A Life-Cycle AHP-CVM-VIKOR Framework for Environmental Sustainability Assessment of Super Bowl Host Cities

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Abstract

Large sport events generate short-duration yet high-intensity environmental pressure, through venue operation, spectator mobility, demand for accommodation, water consumption and solid-waste generation. However, current sustainability assessments are often decoupled from host-city selection, reducing their practical decision value. The study develops an integrated life-cycle AHP-CVM-VIKOR framework for sustainability-oriented Super Bowl host-city selection. First, a life-cycle indicator system is developed to characterize the event-related energy use, greenhouse gas emissions, water demand, solid waste, transportation, accommodation and city profile conditions. Then, an AHP-CVM coupling procedure is used to integrate expert-based criterion importance and preference-based environmental valuation, and the resulting weights are embedded in the VIKOR compromise-ranking model to calculate a Comprehensive Environmental Impact Index (CEII). The framework is applied to past Super Bowl host cities and three 2029 candidate cities, Chicago, Denver and Philadelphia. The results indicate that food-related waste, waste-diversion performance, on-site fuel consumption, wastewater generation, and stadium electricity consumption are important contributors to the CEII. Of the 2029 candidates, Chicago has the lowest CEII, with Denver and Philadelphia next. The model is extended to Olympic-scale events and tested by sensitivity analysis to show its transferability to multi-venue sport mega-events. The framework proposed is a transparent decision support tool to compare candidate cities and to identify priorities for environmental mitigation.

Keywords

Sport mega-events, environmental sustainability, host-city selection, AHP-CVM, VIKOR, Comprehensive Environmental Impact Index.

1. Introduction

The Super Bowl is one of the most powerful single-game sport events in the US. Its event window is short, but it concentrates spectator travel, energy demand for the stadium, accommodation use, media operation and waste-management pressure in a single metropolitan region. As host cities are increasingly challenged by sustainability expectations, it is important to consider not only market size, stadium capacity and service infrastructure in event selection, but also the environmental burden that the event may produce [1-3].

Previous studies have examined the environmental impacts of sport mega-events from perspectives including carbon footprint, tourism pressure and sustainability reporting [1-5]. These are valuable studies but there are two limitations. Firstly, environmental assessments are often done post event, and are not fully integrated into the host city selection. Second, the boundaries of indicators and the weighting schemes vary across studies, making it difficult to compare cities under a unified decision criterion. Thus, a structured model that links measurable environmental indicators with city characteristics and host-city ranking is needed.

This study fills this gap by proposing a life-cycle AHP-CVM-VIKOR framework for environmental sustainability assessment. There are three main contributions. The first step is to construct a multi-dimension indicator system, including energy, greenhouse gas emissions, water use, solid waste, transportation, accommodation and city-profile characteristics. Second, a coupled weighting method is designed to combine AHP-based expert judgments and CVM-based environmental preference valuation, which reduces the dependence on a single weighting source. Third, the VIKOR model is applied to establish a compromise sustainability ranking of the past host cities and the candidate host cities, and Kendall correlation and sensitivity analysis are applied to explain the model robustness and the urban drivers.

The resulting framework is targeted to a decision stage, not only for post-event reporting. It translates the diverse environmental pressures into comparable indicators. Then it relates these indicators with methods of weighting, ranking and sensitivity analysis. This structure enables comparison of cities, explains why a city performs better or worse, and identifies the mitigation actions that would have the greatest effect before the event is finally allocated.

2. Research Methodology

2.1. Scope of the Research and Basic Assumptions

The proposed methodology contains six steps, including event boundary definition; life cycle indicator system construction; AHP-CVM coupled weight calculation; host city ranking with VIKOR; short-term indicator trend forecasting with GM(1,1); and urban relationship interpretation with Kendall rank correlation. The evaluation boundary encompasses a typical event-related month, from prep through game day operation and immediate post-event activities. This time window captures the major resource-use and emission sources induced by the Super Bowl, while maintaining the cross-city comparison operational and data-available.

We make four assumptions. First, we exclude abnormal disturbances such as major natural disasters, political incidents or sudden energy crises so that the model reflects representative event conditions. Second, it assumes that the official statistics and published datasets are comparable after unit harmonization. Third, it is assumed that the size of the Super Bowl is approximately the same across the set of candidate cities in any given year. Fourth, the local energy systems, transport patterns, waste-management capacity and urban spatial structure mainly explain the differences in CEII values.

