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How Sport Mega-Events Aligns with The Sustainability Goals

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Abstract. In recent years, environmental sustainability has become an increasingly important topic when talking about mega events as host cities face growing pressure to address excessive resource consumption, denser pollution, and greater ecological damage. In this paper, our objective was to construct a model to assess the full environmental footprint of large-scale sporting competitions in multiple dimensions. Firstly, we developed a series of specialized models to determine the magnitude of seven key factors for a sport mega-event. Then we are using 2025 Super Bowl LIX in New Orleans, USA as a baseline to evaluate the impact of each factor. Next, each of factors then weighted by Analytic Hierarchy Process (AHP) to determine the contribution of each environmental factor to the city's overall sustainability. Due to the subjectivity of AHP, we additionally applied a more objective method, classification models of Supervised Machine Learning Algorithm, to verify the weight results. Finally, based on the model results, we provided a set of recommendations to minimize the environmental impact of sport mega-events while optimizing operational efficiency.

Keywords: Simulation; Analytic Hierarchy Process (AHP); Classification Models; TOPSIS.

1. Introduction

1.1. Background

Super Bowl, the championship of the National Football League, brings substantial economic benefit each year, yet it also carries a considerable environmental burden. Although various ecological impact assessments currently exist, environmental sustainability has not become the core basis of host cities selection of major sporting events. Hence, systematic models are required to quantify the environmental footprint of large-scale sporting events to inform sustainable decisions. In this paper, we aim to construct a mathematical model to guide event planning based on environmental concerns.

1.2. Problem Restatement

1. Identify key environmental impact areas of Super Bowl, and analyze how these effects vary with the location of the host city.

2. Develop a mathematical model evaluating the most sustainable city choice for hosting Super Bowl.

3. Test the proposed model on 6 experienced host cities and 3 cities that have never hosted before. Determine the optimal sustainable choice from each group of cities.

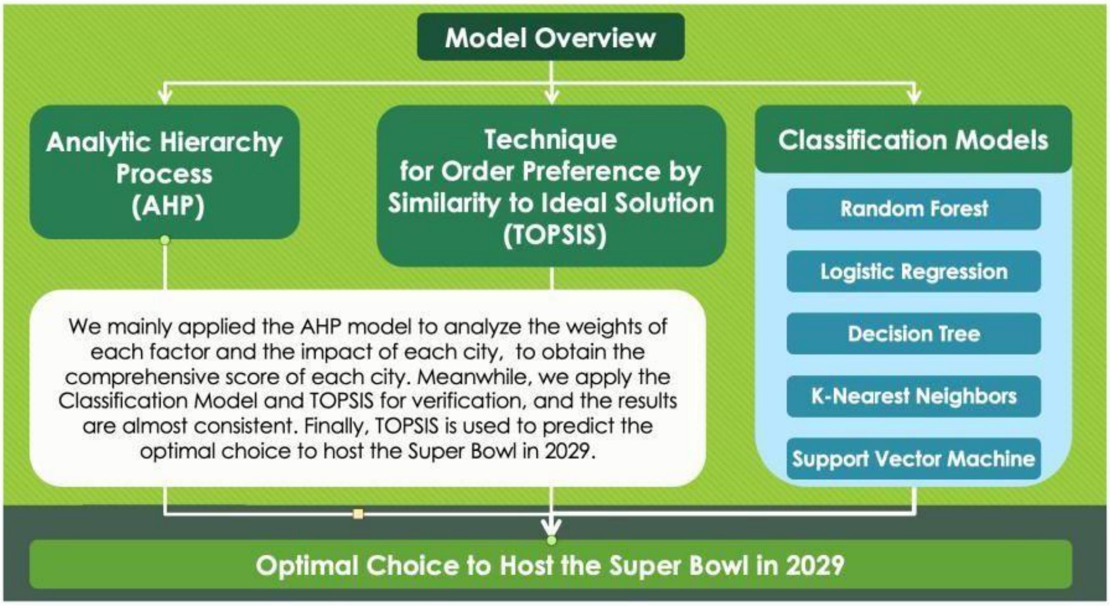

Figure 1. Overview of Model Ideas

2. Assumptions

1. Environmental assessments of the city is also highly correlated with its geographical, climate and human factors.

2. For data unable to be obtained from the 2025 Super Bowl, we used mean data from past Super Bowl events and approximations.

