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Green Operations in Sports Facilities: A Review of Technological Implementation

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A B S T R A C T

The increasing demand for sustainability in sports facilities has driven the adoption of green technologies aimed at reducing energy consumption, water usage, and waste generation. These technologies not only contribute to environmental conservation but also improve operational efficiency and reduce long-term costs for facility management. This article reviews the implementation of green technologies in sports facilities and assesses their impact on operational efficiency and sustainability. A comprehensive review of existing literature was conducted, focusing on renewable energy technologies, smart energy management systems, water conservation technologies, waste management innovations, and the use of sustainable materials in the construction and retrofitting of sports facilities. The review also explores the economic, technological, and operational challenges that affect the adoption of these technologies, as well as potential future directions for innovation and policy support. Green technologies, such as solar panels, smart HVAC systems, rainwater harvesting, and waste-to-energy solutions, have been shown to significantly reduce energy and water consumption while minimizing waste output. Despite the high initial costs, the long-term financial savings from reduced utility bills and maintenance costs make these technologies a valuable investment for sports facilities. However, barriers such as the high cost of installation, technological limitations in certain regions, and operational resistance present challenges to widespread adoption. The article highlights the importance of adopting green technologies in sports facilities to achieve both sustainability and operational efficiency. It calls for more research on scalable solutions and policy initiatives to encourage broader implementation, emphasizing the need for collaboration between facility managers, policymakers, and technology providers.

Keywords: *Green technologies, sports facilities, sustainability, operational efficiency*.

1. Introduction

The environmental impact of sports facilities is significant, as they consume large amounts of energy, water, and other resources to maintain operations. Moreover, these facilities generate substantial waste, including solid waste from events, carbon emissions from energy usage, and air pollution from transportation to and from venues. Sports events often serve as microcosms of broader societal behaviors, where excessive consumption and resource wastefulness are evident, particularly in major global events such as the Olympics and World Cup. This extends to the facilities themselves, which are often built or expanded to host these events, leading to increased environmental stress on local ecosystems (Ahmadvand & Azad, 2019; Chang, 2024).

The environmental footprint of sports facilities is compounded by the large crowds they attract. These venues

must provide for the comfort and safety of thousands or even tens of thousands of spectators, leading to increased demand for energy, water, and transportation. For instance, energy consumption for lighting, heating, ventilation, and air conditioning (HVAC) systems, especially in indoor arenas, is a primary concern. Extensive use of energy in managing these large facilities contributes significantly to carbon emissions, further exacerbating environmental challenges (Elnour et al., 2022). Moreover, these venues generate waste through concession stands, merchandise sales, and the sheer volume of single-use plastics and packaging. Waste management is a critical issue for these facilities, as poorly managed waste systems can lead to pollution and environmental degradation, particularly in urban areas (Huong et al., 2021).

In light of these challenges, the concept of green operations has emerged as a pivotal solution for mitigating the environmental impact of sports facilities. Green operations refer to the integration of environmentally friendly practices and technologies that reduce resource consumption, minimize waste, and enhance the overall sustainability of facility operations. Implementing green operations in sports facilities involves adopting technologies and strategies that focus on energy efficiency, water conservation, waste management, and the use of sustainable materials. By reducing the environmental footprint of these venues, green operations not only contribute to environmental protection but also enhance the economic viability of sports facilities by lowering operational costs in the long term (Yu, 2023; Yu & Ramanathan, 2014).

One of the key aspects of green operations is energy efficiency, which involves the use of renewable energy sources, such as solar and wind power, as well as energy-efficient technologies like LED lighting and smart HVAC systems. Energy efficiency in sports facilities can significantly reduce carbon emissions and energy consumption, leading to more sustainable operations. For example, the adoption of solar panels and energy storage systems in stadiums has shown promising results in reducing reliance on traditional energy grids and lowering operational costs (Karimi et al., 2020). Additionally, smart energy management systems that monitor and optimize energy usage can help facility managers identify areas for improvement and further reduce consumption (Mugoni et al., 2023).

Water conservation is another critical component of green operations in sports facilities. Given the extensive water use in maintaining sports fields, pools, and general facility operations, technologies such as rainwater harvesting systems, low-flow fixtures, and water recycling systems can play a crucial role in reducing water consumption. These systems help facilities use water more efficiently, which is particularly important in regions facing water scarcity (Ghafouri et al., 2019). In addition to reducing water use, these technologies can lower operational costs and contribute to the overall sustainability of the facility.

Waste management is also a vital consideration in the implementation of green operations. Sports facilities generate large amounts of waste, much of which can be diverted from landfills through recycling and composting programs. Advanced waste management technologies, such as automated sorting systems and waste-to-energy solutions, can help facilities reduce their environmental impact while also generating energy from waste materials. Moreover, the use of biodegradable and recyclable materials in packaging and concessions can further enhance waste reduction efforts (Rahmani et al., 2024). Implementing effective waste management systems is essential for minimizing the environmental footprint of sports facilities and promoting sustainability.

Sustainable materials also play a significant role in green operations, particularly in the construction and renovation of sports facilities. The use of eco-friendly building materials, such as recycled steel, bamboo, and low-emission concrete, can reduce the environmental impact of construction projects. Additionally, retrofitting existing facilities with sustainable materials can improve energy efficiency and reduce long-term maintenance costs (Alsarve, 2024). These materials not only contribute to environmental sustainability but also align with broader trends in green building practices, which emphasize the use of materials that are both durable and environmentally responsible.

The shift toward green operations in sports facilities is not without its challenges. One of the primary barriers to adopting sustainable practices is the high initial cost of implementing green technologies. Many sports facilities, particularly those in smaller markets, may lack the financial resources to invest in solar panels, advanced HVAC systems, or water recycling technologies. However, despite the upfront costs, these technologies often lead to significant long-term savings through reduced energy and water bills, lower waste disposal costs, and decreased maintenance expenses. Moreover, government incentives,

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grants, and partnerships with private companies can help offset the initial investment and make green technologies more accessible to a broader range of facilities (Heidari Fard & Sharifian, 2017).

Another challenge is the need for education and training among facility managers and staff. Implementing green operations requires a thorough understanding of the technologies involved and the ability to monitor and optimize their performance. Facility managers must be equipped with the knowledge and skills to operate these systems effectively, which often necessitates ongoing training and support. Additionally, there is a need for greater awareness among fans and stakeholders regarding the importance of sustainability in sports. Engaging fans through sustainability initiatives, such as recycling programs or energy conservation campaigns, can help build support for green operations and encourage broader adoption (Azimi Delarestaghi et al., 2019).

The significance of adopting green operations in sports facilities extends beyond environmental benefits. From a facility management perspective, implementing sustainable practices can enhance the overall efficiency and profitability of operations. For instance, energy-efficient technologies and water conservation measures can reduce utility costs, while waste management systems can lower disposal expenses. These cost savings, combined with the potential for government incentives and increased fan engagement, make green operations a financially viable option for sports facilities (Mohamed et al., 2023). Additionally, embracing sustainability can improve the reputation of sports organizations, as fans and stakeholders increasingly expect venues to operate in an environmentally responsible manner.

From the perspective of sports organizations, green operations align with broader trends in corporate social responsibility (CSR). Many sports organizations have adopted CSR initiatives that emphasize environmental sustainability as a core component of their mission (Almahrog et al., 2018; Irigaray, 2024; Sulaeman, 2024; Suryani, 2024; Wahdi, 2024). By incorporating green operations into their facilities, these organizations can demonstrate their commitment to sustainability and contribute to positive social and environmental outcomes. This alignment with CSR goals not only benefits the environment but also enhances the brand image of sports organizations, helping them attract environmentally conscious fans and sponsors (Varmus, Kubina, et al., 2023; Varmus, Mičiak, et al., 2023).

Furthermore, the shift toward green operations in sports facilities can contribute to broader sustainability efforts at the community and societal levels. Many sports facilities serve as focal points for their communities, hosting events that draw large crowds and generate significant economic activity (Zhang, 2023). By adopting sustainable practices, these facilities can set a positive example for other industries and help promote a culture of environmental responsibility. Additionally, green operations can help sports facilities contribute to local sustainability goals, such as reducing greenhouse gas emissions or conserving water resources (Naderian Jahormi et al., 2018). In summary, the purpose of this review is to examine the technological implementations for green operations in sports facilities.

