

---

## Summary

Large-scale events such as the Super Bowl bring economic value but also substantial environmental pressures. To support sustainable planning and data-driven host-city selection, this study develops an integrated framework that quantifies environmental impacts, evaluates urban sustainability, and proposes hosting and mitigation strategies. The framework combines lifecycle assessment, multi-criteria evaluation, a spatiotemporal sustainability model, and an environment–economy optimization module.

In Problem 1, using Super Bowl LIV in New Orleans as a baseline, we quantify key lifecycle environmental burdens—energy use, water consumption, greenhouse gas emissions, waste treatment, and ecological disturbance—and examine how climate and energy structures affect cross-city environmental loads. This establishes the baseline environmental impact model.

In Problem 2, we construct a sustainability-oriented site selection model using indicators such as energy efficiency, renewable energy share, transportation performance, waste recycling, water management, and infrastructure capacity. By integrating AHP and TOPSIS, we develop a Composite Environmental Sustainability Index for city-level comparison.

In Problem 3, applying the model to 11 U.S. cities shows that Seattle ranks highest across environmental, infrastructure, transportation, historical, and regional resilience factors, making it the optimal host for the 2029 Super Bowl. Sensitivity analysis confirms stable rankings, demonstrating strong model robustness.

In Problem 4, we extend the framework to multi-city, multi-venue settings typical of large multi-sport events. A dual city–venue spatiotemporal structure and an environment–economy optimization module are introduced to evaluate environmental gains, ROI, and payback periods. Applied to the 2036 Olympic candidates, the model identifies London as the most sustainable option. Multi-venue events are shown to create far higher pressures on energy, transport, water, waste, and carbon emissions.

In Problem 5, we prepare a formal recommendation to the NFL summarizing evidence supporting Seattle’s selection and proposing feasible sustainability strategies, including clean-energy adoption, transport optimization, and improved waste management.

Overall, the study provides a transparent and extensible sustainability assessment framework for major sporting events, offering rigorous support for host-city selection, investment planning, and long-term green development.

**Keywords:** Sustainable event planning; Environmental impact assessment; Urban sustainability; Multi-criteria decision analysis; Hosting site selection

## Contents

|                                                                                                        |    |
|--------------------------------------------------------------------------------------------------------|----|
| 1. Introduction.....                                                                                   | 3  |
| 1.1 Problem Background .....                                                                           | 3  |
| 1.2 Problem Restatement .....                                                                          | 3  |
| 2. Assumptions and Rationale.....                                                                      | 3  |
| 3. Notation.....                                                                                       | 4  |
| 4. Model Preparation.....                                                                              | 4  |
| 5. Problem 1: Comprehensive Mathematical Model for the Environmental Impacts of Sport Mega-Events..... | 5  |
| 6. Problem 2: Environmental Sustainability–Based Host City Evaluation Model .....                      | 8  |
| 7. Problem 3: Environmental Performance–Based Host City Ranking and Recommendation Model .....         | 12 |
| 8. Problem 4: Spatiotemporal Sustainability Model for Multi-Venue Mega-Events...                       | 16 |
| 9. Problem 5: Sustainability-Based Hosting Policy Framework .....                                      | 22 |
| 10. Sensitivity Analysis.....                                                                          | 23 |
| 11. Strengths and Limitations .....                                                                    | 24 |
| 11.1 Strengths.....                                                                                    | 24 |
| 11.2 Limitations .....                                                                                 | 24 |
| 12. References.....                                                                                    | 24 |

# 1.Introduction

## 1.1 Problem Background

Large-scale sporting events, as socio-economic phenomena with significant influence, can enhance city branding and stimulate regional development but also generate substantial ecological pressures[1]. The Super Bowl, for example, involves extensive population movement, energy-intensive stadium operations, and concentrated resource consumption, resulting in a high environmental footprint. Although existing studies evaluate energy use, water consumption, waste generation, and carbon emissions, environmental considerations remain insufficiently integrated into site selection, where decisions are often dominated by economic or political priorities[2]. Therefore, a quantitative framework that foregrounds environmental performance and enables systematic comparison among candidate cities is needed to shift event planning from reactive management to proactive, sustainability-oriented decision-making.

## 1.2 Problem Restatement

**Problem 1** focuses on using Super Bowl LIV in New Orleans as a baseline to identify and quantify key environmental impacts of large sporting events—energy use, water consumption, greenhouse gas emissions, waste generation, and ecological disturbance—and to examine how climatic, geographic, and energy-structure differences shape urban environmental burdens.

**Problem 2** requires developing an environmental indicator-based site selection model. The model evaluates urban sustainability through standardized and weighted metrics such as energy efficiency, renewable energy share, transportation systems, waste recycling, water management, and infrastructure, using methods like AHP or TOPSIS to construct a composite index.

**Problem 3** involves applying the model to U.S. cities, ranking potential host locations, and recommending the optimal city for the 2029 Super Bowl. It includes reassessing previous hosts, evaluating non-host NFL cities, and conducting sensitivity analysis to ensure stable and reliable results.

**Problem 4** expands the model to multi-venue, multi-city events, developing a more general spatiotemporal sustainability framework and integrating an environment-economy dual-objective optimization to assess long-term investment, energy supply, and transportation strategies.

**Problem 5** requires preparing a formal recommendation for the NFL, summarizing the environmental rationale for the selected host city and proposing feasible emission-reduction and sustainability strategies.

## 2. Assumptions and Rationale

Assumption 1: Environmental indicators such as energy use, water consumption, emissions, and waste accumulate over the event period and can represent the overall

environmental load.

Assumption 2: Energy consumption, emissions, water use, and waste management are considered independent dimensions, allowing their impacts to be combined after normalization and weighting.

Assumption 3: Urban conditions—including climate, energy structure, water stress, and transportation—remain stable during the event.

Assumption 4: Each indicator has a clear sustainability direction (e.g., higher energy efficiency is more sustainable; higher carbon emissions are less sustainable).

### 3. Notation

| Symbol                    | Description                                                       |
|---------------------------|-------------------------------------------------------------------|
| $E_{\text{total}}$        | Total environmental impact index                                  |
| $P_i(t)$                  | Instantaneous power consumption of facility type $i$ at time $t$  |
| $C_i$                     | Carbon emissions of activity type $i$                             |
| $\Phi(t)$                 | Instantaneous environmental impact function                       |
| $Q_{\text{air}}(t, i)$    | Aviation energy use or emission intensity of type $i$ at time $t$ |
| $P_{\text{grid}}(t, i)$   | Grid electricity consumption of city $i$ at time $t$              |
| $\rho_{\text{carbon}}(i)$ | Carbon intensity coefficient of the local power grid              |

### 4. Model Preparation

Sport Mega-Events are characterized by intensive energy use, large-scale population mobility, and continuous operation of supporting infrastructure, resulting in environmental impacts across energy consumption, greenhouse gas emissions, water use, waste generation, and ecological disturbance[3]. Events such as the Super Bowl impose concentrated environmental burdens not only during the game but also throughout preparation and post-event phases. A systematic modelling framework is therefore required to support quantitative sustainability assessment[4].

The modelling strategy adopted in this study includes: (1) defining the objective of quantifying lifecycle environmental loads and enabling cross-city sustainability comparison; (2) decomposing overall impacts into five modules—energy, emissions, water, waste, and ecological disturbance; (3) establishing a temporal integration framework to represent cumulative environmental intensities; (4) applying normalization and weighting to unify multi-dimensional indicators; and (5) incorporating regional adjustment factors to ensure comparability across cities.

Based on these components, an integrated assessment and decision framework is

constructed. The Environmental Impact Quantification Model generates lifecycle impact indicators; the AHP–TOPSIS Sustainability Evaluation Model synthesizes these indicators into city-level sustainability scores; the Sensitivity and Robustness Analysis Module verifies model stability; and the Extended Multi-Event Optimization Model generalizes the framework to multi-venue events and includes an environment–economy multi-objective optimization scheme. This streamlined framework supports systematic evaluation, verification, and optimization of sustainability outcomes for major sporting events[5].

