
THE 2026 FIFA WORLD CUP IN A CHANGING CLIMATE: A SYSTEMATIC REVIEW OF CLIMATE RISKS, ATHLETE PERFORMANCE, SPECTATOR SAFETY, AND SUSTAINABLE EVENT MANAGEMENT

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ABSTRACT

Climate change has become one of the most significant challenges affecting the planning and management of international sporting events, with increasing implications for athlete health, spectator safety, infrastructure resilience, and environmental sustainability. This systematic review examines the implications of climate change for the 2026 FIFA World Cup, jointly hosted by Canada, the United States, and Mexico. Following the PRISMA 2020 guidelines, the review synthesised evidence from peer-reviewed journal articles and authoritative publications produced by the Intergovernmental Panel on Climate Change (IPCC), the World Health Organization (WHO), the Fédération Internationale de Football Association (FIFA), the United Nations Framework Convention on Climate Change (UNFCCC), Climate Central, FIFPRO, and Jackson et al. (2026). The review focused on climate change and mega sporting events, heat stress and extreme weather impacts on players and match officials, air quality and wildfire smoke risks, public health implications for spectators, climate-resilient stadium design, FIFA's climate commitments and carbon neutrality initiatives, and future research and policy directions. The findings indicate that rising temperatures, prolonged heatwaves, increasing humidity, deteriorating air quality, and more frequent extreme weather events pose significant risks to athlete performance, match officiating, spectator health, tournament operations, and infrastructure. Heat stress is expected to increase physiological strain,

dehydration, fatigue, and the risk of heat-related illnesses, while wildfire smoke and poor air quality may impair respiratory health and physical performance among athletes and spectators. The review further shows that although FIFA has implemented several sustainability initiatives, the expanded 48-team tournament is projected to generate approximately 9 million tonnes of carbon dioxide equivalent emissions, largely because of extensive international and domestic air travel. Addressing these challenges requires climate-resilient stadium infrastructure, evidence-based heat management protocols, comprehensive public health preparedness, sustainable transportation systems, transparent greenhouse gas accounting, and stronger environmental governance. The review concludes that the 2026 FIFA World Cup presents both significant climate risks and an opportunity to strengthen sustainable event management by integrating climate science, public health, technological innovation, and environmental governance into future international football tournaments.

KEYWORDS: Climate change; 2026 FIFA World Cup; Heat stress; Air quality; Spectator safety; Sustainable event management; Carbon neutrality.

INTRODUCTION

Climate change has emerged as one of the most significant global challenges of the twenty-first century, influencing environmental systems, economic development, public health, biodiversity, and human activities across all regions of the world. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), human-induced greenhouse gas emissions have increased the frequency, duration, and intensity of extreme weather events, including heatwaves, droughts, flooding, tropical cyclones, heavy precipitation, and wildfires. These environmental changes are increasingly affecting outdoor sporting events, where athletes, officials, spectators, and supporting personnel are directly exposed to changing climatic conditions. Consequently, climate change is no longer viewed solely as an environmental issue but also as a major challenge for sports governance, public health, infrastructure planning, and sustainable development.

Sport has historically depended on favourable climatic conditions for training, competition, and spectator participation. However, the rapid progression of climate change has altered the environmental conditions under which sporting events are organised. Outdoor sports such as football are particularly vulnerable because competitions occur in open environments where participants are directly exposed to high temperatures, humidity, rainfall, wind, air pollution, and other weather-related hazards. Recent international competitions have demonstrated that

climate-related disruptions can compromise athlete performance, delay competitions, increase medical emergencies, damage infrastructure, and threaten spectator safety (Racinais et al., 2015). As a result, climate adaptation has become an essential component of modern sports management.

Among international sporting competitions, the FIFA World Cup represents one of the world's largest and most influential mega sporting events. Every four years, billions of television viewers follow the tournament while millions of supporters travel internationally to attend matches. The competition generates substantial economic benefits through tourism, broadcasting rights, sponsorship agreements, merchandising, and infrastructure investment. Nevertheless, organising tournaments of this magnitude also requires considerable energy consumption, transportation, accommodation, construction activities, and resource utilisation, all of which contribute to greenhouse gas emissions (Collins & Flynn, 2008). Consequently, balancing commercial growth with environmental sustainability has become an increasingly important objective for FIFA and host nations.

The 2026 FIFA World Cup represents a historic milestone in international football because it will be jointly hosted by Canada, the United States, and Mexico. It is also the first FIFA World Cup to feature 48 participating teams, increasing the number of matches from 64 to 104. Matches will be played across 16 host cities spread over thousands of kilometres throughout North America. Although the expanded tournament increases global participation and commercial opportunities, it also introduces unprecedented environmental, logistical, and public health challenges. Greater geographical dispersion increases transportation demands, energy consumption, accommodation requirements, and operational complexity, thereby enlarging the tournament's environmental footprint (FIFA, 2024).

Climate projections indicate that several host cities are likely to experience increasingly severe environmental conditions during the tournament period. Summer temperatures across parts of the United States and Mexico have risen considerably during recent decades, with climate models projecting more frequent and intense heatwaves throughout the twenty-first century (IPCC, 2023). Climate Central (2026) estimated that nearly half of the scheduled World Cup matches have at least a 50% probability of being played under heat conditions capable of impairing athletic performance. Cities such as Miami, Houston, Dallas, Monterrey, Guadalajara, and Mexico City are expected to experience particularly challenging environmental conditions because of combinations of high temperatures, elevated humidity, intense solar radiation, or high-altitude environments.

Heat stress is expected to become one of the greatest operational and medical challenges during the tournament. Football requires continuous aerobic activity combined with repeated high-intensity movements including sprinting, jumping, tackling, rapid acceleration, and frequent changes in direction. Under extreme environmental conditions, the body's ability to regulate internal temperature becomes compromised, resulting in dehydration, cardiovascular strain, impaired cognitive performance, reduced physical endurance, and increased risks of heat exhaustion and heat stroke (Racinais et al., 2015). Similar physiological risks affect referees, assistant referees, medical teams, volunteers, security personnel, broadcasters, and stadium workers who remain outdoors for prolonged periods throughout competition days.

Climate change also presents important public health concerns for spectators. Millions of supporters attending matches, fan festivals, and tourism activities may experience prolonged exposure to extreme heat, ultraviolet radiation, poor air quality, and severe weather conditions. Older adults, children, pregnant women, and individuals with chronic cardiovascular or respiratory diseases are particularly vulnerable to heat-related illnesses and air pollution. The World Health Organization (WHO, 2021) identifies extreme heat as one of the leading weather-related causes of illness and mortality globally, emphasising the need for comprehensive public health preparedness during mass gathering events.