2. Methods and Materials

2.1. Study Design

The narrative review method, which is based on descriptive analysis, was employed to gather, synthesize, and analyze relevant academic and industry-based sources.

2.2. Data Collection

The data for this study was sourced from a range of peer-reviewed journal articles, industry reports, case studies, and government publications. A systematic search was performed across several online databases, including Google Scholar, ScienceDirect, and Wiley Online Library, to ensure coverage of both academic and practical perspectives on green technologies in sports facilities. Keywords such as "green operations in sports," "sustainability in sports facilities," "technological implementation for sustainability," and "environmental management in stadiums" were used to locate relevant literature. The selection process focused on publications from the last decade (2013–2024) to ensure that the study reflects recent technological advances and current industry practices. However, foundational works in sustainability and sports operations from earlier years were also included when they contributed to an understanding of the field's evolution.

2.3. Inclusion and Exclusion Criteria

For the selection of materials, specific inclusion and exclusion criteria were applied to filter the most relevant sources. The review focused on studies and reports that examined the implementation of technologies specifically

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designed to improve environmental sustainability in sports facilities. This included technologies aimed at energy efficiency, water conservation, waste management, air quality improvement, and sustainable materials usage. Sources that offered quantitative assessments of the impact of such technologies, such as reductions in energy consumption or waste production, were prioritized. Case studies of real-world implementations were also given particular importance for their practical insights.

Conversely, materials were excluded if they solely focused on general sustainability topics without direct reference to sports facilities or technological implementations. Additionally, papers that focused on small-scale sports activities, such as community sports centers, without broader applicability to large-scale facilities like stadiums and arenas, were excluded to maintain a focus on significant technological interventions.

2.4. Descriptive Analysis Method

A descriptive analysis approach was adopted to systematically review and synthesize the findings from the selected literature. This method allowed for an in-depth examination of how different technological solutions have been implemented across various sports facilities, highlighting trends, challenges, and opportunities. Descriptive analysis was used to categorize the technologies into distinct areas such as energy efficiency, water conservation, waste management, air quality control, and the use of sustainable materials. The aim was to identify the most effective technologies, the context of their implementation, and the resulting environmental and operational impacts.

The narrative review method provided flexibility in interpreting the diverse range of sources, including both quantitative data (such as reductions in carbon emissions or water usage) and qualitative insights (such as operational challenges and stakeholder perceptions). By avoiding statistical meta-analysis, the review remained broad and comprehensive, capturing the multifaceted nature of green technology in sports operations.

2.5. Data Synthesis and Presentation

The final stage of the methodology involved synthesizing the data from the various sources. Key themes and technological categories were identified through thematic coding, which helped organize the literature into coherent sections. Case studies were used as illustrative examples to demonstrate the real-world application of green technologies in sports facilities. Where available, numerical data such as energy savings, cost reductions, and environmental impact metrics were incorporated to provide concrete evidence of the technologies' effectiveness.

In presenting the findings, emphasis was placed on drawing connections between technological innovations and their impact on both environmental sustainability and the operational efficiency of sports facilities. Challenges and limitations encountered in the implementation of these technologies were also critically analyzed, providing a balanced view of the current state of green operations in sports.

3. Literature Review

Sustainability in sports facilities has become an increasingly important topic within the broader context of environmental sustainability and corporate social responsibility. As public awareness of climate change and resource depletion continues to grow, sports organizations and facility managers face growing pressure to minimize their environmental footprint. Historically, sports facilities have been significant consumers of energy and water, as well as major contributors to waste generation. The literature highlights that this environmental impact extends beyond the direct operation of the facilities, as events held in these venues often attract large crowds, requiring additional resources for transportation, food services, and waste management. Research has consistently emphasized the importance of integrating sustainability into the design, construction, and operation of sports facilities to reduce their environmental impact and ensure long-term viability. This shift toward sustainable practices reflects not only an environmental imperative but also an economic and reputational necessity for sports organizations (Karimi et al., 2023).

One key area in the literature is the discussion of sustainability frameworks that guide the development of green operations in sports facilities. These frameworks often focus on reducing energy consumption, minimizing water use, and improving waste management practices. A growing body of research has explored the benefits of integrating renewable energy sources, such as solar panels and wind turbines, into the energy systems of sports facilities. This approach reduces reliance on fossil fuels and lowers greenhouse gas emissions. The implementation of energy-efficient technologies, such as LED lighting and

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smart HVAC systems, is also widely discussed in the literature. Studies show that these technologies not only reduce energy consumption but also offer significant cost savings in the long term (Yu, 2023; Yu & Ramanathan, 2014). Water conservation measures, including rainwater harvesting systems and water recycling technologies, have been identified as critical components of sustainable facility operations. These systems are particularly important in regions facing water scarcity, where the efficient use of water resources is essential for maintaining operations while minimizing environmental impact (Ghafouri et al., 2019).

In addition to energy and water conservation, the literature emphasizes the importance of sustainable waste management practices. Sports facilities generate large amounts of waste during events, including plastic, paper, and food waste. Implementing recycling and composting programs can significantly reduce the volume of waste sent to landfills. Recent studies have also explored the potential of waste-to-energy technologies, which convert organic waste into energy that can be used to power facility operations (Rahmani et al., 2024). These technologies offer a dual benefit of reducing waste and generating renewable energy. Moreover, the use of biodegradable and recyclable materials in concession stands and merchandise sales further supports sustainability goals by reducing the environmental impact of packaging and single-use plastics (Alsarve, 2024). The literature underscores the growing importance of adopting a comprehensive approach to sustainability that encompasses energy, water, and waste management.

Technological advancements have been instrumental in driving the shift toward greener operations in sports facilities. The literature reveals a variety of emerging technologies that have transformed how sports facilities operate, with a particular focus on reducing resource consumption and improving operational efficiency. One of the most notable trends in recent years is the increasing use of smart technologies, such as building automation systems (BAS) and energy management platforms, which enable facility managers to monitor and control energy usage in real time. These systems use sensors and artificial intelligence to optimize energy consumption, reducing waste and lowering costs. For example, smart HVAC systems can adjust heating and cooling levels based on occupancy and weather conditions, ensuring that energy is used efficiently without compromising comfort (Elnour et al., 2022). Studies have shown that the implementation of smart technologies in sports facilities can lead to significant reductions in energy consumption and operational costs, making them an attractive option for facility managers seeking to enhance sustainability.

In addition to energy management, advancements in water conservation technologies have played a crucial role in promoting sustainability in sports facilities. The literature highlights the increasing adoption of rainwater harvesting systems, which collect and store rainwater for use in irrigation, toilet flushing, and cooling systems. These systems reduce the demand for potable water and help sports facilities manage water resources more efficiently, particularly in areas prone to drought. Water recycling technologies, such as greywater systems, are also becoming more common in sports facilities. These systems treat and reuse wastewater for non-potable purposes, further reducing water consumption and supporting sustainability goals (Ghafouri et al., 2019). As water scarcity becomes an increasingly pressing issue in many parts of the world, the adoption of these technologies is likely to grow in the coming years.

Another technological advancement driving green operations in sports facilities is the use of renewable energy sources. Solar panels and wind turbines are being integrated into the energy systems of sports venues, reducing reliance on traditional power grids and lowering carbon emissions. Research shows that renewable energy technologies not only provide a sustainable alternative to fossil fuels but also offer significant cost savings over time, particularly as the cost of renewable energy continues to decline (Karimi et al., 2020). Moreover, the installation of energy storage systems, such as batteries, allows sports facilities to store excess energy generated by renewable sources for use during periods of high demand. This enhances the resilience of the facility's energy system and reduces dependence on non-renewable energy sources (Mugoni et al., 2023). The literature suggests that renewable energy technologies will continue to play a central role in the future of green operations in sports facilities.