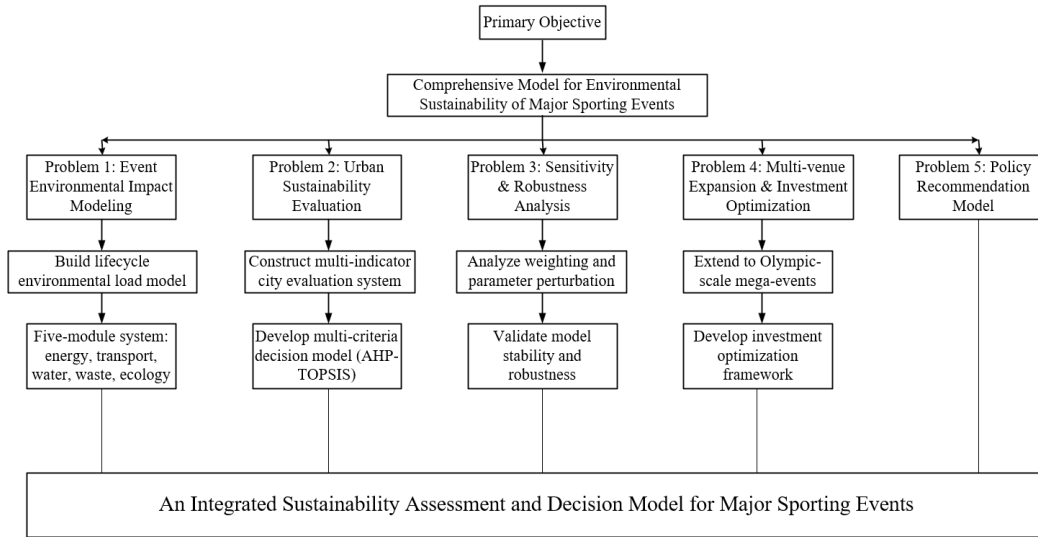


Figure 1. Model Algorithm Framework

## 5.Problem 1: Comprehensive Mathematical Model for the Environmental Impacts of Sport Mega-Events

To quantify the environmental burdens of sport mega-events, we develop a multi-component assessment model over the event period  $t \in [0, T]$ . The impacts are represented through five modules: energy consumption, greenhouse gas emissions, water use, waste treatment, and ecological disturbance[6]. The overall environmental impact function is given by:

$$E_{\text{total}} = f(E_{\text{en}}, E_{\text{ghg}}, E_{\text{water}}, E_{\text{waste}}, E_{\text{other}}) \quad (1)$$

Here,  $E_{\text{total}}$  denotes the total environmental impact index over the full lifecycle of the event, and each component corresponds to a specific environmental subsystem.

The energy consumed during the event primarily arises from stadium operations, accommodation, media centers, and temporary facilities. Its cumulative load over time can be expressed as:

$$E_{\text{en}} = \int_0^T (\alpha_1 P_{\text{venue}}(t) + \alpha_2 P_{\text{hotel}}(t) + \alpha_3 P_{\text{media}}(t) + \alpha_4 P_{\text{temp}}(t)) dt \quad (2)$$

Here,  $P_i(t)$  denotes the instantaneous power consumption (kW) of facility type  $i$  at time  $t$ , and  $\alpha_i$  is the conversion factor from energy use to carbon-equivalent emissions. The integral represents the total energy consumption over the event period.

If the average power  $\bar{P}_i$  is used to approximate the energy load of facility type  $i$  then:

$$E_{\text{en}} = T(\alpha_1 \bar{P}_{\text{venue}} + \alpha_2 \bar{P}_{\text{hotel}} + \alpha_3 \bar{P}_{\text{media}} + \alpha_4 \bar{P}_{\text{temp}}) \quad (3)$$

Next, the greenhouse gas emissions module accounts for multiple sources, including spectator travel, venue operations, and waste treatment. The total emissions are expressed as a weighted sum of all emission sources:

$$E_{\text{ghg}} = \sum_{i=1}^5 \beta_i C_i = \beta_1 C_{\text{flight}} + \beta_2 C_{\text{local}} + \beta_3 C_{\text{energy}} + \beta_4 C_{\text{hotel}} + \beta_5 C_{\text{waste}} \quad (4)$$

Here,  $C_i$  denotes the carbon-equivalent emissions of activity type  $i$ , and  $\beta_i$  is its weighting factor. As air travel accounts for about 65% of total emissions,  $\beta_i$  can be set to 0.65. If emissions are further treated as a function of energy use, the expression becomes:

$$C_i = \int_0^T \kappa_i P_i(t) dt, \Rightarrow E_{\text{ghg}} = \sum_{i=1}^5 \beta_i \int_0^T \kappa_i P_i(t) dt \quad (5)$$

Similarly, event-related water use—mainly from venues, hotels, lodging, public services, and landscape facilities—can be expressed by time integration as in (6):

$$E_{\text{water}} = \int_0^T (\gamma_1 W_{\text{venue}}(t) + \gamma_2 W_{\text{hotel}}(t) + \gamma_3 W_{\text{public}}(t) + \gamma_4 W_{\text{land}}(t)) dt \quad (6)$$

Using average water use  $\bar{W}_j$ , this simplifies to (7):

$$E_{\text{water}} = T(\gamma_1 \bar{W}_{\text{venue}} + \gamma_2 \bar{W}_{\text{hotel}} + \gamma_3 \bar{W}_{\text{public}} + \gamma_4 \bar{W}_{\text{land}}) \quad (7)$$

For waste generation, the recycling rate  $R_{\text{rec}}$  is considered. With  $\delta_i$  denoting the emission factors of different waste types, the total waste impact is given by (8):

$$E_{\text{waste}} = \int_0^T [\delta_1 Q_{\text{solid}}(t)(1 - R_{\text{rec}}(t)) + \delta_2 Q_{\text{food}}(t) + \delta_3 Q_{\text{plastic}}(t)] dt \quad (8)$$

Other impacts—such as noise, light pollution, and ecological disturbance—can also be modeled through time integration as in (9):

$$E_{\text{other}} = \int_0^T (\eta_1 L_{\text{noise}}(t) + \eta_2 L_{\text{light}}(t) + \eta_3 B_{\text{eco}}(t)) dt \quad (9)$$

To unify different scales, all module outputs are normalized. Let  $x_i \in [0,1]$ , be the

normalized indicators; the composite environmental index is then:

$$I_{\text{env}} = \sum_{i=1}^n w_i x_i, \sum_{i=1}^n w_i = 1 \quad (10)$$

Substituting the normalized outputs of the five modules yields:

$$I_{\text{env}} = w_1 \frac{E_{\text{en}}}{E_{\text{en,max}}} + w_2 \frac{E_{\text{ghg}}}{E_{\text{ghg,max}}} + w_3 \frac{E_{\text{water}}}{E_{\text{water,max}}} + w_4 \frac{E_{\text{waste}}}{E_{\text{waste,max}}} + w_5 \frac{E_{\text{other}}}{E_{\text{other,max}}} \quad (11)$$

Because cities differ in climate, energy structure, and water stress, a regional adjustment factor is introduced:

$$I_{\text{adj}} = I_{\text{env}} (1 + \lambda_1 C_{\text{climate}} + \lambda_2 C_{\text{energy}} + \lambda_3 C_{\text{water}}) \quad (12)$$

Substituting (11) into (12) gives:

$$I_{\text{adj}} = \left[ w_1 \frac{E_{\text{en}}}{E_{\text{en,max}}} + w_2 \frac{E_{\text{ghg}}}{E_{\text{ghg,max}}} + w_3 \frac{E_{\text{water}}}{E_{\text{water,max}}} + w_4 \frac{E_{\text{waste}}}{E_{\text{waste,max}}} + w_5 \frac{E_{\text{other}}}{E_{\text{other,max}}} \right] \cdot (1 + \lambda_1 C_{\text{climate}} + \lambda_2 C_{\text{energy}} + \lambda_3 C_{\text{water}}) \quad (13)$$

Equation (13) represents the integrated environmental impact model and is used to quantify the relative environmental burden of candidate cities. Taking New Orleans as the baseline, the relative impact index is:

$$R_i = \frac{I_{\text{adj},i}}{I_{\text{adj},0}} \times 100 \quad (14)$$

Values  $R_i < 100$  indicate lower environmental burden than the baseline, whereas

$R_i > 100$  indicate higher burden.

