Problem Chosen	2025 HiMCM/MidMCM Summary Sheet	Team Number
B		17252

Sport mega-events such as the Super Bowl and the football World Cup generate intense environmental impacts, yet host-city selection rarely treats environmental performance as the primary criterion. Our goal is to use Super Bowl LIX in New Orleans as a baseline to (i) quantify the life-cycle greenhouse-gas (GHG) footprint of a modern Super Bowl, (ii) construct a city-level sustainability index that ranks candidate hosts on environmental grounds alone, (iii) recommend a host city for the 2029 Super Bowl, and (iv) extend the framework to design lower-carbon formats for a future football World Cup.

Our three-layer modeling framework combines life-cycle assessment, city-level scoring, and tournament optimization. Model 1 builds a life-cycle event footprint for Super Bowl LIX by decomposing emissions into long-distance travel, local transport, stadium energy, hotels, food, water, and waste, combining published emission factors with event-specific data to compute total and per-spectator emissions. Model 2 converts city characteristics into a sustainability score S_c by normalizing five indicators—per-spectator GHG emissions (including travel, lodging, and venue energy), electricity carbon intensity, regional water stress, waste-diversion performance, and a travel metric combining transit accessibility and distance from the U.S. fan base—and aggregating them in a weighted linear index, with lower scores indicating more sustainable hosts. Model 3 generalizes the footprint model to tournaments with many games and venues and formulates a mixed-integer optimization that assigns matches to host regions so as to minimize tournament-wide emissions subject to capacity, scheduling, and basic fairness constraints.

Calibrated to New Orleans, Model 1 estimates that Super Bowl LIX generates about 4×10^4 tCO_2e in total, or roughly 0.61 tCO_2e per in-stadium spectator. Long-distance spectator travel accounts for about 75% of this footprint, stadium and venue energy about 21%, and hotels about 3%, with food, water, and solid waste together contributing well under 1%. These per-spectator values are consistent with recent Olympic and World Cup estimates, and sensitivity tests on flight distance and air-travel share confirm that long-distance travel remains the dominant driver. Applying Model 2 to nine U.S. cities (six previous Super Bowl hosts and three potential new hosts), we compute city-specific scores under baseline weights that emphasize GHG emissions while still accounting for water, waste, transit, and distance. Seattle attains the lowest sustainability index ($S_c \approx 0.56$), with Atlanta and Santa Clara forming a robust second tier ($S_c \approx 0.62$–0.64). Among previous Super Bowl hosts, Atlanta is the most sustainable repeat host; among cities that have never hosted, Seattle ranks best. Under the contest requirement to evaluate environmental criteria alone, our model therefore recommends Seattle as the preferred host city for the 2029 Super Bowl, with Atlanta as the leading repeat-host alternative.

In a World Cup case study, we compare three 2034 host-region options: a compact cluster in north-west Europe connected by high-speed rail, a single-country Gulf cluster, and a widely dispersed tri-continental format. Using published ranges for recent tournaments, our extended model yields per-visitor footprints of 0.35, 0.45, and 0.60 tCO_2e, so the compact European cluster emits roughly 40% less per visitor than the tri-continental option. A composite index combining GHG emissions and regional water stress again ranks the European cluster first, the Gulf option second, and the tri-continental format last. Across these applications, the framework is transparent and modular: key drivers such as grid emission factors, travel patterns, and waste-diversion rates can be updated easily, and sensitivity experiments on weights and indicator scores show that the top-ranked Super Bowl cities (Seattle, Atlanta) are robust to reasonable modeling choices. Major limitations include sparse city-specific data for some indicators, simplified treatment of fan travel, an assumption that existing stadiums are reused so embodied construction emissions are only partially captured, and a focus on environmental rather than economic or social criteria; future work could link richer travel-demand models with dynamic scheduling and integrate environmental, financial, and fan-experience objectives into a multi-criteria decision framework for sport mega-event hosts.

1 Introduction

Sport mega-events — including the Super Bowl, the Olympic Games, and the football World Cup — generate intense environmental impacts over relatively short periods of time.[1] These impacts include greenhouse gas (GHG) emissions from international and domestic travel, electricity and fuel used for venues, accommodation and food for visitors, water use, and solid waste generation. At the same time, leagues and organizing committees increasingly publicize sustainability goals and environmental programs.

However, environmental performance rarely determines where an event is held.[2] Host cities are mainly chosen based on economic capacity, sponsorship, media markets, and existing or promised infrastructure. This creates an opportunity: if environmental impact is made an explicit and dominant criterion, host selection and infrastructure planning could significantly reduce the footprint of these events.

In this paper, we address Problem B of the 2025 HiMCM contest. We use Super Bowl LIX in New Orleans as a baseline to understand the environmental impacts of a single Super Bowl, develop a model to evaluate host cities based on environmental concerns alone, select a host city for the 2029 Super Bowl, and extend our framework to other types of sport mega-events. We follow a full mathematical modeling cycle: clarifying the problem, making assumptions, defining variables, building and solving models, analyzing and testing them, and finally communicating our results in both technical and non-technical language.

2 Problem Restatement and Decomposition

The problem can be decomposed into four major tasks:

T1. Understand the baseline. Using Super Bowl LIX in New Orleans as a reference case, identify and structure the main environmental impact categories (e.g., travel, energy, water, waste) and discuss how they might change in other locations.

T2. Create a host city model. Build a model that scores potential Super Bowl host cities purely on environmental criteria. The model should be able to incorporate location-specific characteristics such as climate, electricity mix, transport infrastructure, and waste management.

T3. Select a 2029 host city.

(a) Among U.S. cities that have previously hosted the Super Bowl, determine which city would be the most sustainable choice to host again.

(b) Choose three U.S. cities with NFL teams that have never hosted the Super Bowl and determine which would be the most sustainable new host.

(c) Based on the model, recommend a single city to host the Super Bowl in 2029.

T4. Extend beyond the Super Bowl. Generalize the model to other sport mega-events (either single-sport tournaments or multi-sport competitions). Apply the extended model to recommend a host location for one such event, and discuss how infrastructure investment, energy sourcing, and transport systems influence cities' long-term attractiveness as hosts.

Our modeling framework is designed so that the first task feeds into the second: a structured understanding of the event footprint guides the construction of a quantitative/qualitative scoring model. Tasks 3 and 4 then apply and extend the model.

3 Modeling Framework Overview

We construct a three-layer modeling framework, drawing on established life-cycle assessment methodologies for mega-events:[3, 4]

Model 1: Life-Cycle Event Footprint Model. For any candidate host city c, we estimate a multi-dimensional environmental footprint vector

$$\mathbf{F}_c = \left(E_c^{\mathrm{GHG}},\, W_c^{\mathrm{water}},\, S_c^{\mathrm{waste}},\, R_c^{\mathrm{resource}}\right),$$

where E_c^{GHG} is total GHG emissions (e.g., in metric tons CO_2-eq), W_c^{water} is water consumption weighted by local water stress, S_c^{waste} encodes landfill and recycling performance, and R_c^{resource} includes other resource-related indicators such as land use or biodiversity impact when available.

Model 2: Location Sustainability Scoring Model. We convert the footprints and city-level characteristics into a dimensionless sustainability score $S_c \in [0, 1]$ by:

(a) choosing a set of indicators (for example, GHG intensity, water stress, waste circularity, low-carbon transport, and legacy);

(b) normalizing each indicator to $[0, 1]$ across cities; and

(c) computing a weighted sum of the normalized indicators.

Model 3: Multi-Event Extension. For tournaments or multi-sport events requiring several venues, we generalize Model 1 to all games/venues and then use an optimization model to minimize total environmental impact subject to practical constraints (hosts, schedule, capacity). The Super Bowl case corresponds to one event in one city.

We now describe each model in more detail, beginning with the single-event footprint.

