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Article

# A Methodology to Evaluate GHG Emissions for Large Sports Events

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**Abstract:** Determining whether a large sports event is sustainable or not is one of the main objectives of the sports industry in the coming years. Indeed, there are several sources of greenhouse gas (GHG) emissions within a sports event that are not directly controlled by the sports companies but are linked to the event itself. The literature does not offer a standardized methodology for calculating the $CO_2$ emissions of sports events, and consequently, there are different approaches. The objective of this article is to provide an updated state-of-the-art on the topic and to propose an innovative methodology for the calculation of Greenhouse Gas emission of a large sport event. The methodology entails the analysis of purchased goods and services, fuel and energy consumption, waste generation, business travel, and the impact of accommodations. Within the analysis, tools are provided to calculate carbon emissions for each category based on easily understandable data and utilizing reference conversion factors. The research presented in this paper may be useful for professionals in the sector in identifying a comprehensive methodology to quantify greenhouse gas (GHG) emissions for a large sports event.

**Keywords:** carbon footprint; large sports event; GHG emissions; sustainability

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## 1. Introduction

Environmental sustainability (ES) and sporting events have been intertwined since the early 1990s. In response to mounting environmental concerns, the early 2000s saw a growing emphasis on the development of international and generic standards for environmental performance at sporting events [1]. The global scientific community has sounded the alarm on a climate emergency. The Intergovernmental Panel on Climate Change (IPCC) reported that human activities have already caused approximately 1 °C of global warming above pre-industrial levels [2]. Notably, the travel and transport sector makes significant contributions to greenhouse gas emissions and, consequently, climate change [3].

It is undeniable that all human activities bear consequences for the environment that surrounds us [4]. Major sporting events, as a large-scale human activity, inevitably have a considerable impact on the environment [5–7]. With exponential growth in the number of major events since 2000, the booming mega-event industry, and expansion into emerging markets and non-democratic states, the world of sports is now confronting a range of new and often poorly understood environmental challenges. Over the next decade, major global events like the Olympics and the FIFA World Cup will be hosted in emerging states against a backdrop of ever-changing global risks [8].

In recent decades, the organization of sporting events has significantly increased. The organizers of the London 2012 Olympics teamed up with British Standards, the UK's National Standards Body, to develop an event management system that includes event sustainability objectives and sustainable development principles, subsequently called ISO 20121, a standard for the management of sustainable events [9].

The potential environmental impacts of sporting events are influenced by numerous variables, including the type of sport, event size, location, and duration [8,10]. Even the location of key infrastructure, such as stadiums, airports, and facility establishments, can have substantial environmental effects [11,12].

The emissions caused by fans attending professional team sports leagues have not been studied yet, although these leagues draw sizeable audiences. Given that fans' attendance and travel patterns can vary significantly throughout a season, a season-wide assessment is essential to understanding the environmental impact [13].

The scientific literature reveals a certain lack of consistency in the methods and indicators used to assess the sustainability of sporting events. Early studies, like the one by Collins and colleagues, evaluated the environmental impact of specific events using different approaches [14].

One of the most widely used indicators for assessing the environmental impact of an event is the carbon footprint [15]. Essentially, the carbon footprint encompasses all greenhouse gas (GHG) emissions, whether they originate directly or indirectly from an individual, organization, event, or product [16,17]. This measure ensures that emissions from GHGs other than carbon dioxide are standardized to accurately reflect their contribution to the global warming potential. They are then converted into a single, uniform unit of measurement known as carbon dioxide equivalents ($CO_2e$). This standardized unit, $CO_2e$, enables a comprehensive evaluation of the event's environmental impact [13].

The objective of this article Is to provide an up-to-date overview of the topic, including various case studies and projects. It also aims to present an innovative methodology based on the *Technical Guidance for Calculating Scope 3 Emissions*, published by the Greenhouse Gas Protocol body [18]. This methodology seeks to identify the areas of greatest importance for GHG emissions in the context of sporting events.

The analysis of GHG emissions should encompass a wide range of stakeholders connected to the sporting event. This includes not only the athletes themselves and the entire team but also the staff, coaches, and management attending the game. In addition, the referees and federation officials responsible for overseeing the match should be considered. It is also important to extend this analysis to include the visiting team and, significantly, the fans, both those supporting the home team and those cheering for the away team.

To provide a comprehensive evaluation of GHG emissions, we will examine various aspects related to these emissions, categorizing them as follows.

Category 1 focuses on evaluating the impact of the goods sold at an event, primarily food and beverages, in terms of $CO_2$ emissions. The third category centers on the impact of energy production from all sources, both renewable and non-renewable, used to power the stadium and common areas. Category 5 shows how waste generation plays a significant role in this category. It includes waste produced by fans within the stadium during the match, as well as waste generated before and after the event in areas adjacent to and directly connected to the stadium. Category 6 is arguably the most critical category; it involves quantifying the movement and travel-related emissions. This encompasses the travel of the entire team and organization from their training facility to the stadium. For the visiting team, it involves calculating the journey from their training facility or meeting point in their home city, considering all modes of transportation used to reach the away stadium. Additionally, it takes into account how referees and officials reached the stadium, as well as how home and away fans made their way to the venue. It would also be valuable to include the travel impact of away fans. Importantly, the return journey should also be accounted for. Furthermore, for those coming from out of town, the environmental impact of overnight accommodation for both the visiting team and their fans should be included in the assessment.

We have chosen to exclude certain categories from our analysis, even though they are mentioned in the *Reference Guide*, such as Category 2 (Capital Goods), in order to focus on the short-term impact of these events. Additionally, Category 4 (Transportation and Upstream Distribution) has been omitted, as its components, such as distribution and upstream transportation, are not directly relevant to evaluating greenhouse gas emissions in a single sporting event. Similarly, Categories 14 (Franchises) and 15 (Investments) are other examples of categories that, within the context of our methodology, do not significantly affect the greenhouse gas emissions associated with a single sporting event.