To clarify the meaning of integration, the instantaneous environmental impact function  $\Phi(t)$  is defined as:

$$\Phi(t) = \alpha_1 P_{\text{venue}}(t) + \alpha_2 P_{\text{hotel}}(t) + \dots + \eta_3 B_{\text{eco}}(t) \quad (15)$$

The total environmental impact is then:

$$E_{\text{total}} = \int_0^T \Phi(t) dt \quad (16)$$

Equations (15) and (16) show that  $E_{\text{total}}$  reflects the time-integrated environmental intensity of all subsystems over the entire event lifecycle. Essentially, it captures the cumulative environmental load throughout the event.

In summary, the model offers a unified framework integrating energy use, emissions, water consumption, and waste generation, and serves as the foundation for multi-criteria evaluation (e.g., AHP, TOPSIS, entropy weight). It supports cross-city comparison of environmental performance and highlights key drivers—such as stadium

energy demand, climate, energy mix, and travel intensity—thus characterizing the environmental footprint of mega-events like the Super Bowl.

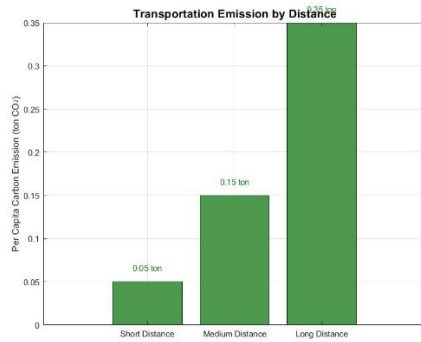


Figure 2. Comparison of transportation emissions at different travel distances

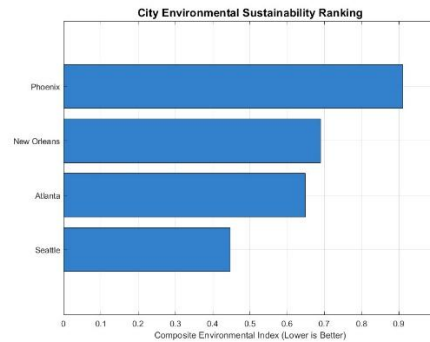


Figure 3. Urban environmental sustainability ranking

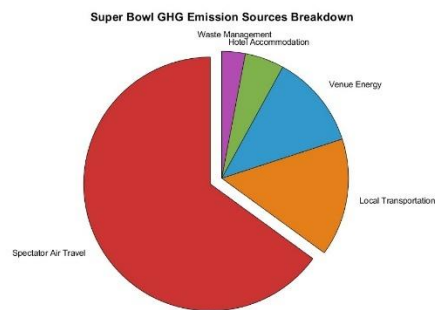


Figure 4. Sources of greenhouse gas emissions

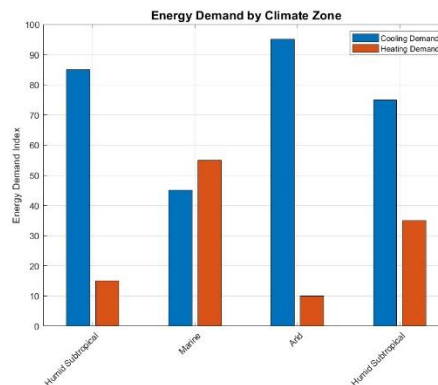


Figure 5. Stadium energy demand across different climate zones

Figure 2 shows that travel distance strongly affects transportation emissions, with long-haul flights as the primary contributor. Figure 3 presents city sustainability rankings, while Figure 4 identifies the major sources of Super Bowl–related greenhouse gases. Figure 5 compares stadium energy demand across climate zones. Together, these results support the necessity of the proposed model and enable cross-city sustainability comparison.

## 6. Problem 2: Environmental Sustainability–Based Host City Evaluation Model

Based on the impact function  $\Phi(t)$  and the baseline environmental burden obtained in Problem 1, we construct a multi-criteria decision model—the Integrated Environmental Sustainability Evaluation Model (IESEM)—to quantify each city’s environmental performance and identify the optimal host city for the next Super Bowl. We assume that a city’s environmental sustainability depends on several subsystems, including transportation, energy, water, waste management, and green infrastructure. The overall sustainability score is defined as:

$$F_i = f(E_{\text{traffic},i}, E_{\text{energy},i}, E_{\text{water},i}, E_{\text{waste},i}, E_{\text{infra},i}) \quad (17)$$

where  $E_{\text{traffic},i}$  represent the environmental performance of city

These quantities are essentially the time-integrated environmental intensity over the evaluation period  $[0, T]$ .

For example, the transportation impact can be written as:

$$E_{\text{traffic},i} = \int_0^T (\alpha_1 Q_{\text{air}}(t,i) + \alpha_2 Q_{\text{local}}(t,i) + \alpha_3 C_{\text{trans}}(t,i)) dt \quad (18)$$

where  $Q_{\text{air}}(t,i)$  denotes aviation energy use or emission intensity,  $Q_{\text{local}}(t,i)$  local transport energy use, and  $C_{\text{trans}}(t,i)$  transport-related carbon emissions;  $\alpha_1, \alpha_2, \alpha_3$  are weighting factors.

Similarly, the energy-system impact is:

$$E_{\text{energy},i} = \int_0^T (\beta_1 P_{\text{grid}}(t,i) \rho_{\text{carbon}}(i) + \beta_2 P_{\text{renew}}(t,i) (1 - \rho_{\text{carbon}}(i)) + \beta_3 A_{\text{air}}(t,i)) dt \quad (19)$$

where  $P_{\text{grid}}(t,i)$  is grid electricity use,  $\rho_{\text{carbon}}(i)$  the local carbon intensity,  $P_{\text{renew}}(t,i)$  renewable energy intensity, and  $A_{\text{air}}(t,i)$  air pollution intensity. Equation (19) captures the combined effect of energy mix and air quality.

The impacts of water use and waste generation are:

$$E_{\text{water},i} = \int_0^T (\gamma_1 S_{\text{stress}}(i) + \gamma_2 U_{\text{eff}}(t,i)) dt, E_{\text{waste},i} = \int_0^T (\delta_1 R_{\text{recycle}}(t,i) + \delta_2 W_{\text{cap}}(t,i)) dt \quad (20)$$

where  $S_{\text{stress}}(i)$  is water stress,  $U_{\text{eff}}(t,i)$  water-use efficiency,  $R_{\text{recycle}}(t,i)$  recycling rate, and  $W_{\text{cap}}(t,i)$  waste-processing capacity.

If the indicators vary slowly over time, the integrals in (17)–(19) can be approximated by their average values scaled by the event duration:

$$E_{k,i} \approx T \cdot \bar{e}_{k,i}, k \in \{\text{traffic, energy, water, waste, infra}\} \quad (21)$$

To eliminate dimensional effects, all indicators are normalized.

Let  $x_{ij}$  be the raw value of city  $i$  on indicator  $j$ ; the normalized value  $r_{ij}$  is computed as:

$$r_{ij} = \begin{cases} \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}, & \text{Benefit-type indicator;} \\ [8pt] \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}, & \text{Cost-type indicator.} \end{cases} \quad (22)$$

All normalized indicators form the matrix  $R = [r_{ij}]_{m \times n}$ .