3. For each of the environmental factors, we only pick 2-3 that have the most significant influence towards the environment.

4. Environmental factors and geographical, climate and human factors are independent of each other.

5. All environmental factors are completely and directly human related.

3. Variable Notations

Table 1. Variable definitions used in the sustainability model.

Symbol	Definition
C_{total}	The total amount of carbon emission unabsorbed in the city
ρc	Density of carbon (ton CO_2/m^2)
F_t	Total number of tons of food waste over time
WF_{total}	The total water footprint
G_{total}	The total amount of garbage produced through the event (tons)
E_{event}	Additional energy consumption due to the event
A_{impact}	The impact of air quality

4. Key Environmental Impact Areas of Super Bowl

4.1. Analysis of Environmental Sustainability Model

Carbon Emission

We begin by defining the total carbon emission in a city throughout the event duration (T days) as the total amount of CO_2 emitted minus the portion absorbed by natural processes, since not all the total carbon emissions will impact the city's environmental sustainability. Therefore, the amount of carbon considered in our criteria will be: The relationship can be represented as:

$$C_{\text{net}} = C_{\text{total}} - C_{\text{absorbed}}$$

Here, C_{absorbed} refers to carbon taken up by vegetation, soil, or purchased offsets. To model the total carbon emissions during a mega-sport event, we consider three dominant contributing factors: transportation, infrastructure construction, and garbage combustion. Based on previous Super Bowl host cities, these three sources account for the majority of total emissions:

$$C_{\text{total}} = C_T + C_I + C_W$$

For the transportation sector:

$$C_T = \sum_{i=1}^{n} N_i \times d_i \times f_i \times \epsilon_i$$

where N_i is the number of vehicles or trips of type i entering or leaving the city, d_i is the average travel distance, f_i is the average fuel consumption per kilometer, and ϵ_i is the emission factor (ton $CO_2/$ liter) of the specific fuel used. This model captures the diverse transportation sources including planes, trains, buses, and private cars. For infrastructure-related emissions:

$$C_I = \sum_{j=1}^{m} M_j \times \eta_j + E_j \times \alpha$$

Here, M_j represents the mass of building material j (such as steel, concrete, or wood), η_j is its emission factor $(\mathrm{tCO_2/t}), E_j$ is the total electrical energy consumed during construction, and α is the emission factor of the local electricity grid. This term accounts for emissions during the setup or renovation of stadiums and supporting facilities. For waste combustion and disposal:

$$C_W = \sum_{k} W_k \times P_k \times \phi_k$$

where W_k represents the total waste mass, P_k is the proportion of waste treated by method k (such as incineration, recycling, or landfill), and ϕ_k is the corresponding carbon emission factor for that method. The total carbon absorption in the city is modeled as:

$$C_{\text{absorbed}} = r_{\text{tree}} \times N_{\text{tree}} + C_{\text{credit}}$$

where r_{tree} is the average annual CO_2 absorption per tree, N_{tree} is the total number of trees maintained or planted as part of the event's sustainability plan, and C_{credit} denotes verified carbon offsets purchased to balance unavoidable emissions.

Food Waste

In large sporting events, food demand increases dramatically due to the influx of tourists and vendors, leading to an increase in food waste. Food waste not only contributes to landfill overflows but also produces methane during decomposition. To estimate this, we employ an ordinary differential equation (ODE) model:

$$\frac{dQ}{dt} = -k_s Q$$

where $Q(t)$ represents the remaining unsold food at time t, k_s is the sales rate constant, and Q_0 is the initial food quantity prepared for sale. The solution is given by:

$$Q(t) = Q_0 e^{-k_s t}$$

To model waste generation over time, we define:

