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Review

The Impact of Stadiums on Carbon Emissions: A Systematic Review

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Abstract

As the global climate change problem becomes increasingly serious, the United Nations has pushed countries to achieve the Carbon Neutrality (CN) goal through the Paris Agreement. In this context, the rapid expansion of the sports market and the increase in sports events have brought about an increase in the demand for stadiums, but high carbon emissions also accompany the construction and operation of stadiums. In this paper, we explore the carbon emissions of stadiums through a systematic review, focusing on analyzing the carbon emissions of stadiums during construction, operation, and after events. We adopt a five-step approach to screen relevant literature and summarize the main sources of carbon emissions from sports stadiums and the measures to manage them. The study shows that carbon emissions from sports venues mainly come from the maintenance of sports turf, energy consumption (e.g., heating, lighting, air conditioning, etc.), and building materials. In addition, some new technologies, such as building-integrated photovoltaic (BiPV) systems and fuel cell technology (PAFC), have shown better application prospects in reducing carbon emissions. Although the carbon emissions of sports stadiums are small compared to industrial emissions, the issue of carbon emissions still needs to attract sufficient attention as the construction of sports stadiums continues to increase. The paper also points out that current research is mostly focused on the fields of environmental science and architecture and that interdisciplinary research should be strengthened in the future, especially considering the differences in carbon emissions from stadiums in different regions and combining disciplines such as economics and public health to provide a more comprehensive perspective. Finally, this paper suggests that policymakers, stadium operators, and architects should work together to adopt measures such as carbon offset policies, green building materials, and optimized energy management to promote stadiums' sustainable development.

Keywords: stadiums, carbon emissions, GHG, carbon offset

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Introduction

In recent years, the world has been suffering from the effects of climate change. To a certain extent, it affects the temperature [1], precipitation [2], humidity [3], air pollution [4], etc., which in turn threatens the life and health of human beings [5-7]. In response to this, the United Nations, to solve the problem of climate warming, by 178 parties, jointly signed The Paris Agreement, the transition towards Carbon Neutrality (CN). It is hoped that the policy will lead to the improvement of environmental protection concepts in each country and that various initiatives will compensate for environmental pollution (interventions in the fields of industry [8-11], agriculture [12, 13], etc.) and mitigate problems such as climate warming [14]. Carbon neutrality, a state of net-zero carbon emissions, can be achieved by balancing the total amount of carbon dioxide or greenhouse gas emissions produced directly or indirectly by a country, company, product, activity, or individual over a certain period via carbon offset or removal initiatives [15]. The goal of carbon neutrality is that the 2.0°C target corresponds to a positive equilibrium of CO_2 emissions (carbon neutrality), and the approximate completion time is about 2070-2080. Greenhouse gas emissions (net zero emissions) should be neutralized around 2080-2090. Carbon neutrality of 1.5°C should be achieved by 2050, and greenhouse gas neutrality should be reached around 2060-2070 [16]. In recent years, the sports market has been further expanding, with more and more sports participants, more and more spectators of sports events [17], and the frequency and quality of sports events at all levels increasing, which ultimately leads to an increase in public demand for stadiums. However, organizing sports events [18, 19] and constructing stadiums [20] will further exacerbate the carbon emission problem. Especially in the case of large-scale sports events such as the Olympic Games [21, 22], the carbon emissions of stadiums have a greater impact on the environment. For example, Ceccon A. et al., after controlling the influence of related factors such as GDP, population, trade, agriculture, and manufacturing, found that the carbon dioxide emissions of the host country would increase significantly both in the two years before the Olympic Games and in the year of the Olympic Games. The research results were consistent in different countries and different periods. And CO_2 emissions will not continue to rise after the Games are over [23]. In this regard, sports event organizers and stadium builders should pay more attention to the issue of stadium carbon emissions and try to implement interventions before, during, and after a sports event to offset the negative impacts of carbon emissions [24].

The environmental impact of stadium construction has been demonstrated [25], and different materials used in stadium construction will also affect the emission of various gasses [26]. The consumption of electrical energy by the various sports equipment types also releases different gasses [20], which ultimately increases the gas emissions of the entire stadium. Stadiums (especially those certified for international sports) host various sports competitions, which can increase the gas emissions of the stadium due to the organization of sports events.