To determine indicator weights, the AHP judgment matrix  $A = (a_{pq})_{n \times n}$  is constructed, where  $a_{pq}$  represents the relative importance of indicator  $p$  to  $q$  satisfying  $a_{pq} = 1/a_{qp}$  and  $a_{pp} = 1$ . The maximum eigenvalue  $\lambda_{\max}$  and its eigenvector  $w$ , yield the normalized weight vector:

$$W = \frac{w}{\sum_{j=1}^n w_j}, Aw = \lambda_{\max} w \quad (23)$$

Consistency is checked using the consistency ratio :

$$CR = \frac{\lambda_{\max} - n}{(n-1)RI} \quad (24)$$

A matrix is acceptable when  $CR < 0.10$ . After obtaining the weights, the weighted sum model (WSM) provides each city's initial score:

$$S_i^{(1)} = \sum_{j=1}^n w_j r_{ij} \quad (25)$$

TOPSIS is then applied for secondary correction. The ideal and anti-ideal solutions are defined as:

$$r_j^+ = \max_i (r_{ij}), r_j^- = \min_i (r_{ij}) \quad (26)$$

Distances to the ideal and anti-ideal points are computed as:

$$D_i^+ = \sqrt{\sum_{j=1}^n w_j (r_{ij} - r_j^+)^2}, D_i^- = \sqrt{\sum_{j=1}^n w_j (r_{ij} - r_j^-)^2} \quad (27)$$

The relative closeness is:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (28)$$

A smaller  $D_i^+$  and larger  $D_i^-$  indicate higher sustainability.

To combine WSM and TOPSIS, the final environmental score is:

$$F_i = \alpha S_i^{(1)} + (1-\alpha)C_i \quad (29)$$

where  $\alpha = 0.5$ , Substituting (30) yields the time-integral form:

$$F_i = \alpha \sum_{j=1}^n w_j r_{ij} + (1-\alpha) \frac{D_i^-}{D_i^+ + D_i^-} \quad (30)$$

This formulation unifies the weighted-sum and distance-based components, providing

good robustness and interpretability.

Substituting the normalized matrix  $R$ , the term  $r_{ij}$  in (22) can be approximated by:

$$r_{ij} = \int_0^T \psi_{ij}(t) dt \quad (31)$$

where  $\psi_{ij}(t)$  is the instantaneous environmental intensity of city  $i$  on indicator  $j$

Substituting into (30), the integrated environmental score becomes:

$$F_i = \int_0^T \left[ \alpha \sum_{j=1}^n w_j \psi_{ij}(t) + (1-\alpha) \frac{\phi_i^-(t)}{\phi_i^+(t) + \phi_i^-(t)} \right] dt \quad (32)$$

Here,  $\phi_i^+(t)$  and  $\phi_i^-(t)$  denote the instantaneous distances to the ideal and anti-ideal solutions. Equation (32) represents the time-averaged sustainability strength and incorporates both static and dynamic effects.

For all candidate cities, the ranking is given by:

$$\text{Rank}(i) = \text{order}(F_i), i = 1, 2, \dots, m \quad (33)$$

The city with  $F_i = \max(F_1, F_2, \dots, F_m)$  is identified as the most environmentally sustainable Super Bowl host.

If the time-integrated score differences under varying weight scenarios satisfy:

$$\int_0^T |F_i^{(s)}(t) - F_i^{(0)}(t)| dt < \epsilon, \text{ the model is considered stable.}$$

In summary, equations (16)–(33) form a complete environmental sustainability evaluation framework. The model integrates multi-indicator quantification with time integration and ideal–anti-ideal distances, providing a consistent and interpretable basis for host city selection. Applying this framework, multiple candidate cities are evaluated and visualized, enabling sustainability-based ranking and cross-method comparison.

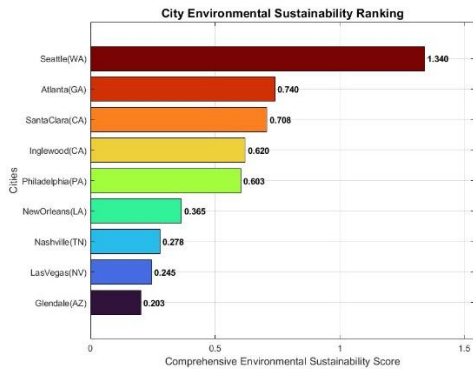


Figure 6. Sustainability ranking of cities

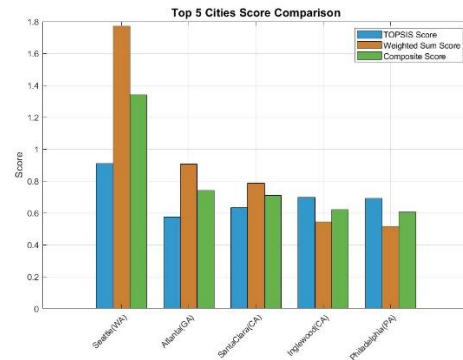


Figure 7. Score comparison of top five cities

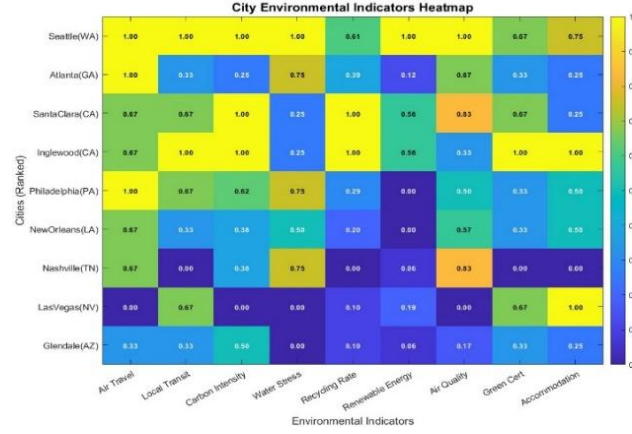


Figure 8. Heatmap of urban environmental indicators

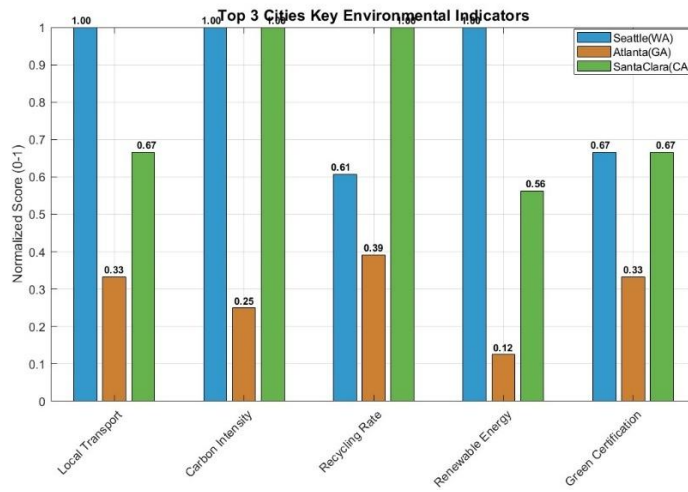


Figure 9. Key indicators of top three cities

Figure 6 shows the overall sustainability ranking of all candidate cities. Figure 7 compares the top five cities across TOPSIS, weighted-sum, and integrated scores. Figure 8 displays the heatmap of standardized environmental indicators. Figure 9 highlights key environmental advantages of the top three cities, supporting the final recommendation.

## 7.Problem 3: Environmental Performance–Based Host City Ranking and Recommendation Model

Building on the previous sections, we integrate the event-level impact model and the urban sustainability evaluation model to construct a host-city recommendation framework that accounts for temporal integration, dynamic weighting, historical experience, and regional adjustments.

We first define the instantaneous environmental intensity of city  $i$  as:

$$E_i(t) = E_{\text{env},i}(t) + E_{\text{infra},i}(t) + E_{\text{trans},i}(t) + H_i(t) + R_i(t) \quad (34)$$

where,  $E_{\text{env},i}(t)$ ,  $E_{\text{infra},i}(t)$  and  $E_{\text{trans},i}(t)$  denote the contributions of the environmental,

infrastructure, and transportation subsystems, while  $H_i(t)$  and  $R_i(t)$  represent adjustments for host experience and regional balance. These variables vary with time and capture changes in a city's environmental performance.