$$E(t) = k_s Q - k_d E(t)$$

where $E(t)$ represents the amount of food waste accumulated by time t , and k_d is the spoilage or disposal rate constant. When solved, the model becomes:

$$W(t) = Q(t) + E(t) = \frac{rQ_0}{k_s - k_d}(e^{-k_s t} - e^{k_d t})$$

Water Consumption and Pollution

Water sustainability is evaluated through the concept of water footprint, divided into three components: blue, green, and grey water. The total footprint is given by:

$$WF_{\text{total}} = WF_{\text{blue}} + WF_{\text{green}} + WF_{\text{grey}}$$

The blue water footprint (WF_{blue}) represents the use of surface or groundwater, green water footprint (WF_{green}) accounts for rainwater stored in soil and used by vegetation, and grey water footprint (WF_{grey}) measures the amount of water required to dilute pollutants to safe levels. Grey water footprint is calculated as:

$$WF_{\text{grey}} = \frac{L}{c_{\max} - c_{\text{nat}}}$$

where L is the pollutant load, $c_{\max}$ is the maximum permissible concentration of the pollutant according to water quality standards, and c_{nat} is the natural background concentration. To assess sustainability, water scarcity indices are used. Blue water scarcity (WS_{blue}) is defined as:

$$WS_{\text{blue}} = \frac{\sum WF_{\text{blue}}[x,t]}{R_{\text{nat}} - EFR}$$

where R_{nat} is the natural runoff and EFR is the environmental flow requirement. If $WS_{\text{blue}} > 100\%$, the use of blue water is unsustainable, indicating overextraction of local water resources.

Similarly, green water scarcity (WS_{green}) is calculated as:

$$WS_{\text{green}} = \frac{WF_{\text{green}}}{ET_{\text{green}} - ET_{\text{env}} - ET_{\text{unprod}}}$$

where ET_{green} represents total evapotranspiration, ET_{env} the portion required by ecosystems, and ET_{unprod} the portion not available for productive use. A value of $WS_{\text{green}} > 100\%$ suggests unsustainable use of soil moisture. Lastly, water pollution level (WPL) measures the proportion of assimilative capacity used for dilution:

$$WPL = \frac{WF_{\text{grey}}}{R_{\text{act}}}$$

where R_{act} is the actual available runoff. If $WPL > 100\%$, the pollutant load exceeds the environment's natural capacity to dilute waste, leading to water quality degradation.

Garbage Waste

Garbage generation is another key sustainability concern in mega-sport events. Waste from spectators, vendors, and operations can accumulate rapidly, stressing local waste management systems. The total waste generated is expressed as:

$$G_{\text{total}} = \sum(G_{\text{daily}} \times D)$$

where G_{total} is the total waste (kg), G_{daily} is the daily waste generation rate, and D is the total number of event days.

Energy Consumption

Energy consumption in a mega-event is primarily determined by crowd behavior and attendance patterns. We model this using a Gaussian distribution to represent fluctuations in visitor numbers over time:

$$\Delta E_{\text{visitor}} = c_e \int_0^{24D} N_{\max} e^{-\frac{(t-t_0)^2}{2\sigma^2}} dt$$

In this equation, c_e is the average energy consumed per visitor per hour, $N_{\max}$ is the maximum visitor count at the event's peak, t_0 is the time corresponding to peak attendance, σ controls the spread of attendance over time, and D is the event duration in days. This integral allows a smooth, time-based estimation with controlled assumptions to maximize its accuracy.

Air Pollution

Large events significantly increase emissions of pollutants such as PM2.5, SO2, and CO_2 due to transportation, energy use, and waste processing. Air quality deterioration not only affects public health but also damages ecosystems and contributes to climate change. We model the total air pollution impact as:

$$A_{\text{impact}} = \beta_{\text{PM2.5}} C_T + \beta_{\text{SO2}} C_F$$

where $\beta_{\text{PM2.5}}$ and β_{SO2} are impact coefficients corresponding to particulate and sulfur emissions, C_T represents the transportation-based carbon emissions, and C_F denotes the emissions resulting from fuel combustion.