Lack of strict control over gas emissions can lead to a range of environmental hazards. For example, greenhouse gas (GHG) emissions can lead to global warming, rising sea levels, extinction of endangered plants and animals, and increasing the number of refugees [27]. Some scholars predicted carbon emissions through machine learning algorithms [28], Tripartite Evolutionary Game Analysis and Simulation Research [29], and the Markov-Flus model [30]. It can reduce the negative impact caused by GHG emissions. In this regard, the control of GHG emissions should be increased at the source of GHG emissions, and we should pay attention to the carbon emissions from sports activities, in which stadiums, as the main carriers of large-scale sports activities, are innovative and important as the object of research.

Although the impact of stadiums on carbon emissions is extremely limited and cannot have as great an impact on the environment as industrial and agricultural emissions, the construction and dismantling of stadiums will generate many unnecessary carbon emissions. In this regard, in recent years, scholars have paid more attention to the study of the secondary use of stadiums, especially the post-game use of stadiums built for large-scale sports events [31]. According to the mandatory green building certification introduced by the Fédération Internationale de Football Association (FIFA) in 2018 [32], all sports buildings, including stadiums, should implement the connotation of "green sports" to reduce the unnecessary carbon emissions generated by stadiums.

Materials and Methods

We used a systematic review to identify the studies we included in our scope [33]. We then screened the literature using a five-step approach to derive key themes and relevant evidence [34, 35].

1) Define the research questions (RQs).
2) Specify the inclusion criteria for literature.
3) Develop a review protocol and search terms.
4) Remove duplication and check eligibility.
5) Codify screened articles by form, title, article form, and research method.

Step 1: Define the research questions (RQs).

RQ1: Carbon emission channels in stadiums.

RQ2: Stadium carbon management initiatives.

Step 2: Specify the inclusion criteria for the literature.

For the inclusion criteria of literature, we firstly require the literature to include "stadiums" and "carbon emissions" in the title or abstract section and exclude literature on unrelated topics such as disaster environment and atmospheric restoration. For the selection of carbon-related emissions, both total carbon emissions and carbon-related gasses (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)) were included in the study.

Step 3: Develop the review protocol and search terms.

We selected six databases, namely Web of Science, PubMed, EBSCO, Scopus, Willy, and SpringerLink, and to ensure that all the included literature (gray literature) is as complete as possible, we did not set search time, and the default search time is until 28 October 2024. We set the search terms as (Stadium), (Gray literature), and (Stadium). For the literature search formula, we chose the Boolean search method [36] to ensure that the literature search results are more accurate and set the search formula as (Stadium OR sports venue OR sports field OR Sports Complex OR Athletic Field OR Track and Field Venue OR Sports Architecture OR sports building OR Sports Complex Architecture OR Stadium Architecture OR Sports Building Architecture OR Sports and Recreational Facility) and (CO_2 Emissions OR Greenhouse Gas Emissions OR Carbon Footprint OR Carbon Discharge OR Carbon Release OR Carbon Exhaust OR Carbon Emission Level OR Carbon Pollution OR Carbon Output OR Carbon Emission Factor OR CH_4 OR N_2O OR HFCs OR PFCs OR SF_6)

Step 4: Remove duplication and check eligibility.

Two rounds of duplication screening were performed for the selected literature. In the first round of screening, Endnote 20.0 comes with software to check the weight, but after the software screening is completed, the problem of duplication of literature data still occurs in the subsequent collation process. In this regard, we carry out the second round of duplicate screening, screening for manual screening, because all the literature is organized in Endnote for collation, so we first sort according to Year, Journal, and Title Sorting, and manually screen and repeat three times. The above two duplicate screening methods performed deletion.

