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A Temperature-Activated Carbon Framework for Sustainable Mega-Event Host Selection

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Abstract. This paper explores the carbon emissions of sporting events, which although deliver significant economic value, emit notable amounts of carbon emissions mainly due to venue activities and spectators' travel. A framework for evaluating and optimizing the choice of cities to host major sporting events, with regard to sustainability concerns, is presented in this paper. This study total emissions into three main categories, namely venue energy use, ground travel emissions, and airline emissions. A key element in the model is a cooling system model that turns on air conditioning systems based on a temperature threshold of 25°C with regard to the local climate, scaled based on a ratio between local temperature intensity and average temperature intensity in North America. Emission calculations for ground and air travel are based on a population-to-distance effect matrix and national modal split assumptions for each city, respectively. The use of publicly available data sources such as energy intensity per source, grid carbon emissions factor, and historic weather conditions allows for the transparent calculation of emissions. Using the proposed approach for the case study of Super Bowl hosting, the best past and prospective locations are found to be Inglewood, California and Seattle, Washington. Finally, this paper concludes that the highest reduction in carbon emissions results from higher vehicle occupancy rates compared to increases in efficiency and use of renewable energies, that means the public transportation system is becoming more and more important in the future.

Keywords: carbon emissions modeling, temperature-activated cooling, sustainable host selection, mega sporting events, Super Bowl

1. Introduction

Mega-sporting event provides significant economic benefits and stimulate public engagement; however, it also generates substantial environmental footprint, primarily through energy consumption, transportation, and waste discharge, etc. Historically, the host-city selection process has prioritized infrastructural capacity and commercial viability, often relegating sustainability to a secondary consideration. This paper addresses this oversight by formulating a quantitative model to evaluate carbon emissions and rank potential host cities based on carbon emission performance. The

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analysis will focus specifically on the Super Bowl which is important mega-sport event in America. The following sections provide a review of existing literature, detail the research methodology, present key findings, analyze practical implications, and offer evidence-based recommendations for future site selection.

2. Literature review

Programs such as the NFL Green initiative track tangible metrics such as recycling rates and energy offsets. Over the recent Super Bowl cycles, these initiatives were able to obtain net-zero energy for their events through procurement of renewable energy credits and partnerships with the local community, as well as drive carbon emissions reductions through similar sources [1]. Both the International Olympic Committee and the United Nations Environment Programme have released protocols that introducing how to measure travel, event operational emissions, and material production emissions so that results are comparable across events. Since then, authors have provided updated calculations by adding both differential impacts between potential outcomes of a single GHRG considering all gases and time-integrated radiative forcing (a composite measure based on carbon dioxide (CO2), methane (CH4), and black carbon) into one single tonne CO2-equivalent number [2, 3].

Empirical studies consistently identify spectators travel as the main source of carbon emissions. For example, an analysis of amateur football spectators found that over 70% of total greenhouse gas emissions were due to travel, while less car-intensive modes of transport contributed around 8% [4]. Venue energy consumption is another important contributor to emissions and varies widely based on climatic conditions; for instance, certain games have seen operational emissions due to air conditioning increase by more than 9% [5]. In total, it is estimated that the carbon footprint of sporting events falls between 1.59 and 4.5 million tonnes with travel and venue operation being by far the largest sources [6, 7].

While the datasets in previous researches are collected from public repositories, there are still three major shortcomings. Most analyses are focused on the retrospective inference which provides little help for prospective selection of host-city. The second issue is that almost none of the models integrates ambient temperature variations to develop the energy consumption pattern of venues. Finally, most current studies fail to consider regional heterogeneities in power grid carbon intensity or the granular details about spectators travel distance. These gaps were filled by this study with a proposed TE cooling indicator and an integration based on contemporaneous grid data available through public records with a population-distance grading system for travel. As a result, such a predictive framework would be particularly useful to assist making decisions before final site selection.

3. Methodology

3.1. Assumptions

The proposed model includes six pragmatic assumptions. First, it is assumed that travel between cities is average but very low within cities when computing in aggregate. Secondly, energy consumption by venues was assumed to be linear with floor area. Third, an average occupancy of 2 for vehicles is used. Fourth, nationwide spectator preference for automotive over aerial was hypothesized to be evenly distributed and lastly, all large scale stadium were assumed to have equal

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energy intensity per square foot. These assumptions were made in order to increase computational efficiency while still ensuring consistency with empirical data.