Material Consumption

To evaluate the material footprint of a mega-sport event, we estimate the total quantity of materials consumed across several categories, including stadium construction materials, paper posters, plastic bottles, and merchandise packaging. The material consumption for category i is given by

$$M_i = N_i m_i (1 - r_i) s_i.$$

For each category i , the model represents material use through the number of items produced or installed N_i , the average mass of each item m_i , the recycling or reuse reduction factor r_i , and the share of the material attributable specifically to the event s_i .

4.2. Data Collection and Input Parameters

Table 2. Input parameters for all sustainability models including material consumption for Super Bowl 2025.

Parameter	Value	Unit	Source / Notes
Event Population & Waste Inputs			
Stadium attendance $(N_{\text{spectators}})$	65,719	persons	Super Bowl LIX attendance
Stadium capacity	73,208	seats	Caesars Superdome
Staff number (N_{staff})	7,320	persons	10% of capacity
Vendor number (N_{vendors})	3,660	persons	5% of capacity
Total event population(N)	76,699	persons	Sum of all attendees
Event duration(D)	5	days	Assumed window
Base waste rate (R_{base})	1.0	kg/person/day	Standard municipal rate
Activity factor (A_f)	1.8	-	Event uplift
Environmental efficiency (E_f)	0.90	-	10% reduction
Energy Model Inputs			
Energy per person-hour (c_e)	0.5	kWh/(person-hour)	Model assumption
Attendance spread (σ)	20	hours	Gaussian spread
Peak attendance (N_{max})	76,699	persons	Same as N
Grid emission factor	0.374	kgCO_2/kWh	Louisiana average
Food Waste Model Inputs			
Initial food prepared (Q_0)	120,000	kg	Estimated for Super Bowl scale
Food sales rate (k_s)	0.55	day^{-1}	Assumed constant
Food spoilage rate (k_d)	0.12	day^{-1}	Assumed
Water Footprint Inputs			
Water use per person(w)	60	L/person/day	Stadium operations estimate
Pollutant load (L)	420	kgN	Event nutrient load
$c_{\text{max}} - c_{\text{nat}}$	0.009	kg/m^3	Water quality standard difference
Material Consumption Model Inputs			
Temporary stadium structures (N_1, m_1)	150,000	kg	Steel, aluminium, mixed materials
Paper posters/programs (N_2, m_2)	250,000 sheets	0.01 kg each	30% recycled $(r_2 = 0.3)$
Plastic bottles (N_3, m_3)	200,000 bottles	0.025 kg each	40% recycled $(r_3 = 0.4)$
Merchandise packaging (N_4, m_4)	120,000 units	0.02 kg each	20% recycled $(r_4 = 0.2)$
Event material share (s_i)	1.0	-	Event-specific

4.3. Model Outputs

Table 3. Outputs from all models including material consumption for Super Bowl 2025.

Model Output	Result	Unit
Food Waste Model		
Remaining food $Q(5)$	7,680	kg
Food waste $E(5)$	921.6	kg
Water Footprint Model		
Blue water footprint WF_{blue}	2.30×10^4	m^3
Green water footprint WF_{green}	0	m^3
Grey water footprint WF_{grey}	4.67×10^4	m^3
Total water footprint WF_{total}	6.97×10^4	m^3
Garbage Waste Model		
Daily waste G_{daily}	124.3	tonnes/day
Total waste G_{total}	621.3	tonnes
Energy Model		
Visitor-related energy ΔE	1.92	GWh
Energy CO_2 emissions	719	tonnes CO_2
Material Consumption Model		
Temporary structures material	150,000	kg
Paper materials	1,750	kg
Plastic bottles material	3,000	kg
Merchandise packaging	1,920	kg
Total material footprint M_{total}	156,670	kg
Carbon Density		
Carbon density ρ_C	0.0022	tonnes CO_2/m^2

5. Evaluate the weights of factors affecting environment

5.1. Factor Weight Analysis for Environmental Sustainability Using AHP Model

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that combines qualitative and quantitative analysis, proposed by the famous American operations researcher Thomas L. Saaty in the 1970s. The distinguishing feature of this method is that after conducting an in-depth analysis of the nature, influencing factors, and internal relationships of complex decision-making problems, a hierarchical model is constructed.