In addition, we set inclusion and exclusion criteria (see Table 1). 1) because the current research involves less literature on sports venues. In order to ensure the accuracy of the research, we only include sports venues (or related terms) and carbon emissions (or related terms) research, excluding sporting event cycle (or related

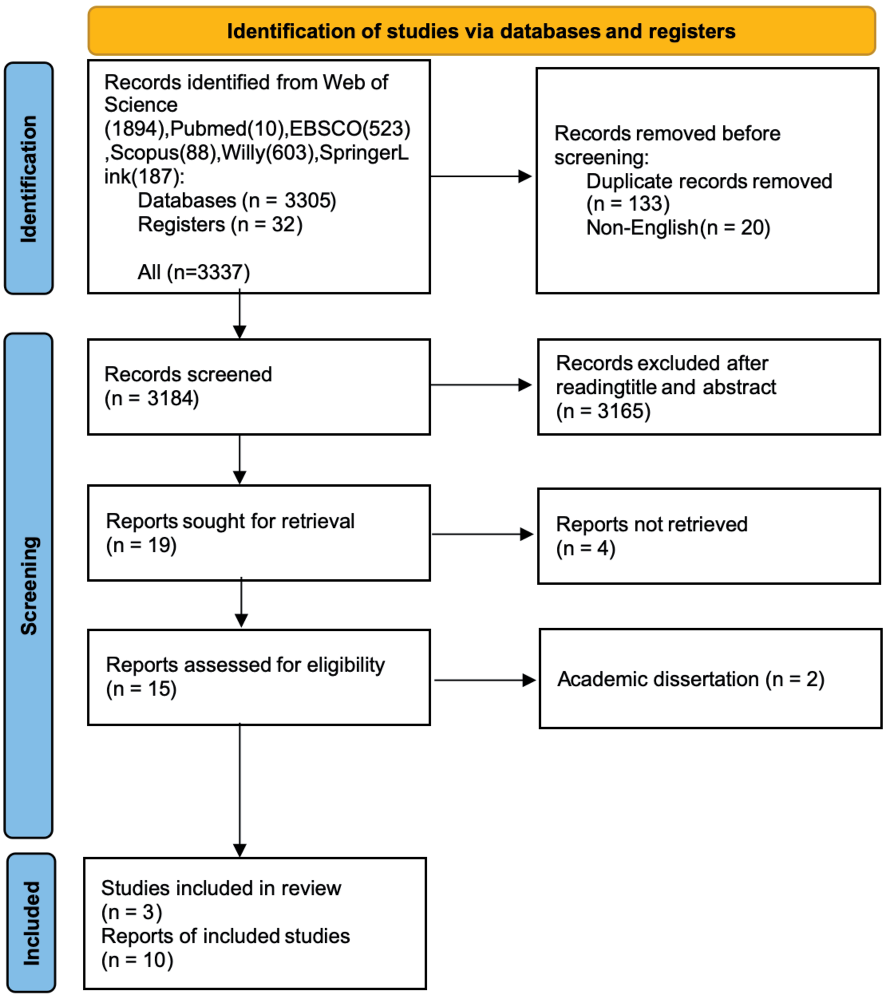

Fig. 1. Literature Screening Flowchart.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Sports venue	Sporting event cycle
Research articles/Reviews	Books/Patents/Academic dissertations
Written in English	Written in other languages

terms) studies, although some of these studies will also be less involved in sports venues, because of the wide range of such studies, we believe that the research is not targeted enough, so we do not include it in the study. 2) We only include research articles and reviews; the reason for including reviews is that we want to find newer ideas in what the previous researchers have said and to make clear the innovativeness and shortcomings of this study. Books, patents, and academic dissertations were not included because we believe there are research results without peer review, which makes it difficult to ensure the quality of the research, and these kinds of research results will be excluded from the study. 3) We required that the literature be written in English, and studies in other languages were excluded from the study. Written in other languages were excluded.

Step 5: Codify screened articles by title, article form, and research method.

Initial categorization of the included literature is done based on the basic characteristics of the article, and a general overview of the included literature is given. This includes the title, article form, and research method. CASP was used to assess the quality of the included articles to ensure they were of high quality.

