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Identifying challenges, benefits, and recommendations for utilizing solar panels in sport stadiums: A thematic analysis

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ABSTRACT

Renewable energies are the need of today's world and future based on the evidences which are available. Actually, there are many types of renewable energy which are now being used. One of the main types is solar energy since it is available and very well known in scientific communities and industrial procedures. Solar energy is the sustainable energy resource and can be utilized in different places. One of the significant parts is in sport arenas. Basically, nowadays sport industry like other sectors are converging to the use of renewable energies especially solar energy. Nonetheless, there are some challenges in this application. Here, the potential draw backs are named and mentioned in details. Moreover, benefits also are embedded. Hence, this study focuses on the mere use of solar energy and its corresponding pros and cons. The comprehensive data are gathered by reviewing the previous work to illuminate the characteristics of this valuable energy resource in sport stadiums and arenas. We used the interviews and thematic method by interviewing in-depth with eight expert. Our finding revealed the challenges: economic and social challenges, the structure of the stadiums, policy and regulations, and the technical aspect. We also presented many benefits such as reducing emissions, reducing costs and sustainable development for sports stadiums.

1. Introduction

Nowadays, the utilization of fossil fuels predominates as the primary energy source catering to the majority of global consumption requirements [1,25,31]. According to the statistics, 83 percent of annual energy consumption in the world is by fossil fuels [34]. unfortunately, the consumption of these finite resources incurs deleterious ramifications [27,69], including atmospheric contamination, the exacerbation of global climate change, and the discharge of greenhouse gases [54,65]. Consequently, it becomes imperative to explore and implement fundamental resolutions aimed at mitigating these adverse consequences [6, 12,25]. In recent years, the global push for sustainable and renewable energy sources has become more prevalent than ever before [47,89]. As the world becomes increasingly aware of the detrimental effects of traditional carbon-emitting power generation methods, the adoption to renewable energy sources are increase [32,96]. Solar panels has emerged as an innovative solution to combat climate change and reduce our carbon footprint [74].

Solar energy is a crucial and increasingly popular source of renewable energy [20], with the potential to meet a significant portion of global energy demand [33,42]. It is a reliable, cost-effective, and sustainable option, particularly in the face of growing energy needs and the limitations of traditional energy sources [28]. The development of solar energy technologies, such as photovoltaic cells and solar arrays, has further enhanced its potential as a viable energy solution [16,77]. One of the fields that needs a basic solution in the field of energy and its consumption is sports stadiums [51]. Despite the advantages of solar energy, although it still only contributes 3.6 % of the world's power generation, solar photovoltaic (PV) capacity has increased dramatically, and by 2022 it will account for 31 % of all installed renewable energy capacity [66].

The competition among countries to host major global sporting events, such as the Olympic Games and World Cups, has resulted in the construction of larger sports stadiums with higher energy demands [57, 59]. These stadiums have expanded to include additional facilities like museums, restaurants, playgrounds, and coffee shops, further increasing their energy requirements [22,51]. Consequently, there is now a growing realization of the need to collectively address and reduce the

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consumption of fossil fuels in these complexes, while transitioning towards renewable energy sources [52]. Because of their potential to provide sustainable energy and have an impact on the community, solar panel applications in sports stadiums need to be thoroughly studied. Stadiums provide special chances for solar power integration because they are large-scale buildings with high energy requirements [30]. According to research, solar photovoltaic systems can be built to handle large electricity requirements. For example, a big stadium in Saudi Arabia requires 111,000 kWh of electricity per day [51]. These installations can be ingeniously incorporated into stadium infrastructure, including parking lot canopies, maximizing area efficiency. Moreover, stadiums have the potential to become multi-functional buildings that not only host sporting events but also serve as renewable energy sources for the local community [72]. By implementing solar technologies, stadiums can transform into energy-efficient structures that promote sustainability, reduce carbon footprints, and potentially generate surplus energy for local use, aligning with global efforts towards green and low-carbon development [30,72].

One notable step in this direction was taken during the 1994 Winter Olympics in Norway. With a strong commitment to environmental responsibility, the organizers made significant decisions to ensure that the Olympic events were conducted in an environmentally friendly manner [22]. This groundbreaking initiative earned the 1994 Winter Olympics the distinction of being the first "Green Games" [8,71].

In recent years, there have been significant advancements in the development of sports stadiums, particularly in integrating renewable energy sources [4]. A noteworthy example is the Mercedes-Benz sports stadium in Atlanta, which has successfully implemented initiatives to reduce pollution by minimizing carbon dioxide emissions [44]. The stadium has employed around 4000 solar panels, strategically designed and installed on the roof, to generate clean and sustainable energy [44,56]. As a result, a substantial portion of the stadium's energy needs are met through renewable sources [44]. Additionally, the stadium has implemented rainwater collection systems to address water-related challenges commonly faced by stadiums and large complexes. The other case is the Johan Cruijff Arena in Amsterdam which has the largest stadium in the Netherlands and one of the most sustainable stadiums in the world [21,85]. The stadium has over 4200 solar panels installed on its roof. These panels generate approximately 930,000 kWh of electricity per year, which can power 270 households [21,86]. In addition to solar panels, the stadium also has two wind turbines installed at the top of the arena. The turbines generate around 1.2 million kWh of electricity annually [5,91]. Using Energy Storage, Heat and Cold Storage, LED Lighting and Energy Efficient HVAC Systems [85]. Therefore, by implementing these renewable energy steps, the Johan Cruijff Arena has become a model for sustainability in the sports industry, reducing its carbon footprint and demonstrating the potential of renewable energy in large-scale venues. The other example of using solar panels are in Beijing winter Olympic (2022), when solar energy played a significant role in powering the Games, with the city of Zhangjiakou, located 160 km northwest of Beijing, providing renewable energy. Zhangjiakou's wind and solar resources account for nearly half of its electricity output, with potential for further expansion up to 70 gigawatts [64]. The successful implementation of these green technologies and practices at the Beijing Olympics serves as a model for future host cities and contributes to the ongoing development of sustainable sporting events [48,75].

In spite of the numerous advantages associated with employing clean and renewable energy in stadiums and sports venues [37,44,85], there are also inherent hurdles and challenges with this kind of energies to use in stadiums. Our research aims to identify the challenges associated with implementing solar energy systems in stadiums and our research is prepared the results with interview with renewable energy experts and during this process defiantly we extract valuable data and results that could possibly expand the knowledge in this area. Additionally, we seek to highlight the benefits of utilizing this clean energy source and propose practical solutions for integrating solar power into sports stadiums.

