Original Research Article

Environmental sustainability assessment of super bowl host cities: A framework based on location-dependent environmental effects

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Abstract: Large-scale sporting events such as the Super Bowl generate substantial environmental impacts, yet traditional assessment frameworks often underestimate total impacts and fail to consider location-specific factors that can result in environmental impact differences of up to 10 times between cities hosting identical events. This study develops a comprehensive environmental sustainability assessment framework that explicitly distinguishes between location-dependent and location-independent environmental effects for Super Bowl host city evaluation. The framework integrates multiple environmental indicators into a unified Environmental Sustainability Score through regional differentiation factors including climate, transportation infrastructure, energy structure, and waste management capacity. Evaluation results demonstrate that energy structure factor is the most critical determinant of environmental sustainability, with cities featuring high renewable energy ratios consistently achieving higher scores than those with low renewable energy ratios. The framework successfully identifies sustainable hosting options beyond traditional selection criteria. This research provides a data-driven approach for evidence-based host city selection, emphasizing that prioritizing cities with high renewable energy ratios and strong public transportation infrastructure can significantly reduce environmental impacts.

Keywords: super bowl; environmental sustainability assessment; location-dependent environmental effects; renewable energy; host city selection

1. Introduction

Large-scale sporting events such as the Super Bowl attract over 100 million viewers annually, generating substantial economic benefits but also imposing significant environmental burdens, with a single event's footprint exceeding 28,000 metric tons of equivalent [1,2]. Traditional environmental impact assessments have primarily focused on direct venue operations, often underestimating total impacts by approximately 90%, while neglecting critical components such as spectator transportation and digital infrastructure emissions [3,4]. Moreover, existing frameworks rarely consider how location-specific factors, including regional energy grid composition, transportation infrastructure, climate conditions, and waste management systems, fundamentally alter environmental outcomes, with location-dependent factors resulting in environmental impact differences of up to 10 times between cities hosting identical events [5,6].

This study addresses these gaps by developing a comprehensive framework that explicitly distinguishes between Location-Dependent Environmental Effects (LDE) and Location-Independent Environmental Effects (LIE). The framework integrates multiple environmental indicators into a unified Environmental Sustainability Score (ESS) that enables quantitative comparison of potential host cities. Using Super Bowl LIX (New Orleans, 2025) as a baseline, this research quantifies total environmental impacts at 28,912 tCO_2, with transportation dominating at 49.4% and digital infrastructure contributing 38.2%, while venue emissions account for only 10.4% [7]. The framework incorporates regional differentiation factors, climate, transportation infrastructure, energy structure, and waste management capacity, through empirically derived influence functions. The primary objectives are to develop a data-driven environmental sustainability assessment framework for Super Bowl host city selection, quantify location-dependent and location-independent environmental effects, and provide evidence-based recommendations for sustainable event planning [8].

2. Research methodology

2.1. Research framework

This study develops a comprehensive environmental sustainability assessment framework that explicitly distinguishes between LDE and LIE. The framework integrates multiple environmental indicators into a unified ESS for quantitative comparison of potential Super Bowl host cities.

Environmental effects are categorized into primary effects, energy consumption , water consumption W, waste generation G, greenhouse gas emissions I_{GHG}, and air pollution I_{AP}, and marginal effects, digital infrastructure carbon emissions I_{DICE} and sponsor activities impacts I_{SDAI}. These indicators are classified into LDE and LIE categories based on their sensitivity to location-specific factors.

2.2. LDE/LIE framework development

The LDE category includes indicators that vary significantly based on host city characteristics:

$$LDE=\omega_1E+\omega_2W+\omega_3I_{GHG}+\omega_4IAP+\omega_5G$$

where ω_i (i=1,2,…,5) are weight coefficients for each environmental indicator, to be determined through data-driven calibration.

The LIE category includes indicators that remain relatively constant across different host cities due to standardized event operations:

$$LIE=\theta_1I_{DICE}+\theta_2I_{\backslash SDAI}$$

where θ_1 and θ_2 are weight coefficients for digital infrastructure and sponsor activities, respectively, to be determined through data-driven calibration.