Results and Discussion

Included Studies

This study is based on a five-step approach to literature screening. The selection process was tight, and six major databases (Web of Science, PubMed, EBSCO, Scopus, Willy, and SpringerLink) were selected to include as many studies as possible that focused on "stadiums" and "carbon emissions". All studies focusing on "stadiums" and "carbon emissions" were included as much as possible. During the search process, the database was searched by (Stadium OR Sports Venue OR Sports Field OR Sports Complex OR Athletic Field OR Track and Field Venue OR Sports Architecture OR Sports Building OR Sports Complex Architecture OR Stadium Architecture OR Sports Building Architecture OR Sports and Recreational Facility) and (CO_2 Emissions OR Greenhouse Gas Emissions OR Carbon Footprint OR Carbon Discharge OR Carbon Release OR Carbon Exhaust OR Carbon Emission Level OR Carbon Pollution OR Carbon Output OR Carbon Emission Factor OR CH_4 OR N_2O OR HFCs OR PFCs OR SF_6) of the Boolean search formula for literature screening, and finally 1894 articles were retrieved from the Web of Science database, respectively. Finally, 1894 articles were retrieved from Web of Science, 10 articles from PubMed, 523 articles from EBSCO, 88 articles from Scopus, 603 articles from Willy, and 187 articles from SpringerLink. A total of 3305 documents were retrieved from the six databases, in addition to 32 documents that were manually retrieved, for a total of 3337 documents. Two rounds of duplicate screening were carried out, the first round using the "Find Duplicates" function

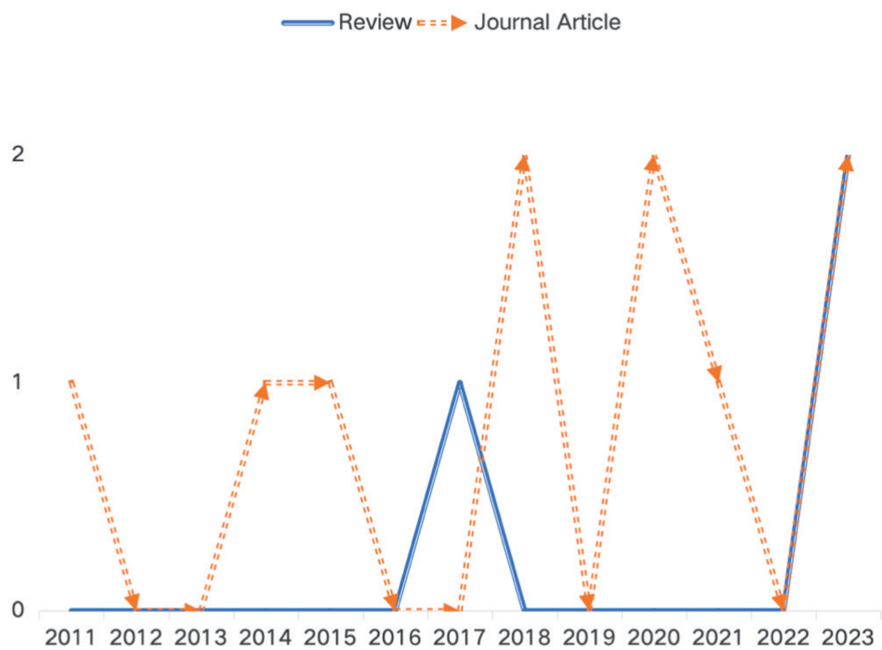

Fig. 2. Review and Journal Article Type and Annual Questions.

in the Library menu of Endnote, and 107 duplicates were finally screened out. In the second round, Jing-Xuan Zhou and Yi-Ning Qin, who have good academic ability and screening experience, completed the manual screening and finally screened out 26 duplicates. Finally, two rounds of duplicate screening were carried out, and 133 duplicate documents were screened out and eliminated. After that, the remaining documents were sorted out again, and all the non-English documents were excluded. Finally, 20 documents were excluded, leaving 3184 documents. After reading the title and abstract, 3165 documents were found to be inconsistent with the research content, and these documents were eliminated again. Most of the excluded studies did not take the impact of sports venues on carbon emissions as the main research object, which is inconsistent with the theme of this study, so they chose to be excluded. If the target literature is included, it will change the research theme of the paper and weaken the impact of sports venues on carbon emissions, which is inconsistent with the research center of the paper. 4 documents were not retrieved in full text, 2 academic dissertations were eliminated, and finally, 13 documents were retained. The results of evaluating the input articles using the CASP tool showed that 70% of the literature was high and 30% was moderate and were ultimately used as target literature for the systematic review (see Table 2). The time period of the final 13 that included literature was 2011-2023 (see Fig. 2).

