [29].

Geothermal energy uses the heat from the Earth's crust to produce useful energy [30,31]. Utilizing geothermal energy involves using the natural heat kept within the Earth to produce steam or hot water, which can then be utilized to generate electricity or direct use in cooling and heating systems [32]. Geothermal energy is harnessed by exploiting the high temperatures found below the Earth's surface [33]. These temperatures are mainly a result of the radioactive decay of minerals and the waste heat from the planet's generation [9,16,34]. Such heat is present everywhere deep in the Earth, but it is more accessible in certain areas, especially near tectonic plate boundaries, volcanic regions, and hot springs [3,35].

Three main types of geothermal energy systems exist: shallow ground source heat pumps [36,37], direct use systems [38,39], and power plants [39]. Shallow ground source heat pumps deliver heat between the ground and buildings for cooling and heating targets [40]. Direct use systems utilize the hot water found underground for applications such as heating greenhouses or spas [41]. Geothermal power plants employ the hot water or steam to power turbines and generate electricity [39]. Geothermal energy has numerous advantages, including its sustainability, high-capacity factor (~90%, compared to ~20-50% for solar/wind), low lifecycle emissions (<45 g CO_2/kWh, versus 400-1000 g CO_2/kWh for fossil fuels) and potential for baseload power generation [34,42]. Since sports facilities have high energy needs, meeting these needs through renewable energy such as geothermal can prevent the greenhouse gases and carbon dioxide and has an effective role in the sustainable creation of the sports industry [43].

The need for clean and renewable energy sources has grown significantly on a global scale in recent years [21]. As stakeholders continue to prioritize environmental responsibility, sports facilities have emerged as valuable platforms to promote green initiatives [44]. Among the different renewable energy forms, geothermal energy stands out like a particularly advantageous and promising option [45,46]. Nonetheless, the adoption of geothermal energy in sports facilities is not free of challenges. This paper explores the barriers which hinder the widespread implementation of geothermal energy in sports facilities and to provide potential ways to overcome these obstacles. This research provides valuable information on geothermal energy use in sports facilities (which has the suitable location to use) and supports sustainable development and clean energy in sports facilities.

2. Literature Review

Geothermal energy has various utilizations in various industries. As the advantages of this form of energy, there are also hazards and obstacles hindering its use and benefits. Here, the issues of this type of energy identified previously are examined, by reviewing past studies, and the primary challenges and obstacles for geothermal energy are identified and presented. Data from various sectors and locations are used. Table 1 summarizes selected key studies done in this field and the main results.

Table 1 includes a summary and analysis of research reported (e.g., review and research articles, case studies) between 2008 and 2023 on challenges associated with geothermal energy. Just over 50% of the examined articles were reviews. These articles covered a variety of regions, including Africa, the European Union, and eastern and western regions of Asia and countries surrounding them. The primary issues addressed in these articles include technology and engineering, finance and economics, initial costs of installing geothermal energy, legal disputes and regulations, and the absence of public knowledge and understanding of this kind of energy.

Table 1. Review of geothermal energy uses and challenges.

Type of paper	Subject	Detailed Challenges of Geothermal Energy	Reference
Case study (Australia)	Issues for geothermal energy utilization	Technological: Limited drilling efficiency in hard rock formations; high exploration risks due to subsurface uncertainty.	[47]
Conference paper	Future of geothermal energy and its challenges	Technical: High-temperature drilling challenges; reservoir engineering complexities. Economic: High upfront capital costs for exploration and infrastructure.	[48]
Case study (Indonesia)	Geothermal in Indonesia	Policy/Regulatory: Unclear permitting processes; lack of government incentives for private investment.	[49]
Case study (China)	Hindrances for using geothermal energy	Technical: High failure rates in exploration; lack of skilled workforce. Economic: High well-drilling costs. Environmental/Social: Public resistance due to perceived land/water impacts.	[50]
Case study (Indonesia)	Geothermal energy development	Upstream: Resource estimation inaccuracies. Downstream: Power plant efficiency issues. Supporting: Weak grid connectivity.	[51]
Case study (Pakistan)	Greener energy issues and challenges	Social: Low public awareness. Managerial: Poor stakeholder coordination.	[52]
Case study (Indonesia)	Review of geothermal development, including current status and issues	Technological: Inadequate R&D for localized solutions. Economic: Uncompetitive tariffs compared to fossil fuels.	[53]
Review	Resolving challenges in classification of deep geothermal potential	Technical: Difficulty in standardizing resource assessment methods across geologies.	[54]
Review	Environmental benefits and challenges associated with geothermal power	Environmental: GHG emissions from geothermal fluids. Social: Land-use conflicts with indigenous communities. Economic: Long payback periods.	[55]
Review	Challenges for geothermal energy	Technological: Corrosion and scaling in pipelines/equipment.	[56]
Review	Materials selection challenges for geothermal energy projects	Technical: Material degradation under high-temperature/pressure conditions.	[57]
Case study (European Union, Spain, Canary Islands)	Ways to remove geothermal energy barriers	Market: Lack of financing mechanisms for small-scale projects.	[58]
Case study (Japan, Korea, the Philippines, Indonesia)	Geothermal energy obstacles, policies and economics in East Asia	Detailed Challenges of Geothermal Energy	[59]
Review	Geothermal energy utilization plans	Technological: Limited drilling efficiency in hard rock formations; high exploration risks due to subsurface uncertainty.	[60]
Review	Geothermal review	Technical: High-temperature drilling challenges; reservoir engineering complexities. Economic: High upfront capital costs for exploration and infrastructure.	[61]
Review	Prospects and challenges of concentrated solar photovoltaic and reformed geothermal energy technologies	Policy/Regulatory: Unclear permitting processes; lack of government incentives for private investment.	[62]
Case study (Iran)	Review of two decades of geothermal energy development, including benefits, challenges, and future hind sights	Technical: High failure rates in exploration; lack of skilled workforce. Economic: High well-drilling costs. Environmental/Social: Public resistance due to perceived land/water impacts.	[63]
Review	Geothermal electricity generation challenges, opportunities and recommendations	Upstream: Resource estimation inaccuracies. Downstream: Power plant efficiency issues. Supporting: Weak grid connectivity.	[64]
Review	Systems analysis, design, and optimization of geothermal energy systems for power and polygeneration	Social: Low public awareness. Managerial: Poor stakeholder coordination.	[65]
Case study (Netherlands)	Using district heating in existing cities, focusing on a geothermal reservoir	Technological: Inadequate R&D for localized solutions. Economic: Uncompetitive tariffs compared to fossil fuels.	[66]
Case study (China)	Geothermal energy in China, including status, challenges, and policy suggestions	Technical: Difficulty in standardizing resource assessment methods across geologies.	[5]
Review	Challenges and opportunities of geothermal drilling for renewable energy production	Environmental: GHG emissions from geothermal fluids. Social: Land-use conflicts with indigenous communities. Economic: Long payback periods.	[67]
Review	Environmental, economic, and social influences of geothermal energy systems	Technological: Corrosion and scaling in pipelines/equipment.	[68]
Case study (Indonesia and the Philippines)	Comparative analysis of geothermal development	Technical: Material degradation under high-temperature/pressure conditions.	[69]
Case study (China)	Opportunity and challenges in large-scale geothermal energy utilization	Market: Lack of financing mechanisms for small-scale projects.	[70]
Review	Technological challenges of geothermal energy systems	Detailed Challenges of Geothermal Energy	[71]
Review	Challenges and opportunities of enhanced geothermal systems	Technological: Limited drilling efficiency in hard rock formations; high exploration risks due to subsurface uncertainty.	[72]
Review	Challenges of geothermal energy piles design	Technical: High-temperature drilling challenges; reservoir engineering complexities. Economic: High upfront capital costs for exploration and infrastructure.	[73]
Case study (Ethiopia)	Review of geothermal resources exploitation	Policy/Regulatory: Unclear permitting processes; lack of government incentives for private investment.	[74]

Table 2 lists publications of studies in the area of geothermal energy and the sports industry. This information is useful for outlining the current challenges to use of geothermal energy in sports facilities. Note that we collect data from previous research in this section and use them during interviews with experts to enhance the results.

Table 2. Review of geothermal energy utilization in sports facilities.

