Climate Adaptation in Sport: Innovative Strategies for Performance, Management, and Policy in a Changing Environment

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Abstract

This study investigates climate adaptation in sport through three interconnected domains: athlete performance, organizational management, and policy governance. Using a qualitative design, data were collected through a systematic literature review of 82 Scopus and ScienceDirect indexed articles published between 2018 and 2025, four case studies, and 15 semi-structured expert interviews. Thematic synthesis revealed four athlete-level strategies—physiological adaptation, psychological resilience, scheduling adjustments, and wearable monitoring technologies. At the organizational level, climate-responsive facilities, mega-event innovations, and sustainability-driven models such as the Bio-Circular-Green (BCG) framework emerged as effective approaches. At the policy level, sport was identified as underrepresented in climate agendas, though evidence suggested opportunities for integration with health expenditures and public awareness campaigns. Cross-level analysis demonstrated that adaptation is most effective when athlete strategies are supported by organizational infrastructure and reinforced by policy frameworks, creating a feedback system of resilience. The study contributes to sport management scholarship by proposing a multi-level framework that positions sport as both vulnerable to climate risks and as a proactive driver of sustainable

development. Recommendations are provided for athletes, organizations, and policymakers to align strategies for enhanced climate resilience in sport systems.

Keywords: Climate adaptation, Sport management, BCG Model, Sustainability, Policy innovation

Introduction

Climate change is reshaping human activity worldwide, and sport is no exception. Increasing temperatures, altered precipitation patterns, and greater frequency of extreme weather events threaten not only natural ecosystems but also the sustainability of outdoor recreation and athletic competition. Shifts in forest composition due to climate change have been shown to influence deer populations and outdoor recreational opportunities, underscoring the interconnection between environmental systems and human activity (Bakshi, Polasky, & Frelich, 2025). Extending such findings to sport highlights that climate change is not a peripheral concern but a central determinant of how, where, and under what conditions athletes can train and compete.

The health implications of climate change are increasingly recognized within sport science. A Delphi study revealed consensus among medical and sport experts about the rising risks athletes face, including heat stress, respiratory conditions, and cardiovascular strain (Schneider, Niederberger, Kurowski, & Bade, 2024a). A subsequent study proposed a sport-specific prevention model, focusing on outdoor activities most exposed to heatwaves and poor air quality (Schneider, Niederberger, Kurowski, & Bade, 2024b). Broader intersections between climate change and rehabilitation medicine have also been reviewed, with findings indicating that physical activity is both vulnerable to environmental pressures and essential for population health (Newman, Kokame, Leochico, Fogarty, Burton, Tenforde, & Alexander, 2025). Climate stressors have further been suggested to amplify cardiovascular risks in physically active populations, underscoring the importance of integrating climate resilience into sport and exercise strategies (Thompson, Alexander, Moneghetti, & Howden, 2024). Collectively, this body of evidence illustrates that athlete well-being is inseparable from environmental health.

Beyond physiological effects, climate change exerts a profound influence on the built environment of sport. Thermal comfort in sport facilities has been shown to vary significantly between exercisers and non-exercisers in hot and humid climates, demonstrating the need for adaptive architecture and ventilation strategies (Haung, Xun, Zhao, Chen, & Gou, 2023). As rising global temperatures intensify thermal discomfort, innovations in stadium design, training facilities, and recreational infrastructure will become critical for maintaining participation and safety. The integration of climate resilience in sport and exercise with public health expenditures in coastal China has also been highlighted, showing that investment in environmentally adaptive sport infrastructure not only protects health but also reduces long-term economic costs (Li, 2024).

Psychological and motivational dimensions of adaptation also warrant attention. Psychoneuroendocrine responses to different motivational climates in sport have been examined, suggesting that environmental stressors, including those linked to climate change, interact with psychological and hormonal processes that shape performance (Hogue et al, 2025). This finding points to the complexity of adaptation: athletes and managers must address not only the physical but also the mental health consequences of competing under new environmental realities.

At the organizational and managerial level, innovation in event management and sport business models plays a vital role in adaptation. The application of the Bio-Circular-Green (BCG) economy model to a rock climbing adventure company in Chiang Mai showed how embedding sustainability into core business strategies can enhance both resilience and competitiveness (Chankuna & Panjatawee, 2025). The development of a competition management model for Ju-Jitsu at the Thailand National Youth Games, also based on the BCG framework, demonstrated how integrating ecological consciousness into event planning can improve organizational efficiency, stakeholder satisfaction, and long-term viability (Chankuna, Ownsungnoen, & Numboonjit, 2024). At the international scale, the Tokyo 2020 Olympic Games faced unprecedented summer heat, requiring organizers to implement hydration hubs, cooling stations, and acclimatization programs (Nakamura et al., 2022). Likewise, the Qatar

2022 FIFA World Cup confronted extreme desert conditions by introducing climate-responsive stadium design and advanced cooling technologies (Lucio & Gomes, 2023). These four cases—global mega-events, a national youth competition, and a local sport enterprise—illustrate diverse adaptation pressures and responses. They also demonstrate how the BCG model offers practical insights with relevance to international sustainability agendas, linking Thai innovations to global discourses on adaptation and resilience.