Based on the normalized indicator functions  $r_{ij}(t) = \psi_{ij}(t) / \sum_j \psi_{ij}(t)$ , the time-integrated environmental score is:

$$E_i = \int_0^T \left[ \sum_{j=1}^n w_j r_{ij}(t) + \lambda_1 H_i(t) + \lambda_2 R_i(t) \right] dt \quad (35)$$

When indicator variation is slow, the integral can be approximated by its mean value:

$$E_i \approx T \left[ \sum_{j=1}^n w_j \bar{r}_{ij} + \lambda_1 \bar{H}_i + \lambda_2 \bar{R}_i \right] \quad (36)$$

Substituting the integrated sustainability score from Problem 2 into (35) yields:

$$E_i = \int_0^T \left[ \alpha \sum_{j=1}^n w_j \psi_{ij}(t) + (1-\alpha) \frac{\phi_i^-(t)}{\phi_i^+(t) + \phi_i^-(t)} + \lambda_1 H_i(t) + \lambda_2 R_i(t) \right] dt \quad (37)$$

To characterize host experience over time, an exponential decay model is introduced:

$$H_i(t) = \int_0^t \chi_i(\tau) (1 - e^{-k(T_{\text{now}} - \tau)}) d\tau \quad (38)$$

where  $\chi_i(\tau)$  is the experience indicator and  $T_{\text{now}}$  is the current year.

Similarly, regional balance is quantified as:

$$R_i(t) = \int_0^t [1 - \rho(\omega_i, \tau)] d\tau \quad (39)$$

where  $\rho(\omega_i, \tau)$  is the hosting density of region  $\omega_i$  at time  $\tau$ .

Substituting (38) and (39) into (37) gives the integrated score:

$$F_i = \int_0^T \left\{ \alpha \sum_{j=1}^n w_j \psi_{ij}(t) + (1-\alpha) \frac{\phi_i^-(t)}{\phi_i^+(t) + \phi_i^-(t)} + \lambda_1 \int_0^t \chi_i(\tau) (1 - e^{-k(T_{\text{now}} - \tau)}) d\tau + \lambda_2 \int_0^t [1 - \rho(\omega_i, \tau)] d\tau \right\} dt \quad (40)$$

Equation (40) captures both short-term variation (outer integral) and cumulative historical effects (inner integrals).

When indicators change smoothly, a mean-value approximation applies:

$$F_i \approx T \left[ \alpha \sum_{j=1}^n w_j \bar{\psi}_{ij} + (1-\alpha) \bar{C}_i + \lambda_1 \bar{H}_i + \lambda_2 \bar{R}_i \right] \quad (41)$$

Considering all five dimensions—environment, infrastructure, transportation, host

history, and regional balance—the overall score is:

$$F_i = T(w_{\text{env}}E_{\text{env},i} + w_{\text{infra}}E_{\text{infra},i} + w_{\text{trans}}E_{\text{trans},i} + w_{\text{hist}}H_i + w_{\text{region}}R_i) \quad (42)$$

The normalized index is:

$$I_i = \frac{F_i}{\max(F_i)} \quad (43)$$

To further quantify the distance between each city and the ideal solution, the Euclidean distance is defined as:

$$D_i = \sqrt{\sum_{j=1}^n w_j (I_i - I_j^+)^2} \quad (44)$$

The relative closeness is:

$$R_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (45)$$

Integrating all subsystem contributions yields the final score:

$$S_i = \int_0^T [w_{\text{env}}E_{\text{env},i}(t) + w_{\text{infra}}E_{\text{infra},i}(t) + w_{\text{trans}}E_{\text{trans},i}(t) + w_{\text{hist}}H_i(t) + w_{\text{region}}R_i(t)]dt \quad (46)$$

The optimal host city satisfies:

$$S^* = \max(S_i), i = 1, 2, \dots, m \quad (47)$$

To emphasize the importance of different time periods, a dynamic weight function  $\omega(t) = e^{-\beta(T-t)}$  is introduced, enhancing the contribution of recent stages. Equation (46) becomes:

$$S_i = \int_0^T \omega(t)[w_{\text{env}}E_{\text{env},i}(t) + w_{\text{infra}}E_{\text{infra},i}(t) + w_{\text{trans}}E_{\text{trans},i}(t) + w_{\text{hist}}H_i(t) + w_{\text{region}}R_i(t)]dt \quad (48)$$

To measure a city's sensitivity to environmental pressure, the environmental elasticity coefficient is introduced:

$$\xi_i(t) = \frac{\partial E_i(t)}{\partial P_i(t)} = \frac{dE_i(t)}{d(\text{population\_density} \times \text{GDP})} \quad (49)$$

The cumulative elasticity index is:

$$\Theta_i = \int_0^T \xi_i(t) |dt \quad (50)$$

To balance sustainability and elasticity, the combined objective is:

$$J_i = S_i - \mu \Theta_i \quad (51)$$

where  $\mu$  is the elasticity penalty. Larger  $J_i$  indicates higher sustainability with lower

fragility.

To test robustness, the temporal variability is defined as:

$$\sigma_i = \sqrt{\frac{1}{T} \int_0^T (E_i(t) - \bar{E}_i)^2 dt} \quad (52)$$

A smaller  $\sigma_i$  indicates greater stability.

The final recommendation index is:

$$U_i = J_i(1 - \sigma_i) = (1 - \sigma_i) \left[ S_i - \mu \int_0^T |\xi_i(t)| dt \right] \quad (53)$$

The city with  $U_i = \max(U_1, U_2, \dots, U_m)$  is selected as the most environmentally sustainable Super Bowl host.

In summary, the model integrates multidimensional impact aggregation, temporal weighting, elasticity adjustment, and stability analysis through the continuous formulation from (35)–(53). It extends the event-level impact integration in Problem 1 and the multi-criteria decision framework in Problem 2, while incorporating dynamic time weights and environmental elasticity to enhance spatial fairness, temporal smoothness, and structural robustness. This provides a comprehensive quantitative tool for sustainability assessment across multi-city and multi-venue events.

To illustrate its applicability, we visualize the model's behavior under extended scenarios. Figures 10–13 show the spatial variation of multi-city sustainability scores, the effect of temporal discounting, the contribution of infrastructure investment, and the differences between single-venue and multi-venue events. These results confirm the model's dynamic consistency and structural soundness, and support the case study analysis in Problem 4.

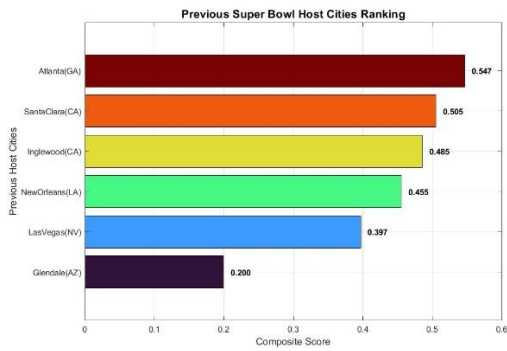


Figure 10. Scores of previously hosted cities

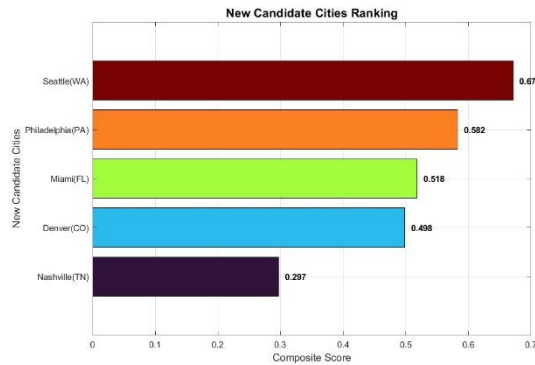


Figure 11. Scores of newly proposed candidate cities

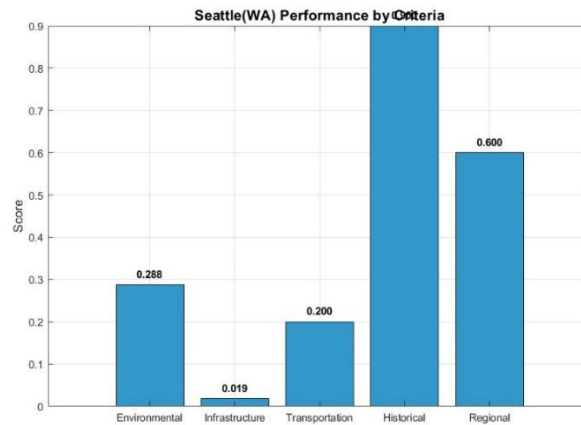


Figure 12. Performance of Seattle across five evaluation criteria



Figure 13. Heatmap of key environmental indicators for candidate cities

Reassessment of the six cities that previously hosted the Super Bowl shows that Atlanta (GA) achieves the highest sustainability score (0.5466), driven by its strong transportation connectivity, hosting experience, and regional suitability. Santa Clara (CA) and Inglewood (CA) follow, while Glendale (AZ) ranks lowest due to weaker environmental and infrastructure performance.