4 Model 1: Life-Cycle Footprint of a Single Super Bowl

4.1 Step 1: Clarifying the Event Footprint

We interpret the "environmental footprint of Super Bowl LIX in New Orleans" as all major environmental impacts directly associated with the event across three phases:

- *Pre-event phase* (roughly one week): build-up events, team and media arrivals, increased hotel occupancy, and fan travel.
- *Game day*: stadium operations, local transport, food and beverages, and waste.
- *Post-event phase* (1–2 days): departures, stadium clean-up, and short-term restoration.

Following the accompanying emissions overview document and publicly available reports on recent Super Bowls, we focus on the main operational categories: fan and staff travel, local transport, stadium and venue energy use, hotel accommodation, food and beverage, water use and wastewater, and solid waste treatment.[1]

[1] Key data sources include the LSU/Opportunity Louisiana economic impact report for Super Bowl LIX[5] (visitor origin and transport mode shares), travel-distance statistics from ticketing and travel platforms for Super Bowl 50[6], league and stadium reports on waste[7–9] and water use at recent Super Bowls, and media reports on concessions volumes[10, 11] (see references for details).

4.2 Step 2: Assumptions and Variables (with Data Support)

We now specify the baseline assumptions and variables for Super Bowl LIX in New Orleans, explicitly distinguishing between values that come from data and those that are modeling assumptions.

(1) Spectator numbers and origin structure

Recent Super Bowls have in-stadium attendance around 65,000–70,000 spectators. Super Bowl LIII at Mercedes-Benz Stadium, for example, hosted 70,081 fans.[11] Combined with the Super Bowl LIX economic impact report for New Orleans,[5] we adopt:

1. Total in-stadium spectators (baseline):

$$N = N_{\text{spectators}} = 70{,}000 \quad \text{(data-consistent, rounded for modeling).}$$

2. According to the LSU/Opportunity Louisiana study, about 96% of game attendees at Super Bowl LIX were from outside Louisiana and 75% of out-of-state game attendees flew to the state, with the remaining 25% using road or other surface transport.[5]

   Hence we define

$$N_{\text{out}} = 0.96N \approx 67{,}200, \quad N_{\text{local}} = 0.04N \approx 2{,}800,$$
$$N_{\text{air}} = 0.75N_{\text{out}} \approx 50{,}400, \quad N_{\text{road,long}} = 0.25N_{\text{out}} \approx 16{,}800,$$

   and total road/surface travelers

$$N_{\text{road,total}} = N_{\text{road,long}} + N_{\text{local}} \approx 19{,}600.$$

Here, the *fractions* 96%, 75%, 25% are directly taken from survey data,[5] while the rounding to 70,000 spectators is a modeling simplification.

(2) Average travel distances by mode

For air travel, ticketing and travel data show that fans often travel well over 1,000 miles to attend the Super Bowl. Vivid Seats and TravelPulse report an average one-way distance of about 1,319 miles for Super Bowl 50 in Santa Clara,[6] while other analyses suggest similar or slightly higher values. Studies of college football events also find that a small fraction of air travelers can contribute more than half of travel-related emissions.[12, 13]

We therefore adopt the following central-value assumptions for distances:

- Air spectators (out-of-state):

$$d_{\text{air, one-way}} = 1{,}400 \text{ miles}, \quad d_{\text{air, round}} = 2d_{\text{air, one-way}} = 2{,}800 \text{ miles}.$$

  This lies within the empirically observed 1,300–1,550 mile range.

- Local in-state spectators (short road trips):

$$d_{\text{local, one-way}} = 25 \text{ miles}, \quad d_{\text{local, round}} = 50 \text{ miles},$$

  consistent with typical commuting distances to stadiums found in event-sustainability literature.[13]

- Out-of-state road travelers (longer drives from neighboring states):

$$d_{\text{road,long, one-way}} = 400 \text{ miles}, \quad d_{\text{road,long, round}} = 800 \text{ miles}.$$

From these, one could define an effective average one-way road distance

$$d_{\text{road,avg}} = \frac{N_{\text{local}} d_{\text{local, one-way}} + N_{\text{road,long}} d_{\text{road,long, one-way}}}{N_{\text{local}} + N_{\text{road,long}}} \approx 350 \text{ miles},$$

but in our calculations we keep the two road groups separate.

(3) Emission factors for transport and energy

We use emission factors consistent with the U.S. EPA GHG Emission Factors Hub and standard stadium LCA practice:

- Gasoline passenger car:

$$\text{EF}_{\text{car}} \approx 0.297 \text{ kg } \text{CO}_2/\text{passenger-mile}.$$

- Air travel, average medium/long-haul economy:

$$\text{EF}_{\text{air}} \approx 0.20 \text{ kg } \text{CO}_2\text{e}/\text{passenger-mile}.$$

- Electricity (New Orleans / Entergy New Orleans grid):

$$\text{CI}^{\text{grid}}_{\text{NOLA}} \approx 0.18 \text{ kg } \text{CO}_2\text{e}/\text{kWh},$$

based on eGRID and utility-reported intensities.[14]

- Natural gas combustion:

$$\text{EF}^{\text{gas}} \approx 52.9 \text{ kg } \text{CO}_2/\text{MMBtu}.$$

These are consistent with values reported by EPA and EIA.[15, 16]

(4) Stadium energy and hotel stays

We assume total event-related electricity use of

$$Q^{\text{elec}}_{\text{NOLA}} = 50{,}000 \text{ MWh}$$

across the Superdome and associated venues over the Super Bowl week, plus

$$Q^{\text{gas}}_{\text{NOLA}} = 2{,}000 \text{ MMBtu}$$

of natural gas. These are scenario values designed to be in the right order of magnitude for a week-long mega-event and are not meter readings.

For hotels, EPA's guidance on indirect emissions from events and conferences suggests typical room-night energy intensities. Combined with the LSU visitor report (average 3.5 overnight stays and high hotel usage), we retain the earlier simplification:

$$40{,}000 \text{ upper-upscale room-nights}, \quad 60{,}000 \text{ midscale room-nights},$$

with per-night electricity and gas use as in EPA's event guidance.[17]

(5) Water use and wastewater

Industry and academic sources estimate that an NFL game at a large stadium such as Gillette Stadium consumes between 600,000 and 1,000,000 gallons of water per game, primarily for toilets and irrigation. This corresponds to roughly 0.03–0.05 m^3 per spectator for a crowd of 70,000.

We therefore adopt:

$$V_{\text{water, per capita}} = 0.045 \text{ m}^3/\text{spectator},$$

so that

$$V_{\text{NOLA}}^{\text{water}} = N \times 0.045 = 3{,}150 \text{ m}^3.$$

Wastewater volume is assumed equal to water intake.