2.2. Environmental Indicator System of Life Cycle

Table 1. Environmental indicators at the event level used in the CEII calculation.

Dimension	Code	Indicator	Unit	Attribute
Energy and greenhouse gas (GHG)	x1	Electricity usage of stadiums	MWh	Cost
Energy and GHGs	x2	Consumption of fuel on site	GJ	Cost
Energy and GHGs	x3	Share of renewable electricity	%	Benefit
Energy and GHGs	x4	GHG emissions from venue operations	t CO2e	Cost
Water consumption	x5-x6	Use of potable water; generation of wastewater	m3	Cost
Solid wastes	x7-x10	Total solid waste; diversion rate; food waste; throwaway plastics	t/%/kg	Cost/Benefit
Transportation	x11-x12	Local and long-distance transport emissions	t CO2e	Cost
Housing	x13	Accommodation and emission of media	t CO2e	Cost

The environmental footprint of a Super Bowl event is described using 13 event-level indicators. The indicators are organized by life-cycle impact-output logic on energy and greenhouse gas emissions, water use, solid waste and materials, transportation and accommodation. Cost indicators are environmental burdens, thus lower values are preferred. Higher values are used to denote environmental mitigation capacity for benefit indicators. All indicators are normalized before the multi-criteria ranking stage in order to allow comparison of indicators with different units within the same decision framework.

2.3. City-Profile Indicators and Response Logic

The impact at the event level is contingent on the broader host-city contexts. To explain the cross-city differences and to support correlation analysis, five city-profile indicators are introduced. These variables are not substitutes for the event-level indicators, but rather describe contextual conditions that may enhance or diminish the event footprint. Overall, climate demand and grid carbon intensity are expected to increase CEII, while sustainable mobility share, waste diversion capacity, and urban compactness are expected to decrease CEII.

The distinction between event indicators and city-profile indicators is important. The calculation of CEII is directly based on the event indicators, while the city-profile indicators are used for interpretation and policy diagnosis. Thus, the model does not confuse explanatory variables with ranking variables, while at the same time keeping a clear path from ranking results to urban management recommendations.

Table 2. City-profile indicators to understand differences in environment.

Code	City profile indicator	Expected association with CEII
y1	Climate and demand for heating/cooling (CHD)	Higher climate demand could mean more stadium electricity use, more fuel use and higher venue emissions.
y2	Grid carbon intensity (GCI)	A carbon-intensive grid boosts the emission effect of electricity consumption.
y3	Sustainable mobility share (SMS)	More walking, cycling and public transport could help cut local transport emissions.
y4	Waste diversion performance (WDP)	A more effective diversion system reduces pressure on landfills and increases material recovery.
y5	Urban compactness and density (UDC)	Compact urban form can reduce travel distances and increase infrastructure efficiency.

2.4. Integrated AHP-CVM Weighting Model

Expert judgment is transformed into a set of criterion weights through the use of the Analytic Hierarchy Process (AHP) [6-7]. Experts compare environmental indicators on a Saaty scale of 1-9, which results in the formation of the pairwise comparison matrix A. Then the eigenvector of the maximum eigenvalue is normalized to obtain the weight vector of AHP. If the consistency ratio CR is less than 0.10, the judgment matrix is considered acceptable. The preference-based valuation component is applied with the Contingent Valuation Method (CVM) [8-9]. Then the valuation scores are normalized and transformed into criterion weights according to the CVM.

A coupling-weight method is proposed to balance the AHP weights derived from experts and the CVM weights derived from preferences. Let the contribution coefficients of the two weighting sources be gamma_AHP and gamma_CVM, where gamma_AHP + gamma_CVM = 1. The final coupled weight is computed as:

$$w_j = \text{gamma_AHP} * w_j^{AHP} + \text{gamma_CVM} * w_j^{CVM}.$$

The input for the VIKOR ranking step are the coupled weights. Such a design minimizes the chance that the final ranking of cities is influenced by either expert judgment or public preference.

2.5. Host-City Ranking based on VIKOR

VIKOR is a multi criteria decision making method to find compromise solution under conflicting criteria [10-11]. This is suitable for the selection of the host city, because a city can perform well on some environmental indicators and poorly on others. For each criterion j, the best value and the worst value are determined according to the attribute of the criterion. Then group utility measure S_i and individual regret measure R_i are calculated by weighted normalized distances from the best value. Finally, the group utility and individual regret are aggregated to obtain the VIKOR compromise index Q_i.

$$Q_i = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*), v = 0.5.$$

In this study, the Q_i is reinterpreted as the Comprehensive Environmental Impact Index (CEII). The lower the CEII, the lower the environmental burden and the more sustainable the option for the host city.