In the upcoming sections, we will introduce key concepts to enhance our understanding of the article. These concepts include the carbon footprint, which quantifies the total greenhouse gas emissions associated with a specific activity or entity [17]. Furthermore, we will delve into the concept of Scopes 1, 2, and 3 emissions, which classify the different sources of emissions within an organization's operations, as required by the Greenhouse Gas Protocol body. We will also discuss specific ISO standards that are relevant to our methodology. The International Organization for Standardization (ISO) has developed several standards related to environmental management and sustainability. These standards provide a framework for organizations to assess and reduce their environmental impact [9]. Throughout the article, we will clarify these fundamental concepts, providing a solid foundation for understanding the methodology and results presented. This background knowledge is essential for readers to comprehend the importance of greenhouse gas emissions in sporting events and the proposed approach.

Next, we will provide detailed numerical examples of greenhouse gas (GHG) emission calculations associated with sporting events. These practical examples will demonstrate the direct application of the introduced concepts, offering a clear and tangible understanding of the methodologies used.

In a subsequent phase, we will conduct a critical analysis, examining areas that have received little attention thus far but have a significant impact on sporting events. We find it interesting to highlight that, although many contributions have provided insights into specific areas, often, this has been limited to one or, at most, two dimensions. In our article, we aim to provide a comprehensive view by categorizing and analyzing even those elements that may have been overlooked or considered irrelevant. For example, we intend to examine in detail aspects such as spending on branded goods in Euros, ceremonial materials, merchandising materials, signage materials, and the environmental impact associated with spending in Euros on information and communication technologies, including cloud services. Our analysis aims to offer a more complete and detailed overview of the various environmental components involved in sports events.

## 2. State-of-the-Art

Sustainability has firmly established itself as an increasingly prevalent factor in sports organizations, events, and actions associated with corporate social responsibility [19]. Since the adoption of the sustainable development goals in 2015, sustainability has become an undeniable factor in the organization of sporting events [20]. Over 280 sports organizations have joined the initiative to commit to the Paris Agreement [21]. Clubs from the English Premier League, for instance, now openly disclose their climate and sustainability aspirations.

However, several authors indicate that mere recognition is not enough; stakeholders need to put in more effort to promote sustainability in sports [22]. It has been observed that there has been a constant, gradual increase over time in the number of publications, with significant peaks in 2012 and 2020 [20,23]. This increase in attention aligns with the growing interest in sustainability within the sports sector.

Sporting organizations, teams, and sponsoring bodies have recognized the imperative to better understand the environmental impacts of their activities, which they sponsor, host, and regulate [24,25]. The attempt to make mega sporting events more environmentally friendly also stands as one of their most high-profile contributions in this realm. While the environmental impact of day-to-day sports activities and organizational processes has received attention, the focus has largely shifted towards making mega-events more sustainable [26].

The relationship between sport and sustainable development is broad and multi-faceted, extending beyond purely environmental considerations [27]. The recognition of major sporting events' potential to significantly impact economic welfare, both positively and negatively, has been a topic of debate since the 1984 Summer Olympic Games in Los Angeles [28].

In recent years, many public and civic agencies have explicitly acknowledged the need to consider the environmental consequences of their activities [29]. Key international agreements resulting from summits like Rio and Kyoto have highlighted the importance of addressing sustainability in various sectors, including sports.

In the past decade, large international organizations have shown significant ambition. While the International Olympic Committee (IOC) has taken the lead in promoting sustainability in the Olympic Games, other initiatives, such as the United Nations (UN) and the Sports for Climate Action framework, are now gaining momentum in the sports world [21]. Sporting organizations are becoming increasingly aware of the environmental impact of their activities and are recognizing the need to incorporate sustainable practices into their management [26].

This growing awareness among sporting organizations reflects a broader recognition of the importance of sustainable strategies among mega-event organizers. It signifies progress in understanding and addressing the environmental impact of these events, indicating a shift towards prioritizing environmental concerns.

One common aspect among various definitions of sustainability is the consensus that economic growth policies must respect the environment and be socially equitable for an endeavor to be truly sustainable [30]. This understanding is crucial in the context of sports and sustainable development, as it goes beyond just environmental considerations.

Interestingly, statistical analyses have shown that multisport disciplines, particularly those represented by the Olympic Games, account for 90% of these events, while single-sport events, such as football, athletics, cycling, and motor racing, make up the majority of the remaining 64.6% [20].

Given the immense popularity of sports like football, basketball, tennis, and baseball, their influence on audiences, both in stadiums and at home, is undeniable. This influence becomes particularly pronounced during mega-events like the FIFA World Cup, the Olympic Games, the Super Bowl, or prestigious tournaments such as the tennis Grand Slams or the Formula 1 Grand Prix [10,31,32].

In the field of scientific research, a significant body of literature focuses on the evaluation of carbon footprints associated with large-scale sporting events. These studies provide valuable insights into the environmental impact of such events. By carefully examining and analyzing selected examples from this extensive body of work, we intend to conduct a rigorous quantitative analysis that will shed light on the notable progress achieved in this particular field.

A study conducted by a Qatar university [33] delves into the social sustainability impact of Qatar's circular economy application in the organization of the FIFA World Cup. It aims to analyze the life cycle and operational scenarios of the Ras Abu Aboud stadium, with the goal of creating lasting positive legacies. During the operational phase, a significant amount of waste, totaling 1750 tons, is generated, thereby impacting the municipal solid waste market [33]. A recent paper [34] thoroughly analyzed waste management strategies at the 2023 World Junior Ice Hockey Championship in Novosibirsk. It covered waste types across competition zones, explored solid waste handling, and proposed eco-friendly schemes. Emphasizing waste minimization, recycling, and reuse, it highlighted their vital role. Five hundred container sets were strategically placed across the 12 stadiums. They had separate zones for recyclable and non-recyclable waste. Additionally, 35 environmental volunteers supported waste collection and sorting in the fan zone. The study's statistics revealed that, on average, individuals—whether fans, volunteers, or organizers—disposed of 0.02–0.03 to 3 kg of garbage per day at the stadium. Notably, more than half of the waste generated consisted of food waste, while less than 25% comprised recyclable materials such as plastic and paper [34].