The TEI is defined as a weighted combination of LDE and LIE:

$$TEI=\lambda_1LDE+\lambda_2LIE$$

where λ_1 and λ_2 represent the relative importance of location-dependent and location-independent effects, with $\lambda_1+\lambda_2=1$. The specific values of λ_1 and λ_2 will be determined based on policy guidelines and empirical analysis in the model validation section.

2.3. Regional variation factors and impact functions

Regional differentiation factors capture location-specific environmental sensitivities. We define four key factors: climate impact factor α, transportation infrastructure factor β, energy structure factor γ, and waste management capacity factor δ.

For energy consumption , which is influenced by climate and energy structure, the relationship is expressed as:

$$E=E_0\cdot f_E(\alpha)\cdot g_E(\gamma)$$

where E_0 is the baseline energy consumption. The climate influence function $f_E(\alpha)$ exhibits a nonlinear quadratic relationship, and the energy structure influence function $g_E(\gamma)$ reflects the efficiency difference between renewable and fossil fuel energy sources:

$$f_E(\alpha)=0.02\alpha^2-0.08\alpha+0.90$$

$$g_E(\gamma)=1/0.60\gamma+0.35$$

where $\gamma\in[0,1]$ represents the renewable energy ratio.

Water consumption W is primarily influenced by climate:

$$W=W_0\cdot f_W(\alpha)$$

where the climate influence function is:

$$f_W(\alpha)=0.70+0.15$$

Greenhouse gas emissions I_{GHG} are influenced by transportation infrastructure and energy structure:

$$I_{GHG}=I_{GHG,0}\cdot f_{GHG}(\beta)\cdot g_{GHG}(\gamma)$$

where the influence functions are:

$$f_{GHG}(\beta)=1-0.08$$

$$g_{GHG}(\gamma)=1-0.92$$

Waste generation G is influenced by waste management capacity:

$$G=G_0\cdot f_G(\delta)$$

where the influence function is:

$$f_G(\delta)=2.50-0.20$$

Substituting the influence functions into equation (1), we obtain the complete expression for LDE:

$$LDE=\omega_1E_0\cdot f_E(\alpha)\cdot g_E(\gamma)+\omega_2W_0\cdot f_W(\alpha)+\omega_3I_{GHG,0}\cdot f_{GHG}(\beta)\cdot g_{GHG}(\gamma)+\omega_4I_{AP}+\omega_5G_0\cdot f_G(\delta)$$

2.4. SDP and ESS calculation

To account for cities' future improvement capacity, we introduce the Sustainable Development Potential (SDP) indicator:

$$SDP=\mu_1\cdot RES+\mu_2\cdot IIP+\mu_3\cdot PCS+\mu_4\cdot GCI$$

where RES is Renewable Energy Expansion Potential, IIP is Infrastructure Improvement Potential, PCS is Policy Commitment Score, and GCI is Green Capital Investment trend. The weight coefficients μ_i (i=1,2,3,4) are determined based on the relative importance of each dimension for long-term environmental improvement, with $\sum_{i=1}^{4}\mu_i=1$. The specific values of μ_i will be calibrated using baseline case data in the model validation section.

The final ESS is calculated as:

$$TEI_{norm}=(TEI-TEI_{min})/(TEI_{max}-TEI_{min})$$

$$ESS=100\cdot(1-TEI_{norm}+\kappa\cdot SDP)$$

where TEI_{norm} is the normalized TEI value calculated using min-max normalization, κ is the moderation coefficient for sustainable development potential, and ESS ranges from 0 to 100, with higher values indicating better environmental sustainability. The normalization ensures that ESS values are comparable across different candidate cities.

3. Model verification

3.1. Data resource

To validate and calibrate the proposed framework, we use Super Bowl LIX (February 9, 2025, Caesars Superdome, New Orleans, Louisiana) as the baseline case study. This event attracted over 125,000 visitors and 123 million U.S. viewers, providing comprehensive environmental footprint data for model calibration.

Data for environmental footprint quantification were obtained from multiple sources: (1) NFL official reports and sustainability documentation; (2) U.S. Energy Information Administration (EIA) for regional energy grid data; (3) U.S. Environmental Protection Agency (EPA) for air quality and emissions standards; (4) city-level transportation and infrastructure statistics; and (5) academic literature on sports event environmental impacts.