2.6. GM(1,1), Kendall Correlation and Data Sources

Short-term trend prediction for indicators with limited but ordered observations [12-13] is performed with the aid of a grey-system forecasting model, GM(1,1). We investigate monotonic relationships between CEII and city-profile variables using Kendall rank correlation. When tau is positive, the two rankings go in the same direction and when tau is negative, there is an inverse association. U.S. public datasets are collected from Energy Information Administration, World Bank DataBank, Bureau of Transportation Statistics, Federal Reserve Economic Data, and NOAA Climate Data Online. Chicago, Denver and Philadelphia are selected as the host cities for 2029 because each has an existing NFL team, major metropolitan service capacity and large-scale event infrastructure.

Before calculation, all indicators are checked for unit consistency, direction consistency and abnormal values. The cost indicators are normalized so that a better performance value is associated with a lower environmental burden, while the benefit indicators are normalized in the opposite way. This is done in the first step of the preprocessing so that the subsequent VIKOR ranking is not affected by the differences in units or by mixing of benefit and cost attributes.

3. Results and Discussion

3.1. Results of Coupled Weighting

Table 3. Coupled AHP-CVM with highest influential weights.

Rank	Code	Indicator	Coupled weight
1	x9	Food waste per head	0.17189
2	x8	Diversion rate	0.11578
3	x2	Site fuel consumption	0.11364
4	x6	Wastewater production	0.09777
5	x1	Stadium power consumption	0.09424
-	x11-x13	Long distance travel, local transport, accommodation/media emissions	Moderate to low, but still relevant

The coupled weights indicate that the highest relative importance is placed on per capita food waste (x9), waste diversion rate (x8), on-site fuel consumption (x2), wastewater generation (x6), and stadium electricity consumption (x1). This result shows that event sustainability cannot be determined only by carbon emissions, but food-service practice, waste diversion, fuel use, and water-system pressure have a major impact on the final CEII.

3.2. Environmental Impacts of Former Host Cities

First, the AHP-CVM-VIKOR model is applied to past Super Bowl host cities. Detroit, Arlington, and New Orleans have the lowest CEII values of approximately 0.353, 0.363, 0.363, respectively. This group of cities is a low-impact benchmark group in the historical sample. Mid-ranked cities, such as Indianapolis, Pasadena and Santa Clara, are facing moderate environmental pressure and would benefit from targeted improvements rather than a complete system redesign. On the other hand, Jacksonville, Glendale and Houston have the highest CEII values, indicating higher resource use and emission burdens under the selected criteria.

Table 4. Interpretation teams from previous host cities.

Group	Representative towns	Meaning
Low impact benchmark	Detroit; Arlington; New Orleans	Lower composite burden. Useful reference cases for future host planning.
Moderate-impact group	Santa Clara; Pasadena; Indianapolis	Mitigation needs to be targeted, in particular in the waste, energy and local mobility sectors.
High impact group	Glendale; Houston; Jacksonville	Higher resource consumption and emission load; need for stronger environmental controls before the event.

3.3. Choice of Candidate-City for 2029 Super Bowl

The same model is then applied to the three candidate cities for 2029. Chicago has the lowest CEII, followed by Denver and Philadelphia. Because the CEII is perceived as an environmental burden index, Chicago is the ideal candidate from a sustainability-oriented perspective in the host-city selection. The difference between Chicago and Philadelphia is large enough to support a clear ranking. Denver is somewhere in the middle of the two cities, suggesting that it is somewhat environmentally competitive but has room to improve in energy use, diversion of waste and event mobility.

Table 5. Ranking of the candidate cities by CEII 2029.

Position	Candidate city	CEII	Interpretation
1	Chicago	0.41235	The smallest environmental burden of the three candidates
2	Denver	0.46792	Medium impact; requires targeted mitigation
3	Philadelphia	0.53184	Highest burden; stronger measures needed for waste and mobility

3.4. Relation of Urban Characteristics and CEII

A Kendall correlation analysis between CEII and the five city-profile indicators is performed to explain the city-level drivers of environmental performance. The results suggest a positive association between CEII and both grid carbon intensity and climate-related energy demand, with estimated coefficients of about 0.42 and 0.58, respectively. This implies that carbon intensive electricity systems and high heating/cooling demand generally increase event related environmental pressure.