In addition to climate-related health risks, concerns regarding the environmental sustainability of the 2026 FIFA World Cup have intensified. While FIFA has introduced sustainability strategies involving greenhouse gas accounting, renewable energy adoption, sustainable procurement, and carbon reduction initiatives, several researchers argue that the tournament's expansion substantially increases its environmental impact. Jackson et al. (2026) estimated that the competition could generate approximately 9 million tonnes of carbon dioxide equivalent (CO₂e), making it the most carbon-intensive FIFA World Cup ever organised. Their analysis further indicated that approximately 85–87% of tournament emissions will originate from transportation, particularly long-distance air travel involving teams, officials, media personnel, sponsors, and millions of spectators travelling across the three host nations. Jackson et al. (2026) further argued that tournament expansion and continued commercial partnerships with fossil fuel industries create important contradictions between FIFA's sustainability ambitions and its operational practices.

The environmental challenges associated with the 2026 FIFA World Cup extend beyond greenhouse gas emissions. Climate change is increasing the likelihood of heatwaves, wildfires, deteriorating air quality, severe thunderstorms, flooding, and other extreme weather events capable of disrupting tournament operations. These hazards threaten athlete health,

spectator safety, infrastructure resilience, transportation systems, emergency response services, and local communities. Consequently, climate resilience has become a central consideration in planning international sporting events. Modern tournament management increasingly requires the integration of climate science, environmental monitoring, engineering innovation, public health preparedness, and evidence-based governance to ensure the safe and sustainable delivery of global competitions.

Against this background, this systematic review synthesises current scientific evidence regarding the implications of climate change for the 2026 FIFA World Cup. Specifically, the review examines heat stress and extreme weather impacts on players and match officials, air quality and wildfire smoke risks, public health implications for spectators, climate-resilient stadium design, FIFA's climate commitments and carbon neutrality initiatives, as well as emerging research gaps and future policy directions. By integrating evidence from environmental science, sports medicine, public health, engineering, sports governance, and the findings of Jackson et al. (2026), this review provides a comprehensive assessment of how climate change is reshaping international football and identifies evidence-based strategies for improving the sustainability and resilience of future mega sporting events.

METHODOLOGY

This study employed a systematic literature review (SLR) to synthesise current scientific evidence on climate change and the 2026 FIFA World Cup. A systematic review was selected because it provides a transparent, structured, and reproducible approach for identifying, evaluating, and integrating evidence from multiple disciplines. Unlike traditional narrative reviews, systematic reviews follow predefined protocols that minimise selection bias and improve the reliability of research findings (Page et al., 2021). Given that climate change affects environmental science, sports medicine, public health, engineering, urban planning, and sports governance simultaneously, the systematic review approach was considered the most appropriate methodology for examining the multidimensional challenges associated with the tournament.

The review followed the principles outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines developed by Page et al. (2021). PRISMA provides internationally recognised standards for conducting systematic reviews through transparent reporting of literature identification, screening, eligibility assessment, inclusion criteria, and evidence synthesis. Applying these guidelines improved

methodological consistency and enhanced the credibility of the review by ensuring that study selection and analysis followed clearly defined procedures.

A comprehensive literature search was conducted using several internationally recognised academic databases. These included Scopus, Web of Science, ScienceDirect, SpringerLink, Taylor & Francis Online, Wiley Online Library, PubMed, and Google Scholar. Additional information was obtained from publications produced by authoritative organisations, including the Intergovernmental Panel on Climate Change (IPCC), the World Health Organization (WHO), the United Nations Framework Convention on Climate Change (UNFCCC), FIFA, FIFPRO, Climate Central, the United States Environmental Protection Agency (USEPA), and the study by Jackson et al. (2026) on climate change and the 2026 FIFA World Cup. These institutional publications complemented peer-reviewed literature by providing current policy documents, technical reports, environmental assessments, and operational guidelines relevant to climate adaptation in international sport.

A structured search strategy was developed using combinations of keywords connected through Boolean operators such as AND, OR, and NOT. The principal search terms included climate change, global warming, 2026 FIFA World Cup, football, heat stress, athlete performance, extreme weather, wildfire smoke, air quality, public health, spectator safety, stadium resilience, sports sustainability, carbon neutrality, greenhouse gas emissions, climate adaptation, and environmental governance. Additional searches combined these terms to identify interdisciplinary studies examining the relationships among climate science, sports medicine, infrastructure resilience, and sustainable event management. Reference lists of eligible publications were also examined manually to identify additional relevant studies that were not retrieved during the initial electronic search.

Clear inclusion and exclusion criteria were established before the screening process. Eligible studies included peer-reviewed journal articles, systematic reviews, technical reports, institutional publications, policy documents, and conference papers published between 2015 and 2026. Studies were required to address one or more aspects of climate change, environmental sustainability, football governance, athlete health, public health, stadium infrastructure, or mega sporting events. Publications written in English and presenting empirical findings or evidence-based analyses were included. Editorials, newspaper opinion articles, duplicate publications, inaccessible full-text documents, and studies unrelated to climate change or international football were excluded from the review. These criteria ensured that only scientifically credible and policy-relevant evidence contributed to the final synthesis.

Following literature retrieval, titles and abstracts were independently screened to determine their relevance to the objectives of the review. Publications meeting the inclusion criteria underwent detailed full-text assessment. Information extracted from each study included authorship, year of publication, geographical coverage, research objectives, methodological approach, climate hazards investigated, principal findings, adaptation strategies, policy recommendations, and identified research gaps. Particular attention was given to studies examining heat stress, air quality, wildfire smoke, stadium resilience, carbon emissions, sustainable event management, and environmental governance. The study by Jackson et al. (2026) was particularly valuable because it provided one of the most comprehensive assessments of the environmental implications of the expanded 2026 FIFA World Cup.

Because the selected studies employed diverse methodologies, geographical contexts, and outcome measures, a narrative thematic synthesis rather than a quantitative meta-analysis was undertaken. Thematic synthesis enabled evidence from environmental science, sports medicine, epidemiology, engineering, public health, and sports governance to be integrated into coherent analytical themes. Six principal themes emerged from the literature: (1) heat stress and extreme weather impacts on players and match officials; (2) air quality and wildfire smoke risks; (3) public health implications for spectators; (4) climate-resilient stadium design; (5) FIFA's climate commitments and carbon neutrality initiatives; and (6) research gaps and future policy directions. These themes formed the analytical framework for discussing the climate-related challenges and opportunities associated with the 2026 FIFA World Cup.