3.2. Venue operational emissions

Annual venue energy consumption is first calculated as:

$$E_{year} = EUI \times A \tag{1}$$

where $EUI$is taken from the ENERGY STAR Portfolio Manager national median for indoor arenas (112 kBtu/ft²), and A is the gross floor area obtained from official stadium specifications. Hourly baseline energy E_{hour} follows:

$$E_{hour} = E_{year}/8760 \tag{2}$$

Event energy consumption E_{event} incorporates a temperature-independent fraction β_0 (typically 0.6–0.8 for lighting and equipment) and a temperature-dependent fraction scaled by the binary cooling indicator $I = 1$ if $T\_avg > 25\,^{\circ}C$, 0 otherwise, and the intensity ratio $k_T = T_{avg}/T_{annual}$, t_{event} means the time of event, in summary the formula is follows:

$$E_{event} = E_{hour} \times t_{event} \times [\beta_0 + (1 - \beta_0) \times k_T \times I] \tag{3}$$

Conversion to kWh and subsequent carbon emissions C_{AC} is:

$$E_{event} = E_{event}/3.412 \tag{4}$$

$$C_{AC} = E_{event} \times C_{factor} \tag{5}$$

The C_{factor} data are directly sourced from the latest state averages of the EPA in 2023. Temperature data are acquired directly from the Visual Crossing Weather website, and grid factors are derived from the latest official records.

3.3. Transportation emissions

Carbon emission estimates for spectator travel comprised private vehicle and commercial aviation components modeled as the sum of two components parameterized from national statistics thereby ensuring parity across urban centers. Using U.S. national leisure travel data modal splits were assigned at 86% for private vechicle and 10% for air travel with residual 4% excluded due to approximate insignificance at aggregated scales.

Consistent with established event attendance profiles, city passengers are the main research subjects of this model, as they account for approximately 70% of the total spectator population in most settings.

Vehicle emissions follow a distance–intensity–scale formulation as follows:

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$$E_{car} = D_i \times E_c \times (0.70 \times 0.86 \times P_i \times \eta^{-1}) \quad (6)$$

where D_i denotes the population-weighted average driving distance to the host city (derived from a gravity-based influence score P/d^2 over the top-20 neighboring cities); $E_c = 254.8$g CO2/km. $E_c = 254$ g CO2/km is the EPA light-duty vehicle emission factor; P_i is the potential spectator number; and $\eta = 2$ represents average vehicle occupancy.

Aviation emissions adopt a per-passenger normalization as follows:

$$E_{air} = \bar{D} \times E_a \times P_a \quad (7)$$

where $\bar{D}$ =1,555 km is the U.S. domestic average flight distance; E_a is the aviation-specific emission factor; and $P_a = 0.10 \times 0.70 \times P_i$

The exclusive use of national-average parameter values during this initial phase ensures that, except where specified, cross-sectional comparability is maintained along all dimensions of analysis to facilitate pre-event host screening. Regionally-specific variations in modal preference and origin–destination distribution can then be successively integrated into the modelling framework postcalibration using event ticketing data or field observations

3.4. Temperature forecasting and data sources

Event-day temperatures for 2029 are projected using ARIMA models applied to historical records from 2005 to 2024 (sourced from Visual Crossing). Prior to modeling, non-stationarity was confirmed and addressed through differencing to achieve stationarity. Attendance is projected at an occupancy rate of 97.1%, derived from historical Super Bowl averages with the exclusion of 2021 data. Carbon emission factors and venue dimensions are sourced from official EPA and stadium documentation, ensuring traceability.

4. Results

Reference from figure 1 Inglewood had the lowest carbon emission profile for a Super Bowl host, thanks to its low-carbon power generation mix and temperate weather. Of the cities investigated for their potential as host locations, Seattle came out on top of the most sustainable area to stage it, with high levels of renewable energy integration and low level average spectator travel distances marginal.

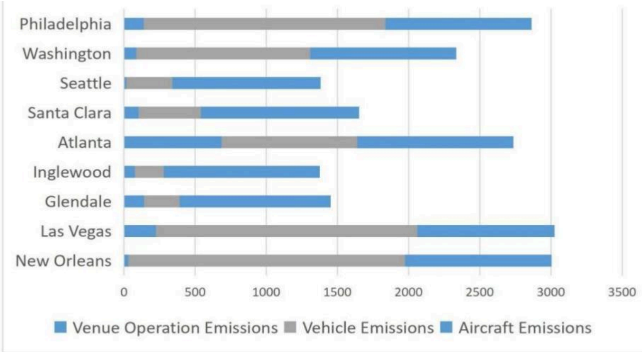

Figure 1. Emissions comparison across all cities

5. Discussion

From the above result, it is evident that climate and electricity profiles play a significant role in determining emissions from venues, especially in smaller stadiums. In terms of crowd impact, vehicle transport plays the most crucial role. In short-term measures, such as promoting carpooling, could prove more effective than equipment modification and shifting partially to renewable energy. In long-term effects, the greatest environmental benefits would come from hosting events in urban areas with large populations and a decarbonized grid system. Despite having some weaknesses, such as using average data instead of hourly data, the model still works effectively in practice.

6. Conclusion

Thus, this becomes a workable option for mega sport event planners, with the organizers of the American football championship using the temperature-driven model to determine that Inglewood and Seattle become their first options. The temperature-driven model can be efficiently used by other organizers of global sporting events in determining how different elements of the environment interact with each other in order to make decisions on sustainability. By providing a viable path forward, this type of model enables the creation of more eco-friendly mega sport events.

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