Despite the clear benefits of adopting green technologies, the literature also highlights several challenges that sports facilities face in implementing these technologies. One of the most commonly cited barriers is the high upfront cost of green technologies, such as solar panels, smart HVAC systems, and water recycling systems. While these technologies offer long-term savings through reduced energy and water bills, the initial investment can

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be prohibitive for many sports facilities, particularly those in smaller markets with limited financial resources (Heidari Fard & Sharifian, 2017). The cost of retrofitting existing facilities with green technologies is also a significant challenge, as older buildings may require substantial upgrades to accommodate new systems. This has led some facility managers to delay or forgo the adoption of green technologies, despite the long-term benefits.

Another challenge identified in the literature is the lack of expertise and training among facility managers and staff. Green technologies, particularly smart systems, require specialized knowledge to operate and maintain effectively. Facility managers must be trained in the use of these technologies, and ongoing support is often necessary to ensure that the systems are functioning optimally. However, many sports facilities lack the resources or infrastructure to provide this training, leading to underutilization of the technologies. Moreover, the complexity of some green technologies can deter facility managers from adopting them, as they may be concerned about the potential for technical issues or system failures (Azimi Delarestaghi et al., 2019). Addressing this knowledge gap is crucial for ensuring the successful implementation of green technologies in sports facilities.

Regulatory and policy challenges also play a role in limiting the adoption of green technologies in sports facilities. The literature points to the lack of standardized regulations governing the environmental performance of sports facilities, particularly in regions where sustainability is not a top priority for policymakers. Without clear regulations or incentives, facility managers may be less motivated to invest in green technologies. However, in regions where government incentives and grants are available, the adoption of green technologies has been more widespread. For example, tax credits and subsidies for renewable energy installations have encouraged many sports facilities to invest in solar panels and wind turbines (Mohamed et al., 2023). The literature suggests that stronger regulatory frameworks and financial incentives are needed to promote the adoption of green technologies on a larger scale.

Cultural and organizational factors also pose challenges to the implementation of green technologies in sports facilities. The literature notes that some sports organizations and facility managers may be resistant to change, particularly if they perceive green technologies as unnecessary or disruptive to existing operations. This resistance may stem from a lack of awareness about the environmental impact of sports facilities or a belief that sustainability is not a priority for the organization's stakeholders. Additionally, some facility managers may be hesitant to adopt green technologies due to concerns about fan reactions, particularly if sustainability initiatives are perceived as inconvenient or costly (Zwane, 2023). Engaging fans and stakeholders in sustainability efforts is critical for overcoming these cultural barriers and building support for green operations in sports facilities.

In conclusion, the literature on sustainability in sports facilities underscores the growing importance of integrating green operations into facility management practices. Technological advancements, including smart systems, renewable energy technologies, and water conservation measures, have made it easier for sports facilities to reduce their environmental impact and improve operational efficiency. However, the adoption of these technologies is not without its challenges. High upfront costs, a lack of expertise and training, and regulatory and cultural barriers have limited the widespread implementation of green technologies in sports facilities. Addressing these challenges will require a concerted effort from sports organizations, facility managers, policymakers, and stakeholders to promote the adoption of green technologies and ensure the long-term sustainability of sports venues (Rostam Zadeh et al., 2019). As the demand for sustainability continues to grow, sports facilities must embrace green operations to meet the expectations of environmentally conscious fans and contribute to broader global sustainability goals.

4. Technological Solutions for Green Operations

In recent years, technological innovations have significantly contributed to the development of green operations in sports facilities. The focus has been on integrating sustainable practices to reduce the environmental impact of these venues, which are often large-scale consumers of energy, water, and other resources. As a result, facility managers and sports organizations have increasingly turned to technologies that enhance energy efficiency, conserve water, improve waste management, ensure better air quality, and utilize sustainable materials in construction and renovation. These technological solutions not only help reduce the environmental footprint of sports facilities but also lead to cost savings and enhanced operational efficiency in the long term.

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Energy efficiency is one of the primary concerns for sports facilities, as they often consume large amounts of electricity for lighting, heating, cooling, and other operations. Renewable energy technologies such as solar panels have become a popular solution for reducing reliance on non-renewable energy sources. Solar panels can be installed on rooftops, parking structures, or nearby land to harness solar energy and convert it into electricity for use within the facility. Many large sports venues have successfully adopted solar power to reduce their carbon emissions and lower energy costs. For example, several football stadiums and arenas have installed solar panels to supplement their energy needs, demonstrating that renewable energy sources can provide reliable power for large facilities. In addition to solar energy, some sports venues have also incorporated wind turbines to generate electricity, further diversifying their renewable energy portfolios (Karimi et al., 2020).

Energy-efficient lighting is another critical aspect of energy management in sports facilities. Traditional lighting systems consume significant amounts of electricity, particularly in stadiums and arenas that require powerful lights for night games and events. The shift to LED lighting, which uses less electricity and has a longer lifespan, has been a major technological advancement in energy efficiency. LED lighting systems not only reduce energy consumption but also provide better illumination, improving visibility for both players and spectators. Moreover, LED lights can be integrated with smart energy management systems that automatically adjust lighting levels based on the time of day, occupancy, and event schedules, further optimizing energy use (Elnour et al., 2022). These smart systems can be programmed to dim or turn off lights when they are not needed, reducing unnecessary energy consumption.

Smart energy management systems have revolutionized how sports facilities monitor and control their energy usage. These systems use sensors and artificial intelligence to track energy consumption in real-time, allowing facility managers to identify inefficiencies and make adjustments to optimize energy use. For example, smart HVAC systems can regulate heating and cooling based on weather conditions and the number of people in the facility. By automatically adjusting temperatures and airflow, these systems ensure that energy is used efficiently without compromising comfort (Yu, 2023; Yu & Ramanathan, 2014). Studies have shown that smart energy management systems can significantly reduce energy consumption and operational costs, making them an attractive investment for sports facilities aiming to improve sustainability.

Water conservation is another essential component of green operations in sports facilities. These venues often use large amounts of water for field maintenance, irrigation, and general operations. Technological advancements in water conservation systems have helped sports facilities reduce their water consumption and manage resources more sustainably. One of the most common water-saving technologies is rainwater harvesting, which involves collecting and storing rainwater for later use. This harvested water can be used for irrigation, cooling systems, and even toilet flushing, reducing the demand for potable water. Rainwater harvesting systems are particularly beneficial for sports facilities in regions facing water scarcity, as they provide a reliable and sustainable water source during dry periods (Ghafouri et al., 2019).

Low-flow fixtures and smart irrigation systems have also played a significant role in reducing water consumption in sports facilities. Low-flow fixtures, such as faucets, showerheads, and toilets, are designed to use less water while maintaining functionality, thereby reducing water usage in restrooms and locker rooms. Similarly, smart irrigation systems use sensors and weather data to determine the optimal amount of water needed for field maintenance, ensuring that water is only used when necessary and preventing over-irrigation. These systems can be programmed to adjust irrigation schedules based on weather conditions, soil moisture levels, and other factors, leading to significant water savings (Alsarve, 2024).

Waste management is a significant challenge for sports facilities, which generate large amounts of waste during events. However, technological innovations have enabled sports venues to implement more effective waste reduction and recycling programs. Many facilities have adopted waste separation technologies that allow for the sorting of recyclable and compostable materials from general waste. Automated sorting systems can separate materials based on their type, ensuring that recyclables and organic waste are properly processed, while reducing the volume of waste sent to landfills (Rahmani et al., 2024). These systems not only improve the efficiency of waste management but also reduce disposal costs and environmental impact.

Composting is another waste management technology that has gained traction in sports facilities. Food waste from concession stands and catering services can be collected and processed into compost, which can then be used to maintain landscaping and fields. Composting programs

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reduce the amount of organic waste sent to landfills while providing a valuable resource for maintaining facility grounds. Some sports facilities have also explored waste-to-energy technologies, which convert organic waste into biogas that can be used to generate electricity or heat (Mugoni et al., 2023). These technologies offer a sustainable solution for managing waste while contributing to the facility's energy needs.

Air quality and ventilation systems have also seen significant improvements in recent years, particularly as indoor air quality has become a growing concern in sports facilities. Traditional HVAC systems can consume large amounts of energy while failing to adequately filter pollutants and allergens from the air. However, advancements in air purification technologies have led to the development of more efficient ventilation systems that improve indoor air quality while reducing energy consumption. High-efficiency particulate air (HEPA) filters and ultraviolet (UV) germicidal irradiation systems are now commonly used in sports facilities to remove contaminants from the air and reduce the spread of airborne diseases (Elnour et al., 2022). These systems are particularly important in indoor arenas and enclosed spaces, where large crowds can lead to poor air quality and increased health risks.