2. Literature review

2.1. Renewable energy

According to [12], renewable energy refers to natural resources that can be replenished within a short period of time. Examples of these resources are solar, wind, hydropower, geothermal, and biomass energy [59]. However, the term "renewable energy" is problematic and suggests using a more precise term [50,57]. On the other hand, Bull [12] stress the significance of renewable energy in addressing climate change and ensuring energy security. Technologies are cost-effective and are progressing towards commercialization. Meanwhile, some researchers specifically points out the importance for renewable energy potential in order to enhance energy security and curb greenhouse gas emissions [5,6,96].

2.2. Solar energy

Solar energy, which is widely available and can be harnessed at a local level, holds great promise for meeting the world's energy needs in a sustainable way [90]. As a result, Many countries are implementing policies to promote solar energy adoption as a sustainable alternative to fossil fuels [36,76]. Developing countries and transition economies are also adopting various policy measures to promote renewable energy [46,60], including price- and quantity-setting policies, fiscal incentives, and market facilitation measures [35]. In Malaysia, policies such as Fit and net energy metering have been implemented to encourage solar system adoption in homes and commercial projects [35]. While solar energy is becoming more cost-effective, it still requires government support to compete with fossil fuels and meet growing energy demands in developing countries.

Solar energy is a promising renewable energy source that has the potential to provide a widespread primary energy source if captured, converted, and stored in a cost-effective fashion [98]. Solar energy can be harnessed through various technologies, including solar cells, Nano generators, and thermal energy storage systems. Wearable electronics can be powered by a hybridized self-charging power textile system that collects outdoor sunshine and random body motion energies and stores them in an energy storage unit [92]. This system utilizes fiber-shaped dye-sensitized solar cells for solar energy and fiber-shaped turboelectric Nano generators for random body motion energy, which can be easily woven into electronic textiles to fabricate smart clothes for sustainable operation of mobile or wearable electronics [88–90]

2.3. Solar energy and sport

The potential for solar energy in sports facilities is a growing area of interest, with studies highlighting its application in sport big stadiums, in 2009 Kaohsiung stadium in Taiwan was used for the world games at that year and was the world's biggest stadium powered by solar energy, Steel girders with spiral shapes were used to form the structure. The 19-hectare solar cell roof is designed like a saddle. There has space for 55,000 spectators. The majority of the power needed for the stadium to operate is produced by the solar panels that cover its large exterior face, as seen in the inset photographs [37]. Solar energy also had the possibility of making sports centers self-sufficient in energy through renewable sources [4]. Solar energy's versatility and potential for power generation, including its use in transportation and solar-powered vehicles are also noted [9,38].

Furthermore, the use of solar energy in various construction industries, including sports facilities, is discussed, with a focus on its economic and environmental benefits [24,78,88]. Solar energy adoption in sports stadiums is gaining traction as a sustainable alternative to fossil fuels. A study on hybrid gas turbine-solar systems for stadium desalination found that 45–50 % of energy could be provided by solar, reducing fuel consumption and CO2 emissions by 47 % [49]. Research on renewable energy diffusion in professional sports facilities revealed that 49 % have adopted at least one renewable source, with solar being the most common [90]. Full diffusion of renewable energy in stadiums is predicted by 2061, with factors like new construction and facility type influencing early adoption. Progress towards Sustainable Development Goal 7 is evident in sports facilities worldwide, with examples of solar, wind, and geothermal integration [40]. There's potential for stadiums to contribute to local community power needs, highlighting the broader impact of renewable energy adoption in sports facilities.

3. Method

In order to realize the goal of the current research, which was to identify the specific challenges and benefits of using solar panels in sports stadiums. The study was designed and implemented using a qualitative method with experts. For this purpose, in-depth interviews were conducted with experts in the field of solar energy and renewable energy, stadiums and sports facilities managers. Eight experts who participated in the interview had sufficient knowledge and experience regarding solar energy and its installation and operation in sports venues. Qualitative research expertise is a complex and debated topic, While some researchers seek expert validation of their findings [81]. The number of people considered for the qualitative research is 5–30 people for the interview section, which will continue in response to the questions according to the sample and until the theoretical saturation is reached [3,81]. In this research, after the eighth interview, the researchers reached a consensus about the results and the interview process was completed. Our goal in this research was to be able to obtain valuable and useful information from experts in this field, so we took the necessary care in selecting the interviewees. For example, the people who were interviewed in the field of stadiums and sports venues had a history of managing sports venues using renewable and solar energy and were experts in this field. Also, the renewable energy specialists who participated in this research had high technical abilities and knowledge in this field and had a history of setting up solar energy in sports venues and stadiums. The next sections will provide more detailed information about the data collection method as well as their analysis.

3.1. Interviews

Before conducting the interviews, an attempt was made to design and write the interview questions appropriately by comprehensively reviewing the research literature in order to help during the interviews, which were conducted over the phone or via Skype. Through reviewing the research literature, comprehensive information was provided to the interviewees about renewable energy and especially solar energy that is used in the sports industry. Also, this information obtained from the literature review section was used during the research and to achieve the desired results. In the following, the challenges and benefits of using this type of energies in industries and other statistical communities were given and an effort was made to clarify the mind of the interviewee about the current research and to be able to answer the questions of the current research well (Tables 1 and 2 shows the summarize of literature review). Then, we ask them to answer about the use of solar panels in stadiums and by using thematic analysis we categorize the results.

As mentioned earlier, eight experts were present in this research and in the process of interviews, whose information is presented in Table 3. These interviews were conducted from September 2023 to October 2023. The process of interviews started by obtaining permission orally from the interviewees and confirmation was obtained from them to participate in the interviews. In the next stage, the main questions of the research were asked and during this process, information from past researches and research literature was also presented to them.

In the next step, we raised questions about the research and its main purpose for the interviewees and experts and asked them about this (Appendix 1. shows the questions). The first question was about the

Table 1
Literature review of solar energy barriers.