The demand for electrical load is highly irregular in a stadium due to its dependence on the activities taking place. For instance, a modern medium-sized stadium accommodating 55,000 spectators has an annual energy consumption of 10,000 MWh [35]. However, a significant amount of electricity is only used for a limited number of hours on specific game days, with the estimated energy consumption ranging from 15,000 to 30,000 kWh (depending on the stadium size, season, temperature, and number of spectators) [36].

Approximately 40% of the total energy consumption during a sporting event is attributed to the operation of floodlights, scoreboards, and LED advertising panels. Additionally, a considerable portion, exceeding 20%, is dedicated to food heating and beverage refrigeration within the stadium. The transmission of matches to a global audience involves the use of robust satellite transmitters, multiple HD cameras, and specially constructed editing rooms, collectively accounting for approximately 11% of the stadium's overall energy expenditure [37].

Another recent study [38] projects a significant increase in participants, from approximately 3.2 million to over 4 million people involved in the FIFA World Cup. This results in a substantial rise in the overall carbon footprint, escalating from 348.087 to 429.853 tons of $CO_2$ equivalent, representing an increase of 81.767 tons of $CO_2$ equivalent, which accounts for a 24% rise. Furthermore, the analysis highlights that some host cities are reaching or surpassing their hotel capacity. These include La Plata, Antofagasta, and Concepcion, while others, such as Santiago del Estero and Ciudad del Este, fall below the desired capacities according to the 2017 FIFA regulations. This assessment focuses on potential host nations like New Zealand, Argentina, Uruguay/Paraguay, and Chile for the 2030 World Cup.

Piccerillo et al. [39] tried to shed light on the growing emphasis on sustainability in major sports events while also drawing attention to the relatively limited focus on smaller sports gatherings and their carbon footprint. Specifically, the study examines 635 partecpants the 2022 University of Cassino and Southern Lazio sports event, where athletes (78.74%), companions (3.78%), managers (4.09%), and technicians/coaches (13.39%) were interviewed to comprehensively assess the environmental impact, including travel and accommodation. The findings of this study reveal a significant carbon footprint of 40,551 kg of $CO_2$e, primarily stemming from transportation (27,360 kg of $CO_2$e) and accommodations (13,191 kg of $CO_2$e). These results underscore the urgent need for sports event committees to adopt eco-friendly strategies in order to mitigate the environmental impact. Furthermore, the study delves into the environmental impact in terms of $CO_2$e emissions, providing a detailed breakdown of the carbon footprint attributed to each participant type during transportation and accommodation. In terms of transportation, athletes contributed the highest amount, accounting for 21,188.3 kg of $CO_2$e (77.4%), followed by managers with 1584.4 kg of $CO_2$e (5.8%), coaches with 3525.4 kg of $CO_2$e (12.9%), and companions with 1061.2 kg of $CO_2$e (3.9%). When it comes to accommodation, athletes were responsible for the majority of the carbon footprint, contributing 10,310.3 kg of $CO_2$e (78.2%) from 1442 overnight stays. Managers accounted for 958.1 kg of $CO_2$e (7.3%) from 134 overnight stays, while coaches generated 1737.5 kg of $CO_2$e (13.2%) from 243 overnight stays. Companions added 185.9 kg of $CO_2$e (1.4%) from 26 overnight stays [39].

Perkumiene et al. [40] aimed to evaluate the carbon footprint per capita that resulted from the transportation of the ice hockey leagues of Turkey and Lithuania during the 2021–2022 season. Our analysis reveals intriguing findings that shed light on the environmental impact of these leagues and the factors contributing to their disparities. In the case of Turkish teams, an average carbon footprint of 88.23 kg/$CO_2$e was observed. This substantial figure can be primarily attributed to the extensive air travel required between cities. The necessity of covering long distances by plane contributes significantly to the carbon emissions generated by the transportation of players and staff. Conversely, Lithuanian teams displayed a significantly lower average carbon footprint of 0.5229 kg/$CO_2$e per person. This remarkable disparity can be attributed to several factors. Firstly, the smaller number of teams in Lithuania compared to Turkey naturally leads to a reduced overall carbon footprint. Additionally, the shorter distances between competition locations in

Lithuania play a crucial role in minimizing carbon emissions. Lastly, the exclusive use of buses for transportation by Lithuanian teams further contributes to their commendable environmental performance.

Finally, the paper by Loewen et al. [13] aimed to estimate the carbon footprint caused by football fans traveling to Bundesliga (first division) matches in Germany during the 2018/19 season. By analyzing the factors influencing the seasonal carbon footprint and identifying fan clusters based on travel behavior, we conducted a national online survey of football fans (n = 539). Participants were asked to report their match-related travel behavior. The average seasonal carbon footprint of a Bundesliga fan was found to be 311.1 kg of carbon dioxide equivalent ($CO_2e$), with car travel accounting for 70% of emissions. The overall carbon footprint of all fans for the entire Bundesliga season amounted to 369,765.2 tons of $CO_2e$. The purchase of these carbon emissions would cost over 9.2 million euros in total. The regression results revealed that club membership and loyalty significantly increased fans' carbon footprints. The choice of the preferred Bundesliga club also predicted the carbon footprint, with FC Bayern Munich and RB Leipzig fans producing significantly higher emissions compared to Borussia Dortmund fans.

## 3. Technical Standards

In the context of current environmental awareness and the need to address climate change, the adoption of technical standards and ISO regulations for emissions management have become crucial elements for businesses and organizations worldwide. These standards and regulations play a key role in helping companies assess and reduce their environmental impact. In this section, we will explore the main concepts related to "carbon footprints", classification into "scopes 1, 2 and 3", and "GHG emissions", while also reviewing the importance of the ISO standards, such as ISO 14001 and ISO 14064, which provide clear guidelines for implementing environmental management systems and measuring emissions. In this way, we will gain a comprehensive overview of the main technical and regulatory issues involved in emissions management and the adoption of environmental best practices.