Smart HVAC systems have also been designed to improve air circulation and reduce energy consumption by adjusting ventilation rates based on occupancy and air quality measurements. For example, smart sensors can detect the number of people in a facility and adjust ventilation accordingly, ensuring that fresh air is circulated only when needed. This reduces the energy required to heat or cool the facility while maintaining a comfortable and healthy environment for spectators and athletes. Improved air quality and ventilation systems not only enhance the overall experience for facility users but also contribute to the health and well-being of staff and visitors (Yu, 2023).

The use of sustainable materials in the construction and renovation of sports facilities is another important aspect of green operations. Eco-friendly materials, such as recycled steel, bamboo, and low-emission concrete, are increasingly being used in the construction of new facilities and the retrofitting of existing ones. These materials have a lower environmental impact compared to traditional building materials and contribute to the overall sustainability of the facility. For example, recycled steel can be used in the construction of structural components, while bamboo, a rapidly renewable resource, is often used in flooring and other interior applications (Karimi et al., 2023). Low-emission concrete, which reduces the carbon footprint of construction projects, is another example of how sustainable materials are being integrated into sports facility design.

Retrofitting existing facilities with sustainable materials and technologies is also an important strategy for improving sustainability. Many older sports venues were built before the advent of green building standards and therefore do not meet current environmental performance criteria. Retrofitting these facilities with energy-efficient windows, insulation, and sustainable building materials can significantly reduce energy consumption and improve indoor environmental quality. In addition to improving sustainability, retrofitting can also extend the lifespan of sports facilities and reduce maintenance costs over time (Rostam Zadeh et al., 2019).

In conclusion, technological solutions for green operations in sports facilities have evolved significantly in recent years, providing facility managers and sports organizations with a wide range of tools to reduce their environmental impact and enhance operational efficiency. From renewable energy technologies like solar panels and energy-efficient lighting to water-saving systems such as rainwater harvesting and smart irrigation, these advancements have made it easier for sports facilities to adopt sustainable practices. Innovations in waste management, air quality, and the use of sustainable materials further support the transition to greener operations. Despite the challenges associated with implementing these technologies, such as high upfront costs and the need for specialized knowledge, the long-term benefits in terms of cost savings, environmental protection, and enhanced facility performance make green operations an essential component of modern sports facility management (Varmus, Kubina, et al., 2023; Varmus, Mičiak, et al., 2023). As the demand for sustainability continues to grow, sports facilities will need to embrace these technological solutions to meet the expectations of fans, stakeholders, and policymakers while contributing to global sustainability goals.

5. Impact of Green Technologies on Operational Efficiency

The implementation of green technologies in sports facilities has become an essential strategy for improving operational efficiency and aligning with sustainability goals. One of the primary drivers of this shift is the cost-

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benefit analysis associated with green operations. While the initial investment in technologies such as renewable energy systems, smart energy management, and water conservation technologies may be high, the long-term financial savings are significant. The cost savings come from multiple areas, including reduced energy and water bills, lower maintenance costs, and waste disposal savings. Over time, these benefits often outweigh the upfront expenses, making green technologies a financially viable option for sports facilities, especially those looking to improve both their environmental and economic performance (Heidari Fard & Sharifian, 2017).

A key aspect of the cost-benefit analysis is the reduction in energy costs that comes with the adoption of renewable energy technologies, such as solar panels and wind turbines. Sports facilities, which consume large amounts of energy for lighting, heating, cooling, and other operations, can significantly reduce their reliance on the traditional power grid by generating their own energy through renewable sources. Solar panels, for instance, can be installed on rooftops or adjacent areas to harness solar energy, providing a sustainable and cost-effective power source. The initial cost of installing solar panels can be offset by government incentives, tax credits, and subsidies designed to promote renewable energy adoption. Over time, the energy savings from reduced reliance on the grid lead to significant reductions in operational costs. This is particularly evident in larger venues where energy consumption is a major operational expense (Karimi et al., 2020).

Similarly, smart energy management systems contribute to long-term cost savings by optimizing energy use and reducing waste. These systems monitor and control energy consumption in real-time, allowing facility managers to make adjustments that minimize unnecessary energy use. For example, smart lighting systems can be programmed to turn off or dim lights in unoccupied areas, while smart HVAC systems can regulate heating and cooling based on occupancy and weather conditions. The ability to fine-tune energy usage not only reduces consumption but also lowers utility bills, contributing to overall operational efficiency. Studies have shown that the implementation of smart energy management systems in sports facilities can lead to significant reductions in energy costs, making these systems a valuable investment for facility managers seeking to enhance both sustainability and financial performance (Elnour et al., 2022).

In addition to energy savings, green technologies also offer financial benefits related to water conservation. Water-saving technologies, such as rainwater harvesting systems and low-flow fixtures, help reduce the demand for potable water, leading to lower water bills and reduced strain on local water resources. Rainwater harvesting systems, which collect and store rainwater for use in irrigation, cooling, and toilet flushing, provide a cost-effective solution for managing water consumption in sports facilities. By utilizing rainwater instead of potable water, these systems reduce the facility's reliance on municipal water supplies, leading to significant cost savings, particularly in regions where water is expensive or scarce. Similarly, low-flow fixtures, such as toilets and faucets, reduce water usage in restrooms and locker rooms, further contributing to operational efficiency (Ghafouri et al., 2019). Smart irrigation systems, which adjust watering schedules based on weather conditions and soil moisture levels, also help facilities use water more efficiently, leading to long-term savings.

The environmental benefits of green technologies in sports facilities are equally significant. One of the most important outcomes of adopting green operations is the reduction of the facility's carbon footprint. Sports facilities are large consumers of energy, and by transitioning to renewable energy sources, they can significantly reduce their greenhouse gas emissions. Solar panels, wind turbines, and other renewable energy technologies generate clean energy without the harmful emissions associated with fossil fuels, helping sports facilities contribute to global efforts to combat climate change. The use of renewable energy also reduces the facility's reliance on non-renewable resources, promoting a more sustainable energy future (Rahmani et al., 2024). In addition to reducing emissions, green technologies also lower the facility's overall energy consumption, further reducing its environmental impact.

Waste reduction is another critical environmental benefit of green technologies. Sports facilities generate large amounts of waste during events, including food waste, packaging, and plastic items. Implementing waste reduction technologies, such as automated waste sorting systems and composting programs, helps facilities divert waste from landfills and reduce their environmental footprint. Waste sorting systems can automatically separate recyclables from general waste, ensuring that valuable materials are recovered and reused, while composting programs turn organic waste into nutrient-rich compost that can be used

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for landscaping or field maintenance. These technologies not only reduce the facility's waste output but also support broader sustainability goals by promoting recycling and composting (Alsarve, 2024).

Water conservation technologies also contribute to environmental sustainability by reducing the facility's overall water consumption. Sports facilities, particularly those with large outdoor fields, often require significant amounts of water for irrigation and general operations. Rainwater harvesting systems, low-flow fixtures, and smart irrigation systems help facilities manage water resources more sustainably by reducing the need for potable water and minimizing waste. These technologies are particularly important in regions facing water scarcity, where efficient water use is essential for maintaining operations without depleting local water supplies. By reducing water consumption, sports facilities not only lower their environmental impact but also contribute to the preservation of local ecosystems and water resources (Ghafouri et al., 2019).

In addition to cost savings and environmental benefits, green technologies also improve the overall performance of sports facilities by enhancing operational efficiency. One of the key performance indicators (KPIs) used to evaluate the success of green operations is energy consumption. Facility managers can track energy usage before and after the implementation of green technologies to measure the effectiveness of these interventions. A significant reduction in energy consumption is a clear indicator that the facility's green operations are working as intended, providing both environmental and financial benefits. Other KPIs related to energy efficiency include the percentage of energy generated from renewable sources and the reduction in greenhouse gas emissions. These metrics provide valuable insights into the facility's progress toward sustainability goals (Yu, 2023).