Although every effort was made to ensure methodological rigour, several limitations should be acknowledged. Climate science and sports sustainability are rapidly evolving fields, and new evidence continues to emerge as the tournament approaches. Some projections regarding future climatic conditions are based on modelling rather than direct observation and are therefore subject to uncertainty. Furthermore, because the 2026 FIFA World Cup had not yet been completed at the time many studies were conducted, some conclusions rely on projected environmental conditions and anticipated operational challenges. Nevertheless, by integrating evidence from high-quality peer-reviewed studies, authoritative institutional reports, and recent analyses such as Jackson et al. (2026), this review provides a comprehensive and evidence-based assessment of the climate risks, sustainability challenges, and policy implications associated with the largest FIFA World Cup ever organised.

Climate Change and Mega Sporting Events

Climate change has fundamentally transformed the planning, organisation, and management of mega sporting events worldwide. Rising global temperatures, prolonged heatwaves, changing precipitation patterns, wildfires, hurricanes, flooding, droughts, and declining air quality increasingly threaten the successful delivery of international sporting competitions. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), human-induced climate change has intensified the frequency and severity of extreme weather events across every inhabited continent. These environmental changes affect not only the physical environment but also athlete health, public safety, infrastructure resilience, tournament scheduling, and economic sustainability. Consequently, climate resilience has become an essential component of sports governance and event management.

Mega sporting events such as the FIFA World Cup, the Olympic Games, the Commonwealth Games, and continental football championships are particularly vulnerable to climate-related risks because they involve millions of spectators, thousands of athletes, large-scale transportation systems, extensive infrastructure, and prolonged outdoor activities. Football competitions are especially exposed because matches are generally played in open stadiums where participants experience direct exposure to high temperatures, humidity, rainfall, solar radiation, strong winds, and deteriorating air quality. These climatic conditions influence athletic performance while simultaneously increasing medical emergencies, disrupting transportation systems, and placing considerable pressure on emergency response services (World Health Organization [WHO], 2021). Climate change has therefore become an operational challenge extending far beyond environmental conservation.

One of the most visible consequences of climate change for international sport is the increasing occurrence of extreme heat. The IPCC (2023) concluded that heatwaves have become more frequent, more intense, and longer-lasting in most regions of the world. Rising temperatures increase physiological strain among athletes by impairing thermoregulation, accelerating dehydration, reducing endurance, slowing cognitive performance, and increasing the risk of heat-related illnesses such as heat exhaustion and heat stroke (Racinais et al., 2015). Match officials, coaches, volunteers, broadcasters, medical personnel, and stadium workers experience similar risks because they often remain outdoors throughout competition periods. These physiological challenges demonstrate that climate change directly affects both sporting performance and occupational health.

Climate change also threatens the resilience of sports infrastructure. Stadiums, transportation systems, communication networks, electricity supply, water infrastructure, and emergency

response facilities are increasingly exposed to severe storms, flooding, droughts, high temperatures, and wildfires. Modern sports facilities therefore require adaptation strategies capable of maintaining operational efficiency under changing climatic conditions. Sustainable engineering solutions such as renewable energy systems, hybrid playing surfaces, efficient drainage networks, rainwater harvesting technologies, passive cooling systems, intelligent environmental monitoring, and climate-resilient construction materials are increasingly incorporated into stadium design (United Nations Environment Programme [UNEP], 2022). These measures reduce environmental impacts while improving infrastructure resilience and long-term operational sustainability.

Another important consequence of mega sporting events is their contribution to greenhouse gas emissions. International competitions generate emissions through international and domestic transportation, stadium operations, accommodation, broadcasting activities, catering services, waste generation, and infrastructure development. Previous studies consistently identify transportation as the largest contributor to emissions associated with major sporting events (Collins & Flynn, 2008). While renewable energy technologies, waste reduction programmes, sustainable procurement policies, and carbon offset initiatives contribute to environmental improvement, these measures frequently compensate for only a proportion of total emissions. Consequently, reducing the environmental footprint of international sport requires structural changes alongside technological innovation.

Recent evidence demonstrates that the environmental footprint of international football has increased considerably because of tournament expansion and increasing global mobility. Jackson et al. (2026) estimated that the 2026 FIFA World Cup could generate approximately 9 million tonnes of carbon dioxide equivalent (CO₂e), making it the most carbon-intensive FIFA World Cup ever organised. Their analysis showed that approximately 85–87% of total emissions are expected to originate from transportation, particularly long-distance air travel between the sixteen host cities located across Canada, the United States, and Mexico. Jackson et al. (2026) further argued that expanding the tournament from 32 to 48 teams and increasing the number of matches from 64 to 104 substantially enlarges the tournament's environmental footprint while creating significant challenges for achieving carbon neutrality.

The relationship between sport and climate change is therefore multidimensional. Climate change increasingly disrupts sporting activities through extreme weather, while sporting events themselves contribute significantly to greenhouse gas emissions. Recognising this reciprocal relationship, organisations such as FIFA, the International Olympic Committee (IOC), and the United Nations Framework Convention on Climate Change (UNFCCC) have

introduced sustainability frameworks designed to reduce emissions, improve environmental governance, strengthen climate adaptation, and promote renewable energy adoption (UNFCCC, 2021). These initiatives demonstrate increasing institutional recognition that environmental sustainability is now fundamental to the long-term future of international sport.

Jackson et al. (2026) further argued that football has evolved alongside industrialisation, economic globalisation, expanding international mobility, and increasing commercialisation, factors that have collectively increased its environmental footprint. According to their study, the growing dependence on fossil fuel-based transportation, expanding broadcasting activities, commercial sponsorship arrangements, and tournament expansion has intensified greenhouse gas emissions associated with international football. The authors recommended stronger environmental governance, more transparent emissions reporting, reduced dependence on fossil fuel-intensive operations, and greater integration of climate science into football administration. These recommendations emphasise that sustainable football requires both technological innovation and institutional reform capable of addressing the underlying drivers of climate change.

The 2026 FIFA World Cup: Climate Context

The 2026 FIFA World Cup represents the largest and most geographically dispersed tournament in the history of international football. For the first time, the competition will be jointly hosted by Canada, the United States, and Mexico, involving 48 participating nations, 104 matches, and 16 host cities distributed across North America. This expanded format reflects FIFA's objective of increasing global participation and commercial growth while creating new opportunities for tourism, infrastructure development, and international cooperation (FIFA, 2024). However, the unprecedented scale of the tournament also introduces significant environmental, logistical, and public health challenges that distinguish it from previous FIFA World Cups.

The climatic diversity of North America means that host cities will experience markedly different environmental conditions throughout the tournament. Northern cities such as Toronto, Vancouver, and Seattle generally experience relatively mild summer temperatures, whereas southern cities including Miami, Houston, Dallas, Monterrey, and Guadalajara frequently experience prolonged heatwaves, elevated humidity, and intense solar radiation. Mexico City presents additional physiological challenges because of its high altitude, lower atmospheric oxygen concentration, and increased ultraviolet radiation. These geographical

differences require location-specific climate adaptation strategies rather than uniform tournament planning.