For operational emissions, we use Zib et al.'s estimates of 0.46 kg CO_2e/m^3 for drinking water supply and 0.38 kg CO_2e/m^3 for wastewater treatment.[18]

(6) Solid waste quantities

Multiple sources indicate that Super Bowls typically generate on the order of 40–60 t of solid waste inside the stadium on game day.[7–9, 19] For example, the NFL and partners targeted recovery of more than 40 t of waste at Super Bowl LII in Minneapolis as part of a "zero-waste legacy project,"[8] and Miami-Dade County cites about 40 t of waste for a typical Super Bowl.[7]

We therefore adopt:

$$m_{\text{waste,total}} = 48 \text{ t},$$

which corresponds to about 0.7 kg of solid waste per spectator:

$$m_{\text{waste, per capita}} = \frac{48 \text{ t}}{70{,}000} \approx 0.7 \text{ kg/spectator},$$

consistent with reports that stadium fans discard roughly 1–2 lb of trash each.[9]

For GHG emissions from waste treatment, we apply average Scope 3 emission factors for mixed municipal waste (a weighted combination of landfill, recycling, composting, and energy-from-waste), consistent with GHG Protocol guidance.[20]

(7) Food and beverage

For food, we distinguish between:

- *Observed minimum red-meat servings:* At Super Bowl LIII, Mercedes-Benz Stadium reported sales of 16,300 hot dogs and 117,400 beers to 70,081 spectators.[10, 11] This corresponds to

  $$n_{\text{hotdog, per capita}} = \frac{16{,}300}{70{,}081} \approx 0.23 \text{ servings per spectator},$$

  which we treat as a lower bound for red-meat main dishes at a Super Bowl.
- *Scenario for total main dishes:* Empirical data on total burger, pizza, chicken and plant-based servings for Super Bowl LIX are not publicly available. We therefore keep a simple scenario for the order of magnitude of food-related emissions, assuming in our baseline that the New Orleans event sells a total of 80,000 main-dish servings, of which 60,000 are red-meat based and 20,000 are plant-based. This is a modeling assumption, constrained by the observed hot-dog minimum and by the presence of vegan options documented in stadium food reports.[21, 22]

- *Emission factors:* For red-meat items we use a representative beef burger footprint of 21.86 kg CO_2e per kg of raw product,[23] and for plant-based sausages a footprint of 2.21 kg CO_2e per kg.[24] With typical serving sizes (about 120 g for beef burgers and 60 g for plant-based items), this yields approximately 2.6 kg CO_2e per beef serving and 0.16 kg CO_2e per plant-based serving.

4.3 Step 3: Mathematical Formulation

Total GHG emissions for a host city c are written as

$$E_c^{\mathrm{GHG}} = E_c^{\mathrm{trav}} + E_c^{\mathrm{loc}} + E_c^{\mathrm{stad}} + E_c^{\mathrm{acc}} + E_c^{\mathrm{food}} + E_c^{\mathrm{H_2O}} + E_c^{\mathrm{waste}}, \tag{1}$$

where the terms represent travel to and from the city, local transport, stadium and venue energy use, accommodation, food and beverage, water and wastewater operations, and solid waste.

In this paper we focus on the components that dominate the footprint and are most sensitive to host-city choice: long-distance spectator travel and electricity use. Local transport E_c^{loc} remains small relative to inter-city travel and is absorbed into E_c^{trav} for the baseline.

(1) Spectator travel (baseline)

For New Orleans (NOLA), using the structure and distances defined above:

Air travel.

$$E_{\mathrm{NOLA}}^{\mathrm{air}} = N_{\mathrm{air}} \cdot d_{\mathrm{air,\,round}} \cdot \mathrm{EF}_{\mathrm{air}} \tag{2}$$

$$\approx 50{,}400 \times 2{,}800 \text{ miles} \times 0.20 \ \frac{\text{kg CO}_2\text{e}}{\text{mile}} \tag{3}$$

$$= 28{,}224{,}000 \text{ kg CO}_2\text{e} \approx 28{,}224 \text{ tCO}_2\text{e}. \tag{4}$$

Road travel. Local (in-state) spectators:

$$E_{\mathrm{NOLA}}^{\mathrm{local\text{-}road}} = N_{\mathrm{local}} \cdot d_{\mathrm{local,\,round}} \cdot \mathrm{EF}_{\mathrm{car}} \tag{5}$$

$$\approx 2{,}800 \times 50 \text{ miles} \times 0.297 \ \frac{\text{kg CO}_2}{\text{mile}} \tag{6}$$

$$\approx 41{,}580 \text{ kg CO}_2 \approx 41.6 \text{ tCO}_2. \tag{7}$$

Out-of-state road travelers:

$$E_{\mathrm{NOLA}}^{\mathrm{road,long}} = N_{\mathrm{road,long}} \cdot d_{\mathrm{road,long,\,round}} \cdot \mathrm{EF}_{\mathrm{car}} \tag{8}$$

$$\approx 16{,}800 \times 800 \text{ miles} \times 0.297 \ \frac{\text{kg CO}_2}{\text{mile}} \tag{9}$$

$$\approx 3{,}991{,}680 \text{ kg CO}_2 \approx 3{,}992 \text{ tCO}_2. \tag{10}$$

So total road travel emissions are

$$E_{\mathrm{NOLA}}^{\mathrm{road}} = E_{\mathrm{NOLA}}^{\mathrm{local\text{-}road}} + E_{\mathrm{NOLA}}^{\mathrm{road,long}} \approx 4{,}033 \text{ tCO}_2.$$

Total spectator travel.

$$E^{\text{trav}}_{\text{NOLA}} = E^{\text{air}}_{\text{NOLA}} + E^{\text{road}}_{\text{NOLA}} \approx 28{,}224 + 4{,}033 \approx 32{,}257\ \text{tCO}_2\text{e}. \tag{11}$$

(2) Stadium and venue energy

Electricity:

$$E^{\text{elec}}_{\text{NOLA}} = Q^{\text{elec}}_{\text{NOLA}} \cdot 1{,}000\ \frac{\text{kWh}}{\text{MWh}} \cdot \text{CI}^{\text{grid}}_{\text{NOLA}} \tag{12}$$

$$= 50{,}000 \times 1{,}000\ \text{kWh} \times 0.18\ \frac{\text{kg CO}_2\text{e}}{\text{kWh}} \tag{13}$$

$$= 9{,}000{,}000\ \text{kg CO}_2\text{e} \approx 9{,}000\ \text{tCO}_2\text{e}. \tag{14}$$

Natural gas:

$$E^{\text{gas}}_{\text{NOLA}} = Q^{\text{gas}}_{\text{NOLA}} \cdot \text{EF}^{\text{gas}} \tag{15}$$

$$= 2{,}000\ \text{MMBtu} \times 52.9\ \frac{\text{kg CO}_2}{\text{MMBtu}} \tag{16}$$

$$\approx 105{,}800\ \text{kg CO}_2 \approx 106\ \text{tCO}_2. \tag{17}$$

So stadium and venue energy emissions sum to

$$E^{\text{stad}}_{\text{NOLA}} = E^{\text{elec}}_{\text{NOLA}} + E^{\text{gas}}_{\text{NOLA}} \approx 9{,}106\ \text{tCO}_2\text{e}.$$

(3) Accommodation

Using EPA's event guidance with the room-night assumptions in Section 2, we obtain approximately:

$$E^{\text{acc}}_{\text{NOLA}} \approx 1{,}200\ \text{tCO}_2\text{e},$$

combining hotel electricity and natural-gas use over all spectators and staff.

(4) Food and beverage

With the scenario of 60,000 red-meat and 20,000 plant-based main dishes:

$$E^{\text{red-meat}}_{\text{NOLA}} \approx 60{,}000 \times 2.6\ \text{kg CO}_2\text{e} \approx 156{,}000\ \text{kg CO}_2\text{e}, \tag{18}$$

$$E^{\text{plant}}_{\text{NOLA}} \approx 20{,}000 \times 0.16\ \text{kg CO}_2\text{e} \approx 3{,}200\ \text{kg CO}_2\text{e}. \tag{19}$$

Thus

$$E^{\text{food}}_{\text{NOLA}} \approx 159{,}200\ \text{kg CO}_2\text{e} \approx 159\ \text{tCO}_2\text{e}.$$

Given the uncertainties, we report a rounded value of

$$E^{\text{food}}_{\text{NOLA}} \approx 140\text{–}160\ \text{tCO}_2\text{e};$$

numerically we will use $E^{\text{food}}_{\text{NOLA}} = 138\text{–}159\ \text{tCO}_2\text{e}$ as a plausible range.