For the five new candidate cities with NFL teams, Seattle (WA) demonstrates clear advantages in environmental quality, renewable energy share, grid cleanliness, public transit, and regional sustainability, achieving the highest score (0.6713) and outperforming Philadelphia (PA), Miami (FL), and others.

Combining both groups, Seattle (WA) not only ranks first among new candidates but also attains the highest sustainability score across all 11 evaluated cities. Therefore, based on the proposed environmental sustainability model, Seattle (WA) is recommended as the optimal host city for the 2029 Super Bowl.

## 8. Problem 4: Spatiotemporal Sustainability Model for Multi-Venue Mega-Events

Building on the previous model, we extend the sustainability framework to multi-

venue and multi-city events. Considering that large events operate over the time interval  $t \in [0, T]$  and involve  $M$  primary venues distributed across  $N$  cities  $C_i (i = 1, 2, \dots, N)$ , the overall sustainability intensity is defined as:

$$F_{\text{event}} = \left\{ \int_0^T \int_0^M (w_1 E_{\text{env}}(t, m) + w_2 E_{\text{infra}}(t, m) + w_3 E_{\text{trans}}(t, m) + w_4 E_{\text{water}}(t, m) + w_5 E_{\text{carbon}}(t, m)) dm dt \right. \quad (54)$$

In equation (54),  $E_{\text{env}}(t, m)$  represents the environmental sustainability performance of venue  $m$  at time  $t$ . The terms  $E_{\text{infra}}$ ,  $E_{\text{trans}}$ ,  $E_{\text{water}}$  and  $E_{\text{carbon}}$  denote the subsystem intensities of infrastructure, transportation, water resources, and carbon emissions, respectively, and  $w_i$  represents the weights of these subsystems.

Time-averaging yields each city's sustainability score:

$$S_i = \frac{1}{TM} \int_0^T \int_0^M (w_1 E_{\text{env},i}(t, m) + w_2 E_{\text{infra},i}(t, m) + w_3 E_{\text{trans},i}(t, m) + w_4 E_{\text{water},i}(t, m) + w_5 E_{\text{carbon},i}(t, m)) dm dt \quad (55)$$

Time-averaging yields each city's sustainability score:

$$S_i \approx \sum_{k=1}^5 w_k \bar{E}_{k,i} = w_1 \bar{E}_{\text{env},i} + w_2 \bar{E}_{\text{infra},i} + w_3 \bar{E}_{\text{trans},i} + w_4 \bar{E}_{\text{water},i} + w_5 \bar{E}_{\text{carbon},i} \quad (56)$$

Equation (56) describes the time-averaged sustainability model under steady-state conditions. By further expressing the subsystem averages as a standardized indicator matrix  $r_{ij}$ , we obtain:

$$\bar{E}_{k,i} = \frac{1}{M} \sum_{j=1}^M r_{ij}^{(k)}, S_i = \sum_{k=1}^5 w_k \bar{E}_{k,i} \quad (57)$$

This formulation constitutes the integrated sustainability model for multi-venue events. Let the standardized indicator matrix be  $R = [r_{ij}]_{n \times m}$  and define the city-level sustainability:

$$F_i^{(\text{Olympic})} = R_i W^T, W = (w_1, w_2, w_3, w_4, w_5) \quad (58)$$

Introducing temporal discounting:

$$F_i^* = \int_0^T \phi(t) F_i^{(\text{Olympic})}(t) dt, \phi(t) = e^{-\rho(T-t)} \quad (59)$$

Here,  $\phi(t)$  denotes the time discount weight for future event periods, and  $\rho$  is the temporal decay coefficient. Substituting equation (58) into equation (59) and

performing integral simplification yields:

$$F_i^* = \frac{1 - e^{-\rho T}}{\rho} \sum_{k=1}^5 w_k \bar{E}_{k,i} \quad (60)$$

The resulting expression describes the proportional relationship between a city's overall sustainability score and its long-term performance. When  $F_i^*$  reaches its maximum, the corresponding city is identified as the optimal host:

$$C^* = \arg \max_i F_i^* \quad (61)$$

To further quantify a city's sustainability improvements under different investment conditions, an infrastructure investment variable  $x_i$  is introduced. By allocating budget across multiple investment options, a city can simultaneously influence environmental and economic objectives. Let the investment vector be  $x = [x_1, x_2, \dots, x_n]$ ; then the following multi-objective optimization model is constructed:

$$\min_{x_i} J = \alpha_{\text{env}} (-E_{\text{gain}}(x)) + \beta_{\text{econ}} (C_{\text{total}}(x) - B_{\text{econ}}(x)) \quad (62)$$

The constraints are given by:

$$\sum_{i=1}^n x_i \leq B, x_i^{\min} \leq x_i \leq x_i^{\max} \quad (63)$$

where  $\alpha_{\text{env}} + \beta_{\text{econ}} = 1$ , representing the environmental and economic weights. The components of equation (62) are defined as follows:

First, the environmental improvement function  $E_{\text{gain}}(x)$  follows a law of diminishing returns, where  $s_i$  is the sustainability coefficient of project  $i$ , yielding:

$$E_{\text{gain}}(x) = E_{\text{max}} \left( 1 - e^{-k \sum_i x_i s_i} \right) \quad (64)$$

where  $k$  is a sensitivity parameter. The total cost  $C_{\text{total}}(x)$  includes both initial investment and maintenance costs:

$$C_{\text{total}}(x) = \sum_i x_i + \sum_i (x_i m_i) \cdot 0.1T \quad (65)$$

Economic benefits follow a Net Present Value (NPV) model. With discount rate  $r$  economic return coefficient  $e_i$  and baseline scaling factor  $A$ , we have:

$$B_{\text{econ}}(x) = A \sum_i x_i e_i \cdot \frac{1 - (1+r)^{-T}}{r} \quad (66)$$

Substituting equations (64)–(66) into equation (62) and simplifying gives:

$$J = \alpha_{\text{env}} \left[ -E_{\text{max}} \left( 1 - e^{-k \sum_i x_i s_i} \right) \right] + \beta_{\text{econ}} \left[ \sum_i x_i (1 + m_i \cdot 0.1T) - A \sum_i x_i e_i \frac{1 - (1+r)^{-T}}{r} \right] \quad (67)$$

Equation (67) describes the trade-off between environmental improvement and economic returns. Under a given budget  $B$ , minimizing  $J$  yields the optimal investment allocation  $x_i^*$ . Furthermore, the return on investment (ROI) is defined as:

$$ROI = \frac{B_{\text{econ}}(x) - C_{\text{total}}(x)}{C_{\text{total}}(x)} \quad (68)$$

If  $ROI > 0$ , the investment generates net benefits. When  $\frac{dJ}{dx_i} = 0$  and all constraints

are satisfied, the resulting allocation is the Pareto-optimal solution. To account for time-related payback performance, the payback period  $\tau$  is introduced and defined as:

$$\tau = \frac{C_{\text{total}}(x)}{A \sum_i x_i e_i}, \tau \leq T \quad (69)$$

This term represents the minimum time required to achieve benefit balance within the evaluation horizon  $T$ . Substituting equations (68) and (69) into equation (67), we obtain the integrated sustainable investment model:

$$F_{\text{invest}} = \int_0^T \left[ \alpha_{\text{env}} E_{\text{gain}}(x, t) + \beta_{\text{econ}} \frac{B_{\text{econ}}(x, t)}{C_{\text{total}}(x, t)} \right] dt \quad (70)$$

Here,  $E_{\text{gain}}(x, t)$  and  $B_{\text{econ}}(x, t)$  denote the marginal environmental improvement and discounted economic return at time  $t$ , respectively. Equation (70) essentially defines a time-integrated environmental–economic dual-objective benefit function, through which the optimal investment strategy maximizing sustainability can be obtained.