Climate projections indicate that many host cities are likely to experience temperatures exceeding long-term historical averages during June and July when the tournament will be played. Climate Central (2026) estimated that nearly half of the scheduled World Cup matches have at least a 50% probability of occurring under environmental conditions capable of impairing athletic performance. These findings highlight the growing influence of climate change on football competitions and reinforce the importance of incorporating long-term climate projections into tournament planning, scheduling, infrastructure design, and public health preparedness.

Climate-related challenges extend beyond extreme heat. Several host cities remain vulnerable to severe thunderstorms, hurricanes, flash flooding, droughts, and wildfire smoke, all of which may disrupt competition schedules, transportation systems, stadium operations, electricity supply, communications infrastructure, and emergency response services. Climate change is increasing both the frequency and severity of these hazards across North America (IPCC, 2023). Consequently, tournament organisers must develop comprehensive emergency management systems capable of responding rapidly to multiple environmental threats occurring simultaneously.

Air quality represents another increasingly important concern. Recent wildfire seasons across Canada and the western United States have demonstrated that smoke can travel thousands of kilometres under favourable atmospheric conditions, exposing distant cities to hazardous concentrations of fine particulate matter (PM_{2.5}). Poor air quality impairs respiratory function, reduces athletic performance, and increases health risks among spectators with cardiovascular and respiratory diseases. Continuous environmental monitoring, early warning systems, and evidence-based public health interventions will therefore be essential throughout the tournament.

From an environmental perspective, the tournament itself is expected to generate unprecedented greenhouse gas emissions. Jackson et al. (2026) estimated that the competition may produce approximately 9 million tonnes of carbon dioxide equivalent, substantially exceeding emissions reported for previous FIFA World Cups. Their analysis demonstrated that transportation accounts for the overwhelming majority of emissions because of extensive international and domestic air travel between widely dispersed host cities. The expansion from 32 to 48 teams, together with the increase to 104 matches, significantly amplifies travel

demand for players, officials, media organisations, commercial partners, and millions of international supporters.

Recognising these challenges, FIFA has introduced several adaptation measures, including mandatory hydration breaks, improved environmental monitoring, greater scheduling flexibility, hybrid playing surfaces, enhanced stadium cooling technologies, and strengthened medical preparedness. Nevertheless, Jackson et al. (2026) argued that technological adaptation alone cannot fully offset the environmental consequences of tournament expansion. They concluded that the 2026 FIFA World Cup represents both the most climate-affected and the most climate-impacting football tournament ever organised, making it an important case study for evaluating future climate resilience, environmental governance, and sustainable event management in international sport.

Heat Stress and Extreme Weather Impacts on Players and Match Officials

Heat stress has become one of the most significant climate-related threats to modern football. Climate change has increased the frequency, duration, and intensity of heatwaves across many regions of the world, exposing athletes and match officials to environmental conditions that were previously uncommon during major international competitions. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), global warming has intensified extreme heat events across North America, with many regions experiencing record-breaking summer temperatures. Since the 2026 FIFA World Cup will be held during June and July, concerns regarding heat-related health risks have become central to tournament planning. Climate projections indicate that several host cities are likely to experience environmental conditions capable of impairing athletic performance and increasing the likelihood of heat-related illnesses (Climate Central, 2026).

Football is a physically demanding sport that requires continuous aerobic activity combined with repeated high-intensity movements such as sprinting, jumping, tackling, rapid acceleration, and sudden changes in direction. These activities generate substantial metabolic heat, which must be dissipated through sweating and increased blood circulation to maintain normal body temperature. However, elevated ambient temperatures and high relative humidity reduce the body's ability to dissipate heat efficiently, resulting in increased cardiovascular strain, accelerated dehydration, electrolyte imbalance, and reduced physical performance (Racinais et al., 2015). Consequently, players competing under extreme environmental conditions experience greater physiological stress, which may compromise both performance and safety.

Scientific evidence consistently demonstrates that prolonged exposure to high temperatures negatively affects football performance. Nybo et al. (2014) reported that extreme heat reduces total running distance, sprint frequency, technical accuracy, passing efficiency, decision-making, and overall work rate during competitive football matches. Heat-induced fatigue also delays physiological recovery following intense exercise and increases the risk of muscle cramps, soft tissue injuries, ligament damage, and exertional heat illnesses. Furthermore, dehydration exceeding two percent of body weight has been associated with measurable reductions in cognitive function, reaction time, and tactical decision-making, all of which are essential components of elite football performance (Sawka et al., 2007).

One of the most reliable indicators for assessing environmental heat stress is the Wet-Bulb Globe Temperature (WBGT). Unlike ordinary air temperature, WBGT incorporates the combined effects of air temperature, humidity, solar radiation, and wind speed, providing a more accurate estimate of environmental heat stress experienced during outdoor physical activity. The International Federation of Professional Footballers (FIFPRO) recommends that football matches should be modified, delayed, suspended, or postponed when WBGT exceeds established safety thresholds because the risks of exertional heat illness increase substantially under such conditions (FIFPRO, 2023). Consequently, WBGT monitoring has become an essential component of medical decision-making during major international football tournaments.

Recent climate assessments indicate that these concerns are particularly relevant to the 2026 FIFA World Cup. Jackson et al. (2026) estimated that nearly half of the tournament's scheduled matches have at least a 50% probability of being played under heat conditions capable of impairing athletic performance. Their study identified host cities such as Miami, Houston, Dallas, Monterrey, and Guadalajara as particularly vulnerable because of their combination of elevated temperatures and high humidity. Jackson et al. (2026) further observed that experiences from recent football competitions in North America demonstrated the increasing frequency of matches played under potentially dangerous environmental conditions, reinforcing the need for stronger heat management protocols during future international tournaments.

Match officials are similarly exposed to considerable physiological stress during football competitions. Referees typically cover between 10 and 13 kilometres during a competitive match while maintaining continuous concentration, rapid movement, accurate positioning, and instantaneous decision-making. Assistant referees also perform repeated high-speed running along the touchlines throughout the game. Unlike players, referees cannot easily be

substituted during competition, meaning that they often remain exposed to extreme environmental conditions for extended periods. Heat stress may impair concentration, reaction time, visual perception, and decision-making accuracy while simultaneously increasing the risks of dehydration and cardiovascular strain (Mohr et al., 2012). Despite these occupational risks, relatively limited research has examined climate-related health outcomes among football officials.