Water usage is another important KPI for evaluating the success of green technologies in sports facilities. Facility managers can monitor water consumption and track reductions achieved through the implementation of water-saving technologies. For example, the volume of water collected through rainwater harvesting systems or the reduction in potable water use from low-flow fixtures can be measured and compared against historical data. These metrics help facility managers assess the effectiveness of their water conservation efforts and identify areas for further improvement. Additionally, monitoring water usage can help facilities comply with local regulations and water conservation initiatives, further enhancing their environmental performance (Huong et al., 2021).

Waste reduction is also a critical KPI for green operations in sports facilities. By tracking the amount of waste generated and the percentage of waste diverted from landfills through recycling and composting programs, facility managers can evaluate the effectiveness of their waste management strategies. A significant reduction in waste output, coupled with an increase in recycling rates, indicates that the facility's waste management systems are functioning efficiently. These metrics are not only important for measuring environmental performance but also for identifying cost savings related to waste disposal. Facilities that successfully reduce waste output often see lower disposal fees and improved operational efficiency (Rahmani et al., 2024).

In addition to energy, water, and waste-related KPIs, sports facilities can also measure the success of their green operations by assessing overall resource consumption. Reducing the consumption of non-renewable resources, such as fossil fuels and potable water, is a key goal of green technologies. By tracking resource consumption over time, facility managers can determine whether their green initiatives are leading to more sustainable operations. For example, a facility that reduces its reliance on fossil fuels by transitioning to renewable energy sources can track the percentage of energy generated from these sources as a performance metric. Similarly, reducing the use of single-use plastics and other non-renewable materials can be measured through procurement and waste management data (Mugoni et al., 2023).

Another important KPI for evaluating green operations is maintenance costs. Green technologies, particularly those related to energy efficiency and water conservation, often lead to lower maintenance costs over time. For example, LED lighting systems have a longer lifespan and require less maintenance than traditional lighting systems, while smart HVAC systems reduce wear and tear on heating and cooling equipment by optimizing usage. By tracking maintenance costs before and after the implementation of green technologies, facility managers can assess the financial benefits of their sustainability initiatives. Lower maintenance costs are a clear indicator that the facility's green technologies are improving operational efficiency (Elnour et al., 2022).

In conclusion, the impact of green technologies on operational efficiency in sports facilities is multifaceted, encompassing financial savings, environmental benefits,

AITBSS AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

and improved performance metrics. Through cost-benefit analysis, it becomes clear that the long-term financial savings from green operations often outweigh the initial investment, particularly in areas such as energy and water consumption. The environmental benefits of reducing carbon emissions, waste output, and resource consumption are equally significant, contributing to global sustainability goals and enhancing the reputation of sports facilities as responsible stewards of the environment. Performance metrics, such as energy consumption, water usage, waste reduction, and maintenance costs, provide valuable insights into the success of green operations, allowing facility managers to track progress and identify areas for further improvement. As the demand for sustainability continues to grow, sports facilities will need to embrace green technologies to remain competitive and aligned with the expectations of fans, stakeholders, and policymakers (Zwane, 2023).

6. Impact of Green Technologies on Operational Efficiency

The adoption of green technologies in sports facilities has become essential not only for improving environmental sustainability but also for enhancing operational efficiency. As energy consumption, water usage, and waste generation have traditionally been high in these large-scale venues, the shift towards green operations is increasingly recognized for its potential to deliver significant cost savings and environmental benefits. By examining the cost-benefit analysis, environmental impact, and performance metrics associated with green technologies, the overall impact on operational efficiency can be clearly understood.

One of the key drivers behind the adoption of green technologies in sports facilities is the long-term financial savings they offer. Although the upfront costs of implementing renewable energy systems, smart energy management platforms, and water conservation technologies can be substantial, these investments often lead to notable reductions in operational costs over time. A key example is the installation of solar panels in sports facilities. Solar energy provides a renewable, low-cost alternative to traditional electricity sources, significantly reducing a facility's dependency on the power grid. Over the long term, solar panels can dramatically lower energy bills, particularly for large stadiums and arenas that require constant energy for lighting, heating, cooling, and ventilation systems (Karimi et al., 2020). The cost savings from using renewable energy can be further enhanced by government incentives and tax credits, which encourage the adoption of green technologies in sports facilities.

Similarly, smart energy management systems contribute to operational efficiency by optimizing energy usage and eliminating waste. These systems use advanced sensors and artificial intelligence to monitor energy consumption in real-time, allowing facility managers to identify inefficiencies and make adjustments as needed. For instance, smart lighting systems can be programmed to adjust lighting levels based on occupancy or daylight availability, ensuring that energy is used only when necessary. This reduces energy consumption and, consequently, operational costs. In some cases, smart energy systems can even predict energy needs based on historical data, allowing facilities to further optimize their energy usage (Elnour et al., 2022). Over time, the savings generated from these systems can outweigh the initial investment, making them a valuable asset for facilities striving to enhance both sustainability and financial performance.

Water conservation technologies also play a crucial role in improving operational efficiency and reducing costs. Sports facilities typically consume large amounts of water, particularly those with fields or large landscaping areas. The implementation of water-saving technologies such as rainwater harvesting systems and low-flow fixtures can significantly reduce water consumption and, by extension, water bills. Rainwater harvesting systems collect and store rainwater for non-potable uses such as irrigation and cooling, providing an alternative to using potable water. This is especially beneficial for facilities located in regions facing water scarcity, where the cost of water is high. Similarly, low-flow fixtures reduce water usage in restrooms and locker rooms without compromising functionality. These technologies help facilities manage their water resources more efficiently, leading to long-term financial savings (Ghafouri et al., 2019).

In addition to financial benefits, green technologies offer substantial environmental advantages by reducing the carbon footprint, waste output, and overall resource consumption of sports facilities. One of the most significant environmental benefits comes from the use of renewable energy sources such as solar panels and wind turbines. These technologies generate clean energy that does not produce the greenhouse gas emissions associated with fossil fuels, thereby helping to combat climate change. As sports facilities are often large consumers of energy, the transition to renewable energy can have a profound impact

AITBSS AI and Tech in Behavioral and Social Sciences E-ISSN: 3041-9433

on reducing the carbon footprint of these venues (Rahmani et al., 2024). Moreover, the use of renewable energy reduces the facility's reliance on non-renewable resources, contributing to a more sustainable energy landscape.

Waste reduction is another important environmental benefit of green technologies in sports facilities. These venues generate large amounts of waste during events, including food waste, plastic packaging, and paper products. By implementing advanced waste management technologies such as automated sorting systems and composting programs, sports facilities can divert a significant portion of this waste from landfills. Automated sorting systems use sensors to separate recyclables from general waste, ensuring that valuable materials such as paper, plastic, and metal are properly recycled. Composting programs, meanwhile, turn organic waste into nutrient-rich compost that can be used for landscaping or field maintenance, further reducing the environmental impact of the facility's operations (Alsarve, 2024). These technologies not only reduce waste output but also promote recycling and composting, helping facilities align with broader sustainability goals.

Water conservation technologies also contribute to environmental sustainability by reducing the overall water consumption of sports facilities. By using rainwater harvesting systems, low-flow fixtures, and smart irrigation technologies, facilities can minimize their reliance on potable water and reduce strain on local water resources. This is particularly important in regions that face frequent droughts or water shortages. Smart irrigation systems, which use weather data and soil moisture sensors to determine the optimal watering schedule, prevent over-irrigation and reduce water waste. These systems can also be programmed to adjust watering times based on weather conditions, ensuring that water is used only when necessary (Ghafouri et al., 2019). By reducing water consumption, these technologies help preserve local water supplies and contribute to the facility's overall environmental sustainability.

To evaluate the success of green operations, sports facilities use a range of performance metrics that provide valuable insights into the effectiveness of their sustainability initiatives. One of the most important performance metrics is energy consumption. By tracking energy usage before and after the implementation of green technologies, facility managers can assess the impact of renewable energy systems and smart energy management platforms on reducing energy consumption. A significant reduction in energy usage is a clear indicator that the facility's green technologies are improving operational efficiency. In addition to total energy consumption, other energy-related metrics include the percentage of energy generated from renewable sources and the facility's carbon emissions. These metrics allow facility managers to monitor progress toward sustainability goals and identify areas for further improvement (Yu, 2023).