Review

1) Scientific production on indoor air quality of environments used for physical exercise and sports practice: Bibliometric analysis [37].

This review is valuable to this study. Here, the focus is on describing the association between physical exercise and indoor air quality, with a large number of gas species included. It was found that European environmentalists from 2007-2017 paid more attention to environmental issues and made some contributions.

2) Environmental Sustainability in Stadium Design and Construction: A Systematic Literature Review [38].

This review defines environmental sustainability (ESS) in stadiums and consists of 12 sub-questions in two parts: General Questions on Environmental Sustainability and Environmental Sustainability Areas. It provides a more comprehensive summary of the state of stadium design, construction methods, and the improvement of stadium sustainability. It is believed that most of the research on designing stadiums

Table 2. The Main Characteristics of the Selected Articles: Title, Article Form, Research Method, and Appraised Quality.

Number	Title	Article Form	Research Method	Appraised Quality
1	Scientific production on indoor air quality of environments used for physical exercise and sports practice: Bibliometric analysis [37]	Review	Bibliometric analysis	High
2	Environmental Sustainability in Stadium Design and Construction: A Systematic Literature Review [38]	Review	Systematic Review	Moderate
3	The impact of sports emissions on climate: Measurement, mitigation, and making a difference [35]	Review	Systematic Review	High
4	A model of greenhouse gas emissions from the management of turf on two golf courses [39]	Journal article	Constructing a balance model between plant-soil system sequestration and greenhouse gas emissions in golf course turf management.	High
5	A greenhouse gas assessment of a stadium in Australia [40]	Journal article	Life Cycle Assessment (LCA)	High
6	A pilot study of indoor air quality in screen golf courses [41]	Journal article	Use a variety of gas testing instruments.	Moderate
7	Debating the success of carbon-offsetting projects at sports mega-events. A case from the 2014 FIFA World Cup [42]	Journal article	Theoretical analysis	Moderate
8	Towards Zero Energy Stadiums: The Case Study of the Dacia Arena in Udine, Italy [43]	Journal article	Contrastive analysis	Moderate
9	Investigating alternative development strategies for sports arenas based on active and passive systems [44]	Journal article	Contrastive analysis	High
10	Soil greenhouse gas emissions from Australian sports fields [45]	Journal article	Use a variety of gas testing instruments.	High

11	Feasibility Study and Economic Analysis of a Fuel-Cell-Based CHP System for a Comprehensive Sports Center with an Indoor Swimming Pool [46]	Journal article	Contrastive analysis	High
12	Indoor air quality in a training center used for sports practice [47]	Journal article	Use a variety of gas testing instruments.	High
13	Markers of Chemical and Microbiological Contamination of the Air in the Sport Centers [48]	Journal article	Use a variety of gas testing instruments.	High

and the environment still focuses on energy and material composition.

3) The impacts of sport emissions on climate: Measurement, mitigation, and making a difference [35].

This review mainly encompasses the relationship between sporting activities and carbon emissions, which are currently sourced from (1) carbon emissions and their measurement; (2) emissions control and decarbonization; (3) carbon sinks and offsets; and (4) carbon emissions and their impacts on the environment. The review also provides future perspectives on the shortcomings of the study.

Journal Article

1) A model of greenhouse gas emissions from the management of turf on two golf courses[39].

Recommendations for golf course management and design include reducing nitrogen fertilizer use, improving operational efficiency when mowing, including appropriate tree planting, and scaling component areas to maximize golf course sequestration capacity.

2) A greenhouse gas assessment of a stadium in Australia [40].