Climate change is also increasing the occurrence of severe weather events capable of disrupting football competitions. Thunderstorms, lightning, heavy rainfall, flash floods, hailstorms, hurricanes, and strong winds have become more frequent across many parts of North America (IPCC, 2023). These hazards threaten not only athlete safety but also stadium infrastructure, broadcasting equipment, transportation systems, electricity supply, and emergency response operations. Lightning poses a particularly serious threat because football is played in open stadiums where players, officials, spectators, and support personnel may be directly exposed. Consequently, tournament organisers must integrate continuous meteorological surveillance into operational planning and develop clearly defined procedures for delaying, suspending, or postponing matches when hazardous weather develops.

Recognising these growing environmental risks, FIFA has introduced several adaptation measures to improve player safety. These include mandatory hydration breaks, enhanced medical preparedness, flexible scheduling, improved environmental monitoring, hybrid playing surfaces, and increased coordination with meteorological agencies. Many matches have also been scheduled during evening hours to reduce exposure to peak daytime temperatures. Although these interventions contribute significantly to protecting player welfare, they remain primarily reactive adaptation measures. Long-term climate resilience requires more comprehensive planning based on projected climatic conditions rather than relying exclusively on short-term weather forecasts (WHO, 2021).

Jackson et al. (2026) further argued that climate change is fundamentally transforming football from both physiological and operational perspectives. According to their study, recent international competitions have demonstrated that heat-related disruptions are becoming increasingly common, highlighting the need for climate-informed scheduling, enhanced environmental monitoring, improved emergency preparedness, and evidence-based heat management policies. The authors recommended integrating long-term climate projections into tournament planning while strengthening collaboration among sports governing bodies, meteorological agencies, sports medicine specialists, and public health

authorities. Such measures would improve athlete safety while enhancing the resilience of future FIFA World Cups under increasingly challenging climatic conditions.

Overall, heat stress and extreme weather have become defining challenges for international football. Rising temperatures and increasingly frequent extreme weather events threaten player health, referee performance, competition schedules, infrastructure resilience, and tournament operations. Addressing these risks requires continuous environmental monitoring, scientifically informed heat management protocols, flexible scheduling, strengthened medical preparedness, and long-term climate adaptation planning. As global temperatures continue to rise, integrating climate science into football governance will become increasingly important for protecting athletes and ensuring the successful organisation of future international sporting events.

Public Health Implications for Spectators

The 2026 FIFA World Cup is expected to attract millions of spectators from every continent, making it one of the largest international mass gathering events ever organised. Beyond spectators attending matches inside stadiums, millions more are expected to participate in fan festivals, public viewing centres, tourism activities, cultural programmes, and commercial events associated with the tournament. While these activities generate substantial economic and social benefits, they also create significant public health challenges that are increasingly influenced by climate change. Rising temperatures, deteriorating air quality, extreme weather events, and changing environmental conditions expose spectators to multiple health risks that require coordinated planning among FIFA, host governments, public health authorities, emergency services, and environmental agencies (World Health Organization [WHO], 2021). Extreme heat represents the most significant climate-related public health threat during the tournament. Unlike elite athletes who undergo intensive physical conditioning and receive continuous medical supervision, spectators comprise individuals of diverse ages, health conditions, and physical abilities. Many supporters spend several hours walking between transportation hubs and stadiums, waiting in security queues, participating in outdoor fan activities, or sightseeing before and after matches. Prolonged exposure to high temperatures and humidity substantially increases the risks of dehydration, heat cramps, heat exhaustion, heat syncope, and potentially fatal heat stroke (Intergovernmental Panel on Climate Change [IPCC], 2023). These risks are particularly important in host cities such as Miami, Houston, Dallas, Monterrey, and Guadalajara, where climate projections indicate increasingly frequent and intense summer heatwaves.

Certain categories of spectators are particularly vulnerable to climate-related illnesses. Older adults generally have reduced thermoregulatory capacity, while infants and young children possess immature physiological systems that limit their ability to regulate body temperature effectively. Pregnant women and individuals living with cardiovascular disease, diabetes, obesity, chronic kidney disease, asthma, or chronic respiratory disorders also experience greater susceptibility to heat-related complications (WHO, 2021). In addition, many international visitors may travel from cooler climatic regions and therefore have limited physiological acclimatisation to the environmental conditions experienced in several North American host cities. These differences highlight the importance of adopting inclusive public health strategies that prioritise vulnerable populations during tournament planning.

Dehydration is expected to constitute one of the most common medical conditions affecting spectators throughout the competition. Elevated temperatures increase perspiration, resulting in substantial losses of body water and essential electrolytes. If fluids are not adequately replaced, dehydration may cause dizziness, headaches, fatigue, muscle cramps, reduced concentration, confusion, and circulatory instability. Severe dehydration may progress rapidly to heat exhaustion or heat stroke, both of which require immediate medical intervention. Consequently, adequate access to safe drinking water, shaded rest areas, cooling centres, misting stations, and emergency medical services should be regarded as essential components of spectator safety throughout the tournament (WHO, 2021).

Air quality represents another important public health concern associated with climate change. Increasing wildfire activity across North America has resulted in more frequent episodes of smoke pollution capable of affecting communities located hundreds or even thousands of kilometres from active fires. Exposure to fine particulate matter (PM_{2.5}), ozone, and other airborne pollutants increases the risks of respiratory irritation, asthma attacks, cardiovascular complications, and reduced lung function. Spectators with pre-existing respiratory or cardiovascular diseases are particularly vulnerable during periods of poor air quality. Continuous monitoring of the Air Quality Index (AQI), timely public health advisories, and appropriate medical preparedness should therefore form part of comprehensive tournament health planning (United States Environmental Protection Agency [USEPA], 2024).

Climate change also increases the likelihood of severe weather events capable of disrupting mass gatherings. Thunderstorms, lightning, heavy rainfall, flash floods, hurricanes, and strong winds may interrupt transportation systems, delay emergency response, damage infrastructure, and complicate stadium evacuation procedures. Large crowds attempting to

enter or leave stadiums simultaneously during severe weather may experience increased risks of congestion, falls, crowd crush incidents, and traumatic injuries. Consequently, emergency preparedness plans should incorporate real-time meteorological monitoring, clearly defined evacuation procedures, effective communication systems, and close coordination among tournament organisers, emergency responders, law enforcement agencies, and public health authorities.

Jackson et al. (2026) emphasised that protecting spectator health should become a central objective of climate-resilient football governance. Their study argued that climate adaptation strategies should extend beyond protecting athletes to include spectators, volunteers, tournament staff, and host communities. The authors recommended strengthening environmental monitoring systems, improving emergency medical preparedness, adopting climate-informed scheduling, expanding cooling infrastructure, and integrating public health planning into every stage of tournament organisation. According to Jackson et al. (2026), comprehensive public health preparedness is essential for ensuring that future FIFA World Cups remain safe, resilient, and sustainable under increasingly challenging climatic conditions.