The concept of the "carbon footprint" finds its origins as a subset of the broader "ecological footprint" framework, initially proposed by Wackernagel and Rees [41].

The rise in global temperatures can be attributed to the "enhanced greenhouse effect", an effect beyond the natural greenhouse phenomenon driven by human-induced emissions of GHGs. These gases vary in their capacity to cause warming, depending on their radiative forcing and atmospheric persistence, leading to the calculation of the 'global warming potential' (GWP), expressed in terms of carbon dioxide equivalents ($CO_2e$) [17].

Fossil fuel combustion, primarily in the form of $CO_2$, contributes significantly to GHG emissions (58.6%). Other GHGs, such as methane ($CH_4$) and nitrous oxide ($N_2O$), also play a role, contributing 14.3% and 7.9%, respectively, to the total $CO_2e$ emissions [17].

The concept of the "carbon footprint" initially evolved as part of the broader ecological footprint, but it later gained independent recognition as the focus shifted, particularly in response to the increasing prominence of global warming. Wiedmann and Minx [42] provided a comprehensive definition of the carbon footprint, quantifying the total carbon dioxide emissions directly and indirectly caused by an activity or accumulated over the life stages of a product.

In essence, the carbon footprint can be defined as "the quantity of greenhouse gases expressed in terms of carbon dioxide equivalent emissions, emitted into the atmosphere by an individual, organization, process, product, or event from within a specified boundary". The specific set of GHGs and boundaries are determined according to the adopted methodology and the objective of the carbon footprint analysis [13].

The carbon footprint has become a vital indicator in event management, particularly in assessing the environmental impact of large-scale events [43]. To calculate the carbon footprint, one must estimate and sum the GHGs emitted, removed, or embodied throughout the product's life cycle. This life cycle encompasses all stages, from raw material procurement to manufacturing, distribution, consumption, and final disposal [17].

Several countries and organizations have developed their own GHG accounting guidelines, such as DEFRA, the Carbon Trust in the United Kingdom, and the Environmental Protection Agency (EPA) in the United States. Registries and consultancies like the World Wildlife Fund Climate Servers and the California Climate Registry have formulated methodologies based on these guidelines.

In the process of calculating a carbon footprint, the selection of GHGs, establishment of boundaries, and collection of GHG emission data are vital steps. Organizational boundaries must be set, and operational boundaries determine the direct and indirect emissions accounted for, often categorized into different scopes. The scopes typically include the following: (1) direct emissions (onsite emissions), (2) embodied emissions in purchased energy, and (3) all other indirect emissions, such as those associated with transportation, product disposal, and other activities not included in the first two scopes. The emissions categories and associated activities are summarized in Table 1.

**Table 1.** Activities included in calculating direct and indirect $CO_2e$ emissions.

| Emission Category | Activities Included |
|---|---|
| Scope 1: Direct emissions from owned sources. | Onsite electricity generation<br>Owned vehicle emissions |
| Scope 2: Indirect emissions from purchased consumption. | Purchased electricity<br>Heating or cooling consumption |
| Scope 3: Indirect emissions from the value chain activities. | Business travel<br>Employee commuting<br>Waste generation |

The table presents a comprehensive overview of different scopes, namely Scope 1, Scope 2, and Scope 3. It highlights specific activities that demonstrate emissions from both direct and indirect sources, which can be either owned, purchased, or beyond the control of the company.

The data on GHGs are typically translated into $CO_2e$ using conversion factors provided by organizations like the Intergovernmental Panel on Climate Change (IPCC). Carbon footprint units vary depending on the entity being considered, with individuals and dynamic processes calculated periodically, while some entities, like events, have one-time emissions. Understanding and accounting for carbon footprints is a crucial step in environmental sustainability, with different entities using various units, like $CO_2e$, to measure their impact. Carbon footprints are calculated periodically for individuals and dynamic processes, while some events, such as conferences and sports events, require one-time calculations.

Furthermore, in the realm of large public events like the FIFA World Cup, understanding the carbon footprint is of increasing importance for event management, and it aligns with global efforts to reduce GHG emissions [44].

As the carbon footprint of tourist accommodations becomes increasingly significant, with a share of 21% in the global carbon footprint, it is essential to address its environmental impact. While transportation remains the largest contributor to the carbon footprint of tourism (70%), the sector of tourist accommodations is expected to generate 25% of all GHG emissions from tourism by 2035 [38,45–47]. The sports and sport-tourism sectors, primarily in high-income countries, contribute to 8% of global tourism's share of greenhouse gas (GHG) emissions, which are responsible for climate change worldwide [48,49]. Consequently, the carbon footprint of tourist accommodations is a critical concern, with the potential to make a substantial societal contribution to environmental sustainability.

During the course of state-of-the-art analysis, it became apparent that numerous complementary studies existed, each focusing on specific aspects of evaluating sustainability within large-scale events. However, a comprehensive analysis that assesses the sustainability of these events as a whole was noticeably absent. Existing articles tended to dissect individual components, such as the transportation of fans [13] or team groups [39,40] to and from the event throughout the sporting season, as well as the sales of food and merchandise within the stadium, including bars and shops, thereby encompassing waste from food and clothing [50].

Furthermore, some articles delved into waste management [33,34], but an interesting observation arose—the scope should extend beyond the waste generated solely within the stadium during the event. It should also encompass the waste generated en route to the stadium and in the surrounding areas after the event. Consideration was also given to energy consumption and potential offset strategies [51–53], although these topics were sparsely covered in the literature due to the complexity of monitoring stadium-related consumption, often under diverse ownership structures.

Additionally, studies examining accommodation for fans [38] and team groups [39] were present in the literature. It is worth noting that our research aimed to consolidate these disparate areas and establish a unified methodology for evaluating the overall sustainability of large events. By synthesizing these diverse aspects, our study sought to bridge the gap by proposing a comprehensive approach to assessing the sustainability of such events.