The assessment shows that the stadium operation accounted for 72.5% of GHG emissions, with baseload heating, ventilation and cooling, lighting, and refrigeration systems dominating. The best opportunity to reduce GHG emissions is to reduce the need for the continual operation of these systems. Construction impacts account for 24.7% of impacts, while replacement materials and end-of-life management of materials are relatively insignificant, contributing to less than 3% of life cycle GHG emissions.

3) A pilot study of indoor air quality in screened golf courses [41].

The average pollutant concentrations in screened golf courses did not exceed the legal limits, but exceedances were found in some locations. The main sources of pollution were smoking, the use of combustion equipment, building materials, and decorative materials.

4) Debating the success of carbon-offsetting projects at sports mega-events. A case from the 2014 FIFA World Cup [42].

Forestry carbon offsetting projects have potential for sporting new-build venues in terms of achieving SDGs, but their success is influenced by a number of factors, including project design, implementation, and monitoring.

5) Towards Zero Energy Stadiums: The Case Study of the Dacia Arena in Udine, Italy [43].

The study proposes a way to improve Dacia Arenas' energy efficiency by comparing two system layouts. It finds that a system combining photovoltaic (PV) panels and heat pumps, as well as a system with PV panels, a biomass unit, and an absorption chiller, effectively reduces operational emissions and has environmental advantages.

6) Investigating alternative development strategies for sports arenas based on active and passive systems [44].

Results demonstrated that a highly reflective coating guarantees a lower impact than a BiPV plant in terms of economics and permits paying back installing costs in a shorter time interval. When it comes to the environmental analyses, the amount of compensated emissions equals around 100 $kgCO_2$-eq/m^2 for the passive scenario and 1,500 $kgCO_2$-eq/m^2 for the active scenario.

7) Soil greenhouse gas emissions from Australian sports fields [45].

Sports turf is a potential source of GHG emissions, with higher emissions than non-sports turf, mainly due to more intensive fertilization, irrigation, and mowing. In southern Australia, N_2O emissions from sports fields are significantly higher than from non-sports turf, while CH_4 emissions are generally negligible unless the soil is waterlogged. Controlled-release and nitrification inhibitor fertilizers did not reduce N_2O, CH_4, or CO_2 emissions.

8) Feasibility Study and Economic Analysis of a Fuel-Cell-Based CHP System for a Comprehensive Sports Center with an Indoor Swimming Pool [46].

The study designed and analyzed a combined heat and power (CHP) system using waste heat and electricity from a phosphoric acid fuel cell (PAFC) system for an indoor swimming pool building. The results showed that the system can significantly improve the efficiency of energy utilization.

9) Indoor air quality in a training center used for sports practice [47].

The study designed and analyzed a Combined Heat and Power (CHP) system using waste heat and electricity from a Phosphoric Acid Fuel Cell (PAFC) system for an indoor swimming pool building. The results showed that the system can significantly improve the efficiency of energy utilization.

10) Markers of Chemical and Microbiological Contamination of the Air in the Sport Centers [48].

In this study, air pollution indicators, including $PM_{2.5}$, CO_2, formaldehyde, 84 VOCs, airborne microbial population and diversity, and the presence of SARS-CoV-2 on surfaces, were evaluated in Polish fitness centers. The results showed a predominance of $PM_{2.5}$, fluctuating CO_2 concentrations, VOCs dominated by phenol, pinene, and toluene, high bacterial and fungal counts, and a wide range of potentially health-hazardous microorganisms were detected. The SARS-CoV-2 virus was detected on the surfaces of the fitness equipment.

Major Problems of Carbon Emissions from Sports Venues

1) The problem of GHG emissions exists in sports venues involving sports turf.

Sports turf is an important part of sports venues, and there are different requirements for sports turf in some sports, such as golf [39], football [49], rugby, and so on. Sports turf is different from ordinary turf, which has higher requirements for rotational torque, surface hardness, water infiltration rate, and other dimensions [50]. In this regard, the maintenance of sports turf is one of the important aspects of the operation of sports venues. Moreover, because the maintenance process requires various fertilizers for turf maintenance [51], it also causes high GHG emissions.