Overall, climate change presents substantial public health challenges for spectators attending the 2026 FIFA World Cup. Rising temperatures, deteriorating air quality, dehydration, extreme weather events, and environmental uncertainty require comprehensive adaptation strategies that integrate climate science, public health, emergency management, and sports governance. Protecting spectator health will depend upon evidence-based planning, continuous environmental monitoring, effective risk communication, and coordinated institutional responses capable of reducing climate-related health risks throughout the tournament.

Climate-Resilient Stadium Design

Climate-resilient stadium design has become an essential component of sustainable sports infrastructure as climate change continues to intensify extreme weather events worldwide. Modern football stadiums are expected not only to accommodate sporting competitions and large crowds but also to withstand prolonged heatwaves, heavy rainfall, flooding, hurricanes, droughts, strong winds, and deteriorating air quality while maintaining safe and efficient operations. The 2026 FIFA World Cup provides an important opportunity to demonstrate how climate-resilient infrastructure can improve athlete performance, spectator safety, environmental sustainability, and long-term operational resilience. Because the tournament

spans three countries with diverse climatic conditions, climate adaptation has become a fundamental consideration in stadium planning and management.

Unlike several previous FIFA World Cups that required extensive construction of new facilities, most venues selected for the 2026 tournament are existing stadiums that have previously hosted major sporting events. The decision to utilise existing infrastructure substantially reduces greenhouse gas emissions associated with new construction, including emissions generated through cement production, steel manufacturing, transportation of construction materials, land clearing, and large-scale infrastructure development (FIFA, 2024). Renovating and upgrading existing facilities rather than constructing entirely new stadiums also supports sustainable development by conserving natural resources and reducing environmental impacts.

One of the primary objectives of climate-resilient stadium design is maintaining thermal comfort under increasingly extreme environmental conditions. Modern stadium architecture increasingly incorporates passive cooling strategies such as improved natural ventilation, reflective roofing materials, high-performance insulation, green roofing technologies, and strategic building orientation that maximises airflow while reducing solar heat gain. Where passive cooling alone is insufficient, energy-efficient air-conditioning systems, evaporative cooling technologies, and advanced ventilation systems provide additional protection against excessive heat. These engineering innovations improve athlete and spectator comfort while reducing energy consumption compared with conventional cooling technologies (United Nations Environment Programme [UNEP], 2022).

Protection from direct solar radiation is equally important. Architectural features including extended roof structures, tensile membrane canopies, external shading devices, and covered spectator seating significantly reduce exposure to intense sunlight during daytime matches. These adaptations lower surface temperatures, improve thermal comfort, and reduce the incidence of heat-related illnesses among spectators, volunteers, and tournament personnel. In regions expected to experience prolonged heatwaves, shaded environments become particularly important for protecting vulnerable population groups, including children, older adults, and individuals with chronic health conditions.

Water resource management represents another important aspect of climate-resilient stadium infrastructure. Several host regions periodically experience drought conditions, increasing the importance of water conservation technologies. Rainwater harvesting systems, wastewater recycling for pitch irrigation, low-flow sanitary fixtures, drought-resistant landscaping, and automated irrigation technologies reduce freshwater consumption while maintaining high-

quality playing surfaces. Conversely, cities vulnerable to heavy rainfall require sustainable drainage systems incorporating permeable pavements, underground drainage networks, retention basins, and flood management infrastructure capable of preventing water accumulation within stadium complexes and surrounding urban environments.

Technological innovation further strengthens climate resilience through intelligent environmental monitoring systems. Modern stadiums increasingly employ digital technologies capable of continuously monitoring temperature, humidity, air quality, energy consumption, water use, crowd movement, structural performance, and weather conditions. These systems enable facility managers to respond rapidly to changing environmental conditions while improving operational efficiency and emergency preparedness. Jackson et al. (2026) argued that although these technological improvements substantially enhance stadium resilience, infrastructure innovation alone cannot ensure environmental sustainability. The authors emphasised that technological adaptation should be accompanied by stronger environmental governance, transparent emissions reporting, reduced greenhouse gas emissions, and greater integration of climate science into football administration.

Overall, climate-resilient stadium design represents a fundamental pillar of sustainable mega sporting events. Investments in renewable energy systems, efficient cooling technologies, sustainable water management, intelligent environmental monitoring, resilient infrastructure, and environmentally responsible facility management improve athlete safety, protect spectator health, reduce operational emissions, and strengthen long-term resilience. As Jackson et al. (2026) concluded, the future sustainability of international football will depend not only on technological innovation but also on comprehensive governance reforms that integrate climate adaptation, environmental stewardship, and evidence-based decision-making into every stage of tournament planning and operation.

FIFA's Climate Commitments and Carbon Neutrality Initiatives

Climate change has become an important governance issue within international football, prompting FIFA to strengthen its environmental sustainability agenda. As the global governing body for football, FIFA recognises that the sport both contributes to greenhouse gas emissions and is increasingly affected by climate change. Consequently, environmental sustainability has become integrated into tournament planning, infrastructure development, operational management, procurement, and legacy programmes. These initiatives aim to reduce greenhouse gas emissions, improve energy efficiency, promote renewable energy,

conserve water resources, minimise waste generation, and strengthen climate resilience while maintaining the global growth of football (FIFA, 2023).

One of FIFA's most significant environmental commitments is its participation in the United Nations Framework Convention on Climate Change (UNFCCC) Sports for Climate Action Framework. Through this initiative, FIFA has committed itself to measuring greenhouse gas emissions, establishing science-based emission reduction targets, improving environmental transparency, promoting renewable energy, supporting sustainable infrastructure, and contributing to the objectives of the Paris Agreement, which seeks to limit global warming to well below 2°C while pursuing efforts to limit warming to 1.5°C (UNFCCC, 2021). These commitments reflect growing recognition that international sporting organisations have an important role in advancing global climate action.

FIFA has progressively incorporated sustainability principles into recent World Cup tournaments through comprehensive environmental management strategies. These include greenhouse gas accounting, renewable electricity procurement, energy-efficient stadium operations, sustainable procurement practices, biodiversity conservation, water conservation, waste reduction, recycling programmes, and environmental awareness campaigns. Host cities have also been encouraged to improve public transportation, reduce dependence on fossil fuels, and adopt environmentally responsible operational practices throughout tournament preparation and delivery (FIFA, 2024). These initiatives demonstrate FIFA's increasing commitment to integrating environmental sustainability into football governance.