When a company hosts an event, it is important to consider the fuel and electricity consumption that are not directly owned or controlled by the company. These types of consumption are typically included in Scope 3 emissions. Scope 3 emissions refer to the indirect emissions that are beyond the direct operational control of the organizing company. This categorization is based on greenhouse gas accounting protocols and standards.

## 4. Methodology for Calculating the Carbon Footprint of an Event

### *4.1. Definition of System Boundaries*

The areas of interest for calculating GHG emissions within a sports event are numerous. In fact, such events concentrate a large number of people in a small space of time, resulting in very high consumption rates. In order to conduct the research, the "*Technical Guidance for Calculating Scope 3 Emissions*" from the Greenhouse Gas Protocol body [18] was used to identify the areas of interest. These categories represent the main areas of interest that contribute to GHG emissions in a sports event.

The categories considered are Category 1 (purchased goods and services), Category 3 (fuel and energy-related activities), Category 5 (waste generated in operations) and Category 6 (business travel). In addition, the impact of accommodation, although not directly included in the guide, was considered in the study, as athletes and event participants often require lodging, making this impact relevant.

Figure 1 illustrates the sequence of impact categories that occur during the event. The analysis starts with Category 6, which pertains to the business travel undertaken by athletes, fans, and staff. This is followed by the consideration of potential accommodations. Moving forward, the focus shifts to Category 1, which encompasses the goods and services sold during the event. Additionally, Category 3 is examined, which involves energy and fuel consumption, such as for heating, cooling, or hot water systems. Lastly, the assessment concludes with Category 5, which addresses waste generation. This includes both the waste generated during the event itself and in the surrounding pre/post-event areas. It is important to note that the assessment also extends to the return journey, taking into account potential accommodations.

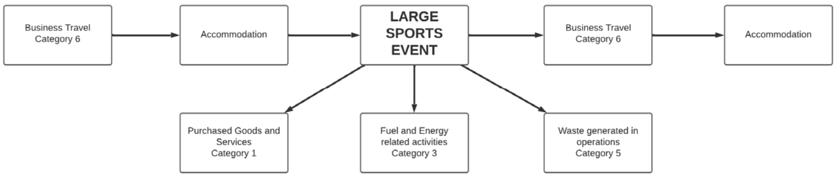

**Figure 1.** Impact categories' trends throughout large sports events.

By presenting this sequence of impact categories, we gain a comprehensive understanding of the various aspects that contribute to the overall impact of the event.

There are various formulas that are presented in the following paragraphs, which are taken from the *Technical Guidance for Calculating Scope 3 Emissions* from Greenhouse Gas Protocol.

### *4.2. Purchased Goods and Services*

This particular category encompasses all upstream emissions, from cradle-to-gate, related to the production of goods and services that have been purchased or acquired by the reporting company during the current reporting year. This includes both tangible products (goods) and intangible products (services).

Listed below are the methods that companies can utilize to calculate their Scope 3 emissions from purchased goods and services. The first two methods—supplier-specific and hybrid—necessitate the reporting company to gather data from their suppliers. On the other hand, the second two methods—the average-data and spend-based methods—utilize secondary data, such as industry average data. These methods are arranged based on the level of specificity they provide with regard to the individual supplier of a good or service.

- Supplier-specific method: This collects product-level cradle-to-gate GHG inventory data from goods or services suppliers.
- Hybrid method: This uses a combination of supplier-specific activity data (where available) and secondary data to fill the gaps.
- Average-data method: This estimates emissions for goods and services by collecting data on the mass (e.g., kilograms or pounds) or other relevant units of goods or services purchased and multiplying by the relevant secondary (e.g., industry average) emission factors (e.g., the average emissions per unit of a good or service).
- Spend-based method: This estimates emissions for goods and services by collecting data on the economic value of goods and services purchased and multiplying it by relevant secondary (e.g., industry average) emission factors (e.g., average emissions per monetary value of goods).

It is crucial to identify the calculation method that best suits the characteristics of the research. For the supplier-specific method and hybrid method, upstream data from suppliers is required, which is not easily obtainable. Moreover, it is often challenging to obtain precise data on the quantities consumed during the event, both by fans and athletes.

There are specific areas within the stadium dedicated to premium fans where meals are consumed in a restaurant, while standard fans can buy food or drinks from various points of sale.

Therefore, the average-data method and spend-based method are better suited to the research object, as they can be used with the quantity of goods sold based on financial or physical aspects.

Figure 2 illustrates the correlation between the method choice, data significance, and widespread utilization, highlighting the profound impact of capillarity on the selection process.

The average-data method and spend-data method enable the calculation of the $CO_2e$ emissions resulting from the sale of goods and services using data that are easily accessible. In the following, we will provide a detailed analysis of the data required for the calculation process, as well as the emission factors necessary for both methods.

In the average-data method, the company collects data on the mass or other relevant units of purchased goods or services and multiplies them by secondary emission factors obtained from process-based life cycle inventory databases. To simplify the process, companies can differentiate purchased goods or services into mass units and other categories. The emission factors required for this method include the cradle-to-gate emission factors of the purchased goods or services per unit of mass or product, such as kg $CO_2e$/kg or kg $CO_2e$/hour spent.