(5) Water and wastewater

Total water and wastewater volumes:

$$V_{\text{NOLA}}^{\text{water}} = V_{\text{NOLA}}^{\text{wastewater}} = 3{,}150\ \text{m}^3.$$

Emissions:

$$E_{\text{NOLA}}^{\text{water}} = 3{,}150 \times 0.46 \approx 1{,}449\ \text{kg CO}_2\text{e} \approx 1.45\ \text{tCO}_2\text{e}, \tag{20}$$
$$E_{\text{NOLA}}^{\text{wastewater}} = 3{,}150 \times 0.38 \approx 1{,}197\ \text{kg CO}_2\text{e} \approx 1.20\ \text{tCO}_2\text{e}. \tag{21}$$

Therefore

$$E_{\text{NOLA}}^{\text{H}_2\text{O}} = E_{\text{NOLA}}^{\text{water}} + E_{\text{NOLA}}^{\text{wastewater}} \approx 2.65\ \text{tCO}_2\text{e}.$$

(6) Solid waste

With $m_{\text{waste,total}} = 48$ t and an average emission factor of 0.13 tCO_2e per tonne of mixed municipal waste (combining landfill, recycling, composting, and energy-from-waste), we obtain:

$$E_{\text{NOLA}}^{\text{waste}} \approx 48 \times 0.13 \approx 6.2\ \text{tCO}_2\text{e}.$$

4.4 Numerical Baseline for Super Bowl LIX in New Orleans

Summing all contributions (using $E_{\text{NOLA}}^{\text{food}} \approx 138\ \text{tCO}_2\text{e}$ for definiteness), we have:

$$E_{\text{NOLA}}^{\text{GHG}} = E_{\text{NOLA}}^{\text{trav}} + E_{\text{NOLA}}^{\text{stad}} + E_{\text{NOLA}}^{\text{acc}} + E_{\text{NOLA}}^{\text{food}} + E_{\text{NOLA}}^{\text{H}_2\text{O}} + E_{\text{NOLA}}^{\text{waste}} \tag{22}$$
$$\approx 32{,}257 + 9{,}106 + 1{,}200 + 138 + 2.65 + 6.2 \tag{23}$$
$$\approx 42{,}700\ \text{tCO}_2\text{e} \quad \text{(rounded)}. \tag{24}$$

Average per-spectator footprint:

$$\frac{E_{\text{NOLA}}^{\text{GHG}}}{N} \approx \frac{42{,}700}{70{,}000} \approx 0.61\ \text{tCO}_2\text{e per spectator}.$$

Table 1 summarizes the baseline by category.

As in other sport-event LCAs,[1, 25] spectator travel dominates the footprint (about 75%), followed by stadium energy (about 21%) and hotels (about 3%). Food, water, and solid waste together contribute well under 1% of total GHG emissions, although they are important for other environmental dimensions (waste diversion, water stress, etc.).

4.5 Step 4: Normalized Impact Indices for Use in Model 2

We define a per-spectator GHG index for each candidate host city c:

$$G_c = \frac{E_c^{\text{GHG}}/N}{E_{\text{NOLA}}^{\text{GHG}}/N}.$$

Table 1: Illustrative baseline emissions for Super Bowl LIX in New Orleans by category.

Category	Emissions (tCO_2e)	Share of total (%)
Spectator travel (air + road)	32,257	75.5
Stadium and venue energy	9,106	21.3
Accommodation (hotels)	1,200	2.8
Food and beverage	138	0.3
Water and wastewater	2.7	0.0
Solid waste	6.2	0.0
Total	42,700	100.0

By construction, $G_{\mathrm{NOLA}} = 1$. Cities with lower per-spectator emissions will have $G_c < 1$, and less sustainable cities will have $G_c > 1$.

Analogous normalized indicators can be defined for other dimensions (water stress, waste diversion rate, share of low-carbon transport), using New Orleans or the min–max range across all candidate cities as the reference. Model$\tilde{2}$ then aggregates these indicators into an overall sustainability score for host-city selection.

4.6 Link to existing sustainability rating systems (Task 1)

In addition to our own life-cycle assessment, existing sustainability rating systems for stadiums and events help interpret the footprint of Super Bowl LIX in New Orleans.

For stadium design and operations, several U.S. venues have pursued third-party certifications such as LEED or net-zero labels. For example, Mercedes-Benz Stadium in Atlanta was the first professional sports venue to achieve LEED Platinum,[26] and Seattle's Climate Pledge Arena has been announced as the first net-zero certified arena, relying on renewable electricity and extensive transit incentives for fans.[27] Such certifications provide external validation that building energy and on-site operations have been systematically optimized.[28]

For waste, programs such as the NFL's "zero waste" Super Bowl legacy projects and the Council for Responsible Sport standard supply quantitative diversion metrics (e.g. percentage of waste diverted from landfill) and qualitative criteria on procurement and reuse.[2] These data support our assumptions about the order-of-magnitude of waste quantities and diversion rates and highlight opportunities for further improvement in future New Orleans events (e.g. moving from a $\sim$ 3% city-wide diversion rate towards 50–90% levels in-stadium during the Super Bowl).

Finally, recent Olympic and World Cup sustainability reports show that spectator travel typically accounts for 50–60% of total Games emissions, with construction and venue energy making up most of the remainder.[1, 3] These independent assessments corroborate our finding that travel should be the primary focus of location-based sustainability decisions.

[2]The Rush2Recycle initiative at Super Bowl LII in Minneapolis reported more than 90% waste diversion[8], while the Council for Responsible Sport standard is widely used to certify running and multi-sport events on their environmental and social performance.[29]

4.7 Sanity check and basic sensitivity analysis

Our baseline estimate of about 42,700 tCO_2e for Super Bowl LIX, corresponding to approximately 0.61 tCO_2e per spectator, can be compared to other mega-events.

Recent synthesis work on Olympic and World Cup footprints reports that the total carbon emissions of Summer Olympics since 2000 have typically ranged from 2.0 to 4.5 $MtCO_2e$, while men's FIFA World Cups have emitted about 1.65–3.6 $MtCO_2e$ in total.[1, 2] Normalizing by spectators, the Paris 2024 Olympic and Paralympic Games report about 0.52 tCO_2e per visitor[30], while the 2023 Rugby World Cup in France is estimated at about 0.92 tCO_2e per spectator.[31] Our value of 0.61 tCO_2e per spectator for a single high-profile NFL event is therefore in the same order of magnitude and lies between these two benchmarks.

We also conduct a simple sensitivity analysis on the main driver: long-distance air travel. In the baseline, spectator travel accounts for about 75% of total emissions. If the average flight distance for air spectators were 20% lower (e.g. 1,120 instead of 1,400 miles one-way), total event emissions would decrease by roughly 15%, but travel would still contribute more than 65% of the footprint. If, conversely, the share of spectators arriving by air increased by 10 percentage points (from 75% to 85% of out-of-state visitors), total emissions would increase by about 10–12%, again without changing the qualitative conclusion that spectator travel dominates.

These sanity checks suggest that, although our baseline relies on scenario assumptions, both the overall magnitude and the relative importance of travel are consistent with independent studies of other mega-events.

5 Model 2: Location-Specific Sustainability Index for Candidate Super Bowl Cities

In Model 1 we built a transparent life-cycle model for Super Bowl LIX in New Orleans, focusing on six operational categories: long-distance travel, local transport, stadium energy, hotels, food and beverage, water and wastewater, and solid waste. In Model 2 we extend this structure to compare potential host cities based purely on environmental criteria, as required in Problem B.

We assume that, for a given Super Bowl, the *activity levels* (number of spectators, length of stay, number of hotel nights, number of meals served) are similar across cities. What differs by location are:

- electricity grid emission factors CI_c (kg CO_2e/kWh);
- waste management structure (recycling / composting vs. landfill);
- local water scarcity and energy intensity of water supply;
- public transport and airport accessibility (affecting mode split for travel);
- local climate (affecting heating / cooling profiles).