Ref.	Location	Subject	Barriers to deployment of solar energy
[7]	USA	Potential of conservation and solar energy in the northern industrial	Economic, informational, and institutional policy
[62]	Nigeria	Solar energy applications and development	Variability and intermittency of radiation, Grid unreliability, Lack of awareness and information, High initial investment cost, Operation and maintenance costs, Government policy and incentives, Ineffective quality control of products, Insecurity of solar plant infrastructure and Competition with land uses
[99]	Hong Kong	Identified key barriers to the deployment of solar photovoltaic (PV) energy systems	High initial and repair costs, long payback periods, and inadequate installation space and service infrastructure
[53]	Review	Reviewed nontechnical barriers to solar energy use	Lack of government policy supporting energy efficiency and renewable energy (EE/RE), lack of information dissemination and consumer awareness, high costs of solar and other EE/RE technologies, and inadequate financing options for EE/RE
[39]	Pakistan	Focused on solar energy development identifying key barriers	Economical, policy, technological, information and human resource and social barriers
[26]	Brazil	Diffusion of distributed generation of photovoltaic energy	Technical, economic, social, managerial, and political barriers, Poor quality of photovoltaic systems, high initial investment costs, and lack of knowledge about photovoltaic technology as key barriers
[63]	India	Sociocultural study on solar photovoltaic energy systems and found that barriers to PV adoption by different citizen groups	Technical, human, and socio-economic components
[58]	India	Examined the barriers to solar power implementation in Indian thermal power plants	Investment, longer recovery period, safety implications, environmental implications, and societal concerns were identified as top-level barriers. Lack of adequate government policies and political leadership were also identified as influential barriers
[43]	Review	Importance of considering the impacts, drivers, and barriers of solar electricity deployment	Material culture of the people and policy implications

benefits of using solar energy in sports stadiums (e.g., "what do you think about the specific benefits of using solar energy in sport stadiums?). We asked them to express their opinion in this regard and from the point of view of an expert. The next question was their perception of the obstacles that exist for establishing the use of solar panels in sports stadiums (e.g., "what are the challenges and barriers of utilizing solar energy in stadiums"). Next, it was about solutions and expert recommendations to facilitate these processes (e.g., "What is your opinion regarding the provision of operational solutions in this field according to all the conditions raised"). We also asked their opinions about the existing laws and regulations in this field (e.g., "Are there any

Table 2
Literature review of solar energy benefits.

Ref.	Subject	Benefits of solar energy deployment
[83]	Growth of solar energy in recent years due to technological improvements	They highlight the benefits of solar energy from fiscal and regulatory incentives, including tax credits and exemptions, feed-in-tariff, preferential interest rates, renewable portfolio standards, and voluntary green power programs in many countries
[73]	Potential of solar energy in developing countries for reducing energy-related emissions	Reduction of greenhouse gas emissions and indoor air pollution, especially in remote rural areas where grid extensions are not viable
[13]	Evaluate renewable energy and energy efficiency technologies across regional power systems in the United States	Reduction of Co2 emission, cost reduction
[11]	Describe selected results with solar technologies	From a study examining the benefits meeting up to 20 % of U.S. electricity demand
[94]	The environmental and public health benefits of achieving high penetrations of solar energy in the United States	Environmental and public health benefits of achieving high penetrations of solar energy in the United States, reduces greenhouse gas and air pollutants, providing significant climate and air quality benefits
[70]	Study on the impact of shared battery energy storage systems on photovoltaic self-consumption and electricity bills in apartment buildings	Economical, reduce overall building peak demand
[80]	The importance of financial de-risking to unlock the renewable energy potential in Africa	Lowering financing costs could result in a much higher deployment of renewables, with solar PV potentially accounting for 10–15 % of total electricity generation by 2050, reducing financing costs for renewables could be an efficient way to lower greenhouse gas emissions
[87]	Reviewed the recent developments in the thermal performance enhancement methods of flat plate solar water heaters	Economic importance
[25]	Focused on the role of solar photovoltaic technology advances in fast-tracking hybrid renewable energy systems	Economic benefits and environmental consequences of fossil fuels

Table 3
Interview participant.

Interviewee	Job Description	Executive experience in solar energy
Int1	Sport stadium's Research and Development Manger	Yes
Int2	Sport stadium Manager	Yes
Int3	Renewable and Sustainability prof.	No
Int4	Designer and Constructor of sport Mega project	Yes
Int5	Counselor of Solar energy projects	Yes
Int6	Counselor of Sport renewable energy projects	Yes
Int7	Renewable energy and solar energy academic staff	No
Int8	Sport management academic staff	No

prohibiting or facilitating laws in this regard?"), and also provided information to the interviewees about the obstacles and benefits identified in the previous research literature so that they could give a complete and appropriate opinion in this regard. Be specific and the interview information is useful and effective.

The interviews were conducted in approximately 30–45 min and all of them were recorded. Later, the interviews were converted into text and to ensure the validity of this process, this process was done by two people from the research team separately. After completing this stage, we had almost all the necessary information to reach the main research questions and we only had to categorize them.

3.2. Qualitative data analysis

In this section, considering the qualitative method of the research process and extracting information from the interviews, we used one of the most common methods in this field, which is theme analysis. This method allows us to extract codes (initial variables) from qualitative findings and interviews. Thematic Analysis is a method for identifying and analyzing patterns of meaning in a dataset [10]. It illustrates which themes are important in the description of the phenomenon under study [82]. The end result of a thematic analysis should highlight the most salient group of meanings present in the dataset [15].

This method includes two coding steps. In the first stage, it includes reviewing and reading several times the texts of the interviews, from which the codes and answers to the research questions are extracted and brought out. At this stage, the codes were identified and highlighted manually by the research team, and the necessary additional information was noted next to them. In the next step of coding, the researcher grouped and summarized the found codes and placed them in smaller themes. At this stage, the members of the research team also participated in the process and expressed their opinions to increase the validity and reliability of the findings. In some cases, the opinions of experts outside the research team were also used so that we could achieve a correct summary of the interview and coding information. This process helped a lot to increase the accuracy and validity of the work [17] and it helps to improve the work [93] states that in qualitative research, especially with the interview method, using small size groups as samples can provide valuable and priceless information to the researcher, and the researcher can use their ideas and experiences in his research. Another important case in qualitative research is related to reaching the saturation point in the interview process, when no new information is received by the researcher in the interviews [29]. In this research and after interview number eight, the researcher reached complete theoretical saturation regarding the research questions and the purpose of the research, and the process of interviews ended after eight interviews.

4. Results

4.1. Solar energy barriers in sport stadiums

The first question that the current research answered was regarding the challenges to solar energy in sports stadiums. The answer to this question can help us understand the main challenges in deploying solar energy in stadiums and sports venues. To get an answer, we asked people in this regard and according to the answers received from them through interviews, we were able to identify 5 main obstacles in this field: *Economic, Technical, Social, Regulatory and policy and sport facility structure*.

4.1.1. Economic barriers

The first theme identified regarding the challenges to using solar energy in stadiums is economic and financial barriers. This obstacle expresses the problems and challenges that exist before and after the installation of the solar system in the sports stadium. For example, (Int 1) stated: "*One of the main problems of renewable energy and especially solar energy is related to their financial costs and economic discussion. Sports stadiums themselves have high costs. Maintenance and repairs throughout the year, if the installation and commissioning costs of solar panels are added to them, it will bring many economic problems for them*". The third interviewee (Int 3) stated that "*basically, setting up solar systems has a lot of initial costs that require high investment at the beginning of the work.*

"Starting up is a big problem, especially since the capital return is gradual and slow". Also, in this part of the research, we have 3 sub-themes including high initial cost, repair and maintenance cost and long payback period. These three economic factors were identified as challenges in the construction and operation of solar systems in sports stadiums through interviews with experts.