Subject	Utilization in Sport Facilities	Reference
Sustainable use of geothermal energy	Soil heating in sports spots may increase in next decade resulting in an annual utilization of 20 GWh/yr	[75]
Geothermal options for sustainability for Challenge Stadium	Key advantages from Challenge Geothermal include lower consumption of fossil-based fuel, cost savings, water supply and water infrastructure development, enhanced sustainability profile for sports and recreation facility	[45]
Utilization of geothermal energy resources in the tourism industry	Utilization of geothermal energy in spas and sports–recreational centers	[76]
Geothermal energy application in swimming pool buildings	Heating water in swimming pools	[77]
Outdoor pool in a cold climate	Geothermal energy in recreational sport pools	[78]
Possibilities of geothermal energy utilization for economic tourist development	Possibilities of using water springs (temperatures up to 37 °C) in agriculture, industry, sports activities, etc.	[79]
Feasibility of a geothermal energy system for indoor swimming pool	Heating pool water	[80]
Enhancing the efficiency of geothermal energy use for recreation	Using geothermal energy in spa and recreational center	[81]
Increasing the energy system efficiency by a ground source heat pump system in a sport center	Energy system using geothermal	[82]
Optimization on a novel geothermal system for a sport spot	Design of an energy system based upon geothermal energy	[83]
Renewable energy source diffusion in professional sport facilities	Renewable energy source adoption in 175 professional sport stadia in the United States and Canada.	[44]
Geothermal systems for sport arena applications	3D multi-objective optimization to name the optimal condition with respect to target parameters, for a sports arena	[84]

Based upon the articles in this section, it is evident that geothermal energy has a different use in the sports industry. It may be employed in recreation centers and sports complexes, including swimming pools. The objectives of geothermal energy applications may include cost and energy consumption reductions as well as sustainable development.

3. Methodology

Here, a study was designed and implemented qualitative and quantitative methods (mixed method). The method involves in three steps: 1. Review of the previous papers in this area and Interview with experts (23 experts), 2. Transforming the initial variables (extracted from previous section) to survey 1 and performing with exploratory factor analysis (EFA) via an online survey of 123 sport science and mechanical engineering graduates and professors, and step 3. Survey 2 based on confirmatory factor analysis (CFA) via an online survey of 137 sport science and mechanical engineering graduate and professors. Before starting the research process, the literature review and research background of the last section was examined to provide an appropriate perspective. Figure 1 depicts the research process employed and its steps.

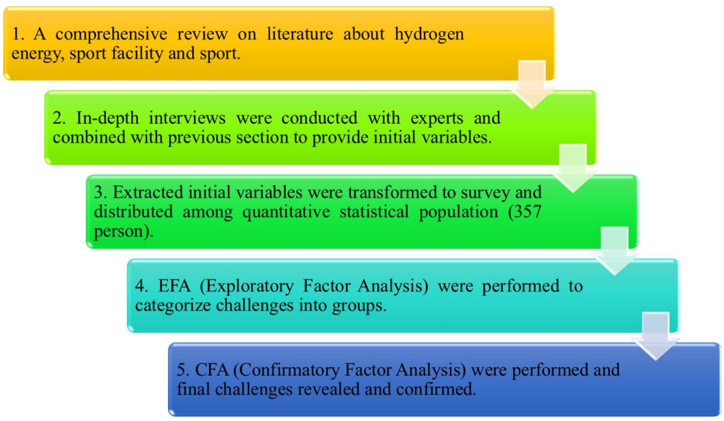

Figure 1. Research process employed.

3.1 Qualitative Approach (Thematic Analysis)

Deep-interviews with geothermal and renewable energy professionals, sport management academics, and sports facility managers were carried out. Twenty-three (23) professionals who volunteered to participate in the interview had a wide range of knowledge and experience in renewable energies and especially geothermal energy and its installation and operation.

As the objective here was to have useful information from experts in this field, the required care was taken in selecting people to interview. For instance, people who were interviewed in the category of sports venues who had a history of operating sports venues using renewable energy and were experts in this field. Additionally, the renewable energy professionals involved had good technical expertise and experience in this field and a history of installing some type of renewable energies in sports complexes.

3.1.1 Interviews

Interview questions were built from a review of research literature. This information was also used when performing the interviews, which were done by telephone or Skype. General information was given to interviewees through the research literature on renewable energy and specifically geothermal energy that is utilized in the sporting industry.

Next, challenges of using geothermal energy in industries and other sectors and communities, and exploitation of geothermal energy in sport section and facilities, were examined and used to inform the interviewee about this investigation so as to be capable to respond the questions perfectly (Tables 1 and 2 summarize the literature review). Then, interviewees are asked to respond questions related to the use of geothermal energy in sport facilities and by using thematic analysis we frame the results. A joint effort was made to understanding the barriers associated with utilizing this energy in sporting fields and to offer solutions for its development from the standpoints of experts and specialists in the field of sports.

As noted earlier, twelve experts were involved in the interviews, as explained in Table 1. These interviews were done from November 2023 to February 2024. The interview process began with the oral collection of consent from the interviewees and consent was taken from them of their willingness to give the interviews. The study's major questions were posed in the second phase and, during this phase, information collected by prior research was disclosed to them.

In the second step, research-related questions and the main research objective were asked for the experts and interviewees. The first question was about the restrictions of using geothermal energy in sports complexes (e.g., “What do you think about the specific challenges of using geothermal energy in sport facilities?”). We inquired them to give their opinion from the point of view of a specialist. Then, the focus was on solutions and expert suggestions to facilitate these (e.g., “What is your opinion regarding the provision of operational solutions in this field according to all the conditions raised?”). Their opinions were also sought about the possibilities of using geothermal energy in sport industry (e.g., “What do you think about the using geothermal energy in sport industry?”). At this stage, data was provided to the interviewees about the challenges and utilization of geothermal energy that was identified in the literature so that they could give informed opinions in this regard.

3.1.2 Process of Interviews

The interviews lasted approximately 25-40 minutes and were all recorded. The interviews were later transcribed and, in a bid to guarantee the validity of this procedure, conducted independently by two members of the research team. By this stage, almost all of the information required to respond to the central research questions was available and only had to be categorized.

3.1.3 Qualitative Data Analysis (Thematic Analysis)

Here, employing the qualitative research process technique and extracting data from interviews, thematic analysis is utilized, one of the most common techniques in this field. It is possible to extract variables from qualitative findings and interviews. Thematic analysis is a method of identifying and scrutinizing patterns of meaning within a dataset [85]. It declares which themes are necessary in the explanation of the phenomenon under study [86]. The end result of a thematic analysis should be the most salient cluster of meaning in the dataset [87].

There are two coding stages that occur in this process. The first of these entails reading and rereading many times the interview texts from which variables and answers to research questions derive. In this phase, the variables are hand-stamped and marked by the research team, and additional information necessary is documented beside them. During the second coding stage, the researcher brought together and aggregated identified variables and placed them under minor themes. At this stage, members of the research team also participated in the process and gave their views in a bid to elevate the validity and reliability of the findings. At times, even opinions of outsiders in the form of expertise were being utilized so that we were able to give a proper synopsis of the coding and interview data. This exercise immensely contributed to enhancing more correctness and validity in the work [88] and it helps in improving the work. Researchers suggests that in qualitative study, especially with the method of interview, using small size groups as samples can give significant information to the researcher, and the researcher can apply his ideas and knowledge in his study [89].

The second main case in qualitative research pertains to reaching the point of saturation in the interviewing process, in which no more information is gathered by the researcher in the interviews [90]. In this research and after interview number twelve, the researcher reached complete theoretical saturation regarding the research questions and the study's objective, and the interview process ended after twelve interviews. Finally, we extracted 30 variables from interviews and divided them into 6 main challenges in geothermal energy in sport facilities (Appendix 1 shows the final 30 initial variables). In the next step, we transform the variables into survey (1) to evaluate with EFA and explore the factor structure. We used a 7-point Likert scale to assess the survey items.

3.2 Exploratory Factor Analysis and Confirmatory Factor Analysis

CFA and EFA are used to investigate the data from Surveys 1 and 2, separately. A total of 180 responses were initially gathered for Survey 1, but 57 were discarded because of doubtful response patterns (e.g., all answers were marked the same for every question) or because over half of the data was missing. This left 123 responses that were considered appropriate for further analysis. The factor structure behind the geothermal energy challenge was further examined using EFA. The factor structure identified in the previous EFA was been verified for Survey 2 using CFA. A total of 137 usable replies for CFA out of the 200 responses once 63 were eliminated for having more than 50% missing data or doubtful response patterns. Table 3 provides a description of Surveys 1 and 2. The statistical software SPSS 22.0 and Smart-PLS 3.0 was used for both analyses. The Shapiro-Wilk test was used to confirm that parametric tests were being used correctly and, thereafter, by determining whether Variance Inflation Factors (VIFs) were less than 10 in order to check for multicollinearity among variables. The accuracy and reliability of the final picture items in both surveys were then approved using Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Nine variables were eliminated from the 30 initial variables that were used in the exploratory factor analysis. These variables were derived from topic analysis and expert interviews. Therefore, out of these findings, 21 factors showed acceptable factor loadings and advanced to the CFA stage. By conducting the tests, 18 final variables were identified and validated as the main challenges to the use of geothermal energy in the sports industry and sports facilities.

Table 3. Respondent characteristics of Survey 1 and 2.