Below we formalize these differences and use them to build a location-specific sustainability index S_c for each candidate host city c.

5.1 City-level input parameters

5.1.1 Electricity grid intensity

For each city c we define an average grid emission factor CI_c in kg CO_2e per kWh delivered, based

on EPA eGRID / utility disclosures and secondary compilations.[14] For example, Entergy New Orleans' supplier-specific factor is about 0.17 kg CO_2e/kWh in recent years, substantially below the Louisiana state average, while Arizona and Nevada grids are more carbon intensive.[14]

For comparability we use the following representative values (summarizing New Orleans–Glendale–Las Vegas–Inglewood–Santa Clara–Atlanta–Seattle–Denver–Charlotte data sheets):

Table 2: Electricity grid emission factors by city (simplified).

City c	Grid factor CI_c [kg CO_2e/kWh]
New Orleans, LA	0.18
Glendale, AZ	0.44
Las Vegas, NV	0.55
Inglewood, CA	0.15
Santa Clara, CA	0.17
Atlanta, GA	0.45
Seattle, WA	0.15
Denver, CO	0.35
Charlotte, NC	0.40

These values are designed to be *representative* rather than exact, and can be updated if better local grid factors become available.

For hotel stays we retain the EPA "Indirect Emissions from Events and Conferences" benchmarks used in Model 1:

$$E_{\text{hotel}}^{\text{elec}} \approx 35 \text{ kWh/room-night}, \tag{25}$$

$$E_{\text{hotel}}^{\text{gas}} \approx 0.094 \text{ MMBtu/room-night}, \tag{26}$$

assumed constant across cities due to lack of city-specific hotel energy statistics.

5.1.2 Waste management structure

Let R_c be the overall recycling/composting diversion rate for municipal solid waste in city c, and $L_c = 1 - R_c$ the landfill share (we neglect incineration with energy recovery at this scale). Using the New Orleans / Glendale / Las Vegas / Inglewood / Santa Clara / Atlanta / Seattle / Denver / Charlotte fact sheet and local reports, we adopt the following approximate diversion rates:

These values are based on city and county solid waste reports for each region [32–41].

Given a total game-day solid waste mass $m_{\text{waste,total}}$ (tonnes) for all spectators (estimated in Model 1), we model city-specific waste emissions as

$$E_c^{\text{waste}} = L_c \, m_{\text{waste,total}} \, EF_{\text{landfill}} + R_c \, m_{\text{waste,total}} \, EF_{\text{recycle/compost}}, \tag{27}$$

where EF_{landfill} and $EF_{\text{recycle/compost}}$ are generic emission factors (kg CO_2e/t) aligned with the GHG Protocol Scope 3 Category 5 guidance and U.S. inventories.[20] In the absence of consistent city-specific waste LCAs, we keep these factors identical across cities.

Table 3: Approximate diversion (recycling+compost) rates by city.

City c	Diversion R_c	Landfill share L_c
New Orleans, LA	0.03	0.97
Glendale, AZ	0.10	0.90
Las Vegas (Clark Co.), NV	0.20	0.80
Inglewood (L.A. Co.), CA	0.42	0.58
Santa Clara (Santa Clara Co.), CA	0.65	0.35
Atlanta, GA	0.23	0.77
Seattle, WA	0.55	0.45
Denver, CO	0.26	0.74
Charlotte (Mecklenburg Co.), NC	0.12	0.88

5.1.3 Water and wastewater

Following the U.S. water-sector study by Zib et al. we keep the operational footprints of drinking water and wastewater treatment *constant* across cities:[18]

$$EF_{\text{water}} \approx 0.46 \text{ kg } CO_2\text{e/m}^3, \tag{28}$$

$$EF_{\text{wastewater}} \approx 0.38 \text{ kg } CO_2\text{e/m}^3. \tag{29}$$

However, the *water scarcity* implications of additional demand differ strongly by climate. We therefore introduce a qualitative water-stress index $W_c \in [0, 1]$:

- $W_c \approx 0.2$ for humid, water-abundant cities (New Orleans, Seattle, Atlanta, Charlotte);
- $W_c \approx 0.5$ for Mediterranean / semi-arid climates with moderate stress (Inglewood, Santa Clara);
- $W_c \approx 0.7$–0.9 for semi-arid or desert climates with frequent drought and heavy reliance on imported water (Glendale, Las Vegas, Denver).

Formally, we treat W_c as a penalty term in the composite index rather than an explicit CO_2 emission term, because water scarcity is a location-specific environmental dimension distinct from greenhouse gases.

5.1.4 Public transport and airport accessibility

Finally, to capture differences in mode split for spectator travel, we define a transit-accessibility index $T_c \in [0, 1]$, where higher values mean better public transport and airport connectivity:

- $T_c \approx 0.8$ for cities with dense transit and rail links to the airport, such as Seattle (light rail to SEA) and Atlanta (MARTA heavy rail to ATL).
- $T_c \approx 0.6$ for cities with moderate rail/bus coverage and good airport access, such as Denver (RTD rail to DEN), Santa Clara (VTA light rail + Caltrain to SJC), and Inglewood (proximity to LAX and expanding Los Angeles Metro network).
- $T_c \approx 0.5$ for New Orleans and Las Vegas, which have basic bus/rail networks and accessible airports but remain largely car-oriented.
- $T_c \approx 0.3$–0.4 for Glendale and Charlotte, where transit coverage is weaker and most spectators are expected to rely on cars or charter buses.

Again, T_c is a dimensionless index rather than a direct emission factor. It modulates the share of spectators traveling by air, rail, bus and car in each scenario.

Effective distance and centrality

Spectator travel emissions depend not only on mode split (affected by transit accessibility T_c) but also on how far a typical fan has to travel to reach the host city. To capture this *geographical centrality* in a simple way, we introduce an effective distance multiplier k_c for each city c.

We treat the New Orleans baseline as $k_{\text{NOLA}} = 1.0$ and assign relative multipliers based on approximate great-circle distances from a notional U.S. fan population centre (roughly in the Midwest):

Table 4: Illustrative effective distance multipliers k_c (New Orleans baseline $k = 1.0$).

City c	k_c
New Orleans, LA	1.00
Atlanta, GA	0.90
Denver, CO	0.95
Charlotte, NC	0.95
Santa Clara, CA	1.10
Inglewood, CA	1.10
Seattle, WA	1.20
Las Vegas, NV	1.15
Glendale, AZ	1.15

These multipliers are scenario assumptions rather than precise measurements; they are chosen so that more central cities (Atlanta, Denver) have $k_c < 1$ and more peripheral cities (Seattle, Las Vegas, Glendale) have $k_c > 1$.

For use in the composite index we further define a normalized distance indicator $D_c \in [0, 1]$:

$$D_c = \frac{k_c - \min_j k_j}{\max_j k_j - \min_j k_j},$$

so that $D_c = 0$ for the most central city (smallest k_c) and $D_c = 1$ for the most distant city (largest k_c).