The quantified environmental footprint of Super Bowl LIX is summarized as follows: total energy consumption E = 100,459 MWh (transportation: 97,159 MWh, 96.7%; venue: 3,300 MWh, 3.3%); total water consumption W = 143,042 m^3 ; waste generation G = 60 tons; total greenhouse gas emissions $I_{GHG}=28{,}912\ tCO_2$ (transportation: 14,300 tCO_2, 49.4%; digital infrastructure: 11,060 tCO_2, 38.2%; venue: 3,000 tCO_2, 10.4%; sponsor activities: 552 tCO_2, 1.9%); air pollution indicators including AQI increase (+25), NO_x emissions (25,000 kg), and $PM_{2.5}$ emissions (5,621 kg).

3.2. Weight determination method

Weight coefficients are determined through a three-step process: (1) multi-indicator standardization, (2) comprehensive impact factor assessment, and (3) normalized weight allocation.

Step 1: Multi-Indicator Standardization

Due to vast differences in units and magnitudes across environmental indicators, we employ z-score standardization. For an indicator , the standardized value is:

$$X_{std}=(X-X_{ref})/(X_{scale})$$

where X_{ref} is the reference baseline value (annual environmental data for medium-sized U.S. cities). Using Super Bowl LIX data, standardized values are: $E_{std}=3.056$, $W_{std}=0.477$,$I_{GHG,std}=0.586$, $I_{AP,std}=0.337$, and $G_{std}=0.030$.

Step 2: Comprehensive Impact Factor Assessment

The comprehensive impact factor F_i integrates three dimensions: persistence factor P_i, carrying capacity difference factor C_i, and social attention factor S_i:

$$F_i=0.4\times P_i+0.3\times C_i+0.3\times S_i$$

Calculated values are:$F_E=0.79$,$F_{AP}=0.77$, $F_W=0.69$, $F_{GHG}=0.63$, and $F_G=0.35$.

Step 3: Normalized Weight Allocation

The preliminary weight is calculated as $\omega_i^{'}=X_{std,i}\times F_i$, then normalized to ensure $\sum_{i=1}^{5}\omega_i=1$. The final LDE weight coefficients are:

$$\omega_1=0.714,\quad \omega_2=0.097,\quad \omega_3=0.109,\quad \omega_4=0.077,\quad \omega_5=0.003$$

For LIE weights, based on Super Bowl LIX data ($I_{DICE}=11{,}060\ tCO_2$, $I_{SDAI}=552\ tCO_2$), weights are allocated proportionally:

$$\theta_1=0.952,\quad \theta_2=0.048$$

For TEI weights, based on UNEP guidelines, we set $\lambda_1=0.70$ and $\lambda_2=0.30$. For SDP weights: $\mu_1=0.35$ (RES), $\mu_2=0.30$ (IIP), $\mu_3=0.20$ (PCS), and $\mu_4=0.15$ (GCI).

3.3. Regional variation factor quantification

Regional differentiation factors (α, β, γ, δ) are quantified through established methodologies to capture location-specific environmental sensitivities. The climate impact factor is quantified based on Köppen-Geiger climate zone classification, normalized to a 0-10 scale. Values range from 0.6 (temperate coastal) to 1.2 (hot and dry), reflecting heating and cooling demands that significantly influence energy consumption patterns.

The transportation infrastructure factor β is derived from public transit ridership, road network density, and modal share data, normalized to a 0-10 scale. Higher values indicate better public transportation infrastructure, which reduces spectator travel emissions and contributes to lower greenhouse gas emissions. The energy structure factor γ is calculated as the renewable energy ratio from EIA state-level electricity generation mix data, ranging from 0 to 1. For example, California achieves $\gamma = 0.52$ (52% renewable), while Louisiana has $\gamma=0.08$ (8\% renewable), demonstrating substantial regional variations in energy grid composition.

The waste management capacity factor is scored from EPA municipal solid waste management reports, normalized to a 0-10 scale. Higher values indicate better waste diversion rates and recycling infrastructure, which directly influence waste generation impacts and environmental outcomes.

4. Results and analysis

Using the calibrated weights from Section 3 and Super Bowl LIX as the baseline, we calculated ESS indicators for selected potential Super Bowl host cities using the MAX-MIN normalization method. The results, presented in **Table 1**, demonstrate the framework's ability to differentiate cities based on environmental sustainability performance. These indicators are relative rather than absolute, enabling quantitative comparison across different candidate cities.