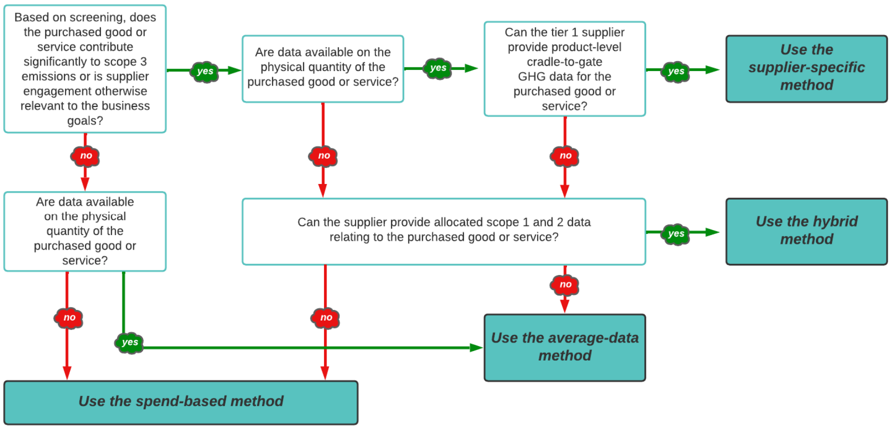

**Figure 2.** Decision tree for selecting a calculation method for emissions from purchased goods and services. Graphical representation of the "*Technical Guidance for Calculating Scope 3 Emissions*".

The amount of $CO_2e$ emissions resulting from the sale of goods and services through the average-data method can be evaluated as follows:

$$CO_2e \text{ emissions for purchased goods or services} = \sum (M_p \times E_p) \tag{1}$$

Equation (1) calculates the amount of $CO_2e$ emissions from the sale of goods and services using the average-data method. The variable "M" represents the mass of goods or services purchased in kilograms [kg], while "p" belongs to the set P that represents each type of purchased goods or services. Finally, "E" represents the emission factor of each purchased goods or services "p" per unit of mass [kg $CO_2e$/kg].

To calculate the $CO_2e$ emissions from purchased semi-finished components, the quantities of materials are multiplied by their respective emission factors. For example, the purchase of a 400 kg hard disk with an emission factor of 20 kg $CO_2e$/kg contributes 8000 kg $CO_2e$. By repeating this calculation for all purchased semi-finished components, the sum of emissions associated with the goods acquired by the company is obtained.

On the other hand, in cases where the supplier-specific method, hybrid method, and average-data method are not viable due to data limitations, companies can use the average spend-based method. This method involves collecting data on the economic value of purchased goods and services and multiplying it by the relevant EEIO emission factors.

The amount of $CO_2e$ emissions resulting from the sale of goods and services through the spend-based method can be evaluated as follows:

$$CO_2e \text{ emissions for purchased goods or services} = \sum (V_p \times E_p) \tag{2}$$

Equation (2) calculates the amount of $CO_2e$ emissions from the sale of goods and services using the spend-based method. The variable "V" represents the value of goods or services purchased [USD], while "p" belongs to the set P that represents each type of purchased goods or services. Finally, "E" represents the emission factor of each purchased goods or service "p" per unit of economic value [kg $CO_2e$/USD].

To calculate the $CO_2e$ emissions from purchased goods, we multiply the quantities/values purchased by their respective emission factors. For instance, the purchase of PS plastic for USD 5000 with an emission factor of 0.3 kg $CO_2e$/USD contributes to 1500 kg $CO_2e$. By repeating this calculation for all materials purchased, we obtain the total sum of emissions associated with the company's purchases.

### *4.3. Fuel and Energy-Related Activities*

In the context of a sports event, it is essential to consider the electricity consumption and sources utilized for the various activities involved in the event's operations. While this consumption typically occurs within the stadium, it is important to note that stadium ownership is not always attributed to the sports clubs, especially in Italy, where they may not directly own the facilities.

Given this scenario, it becomes apparent that a separate category should be established to account for the fuel and energy-related activities specific to the event. This category acknowledges that the consumption in question takes place outside the sports clubs' regular assets, such as administrative offices or sports centers, and within the stadium itself.

Recognizing the distinct nature of these consumption patterns enables a more comprehensive assessment of the event's environmental impact and provides a foundation for targeted strategies aimed at reducing emissions associated with the event's operations.

This category, however, excludes emissions resulting from the combustion of fuels or electricity consumed by the reporting company. The reason for this exclusion is that these emissions are already accounted for in Scope 1 or Scope 2. Scope 1 specifically includes emissions from the combustion of fuels by sources that are directly owned or controlled by the reporting company. On the other hand, Scope 2 includes emissions from the combustion of fuels used to generate electricity, steam, heating, and cooling, which are then purchased and consumed by the reporting company.

Listed below are the methods companies can use to calculate their Scope 3 emissions from upstream emissions of purchased fuels:

- Supplier-specific method: This approach entails gathering data directly from suppliers regarding the upstream emissions associated with the extraction, production, and transportation of the fuel and electricity consumed by the reporting company.
- Average-data method: This involves estimating emissions by utilizing secondary data, such as industry averages, to determine the emission factors for upstream emissions per unit of consumption.

Figure 3 exemplifies the systematic approach to method selection, hinging upon the significance of data and the accessibility of supplier-specific emission data pertaining to energy and fuel. If the average-data method is used, it means that activities related to fuels and energy do not have a significant impact on Scope 3 emissions, and this approach is followed. However, if it is believed that such activities have a relevant impact, the supplier method is chosen. The supplier method requires more detailed and specific data on the entire upstream production chain of energy and fuel suppliers. If suppliers are able to provide direct data on the emissions along the entire production chain, this more accurate method is used. However, it should be emphasized that obtaining such data from suppliers can be more complex and requires greater cooperation and precision. In the absence of detailed data, the average-data method can be used to estimate emissions.

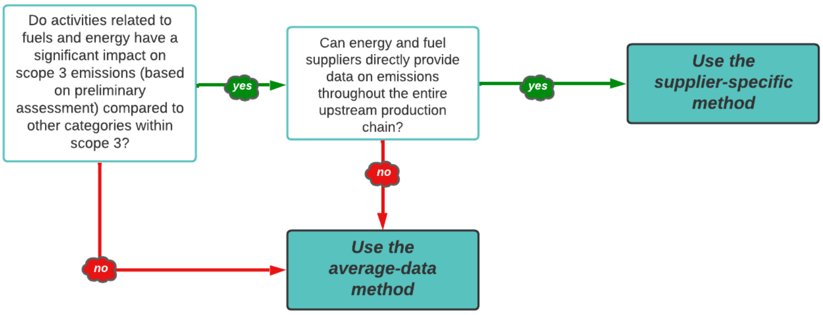

**Figure 3.** Decision tree for selecting a calculation method for emissions from fuel- and energy-related activities. Graphical representation of the "*Technical Guidance for Calculating Scope 3 Emissions*".