4.1.2. Technical barriers

The second theme identified in the current research was related to technical barriers in the way of using solar energy panels in sports stadium. This theme expresses the problems and challenges that are technically related to solar energy deployment in stadiums. For example, (Int 4) stated that "*according to the structures of sports stadiums, one of the main issues in the installation of solar panels is technical and technological discussions. The use of suitable solar panels in these places, the presence of experts in this field, the way to connect this produced energy to the stadium's electrical circuit and system, etc., are among the important issues in the discussion of installing solar energy in stadiums*". Furthermore, (Int 7) stated that "*in discussing the installation of solar energy in a sports venue such as a stadium, it is very important to pay attention to technical issues, creating an efficient solar system that can supply electricity requires appropriate technological infrastructure and the presence of experts in this field*". (Int 5) indicated,

> "*One of the most important points in the installation of solar systems is related to the proper quality of this system that can meet the needs of the complex. Also, suitable location for the installation of solar panels in old stadiums and the quality of their installation are effective in this field*".

(Int 1), also said, "*In discussing the use of solar energy in stadiums, issues such as maintenance and cleaning of solar panels, necessary technical structures on the roof of stadiums, limitations of energy storage and transmission system, etc. should be fully considered*".

As stated in this section, technical issues in solar energy installation in stadiums are very important. We also dedicates 4 sub-themes for this specific theme includes: Poor quality of solar system, lack of experts, Service infrastructure and safety and environmental implications.

4.1.3. Social barriers

The third theme as barriers to using solar energy in stadiums is related to social barriers. This theme states that many people, including those involved in sports, may not have a comprehensive understanding of solar energy and its benefits. This lack of awareness and information can make it challenging for them to embrace and invest in solar energy systems for sporting facilities. The interviewees state that the understanding and knowledge of the people in the society is one of the main factors in the acceptance and use of new technologies. This factor creates a general attitude about a new field, which itself is the basis for its use among people. (Int 2), explained that, "*Sometimes the lack of information of people in the society and the negative attitude towards this issue can prevent the use of that technology for years. Positive advertising and giving awareness and information to people and business owners in the society will play a significant role in using such renewable energy tools in the future*".

Furthermore, (Int 8) said, "*Lack of knowledge about the pollution caused by fossil fuels and the amount of energy consumed in the stadium during a match can prevent the use of new energy methods (like solar energy). Regarding renewable energies and sustainable development discussions, appropriate information should be provided to the people of the community and managers of stadiums and sports complexes*".

As stated in this section, the social barrier is one of the most important areas in the establishment and use of renewable energy in sports and sports facilities. We considered two sub-themes including lack of knowledge and lack of awareness for this theme based on experts' opinions.

4.1.4. Regulatory and policy

The fourth barrier regarding the Solar energy Barriers in sport Stadiums was regulatory and policy. This theme emerged from the interviews when the interviewees discussed the structural and legal barriers of renewable energies in the sports facilities. (Int 6) indicated that, "*Sports facilities may face difficulties in accessing affordable financing options for solar energy projects. The lack of proper financial mechanisms and incentives can deter potential investors and make it harder for sports facilities to transition to solar energy*". Also, (Int 8), stated, "*The absence of standardized regulations and codes specific to solar installations in sports facilities can pose challenges. This can result in confusion, delays, and increased costs for these installations*".

Furthermore, (Int 1), said, "*The process of obtaining permits and complying with zoning regulations can be complex and time-consuming. Sports facilities may encounter challenges in securing the necessary approvals to install solar panels, especially if there are aesthetic or height restrictions in place*". As the experts admitted, the regulatory and policy barrier is one of the most important challenges in the way of using and deploying solar panel systems in sports stadiums. So, addressing these regulatory and policy barriers is essential for promoting the widespread utilization of solar energy in sports and enabling environmental sustainability initiatives within the industry.

4.1.5. Sport stadiums structure

Finally, the fifth theme is about the stadiums specific structure that could be a barrier in the way of using solar energy panels within it. This theme refers to the special features that a sports stadium has and can create obstacles in the utilization and use of solar panels. (Int 3) explained that, "*Sports stadiums are generally built inside cities and suitable commuting routes, which have special features in terms of structure. The use and exploitation of renewable energy depends on the location and appropriate structure of sports venues. Basically, solar panels are installed and used on the roofs of stadiums, which require accurate and appropriate design with regard to load bearing and other features. Some old stadiums that are not properly designed and built cannot use and make maximum use of these renewable energies. Other areas such as empty parking spaces and around stadiums are also suitable places to install and use these panels. Therefore, the proper structure and design of a sports venue plays an important role in the use of solar and renewable energies*". Therefore, the special characteristics of a sports stadium can be both an effective factor in the use and a great obstacle and challenge in the maximum use of these energies.

(Int 2) indicated that, "*Sports stadiums have the most potential for using solar energy and installing special panels due to the size of their roofs and open spaces. Of course, there are some problems related to the aesthetic discussions of stadiums, safety problems in installing panels on the roof, limited weight capacity for installing solar panels in stadiums, and a specific angle to absorb sunlight. In general, the use of solar panels in stadiums and sports venues for use in the direction of renewable energies can be very effective in advancing the discussions of sustainable development of sports venues, but their dilemmas and problems must be resolved with correct decisions*".

(Int 4), echoed this, the structure of sports stadiums should be designed from the beginning in accordance with the use of solar panels and systems in order to maximize the use and efficiency of sports venues in terms of energy supply, and (Int 7) said that In the design discussion, the amount of sufficient space for the installation of solar panels should be considered, and the location of the stadium and the solar radiation in that place should also be considered. Fig. 2. Shows the barriers schematically.