		First Survey (N = 123)		**Second Survey (N = 137)**	
Category	Sub-category	N	%	N	%
Gender	Male	98	79/67%	105	76/64%
	Female	25	20/32%	32	23/35%
Age	<30	4	3/25%	6	4/37%
	31-40	12	9/75%	32	23/35%
	41-50	38	30/89%	64	46/71%
	51-60	32	26/01%	28	20/43%
	>60	37	30/08%	7	5/10%
Field of study	Sport science	57	46/34%	65	47/44%
	Sport management	41	33/3%	38	27/73%
	Mechanical engineering	25	20/32%	34	24/81%
Education level	Bachelor	-	-	-	-
	Master	12	9/75%	18	13/13%
	PhD	74	60/16%	66	48/17%
	Assistant professor	9	7/31%	12	8/75%
	Associate professor	12	9/75%	20	14/59%
	Professor	16	13%	21	15/32%

3.2.1 Missing Data Protocol

Screening: Surveys with >50% missing responses (n = 57 in Survey 1; n = 63 in Survey 2) were excluded entirely to ensure data quality.

Missingness by Item: For retained surveys, missing values per item ranged from 0.8% to 3.2% (mean = 1.9%) in Survey 1 and 0.7% to 2.9% (mean = 1.7%) in Survey 2.

Imputation Method: Missing values were imputed using expectation-maximization (EM) algorithm, which preserves covariance structures for factor analysis (Enders, 2010). Sensitivity analyses confirmed imputation did not alter factor structures (ΔCFI < 0.01 between original/imputed datasets).

Bias Assessment: Little's MCAR test indicated data were missing completely at random (Survey 1: $\chi^2 = 18.24$, $p = 0.251$; Survey 2: $\chi^2 = 15.37$, $p = 0.357$), supporting unbiased imputation. Table 4 shows the missing data summary.

Table 4. Missing data summary.

Survey	Total Responses	Excluded (>50% Missing)	Retained	Max Item Missingness	Imputation Method	MCAR Test (p-Value)
1 (EFA)	180	57	123	3.2%	EM	0.251
2 (CFA)	200	63	137	2.9%	EM	0.357

3.2.2 Sample Size Justification

The sample sizes for EFA (N = 123) and CFA (N = 137) were determined based on widely accepted guidelines for factor analysis. For EFA, despite a slightly lower subject-to-item ratio (4:1), the high communalities (>0.5), strong factor loadings, and excellent KMO value (0.947) supported sample adequacy. The CFA sample exceeded the minimum threshold of N = 100 for stable estimates and demonstrated strong model fit (CFI > 0.9, RMSEA < 0.05), aligning with simulation studies.

4. Results

4.1. Main Challenges of Geothermal Energy in Sports Facilities

In order to determine the fundamental factor structure of the geothermal challenges, EFA was carried out on the data collected from Survey 1 (N = 123). In advance of conducting EFA, the Kaiser-Meyer-Olkin (KMO) test and the Bartlett test of sphericity are applied to assess if the data was appropriate to perform the analysis of principal components. A value of 0.5 or higher for the KMO test and a significance level of 0.05 or lower for the Bartlett test indicate that the data has significant correlations among the variables and therefore can be divided into a few factors. For the data collected from Survey 1, The KMO measure of sampling adequacy yielded a value of 0.947, significantly exceeding the 0.50 threshold ($p < 0.001$, Bartlett's test). To further validate this result, we conducted a Monte Carlo simulation (1,000 iterations) using the null hypothesis of zero variable correlations. The observed KMO value (0.947) fell above the 99th percentile of simulated values (95% CI: 0.912-0.938), confirming robust sampling adequacy.

Nine factors with eigenvalues greater than one were found in the preliminary findings of factor extraction using varimax rotation. Items were cross-loaded on several variables in order to purify the data, and those with commonalities less than 0.4 or factor loadings less than 0.5 are eliminated. This process was repeated until the smallest number of factors describing the shared variance were found. The final factor structure obtained from EFA, which included six factors with 21 items and explained 81.29% of the variation overall, is shown in Table 5. Cronbach's alpha was used to assess the items' internal consistency reliability; all results were higher than 0.84, which is above the suggested level of acceptability.

Table 5. EFA results from Survey 1.

Factor	Item	Factor						Cronbach' α
		1	2	3	4	5	6	
Social	Lack of awareness and information	**0.854**	0.006	0.003	-0.064	0.069	0.058	0.842
	Lack of knowledge about renewables	**0.837**	0.024	0.009	0.012	0.095	0.001	
	Socio cultural issues	**0.824**	-0.007	0.129	0.039	0.189	0.009	
Environmental	Land use	0.179	**0.794**	0.446	0.025	0.341	0.012	0.859
	Water consumption	0.241	**0.758**	-0.023	0.195	0.214	0.041	
	Noise	0.005	**0.739**	0.165	0.007	0.214	0.042	
	Air pollution	0.041	**0.718**	0.101	0.114	0.025	0.016	
Technological	Standardization for construction	0.151	0.170	**0.709**	0.095	0.084	0.012	0.897
	Location and quality of resources	0.094	0.215	**0.694**	0.0354	0.028	0.007	
	Lack of experienced with geothermal	0.195	0.213	**0.674**	0.097	0.114	0.187	
	Infrastructure	0.147	0.198	**0.624**	0.247	0.198	0.009	
Economic	High capital cost	0.267	-0.067	0.113	**0.726**	0.102	0.098	0.901
	High initial investment	0.289	0.021	0.124	**0.708**	0.136	0.052	
	Financial investment and support	0.307	0.155	0.115	**0.706**	0.0341	0.069	
	Maintenance service	0.164	0.195	-0.184	**0.698**	0.027	0.006	
Sport facility challenges	Convenient location to use	0.308	0.152	-0.170	0.098	**0.671**	0.004	0.932
	Risk of use in sport facility	0.352	0.042	0.152	0.062	**0.642**	0.025	
	Managerial challenges	0.429	0.101	-0.118	0.072	**0.632**	0.041	
Regulatory and policy	Policy framework	0.356	-0.017	0.056	0.124	0.028	**0.611**	0.887
	Lack of supportive laws	0.321	0.025	0.036	-0.158	0.036	**0.598**	
	Legislation geothermal law	0.425	0.124	-0.014	0.048	0.117	**0.572**	
Eigenvalue		24.21	12.25	7.25	3.54	1.35	1.02	-
Cumulative		24.88	16.98	12.65	8.23	7.98	5.55	-
Total variance explained (%)		24.88	41.25	55.64	65.35	70.24	81.29	-
KMO		0.947						
Bartlet		<0.001						

The six EFA-derived components were thoroughly evaluated and given the proper labels, as indicated in Table 5. The last six elements were identified as social, environmental, economic, technological, sport facility challenges and regulatory and policy.

The correlation matrix determinant in EFA is shown in Table 6. The correlation matrix determinant (3.72×10^{-5}) confirmed the absence of multicollinearity/singularity, supported by item correlations (range: r = 0.12-0.69) and VIFs < 3.0. The determinant and ancillary diagnostics confirm our EFA's robustness against multicollinearity/singularity.

Table 6. Correlation matrix determinant in EFA.

Diagnostic	Value/Range	Threshold
Determinant	3.72×10^{-5}	$>1 \times 10^{-8}$
Largest Item Correlation	0.69 (Item 4 ↔ Item 7)	<0.90
VIF Range	1.08-2.34	<3.0

The CFA was carried out using the data set gathered from Survey 2 (N = 137) in order to validate the factor structure found in the EFA. As previously indicated, we viewed the six components that were taken out of the EFA. To ensure that the 21 elements were correctly categorized into their corresponding dimensions, further analysis was necessary. So, confirmatory factor analysis was applied to ensure factors and their items. In addition, the results were validated with model fit criteria including χ2/df = 732.01/298 = 2.45, Root Mean Square Error of Approximation (RMSEA) = 0.048, Tucker-Lewis's index (TLI) = 0.910, and Comparative Fit Index (CFI) = 0.918. Table 7 shows the CFA results for the items identified from EFA and Table 8 shows the Goodness of fit indices for models.

Table 7. Results of CFA for Survey 2.

Factor	Item	b	SE	CR	AVE	α
Social	Lack of awareness and information	0.842**	0.012	0.884	0.624	0.926
	Socio cultural issues	0.786*	0.015			
Environmental	Land use	0.851**	0.016	0.863	0.623	0.924
	Water consumption	0.676*	0.025			
	Noise	0.703*	0.011			
	Air pollution	0.727*	0.019			
Technological	Standardization for construction	0.692*	0.029	0. 818	0.611	0.912
	Location and quality of resources	0.836**	0.024			
	Lack of experienced with geothermal	0.710*	0.026			
	Infrastructure	0.653*	0.011			
Economic	High capital cost	0.812**	0.014	0.802	0.587	0.949
	Financial investment and support	0.729*	0.015			
	Maintenance service	0.619*	0.016			
Sport facility challenges	Convenient location to use	0.608*	0.020	0.814	0.601	0.904
	Risk of use in sport facility	0.817**	0.019			
	Managerial challenges	0.642*	0.017			
Regulatory and policy	Policy framework	0.749*	0.026	0.842	0.648	0.915
	Legislation geothermal law	0.892**	0.021			

*p < 0.05, ** < 0.01

Table 8. Goodness of fit indices for models.