Taken together, current evidence paints a picture of fragmented but promising adaptation efforts. At the athlete level, studies point to the need for physiological and psychological resilience strategies (Hogue et al., 2025; Schneider et al., 2024b; Thompson et al., 2024). At the organizational level, facility design, financial investment, and sustainable event management emerge as essential adaptation levers (Chankuna & Panjatawee, 2025; Chankuna et al., 2024; Haung et al., 2023; Li, 2024). At the policy level, broader frameworks linking health, environment, and sport remain underdeveloped, though opportunities for integration into climate and health agendas have been suggested (Newman et al., 2025). Although studies exist at the athlete, organizational, and policy levels, no integrated framework systematically connects these domains. Most prior studies focus on single contexts and lack cross-level comparisons, underscoring the need for an integrated approach.

Hence, the present study addresses this gap by proposing an integrated framework of climate adaptation in sport that unites performance, management, and policy dimensions. The objectives of this study are to: (1) To identify athlete-centered strategies that mitigate risks and maintain performance under climate stress; (2) To examine organizational innovations that build resilience in facilities, events, and sport enterprises; (3) To situate sport within broader policy and governance structures for climate adaptation and public health; and (4) To identify synergies among these domains, demonstrating how adaptation at one level can reinforce adaptation at others.

This manuscript contributes in several ways. It integrates environmental science, sport management, and health research, advancing a multidisciplinary perspective on climate adaptation. It synthesizes international and Thai evidence to highlight best practices and gaps.

It provides actionable recommendations for athletes, sport managers, and policymakers to enhance climate resilience. By aligning with innovation frameworks such as the BCG model, it underscores that adaptation is not merely about survival but about reimagining sport as a proactive actor in sustainable development.

The research article proceeds by reviewing the literature on climate change and sport, illustrating key strategies and challenges. A conceptual framework will then be introduced, followed by a mixed-methods methodology incorporating systematic review, case studies, and expert interviews. The results will categorize adaptation strategies across athlete, organizational, and policy levels. Discussion will interpret these findings through resilience and innovation theories, and the paper will conclude with recommendations for embedding climate adaptation into sport systems at multiple scales.

Literature Review

Concepts and Theoretical Foundations

Climate adaptation in sport can be understood through two core conceptual lenses: resilience theory and evaluation theory. Resilience theory emphasizes the capacity of individuals, organizations, and systems to absorb shocks and maintain function under stress (Folke, 2016; Newman et al., 2025), while evaluation theory highlights the structured assessment of strategies and interventions to determine their effectiveness in practice (Chen, 2018). Together, these frameworks provide the analytical foundation for this study, enabling the systematic assessment of adaptation strategies across athlete, organizational, and policy domains. By combining resilience and evaluation perspectives, sport adaptation can be approached not merely as a reactive response but as a proactive process that can be measured, refined, and scaled (Schneider et al., 2024a; Li, 2024).

Athlete-Level Adaptation

Research at the athlete level has predominantly emphasized physiological responses to climate stress. Strategies such as heat acclimatization, hydration, cooling protocols, and scheduling adjustments have been widely investigated to mitigate risks of heat stress, dehydration, and cardiovascular strain (Schneider et al., 2024a; Thompson et al., 2024).

Wearable technologies are increasingly deployed to monitor hydration levels, heart rate, and core temperature, contributing to individualized adaptation strategies.

Beyond physiology, psychological adaptation has also been studied. Psychoneuroendocrine evidence demonstrates how motivational climates influence hormonal and psychological responses under environmental stress, highlighting the dual importance of resilience training and supportive climates (Hogue et al., 2025). Despite this growing body of knowledge, most studies remain narrowly focused on physiological risk management, leaving psychological and socio-cultural dimensions comparatively underexplored.

Organizational-Level Adaptation

At the organizational level, research highlights the role of climate-responsive facility design, event management, and sustainability-driven business models. Thermal comfort studies reveal how facility design affects both exercisers and non-exercisers in hot and humid climates, emphasizing the need for adaptive architecture and ventilation (Haung et al., 2023). Event management literature highlights the importance of cooling hubs, rescheduling, and medical readiness, particularly in mega-events such as the Tokyo 2020 Olympics and Qatar 2022 World Cup, which pioneered large-scale climate adaptations in stadium infrastructure and competition scheduling (Nakamura et al., 2022; Lucio & Gomes, 2023).

Local and national examples also provide valuable lessons. The application of the Bio-Circular-Green (BCG) model to a rock climbing enterprise in Chiang Mai and to the Ju-Jitsu competition at the Thailand National Youth Games demonstrated how ecological principles can be embedded in business operations and event management (Chankuna & Panjatawee, 2025; Chankuna et al, 2024). While grounded in the Thai context, these cases illustrate globally relevant strategies: how sustainability principles can be applied at different scales of sport, from grassroots businesses to national competitions. They contribute to theory-building by showing how locally developed sustainability frameworks such as BCG can be generalized as models for embedding adaptation in sport management worldwide.