Construction of Judgment Matrix

Based on seven key environmental impact assessment indicators, the following judgment matrix was constructed:

Table 4. Pairwise Comparison Matrix for Environmental Impact Criteria of Super Bowl

	Carbon	Food	Material	Water	Waste	Energy	Air
Carbon	1	3	6	2	4	3	4
Food	1/3	1	3	2/3	2	5/4	5/2
Material	1/6	1/3	1	1/3	1/2	1/3	3/4
Water	1/2	3/2	3	1	2	3/2	5/2
Waste	1/4	1/2	2	1/2	1	1/2	1
Energy	1/3	4/5	3	2/3	2	1	4/3
Air	1/4	2/5	4/3	2/5	1	3/4	1

The judgment matrix is normalized by dividing each element by the sum of its respective column:

$$N_{ij} = \frac{C_{ij}}{\sum_{k=1}^{7} C_{kj}}, \quad \text{for } i,j = 1,2,\dots,7$$

The weight for each criterion is calculated by averaging the normalized values across each row:

$$w_i = \frac{\sum_{j=1}^{7} N_{ij}}{7}, \quad \text{for } i = 1,2,\dots,7$$

The calculated priority vector is:

$$\mathbf{w} \approx [0.3449 \quad 0.1465 \quad 0.0501 \quad 0.1778 \quad 0.0801 \quad 0.1255 \quad 0.0753]$$

Alternatively, the priority vector can be derived as the principal eigenvector of the pairwise comparison matrix $\mathbf{C}$: $\mathbf{Cv} = \lambda \mathbf{v}$, where λ is the eigenvalue, $\mathbf{v}$ is the corresponding eigenvector. The principal eigenvalue $\lambda_{\max}$ is the largest eigenvalue of $\mathbf{C}$, and the corresponding eigenvector $\mathbf{v}$ is normalized to obtain the weight vector $\mathbf{w}$:

$$\mathbf{w} = \frac{\mathbf{v}}{\sum_{i=1}^{7} v_i}$$

Using the pairwise comparison matrix, $\lambda_{\max} \approx 7.175$:

$$\mathrm{CI} = \frac{7.175 - 7}{7 - 1} = \frac{0.175}{6} \approx 0.0292, \ \mathrm{CR} = \frac{0.0292}{1.32} \approx 0.0221$$

Since $\mathrm{CR} = 0.0221 < 0.1$, the consistency of pairwise comparisons is acceptable.

5.2. AHP Evaluation

Using the AHP method, the relative importance of four first-level dimensions was validated, with Carbon Emission (34%) and Water Waste (18%) confirmed as the two most important dimensions.

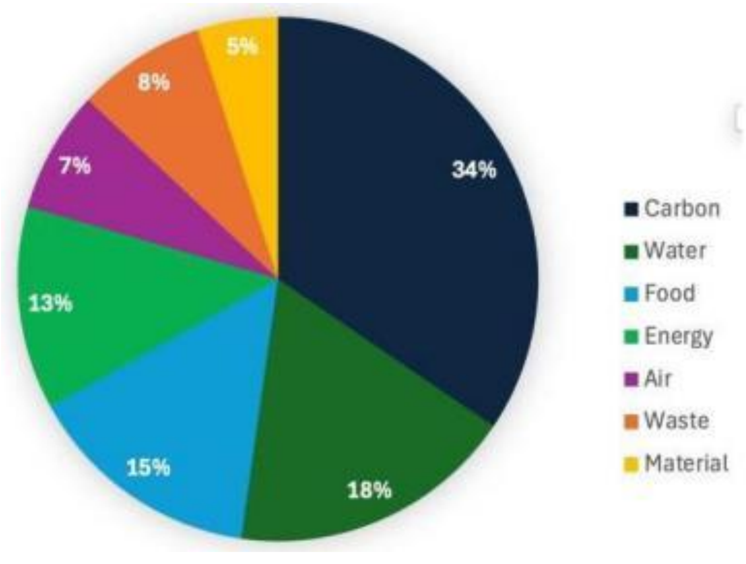

Figure 2. Factor Weight Analysis for Environmental Sustainability Using AHP Model