Fit Index	Value	Criteria
Ratio of chi-square* per its degree of freedom (CMIN/DF)	732.01/298=2/45	<3
P (Probability level)	0.226	>0.05
Goodness of fit index (AGFI)	0.861	>0.8
Comparative fit index (CFI)	0.918	>0.9
Incremental fit index (IFI)	0.934	>0.9
Tucker Lewis index (TLI)	0.910	>0.9
Non-normed fit index (NNFI)	0.942	>0.9
Approximation for root mean square error (RMSEA)	0.048	<0.08
P-Close	0.914	>0.05

*p < 0.05.

Three items from CFA were eliminated based on low coefficients; low coefficients suggest that the items are not strongly related to the construct being measured, and therefore decrease the effectiveness of the model in explaining the phenomenon. Finally, there were 18 items in 6 main challenges of using geothermal power to sports locations. Figure 2 shows the last variables of the challenges in using geothermal power to sports spots.

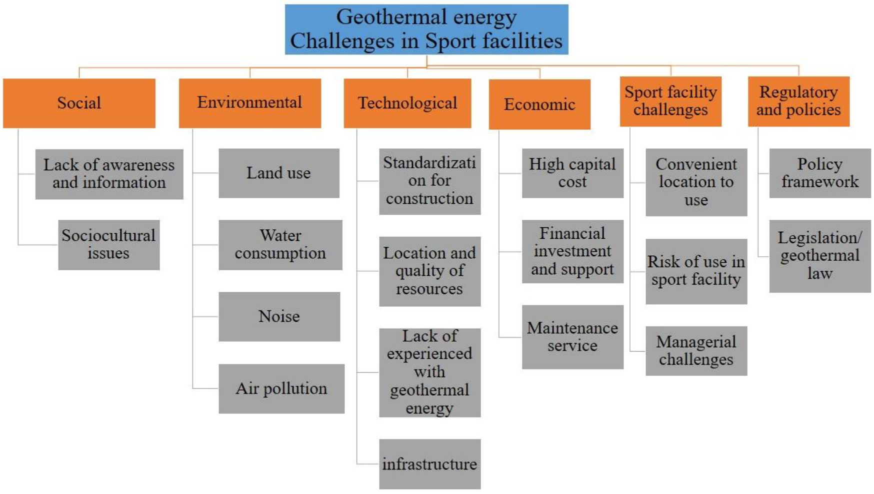

Figure 2. Schematic of geothermal energy challenges in sport facilities.

Reliability and validity of the developed framework were checked using the CR values, which measure how strongly an instrument on measurement reflects a factor underlying, were also used to assess the reliability of constructs. All constructs that scored above the recommended minimum of 0.6 of factor loadings for general dimensions were accepted (Table 6).

Besides, one particular construct validity category, known as convergent validity, tests the degree of correspondence between dimensional measures of the similar concept. Convergent validity is captured through the (AVE), and each construct should have convergent validity higher than the given threshold of 0.5 (Table 7). Finally, Cronbach's α were calculated and values indicate the favorable result of reliability.

Based on the results from above Table 9, no item had >15% of responses at min/max values. The highest extreme response rate was 12.4% ("High capital cost" at max), well below the 20% threshold for concern (no floor/ceiling effects). SDs ranged from 1.09 to 1.48, indicating adequate dispersion. Skewness/Kurtosis: All items fell within ±1.5, suggesting acceptable normality for parametric tests. Overall, Item-level descriptive statistics, confirmed no floor/ceiling effects (<15% min/max responses) and adequate variability (SDs > 1.0; skewness/kurtosis within ±1.5).

Table 9. Range and variance of items (final 18 items).

Factor	Item	Mean	SD	Skewness	Kurtosis	Min	Max	% Min/Max Responses*
Social	Lack of awareness and information	5.12	1.21	-0.82	0.73	2	7	3.2%/8.1%
	Socio-cultural issues	4.87	1.34	-0.51	0.12	1	7	5.1%/6.6%
Environmental	Land use	4.95	1.28	-0.63	0.45	2	7	4.4%/7.3%
	Water consumption	5.33	1.17	-0.91	1.02	2	7	2.9%/9.5%
	Noise	4.56	1.41	-0.32	-0.21	1	7	6.6%/4.4%
	Air pollution	5.21	1.23	-0.78	0.87	2	7	3.6%/8.8%
Technological	Standardization for construction	4.78	1.37	-0.47	0.05	1	7	5.8%/5.1%
	Location/quality of resources	5.02	1.31	-0.69	0.52	2	7	4.4%/7.3%
	Lack of experience with geothermal	4.65	1.39	-0.41	-0.11	1	7	6.6%/4.4%
	Infrastructure	4.89	1.35	-0.58	0.23	1	7	5.1%/6.6%
Economic	High capital cost	5.67	1.09	-1.12	1.87	2	7	2.2%/12.4%
	Financial investment/support	5.44	1.14	-0.94	1.32	2	7	2.9%/10.9%
	Maintenance service	5.12	1.22	-0.81	0.76	2	7	3.6%/8.8%
Sport Facility	Convenient location to use	4.32	1.45	-0.21	-0.42	1	7	8.0%/3.6%
	Risk of use in sport facility	4.45	1.42	-0.29	-0.31	1	7	7.3%/4.4%
	Managerial challenges	4.21	1.48	-0.15	-0.51	1	7	8.8%/2.9%
Regulatory & Policy	Policy framework	4.98	1.33	-0.67	0.48	2	7	4.4%/7.3%
	Legislation for geothermal law	5.11	1.24	-0.79	0.71	2	7	3.6%/8.8%

*(Based on final 18 items from CFA, 7-point Likert scale) *

Item-total correlations and item-deleted reliability statistics were computed to assess scale consistency (Table 10). All items met minimum thresholds (item-total r > 0.50; α-if-deleted within ±0.05 of scale α), though four items (‘Noise,’ ‘Standardization for construction,’ ‘Maintenance service,’ and ‘Managerial challenges’) showed marginal correlations (0.58-0.69). These were retained due to theoretical importance and lack of material improvement in α upon deletion.

Table 10. Item reliability statistics for final 18-item scale.

Factor	Item	Item-Total Correlation	Cronbach’s α if Item Deleted	Retention Decision
Social	Lack of awareness and information	0.78	0.81	Retained (strong)
	Socio-cultural issues	0.71	0.84	Retained
Environmental	Land use	0.82	0.89	Retained (strong)
	Water consumption	0.76	0.91	Retained
	Noise	0.69	0.92	Marginal
	Air pollution	0.81	0.89	Retained
Technological	Standardization for construction	0.68	0.85	Marginal
	Location/quality of resources	0.83	0.82	Retained (strong)
	Lack of experience with geothermal	0.65	0.86	Marginal
	Infrastructure	0.72	0.84	Retained
Economic	High capital cost	0.85	0.88	Retained (strong)
	Financial investment/support	0.79	0.90	Retained
	Maintenance service	0.63	0.93	Marginal
Sport Facility	Convenient location to use	0.61	0.76	Marginal
	Risk of use in sport facility	0.74	0.72	Retained
	Managerial challenges	0.58	0.78	Marginal
Regulatory & Policy	Policy framework	0.77	0.80	Retained
	Legislation for geothermal law	0.81	0.78	Retained

*(7-point Likert scale; N = 137 for CFA sample) *Item-total correlation >0.70 = Strong (ideal), 0.50-0.70 = Acceptable (revise if α improves significantly upon deletion), <0.50 = Problematic (consider removal).

4.2 Description of Geothermal Energy Challenges in Sport Facilities

Sports facilities use a large amount of energy; consequently, experts and academics are interested in finding ways to reduce and improve this energy consumption. Under these conditions, using renewable energies (geothermal energy being one of them) is one of the acceptable and practical alternatives. Moreover, there are challenges to the utilization and exploitation of this kind of energy in the field of sports, and this section of the research aims to provide an extensive and comprehensive presentation of these challenges and obstacles.

4.3 Social Challenges

The challenges essentially stem from societal attitudes and awareness regarding the adoption and utilization of renewable energy sources [74]. One of the challenges in geothermal energy deployment is the scarcity of awareness and information about this renewable energy source and its utilization in sport facilities [52,74]. This lack of awareness can be seen among the general public, as well as policymakers and investors. Many people are not familiar with geothermal energy and its potential as a reliable and sustainable type of energy. This lack of awareness leads to a lack of interest and support for geothermal projects [55]. Policymakers may also lack the necessary knowledge and understanding of geothermal energy. This can result in a lack of supportive policies and regulations, which can hinder the development and deployment of geothermal projects [52]. Additionally, investors may also be unaware of the potential returns and benefits of geothermal projects. The lack of information about the financial viability and long-term prospects of geothermal energy can deter investors from allocating funds towards this renewable energy source in sport facilities.