Finally, to compare the sustainability differences between single-venue and multi-venue mega-events, an environmental impact metric is defined as:

$$\mathbf{E}(t) = [E_{\text{energy}}(t), E_{\text{traffic}}(t), E_{\text{water}}(t), E_{\text{waste}}(t), E_{\text{infra}}(t), E_{\text{carbon}}(t), E_{\text{duration}}(t)] \quad (71)$$

: By integrating the environmental impact of single-venue and multi-venue events over time:

$$E_{\text{single}} = \int_0^T \mathbf{w}_s \cdot \mathbf{E}(t) dt, E_{\text{multi}} = \int_0^T \mathbf{w}_m \cdot \mathbf{E}(t) dt \quad (72)$$

Among them,  $\mathbf{w}_s$  and  $\mathbf{w}_m$  represent the weight vectors of the two types of events across the environmental dimensions. Accordingly, the relative environmental pressure difference is defined as:

$$\Delta E_j = \frac{E_{\text{multi},j} - E_{\text{single},j}}{E_{\text{multi},j}}, j = 1, 2, \dots, 7 \quad (73)$$

combining equations (72) and (73), we obtain the unified expression that characterizes the lifecycle environmental differences between the two types of events:

$$\Delta E_{\text{total}} = \int_0^T \frac{\mathbf{w}_m \cdot \mathbf{E}(t) - \mathbf{w}_s \cdot \mathbf{E}(t)}{\mathbf{w}_m \cdot \mathbf{E}(t)} dt \quad (74)$$

The integral value in equation (74) reflects the overall environmental impact gap between the two event types across their full life cycles. If  $\Delta E_{\text{total}} < 0.3$ , then single-venue events exhibit significantly better sustainability than multi-venue events. If  $\Delta E_{\text{total}} > 0.7$ , green energy adoption, carbon offsetting, and intelligent transportation strategies should be introduced to reduce the overall environmental burden.

To generalize the earlier single-city and single-venue models to realistic multi-venue, multi-city mega-events, this subsection develops a spatiotemporal dual-integration framework. The model extends equations (51)–(53) by coupling multiple cities, multiple venues, and the full event timeline, and incorporates a discount factor  $\phi(t)$  to reflect increasing environmental sensitivity near the event. After standardizing cities' long-term performance across five environmental subsystems and adding venue disturbance effects, a comprehensive sustainability index is obtained. Figures 14 and 15 show the resulting city-level sustainability scores and radar plots of the indicator categories.

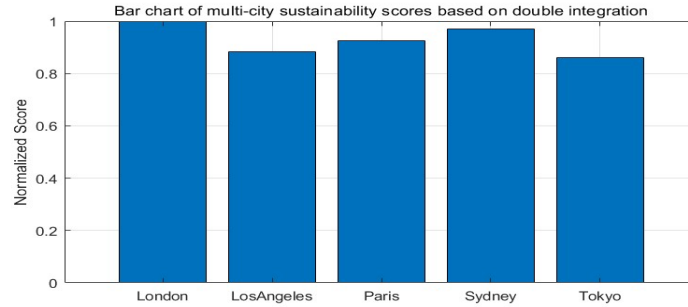


Figure 14. Multi-city dual-integration sustainability score bar chart

After extending the sustainability model for large-scale events, this subsection applies it to the scenario of potential host cities for the 2036 Olympics. Using the city-level sustainability function in equations (54)–(55) and the multi-venue dual-integration results from the previous section, five candidate cities are ranked based on their performance in environment, infrastructure, transportation, water resources, and carbon emissions. To illustrate cross-city differences, bar charts of overall sustainability scores and stacked comparisons of the five environmental subsystems are generated, highlighting each city's structural advantages and hosting potential.

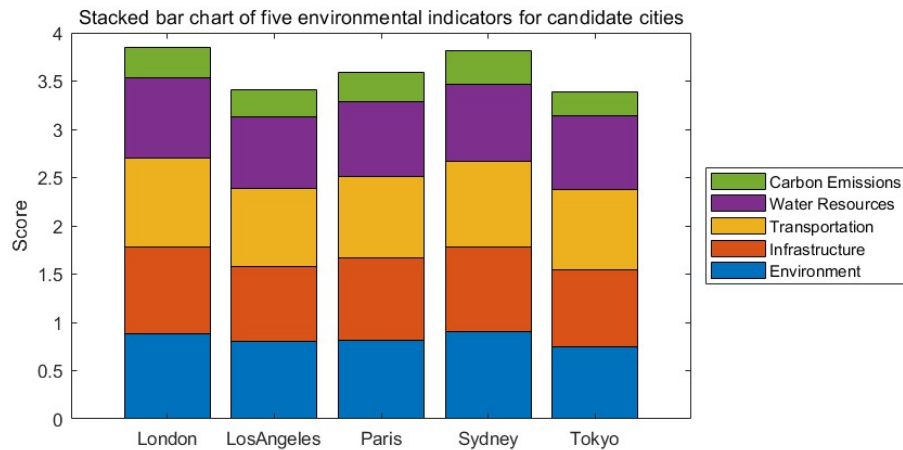


图 15 Stacked bar chart of five environmental indicators for candidate cities

To evaluate potential infrastructure investment strategies that could enhance a city's sustainability before hosting a major event, this subsection develops the multi-objective optimization model defined in equations (57)–(65). The environmental improvement follows a diminishing-returns function, while economic benefits are evaluated using a discounted net present value (NPV) model under a budget constraint. Solving for the optimal investment vector  $x$  yields a balanced improvement between environmental and economic outcomes, as illustrated in Table 1.

Table 1. Relationship among investment budget, environmental benefits, and economic returns

| Budget (M) | Environmental Gain | ROI (%) | Payback Period (years) |
|------------|--------------------|---------|------------------------|
| 50         | 0.190              | 191.2   | 2.7                    |
| 100        | 0.283              | 229.9   | 2.3                    |
| 150        | 0.317              | 185.7   | 2.7                    |
| 200        | 0.320              | 177.3   | 2.8                    |

To illustrate how sustainability improves under different budget levels, this subsection presents the ROI–environmental improvement curves for various investment plans. As shown in Figure 16, the results clearly reveal the quantitative relationships among budget size, investment structure, and environmental gains.

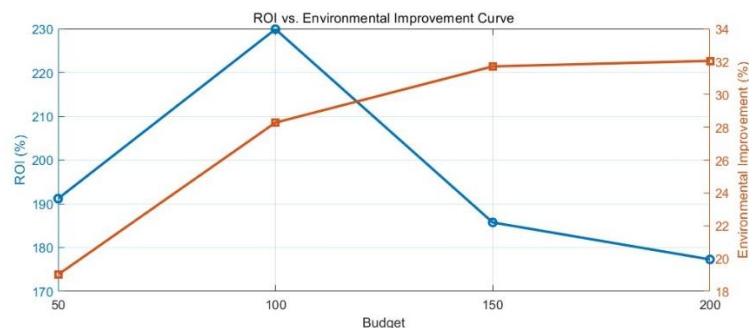


Figure 16. ROI and environmental improvement curves under different investment budgets

Finally, to compare the environmental burdens of single-venue events (e.g., the Super Bowl) and multi-venue mega-events (e.g., the Olympic Games), this study develops a multi-dimensional environmental comparison framework based on

equations (66)–(69). Seven indicators—energy consumption, transportation emissions, water use, waste treatment, infrastructure pressure, total carbon emissions, and event duration—are standardized to capture structural differences in lifecycle impacts. As shown in Figure 18, multi-venue events place substantially higher pressure across most environmental dimensions compared with single-venue events.