5.3. Factor Weight Analysis Using Supervised Machine Learning Algorithm

As the AHP model is mainly based on subjective judgments, to enhance objectivity, we collected relevant data and applied classification models. By reviewing relevant literature, we discovered that temperature is associated with energy consumption, and energy consumption is in turn linked to carbon emissions. Thus, we confirm that the most critical factor affecting the environment is carbon emission, which is as the same as shown in AHP model.

6. Factor Weight Analysis

The main idea is to apply the AHP and TOPSIS model to analyze the environmental impact of each city to obtain the comprehensive score of each city. Afterwards, TOPSIS is used to predict the optimal choice to host the Super Bowl in 2029.

6.1. AHP Model

All collected data were normalized using min-max scaling to ensure they are comparable. Carbon Emission (0.233) and Water Consumption and Pollution (0.201) have the top two highest weights due to their irreversible global impacts and importance to ecological stability. These two factors received more emphasis in our pairwise comparison matrices, reflecting their critical role in long-term environmental sustainability. We constructed pairwise comparison matrices for each city across the seven criteria. The final score for each city was calculated as the weighted sum of its normalized performance scores across all criteria:

$$\text{Score} = \sum_{i=1}^{7} w_i \times s_{i,\text{city}}$$

Where w_i represents the weight of criterion i and $s_{i,city}$ represents the city's score on criterion i .A lower score indicates the city is more environmentally sustainable in hosting the Super Bowl.

6.2. TOPSIS Model

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was originally developed by Ching-Lai Hwang and Yoon in 1981, is a multi-criteria decision analysis method. Data includes latitude, longitude, daily average Max (Min) temperature in February (affect energy emissions), Sunny Percentage, GDP (affects garbage waste), Population Density per Square (affects food waste) Mile, Traffic Index(affects air pollution) and CO_2 Emission Index. Then we performed data normalization to eliminate dimensional differences:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

We categorized indicators into three types and defined their ideal solutions accordingly:

Positive Indicators (direction = 1): Maximizing indicators where larger values are preferable, including GDP and percentage of sunny days.

Negative Indicators (direction = -1): Minimizing indicators where smaller values are preferable, including Population Density, Traffic Index, Carbon Emission, CO_2 Index, Inefficiency Index and Time Index.

The Euclidean distances to ideal solutions were calculated as:

$$\text{dist}_{\text{best}} = \sqrt{\sum_{j=1}^{m} \left(\text{weighted\_data}_{ij} - \text{ideal\_best}_{ij}\right)^2}, \quad \text{dist}_{\text{worst}} = \sqrt{\sum_{j=1}^{m} \left(\text{weighted\_data}_{ij} - \text{ideal\_worst}_{ij}\right)^2}$$

The final relative closeness score was computed with numerical stability consideration:

$$\text{score} = \frac{\text{dist\_worst}}{\text{dist\_best} + \text{dist\_worst} + \epsilon}$$

We took weight vectors (average weight for each factor) to calculate the weighted Euclidean distances:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} \omega_j \left(Z_j^+ - z_{ij}\right)^2},\ D_i^- = \sqrt{\sum_{j=1}^{m} \omega_j \left(Z_j^- - z_{ij}\right)^2},\ S_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

where $S_i \in [0,1]$, with higher values indicating better performance relative to the ideal solution.

6.3. Combine the AHP and TOPSIS Model for Forecasting

Since the results of TOPSIS and AHP are almost consistent, we believe that using the TOPSIS ranking for prediction is more intuitive, so we obtained the following results. Our recommendation principle is to prioritize higher-ranked cities in TOPSIS and consider whether the city has a large stadium capacity for the Super Bowl. If there is a sufficiently large stadium for their NFL, a new stadium would be not needed. This is an efficient way to reduce the environmental impact. As shown, for potential cities with NFL, the top 3 is Kansas City, Nashville and Charlotte.