4.4 Environmental Challenges

The use of geothermal energy in sports spots has environmental challenges, which can cause problems for the environment due to the location of sports complexes. Among these challenges is the creation of noise pollution from drilling wells [68]; geothermal power plants can have visual and noise impacts on the surrounding environment [74]. In addition, these facilities often have large structures, cooling towers, and steam vents, which can alter the landscape and scenic beauty. Noise from drilling operations and power plant equipment can also impact nearby communities and wildlife [5]. The need for large land area is also problematic, since geothermal power plants need a significant amount of land for their installation and infrastructure. This can result in habitat destruction and fragmentation, especially in areas with sensitive ecosystems [91]. High water consumption is also a concern since geothermal energy uses water to generate power. One of the primary challenges is the potential depletion of local water resources due to the high demand for water in geothermal power plants. This can have negative impacts on aquatic ecosystems and water availability for other needs [92]. Finally, air pollution caused by this type of energy is a challenge since, during the extraction of geothermal energy, fluids containing various gases and chemicals are pumped to the surface. If not properly controlled and treated, these emissions can potentially emit pollutants into the air, including volatile organic compounds (VOCs) and mercury [93].

4.5 Technological Challenges

The application of geothermal energy in sports venues is hindered by various limitations and technological challenges. These factors impose restrictions on the utilization of this renewable energy source in sports facilities. Limitations such as inadequate infrastructure and lack of expertise can hinder the implementation of geothermal energy near sports venues [47,48]. Furthermore, the suitability of the land surface for harnessing this energy [50], availability of high-quality resources for exploitation [51], adherence to construction standards, and the use of appropriate piping systems for drilling and water transportation are amongst the technical and technological considerations that can restrict the use of geothermal energy in sports venues [48,53].

4.6 Economic Challenges

Economic and financial aspects pose significant challenges to harnessing geothermal energy for sports and other industries. (1) High upfront costs: Geothermal power plants require significant initial investment and long payback period for drilling wells, constructing infrastructure, and installing specialized equipment [55,60]. These costs can be prohibitive for many sports facilities and industries, especially smaller organizations with limited financial resources [53,60,74]. (2) Maintenance and Operation: Geothermal energy systems require regular maintenance to ensure their efficiency and proper functioning [55]. This includes maintaining equipment, monitoring fluid levels, and conducting periodic inspections [94,95]. All these factors, along with the costs of sports complexes, can be major challenges to using geothermal energy in sports and sports venues. Also, the specialized knowledge and expertise required to operate and maintain these systems can add further challenges. Finally lack of financial investment and support are considered the main challenges in the economic section.

4.7 Sport Facility Challenges

In terms of meeting energy needs and supplying energy in sports facilities, geothermal energy has a number of applications [45,77,83]. As already noted, swimming pools and recreation facilities are where this form of energy is most commonly used, and this is the subject of the study [77,96]. However, in addition to its advantages, this kind of energy can also be utilized in other sports facilities, although it is not without challenges. The accessibility and appropriateness of sporting facilities' locations for the utilization of geothermal energy is one of these difficulties [45]. Many challenges may arise from distance, transfer, excavation, and other factors close to a sports stadium. All requisite safety precautions must be taken to address the risks associated with utilizing this kind of energy in sports arenas, when a large number of people meet to play sports or watch competitions [60]. The last issues facing this industry are a lack of preparation and knowledge, which other researchers have noted [63,97]. Generally, we convey in this section the challenges that are particular to geothermal energy in sports arenas and have not been examined or covered in previous research, regarding the utilization of this kind of renewable energy in sporting arenas.

4.8 Regulatory and Policy Challenges

Geothermal energy projects require various licenses and permit from government authorities to ensure compliance with safety and environmental regulations. The process of obtaining these permits can be time-consuming and complex [49,59]. In addition, regulatory and policy frameworks can significantly impact the viability of geothermal energy projects. Generally, stability and long-term support from governments are necessary to ensure the financial and operational success of such projects [5,59].

5. Discussion

The analysis of the challenges and barriers in using geothermal energy in sport facilities indicates that, although there are several challenges to overcome, it is a promising and viable solution in the long run. Geothermal energy offers various benefits, including cost savings, environmental sustainability, and reduced reliance on fossil fuels [63,98]. However, the initial capital investment, lack of awareness, and technical complexity pose substantial challenges for widespread adoption and using.

The financial aspect is a key challenge, as the upfront costs of installing geothermal systems can be higher than for traditional energy sources. However, it is important to recognize that geothermal energy provides significant long-term cost savings. This, combined with government incentives and financing options, can help overcome the financial challenge. Other investigations in different sections show similarity with our findings in this paper.

Another significant challenge is the lack of awareness and understanding of geothermal technology. Education and outreach programs are necessary to increase knowledge and acceptance among sports facility owners, managers, and stakeholders. Collaboration with renewable energy organizations, technology providers, and experts can bridge this knowledge gap and showcase the benefits of geothermal energy effectively. Technical complexities, such as drilling and heat exchange system design, require specialized knowledge and expertise. Engaging experienced geothermal professionals early in the facility planning and design phase is important to ensure successful implementation. Training programs and certifications should be established to develop a skilled workforce, further advancing geothermal technology adoption.

To alleviate these challenges, collaboration between stakeholders is necessary. Partnerships between sports facility owners, energy consultants, government entities, and technology providers can make a supportive ecosystem for geothermal energy adoption. Additionally, policy interests, such as tax credits, grants, and streamlined permitting processes, can encourage sport facility owners to invest in geothermal systems. While overcoming these challenges may seem daunting, the potential benefits make geothermal energy adoption in sport facilities worthwhile. The use of geothermal energy can reduce carbon emissions, enhanced energy independence, and increased public perception of sports facilities as sustainable entities. Moreover, sport facilities can serve as role models for other industries, inspiring a wider transition towards renewable energy sources.

Following a broad overview of the challenges and obstacles associated with geothermal energy usage in sport facilities, we offer several of practical suggestions in order to enhance the utilization of this energy source in sports facilities. Promoting the utilization of geothermal energy in sport facilities can be done through various methods. Some effective strategies that are extracted through the interviews follow (Figure 3):

(1) Educate and raise awareness: Start by creating educational materials and campaigns to inform the public, facility owners, sports enthusiasts, policymakers and investors about the benefits of geothermal energy. Also, by increasing awareness about geothermal energy, more support can be generated, leading to increased deployment and use of this renewable energy source in sport facilities around the world.

(2) Develop case studies: Showcase successful examples of sport facilities that have already transitioned to geothermal energy. By highlighting the positive impacts, such as reduced carbon footprint, energy cost savings, and improved energy efficiency, we can make very good data about efficiency of geothermal energy in sport facilities.

(3) Collaborate with industry experts: Partner with geothermal energy providers and experts in the field to provide professional advice and guidance to sport facility owners. Arranging workshops, seminars, and conferences to explain the implementation process, financial benefits, and overall feasibility of geothermal energy in their facilities are very impressive.

(4) Engage with government entities: This means, work closely with local and national government bodies to promote the use of geothermal energy in sport facilities. Create advocacy campaigns, attend meetings, and lobby for policy changes and financial incentives that support and encourage the use of renewable energy sources in sport facilities.

(5) Demonstrate cost-effectiveness: Conduct thorough cost-benefit analyses that showcase the long-term financial advantages of using geothermal energy compared to traditional energy sources. We can highlight the potential return on investment, reduced operational costs, and improved facility performance, which can be attractive to sports facility owners and operators.

(6) Organize demonstrations and events: Arrange on-site visits and public events to demonstrate how geothermal systems operate in sport facilities. By allowing visitors to experience the benefits first hand, including the ability to tour geothermal heating and cooling systems and witness their operation, we can show the possibility and beneficial effect of using this kind of renewable energy in sport industry.

(7) Using social media and online platforms: Nowadays, we can leverage the power of social media to have a broader audience. Create engaging content, share success stories, videos, and info graphics showcasing the benefits of geothermal energy, have positive impact on society and policy makers in this section and could create positive image of using geothermal energy in sport facilities. Also, we could encourage discussions and interaction to build a community of supporters due to implementing renewable energy potentials in sport section.

(8) Offer financial incentives: Explore financial incentives and grants that can encourage sport facility owners to invest in geothermal energy systems. Collaborate with financiers, non-profit organizations, and green energy funds to provide attractive funding options exclusively for sports facilities, are very impressive tool in this way.

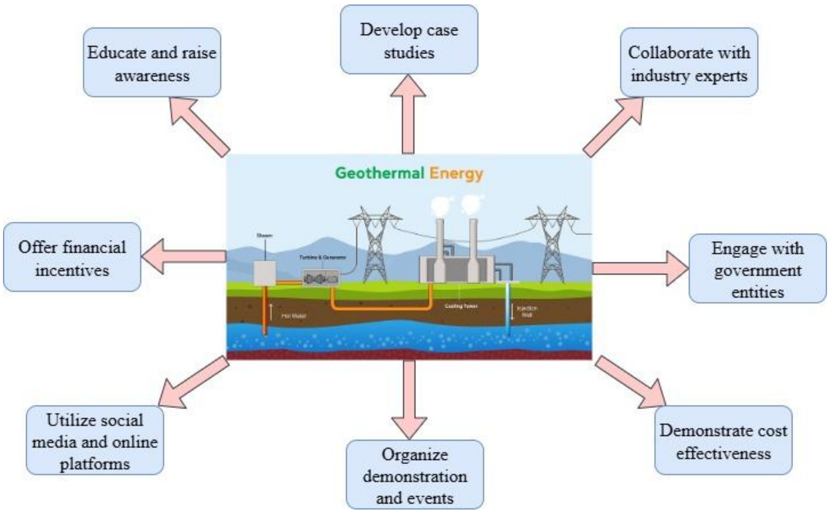

Figure 3. Promotions to use geothermal energy in the sport industry.