Water usage is another critical performance metric for evaluating the success of green operations. Facilities can track water consumption over time and measure reductions achieved through the implementation of water-saving technologies. Metrics such as the volume of water collected through rainwater harvesting systems, the reduction in potable water usage from low-flow fixtures, and the efficiency of smart irrigation systems provide valuable data on the facility's water conservation efforts. These metrics not only demonstrate the effectiveness of the facility's green technologies but also help managers identify opportunities for further improvements in water management (Huong et al., 2021). Monitoring water usage is particularly important in regions with strict water conservation regulations, as compliance with these regulations is often tied to operational efficiency.

Waste reduction is also an important KPI for evaluating the impact of green technologies in sports facilities. By tracking the total amount of waste generated and the percentage of waste diverted from landfills through recycling and composting programs, facilities can assess the effectiveness of their waste management strategies. A significant reduction in waste output, coupled with an increase in recycling and composting rates, indicates that the facility's green technologies are functioning as intended. These metrics are not only important for demonstrating environmental performance but also for identifying cost savings related to waste disposal. Facilities that successfully reduce waste output can often lower their disposal fees and improve overall operational efficiency (Rahmani et al., 2024).

Resource consumption is another key performance metric that facilities use to evaluate the success of their green operations. Reducing the consumption of non-renewable resources, such as fossil fuels and potable water, is a central goal of green technologies. By tracking resource consumption before and after the implementation of green technologies, facilities can determine whether their sustainability initiatives are leading to more efficient operations. For example, a facility that reduces its reliance

AITBSS AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

on fossil fuels by transitioning to renewable energy sources can track the percentage of energy generated from renewables as a key performance indicator. Similarly, facilities that reduce their use of single-use plastics and other non-renewable materials can measure the impact of these efforts through procurement and waste management data (Mugoni et al., 2023).

Maintenance costs are another important KPI for evaluating the operational efficiency of green technologies. Many green technologies, such as LED lighting and smart HVAC systems, have lower maintenance costs compared to traditional systems. LED lights, for example, have a longer lifespan and require less maintenance than traditional incandescent or fluorescent bulbs. Similarly, smart HVAC systems optimize heating and cooling usage, reducing the wear and tear on the system and lowering maintenance costs. By tracking maintenance expenses before and after the implementation of green technologies, facility managers can assess the financial benefits of their sustainability initiatives. A reduction in maintenance costs is a clear indicator that the facility's green technologies are improving operational efficiency and reducing long-term operational expenses (Elnour et al., 2022).

In conclusion, the impact of green technologies on operational efficiency in sports facilities is significant, encompassing financial savings, environmental benefits, and improved performance metrics. Through a cost-benefit analysis, it is clear that while the initial investment in green technologies may be high, the long-term financial savings, particularly in energy and water consumption, make these technologies a sound investment. The environmental benefits of reducing carbon emissions, waste output, and resource consumption further contribute to the overall sustainability of sports facilities. By tracking key performance indicators such as energy consumption, water usage, waste reduction, and maintenance costs, facility managers can evaluate the success of their green operations and identify areas for continuous improvement. As the demand for sustainable operations continues to grow, sports facilities must embrace green technologies to remain competitive and meet the expectations of environmentally conscious fans, stakeholders, and policymakers (Zwane, 2023).

7. Challenges and Limitations

The adoption of green technologies in sports facilities, though beneficial for long-term sustainability and operational efficiency, is fraught with several challenges and limitations. One of the most significant barriers is the economic cost associated with implementing these technologies. Sports facilities, particularly large stadiums and arenas, require considerable investment in renewable energy systems, water conservation technologies, waste management systems, and smart energy solutions. The initial costs of installing solar panels, wind turbines, smart HVAC systems, and water recycling technologies can be prohibitively high for many facilities, especially smaller or community-based venues. While the long-term financial savings from reduced energy and water consumption can offset these upfront costs, many facility managers are deterred by the substantial capital outlay required for installation and integration (Heidari Fard & Sharifian, 2017). In addition to the cost of the technology itself, there are often ancillary expenses related to the retrofitting of existing infrastructure, which may not be equipped to handle modern green technologies.

The high cost of green technologies is compounded by the fact that financial returns are often realized over a long period. For example, the financial benefits of installing solar panels may only become evident after several years, depending on energy savings and potential government incentives. For many facilities, especially those operating on tight budgets, this delayed return on investment is a major hurdle. Moreover, some sports facilities operate on short-term event cycles or seasonal schedules, which may not provide the steady revenue streams needed to support significant capital investments. As a result, the economic barriers to adopting green technologies are particularly acute in regions where sports facilities do not have access to government subsidies or private funding sources (Rahmani et al., 2024).

Beyond the economic constraints, there are technological limitations that pose challenges to the widespread adoption of green technologies in sports facilities. Not all technologies are universally scalable or suitable for all types of facilities. For instance, while solar panels and wind turbines are effective for generating renewable energy, they require ample space and specific environmental conditions to function optimally. In urban areas where space is limited, or in regions where sunlight and wind are inconsistent, these technologies may not be viable options. Similarly, water recycling systems and rainwater harvesting technologies are highly effective in regions with ample rainfall but are less useful in arid or drought-prone areas (Ghafouri et al., 2019). This

AITBSS AI and Tech in Behavioral and Social Sciences E-ISSN: 3041-9433

geographical variability in the effectiveness of certain green technologies means that facilities must carefully evaluate their specific environmental conditions before investing in such systems, which can limit the scalability of these solutions.

The availability of green technologies also varies across regions, particularly between developed and less-developed countries. In more advanced economies, there is greater access to cutting-edge technologies and the infrastructure needed to support them. In contrast, facilities in less-developed regions may struggle with access to the latest green technologies due to logistical challenges, supply chain issues, or higher costs associated with importing specialized equipment. Furthermore, the lack of local expertise in installing and maintaining these technologies can further hinder their adoption (Alsarve, 2024). These technological limitations highlight the need for context-specific solutions that consider the unique environmental, geographical, and economic circumstances of different regions.

Operational and management barriers also play a significant role in limiting the adoption of green technologies in sports facilities. Facility managers, staff, and operators may resist changes due to a lack of understanding or familiarity with green technologies. The implementation of renewable energy systems, smart energy management platforms, or water conservation systems requires a level of technical knowledge that may not be readily available among facility staff. Training programs are necessary to ensure that staff can effectively operate and maintain these systems, but such programs are often costly and time-consuming. Moreover, facility managers may be reluctant to invest in staff training if they are unsure of the long-term benefits of the technology, leading to a cycle of resistance and underutilization of green technologies (Azimi Delarestaghi et al., 2019).

Another operational challenge is the perceived disruption that green technologies may cause to existing facility operations. For example, retrofitting a stadium with solar panels or upgrading to a smart HVAC system may require temporary shutdowns or reduced capacity, which can affect event scheduling and revenue generation. Facility managers may be hesitant to undertake such projects if they believe the short-term disruptions will outweigh the long-term benefits. Additionally, there may be concerns about the reliability of new technologies, especially in high-pressure environments such as sports venues, where equipment failure during a major event could lead to significant operational disruptions and financial losses (Yu, 2023).

8. Future Directions

Despite the challenges and limitations, the future of green technologies in sports facilities is promising, with several emerging technologies poised to enhance sustainability efforts. One of the most exciting developments is the integration of artificial intelligence (AI) into energy management systems. AI-driven technologies can analyze energy usage patterns in real-time and make autonomous adjustments to optimize energy consumption. For instance, AI can predict peak energy usage based on event schedules, weather conditions, and historical data, allowing facilities to preemptively adjust lighting, heating, and cooling systems for maximum efficiency. AI can also be integrated with renewable energy systems, such as solar panels or wind turbines, to automatically switch between different energy sources based on availability and cost (Elnour et al., 2022). This level of automation not only reduces energy consumption but also minimizes human error, making operations more efficient and sustainable.