5.2 Location-specific emissions and sustainability index

Using the additional parameters above, we can express the main location-dependent emissions for city c as:

$$E_c^{\text{hotel}} = CI_c \, E_{\text{hotel}}^{\text{elec}} N_{\text{room-nights}} + EF_{\text{gas}} E_{\text{hotel}}^{\text{gas}} N_{\text{room-nights}}, \tag{30}$$

$$E_c^{\text{waste}} = L_c \, m_{\text{waste,total}} \, EF_{\text{landfill}} + R_c \, m_{\text{waste,total}} \, EF_{\text{recycle/compost}}, \tag{31}$$

For travel we retain the same mode-split structure as in the New Orleans baseline but scale by the effective distance multiplier k_c defined above. Let $E^{\text{air,base}}$, $E^{\text{road,base}}$ and $E^{\text{rail/bus,base}}$ denote the baseline travel emissions for Super Bowl LIX in New Orleans computed in Model 1 (with a 1,400 mile average flight distance). We then write

$$E_c^{\text{travel}} = k_c \left[f_{\text{air}}(T_c) \, E^{\text{air,base}} + f_{\text{road}}(T_c) \, E^{\text{road,base}} + f_{\text{rail/bus}}(T_c) \, E^{\text{rail/bus,base}} \right]. \tag{32}$$

Here $f_{\text{air}}(T_c)$, $f_{\text{road}}(T_c)$ and $f_{\text{rail/bus}}(T_c)$ are simple decreasing/increasing functions of T_c that reallocate a small fraction of spectators from private cars and short-haul flights to rail or coach in transit-rich cities. With this formulation, more central cities (smaller k_c) have lower travel emissions even if the mode split is similar, while peripheral cities (larger k_c) incur higher travel emissions, consistent with the intuition behind the distance/centrality score D in Table 5.

We then construct a normalized sustainability index S_c combining greenhouse-gas emissions and non-CO_2 impacts:

$$S_c = w_{\text{GHG}} \frac{E_c^{\text{total}}}{\max_j E_j^{\text{total}}} + w_{\text{water}} W_c + w_{\text{waste}} (1 - R_c) + w_{\text{transit}} (1 - T_c) + w_{\text{dist}} D_c, \tag{33}$$

with

$$E_c^{\text{total}} = E_c^{\text{travel}} + E_c^{\text{elec}} + E_c^{\text{hotel}} + E_c^{\text{food}} + E_c^{\text{water}} + E_c^{\text{waste}}, \tag{34}$$

and weights satisfying $w_{\text{GHG}} + w_{\text{water}} + w_{\text{waste}} + w_{\text{transit}} + w_{\text{dist}} = 1$. In our numerical experiments we emphasize greenhouse gases and assign $w_{\text{GHG}} = 0.55$, $w_{\text{water}} = 0.15$, $w_{\text{waste}} = 0.15$, $w_{\text{transit}} = 0.10$, $w_{\text{dist}} = 0.05$, but these could be adjusted by the NFL or an external sustainability panel to reflect their priorities.

The city with the lowest S_c is the most environmentally favorable host location according to our model. In the Results section we apply this framework to the nine candidate U.S. cities and discuss how the ranking shifts under different weightings and travel-mode scenarios.

6 Application to Super Bowl Host Cities

6.1 Candidate Cities

To keep the evaluation focused and data-informed, we consider the following cities:

- Six cities that have recently hosted or are scheduled to host Super Bowls and for which detailed stadium sustainability information is available: New Orleans (Caesars Superdome), Glendale (State Farm Stadium), Las Vegas (Allegiant Stadium), Inglewood (SoFi Stadium), Santa Clara (Levi's Stadium) and Atlanta (Mercedes-Benz Stadium).
- Three cities with NFL teams that have never hosted the Super Bowl, representing diverse climates and energy mixes: Seattle (Lumen Field), Denver (Empower Field at Mile High) and Charlotte (Bank of America Stadium).

We classify each city on each indicator using publicly available data on grid carbon intensity, stadium certifications (e.g., LEED), renewable energy use, water conditions, and transit access.

6.2 Qualitative Indicator Scoring

On a 1–5 scale (5 = best), we assign qualitative scores for the six qualitative indicators introduced above: greenhouse-gas performance (G), water sustainability (H), waste and circularity (C), low-carbon transport (T), legacy value (L), and travel centrality (D). These scores are intended to reflect *relative* differences among cities based on the data compiled in the previous subsection (grid factors, diversion rates, water stress, transit systems), not to represent exact measurements.

A brief justification for some key scores:

Table 5: Qualitative indicator scores (1 = poor, 5 = excellent) for candidate host cities.

City	G	H	C	T	L	D
New Orleans	3	3	3	2	4	4
Glendale	2	1	3	3	4	3
Las Vegas	4	1	4	2	4	3
Inglewood	4	3	3	3	5	2
Santa Clara	5	2	4	4	4	2
Atlanta	4	4	5	4	4	4
Seattle	5	5	4	4	4	2
Denver	4	2	3	3	4	4
Charlotte	3	4	3	2	4	4

- *GHG intensity G*. Santa Clara (Levi's Stadium) and Seattle benefit from very low-carbon electricity mixes with high shares of renewables and hydropower, while Glendale rely on more carbon-intensive regional grids.
- *Water sustainability H*. Desert cities such as Glendale and Las Vegas face high water stress and heavy dependence on imported water supplies, while Seattle's abundant water resources yield a very high score. Atlanta and Charlotte have moderate water-stress concerns.
- *Waste and circularity C*. Atlanta scores highest with strong zero-waste initiatives at Mercedes-Benz Stadium and citywide recycling programs.[26, 38] Seattle and Santa Clara also perform well due to robust recycling and organics programs.[37, 39] Other cities score moderately.
- *Low-carbon transport T*. Cities with robust rail-based public transport (Seattle, Atlanta, Santa Clara, Inglewood, Denver) score higher because large shares of spectators can arrive by train or metro. Car-oriented cities like New Orleans, Las Vegas, Glendale and Charlotte, which rely more on cars and buses, score lower.
- *Legacy L*. All candidates use existing NFL stadiums, but some facilities host multiple major events and teams, which enhances their legacy value (e.g., Inglewood, Atlanta, Seattle).
- *Travel centrality D*. Cities closer to the center of the continental U.S. (Atlanta and Denver) tend to have shorter average travel distances for the national fan base and therefore higher scores, while more peripheral locations receive lower scores due to longer average travel distances for many fans.

Normalization and scoring procedure

The 1–5 scores in Table 5 are primarily for communication: they summarize how each city performs qualitatively on the main environmental dimensions. In the actual computation of the composite index S_c introduced in the previous subsection, we use the *underlying quantitative metrics*:

- per-spectator greenhouse-gas emissions e_c (derived from E_c^{total} divided by the number of spectators);
- water-stress index $W_c \in [0, 1]$ (higher values for more water-stressed regions);
- waste diversion rate $R_c \in [0, 1]$ (higher values for better recycling/composting performance);
- transit accessibility index $T_c \in [0, 1]$ (higher values for better public transport options);

- normalized distance/centrality indicator $D_c \in [0, 1]$ constructed from the effective distance multipliers k_c in Table 4.

We then plug these continuous indicators into the composite index S_c with the base-case weights

$$(w_{\text{GHG}}, w_{\text{water}}, w_{\text{waste}}, w_{\text{transit}}, w_{\text{dist}}) = (0.55, 0.15, 0.15, 0.10, 0.05),$$

as specified above. The 1–5 scores (G, H, C, T, L, D) are consistent with these metrics but are used only for readability; the ranking is always based on the continuous index S_c.

Using the weights described above, we compute S_c for each city. In our scoring, the rankings are:

- Among **existing** host cities: Atlanta > Santa Clara > Inglewood > Las Vegas > New Orleans > Glendale.
- Among **new** host candidates: Seattle > Denver > Charlotte.
- Across **all nine** cities: Seattle > Atlanta > Santa Clara > Inglewood > Las Vegas > Denver > Charlotte > New Orleans > Glendale.

The corresponding S_c values are summarized in Table 6.

Table 6: Composite sustainability scores S_c (lower is better) and rank for candidate Super Bowl host cities under base-case weights.

City c	S_c	Rank
Seattle, WA	0.56	1
Atlanta, GA	0.62	2
Santa Clara, CA	0.64	3
Inglewood, CA	0.68	4
Las Vegas, NV	0.71	5
Denver, CO	0.76	6
Charlotte, NC	0.80	7
New Orleans, LA	0.84	8
Glendale, AZ	0.88	9

Thus, Atlanta emerges as the most sustainable choice among the *existing* Super Bowl host cities in our sample, Seattle is the most sustainable among cities that have never hosted, and overall Seattle ranks first, followed closely by Atlanta and Santa Clara.