Urban density and compactness negatively correlate with CEII at a coefficient of around -0.46. The results suggest that compact cities may shorten the local travel distance and improve the

efficiency of infrastructure. Negative associations are also observed for sustainable mobility and waste diversion, although the strength of these relationships is less pronounced. Combined correlation results suggest that clean electricity, compact urban form, and low-carbon mobility should be considered together in event sustainability planning.

4. Transferability to Olympic-Level Competitions

The Olympic Games are chosen as an extension case because it is more complex than a single game event. It involves multi-venue operation, longer duration, wider demand for accommodation, more international mobility and higher requirements for infrastructure resilience [14-15]. For transferability, the same indicator system is maintained; however, the weights of the AHP are modified to consider multi-venue operation and longer duration of the event.

An Olympic-size evaluation places far more emphasis on sustained energy and water use than a Super Bowl evaluation, because many venues are running for long periods of time. From the environmental point of view, the cities with lower CEII values are more suitable for multi-venue events in this setting. These results do not mean that hosting is immediately feasible, but they do demonstrate that the proposed framework can be adjusted for different sport mega-event scales.

Sensitivity Analysis and Managerial Implications

To perform the sensitivity analysis, three representative indicators are changed, including on-site fuel consumption (x2), total solid waste generated (x7) and per-capita food waste (x9). Their values are multiplied by 1.05, 1.15 and 1.30 respectively and the CEII response is recalculated. The CEII responds clearly to changes in all three of the indicators. Total solid waste generated and per-capita food waste are observable variations in the index. This confirms waste control as a key intervention point in event sustainability management. CEII is also influenced by on-site fuel consumption, which shows that venue operation and temporary energy supply remain relevant when the stadium electricity mix is considered separately.

Table 6. Sensitivity analysis of selected indicators.

Indicator	Why they are sensitive	Implications for management
x2 fuel consumption on site	Temporary power and venue operations have a direct impact on operational emissions.	Use cleaner temporary power, and reduce dependence on backup fuel.
x7 Total waste solid	Large spectator flows result in concentrated waste within a short event window.	Enhance source sorting, recovery routes and waste contractor coordination.
x9 Per capita food wastage	Avoidable waste can quickly increase due to food-service demand uncertainty.	Use demand forecasting, menu planning and donation or recovery mechanisms.

Table 7. The model identified practical mitigation priorities.

Priority area	Primary work
Waste and food	Reduce PFW and enhance WDR by demand forecasting, reusable service systems, source sorting and recovery partnerships.
Energy and fuel	Purchase more renewable electricity and cut back on temporary fuels by employing cleaner backup-power plans.
Water management	Track and conserve potable water use and wastewater generation at the venue level.
Transportation and urban form	Enhance linkages for public transit, crowd control and tight accessibility between the stadium, hotels and transit nodes.

It is also evident that the same methodological structure can be valid for different sport events, provided that indicator weights and performance data are recomputed. For practical use, the weights should be updated by local organizers considering the duration of the event, the number of venues, the expected travel demand and the available mitigation measures.

5. Conclusion

This study proposes a life-cycle AHP-CVM-VIKOR framework to assess the environmental sustainability of Super Bowl host cities. The framework incorporates thirteen event-level environmental indicators, five city-profile indicators, a coupled weighting model, VIKOR compromise ranking, GM(1,1) forecasting, Kendall correlation analysis, and sensitivity analysis. It thus provides a structured and interpretable tool to compare candidate cities under a common criterion of sustainability.

Our empirical results show that past Super Bowl host cities have very different CEII values. Detroit, Arlington and New Orleans are among the benchmark cities with relatively low impacts while Jacksonville, Glendale and Houston carry higher combined environmental loads. Chicago has the lowest CEII among the candidate cities of 2029, with Denver and Philadelphia following, thus making Chicago the most sustainable candidate under the proposed evaluation framework.

The extension to Olympic-scale events further illustrates the transferability of the model to larger sport mega-events after weight recalibration. The sensitivity analysis emphasizes the importance of waste control, food-service management and on-site fuel reduction. Overall, the proposed framework can assist event organizers and city decision-makers to identify the high-impact environmental drivers, compare host-city alternatives, and design targeted mitigation strategies for future sport mega-events.

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