6. Conclusions

This study provides a pioneering examination of geothermal energy integration challenges specific to sports facilities through a rigorous mixed-methods approach. By combining expert interviews with dual-stage survey validation (EFA/CFA), we identified and verified six key challenge categories—Social, Environmental, Technological, Economic, Sport Facility-Specific, and Regulatory/Policy—encompassing 18 sub-challenges, thus offering the first comprehensive framework tailored to the sports industry. The statistical validation confirmed the model's robustness, with excellent results (KMO = 0.947, 81.29% variance explained in EFA; CFA fit indices of CFI = 0.918 and RMSEA = 0.048; and high reliability with Cronbach's α and CR > 0.80 for all constructs). Our research makes significant contributions by (1) revealing previously understudied sport-specific barriers, (2) developing this statistically robust measurement model, and (3) proposing targeted practical solutions derived from the findings, including facility-specific financial incentives (e.g., subsidies, PPPs), technical training programs, stakeholder awareness campaigns, and streamlined permitting processes. The findings advance renewable energy literature by addressing the unique operational and spatial constraints of sports venues, while providing actionable insights for facility managers and policymakers. This work bridges a critical gap between renewable energy research and sports facility management, supporting global sustainability goals (SDG 7) through sector-specific implementation strategies. Future research should explore regional adaptations and hybrid renewable systems to further optimize geothermal integration in sports environments, building upon the foundation established by this framework to accelerate sustainable energy transitions in this high-impact sector.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Abbreviations

EFA: Exploratory Factor Analysis
CFA: Confirmatory Factor Analysis
CO_2: Carbon Dioxide
KMO: Kaiser-Meyer-Olkin (measure of sampling adequacy)
RMSEA: Root Mean Square Error of Approximation
CFI: Comparative Fit Index
TLI: Tucker-Lewis Index
AVE: Average Variance Extracted
CR: Composite Reliability
VIF: Variance Inflation Factor
EM: Expectation-Maximization (algorithm for missing data imputation)
MCAR: Missing Completely at Random
SD: Standard Deviation
VOCs: Volatile Organic Compounds

References

[1] Nur S, Burton B, Bergmann A. Evidence on optimal risk allocation models for Indonesian geothermal projects under PPP contracts. Utilities Policy, 2023, 81, 101511. DOI: 10.1016/j.jup.2023.101511
[2] e Silva FA, da Costa VB, dos Santos IF, Bonatto BD. Electric sector modernization in Brazil: Milestones, challenges, and prospects. Utilities Policy, 2024, 90, 101793. DOI: 10.1016/j.jup.2024.101793
[3] Safarpour A, Laleh SS, Soltani S. Identifying challenges, benefits, and recommendations for utilizing solar panels in sport stadiums: A thematic analysis. Progress in Engineering Science, 2025, 2(1), 100035. DOI:10.1016/j.pes.2024.100035
[4] Le Billon P, Kristoffersen B. Just cuts for fossil fuels? Supply-side carbon constraints and energy transition. Environment and Planning A: Economy and Space, 2020, 52(6), 1072-1092. DOI: 10.1177/0308518X18816702
[5] Wang Y, Liu Y, Dou J, Li M, Zeng M. Geothermal energy in China: Status, challenges, and policy recommendations. Utilities Policy, 2020, 64, 101020. DOI: 10.1016/j.jup.2020.101020
[6] Wang Q, Guo J, Li R, Jiang XT. Exploring the role of nuclear energy in the energy transition: A comparative perspective of the effects of coal, oil, natural gas, renewable energy, and nuclear power on economic growth and carbon emissions. Environmental Research, 2023, 221, 115290. DOI: 10.1016/j.envres.2023.115290
[7] Kulkarni N, Al-Dossari M, Tawade J, Alqahtani A, Khan MI, Abdullaeva B, et al. Thermoelectric energy harvesting from geothermal micro-seepage. International Journal of Hydrogen Energy, 2024, 93, 925-936. DOI: 10.1016/j.ijhydene.2024.10.400
[8] Rehman A, Ma H, Chishti MZ, Ozturk I, Irfan M, Ahmad M. Asymmetric investigation to track the effect of urbanization, energy utilization, fossil fuel energy and CO2 emission on economic efficiency in China: another outlook. Environmental Science and Pollution Research, 2021, 28, 17319-17330. DOI: 10.1007/s11356-020-12186-w
[9] Safarpour A, Abdalmalek AE, Soltani S. Identifying challenges for implementing hydrogen energy in sport facilities: A mixed-method study. International Journal of Hydrogen Energy, 2025, 118, 500-508. DOI: 10.1016/j.ijhydene.2025.03.243
[10] Yu C, Moslehpour M, Tran TK, Trung LM, Ou JP, Tien NH. Impact of non-renewable energy and natural resources on economic recovery: Empirical evidence from selected developing economies. Resources Policy, 2023, 80, 103221. DOI: 10.1016/j.resourpol.2022.103221
[11] Zhang Y, Li L, Sadiq M, Chien F. The impact of non-renewable energy production and energy usage on carbon emissions: evidence from China. Energy & Environment, 2023, 35(4). DOI: 10.1177/0958305X221150432
[12] Voumik LC, Ridwan M, Rahman MH, Raihan A. An investigation into the primary causes of carbon dioxide releases in Kenya: Does renewable energy matter to reduce carbon emission?. Renewable Energy Focus, 2023, 47, 100491. DOI: 10.1016/j.ref.2023.100491
[13] Fagundes TS, Marques RC. Challenges of recycled water pricing. Utilities Policy, 2023. 82, 101569. DOI: 10.1016/j.jup.2023.101569
[14] Kulkarni N, Tawade JV, Sampathi S, Hanumagowda BN, Abdelmohsen SA, Khan MI, et al. Sustainability and feasibility of low-grade heat utilization for thermoelectric systems in geothermal micro-seepages. Energy Reports, 2025, 13, 4769-4780. DOI: 10.1016/j.egyr.2025.04.033
[15] Zito AM, Clarke LE, Barlow JM, Bím D, Zhang Z, Ripley KM, et al. Electrochemical carbon dioxide capture and concentration. Chemical Reviews, 2023, 123(13), 8069-8098. DOI: 10.1021/acs.chemrev.2c00681
[16] Laleh SS, Safarpour A, Shahrak AS, Alavi SH, Soltani S. Thermodynamic and exergoeconomic analyses of a novel biomass-fired combined cycle with solar energy and hydrogen and freshwater production in sports arenas. International Journal of Hydrogen Energy, 2024, 59, 1507-1517. DOI: 10.1016/j.ijhydene.2024.02.146
[17] Kabir M, Habiba U, Iqbal MZ, Shafiq M, Farooqi ZR, Shah A, et al. Impacts of anthropogenic activities & climate change resulting from increasing concentration of Carbon dioxide on environment in 21st Century; A critical review. IOP Conference Series: Earth and Environmental Science, 2023, 1194 (1), 012010. DOI: 10.1088/1755-1315/1194/1/012010
[18] Adetona AB, Layzell DB. Diverting residual biomass to energy use: Quantifying the global warming potential of biogenic CO2 (GWPbCO2). GCB Bioenergy, 2023, 15(5), 697-709. DOI: 10.1111/gcbb.13048

[19] Laleh SS, Mousavi HS, Rabet S, Nojavan F, Yari M, Soltani S. Solar thermal assisted proton exchange membrane electrolyzer and solid oxide fuel cell system based on biomass gasification for green power and hydrogen production: Multi-objective optimization and exergoeconomic analysis. Energy Conversion and Management, 2025, 337, 119900. DOI: 10.1016/j.enconman.2025.119900

[20] Arashrad P, Sharafi Laleh S, Rabet S, Yari M, Soltani S, Rosen MA. Real-time modeling of a solar-driven power plant with green hydrogen, electricity, and fresh water production: Techno-economics and optimization. Sustainability (2071-1050), 2025, 17(8). DOI: 10.3390/su17083555

[21] Abas N, Kalair A, Khan N. Review of fossil fuels and future energy technologies. Futures, 2015, 69, 31-49. DOI: 10.1016/j.futures.2015.03.003

[22] Wang Z, Li S, Jin Z, Li Z, Liu Q, Zhang K. Oil and gas pathway to net-zero: Review and outlook. Energy Strategy Reviews, 2023, 45, 101048. DOI: 10.1016/j.esr.2022.101048

[23] Li W, Chen Z, Li M, Zhang H, Li M, Qiu X, et al. Carbon emission and economic development trade-offs for optimizing land-use allocation in the Yangtze River Delta, China. Ecological Indicators, 2023, 147, 109950. DOI: 10.1016/j.ecolind.2023.109950

[24] Siddik AB, Khan S, Khan U, Yong L, Murshed M. The role of renewable energy finance in achieving low-carbon growth: contextual evidence from leading renewable energy-investing countries. Energy, 2023, 270, 126864. DOI: 10.1016/j.energy.2023.126864

[25] Aljarrah R, Fawaz BB, Salem Q, Karimi M, Marzooghi H, Azizipanah-Abarghooee R. Issues and challenges of grid-following converters interfacing renewable energy sources in low inertia systems: A review. IEEE Access, 2024, 12, 5534-5561. DOI: 10.1109/ACCESS.2024.3349630

[26] Karduri RK, Ananth C. The economics of transitioning to renewable energy sources. International Journal of Advanced Research In Basic Engineering Sciences and Technology (IJARBEST), 2023, 10.