Blockchain technology is another emerging tool that holds potential for improving green operations in sports facilities. Blockchain can be used to track the facility's compliance with sustainability regulations and goals, providing a transparent and verifiable record of energy usage, waste management, and carbon emissions. This technology can be particularly useful for facilities seeking to achieve certifications such as LEED (Leadership in Energy and Environmental Design) or ISO 14001, as it offers an immutable record of compliance with environmental standards. Blockchain can also be used to create decentralized energy grids, where sports facilities can trade excess renewable energy with other buildings in the surrounding area, further promoting sustainability (Mohamed et al., 2023). While blockchain technology is still in its early stages of adoption, its potential to streamline sustainability tracking and energy trading could have a transformative impact on green operations in sports facilities.

There are also significant research gaps that need to be addressed to further advance the adoption of green technologies in sports facilities. One area where more research is needed is the development of context-specific solutions for less-developed regions. Much of the existing

AITBSS AI and Tech in Behavioral and Social Sciences E-ISSN: 3041-9433

research on green technologies focuses on developed economies with advanced infrastructure, but there is a lack of studies exploring how these technologies can be adapted for use in regions with limited resources. For example, research could focus on developing low-cost, scalable renewable energy systems or water-saving technologies that are suitable for facilities in rural or low-income areas (Ghafouri et al., 2019). Additionally, more case studies are needed to examine the long-term operational impacts of green technologies in different types of sports facilities, from small community centers to large international stadiums. These case studies would provide valuable insights into best practices, common challenges, and the real-world benefits of green operations.

Policymakers also have an important role to play in supporting the adoption of green technologies in sports facilities. One of the most effective ways to promote green operations is through the creation of financial incentives, such as tax credits, grants, and subsidies for facilities that invest in renewable energy, water conservation, or waste reduction technologies. Government programs that provide funding for the installation of solar panels, wind turbines, or smart energy management systems can help offset the initial costs, making these technologies more accessible to a wider range of facilities (Heidari Fard & Sharifian, 2017). Additionally, policymakers can implement regulations that require sports facilities to meet certain sustainability benchmarks, such as reducing energy consumption or water usage by a specified percentage. These regulations would encourage facilities to adopt green technologies as a way to comply with environmental standards while also improving their operational efficiency (Rahmani et al., 2024).

Collaboration between government agencies, private industry, and sports organizations is essential for the successful implementation of green operations. Public-private partnerships can provide the financial and technical support needed to scale green technologies across the sports industry. For example, partnerships between renewable energy companies and sports venues can facilitate the installation of solar panels or wind turbines at reduced costs, while providing ongoing maintenance and technical support. Similarly, collaboration between water conservation experts and facility managers can lead to the development of customized solutions for managing water resources more efficiently (Yu, 2023). These partnerships are crucial for overcoming the financial and operational barriers that currently limit the adoption of green technologies in many sports facilities.

In conclusion, while the adoption of green technologies in sports facilities faces significant challenges related to economic costs, technological limitations, and operational resistance, the future holds exciting possibilities for overcoming these barriers. Emerging technologies such as AI and blockchain offer new ways to optimize energy usage, track sustainability compliance, and enhance operational efficiency. However, more research is needed to develop context-specific solutions for less-developed regions and to provide concrete case studies that demonstrate the long-term benefits of green operations. Policymakers and industry leaders also have a critical role to play in promoting the adoption of green technologies through financial incentives, regulations, and collaborative partnerships. As sustainability becomes an increasingly important priority for sports organizations and their stakeholders, the successful integration of green technologies will be essential for ensuring the long-term viability and environmental responsibility of sports facilities worldwide (Zwane, 2023).

9. Challenges and Limitations

The integration of green technologies in sports facilities has demonstrated significant potential to enhance both operational efficiency and environmental sustainability. This review has highlighted several key technological solutions that are driving the shift towards greener operations. Renewable energy systems, such as solar panels and wind turbines, have emerged as critical tools for reducing the dependency on non-renewable energy sources. These technologies not only lower energy costs but also contribute to the reduction of carbon emissions, helping sports facilities mitigate their environmental impact. Furthermore, smart energy management systems, which utilize sensors and artificial intelligence to optimize energy use, have shown to improve operational efficiency by reducing unnecessary energy consumption. These systems, combined with energy-efficient technologies like LED lighting, offer long-term financial savings and promote a more sustainable energy footprint for facilities (Elnour et al., 2022; Karimi et al., 2023).

Water conservation technologies have also proven essential in reducing the resource consumption of sports facilities. Systems such as rainwater harvesting and smart irrigation have enabled facilities to significantly cut down on potable water use, particularly in regions where water scarcity is a pressing issue. Low-flow fixtures and water

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recycling technologies further contribute to these efforts, enabling facilities to maintain high standards of functionality while minimizing water consumption. The environmental benefits of these water conservation systems are clear, as they help preserve valuable water resources and reduce the environmental footprint of sports operations (Ghafouri et al., 2019). Waste management innovations, including automated waste sorting systems and composting programs, have also demonstrated their value in reducing the amount of waste sent to landfills. By promoting recycling and composting, sports facilities can reduce waste disposal costs while supporting broader sustainability goals (Alsarve, 2024; Rahmani et al., 2024).

This article's contribution to the field lies in its comprehensive analysis of how technological solutions can enable sustainability in sports facilities. By examining various green technologies across multiple dimensions—energy efficiency, water conservation, waste management, and air quality—this review provides a holistic view of how sports facilities can reduce their environmental impact while improving operational performance. The adoption of green technologies is not merely a matter of environmental responsibility; it also presents a strategic opportunity for sports facilities to enhance their competitiveness, lower operational costs, and meet the growing expectations of environmentally conscious fans, stakeholders, and policymakers. This review underscores the importance of integrating sustainability into the core operational strategies of sports facilities, as the long-term benefits of green technologies outweigh the initial costs, providing both financial and environmental returns (Heydari Rad et al., 2023; Yu, 2023; Yu & Ramanathan, 2014).

The article also highlights the barriers to the widespread adoption of green technologies in sports facilities, including economic, technological, and operational challenges. While the upfront costs of installing renewable energy systems or water conservation technologies may be high, this review emphasizes the need for facility managers and policymakers to focus on the long-term financial savings and sustainability benefits these technologies provide. Furthermore, the technological limitations, such as the scalability of certain solutions and the availability of green technologies in less-developed regions, present areas where more research and innovation are needed. Facility managers must also overcome operational barriers by investing in staff training and promoting a culture of sustainability within their organizations. These challenges are not insurmountable, but they require concerted effort from all stakeholders involved in the management and operation of sports facilities (Azimi Delarestaghi et al., 2019; Rahmani et al., 2024).

Moving forward, the adoption of green technologies in sports facilities must be further encouraged through policy initiatives, industry partnerships, and continued technological innovation. Policymakers can play a pivotal role by offering financial incentives, such as tax credits and grants, to offset the initial costs of green technologies. Collaborations between sports organizations, technology providers, and research institutions can also drive the development of new, scalable solutions that address the specific needs of sports facilities across different regions. Moreover, future research should focus on identifying the most effective green technologies for different types of sports facilities, taking into account factors such as facility size, location, and available resources (Ghafouri et al., 2019; Karimzadeh et al., 2024; Mohamed et al., 2023).

In conclusion, the adoption of green technologies in sports facilities is both a necessity and an opportunity. The environmental and financial benefits of renewable energy systems, smart energy management platforms, water conservation technologies, and waste management innovations are undeniable. However, to fully realize these benefits, there must be a collective effort to overcome the challenges that currently limit the widespread implementation of these technologies. Facility managers, sports organizations, policymakers, and researchers must work together to promote the adoption of green technologies and ensure that sports facilities can operate sustainably for years to come. As the global focus on sustainability intensifies, the sports industry has a unique opportunity to lead by example, showcasing how technological innovation can drive positive environmental change while enhancing operational efficiency.