4.2. Solar energy benefits in sport stadiums

The second question of the current research was about the benefits of installing solar panels in sport stadiums. The answer to this question can be effective in motivating more use of this type of renewable energy in sport stadiums and facilities. To answer this question, the interviewees were asked about this and based on their answers, we were able to identify three main themes in this regard, which included *economic,*

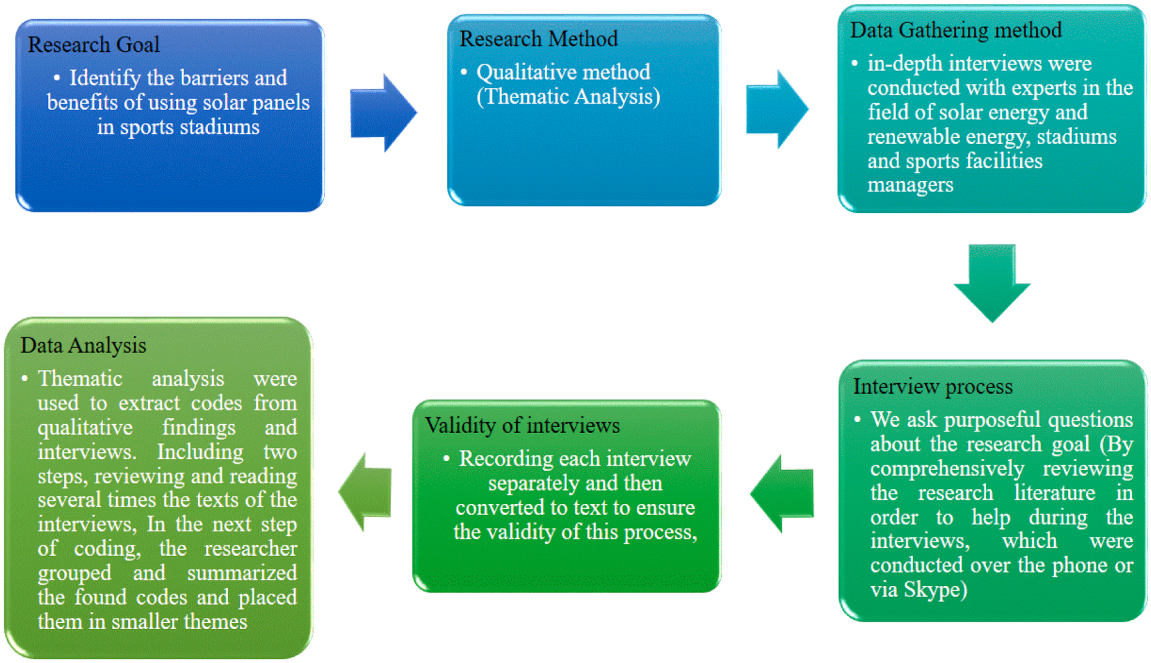

Fig. 1. Graphical process of the research methodology.

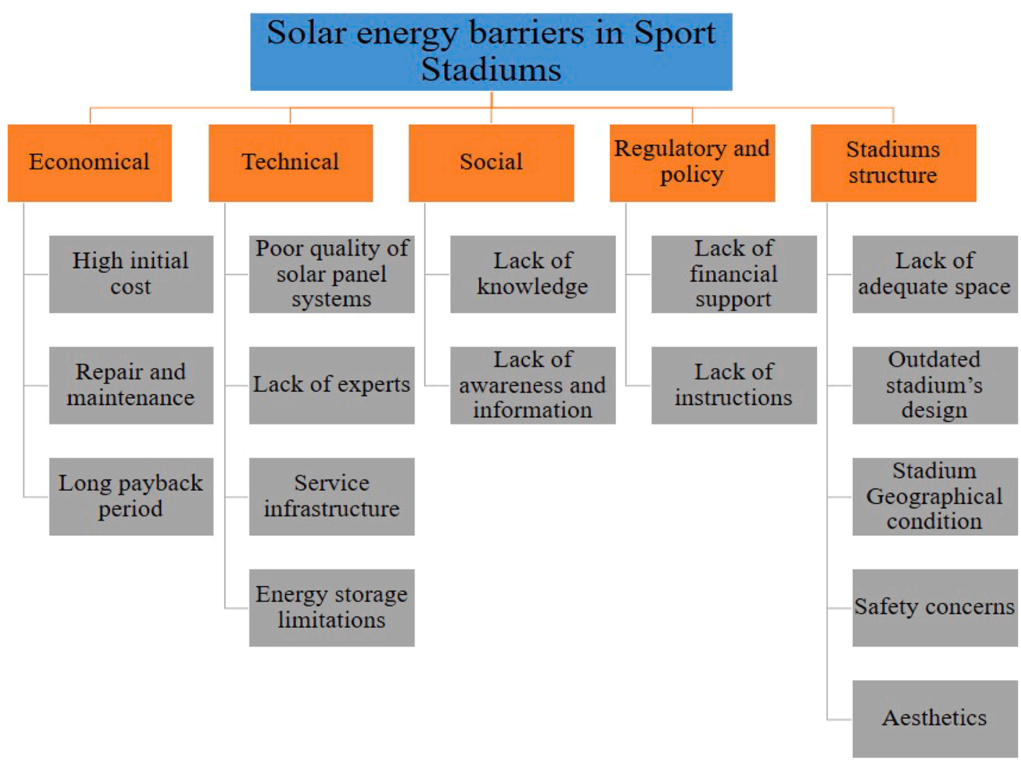

Fig. 2. Solar energy barriers in Stadiums.

social and sports stadium related benefits.

4.2.1. Economical benefits

The first theme in this regard is related to the long-term economic benefits of installing and using solar energy in sports stadiums. Apart from the initial costs for the installation of solar panels, in the long term, the use of these renewable energies can result in return of capital and even profitability for sports stadiums. (Int 3) said, "*The use of solar panels in sports stadiums can bring economic benefits for the stadium. Costs saving in the long term may be considered one of the most important advantages of this method*". (Int 6), indicated "*Installing solar panels in sports stadiums has both high initial costs and economic advantages in the long term. If it is possible to attract the necessary investment resources in this field, the best place to supply energy in stadiums is these solar panels*".

4.2.2. Social benefits

The second theme in this regard is related to the social benefits of installing and operating solar panels in sports stadiums. Despite the social challenges in the installation of solar panels on the opposite point, there are also many social advantages and benefits for the installation and operation of solar panels in sports stadiums. (Int 8) explained that "*The use of solar energy and renewable energy in general in stadiums can be effective in preventing the consumption of fossil fuels and of course the emission of greenhouse gases and carbon dioxide. These environmental effects gradually lead to the development of the concept of sustainable development in the field of sports stadiums, and due to the high energy consumption in them during competitions, it leads to the control of consumption and less damage to the environment*". (Int 3) said, "*The use of solar energy in sports stadiums, in addition to social discussions, such as increasing the knowledge and awareness of people in the community about renewable energies, causes sustainable development and reduce carbon footprint in the environment*".

Therefore, based on the opinion of the interviewees, it can be understood that there are very important social benefits in the construction and operation of solar panels in sports stadiums. Furthermore, (Int 6) indicated that, "*Supplying the required energy of a large sports stadium through solar energy, along with the discussions of sustainable development in the environment, can also create employment in this field. The presence of specialists in the fields of repair, maintenance and cleaning of these solar panels will also create related jobs, which will improve the brand and image of the sports complex among the people of society*". Finally, in this section we considered five sub-theme for social benefits of using solar panels in sport stadiums: Sustainability, Reduce emissions, Public image and branding, Job creation and Educational opportunities.