Policy and Governance-Level Adaptation

Compared to athlete and organizational research, studies at the policy and governance level remain less developed. International frameworks, however, provide strong guidance for embedding sport within climate agendas. The United Nations Framework Convention on Climate Change (UNFCCC) recognizes sport both as a sector vulnerable to climate risks and as

a platform for promoting sustainability awareness (United Nations Framework Convention on Climate Change, 2021). Similarly, the International Olympic Committee (IOC) Sustainability Strategy mandates integration of environmental responsibility into all aspects of Olympic planning and operations, setting a global precedent for governance alignment (International Olympic Committee, 2020). Yet, despite these international frameworks, national-level integration of sport into adaptation policy remains inconsistent (Schneider et al., 2024a).

Evidence from rehabilitation and public health demonstrates the potential value of integration. Newman et al. (2025) emphasize that physical activity is both vulnerable to and protective against climate risks, while Li (2024) shows that investment in adaptive sport infrastructure can reduce long-term health expenditures. However, governance frameworks rarely connect these insights systematically. Sport is often treated as peripheral to climate planning, reflecting a persistent gap between international aspirations and national implementation.

Gaps and Pathways

A review of the literature reveals four critical weaknesses that shape the research gap. First, there is an overemphasis on physiological studies, as most athlete-level research narrowly addresses heat and hydration while underexploring psychological, social, and cultural dimensions (Schneider et al., 2024a; Thompson et al., 2024). Second, organizational frameworks remain fragmented; although facility and event innovations exist, they are rarely integrated into systematic models that can be applied across diverse contexts (Chankuna & Panjatawee, 2025; Haung et al., 2023). Third, sport continues to play only a marginal role in policy, often excluded from national climate adaptation agendas despite its vulnerability and its potential as a powerful driver of social awareness (International Olympic Committee, 2020; Newman et al., 2025; United Nations Framework Convention on Climate Change, 2021) Finally, adaptation strategies at athlete, organizational, and policy levels are typically studied in isolation, with limited attempts to demonstrate how they reinforce each other (Li, 2024; Schneider et al., 2024b). Addressing these gaps requires an integrated framework that systematically connects these levels, allowing climate adaptation in sport to evolve from fragmented responses into a coherent system of resilience.

Conceptual Framework

Building on resilience and evaluation theory, this study proposes a multi-level conceptual framework for climate adaptation in sport. The framework integrates three domains. First, athlete performance strategies – physiological, psychological, and technological adaptation. Second, organizational management strategies – climate-responsive facilities, event innovations, and sustainability models such as BCG. Third, policy and governance strategies – alignment with global sustainability agendas (UNFCCC, IOC) and national adaptation frameworks. These domains are interconnected through feedback loops: athlete-level data inform organizational decisions; organizational practices shape policy credibility; and policy provides the enabling environment for both athletes and organizations. Figure 1 illustrates the conceptual framework, showing how adaptation operates as a multi-level system with bidirectional reinforcement among athlete, organizational, and policy domains.