Despite these efforts, achieving carbon neutrality during the 2026 FIFA World Cup remains extremely challenging because of the unprecedented scale of the tournament. Jackson et al. (2026) estimated that the competition could generate approximately 9 million tonnes of carbon dioxide equivalent (CO₂e), making it the highest-emitting FIFA World Cup ever organised. Their analysis demonstrated that approximately 85–87% of total emissions will originate from transportation, particularly international and domestic air travel involving teams, officials, media personnel, commercial partners, and millions of supporters travelling among sixteen widely dispersed host cities across Canada, the United States, and Mexico. According to Jackson et al. (2026), expanding the tournament from 32 to 48 teams and increasing the number of matches from 64 to 104 substantially increase transportation requirements and consequently enlarge the tournament's environmental footprint.

To compensate for unavoidable emissions, FIFA has increasingly adopted carbon offsetting initiatives involving afforestation, ecosystem restoration, renewable energy development, and other climate mitigation projects. Although these programmes contribute to climate action by

supporting emission reduction elsewhere, many environmental scientists argue that carbon offsets should complement rather than replace direct emission reductions (IPCC, 2023). Long-term sustainability requires reducing dependence on fossil fuels, improving transportation efficiency, strengthening renewable energy deployment, and integrating environmental considerations into tournament planning rather than relying primarily on offset mechanisms.

Jackson et al. (2026) questioned the consistency of FIFA's environmental commitments, arguing that tournament expansion, increasing dependence on long-distance aviation, and continued commercial relationships with fossil fuel industries create important contradictions between FIFA's sustainability ambitions and its operational practices. The authors recommended stronger environmental governance, greater transparency in greenhouse gas accounting, reduced dependence on carbon-intensive transportation, increased investment in low-carbon mobility, and closer alignment between commercial partnerships and climate objectives. According to Jackson et al. (2026), meaningful climate leadership within international football requires institutional reforms alongside technological innovation.

Overall, FIFA has made important progress by recognising climate change as a strategic governance issue and introducing sustainability initiatives across tournament planning and operations. Nevertheless, the environmental challenges associated with the 2026 FIFA World Cup demonstrate that achieving meaningful carbon neutrality will require more ambitious policies addressing transportation emissions, tournament expansion, infrastructure development, commercial governance, and long-term climate adaptation. Future FIFA competitions should therefore integrate climate science more comprehensively into decision-making while strengthening environmental accountability across all aspects of tournament organisation.

Research Gaps and Future Policy Directions

Although scientific research examining climate change and sport has expanded considerably during the past decade, important knowledge gaps remain regarding the long-term implications of climate change for international football tournaments. Most existing studies focus on greenhouse gas emissions, athlete heat stress, environmental sustainability, or stadium infrastructure individually, whereas relatively few investigations integrate climate science, sports medicine, engineering, public health, urban planning, economics, and sports governance into a single analytical framework. Future research should therefore adopt

multidisciplinary approaches capable of addressing the complex interactions between climate change and mega sporting events.

One major research gap concerns the limited availability of city-specific climate risk assessments for World Cup host venues. While regional climate projections are widely available, relatively few investigations evaluate the combined effects of heatwaves, humidity, flooding, hurricanes, severe thunderstorms, droughts, wildfire smoke, and urban heat islands for individual host cities. Developing high-resolution climate projections capable of identifying local environmental hazards would improve tournament scheduling, infrastructure planning, emergency preparedness, and public health protection.

Further research is also needed to examine the cumulative physiological effects of multiple environmental stressors on football players and match officials. Most current investigations evaluate heat stress independently, despite the reality that athletes are frequently exposed simultaneously to elevated temperatures, humidity, solar radiation, poor air quality, travel fatigue, psychological stress, and high competitive workloads. Understanding these combined effects would improve evidence-based recommendations for training, competition scheduling, recovery, injury prevention, and athlete health protection.

Additional epidemiological research is required to examine the public health impacts of climate change on spectators attending mega sporting events. Millions of supporters attend international tournaments every four years, yet relatively little evidence exists regarding heat-related illnesses, dehydration patterns, behavioural adaptation, respiratory complications associated with wildfire smoke, healthcare utilisation, or the effectiveness of emergency public health interventions during major sporting competitions. Expanding research in these areas would strengthen public health preparedness and improve climate adaptation strategies for future tournaments.

Future policy should require mandatory climate risk assessments during the selection of host cities for international sporting events. Climate projections should influence decisions regarding tournament scheduling, infrastructure investment, transportation planning, stadium design, emergency preparedness, and public health protection. International sports governing bodies should also strengthen heat management protocols using Wet-Bulb Globe Temperature (WBGT) thresholds and adopt standardised Air Quality Index (AQI) guidelines governing training modification, match postponement, and emergency response during hazardous environmental conditions.

Jackson et al. (2026) recommended greater transparency in greenhouse gas accounting, stronger environmental governance, increased investment in low-carbon transportation,

improved environmental monitoring systems, and closer collaboration among FIFA, governments, climate scientists, engineers, sports medicine specialists, and public health agencies. According to the authors, sustainable football requires both technological innovation and institutional reform capable of addressing the underlying causes of greenhouse gas emissions while strengthening climate resilience throughout international football.

Overall, future climate adaptation within football should emphasise interdisciplinary research, evidence-based policymaking, transparent environmental reporting, international collaboration, continuous climate monitoring, and sustainable governance. Lessons learned from the 2026 FIFA World Cup should guide preparations for future FIFA World Cups, Olympic Games, continental championships, and other mega sporting events as climate change continues to reshape global sport.

Future Policy Directions

The findings of this review demonstrate that climate change should become a central consideration in the governance and organisation of future FIFA World Cups and other mega sporting events. Traditional tournament planning has largely focused on logistics, infrastructure, broadcasting, security, and commercial operations. However, increasing climate variability requires a broader planning framework that integrates climate science, public health, environmental engineering, disaster risk management, and sustainable development. Future tournament policies should therefore move beyond reactive responses to extreme weather by adopting proactive climate adaptation strategies based on long-term scientific projections rather than historical climate patterns (IPCC, 2023).

One important policy priority is the integration of climate risk assessments into the process of selecting host countries and host cities. Future bidding processes should require comprehensive environmental assessments that evaluate projected temperatures, humidity, wildfire risk, flooding potential, hurricane exposure, water availability, air quality, and urban heat island effects throughout the tournament period. These assessments should complement existing evaluations of infrastructure, accommodation, transportation, and security capacity. Integrating climate projections into host city selection would reduce environmental risks while improving athlete welfare, spectator safety, and operational resilience (UNEP, 2022).

Future FIFA tournaments should also strengthen heat management policies through evidence-based environmental monitoring. Continuous measurement of Wet-Bulb Globe Temperature (WBGT) should become mandatory at every training venue and competition stadium.