Authors' Contributions

A. S. N., L. S., and N. M. contributed equally to this review article. A. S. N. led the conceptualization and literature review process, focusing on the integration of green technologies in sports facilities. L. S. contributed to the analysis of technological impacts on operational efficiency and sustainability, as well as identifying the challenges and future directions for green technology adoption. N. M. was responsible for synthesizing the findings, structuring the article, and editing the manuscript

AITBSS AI and Tech in Behavioral and Social Sciences
E-ISSN: 3041-9433

for coherence and clarity. All authors participated in reviewing and approving the final manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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References

Ahmadvand, M., & Azad, N. (2019). The role of logistics in crisis management (Case study: Kermanshah earthquakes). *Journal of Disaster Prevention and Management Knowledge*, *8*(4), 339-348. https://www.magiran.com/paper/1908179

Almahrog, Y., Ali Aribi, Z., & Arun, T. (2018). Earnings management and corporate social responsibility: UK evidence. *Journal of Financial Reporting and Accounting*, *16*(2), 311-332. https://doi.org/10.1108/JFRA-11-2016-0092

Alsarve, D. (2024). Achieving gender equity: Barriers and possibilities at board level in Swedish sport. *European Sport Management Quarterly*, *24*(1), 286-302. https://doi.org/10.1080/16184742.2022.2112256

Azimi Delarestaghi, A., Razavi, S. M. H., & Boroumand, M. R. (2019). Identifying the Effective Context Conditions of Strategic Entrepreneurship Deployment in Sports Business. *Sport Management and Development*, *7*(4), 70-87. https://doi.org/10.22124/jsmd.2019.3253

Chang, C. (2024). Research on Gender Treatment and Discrimination of World Mainstream of World Mainstream Sports Events. *Highlights in Business, Economics and Management*, *27*, 114-118. https://doi.org/10.54097/rerxkp33

Elnour, M., Himeur, Y., Fadli, F., Mohammedsherif, H., Meskin, N., Ahmad, A. M., Petri, I., Rezgui, Y., & Hodorog, A. (2022). Neural Network-Based Model Predictive Control System for Optimizing Building Automation and Management Systems of Sports Facilities. *Applied Energy*, *318*, 119153. https://doi.org/10.1016/j.apenergy.2022.119153

Ghafouri, F., Memarzadeh, M. S., & Alavi, S. (2019). Determining the Contribution and Role of the Executive Organizations in Development of community Sport. *Applied Research in Sport Management*, *8*(1), 11-32. https://doi.org/10.30473/arsm.2019.5843

Heidari Fard, S., & Sharifian, I. (2017). Identify and compare barriers to charitable participation in the development of sports facilities. *Sports Management Studies*, *9*(41), 81-96. https://smrj.ssrc.ac.ir/article_916.html?lang=en

Heydari Rad, P., Hamidi, M., Sajjadi, S. N., & Rajabi Noushabadi, H. (2023). Providing a Framework of Analyzing the Effective Factors on the Success of Small Businesses of Sports Service [Research Article]. *Iranian Journal of Educational Sociology*, *6*(2), 97-111. https://doi.org/10.61186/ijes.6.2.97

Huong, P. T., Cherian, J., Hien, N. T., Sial, M. S., Samad, S., & Tuan, B. A. (2021). Environmental Management, Green Innovation, and Social–Open Innovation. *Journal of Open Innovation Technology Market and Complexity*, *7*(1), 89. https://doi.org/10.3390/joitmc7010089

Irigaray, H. A. R. (2024). Reflections on Business Resilience, Corporate Governance, and Corporate Social Responsibility. *Cadernos Ebape Br*, *22*(1). https://doi.org/10.1590/1679-395190025x

Karimi, A., Jahan, J., & Yaghoubi Alamshiri, R. (2023). The Effect of Internet Marketing and Advertising on the Income of Sports Venues (CASE Study: Damavand Sports Facilities). *Dynamic Management and Business Analysis*, *2*(1), 18-25. https://doi.org/10.22034/dmbaj.2024.2025101.1026

Karimi, J., Soltanian, L., & Bejani, A. (2020). Designing the Model of the Development of Adventure Sports Tourism: Grounded Theory. *Sport Management Studies*, *12*(60), 61-82. https://doi.org/10.22089/smrj.2019.6327.2288

Karimzadeh, M. S., Naderinasab, M., Taheri, M., & Biniyas, S. A. (2024). Identification and Analysis of Factors Influencing the Development of Sports in the Islamic Republic of Iran's Army Using Foresight Methodology (Focusing on Health and Lifestyle). *International Journal of Sport Studies for Health*, 1-11. https://journals.kmanpub.com/index.php/Intjssh/article/view/2634

Mohamed, S. B., Haddad, S. S. G., & Barakat, M. (2023). Blockchain Technology Adoption for Improved Environmental Supply Chain Performance: The Mediation Effect of Supply Chain Resilience, Customer Integration, and Green Customer Information Sharing. *Sustainability*, *15*(10), 7909. https://doi.org/10.3390/su15107909

Mugoni, E., Nyagadza, B., & Hove, P. K. (2023). Green reverse logistics technology impact on agricultural entrepreneurial marketing firms' operational efficiency and sustainable competitive advantage. *Sustainable Technology and Entrepreneurship*, *2*(2). https://doi.org/10.1016/j.stae.2022.100034

Naderian Jahormi, M., Derishi, M., Mostefezian, S., & Rahbari, S. (2018). Comparison of the quality of life of physically active and inactive citizens (case study: sports facilities of Isfahan Municipality). *Journal of Sports Management and Movement Behavior*, *12*(24), 215-228. https://msb.journals.umz.ac.ir/article_1301.html

Rahmani, N., Naderi Nasab, M., Taheri, M., & Biniaz, S. A. (2024). Exploring the Future of the Sports Industry Through an Economic Lens in 2031. *International Journal of Innovation Management and Organizational Behavior*

AITBSS
E-ISSN: 3041-9433

(IJIMOB), *4*(1), 170-179. https://doi.org/10.61838/kman.ijimob.4.1.20

Rostam Zadeh, N., Afshari, M., Alam, Z., & Ghorbani, S. (2019). Providing a Good Electronic Governance Model at the Ministry of Sports and Youth. *Sport Management Studies*, *11*(56), 43-62. https://doi.org/10.22089/smrj.2019.6168.2244

Sulaeman, A. (2024). The Influence of Capital Intensity, Leverage, Profitability, and Corporate Social Responsibility on Tax Avoidance With Firm Size as a Moderating Variable. *Asian Journal of Economics Business and Accounting*, *24*(5), 433-442. https://doi.org/10.9734/ajeba/2024/v24i51320

Suryani, Y. (2024). Shariah Governance, Leverage, and Their Impact on Islamic Corporate Social Responsibility in Sharia Banking in Indonesia. *International Journal Ihya Ulum Al-Din*, *26*(1), 143-155. https://doi.org/10.21580/ihya.26.1.20482

Varmus, M., Kubina, M., Mičiak, M., Sarlak, M. A., & Greguška, I. (2023). Sustainable Management of the Public Financial Model for Sports Support in Slovakia. *Sustainability*, *15*(14), 11310. https://doi.org/10.3390/su151411310

Varmus, M., Mičiak, M., Kubina, M., Piatka, A., Stoják, M., Sýkora, A., & Greguška, I. (2023). Determination and Quantification of Foreign Interest in Sports Using Selected Variables for the Support of Appraising Investments in Sports by Businesses and States. *Journal of Risk and Financial Management*, *16*(3), 162. https://doi.org/10.3390/jrfm16030162

Wahdi, N. (2024). The Influence of Corporate Social Responsibility and Profitability on Tax Avoidance. *Innovation Business Management and Accounting Journal*, *3*(1), 30-36. https://doi.org/10.56070/ibmaj.2024.004

Yu, C. (2023). The Application Practice of Sports Marketing and Branding in Social Media: A Case Study of Li-Ning. *Highlights in Business Economics and Management*, *23*, 1071-1081. https://doi.org/10.54097/v3rhfp55

Yu, W., & Ramanathan, R. (2014). An Empirical Examination of Stakeholder Pressures, Green Operations Practices and Environmental Performance. *International Journal of Production Research*. https://doi.org/10.1080/00207543.2014.931608

Zhang, Y. (2023). Artificial Intelligence Carbon Neutrality Strategy in Sports Event Management Based on STIRPAT-GRU and Transfer Learning. https://doi.org/10.21203/rs.3.rs-3264821/v1

Zwane, B. S. (2023). The Factors Influencing Entrepreneurial Intentions Amongst Sport Management Students. *Ijebd (International Journal of Entrepreneurship and Business Development)*, *6*(6), 1036-1045. https://doi.org/10.29138/ijebd.v6i6.2342

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