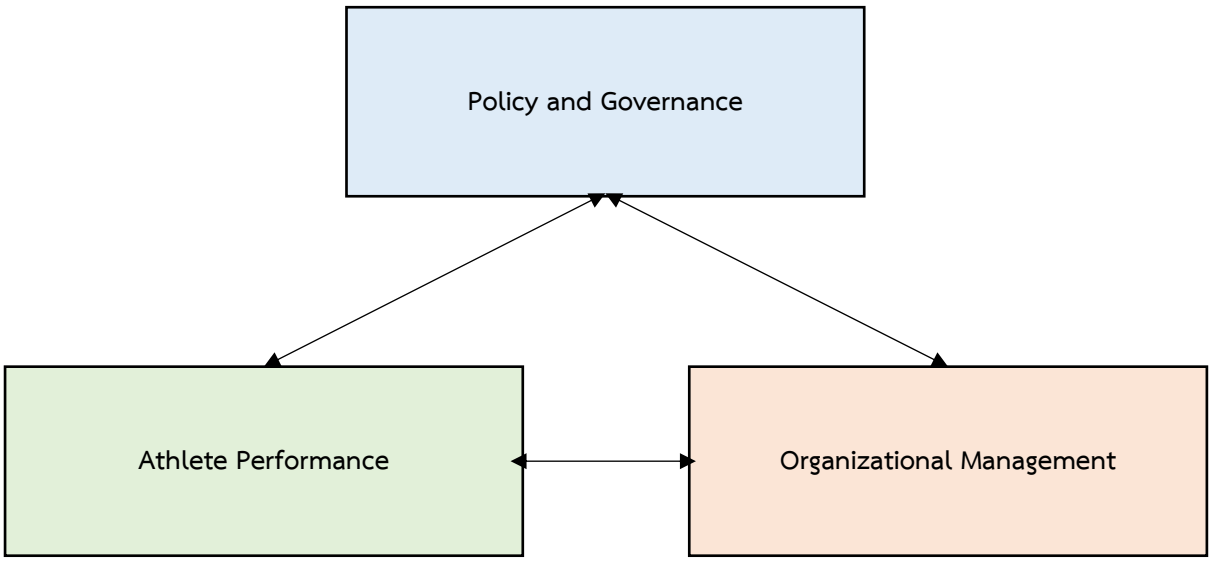

Figure 1 Conceptual Framework

Methodology

Research Design

This study employed a qualitative research design to examine climate adaptation strategies in sport across three dimensions: athlete performance, organizational management, and policy governance. A qualitative orientation was appropriate given the study's emphasis on meaning, context, and the interconnections between adaptation practices. Three complementary methods were used: a systematic literature review, case studies, and expert

interviews. Triangulation across these sources enhanced the credibility and depth of the findings (Newman et al., 2025; Li, 2024).

Systematic Literature Review

A systematic review of peer-reviewed articles was conducted using the Scopus and ScienceDirect databases to identify adaptation strategies in sport. The search was limited to 2018–2025 and employed keywords such as “climate change,” “sport,” “athlete adaptation,” “sport management,” and “policy.” Articles were included if they addressed sport-related adaptation strategies within performance, organizational, or policy contexts. Studies unrelated to sport were excluded. In total, 82 articles were included in the review.

A qualitative thematic synthesis was used to analyze the selected literature. Each article was read in full and coded for adaptation measures, contexts, and conceptual insights. Themes were then clustered into athlete, organizational, and policy domains. This process allowed for the identification of cross-cutting adaptation strategies and highlighted areas requiring further investigation (Schneider et al., 2024a; Schneider et al., 2024b; Thompson et al., 2024).

Case Studies

The case studies were purposively selected to capture different levels of climate adaptation in sport, ranging from global mega-events to national competitions and local organizational enterprises. At the global level, the Tokyo 2020 Olympic Games confronted unprecedented summer heat, requiring evidence-based countermeasures such as acclimation training, forearm immersion, ice slurry ingestion, and hydration protocols, which were implemented alongside pandemic-related restrictions (Nakamura et al., 2022). Similarly, the Qatar 2022 FIFA World Cup addressed the challenges of a desert climate through empirical climate modeling and principal components analysis, which informed semi-open stadium architecture and innovative venue planning to improve athlete and spectator comfort (Lucio & Gomes, 2023). At the national scale, the Ju-Jitsu competition at the 2023 Thailand National Youth Games in Mae Hong Son demonstrated how the Bio-Circular-Green (BCG) model could be integrated into event management, promoting sustainability, resource efficiency, and competitive integrity (Chankuna et al., 2024). At the local organizational level, a rock-climbing enterprise in Chiang Mai applied the BCG model to its business operations, embedding ecological responsibility into growth strategies and enhancing resilience against environmental disruption (Chankuna & Panjatawee, 2025). Collectively, these four cases

provide a multi-level perspective on how climate adaptation strategies manifest across performance, organizational, and governance dimensions, offering diverse and transferable insights for advancing resilience in sport.

Expert Interviews

Purposive sampling was employed to ensure that all participants had direct experience with climate adaptation in sport. The semi-structured interviews included 15 participants—5 athletes, 5 coaches, 2 sport managers, and 3 policymakers—thereby providing a balanced perspective across practice, management, and governance. The interview guide was structured around four themes: (a) perceptions of climate risks, (b) current adaptation strategies, (c) organizational and policy barriers, and (d) recommendations for future adaptation. This approach enhanced both the depth and breadth of insights by capturing diverse stakeholder experiences. Each interview lasted between 45 and 60 minutes, was audio-recorded with consent, and transcribed verbatim. Data were analyzed using thematic coding to identify recurrent ideas and emergent perspectives (Hogue et al., 2025).

Instrument

The main research instrument was a semi-structured interview guide developed based on themes identified in the literature review and case study analysis. The guide was reviewed by two senior sport management scholars and one environmental policy expert to ensure content validity and alignment with the study's objectives. Pilot interviews with two participants were conducted to refine question clarity and sequencing. This process enhanced the trustworthiness and dependability of the instrument, ensuring that the questions were relevant, unbiased, and capable of eliciting rich, reflective responses (Newman et al., 2025).

Data Collection

Data collection was conducted in three stages. First, the systematic literature review was completed through database searches and coding of peer-reviewed articles. Second, case study data were collected through document review of published articles, organizational reports, and secondary sources. Finally, interviews were carried out with experts via online video calls and in-person sessions where feasible. Each interview was conducted by the principal researcher, lasted between 45–60 minutes, and was digitally recorded with permission. Data collection continued until thematic saturation was achieved, indicating that no new insights were emerging from additional interviews.