Bartlett M.D. and James I.T. concluded that GHG emissions from golf courses originate from the grounds maintenance process, especially using nitrogen fertilizers [39]. Riches D. et al. found that N_2O emissions from sports turf were higher than those from non-sports turf or open spaces [45]. Therefore, GHG emissions are higher for sports that require turf maintenance.

2) The problem of high carbon emissions caused by heating and lighting in sports venues exists.

Electricity consumption continues to be the main cause of carbon emissions in sports stadiums. The carbon emissions caused by electricity consumption are particularly serious for sports that require specific temperatures [20]. Carbon emissions from stadiums also vary in different seasons, increasing in winter or summer when the temperature of the stadium needs to be kept within the appropriate range.

Hedayati M. et al. suggest that the operation of stadiums is the main cause of GHG emissions, accounting for 72.5% of the total emissions, with heating, cooling, lighting, etc., resulting in a significant use of electricity [40]. Manni M. et al. suggest that applying innovative electric power systems can be an effective solution to the problem of carbon emissions from lighting, heating, and other purposes [43]. Carbon emissions from swimming pool heating have also been mentioned [46].

3) The current indoor stadiums have problems with carbon emissions and greenhouse gas emissions exceeding the standards.

Indoor sports venues are an important component of sports venues. Along with the rise of screen golf, indoor baseball, and other programs, the location of sports participation is no longer limited to event venues but is changing towards more innovative and playable sports activities. However, because the space is relatively closed, there is a large gap between indoor and outdoor air quality. In this regard, indoor stadiums currently suffer from carbon emissions and excessive greenhouse gas emissions.

Because indoor stadiums are partially poorly ventilated, serious air pollution occurs due to factors such as smoking and combustion, and in some stadiums, there are also problems such as excessive carbon emissions [41], and indoor CO_2 levels basically exceed outdoor CO_2 levels at all times [47]. Szulc J. et al. suggested that the monitoring proposal for the assessment of the air quality at a sports center includes total particle concentration with the $PM_{2.5}$ fraction, and the CO_2 assessment of the air quality at a sports center includes total particle assessment [48].

4) Stadium building materials as one of the carbon emission factors.

The green development of stadium building materials has become an important global issue [52, 53]. However, due to the increasing public demand for sports events, the frequency of stadium construction is increasing, especially for the high quality of large-scale sports events; the organizers or the state will build more suitable stadiums [54]. However, the carbon emissions from stadium construction have been neglected, and the materials used in the construction of stadiums are one of the most important factors. Hedayati M. et al. concluded that the construction materials used in the construction of stadiums in Australia have a small impact on carbon emissions, accounting for only 3% of the total emissions [40]. However, the increase in the total number of stadiums has forced us to pay attention to the impact of building materials on carbon emissions.

Carbon Reduction Strategies for Sports Stadiums

1) Carbon offsetting value of forests.

The United Nations Framework Convention on Climate Change highlights the important value of forests for carbon offsetting. As one of the largest carbon sinks on earth, forests absorb a large amount of carbon dioxide (CO_2) through photosynthesis, which helps to reduce the concentration of greenhouse gasses (GHG) in the atmosphere, thus combating global warming. And it has an important offsetting effect on GHGs such as CO_2 released by sports stadiums, which can effectively alleviate problems such as environmental pollution [42].

Improving forest coverage requires the joint efforts of the government and society, and relevant policies should be introduced to support this action. In addition, it is necessary to focus on raising public awareness of environmental protection so that the public can take the initiative to plant trees [55, 56]. This is a long-standing proposal that requires all parties to move forward together. When public awareness of environmental protection is raised, it will enter a virtuous circle and help combat the carbon emission problem of sports venues.

2) New technologies help stadiums reduce carbon emissions.

The invention and application of new technologies will provide more accurate data for the monitoring, prediction, and subsequent management of carbon emissions in stadiums or directly reduce the carbon emissions of stadiums. The application of a building-integrated photovoltaic (BiPV) plant and a cool surface treatment will reduce carbon emissions [44]. Moreover, the application of some new technologies can effectively solve the carbon emissions caused by heating areas in sports stadiums [43]. Liu J. et al. based on the Phosphoric Acid Fuel Cell (PAFC) system to reduce the electricity consumption caused by swimming pool heating, which achieves the goal of energy saving, emission reduction, and economic maximization [46].