9 cities hosted or will host Super Bowl
New Potential Cities with NFL

City	TOPSIS	Rank	Current world-class sports facility	Recommendation
Kansas City	84.0%	1	Arrowhead Stadium (capacity: 76,416) NFL Kansas City Chiefs' home	High
New Orleans	82.1%	2	Caesars Superdome (capacity: 73,208) NFL New Orleans Saints' home	High
Nashville	80.3%	3	Nissan Stadium (Capacity: 69,143) NFL Tennessee Titans's home	High
Charlotte	76.9%	4	Spectrum Center (Capacity:19,000 to 21,000) for NBA Not large enough for Super Bowl	Low
Tampa	76.0%	5	Raymond James Stadium (Capacity: 65,618) NFL Tampa Bay Buccaneers's home	High
Dallas	75.2%	6	American Airlines Center(Capacity:19,000 to 21,000) for NBA Not large enough for Super Bowl	Low
Denver	74.7%	7	Empower Field at Mile High (capacity: 69,143) NFL Denver Broncos's home	High
Atlanta	71.4%	8	Mercedes-Benz Stadium (Capacity: 71,000 / Expandable to 83,000) Home of the NFL Atlanta Falcons and MLS Atlanta United FC	Medium
Houston	71.2%	9	NRG Stadium (capacity: 72,220) NFL Houston Texans's home	Medium
Santa Clara	66.6%	10	Levi's Stadium (Capacity: 68,500) NFL San Francisco 49ers's home	Medium
Minneapolis	65.6%	11	U.S. Bank Stadium (Capacity: 66,655) NFL Minnesota Vikings's home	Medium
Miami	64.2%	12	Hard Rock Stadium (Capacity: 65,326 / Expandable to 75,000) Home of the NFL Miami Dolphins and MLB Miami Marlins	Medium
Detroit	62.7%	13	Ford Field (capacity: 65,000) NFL Detroit Lions's home	Medium
Seattle	58.6%	14	Lumen Field (capacity: 68,740) NFL Seattle Seahawks' home	Low
Chicago	54.3%	15	Soldier Field (capacity: 61,500) NFL Chicago Bears's	Low
Philadelphia	53.5%	16	Lincoln Financial Field (capacity: 69,000+) NFL Philadelphia Eagles's home	Low
Washington	53.4%	17	Northwest Stadium (capacity: 64,000) NFL Washington Commanders's	Low
Glendale	46.6%	18	State Farm Stadium (capacity: 63,400) NFL Arizona Cardinals' home	Low
Las Vegas	27.6%	19	Allegiant Stadium (capacity: 65,000) NFL Las Vegas Raiders' home	Low
Inglewood	27.0%	20	Nissan Stadium (Capacity: 69,143) NFL Tennessee Titans's home	Low

Figure 3. Analysis of Super Bowl Host City in 2029 by TOPSIS

7. Results and Implications

Through our analysis, the most significant factor is CO_2 emissions. We propose that sports event organizers consider following aspects to mitigate environmental footprints.

1. Prioritize host cities with around 15-25 Degrees Celsius: In a moderate temperature, we can reduce the reliance on cooling systems during the event to reduce carbon emission and energy waste.

2. Prioritize host cities with existing large-scale sports venues: Pre-built facilities can effectively avoid the material waste, such as wood, concrete, bricks and so on.

3. Renewable materials for food packaging: Reduce environmental pressure by minimizing garbage waste in landfills or oceans.

Our model is based on subjective weight setting for direction (AHP), objective ranking for optimal decision-making (TOPSIS) and data-driven classification for effectiveness (Classification Models). Due to subjectivity of AHP, we adopted TOPSIS and classification models, which is more objective for validation. However, classification models require sufficient data we have collected Super Bowl data this time. To apply them for other sports events, it might require time for data collection.

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