Data Analysis

Thematic analysis was used to integrate findings across the literature review, case studies, and interviews. Codes were generated inductively and organized into categories corresponding to athlete, organizational, and policy adaptation. NVivo software supported the coding and analysis process. Triangulation across data sources ensured that interpretations were robust and that the conceptual framework reflected multiple perspectives (Bakshi et al., 2025).

Trustworthiness

Rigor in qualitative research was maintained through strategies appropriate to each method. The literature review employed a transparent search protocol and peer debriefing. Case study credibility was enhanced by triangulating data sources, including published research, organizational documents, and secondary reports. Interview credibility was strengthened through member checking with selected participants. An audit trail was maintained to document analytic decisions and ensure dependability (Adler, 2022).

Ethical Considerations

Ethical considerations were carefully addressed throughout the study. Participation was entirely voluntary, informed consent was obtained from all interviewees, and data confidentiality was strictly maintained. Ethical approval from an institutional review board (IRB) was not required, as the research involved non-sensitive interviews; however, all procedures complied with institutional standards and adhered to the principles of the Declaration of Helsinki (2013 revision). In addition, standard practices of qualitative research ethics were observed: participants' anonymity was preserved, interview data were stored securely, and prior studies serving as case evidence were properly acknowledged and cited (Chankuna & Panjatawee, 2025; Chankuna et al., 2024; Nakamura et al., 2022; Lucio & Gomes, 2023).

Results

The findings of this study are presented across three thematic domains—athlete performance, organizational management, and policy governance—reflecting the structure of the conceptual framework. Data derived from the literature review, case studies, and expert interviews converged to highlight both common strategies and context-specific innovations.

Athlete-Level Adaptation

Athletes face direct physiological and psychological risks from climate change. Thematic synthesis identified four primary adaptation strategies: physiological protocols, psychological resilience, scheduling modifications, and wearable technology use. Physiological protocols included heat acclimatization, hydration interventions, and cooling strategies such as forearm immersion and ice slurry ingestion, which were notably applied during the Tokyo 2020 Olympic Games (Nakamura et al., 2022). Psychological resilience strategies, such as fostering supportive motivational climates and resilience training, were emphasized as important in managing environmental stress (Hogue et al., 2025). Interview data further confirmed that grassroots athletes rely on simpler adjustments such as rescheduling training and competitions, while elite athletes benefit from monitoring technologies that track hydration, core temperature, and cardiovascular strain.

As one grassroots athlete noted, *"We just moved our training sessions earlier in the morning to avoid the heat, because we don't have access to cooling technologies." In contrast, an elite athlete emphasized, "With the hydration trackers and core temperature sensors, I can push further but still feel safe, even in extreme conditions."*

These themes are synthesized in Table 1, which categorizes athlete-level strategies and illustrates how the evidence is distributed across sources. The table highlights the predominance of physiological approaches in published research, while psychological and technological innovations were emphasized primarily by interviewees, indicating areas where applied practice is moving ahead of scholarship.

Table 1 Athlete Adaptation Strategies to Climate Stressors

Category	Examples of Strategies	Sources of Evidence
Physiological	Heat acclimatization, hydration protocols, ice slurries	Nakamura et al., 2022; Schneider et al., 2024a; Schneider et al., 2024b
Psychological	Resilience training, motivational climate interventions	Hogue et al., 2025
Scheduling	Training/competition at cooler times, seasonal adjustment	Thompson et al., 2024
Technology	Wearable sensors for hydration, temp & HR monitoring	Expert interviews, field practice

Organizational-Level Adaptation

At the organizational level, strategies centered on facility design, event management, and sustainability-driven business models. Studies of thermal comfort revealed that design features such as ventilation and shading significantly influence conditions in sport facilities, especially in hot and humid climates (Haung et al., 2023). Evidence from coastal China demonstrated that investments in climate-resilient infrastructure reduced health expenditures, supporting the economic case for adaptation (Li, 2024).

Case study analysis provided concrete examples. At the Qatar 2022 World Cup, semi-open stadiums incorporating advanced cooling systems were informed by empirical climate modeling, creating safer conditions for athletes and spectators (Lucio & Gomes, 2023). At the Tokyo 2020 Olympics, event organizers implemented cooling hubs and hydration stations to reduce heat-related risks, showing how operational decisions supported athlete performance in extreme heat (Nakamura et al., 2022). At the local level, integration of the Bio-Circular-Green (BCG) model into both a rock climbing enterprise and the Thailand National Youth Games demonstrated how sustainability principles can be embedded in sport management (Chankuna & Panjatawee, 2025; Chankuna et al., 2024).

As one sport manager explained, *"Our priority was not just to keep athletes safe but also to make spectators comfortable, so ventilation and shaded areas became part of our design." Another policymaker highlighted, "The BCG model helped us plan the event with fewer resources but greater efficiency, ensuring sustainability was not just a slogan."*

These insights are consolidated in Table 2, which compares organizational adaptation strategies across facility design, event management, mega-event innovation, and sustainable business models. The table illustrates that while mega-events adopt highly technical solutions, local enterprises emphasize ecological and community-based strategies, revealing the diversity of organizational adaptation pathways.