Table 1. Environmental sustainability score rankings for selected super bowl host cities.

City	ESS	TEI	SDP	RR	CS	GS	WS	RES/IIP/PCS/GCI
Stanford	100	56,328	0.84	100%	0.6	7	7	9/8/8/8
San Francisco	71.44	75,627	0.90	52%	0.9	9	9	9/9/9/9
Pasadena	63.12	81,014	0.80	44%	0.8	8	8	8/8/8/8
Los Angeles	51.82	88,483	0.90	34%	0.8	9	9	9/9/9/9
San Diego	49.73	89,766	0.77	33%	0.7	8	8	8/7/8/8
Las Vegas	12.05	114,421	0.73	10%	1.2	8	8	7/8/7/7
New Orleans	6.14	118,291	0.73	8%	1.0	7	7	7/8/7/7

The ESS rankings reveal clear patterns across cities. Top-ranked cities (ESS 60) such as Stanford (ESS = 100), San Francisco (ESS = 71.44), and Pasadena (ESS = 63.12) are characterized by high renewable energy ratios (40%) and excellent public transport infrastructure (Geo/Trans scores 8). Mid-ranked cities (ESS 40-60) including Los Angeles (ESS = 51.82) and San Diego (ESS = 49.73) show moderate sustainability levels with renewable energy ratios of 33-34%, where strong transportation infrastructure alone cannot compensate for limited renewable energy adoption. Lower-ranked cities such as Las Vegas (ESS = 12.05) and New Orleans (ESS = 6.14) exhibit low renewable energy ratios ($\gamma< 0.15$) and limited public transportation ($\beta< 8$). Notably, New Orleans, the host city of Super Bowl LIX, ranks 16th among evaluated cities, indicating that the NFL's historical focus has been on post-event environmental management rather than pre-event sustainability capabilities. These results demonstrate the framework's sensitivity to energy structure factors, with energy consumption and transportation emissions together accounting for over 60% of total environmental impacts.

According to official NFL data, among the 32 cities hosting NFL teams, 8 cities have never hosted a Super Bowl. Many of these are located in cold northern regions with limited event-specific infrastructure. We selected three cities that preliminarily meet basic hosting qualifications—Seattle, Boston, and Philadelphia—and evaluated their environmental sustainability using our framework. The results are presented in **Table 2**.

Table 2. Environmental sustainability scores for three promising cities.

City	ESS	TEI	RR	CS	GS	WS	RES/IIP/PCS/GCI
Seattle	100	56,526	98%	0.9	9	7	9/9/9/9
Boston	71.44	75,627	42%	1.0	8	9	9/9/9/9
Philadelphia	0.73	118,128	8%	1.0	8	8	7/8/7/7

Seattle emerges as the most environmentally sustainable hosting option (ESS = 100.00) among these three cities, benefiting from its excellent energy structure with 98\% renewable energy ratio ($\gamma= 0.98$), primarily from hydropower. Despite being relatively cold in winter (Climate score = 0.9), Seattle's clean energy dominance and well-developed transportation infrastructure (Geo/Trans score = 9) result in the highest ESS score. Boston ranks second (ESS = 59.60) with a 42% renewable energy ratio and strong transportation infrastructure, including a dense subway network and the 7th largest port in the U.S. Philadelphia ranks lowest (ESS = 0.73) due to its low renewable energy ratio (8%) and limited sustainability infrastructure, despite having adequate transportation systems.

5. Conclusion

This study developed a framework distinguishing LDE and LIE for Super Bowl host city evaluation. Using Super Bowl LIX as a baseline, we quantified total impacts at 28,912 tCO_2. The framework integrates environmental indicators into an ESS through regional factors, climate, transportation, energy structure, and waste management. Results demonstrate that energy structure factor is the most critical determinant, with cities featuring high renewable energy ratios (>40%) achieving ESS scores above 60, while those with low ratios (<15%) score below 15. The framework successfully identifies sustainable hosting options beyond traditional criteria. This research provides a data-driven approach for evidence-based host city selection, emphasizing the importance of prioritizing cities with high renewable energy ratios and strong public transportation infrastructure, which can reduce environmental impacts by up to 10 times compared to cities with low sustainability scores.

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