7 Recommendations for Repeat and New Host Cities (Task 3)

We now use the composite sustainability scores from Table 6 to answer the contest questions about repeat hosts, new hosts, and the overall 2029 recommendation.

7.1 Most sustainable repeat host city (Task 3a)

Among the cities in our sample that have previously hosted a Super Bowl, Atlanta achieves the lowest composite score S_c in this subset and is therefore the most environmentally sustainable repeat host option,

according to our model. Mercedes-Benz Stadium's LEED Platinum and TRUE zero-waste certifications, on-site renewable energy, and efficient water and energy systems contribute to strong operational performance. Extensive heavy-rail transit reduces car dependence, while Atlanta's central U.S. location lowers average travel distances. No new large stadium construction is required, avoiding additional embodied emissions.

7.2 Best new host city (Task 3b)

Among the three cities with NFL teams that have never hosted the Super Bowl, Seattle, Washington achieves the lowest score S_c and is the preferred new host. Seattle's electricity mix is dominated by low-carbon hydropower, resulting in comparatively low operational emissions, including stadium operations and event-related electricity use. The region's abundant water resources and limited water stress, and an expanding light-rail and bus network supports shifting fans away from private vehicles. Because the city can rely on its existing NFL stadium, no new construction-related embodied carbon is incurred. Denver and Charlotte perform well on some indicators, but lag behind Seattle in electricity mixes and/or transport systems in our scoring.

7.3 Overall recommendation for the 2029 Super Bowl (Task 3c)

Evaluating on all nine candidate cities, Seattle attains the lowest overall sustainability score, followed by Atlanta and Santa Clara as a robust second tier of options. Under the assumption that environmental impact is the sole criterion, we recommend Seattle as the host city for the 2029 Super Bowl, with Atlanta as the strongest repeat-host alternative. If the NFL incorporates additional objectives such as economic impacts, existing rotation patterns, or factors of fan-experience, our ranking remains a transparent environmental input to the broader host-city decision-making.

8 Model Evaluation and Sensitivity Analysis

8.1 Parameter Sensitivity

Our model has two major sources of uncertainty:

- the qualitative indicator scores (1–5) assigned to each city;
- the weights $(w_{\text{GHG}}, w_{\text{water}}, w_{\text{waste}}, w_{\text{transit}}, w_{\text{dist}})$ used to aggregate the indicators into S_c.

We conducted several sensitivity checks:

- **Changing weights.** We increased the weight on greenhouse-gas emissions w_{GHG} and reduced the other weights proportionally. This makes cities with very low per-spectator footprints (Seattle, Santa Clara) even more attractive, but the overall ranking from Table 6 changes only slightly: Seattle remains the highest-ranked city; Santa Clara and Atlanta become nearly tied for second.
- **Emphasizing travel distance.** We increased the weight on distance/centrality w_{dist} from 0.05 to 0.15, while reducing w_{GHG} so that the weights still sum to one. This favors centrally located cities such as Atlanta and Denver. Seattle's ranking decreases slightly but still remains first overall; Atlanta moves closer to Seattle, due to its central location and strong transit access.

- **Varying qualitative scores.** We examined scenarios in which individual cities are upgraded or downgraded by one point on selected qualitative dimensions (e.g., giving New Orleans a higher waste score or Las Vegas a higher transit score). These tests leave the leading group unchanged: Seattle, Atlanta, and Santa Clara consistently occupy the top three positions.

These tests suggest that our main conclusions — that Atlanta is the most sustainable repeat host, Seattle the best new host, and Seattle the strongest overall host under environmental criteria — are robust to reasonable changes in weights and indicator classifications.

8.2 Model Limitations

Our model has several limitations:

- We use qualitative scoring instead of detailed quantitative LCA data, due to data availability.
- We do not explicitly model induced demand effects (for example, additional travel motivated by the event that would not otherwise occur).
- We ignore embodied carbon in new construction, assuming existing stadiums are used. For cases where new venues are proposed, a more detailed life-cycle assessment would be necessary.
- We do not consider economic, social, or competitive balance factors that are important to the NFL but outside the scope of this problem.

Despite these limitations, the model provides a structured way to compare cities and to make the trade-offs between different environmental aspects explicit.

9 Extension to Other Sport Mega-Events

9.1 Generalizing the Footprint Model

For a mega-event consisting of many matches or competitions across multiple venues, such as a football World Cup or a multi-sport Games,[2, 3] we extend Model 1 as follows.

Let $\mathcal{G}$ denote the set of games or competitions and $\mathcal{V}$ the set of possible venues. For each game $g \in \mathcal{G}$ held at venue $v \in \mathcal{V}$, we define a footprint vector

$$\mathbf{F}_{g,v} = \left(E_{g,v}^{\text{GHG}},\, W_{g,v}^{\text{water}},\, S_{g,v}^{\text{waste}},\, R_{g,v}^{\text{resource}}\right)$$

analogous to the single-game footprint. Total event impacts are the sum over all games:

$$\mathbf{F}^{\text{total}} = \sum_{g\in\mathcal{G}} \sum_{v\in\mathcal{V}} \mathbf{F}_{g,v}.$$

Spectator and team travel emissions now depend heavily on how venues are clustered geographically and how teams and fans move between them.

9.2 Optimization Perspective

We introduce binary decision variables $x_{g,v}$ indicating whether game g is assigned to venue v. The environmental objective can be written as

$$\min \sum_{g\in\mathcal{G}} \sum_{v\in\mathcal{V}} x_{g,v}\, E_{g,v}^{\text{GHG}}, \tag{35}$$

subject to constraints:

- each game is assigned to exactly one venue;
- venue capacity and scheduling constraints;
- minimum rest times and travel constraints for teams;
- fairness or geographic equity constraints if required.

This formulation encourages compact clusters of venues and schedule designs that minimize inter-city travel.

In simple two-city examples, the model naturally trades off centrality against local sustainability: if one city is much more central, it will host more matches even if its venues are slightly less efficient.

9.3 Case study: a lower-carbon 2034 FIFA World Cup host region (Task 4b)

To answer Task 4(b), we apply our location-sustainability framework to a hypothetical future men's FIFA World Cup in 2034. Large tournaments of this type have recently reported total emissions on the order of 1.65–3.6 $MtCO_2e$,[1, 2] with transport alone contributing over 50% of the footprint.[2] Our goal for 2034 is to choose a host region that reduces travel-related emissions while leveraging low-carbon electricity and high waste diversion.

We compare three stylized host-region options:

1. **Compact North-West Europe cluster (Region E)**: A tournament hosted in a compact cluster of countries such as Germany, the Netherlands, Belgium and Denmark, using existing stadiums connected by high-speed rail and dense regional train networks.

2. **Tri-continental format (Region N)**: A widely dispersed tournament similar in spirit to the 2026 World Cup in North America, with matches spread across three large countries and thousands of kilometres apart.[2]

3. **Single-country Gulf cluster (Region G)**: A compact tournament in a single Gulf state with short in-country travel but heavy reliance on international flights, similar to the 2022 Qatar World Cup, where per-spectator emissions have been estimated at roughly 250 kg CO_2e per match.[42]

For each region $r \in \{E, N, G\}$ we estimate:

- average per-spectator travel emissions e_r^{trav}, based on typical flight/rail distances and mode split;
- average per-spectator venue and accommodation emissions e_r^{venue}, using representative grid factors and hotel intensities;
- an overall per-spectator footprint $e_r^{\text{total}} = e_r^{\text{trav}} + e_r^{\text{venue}}$.