Standardised international thresholds should guide decisions regarding match scheduling, hydration breaks, temporary suspension of play, or postponement when environmental conditions threaten participant safety (FIFPRO, 2023). Similar protocols should be established for deteriorating air quality using internationally recognised Air Quality Index (AQI) standards to protect athletes, officials, spectators, volunteers, and stadium personnel from harmful exposure to wildfire smoke and particulate pollution (United States Environmental Protection Agency [USEPA], 2024).

Transportation policy represents another critical area requiring reform. Research consistently demonstrates that air travel constitutes the largest contributor to greenhouse gas emissions associated with international football tournaments (Collins & Flynn, 2008). Jackson et al. (2026) estimated that approximately 85–87% of the projected emissions from the 2026 FIFA World Cup will originate from transportation, primarily because of extensive international and domestic flights across Canada, the United States, and Mexico. The authors recommended strengthening low-carbon transportation systems through greater investment in high-speed rail where feasible, electric public transportation, coordinated regional scheduling, and improved travel planning to reduce unnecessary aviation emissions. Such measures would contribute significantly to reducing the environmental footprint of future tournaments. Environmental sustainability should also become more deeply integrated into stadium design and tournament operations. Future FIFA competitions should prioritise renewable energy technologies, energy-efficient lighting, sustainable construction materials, rainwater harvesting systems, wastewater recycling, intelligent building management systems, waste reduction programmes, and circular economy principles throughout tournament planning and legacy development (FIFA, 2024). Investment in climate-resilient infrastructure would not only reduce greenhouse gas emissions but also improve resilience against increasingly frequent heatwaves, heavy rainfall, flooding, droughts, and other climate-related hazards.

Another important policy direction involves strengthening environmental governance and institutional accountability. Jackson et al. (2026) argued that meaningful climate action within international football requires transparent greenhouse gas accounting, independent environmental auditing, stronger sustainability reporting, and greater consistency between FIFA's environmental commitments and its commercial practices. The authors further recommended reducing dependence on fossil fuel-intensive operations and ensuring that commercial partnerships align more closely with global climate objectives. Strengthening environmental governance would enhance public confidence in FIFA's sustainability agenda while supporting international efforts to reduce greenhouse gas emissions.

International collaboration should also be strengthened to improve climate resilience in sport. FIFA should work more closely with organisations such as the World Health Organization (WHO), the United Nations Framework Convention on Climate Change (UNFCCC), the World Meteorological Organization (WMO), national meteorological agencies, public health authorities, and climate scientists to develop standardised international guidelines for managing climate-related risks during major sporting events. Such collaboration would facilitate knowledge sharing, improve environmental monitoring, strengthen emergency preparedness, and encourage the adoption of best practices across future international competitions.

Finally, future research should continue expanding the scientific evidence base supporting climate adaptation in football. Multidisciplinary studies involving environmental science, sports medicine, engineering, epidemiology, urban planning, economics, and governance are needed to evaluate emerging climate risks and identify effective adaptation strategies. Lessons learned from the 2026 FIFA World Cup should inform future FIFA tournaments and other mega sporting events, ensuring that sport contributes positively to global climate action while protecting athletes, spectators, host communities, and the natural environment.

CONCLUSION

Climate change has become one of the defining challenges confronting international sport during the twenty-first century, and the 2026 FIFA World Cup clearly demonstrates the growing interaction between environmental change and global sporting events. Rising temperatures, increasingly frequent heatwaves, deteriorating air quality, wildfire smoke, extreme weather events, and expanding greenhouse gas emissions have fundamentally altered the environmental conditions under which football tournaments are organised. These climate-related changes affect athlete performance, match officiating, spectator health, infrastructure resilience, tournament logistics, and environmental sustainability simultaneously, making climate adaptation an essential component of modern sports governance.

This systematic review has shown that heat stress represents one of the greatest threats to player welfare during the 2026 FIFA World Cup. Scientific evidence consistently demonstrates that elevated temperatures and humidity impair thermoregulation, accelerate dehydration, reduce physical endurance, impair cognitive performance, and increase the risks of heat exhaustion and heat stroke (Nybo et al., 2014; Racinais et al., 2015). Match officials experience similar physiological challenges because of prolonged exposure to demanding environmental conditions. These findings emphasise the importance of integrating

environmental monitoring, evidence-based heat management protocols, flexible scheduling, and comprehensive medical preparedness into tournament operations.

The review further highlights the increasing importance of air quality as a climate-related health concern. Climate-driven wildfire activity across North America has increased the frequency of smoke pollution events capable of exposing athletes, officials, spectators, and tournament personnel to hazardous concentrations of fine particulate matter. Continuous monitoring of the Air Quality Index (AQI), timely public health communication, and evidence-based operational guidelines will become increasingly important as climate change continues to intensify wildfire activity and associated respiratory health risks.

Protecting the health of millions of spectators attending the tournament also requires comprehensive public health planning. Adequate access to drinking water, cooling centres, shaded facilities, emergency medical services, effective risk communication, and coordinated disaster preparedness should become integral components of tournament management. Special attention should be given to protecting vulnerable populations, including older adults, children, pregnant women, and individuals living with chronic medical conditions who face greater risks during periods of extreme heat and poor air quality.

This review also demonstrates that climate-resilient infrastructure and sustainable stadium design are essential for reducing both environmental impacts and operational risks. Renewable energy systems, efficient cooling technologies, sustainable water management, intelligent environmental monitoring, resilient construction, and environmentally responsible facility management improve athlete safety, spectator comfort, and long-term sustainability. However, technological innovation alone cannot fully address the environmental challenges associated with increasingly large international sporting events.

Jackson et al. (2026) demonstrated that the 2026 FIFA World Cup is likely to become both the most climate-affected and the most climate-impacting tournament in FIFA history. Their analysis estimated that the tournament could generate approximately 9 million tonnes of carbon dioxide equivalent, with transportation accounting for approximately 85–87% of total emissions. The authors argued that tournament expansion, increasing dependence on long-distance aviation, and inconsistencies between environmental commitments and commercial practices present major challenges for achieving meaningful sustainability. They concluded that future FIFA competitions should strengthen environmental governance, improve emissions transparency, reduce dependence on fossil fuel-intensive operations, and integrate climate science into all stages of tournament planning and management.

In conclusion, the 2026 FIFA World Cup represents a critical opportunity to redefine how international football responds to climate change. The lessons generated from this tournament should guide future FIFA World Cups and other mega sporting events toward more sustainable, climate-resilient, and evidence-based models of organisation. By integrating climate science, environmental stewardship, public health protection, technological innovation, and transparent governance, international football can continue to inspire global audiences while contributing meaningfully to worldwide efforts to address climate change and promote sustainable development.

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