4.2.3. Stadium benefits

The third theme among the benefits identified for the use of solar panels in stadiums was related to the specific benefits of the sports stadium. The use of solar energy in sport stadiums is very important and useful for the stadiums and sport venues in addition to the other benefits it brings to the society. The participants in this research also pointed out the many benefits of using solar panels in sports stadiums and emphasized on the optimal use of this type of renewable energy in sports venues. (Int 7) stated that, "*A sports stadium has high energy needs during competitions, and responding to this high volume through urban systems can cause a lot of energy and cause more emissions through fossil fuels. Renewable energies are a good way to prevent this energy waste. The use of solar energy in the stadium helps a lot in reducing the energy consumption of the stadium, and besides, it reduces the dependence of stadiums and large sports complexes on the city electricity flow and reduces the pressure on it*".

(Int 1) Emphasizing the storage and reuse of this energy in sports stadiums and said, "*The electricity produced by solar energy in stadiums can meet a significant amount of the needs of these complexes. Due to holding competitions on certain days of the week and generally at night, the energy produced by the sun can be stored and used in times of need and emergency*". Fig. 3. Shows the graphical results of the solar energy benefits.

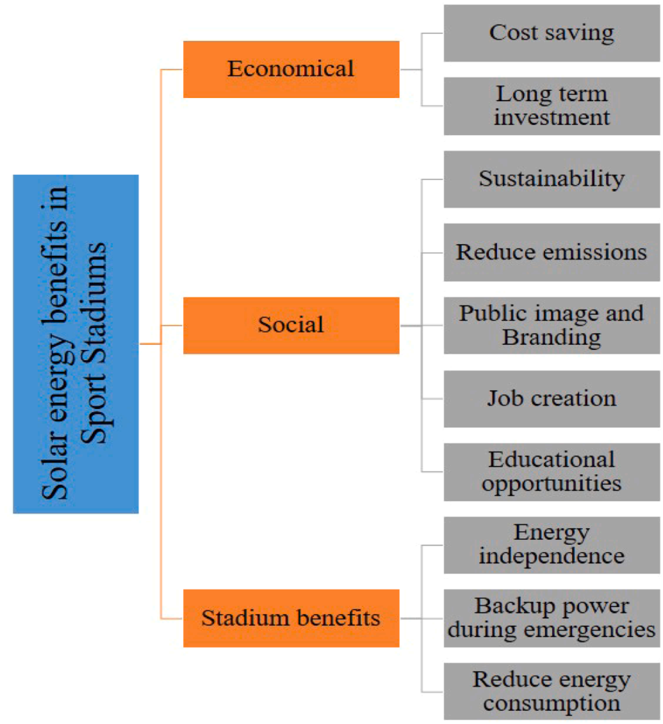

Fig. 3. Solar energy benefits in sport stadiums.

4.3. Practical solutions for integrating solar power into sports stadiums

In this part of the research, according to the challenges identified in the previous parts, it has been tried to provide practical solutions for the development of the use of solar panels in stadiums with the help of experts' opinions. In this section, we were able to provide eight practical and operational solutions for installing and using solar energy in sports stadiums.

1. *Installing solar panels on the stadium roof:* One practical solution is to install solar panels on the stadium roof. This can help generate clean energy by harnessing sunlight and converting it into electricity. The panels can be strategically positioned to maximize solar exposure, providing a significant amount of power for the stadium's needs. The implementation of solar panels in large structures like stadiums can significantly reduce carbon emissions and increase energy efficiency. Dual-axis solar tracking systems can maximize solar energy capture by ensuring panels are always perpendicular to the sun's rays [51]. For sports stadiums, parking lot canopies with photovoltaic arrays can be a viable solution, potentially meeting substantial electricity needs through net-metering arrangements with utility companies. When selecting solar panels, factors such as efficiency, power peak, maintenance, and price should be considered, with polycrystalline panels often emerging as the optimal choice [68]. Proper positioning of panels on rooftops can ensure maximum sunlight exposure and energy generation efficiency. The implementation of solar panels can lead to significant reductions in carbon emissions, with one study estimating a potential reduction of 21,057.95 tons CO2 eq per year for a large mosque [68].
2. *Utilize solar carports*: Another option is to install solar carports in the stadium's parking areas. These carports can act as shade structures for parked cars while also generating solar energy. They are an effective way to maximize solar power generation while also providing shelter for vehicles. Solar carports are an effective solution for generating renewable energy while providing shade for vehicles in parking areas. These structures can be designed and optimized for maximum power generation, with mono pitch canopies at a 10° tilt angle proving most efficient [84]. Implementation of solar carports can significantly reduce electricity costs and grid energy consumption, with payback periods of 6–7 years [84]. Large-scale deployments in stadium parking lots can meet substantial energy needs, such as 111,000 kWh per day, using net-metering to manage nighttime loads [51]. Solar carports can be integrated with wireless sensor networks for parking guidance systems, combining energy harvesting and adaptive duty-cycling technologies. Utilizing parking areas for solar installations can yield significant power generation capacity, with case studies demonstrating potential for 36.4 MWp installations generating 66.2 GWh annually [2].
3. *Implement solar-powered LED lighting*: Sports stadiums require extensive lighting systems, which can consume significant energy. By

installing solar-powered LED lighting, stadiums can reduce their dependence on conventional electricity and tap into sustainable energy sources. LED lights are highly efficient and can be powered by solar panels, saving both energy and costs. Solar-powered LED lighting systems offer significant energy savings and environmental benefits for various applications. These systems typically consist of solar photovoltaic modules, batteries, charge controllers, and LED fixtures [79]. Implementation in office spaces and roadways has demonstrated their effectiveness in replacing conventional lighting while reducing energy consumption and costs [45]. Recent technological advancements have further improved the efficiency of solar panels and LED technology, with projections suggesting LED lighting could reduce energy consumption by 15 % in 2020 and 40 % by 2030 [67].