If the supplier-specific method is used, companies must capture supplier-specific emission factors for the extraction, production, and transport per unit of fuel and electricity consumed. These emission factors must be specific to the type of fuel or electricity and the country or region of origin. They are usually expressed in units such as kilograms of $CO_2$ equivalent per kilowatt hour [kg $CO_2e$/kWh].

If the average-data method is chosen, companies must use average emission factors for the upstream emissions per unit of consumption. These emission factors are usually expressed in units such as kilograms of $CO_2$ equivalent per kilowatt hour [kg $CO_2$e/kWh].

The amount of $CO_2$e emissions resulting from the purchase of electricity and fuels can be evaluated as follows:

$$\text{CO}_2\text{e emissions for electricity consumed} = \sum [(\text{EL}_c \times \text{E}_c) + (\text{S}_c \times \text{E}_c) + (\text{H}_c \times \text{E}_c) + (\text{C}_c \times \text{E}_c) + (\text{F}_c \times \text{E}_c)] \quad (3)$$

Equation (3) calculates the amount of $CO_2$e emissions from the sale of electricity and fuel using the average-data method. The variable “EL” represents the quantity of electricity consumed [kWh], the variable “S” represents the quantity of steam consumed [kWh], the variable “H” represents the quantity of heating consumed [kWh], the variable “C” represents the quantity of cooling consumed [kWh], the variable “F” represents the quantity of fuel consumed [kWh], while “c” belongs to the set C that represents each type of variable consumed. Finally, “E” represents the combustion emission factor of each variable consumed [kg $CO_2$e/kWh].

To further clarify Equation (3), let us provide an illustrative example using hypothetical values. Let us consider a facility that consumes 1000 kWh of electricity (EL), 200 kWh of steam (S), 150 kWh of heating (H), 80 kWh of cooling (C), and 50 kWh of fuel (F). By utilizing specific combustion emission factors (E) for each category, we can calculate the total $CO_2$e emissions.

### 4.4. Waste Generated in Operations

Effective waste management at a sporting event holds paramount importance, as it exerts a substantial influence on various aspects, such as the environment, the event’s image, regulatory compliance, the promotion of recycling, and community involvement. By efficiently managing waste, we can unlock a multitude of environmental, economic, and social benefits.

Category 5 encompasses emissions resulting from the third-party disposal and treatment of waste generated within the reporting company’s owned or controlled operations during the reporting year. This category specifically accounts for emissions stemming from the disposal of both solid waste and wastewater.

Within a sporting event, various types of waste can be observed, which vary depending on the nature of the event, the type of sport being played, and the associated activities.

Companies employ different methodologies to calculate the emissions resulting from the waste generated in their operations but handled by third parties. These approaches aid companies in comprehending and documenting the environmental consequences linked to their waste management practices. Below, we outline several prevalent methods utilized in this regard:

- Supplier-specific method: This process entails directly gathering waste-specific Scope 1 and Scope 2 emissions data from waste treatment companies, such as those involved in incineration or recovery for recycling.
- Waste-type-specific method: This process entails utilizing emission factors tailored to specific waste types and waste treatment methods.
- Average-data method: This process entails estimating emissions by considering the total waste directed towards various disposal methods, such as landfills, and utilizing average emission factors associated with each disposal method.

Referring to Figure 4, the selection of a method relies on the significance of the data and its wide-ranging applicability, effectively demonstrating the influence of capillarity on the decision-making process. If it is believed that activities related to fuels and energy have a significant impact, the next decision depends on the company’s ability to provide specific data on waste for Scope 1 and Scope 2 emissions. If the company is able to provide such data, the supplier-specific method can be used, which is more accurate but requires greater effort and detail in data collection. However, if the company does not consider activities related to fuels and energy to have a significant impact on Scope 3 emissions or is unable to obtain data on Scopes 1 and 2, the next evaluation concerns the company's ability to differentiate waste streams. If the company can distinguish waste streams, the waste-type-specific method can be chosen. Otherwise, in the absence of detailed data, the average-data method is used to estimate the Scope 3 emissions.

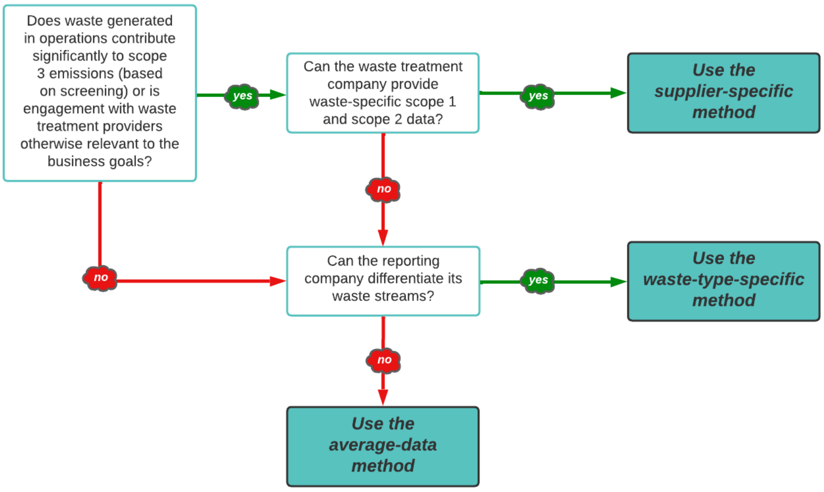

**Figure 4.** Decision tree for selecting a calculation method for emissions from waste generated in operations. Graphical representation of the "*Technical Guidance for Calculating Scope 3 Emissions*".