Table 2 Organizational Adaptation Strategies

Category	Examples of Strategies	Sources of Evidence
Facility Innovation	Climate-responsive architecture, ventilation systems	Haung et al., 2023; Li, 2024
Event Management	Cooling hubs, rescheduling, medical readiness	Nakamura et al., 2022

Table 2 (continue)

Category	Examples of Strategies	Sources of Evidence
Mega-Event Design	Stadium cooling systems, climate modeling	Lucio & Gomes, 2023
Sustainable Models	BCG-driven event & business strategies	Chankuna & Panjatawee, 2025; Chankuna et al., 2024

Policy and Governance-Level Adaptation

At the governance level, sport remains underrepresented in climate adaptation frameworks, though recent evidence signals increasing recognition of its importance. Reviews highlighted the dual role of sport: highly vulnerable to environmental risks but also central to maintaining physical activity and public health under changing conditions (Newman et al., 2025). Ecological modeling demonstrated how climate-driven shifts in natural environments affect recreational access and participation equity, raising governance concerns about fairness and inclusion (Bakshi et al., 2025).

Expert interviews confirmed that in Thailand, sport is largely absent from formal adaptation plans, even as government strategies evolve for infrastructure and health. Nonetheless, participants saw opportunities for leveraging sport's social influence to raise awareness and integrate adaptation strategies into broader policy frameworks.

A policymaker remarked, *"Sport has not been prioritized in national adaptation plans, but it could be a bridge to engage communities in climate awareness." Similarly, one expert emphasized, "If sport policy linked more directly to health and environment, funding for adaptive facilities would follow naturally."*

Table 3 summarizes governance strategies, ranging from integration with health agendas to resource allocation for adaptive facilities. The table shows that while health integration is increasingly supported in the literature, resource allocation and governance frameworks were emphasized primarily by practitioners, pointing to the gap between academic recognition and policy implementation.

Table 3 Policy and Governance Adaptation Strategies

Category	Examples of Strategies	Sources of Evidence
Health Integration	Linking sport participation with climate resilience	Newman et al., 2025
Environmental Policy	Addressing access inequities due to environmental shifts	Bakshi et al., 2025
Resource Allocation	Public funding for adaptive facilities and programs	Expert interviews
Governance Frameworks	Incorporating sport into national climate strategies	Policy review & expert input

Cross-Level Synergies

A key finding of this study is the interdependence of adaptation strategies across levels. Athlete-focused interventions such as cooling protocols and motivational training were found to be more effective when supported by organizational infrastructure like cooling hubs or adaptive scheduling. In turn, organizations were able to implement these measures when backed by policy frameworks that provided funding and regulatory guidance. Conversely, policy frameworks became more robust when informed by evidence from athlete health data and organizational best practices.

These relationships are visualized in Figure 2, which depicts the bidirectional interactions among athlete, organizational, and policy domains. The figure highlights how strategies at each level reinforce one another, creating a feedback system of adaptation. For example, athlete-level physiological adaptation is reinforced by organizational investment in climate-resilient facilities, while both depend on supportive policy frameworks to sustain long-term change.