4. *Integrate solar-powered water heating*: Sports stadiums often require hot water for showers, kitchens, and other facilities. Solar thermal systems can be integrated to provide hot water by using the sun's heat. This can substantially reduce the reliance on traditional water heating methods, helping to decrease energy consumption and costs. Solar-powered water heating systems offer significant energy-saving benefits for sports stadiums. Air-source heat pump-assisted solar water heating systems can replace up to 91 % of conventional energy use in large stadiums [95]. Hybrid gas turbine-solar energy systems can reduce fuel consumption and carbon dioxide emissions by 47 %, with solar energy providing 45–50 % of the required energy [49]. Solar-combi systems, combining solar collectors, biomass heaters, and thermal storage tanks, can cover 55 % of thermal energy demands for hot water and swimming pool heating in large sports facilities [41]. For electricity needs, photovoltaic systems installed as parking lot canopies can be a viable option, with a case study showing positive cash flow after 16 years for a 13,344 kW system [51]. These solutions demonstrate the potential for integrating solar-powered systems in sports stadiums to reduce energy consumption and costs.
5. *Implement energy storage systems*: To ensure uninterrupted power supply, integrating energy storage systems is crucial. Batteries can be used to store excess solar energy generated during the day and discharge it during peak demand or when sunlight is not available. This allows stadiums to use solar power even at night or during cloudy days, making the integration of solar energy more reliable. Battery energy storage systems play a crucial role in integrating solar power into the electrical grid by addressing the intermittency challenges of photovoltaic (PV) generation. These systems can absorb and deliver both real and reactive power with sub-second response times, mitigating issues such as ramp rate, frequency, and voltage fluctuations [19,97]. Implementing energy storage allows for various operational modes, including ramp rate control, frequency droop response, power factor correction, and solar time-shifting, which enhance grid stability and make solar resources more economical [19]. A practical implementation of PV output smoothing using energy storage demonstrated the effectiveness of a simple algorithm in reducing power output variability [18].
6. *Educate and engage the community*: It is important to educate and engage the community, including fans, athletes, and staff, about the benefits of solar power integration in sports stadiums. Promoting the use of renewable energy and providing information about energy-saving initiatives can create awareness and encourage sustainable practices. Also, Sport stadium operators can differentiate themselves by communicating their renewable energy initiatives to stakeholders through web-based platforms [98]. Community engagement in renewable energy integration varies across different contexts, but case studies from Tashkent, Uzbekistan, show increased community involvement in such initiatives [14,98]. However, more work is needed to enhance transparency, inclusion, and capacity building.
7. *Collaborate with local utility companies*: Collaborating with local utility companies can help stadiums take advantage of net-metering programs. Excess solar energy generated by the stadium can be fed back into the grid, earning credits or financial incentives. This collaboration can make the integration of solar power economically viable for sports stadiums. Collaboration with utility companies is crucial for successful implementation, as it allows for net-metering and integration of excess energy into the grid [51]. The adoption of energy management systems, such as ISO 50001, can lead to substantial cost savings, as evidenced by Aviva Stadium's €1 million energy cost avoidance over three years. Furthermore, utilities can support solar and solar + storage deployment in underserved communities through financing assistance, modernized rate designs, and technical support, potentially addressing energy equity issues and improving community resilience [23].
8. *Engage in partnerships and sponsorships*: Sports stadiums can seek partnerships and sponsorships from renewable energy companies. These collaborations can provide financial support for installing solar power systems while also promoting sustainable practices. Such partnerships can be beneficial for both the stadium and the renewable energy company, creating a win-win situation. Sports stadiums can implement renewable energy initiatives and promote sustainable practices through partnerships and sponsorships. Canadian stadiums have begun communicating their renewable energy efforts via web-based platforms [14]. Partnerships in renewable energy projects are crucial for success, involving diverse stakeholders and capitalizing on dynamic capabilities [61]. Sport sponsorship can effectively promote socially responsible companies and sustainable practices, influencing fans' purchasing decisions and creating a loyal consumer base [55]. The Philadelphia Eagles' Lincoln Financial Field exemplifies this approach, featuring one of the NFL's largest solar energy plants and a comprehensive sustainability program. Their initiatives include green energy production, recycling, composting, and water conservation, driven by team leadership and aligned with the city's sustainability goals [61]. These efforts demonstrate how sports stadiums can leverage partnerships to implement renewable energy solutions and promote sustainability.

By implementing these practical solutions, sports stadiums can reduce their carbon footprint, lower operating costs, and support the transition towards clean and sustainable energy sources. Fig. 4. Shows the schematic of this solutions.

5. Discussion

Traditionally, stadiums have heavily relied on fossil fuels, particularly electricity from the grid, to meet their vast energy demands [37]. However, this dependence on non-renewable energy sources contributes to greenhouse gas emissions and strains natural resources [85]. The integration of solar panels in stadiums offers an attractive alternative, providing an abundant, renewable, and clean energy source. By converting sunlight into electricity through a photovoltaic process, solar panels can harness the immense power of the sun, offering a sustainable and carbon-neutral energy option for stadiums [51]. Renewable energy sources, such as solar power, have gained immense momentum in recent years due to their potential to mitigate the adverse effects of climate change and promote sustainable development.

In this study, we explore the remarkable potential of solar panels in powering stadiums and their role in promoting green sports. In this research, we were able to obtain the barriers and benefits of using solar energy in stadiums through interviews with experts by using the method of theme analysis. Research works like this can provide a better view of the use and utilization of renewable energy in sports venues, and with the solution presented in this research, better decisions can be made in this field. Various researches have been conducted in the field of investigating the barriers, problems and benefits of using renewable energies [58,62,63,99], but the present research is one of the first researches that is carried out in the field of sports and sports stadiums, and

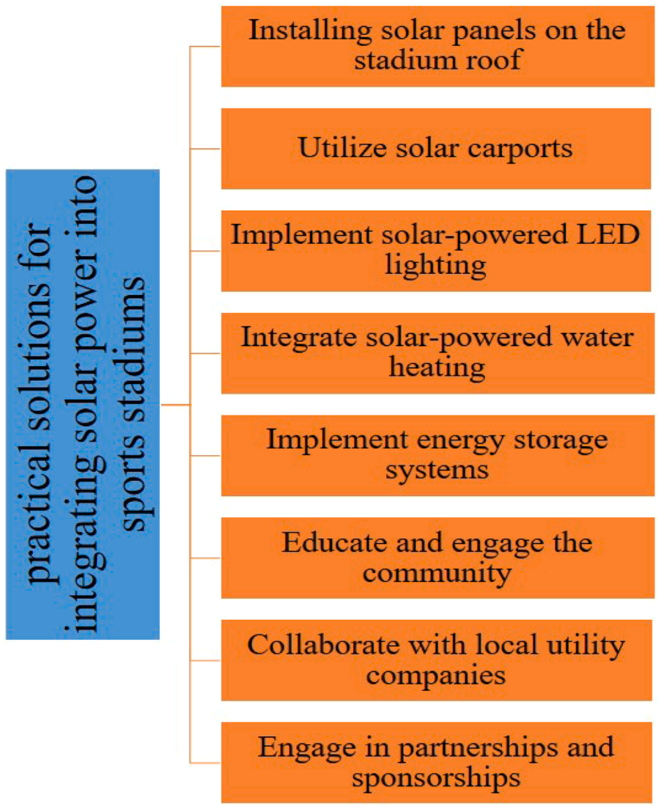

Fig. 4. Practical solutions for integrating solar power into sports stadiums.

in this sense, it can provide useful information to the sport society. Especially, through in-depth interviews with experts, we were able to examine the different angles of this case and provide valuable information.