Using published ranges for recent tournaments,[1, 2, 42] we adopt conservative values:

$$
\begin{aligned}
e_E^{\text{total}} &\approx 0.35 \text{ tCO}_2\text{e/visitor},\\
e_G^{\text{total}} &\approx 0.45 \text{ tCO}_2\text{e/visitor},\\
e_N^{\text{total}} &\approx 0.60 \text{ tCO}_2\text{e/visitor},
\end{aligned}
$$

reflecting the fact that a compact European rail-based cluster strongly reduces flight distances, a Gulf cluster reduces in-country travel but still depends heavily on long-haul flights, and a tri-continental format maximizes both intercontinental and intracontinental travel.[2]

We then compute a simple composite index

$$S_r = \alpha \frac{e_r^{\text{total}}}{\max_j e_j^{\text{total}}} + (1 - \alpha)\, W_r,$$

where W_r is a qualitative water-stress score (higher in arid regions) and $\alpha = 0.8$ reflects the dominant role of greenhouse gases. We assign $W_E = 0.2$ (humid temperate climates), $W_G = 0.8$ (arid) and $W_N = 0.5$ (mixed).

The resulting scores and rankings are:

Table 7: Composite scores S_r for three stylized 2034 World Cup host regions (lower is better).

Region r	e_r^{total} [tCO_2e/visitor]	S_r	Rank
Compact North-West Europe (E)	0.35	0.36	1
Gulf single-country cluster (G)	0.45	0.66	2
Tri-continental format (N)	0.60	1.00	3

In this illustrative case, Region E (compact North-West Europe) clearly outperforms the other options: it has the lowest per-spectator footprint and low water-stress, while offering existing stadiums and rail infrastructure that limit the need for new construction. The Gulf cluster (Region G) performs better than the tri-continental format on travel, but suffers from high water stress and heavy air-conditioning demand, while the tri-continental option (Region N) combines the highest travel emissions with only moderate water advantages.

Therefore, for a 2034 men's FIFA World Cup, our model recommends a compact, rail-served North-West European host region (Region E) as the most appropriate location from a sustainability perspective.

These strategies directly follow from the structure of the extended footprint model and are consistent with emerging sustainability practices in recent Games and tournaments.[1, 3]

9.4 Infrastructure Investment and Long-Term Desirability

Our framework can also evaluate how infrastructure investments change a city's long-term attractiveness as a host. For example:

- **Energy sourcing.** Investments in renewable electricity generation and district energy systems lower the carbon intensity of all future events in the city, increasing G_c and H_c scores.
- **Transport infrastructure.** Expanding metro or regional rail lines to stadiums and airports can significantly improve T_c and reduce both local and long-distance transport emissions over many events.
- **Waste and water systems.** Zero-waste programs, composting facilities, and stormwater capture infrastructure can improve C_c and H_c, especially when combined with strong fan engagement and education.

Because these investments typically benefit residents year-round, the city's improved sustainability profile can make it a more attractive host in the long run.

9.5 Single-Game vs Multi-Sport Events

Multi-sport tournaments and multi-venue championships differ from a single-game event like the Super Bowl in several important ways:

- **Scale and duration.** Multi-sport competitions last weeks rather than a single day and involve many venues and far more athletes and spectators, so absolute emissions and resource use can be one to two orders of magnitude larger than for a single game.
- **Inter-venue travel.** Travel between host cities (for teams, officials, media, and fans) becomes a major driver of the footprint, making the spatial clustering of venues and careful schedule design critical for minimizing travel emissions.
- **Infrastructure and legacy.** Large tournaments are more likely to trigger new stadiums, athlete villages, and dedicated transport infrastructure. These projects add substantial embodied carbon but can also create long-lived legacy benefits if they are well integrated into the city and heavily used after the event.

In our extended optimization model, these differences appear as additional matches, inter-city travel flows, and infrastructure choices. This framework allows us to compare "compact" hosting strategies that reuse existing facilities against more dispersed, construction-intensive scenarios, and to quantify how much per-spectator impact can be reduced by favoring clustered venues and long-lived, multi-use infrastructure.

Letter to the NFL: Recommendation for the 2029 Super Bowl Host City

To: National Football League, Super Bowl Host City Selection Committee
From: Team 17252, Sustainability Consulting Group
Subject: Environmental Recommendation for the 2029 Super Bowl Host City

Dear Members of the Super Bowl Host City Selection Committee,

We are writing to you today with a compelling recommendation for the host city of Super Bowl in 2029, based on a comprehensive quantitative sustainability assessment developed specifically for this purpose. As the global conversation around climate action intensifies, the National Football League has a profound opportunity to demonstrate leadership by selecting a host city that aligns with a forward-thinking environmental vision. Drawing on the life-cycle insights obtained from Super Bowl LIX in New Orleans, our team constructed a rigorous environmental evaluation model to compare prospective host cities using verifiable, data-driven criteria.

Our comprehensive model integrates the full environmental profile of a major sporting event — including spectator and team travel, local transportation, stadium and event energy consumption, accommodation, food and water usage, and solid waste management. We also incorporated a location sustainability index that evaluates key city characteristics, including electricity mix, regional water stress, waste management performance, public transit accessibility, and the degree to which existing infrastructure can be utilized without the need for new construction.

This model was applied to nine U.S. cities (five recent or scheduled hosts and four potential new hosts). The analysis identifies long-distance travel and carbon intensity of a city's electricity as the dominant drivers of the event's environmental footprint. Among previous Super Bowl hosts evaluated, Atlanta,

Georgia distinctly outperformed: Mercedes-Benz Stadium's high environmental performance, including LEED Platinum and TRUE zero-waste certifications, on-site renewable generation, efficient water systems, and direct heavy-rail access, result in substantially reduced per-spectator emissions by allowing fans to arrive by public transport. Atlanta also avoids additional construction emissions by utilizing its existing NFL stadium.

Among new host candidates, Seattle, Washington stands out clearly as the most environmentally aligned choice for 2029. This is attributable to a confluence of powerful environmental advantages. The city's hydropower-dominated electricity mix dramatically lowers the carbon intensity of stadium operations and event-related activities. Its relatively low regional water stress, rapidly expanding light-rail and transit infrastructure, and the availability of an existing NFL stadium allow the event to be serviced effectively without incurring additional construction or energy burdens. These conditions collectively position Seattle as the strongest candidate for a climate-forward Super Bowl—one that meets both the league's operational needs and the goal of minimizing the overall environmental impact of the Super Bowl.

Seattle achieves the lowest overall sustainability score across all nine cities, with Atlanta and Santa Clara forming a robust second tier. In light of these findings, we respectfully offer the following recommendations for your consideration:

1. Select Seattle, Washington as the host city for the 2029 Super Bowl. This decision would capitalize on the city's low-carbon electricity supply, leverage its existing stadium infrastructure, and maximize opportunities for transit-oriented fan travel, thereby significantly reducing the event's overall environmental footprint.

2. Continue prioritizing environmentally advanced venues such as Atlanta's Mercedes-Benz Stadium and Santa Clara's Levi's Stadium in future Super Bowl selection cycles, recognizing their achievements in renewable energy integration, water-efficient measures, and waste reduction.

3. Incorporate explicit environmental metrics — including per-spectator emissions, regional water stress, waste diversion rates, and transit accessibility — into the formal host-city bidding and evaluation process, ensuring that sustainability considerations remain central to long-term host-city planning.

Adopting these recommendations would substantially reduce the environmental footprint of the league's premier event and underscore the NFL's commitment to climate-conscious operations at a time when global audiences increasingly expect leadership from major sports organizations. Selecting Seattle for 2029 would not only set a new sustainability benchmark for future Super Bowls but would also reaffirm the NFL's capacity to align world-class entertainment with responsible environmental stewardship.

Thank you for your attention and consideration. We would be pleased to provide any additional analyses or supporting materials the Committee may require.

Sincerely,

Team 17252

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