[27] Guo J, Mallinson DJ, Ortiz SE, Iulo LD. Collaborative governance challenges in energy efficiency and conservation: The case of Pennsylvania. Utilities Policy, 2024, 87, 101721. DOI: 10.1016/j.jup.2024.101721

[28] Yu Z, Ridwan IL, Tanveer M, Khan SA. Investigating the nexuses between transportation Infrastructure, renewable energy Sources, and economic Growth: Striving towards sustainable development. Ain Shams Engineering Journal, 2023, 14(2), 101843. DOI: 10.1016/j.asej.2022.101843

[29] Apergi M, Eicke L, Goldthau A, Kurniawan J, Schuch E, Weko S. Pathways to a sustainable electricity sector in Kenya: Challenges and transformational factors. Utilities Policy, 2024, 91, 101854. DOI: 10.1016/j.jup.2024.101854

[30] Glassley WE. Geothermal energy: renewable energy and the environment. CRC Press, 2014.

[31] Avci AC, Kaygusuz O, Kaygusuz K. Geothermal energy for sustainable development. Journal of Engineering Research and Applied Science, 2020, 9(1), 1414-1426.

[32] Younger PL. Geothermal energy: Delivering on the global potential. Energies, 2015, 8(10), 11737-11754. DOI: 10.3390/en81011737

[33] Bagher AM, Vahid M, Mohsen M. Geothermal energy. Journal of Engineering and Technology Research, 2014, 6(8), 146-150. DOI: 10.5897/JETR2014.0526

[34] Barbier E. Geothermal energy technology and current status: An overview. Renewable and Sustainable Energy Reviews, 2002, 6(1-2), 3-65. DOI: 10.1016/S1364-0321(02)00002-3

[35] Tester JW, Anderson BJ, Batchelor AS, Blackwell DD, DiPippo R, Drake EM, et al. The future of geothermal energy. Massachusetts Institute of Technology, 2006, 358, 1-3.

[36] Hein P, Zhu K, Bucher A, Kolditz O, Pang Z, Shao H. Quantification of exploitable shallow geothermal energy by using Borehole Heat Exchanger coupled Ground Source Heat Pump systems. Energy Conversion and Management, 2016, 127, 80-89. DOI: 10.1016/j.enconman.2016.08.097

[37] Safarpour A, Soltani S. How sport management can address sustainability: Creating and testing a scale. Sustainable Futures, 2025, 10, 101102. DOI: 0.1016/j.sftr.2025.101102

[38] Lund JW, Toth AN. Direct utilization of geothermal energy 2020 worldwide review. Geothermics, 2021. 90, 101915. DOI: 10.1016/j.geothermics.2020.101915

[39] Moya D, Aldás C, Kaparaju P. Geothermal energy: Power plant technology and direct heat applications. Renewable and Sustainable Energy Reviews, 2018, 94, 889-901. DOI: 10.1016/j.rser.2018.06.047

[40] Narsilio GA, Aye L. Shallow geothermal energy: an emerging technology. Low Carbon Energy Supply: Trends, Technology, Management, 2018, 387-411. DOI: 1007/978-981-10-7326-7_18

[41] Lund JW, Boyd TL. Direct utilization of geothermal energy 2015 worldwide review. Geothermics, 2016, 60, 66-93. DOI: 10.1016/j.geothermics.2015.11.004

[42] Brophy P. Environmental advantages to the utilization of geothermal energy. Renewable Energy, 1997, 10(2-3), 367-377. DOI: 10.1016/0960-1481(96)00094-8

[43] Shortall R, Davidsdottir B, Axelsson G. Geothermal energy for sustainable development: A review of sustainability impacts and assessment frameworks. Renewable and Sustainable Energy Reviews, 2015, 44, 391-406. DOI: 10.1016/j.rser.2014.12.020

[44] Wanless L, Seifried C, Kellison T. Renewable energy source diffusion in professional sport facilities. Journal of Sport Management, 2023, 38(1), 40-52. DOI: 10.1123/jsm.2023-0081

[45] Oldmeadow E, Marinova D. Into geothermal solutions: the sustainability case for Challenge Stadium in Perth, Western Australia. Environmental Progress & Sustainable Energy, 2011, 30(3), 476-485. DOI: 10.1002/ep.10476

[46] Veleska V, Josifovski J. Open-loop geothermal heat exchanger system for heating and cooling of the Sport arena in Skopje. ce/papers, 2018, 2(2-3), 827-832. DOI: 10.1002/cepa.773

[47] Gurgenci H, Rudolph V, Saha T, Lu M. Challenges for geothermal energy utilisation. In Thirty-Third Workshop On Geothermal Reservoir Engineering, Stanford University, SGP-TR-185. 2008.

[48] Rybach L. The future of geothermal energy and its challenges. Proceedings World Geothermal Congress, 2010, 29.

[49] Darma S, Harsoprayitno S, Ibrahim HD, Effendi A, Triboesono A. Geothermal in Indonesia: government regulations and power utilities, opportunities and challenges of its development. In Proceedings of the World Geothermal Congress, International Geothermal Association Bali, Indonesia, 2010, pp. 1-9.