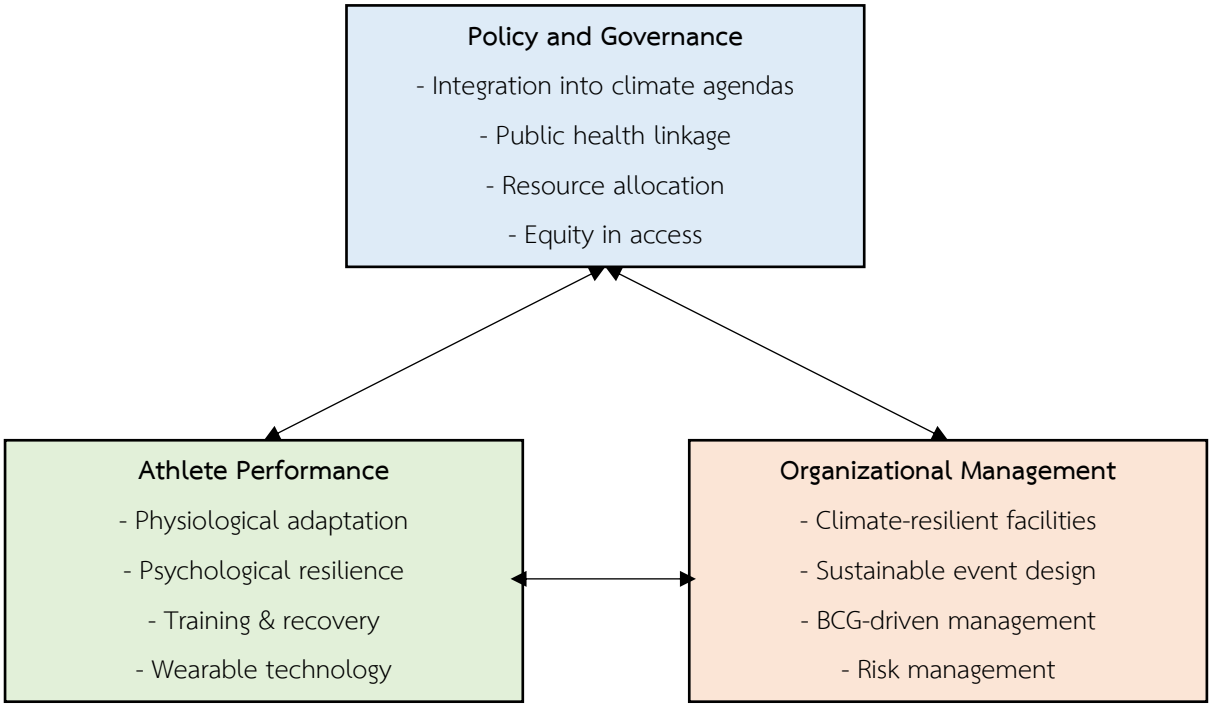

Figure 2 Cross-Level Interactions in Climate Adaptation for Sport

Summary of Findings

Overall, the results indicate that adaptation strategies are being developed across athlete, organizational, and policy domains, but implementation remains uneven. Athlete-level adaptation is the most widespread but varies according to resource availability. Organizational adaptation demonstrates innovation at both global and local scales but lacks systematic frameworks for scaling. Policy adaptation remains emergent, with gaps between academic recognition and institutional practice. The three domains are deeply interdependent, as summarized in the conceptual framework and illustrated in Figure 2. These findings set the foundation for the discussion, which connects the results to theoretical frameworks of innovation and resilience while identifying practical recommendations for sport systems.

Discussion

The purpose of this study was to examine innovative strategies for climate adaptation in sport across performance, management, and policy dimensions, while addressing gaps in current research. Specifically, it responded to four gaps identified in the literature: the overemphasis on physiological studies at the athlete level, fragmented organizational

frameworks, the marginal role of sport in policy, and the lack of cross-level integration. The study's objectives were therefore to: (1) identify athlete-centered strategies; (2) examine organizational innovations; (3) explore policy and governance frameworks; and (4) highlight cross-level synergies.

Athlete Adaptation: Bridging Physiological and Psychological Strategies

Findings confirmed that physiological protocols such as acclimatization, hydration, and cooling remain the dominant strategies, consistent with earlier research on heat countermeasures in elite sport (Nakamura et al., 2022). However, this study contributes new perspectives by demonstrating that psychological resilience and motivational climates are equally critical but less documented in existing literature. Interviewees emphasized that resilience training and supportive team cultures helped sustain performance under stress, aligning with psychoneuroendocrine evidence (Hogue et al., 2025). Importantly, wearable technologies emerged as a cross-cutting factor, serving both physiological monitoring and psychological reassurance. This reinforces resilience theory by showing how adaptation is not only biomedical but also socio-psychological, integrating multiple dimensions of athlete well-being.

Organizational Adaptation: From Mega-Events to Local Enterprises

At the organizational level, mega-events such as Tokyo 2020 and Qatar 2022 exemplify highly technical responses, deploying infrastructure innovations like advanced cooling systems and shaded rest areas (Lucio & Gomes, 2023; Nakamura et al., 2022). By contrast, local enterprises and national events illustrated resource-efficient sustainability models, particularly through the application of the Bio-Circular-Green (BCG) framework (Chankuna & Panjatawee, 2025; Chankuna et al., 2024). This contrast demonstrates that adaptation is shaped by scale and resources—mega-events innovate through technology, while smaller organizations innovate through sustainability integration. From a theoretical standpoint, this reflects diffusion of innovation, where strategies differ by resource availability but contribute to system-wide resilience.

Policy and Governance Adaptation: An Emerging but Underdeveloped Domain

Findings revealed that sport remains marginal in formal adaptation frameworks, particularly in Thailand, echoing international critiques that governance often treats climate change as peripheral to sport policy (Newman et al., 2025). Nonetheless, opportunities exist to leverage sport's cultural visibility for awareness and policy integration. This aligns with

international frameworks such as the UNFCCC Sports for Climate Action (2021) and the IOC Sustainability Strategy (2020), which position sport as both a vulnerable sector and an agent of change. Linking sport adaptation to public health financing, as shown in Li (2024) study in China, further underscores the potential for policy integration. Thus, while governance remains underdeveloped, comparative insights reveal global opportunities for embedding sport within adaptation agendas.

Cross-Level Interdependencies and Theoretical Contributions

The most significant contribution of this study is the demonstration of cross-level interdependencies. Adaptation is most effective when athlete-level strategies are reinforced by organizational practices and supported by enabling policies. For example, hydration and cooling protocols are maximized when infrastructure investments and regulatory standards are in place. This interdependence supports theories of organizational resilience and systemic adaptation. The application of the BCG model as a unifying framework underscores the importance of integrating environmental, social, and economic dimensions.