Our results regarding the barriers of using solar panels in stadiums showed that we can classify and identify five barriers including economical, technical, social and regulatory and policy and finally stadium structure. Berg et al. [7] discussed the potential of conservation and solar energy in the northern industrial states of the USA, identifying barriers like economic, informational, and institutional policy options for consideration. Zhang et al. [99] identified key barriers to the deployment of solar photovoltaic (PV) energy systems in Hong Kong, such as high initial and repair costs, long payback periods, and inadequate installation space and service infrastructure. In another research, Margolis et al. [53] reviewed nontechnical barriers to solar energy use, including lack of government policy supporting energy efficiency, lack of information dissemination and consumer awareness, high costs of solar technologies, and inadequate financing options for projects. Irfan et al. [39] focused on solar energy development in Pakistan, identifying key barriers and proposing policy recommendations for institutions and the government to overcome these barriers and utilize maximum solar energy in the country. Also, Garlet et al. [26] identified technical, economic, social, managerial, and political barriers to the diffusion of distributed generation of photovoltaic energy in the Southern region of Brazil and also highlighted the poor quality of photovoltaic systems, high initial investment costs, and lack of knowledge about photovoltaic technology as key barriers. In India, Padmanathan et al. [63] conducted a sociocultural study on solar photovoltaic energy systems and found that barriers to PV adoption by different citizen groups include technical, human, and socio-economic components. Additionally, Nandal et al. [58] examined the barriers to solar power implementation in Indian thermal power plants and found that the requirement of significant investment, longer recovery period, safety implications, environmental implications, and societal concerns were identified as top-level barriers. Lack of adequate government policies and political leadership were also identified as influential barriers, and finally, Khan [43] highlight the significant barriers belong to the material culture of the people and policy implications.

Overall, the literature review for this section of research, indicates that while solar energy has the potential to address energy needs and minimize environmental impacts, there are various barriers to its adoption, including technical, economic, social, managerial, and political factors. (Int 5) indicated that,

> "*Understanding these barriers and implementing appropriate policies and measures is crucial for promoting the widespread adoption of solar energy in sport stadiums*".

The next aspect of the current research and its findings were about the benefits of using solar energy in stadiums. Our finding shows, implementing solar panels in stadiums not only provides a sustainable energy source but also offers several economic, social and environmental benefits. Beside this, solar energy has special benefits for stadiums. Firstly, stadiums can significantly reduce energy costs by relying on solar power and potentially sell excess electricity back to the grid. (Int 2) said, "*The long-term financial viability of solar panel installations allows stadiums to allocate the saved funds towards other development projects and enhancing the overall sports experience*".

Moreover, by shifting to solar power, stadiums significantly reduce their carbon footprint and contribute to the overall drive towards a low-carbon economy. The adoption of solar panels in stadiums can serve as a key visual marker for promoting green initiatives. This, in turn, helps raise awareness among the general public, athletes, and sponsors about climate change and the importance of sustainable development, effectively promoting green sports and environmental stewardship. (Int 7), indicated that, "*Stadiums are ideal candidates for solar energy integration, as they have ample roof space, parking lots, and open fields that can accommodate solar panels. Moreover, stadiums can benefit from solar energy in terms of cost savings, energy security, and environmental performance*". Additionally, (Int 5) states, "*stadiums can also play a significant role in promoting solar energy awareness and education among the public, especially sports fans, who can be influenced by the actions and values of their favorite teams and players*". Finally, other researches have also identified and introduced benefits similar to the current research [11,70,73,83,94]. Therefore, as the results of the research and also the current research show, the use of solar panels in sports stadiums has many benefits that can reduce the carbon footprint, sustainable development of the environment, and most importantly, promote the culture of using these types of renewable energies, To have green and clean for the people of the society.

As the last result of the research, during the process of interviewing experts to provide solutions for using solar energy in stadiums, some things were stated that can be effective in the development and better use of this type of energy. As (Int 2) states, "*Stadiums usually have large roofs that are often utilized for various purposes like lighting, cameras, and sound systems, beside this applications, stadiums can use this massive and empty place for establishing solar panels. Furthermore, the roof of the parking can be covered with solar panels and the required lighting can be provided by using solar LED lighting*". In general, aside from the discussion of sports stadiums, the use of solar panels in other sports venues can also be widely used, and with a correct environmental assessment, the panels can be installed in suitable locations for use. As mentioned in the obstacles section, the initial cost to implement solar energy projects is very high, but this problem and challenge can be solved with proper consultation and marketing in order to find financial sponsors. In addition to this issue, in order to increase people's awareness and knowledge about renewable energies. it is possible to use the discussion of cooperation between local companies and also to create education and learning among people in the society to increase peoples' information level can be moved towards more use of these types of energies. The previous researches about renewable energies also emphasize the issue of awareness and knowledge in the field of development of these kinds of energies.

6. Conclusion

In order to promote and expand renewable energy in sports venues, our research helped us understand the advantages and disadvantages of solar panels in sports stadiums from the perspective of specialists. As a result, we were able to develop eight practical solutions. Beyond the residential and commercial sectors, solar panels have shown incredible potential in powering sport stadiums and promoting the concept of green sports. By harnessing the sun's energy, these solar panels can provide clean and sustainable electricity to stadiums, resulting in reduced reliance on fossil fuels and helping to cultivate a greener future for the sports industry. In this modern era of heightened environmental consciousness, the integration of solar panels into stadiums not only highlights the importance of sustainability but also serves as a compelling catalyst for promoting green sports and inspiring positive change on a larger scale.

CRediT authorship contribution statement

Saeed Soltani: Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Shayan Sharafi Laleh:** Writing – review & editing, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Ali Safarpour:** Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

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

Appendix 1. Research interview questions (with experts)

1	What do you think about the specific benefits of using solar energy in sport stadiums?
2	What are the challenges and barriers of utilizing solar energy in stadiums?
3	What is your opinion regarding the provision of operational solutions in this field according to all the conditions raised?
4	Are there any prohibiting or facilitating laws in this regard?
5	Have you ever participated in a solar energy project?
6	What is the real consequences of using solar panels in sport section?
7	What is the most challenging side of the using and implementing solar panels in sport stadiums?
8	Are sport industry and facilities have the potential to use renewable energies (especially solar energy)?
9	What is your experiences with projects about solar energy in sport facilities (benefits and technology)?

Data availability

The authors do not have permission to share data.

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