[50] Bai M, Patil PA. The identification of growth barriers for exploitation of geothermal energy in China. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2014, 36(22), 2482-2491. DOI: 10.1080/15567036.2012.738285
[51] Setiawan H. Geothermal energy development in Indonesia: Progress, challenges and prospect. Gas, 2014, 1, 280.
[52] Abbas T, Bazmi AA, Bhutto AW, Zahedi G. Greener energy: Issues and challenges for Pakistan-geothermal energy prospective. Renewable and Sustainable Energy Reviews, 2014, 31, 258-269. DOI: 10.1016/j.rser.2013.11.043
[53] Poernomo A, Satar S, Effendi P, Kusuma A, Azimudin T, Sudarwo S. An overview of Indonesia geothermal development-current status and its challenges. Proceedings World Geothermal Congress, 2015.
[54] Breede K, Dzebisashvili K, Falcone G. Overcoming challenges in the classification of deep geothermal potential. Geothermal Energy Science, 2015, 3(1), 19-39. DOI: 10.5194/gtes-3-19-2015
[55] De Jesus AC. Environmental benefits and challenges associated with geothermal power generation. Geothermal Power Generation, 2016, 477-498. DOI: 10.1016/B978-0-08-100337-4.00017-6
[56] Manzella A, Donato A, Gola G, Santilano A, Trumpy E. The Italian challenge for geothermal energy. Perspectives for Geothermal Energy in Europe, 2017, 127-155. DOI: 10.1142/9781786342324_0005
[57] Lichti K. Materials selection challenges for geothermal energy projects. In NACE CORROSION, 2017. NACE.
[58] Colmenar-Santos A, Palomo-Torrejón E, Rosales-Asensio E, Borge-Diez D. Measures to remove geothermal energy barriers in the European Union. Energies, 2018, 11(11), 3202. DOI: 10.3390/en11113202
[59] Anbumozhi V. Geothermal energy barriers, policies and economics in East Asia. In Sayigh, A. (eds) Transition Towards 100% Renewable Energy. Innovative Renewable Energy. Springer, Cham. 2018, pp. 11-20. DOI: 10.1007/978-3-319-69844-1_2
[60] Pan SY, Gao M, Shah KJ, Zheng J, Pei SL, Chiang PC. Establishment of enhanced geothermal energy utilization plans: Barriers and strategies. Renewable Energy, 2019, 132, 19-32. DOI: 10.1016/j.renene.2018.07.126
[61] Phi T, Elgaddafi R, Al Ramadan M, Ahmed R, Teodoriu C. Well integrity issues: Extreme high-pressure high-temperature wells and geothermal wells a review. SPE Thermal Integrity and Design Symposium, 2019. DOI: 10.2118/198687-MS
[62] Wilberforce T, Baroutaji A, El Hassan Z, Thompson J, Soudan B, Olabi AG. Prospects and challenges of concentrated solar photovoltaics and enhanced geothermal energy technologies. Science of The Total Environment, 2019, 659, 851-861. DOI: 10.1016/j.scitotenv.2018.12.257
[63] Noorollahi Y, Shabbir MS, Siddiqi AF, Ilyashenko LK, Ahmadi E. Review of two decade geothermal energy development in Iran, benefits, challenges, and future policy. Geothermics, 2019, 77, 257-266. DOI: 10.1016/j.geothermics.2018.10.004
[64] Kabeyi MJ. Geothermal electricity generation, challenges, opportunities and recommendations. International Journal of Advances in Scientific Research and Engineering (ijasre), 2019, 5(8), 53-95.
[65] Lee I, Tester JW, You F. Systems analysis, design, and optimization of geothermal energy systems for power production and polygeneration: State-of-the-art and future challenges. Renewable and Sustainable Energy Reviews, 2019, 109, 551-577. DOI: 10.1016/j.rser.2019.04.058
[66] Acheilas I, Hooimeijer F, Ersoy A. A decision support tool for implementing district heating in existing cities, focusing on using a geothermal source. Energies, 2020, 13(11), 2750. DOI: 10.3390/en13112750
[67] Vivas C, Salehi S, Tuttle JD, Rickard B. Challenges and opportunities of geothermal drilling for renewable energy generation. GRC Transactions, 2020, 44, 904-918.
[68] Soltani M, Kashkooli FM, Souri M, Rafiei B, Jabarifar M, Gharali K, et al. Environmental, economic, and social impacts of geothermal energy systems. Renewable and Sustainable Energy Reviews, 2021, 140, 110750. DOI: 10.1016/j.rser.2021.110750
[69] Chelminski K. Climate finance effectiveness: a comparative analysis of geothermal development in Indonesia and the Philippines. The Journal of Environment & Development, 2022, 31(2), 139-167. DOI: 10.1177/10704965211070034
[70] Hu Y, Cheng H, Tao S. Opportunity and challenges in large-scale geothermal energy exploitation in China. Critical Reviews in Environmental Science and Technology, 2022, 52(21), 3813-3834. DOI: 10.1080/10643389.2021.1971004
[71] Kumar L, Hossain MS, Assad ME, Manoo MU. Technological advancements and challenges of geothermal energy systems: a comprehensive review. Energies, 2022, 15(23), 9058. DOI: 10.3390/en15239058
[72] Kang FC, Tang CA, Li YC, Li TJ, Men JL. Challenges and opportunities of enhanced geothermal systems: A review. Chinese Journal of Engineering, 2022, 44(10), 1767-1777. DOI: 10.13374/j.issn2095-9389.2022.04.07.004
[73] Zayed ME, Shboul B, Yin H, Zhao J, Zayed AA. Recent advances in geothermal energy reservoirs modeling: Challenges and potential of thermo-fluid integrated models for reservoir heat extraction and geothermal energy piles design. Journal of Energy Storage, 2023, 62, 106835. DOI: 0.1016/j.est.2023.106835
[74] Benti NE, Woldegiyorgis TA, Geffe CA, Gurmesa GS, Chaka MD, Mekonnen YS. Overview of geothermal resources utilization in Ethiopia: Potentials, opportunities, and challenges. Scientific African, 2023, 19, e01562. DOI: 10.1016/j.sciaf.2023.e01562
[75] Gunnlaugsson B, Agustsson MA, Adalsteinsson S. Sustainable use of geothermal energy in Icelandic horticulture. International Geothermal Conference, 2003, 6, 2011.
[76] Tomić N, Stojsavljević R, Stamenković I, Berić D. The use of geothermal energy resources in the tourism industry of Vojvodina (Northern Serbia). European Researcher, 2013, 42(2-3), 443-454.
[77] Barbato M, Cirillo L, Menditto L, Moretti R, Nardini S. Feasibility study of a geothermal energy system for indoor swimming pool in Campi Flegrei area. Thermal Science and Engineering Progress, 2018, 6, 421-425. DOI: 10.1016/j.tsep.2018.02.013
[78] Jónsson ÖD, Rastrick Ó. Enjoying the outdoor pool in a cold climate: Appropriate technology, utilisation of geothermal resources and the socialisation of everyday practices in Iceland. Geothermal Energy, 2017, 5, 1-14. DOI: 0.1186/s40517-017-0060-5
[79] Marić A. Conditions and possibilities of geothermal energy utilization for economic-touristic development. Зборник радова Географског института" Јован Цвијић" САНУ, 2018, 68(2), 233-248.
[80] Barbato M, Cirillo L, Menditto L, Moretti R, Nardini S. Geothermal energy application in Campi Flegrei Area: The case study of a swimming pool building. International Journal of Heat and Technology, 2017, 35(1), S102-S107.
[81] Gažíková S, Takács J, Krajčík M. Improving the efficiency of geothermal energy use for recreation and balneology: a case study of spa Kremnica. Russian Journal of Construction Science and Technology, 2018, 4(2).
[82] Alimonti C, Soldo E, DI LEGINIO L. Improvement of the energy system efficiency by a ground source heat pumps system in a sport center. In European geothermal congress 2019. The Hague, 11-14 june 2019. Proceedings 2019.EGEC. https://hdl.handle.net/11573/1341286 (accessed on 14 June 2019).

[83] Xu J, Su Z, Meng J, Yao Y, Vafadaran MS, Salavat AK. A thermodynamic, exergoeconomic, and exergoenvironmental investigation and optimization on a novel geothermal trigeneration system to sustain a sport arena. Process Safety and Environmental Protection, 2023, 177, 278-298. DOI: 10.1016/j.psep.2023.07.017
[84] Cai J, Fei J, Li L, Fei C, Maghsoudniazi M, Su Z. Multicriteria study of geothermal trigeneration systems with configurations of hybrid vapor compression refrigeration and Kalina cycles for sport arena application. Renewable Energy, 2023, 219, 119390. DOI: 10.1016/j.renene.2023.119390
[85] Braun V, Clarke V. Using thematic analysis in psychology. Qualitative Research in Psychology, 2006, 3(2), 77. DOI: 10.1191/1478088706qp063oa
[86] TTerry G, Hayfield N, Clarke V, Braun V. Thematic analysis. The SAGE Handbook of Qualitative Research in Psychology, 2017, 2(17-37), 25.
[87] Clarke V, Braun V. Thematic analysis. The Journal of Positive Psychology, 2016, 12(3), 1-12. DOI: 10.1080/17439760.2016.1262613
[88] Creswell JW, Creswell JD. Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications; 2017.
[89] Wimmer RD, Dominick JR. Mass media research: An introduction 8th ed. Belmont, CA: Thomson Higher Education. 2006.
[90] Chris G, Ian J. Research methods for sports studies. 2004: Routledge.
[91] Pasqualetti MJ. The site specific nature of geothermal energy: The primary role of land use planning in nonelectric development. Natural Resources Journal, 1983, 23(4), 795-814.
[92] Lund JW, Bjelm L, Bloomquist G, Mortensen AK. Characteristics, development and utilization of geothermal resources-a Nordic perspective. Episodes Journal of International Geoscience, 2008, 31(1), 140-147. DOI: 10.18814/epiiugs/2008/v31i1/019
[93] Paoli L, Loppi S. A biological method to monitor early effects of the air pollution caused by the industrial exploitation of geothermal energy. Environmental Pollution, 2008, 155(2), 383-388. DOI:10.1016/j.envpol.2007.11.004
[94] Thorhallsson S. Geothermal well operation and maintenance. Geothermal Training Program IGC Short Course, 2003.
[95] Parada AFM. Geothermal binary cycle power plant principles, operation and maintenance. Geothermal Training Pro-gramme Reports Orkustofnun, 2013, 20, 443-476.
[96] Halaj E. Geothermal bathing and recreation centres in Poland. Environmental Earth Sciences, 2015, 74(12) 7497-7509. DOI: 10.1007/s12665-014-3740-5
[97] Kubota H, Hondo H, Hienuki S, Kaieda H. Determining barriers to developing geothermal power generation in Japan: Societal acceptance by stakeholders involved in hot springs. Energy Policy, 2013, 61, 1079-1087. DOI: /10.1016/j.enpol.2013.05.084
[98] Palomo-Torrejón E, Colmenar-Santos A, Rosales-Asensio E, Mur-Pérez F. Economic and environmental benefits of geothermal energy in industrial processes. Renewable Energy, 2021, 174, 134-146. DOI: 10.1016/j.renene.2021.04.074

Appendix

Appendix 1. Extracted variables from interviews with experts.

No	Extracted Variable
1	Lack of awareness and information
2	Lack of knowledge about renewables
3	Lack of understanding about renewables benefit
4	Lack of true basic social strategy about renewables
5	Socio cultural issues
6	Land use by geothermal
7	Water consumption by geothermal activity
8	Noise by geothermal activity
9	Air pollution by geothermal usage
10	Standardization for construction
11	Lack of expert had experience with geothermal energy and renewables
12	Lack of updated technology in using geothermal energy
13	Very expensive technological instrument for caving
14	Having technological problems with coworkers
15	Location and quality of resources
16	Lack of experienced with geothermal
17	Infrastructure need for geothermal usage
18	High capital cost
19	Lack of sufficient money for starting and continue project
20	High initial investment
21	Financial investment and support
22	Maintenance service
23	Convenient location to use
24	Sport facility structure
25	Amount of sport facility able to use geothermal
26	Risk of use in sport facility
27	Managerial challenges
28	Policy framework
29	Lack of supportive laws
30	Legislation geothermal law