Limitations and Future Directions

This study is not without limitations. The interview sample, while diverse, was limited to 15 participants, and the case studies focused on selected events and enterprises. These limitations may constrain generalizability but provide rich contextual insights that advance understanding. Future research could expand comparative analyses across more regions, incorporate longitudinal data, and further explore the interaction of psychological and technological adaptations.

Novelty and Contribution to Knowledge

This study makes three distinct contributions to the field of sport management and climate adaptation. First, it integrates athlete physiological, psychological, and technological adaptations into a single framework, addressing a gap in current scholarship. Second, it demonstrates how organizational adaptation varies across scale, with mega-events relying on technology and local enterprises relying on sustainability models such as BCG. Third, it positions sport as both a vulnerable sector and a potential driver of societal resilience, emphasizing the importance of governance integration.

By connecting these insights, the study advances the field of sport management by positioning climate adaptation as a multidimensional challenge requiring innovative, coordinated, and context-sensitive responses.

Recommendations

The findings of this study underscore the need for coordinated and context-sensitive strategies to address climate adaptation in sport. Recommendations are presented at three levels: athlete performance, organizational management, and policy governance. Together, they provide a roadmap for advancing resilience in sport systems.

Athlete-Level Recommendations

Findings revealed that athletes primarily rely on physiological protocols (hydration, acclimatization, cooling) while psychological resilience and equitable access to adaptation technologies remain underdeveloped.

1. Integrate physiological and psychological adaptation: Coaches and training institutions should design programs that combine heat acclimatization and hydration protocols with resilience training and stress management. This dual approach acknowledges the evidence that both body and mind are impacted by climate stressors.

2. Promote equitable access to adaptation tools: National sport federations and local associations should provide low-cost monitoring tools (e.g., hydration indicators, temperature bands) and hydration support for grassroots athletes who cannot afford advanced wearable technologies. This reduces inequality in adaptation opportunities.

3. Enhance awareness and education: Universities, coaching bodies, and national federations should develop and disseminate standardized guidelines for safe training and competition under extreme heat or poor air quality, supported by regular workshops for athletes and coaches.

Organizational-Level Recommendations

Findings showed that mega-events adapt through high-technology solutions, while smaller enterprises rely on sustainability frameworks such as the BCG model. Both approaches are effective but require broader application.

1. Invest in climate-responsive facilities: Sport organizations, in collaboration with architects and local governments, should prioritize ventilation, shading, and cooling systems in facility design. Long-term planning should incorporate climate projections to avoid costly retrofits.

2. Embed sustainability frameworks in management: National sport federations and event organizers should adopt the Bio-Circular-Green (BCG) model as a guiding standard for

integrating ecological responsibility into event planning and business operations, scaling it beyond isolated Thai case studies to international contexts.

3. Adopt risk management protocols for events: Event organizers at all levels should conduct climate risk assessments, ensure medical readiness, and establish contingency plans such as flexible scheduling and cooling stations. International mega-events (Tokyo 2020, Qatar 2022) provide models that can be adapted to national and local events.

Policy and Governance-Level Recommendations

Findings highlighted that sport is still underrepresented in national adaptation frameworks, despite international examples (UNFCCC, IOC) showing its potential as both a vulnerable sector and an adaptation platform.

1. Integrate sport into national adaptation frameworks: Ministries of Sport, Health, and Environment should explicitly include sport in climate adaptation policies, with dedicated budget lines for climate-resilient facilities and grassroots programs.

2. Leverage sport for climate awareness: Policymakers should partner with sport organizations and environmental agencies to design public campaigns that use sporting events as platforms for climate awareness, targeting both athletes and spectators.

3. Promote equity in adaptation: Governments should ensure that adaptation policies extend support to athletes at all levels—elite, grassroots, and across regions with differing vulnerabilities—by subsidizing access to safe training environments.

4. Support research and monitoring: National research councils and sport science institutions should invest in longitudinal studies to track climate impacts on athlete health, facility conditions, and participation patterns. This evidence base will strengthen data-driven policy development.

Cross-Level Recommendations

Findings confirmed that adaptation is most effective when strategies at the athlete, organizational, and policy levels are closely aligned. For instance, hydration and cooling protocols implemented at the athlete level are strengthened by climate-responsive facility design at the organizational level, which in turn depends on regulatory and financial support at the policy level. To coordinate action across these domains, governments should establish cross-sectoral task forces that include ministries, sport federations, and athlete representatives to ensure coherence in adaptation strategies. Furthermore, feedback loops should be institutionalized, whereby athlete health data inform organizational infrastructure planning,

and organizational practices, in turn, guide policy agendas. This cyclical process enables evidence-based adaptation that is both systematic and sustainable.

In summary, climate adaptation in sport requires a multi-level, mutually reinforcing approach. Athletes must adopt holistic adaptation practices, organizations must integrate sustainability and risk management into their operations, and policymakers must institutionalize sport within climate agendas. By aligning strategies across these levels, sport can evolve from a vulnerable sector to a proactive contributor to societal resilience in the face of climate change.

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