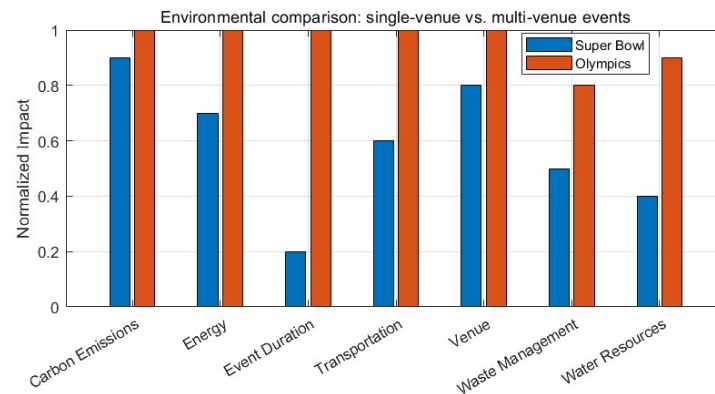


Figure 17. Environmental impact comparison between single-venue and multi-venue events

Using the extended spatiotemporal sustainability model, we evaluated five representative multi-venue cities and found that London achieved the highest overall score, indicating the strongest environmental performance and event-hosting capacity. Applying the model to the 2036 Olympic scenario further confirmed London as the most sustainable host city, supported by its balanced environmental indicators, efficient venue distribution, and strong urban resilience. The infrastructure investment analysis shows that a budget range of USD 50–100 million provides the optimal balance between environmental improvement (0.190–0.283) and economic feasibility, yielding the highest ROI (191%–230%) with payback periods under three years. A comparison between the Super Bowl and the Olympic Games reveals that multi-venue mega-events generate significantly higher environmental burdens across energy, transportation, water, waste, and carbon dimensions. Overall, the extended model demonstrates strong applicability across different event types and provides a robust quantitative foundation for sustainable planning and host-city selection.

## 9.Problem5: Sustainability-Based Hosting Policy Framework

To: Super Bowl Host Committee, National Football League (NFL)

Subject: Sustainability-Based Recommendation for the Optimal Super Bowl Host City

Dear Committee Members,

Using the environmental impact model, multi-criteria decision framework, extended urban sustainability model, and investment optimization analysis developed in this study, we conducted a comprehensive assessment of all candidate cities. The evaluation covered environmental quality, infrastructure capacity, transportation systems, water resource efficiency, and carbon emissions, supported by time-integration methods, AHP–TOPSIS weighting, multi-city coupling, and ROI-based investment analysis.

Our results show that Seattle, Washington, achieves the highest overall sustainability score among all 11 candidate cities. Seattle leads in renewable energy share, grid cleanliness, public transit accessibility, regional environmental resilience, and overall infrastructure readiness—key factors for supporting the high-intensity operational demands of the Super Bowl.

Investment analysis further indicates that targeted upgrades—especially in public transit, renewable energy, and waste/water management—would substantially increase Seattle’s sustainability performance. Budget plans in the USD 50–100 million range deliver the best combined environmental gains and economic returns (ROI 191%–230%), confirming the city’s strong improvement potential and financial viability.

Recommendation:

We recommend Seattle, WA as the optimal host city for the upcoming Super Bowl, given its superior environmental performance, infrastructure robustness, and alignment with long-term sustainable event goals.

We are prepared to provide additional analyses or scenario evaluations upon request and hope these findings support the committee’s informed decision-making.

Sincerely,

Team#16752

## 10. Sensitivity Analysis

As shown in Figure 18, small perturbations in the input parameters lead to only minor changes in city scores, and the overall ranking remains stable. Seattle’s score increases slightly from 0.671 to 0.678 and continues to rank first. Philadelphia and Miami show score changes of about  $\pm 2\%$ , but without altering their positions. Denver and Nashville exhibit even smaller fluctuations.

Overall, score variations for all cities remain within 0.02, and the final ranking is unchanged, indicating strong robustness of the model to parameter perturbations. In other words, Seattle maintains a clear leading advantage under all tested scenarios, confirming that the recommendation does not depend on specific parameter settings.

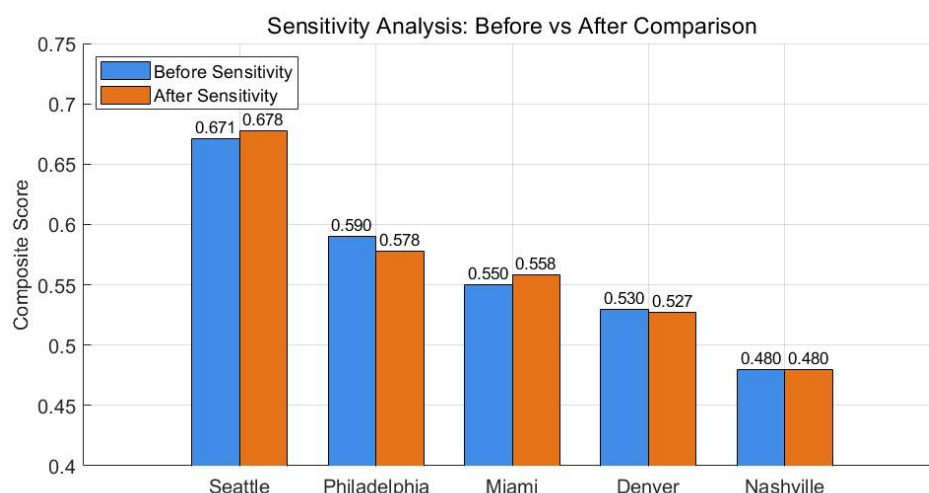


Figure 18. Sensitivity comparison

## 11.Strengths and Limitations

### 11.1 Strengths

1.Strong multidimensional integration:The proposed model incorporates multiple dimensions—environment, transportation, infrastructure, water resources, and carbon emissions—providing a comprehensive and balanced evaluation of urban sustainability and avoiding biases associated with single-indicator decisions.

2.Rigorous mathematical structure:The time-integration model in Problem 1, the AHP–TOPSIS decision framework in Problem 2, and the dual-integration multi-city model in Problem 4 form a coherent and interpretable mathematical system, ensuring scientific rigor and internal consistency.

### 11.2 Limitations

1.Data gaps and approximation in certain indicators:Some data—such as energy structure, waste recycling rates, and transportation carbon intensity—are incomplete or inconsistent across cities, requiring estimation or approximation, which may introduce minor deviations.

2.Economic parameters in the investment model require further validation:The ROI evaluation relies on economic assumptions (e.g., discount rates, benefit coefficients, maintenance costs), which may vary by region and should be validated with real-world policy and market conditions.

## 12.References

- [1]. Collins A, Jones C. An environmental assessment of major sporting events: The case of the UK's FA Cup Final. *Journal of Sport Management*, 2009; 23(3): 361–375.
- [2]. Li S, Blake A, Cooper C. Modelling the economic and environmental impacts of major sports events. *Annals of Tourism Research*, 2013; 40: 406–428.
- [3]. Gössling S, Peeters P, Hall C M. Air travel and climate change: Implications for large-scale events. *Journal of Transport Geography*, 2010; 18(3): 467–479.
- [4]. Silva C, Mendes A, Ribeiro B. Sustainability assessment of sports mega-events: A multi-criteria approach. *Sustainable Cities and Society*, 2019; 46: 101–119.
- [5]. M. Asadi, R. Gu. Multi-city energy and carbon modelling for mega-events: A spatiotemporal evaluation framework. *Energy Policy*, 2021; 149: 112–125.
- [6]. Shabani A, Sheikhmohammady M. A hybrid AHP–TOPSIS model for evaluating sustainable urban performance. *Sustainable Development*, 2019; 27(1): 27–42.

## **Reports AI Tool Usage**

1. *DeepSeek Transation* (DeepSeek Translator v3.0, 2025 version)  
Uploaded entire paper written in Mandarin to be translated into English.  
The team manually checked all translated text, corrected errors, and ensured that the scientific content, mathematical reasoning, and modeling decisions remained entirely team-generated.
2. OpenAI ChatGPT (ChatGPT-5.1, November 2025 version)  
Uploaded entire paper after translation to check grammar and clarity of the text drafted by the team.  
OpenAI ChatGPT was used only for English language polishing. It did not generate any mathematical modeling, equations, reasoning, etc.