However, there are limits to how much new technology can help stadiums reduce carbon emissions. First, the application of new technologies requires early and long-term experiments. Second, the technology needs to be adjusted according to different stadiums, so the large-scale application of new technologies takes a long time. Third, the application of new technologies requires high financial support, which will also affect the application speed of new technologies [57].

3) Use of more environmentally friendly building materials.

Building materials are inseparable from the construction of stadiums, and the carbon emissions of stadiums cannot be separated from the influence of building materials. Although some scholars believe that construction materials do not account for a high proportion of total carbon emissions [40], they do not consider that materials are also indirectly generating carbon emissions in the process of acquisition and processing [9, 58, 59]. Because of the variability in the carbon storage capacity of different materials and their impact on carbon emissions [60], studies have concluded that attention should be paid to using more environmentally friendly building materials, especially those with better carbon storage capacity [61-63].

Due to the high production cost of environmentally friendly building materials at present, using more environmentally friendly building materials in the construction of stadiums will increase the construction cost, resulting in less use of environmentally friendly materials at present [64]. This requires increased environmental awareness and policy constraints.

Conclusions

The construction of stadiums is an important facility to ensure the operation of the sports industry and the public sports and fitness services and is also an important facility base for hosting large-scale sports events. This has led to a gradual increase in demand for stadiums, and the number of stadiums has increased in the context of sports events. The problem of carbon and GHG emissions due to the maintenance of sports turf [65], electricity consumption [44], spectator participation [66], and construction materials [67] has become progressively more serious, and certain measures have to be taken to cope with it.

This study reviews the relationship between sports venues and carbon emissions from an innovative perspective. Existing reviews of the sports environment have paid more attention to the impact of the environment on sports participants [68-70]. The role of sports venues is neglected. We hope that through this review, more scholars will pay attention to the impact of sports venues on carbon emissions and provide more strategies to promote carbon neutrality. Despite the abundance of research on stadiums and carbon emissions, some results and progress have been achieved. However, based on the above review and assessment of the relevant literature, it is believed that the current research is still deficient in some aspects. Subsequent studies should be more systematic from the following perspectives.

1) It is suggested that interdisciplinary research should be strengthened. Current research focuses on environmental sciences and architecture, and the lack of participation from economics, public health, and other disciplines will limit the comprehensive perspective of the impact of stadiums on carbon emissions. Strengthening interdisciplinary research makes it easier to generate innovative ideas and provide new ideas for solving the problem of excessive carbon emissions generated by sports venues [71]. Such a move is relatively easy to implement and does not require excessive financial support. Long-term development can promote the development of sports ecology and provide more disciplinary suggestions for the subsequent construction of sports venues.

2) It is recommended that the relationship between stadiums and carbon emissions in different countries and regions be considered. Current research mainly focuses on the better-developed countries and neglects the construction of stadiums in backward regions. Different countries and regions still have different usage rates and degrees of stadiums.

3) It is suggested that the role of new technologies in different stadium sizes be considered. Although new technologies or systems such as building-integrated photovoltaics (BiPV) [44] and Phosphoric Acid Fuel Cell (PAFC) [46] have been applied to the construction and operation of stadiums, the differences in stadium sizes and the carbon emissions of stadiums with different

sports have not been considered. Therefore, future research should be more systematic.

Therefore, future research should be more systematic from the above perspectives in order to comprehensively assess the environmental impacts of stadiums and develop effective mitigation strategies. In addition, policymakers, stadium operators, and architects should work together, and governments should introduce specific policies to reduce the carbon emissions of local stadiums according to their carbon emissions and the extent of their impact on the local environment. Stadium operators should optimize energy management and cultivate environmental awareness among relevant personnel. Architects should promote using environmentally friendly materials in the design and construction phase of stadiums. Finally, realize the sustainable development of the stadium.

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Conflict of Interest

The authors declare no conflict of interest.

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