The supplier-specific method for calculating emissions from waste generated and managed by third parties entails gathering emissions data directly from waste treatment companies or service providers. This approach eliminates the need for relying on emission factors, as the reporting company obtains emissions information directly from its suppliers. By adopting this method, the reporting company ensures a more accurate and reliable assessment of its emissions footprint associated with waste management. When utilizing the supplier-specific approach to calculate emissions from waste generated and managed by third-party waste treatment companies, the reporting company must gather the allocated Scope 1 and Scope 2 emissions of the waste treatment company that can be directly attributed to the waste collected from the reporting company.

The waste-type-specific method necessitates companies to diligently gather crucial data regarding waste management practices within their operations. Specifically, they must collect information on the quantity of waste generated, typically measured in units such as tons or cubic meters, and categorize the waste by type. Moreover, for each distinct waste type, it is imperative to document the precise treatment or disposal method employed, such as landfilling, incineration, recycling, or other waste management processes. One notable aspect is that many waste operators determine their disposal fees based on the chosen waste disposal method. Consequently, companies can gain valuable insights into the specific disposal methods utilized by scrutinizing their utility bills from these waste operators. These bills often itemize charges based on the disposal approach, enabling companies to identify the specific methods applied to their waste streams. Furthermore, to accurately calculate the emissions associated with the waste-type-specific method, companies should compile specific emission factors tailored to each waste type and corresponding waste treatment methods. These emission factors should solely account for end-of-life processes, encompassing emissions generated during processes such as landfill decomposition, incineration, and recycling. It is essential to note that emission factors may also incorporate the emissions resulting from the transportation of waste materials.

The amount of $CO_2$e emissions resulting from the waste generated in operations using the waste-type-specific method typically involves the following elements:

$$CO_2\text{e emissions for waste generated in operations} = \Sigma\ (G_w \times E_w) \tag{4}$$

Equation (4) calculates the amount of $CO_2e$ emissions from the waste generated using the waste-type-specific method. The variable "G" represents the quantity of waste generated [tons or $m^3$], while "w" belongs to the set W that represents each type of waste generated. Finally, "E" represents the waste type and waste treatment-specific emission factor [kg $CO_2e$/ton or $m^3$].

To calculate the emissions resulting from the waste generated in operations, the company, which produces plastic components, collects data on the various types of waste produced and their respective treatments. We then utilize specific emission factors for each type of waste. For instance, let us consider the waste type "plastic," of which 2000 tons were produced, with an emission factor of 40 kg $CO_2e$/ton if destined for landfill. The total emission for this waste type alone would amount to 80,000 kg $CO_2e$. By repeating this calculation for all waste types, we obtain the overall sum of emissions associated with the waste generated by our company.

### *4.5. Business Travel*

This category encompasses the emissions resulting from the transportation of employees for business-related activities in vehicles owned or operated by third parties, such as aircraft, trains, buses, and passenger cars. Emissions arising from transportation in vehicles owned or controlled by the reporting company are recorded under either Scope 1 (for fuel use) or, in the case of electric vehicles, Scope 2 (for electricity use). Emissions from leased vehicles operated by the reporting company, which are not included in Scope 1 or Scope 2, are accounted for under Scope 3, Category 8 (upstream leased assets). Additionally, emissions resulting from the transportation of employees to and from work are accounted for under Scope 3, Category 7 (employee commuting).

In order to accurately assess the environmental impact, it is crucial to consider the emissions generated by the transportation of employees for business-related purposes. These emissions primarily stem from the use of vehicles owned or operated by third parties, including aircraft, trains, buses, and passenger cars. By comprehensively considering these various categories, we can effectively evaluate and manage our transportation-related emissions, thereby contributing to our overall sustainability goals.

Emissions stemming from business travel can arise due to various factors as follows:

- Air travel;
- Rail travel;
- Bus travel;
- Automobile travel;
- Other modes of travel.

Accounting for employee transportation across the value chain involves assessing and quantifying the greenhouse gas emissions associated with the movement of employees to and from their workplaces and other locations as part of their job responsibilities. This is important for understanding and mitigating the carbon footprint of employee commuting and business travel. Table 2 presents the key steps to account for emissions from employee transportation throughout the value chain:

**Table 2.** Activity-based accounting of employee transportation.

| Activity | Relevant Category of Emission |
|---|---|
| Vehicles owned or controlled by the reporting company | Scope 1 (for vehicles that consume fuel) and Scope 2 (for vehicles that consume electricity) |
| Employees for business-related activities in vehicles owned or operated by third parties | Scope 3, Category 6 (business travel) |
| Employees to and from work | Scope 3, Category 7 (employee commuting) |
| Leased vehicles operated by the reporting company not included in Scope 1 or Scope 2 | Scope 3, Category 8 (upstream leased assets) |

Companies have the option to employ any of the subsequent approaches for calculating the Scope 3 emissions arising from business travel:

- Fuel-based method: This involves quantifying the fuel consumption associated with business travel, specifically encompassing Scope 1 and Scope 2 emissions from transport providers. This approach necessitates the application of an appropriate emission factor corresponding to the specific type of fuel used.
- Distance-based method: This entails determining the distance and mode of business trips and subsequently applying the suitable emission factor corresponding to the mode employed.
- Spend-based method: This entails assessing the financial expenditure associated with various modes of business travel transportation and subsequently applying secondary emission factors derived from the environmental extended input–output (EEIO) analysis.

Figure 5 illustrates the selection of methods based on the relevance of data and their widespread usage, emphasizing the significant impact of capillarity in the overall process. If the contribution of business travel to Scope 3 is considered significant, it is essential to verify the availability of data on the quantity and cost of the fuel consumed during the trip. When such data are available, it is recommended to use the fuel-based method for a more accurate assessment. However, in cases where detailed information is not available or the impact of business travel is deemed irrelevant for the category, considering the collection of data on the distance traveled is possible. When such data are present, the distance-based method can be chosen. In situations where distance-traveled data are not available but information on travel costs is accessible, it is advisable to utilize the spend-based method. It should be emphasized that if available, the fuel-based method is more precise, but the distance-based method can provide a good approximation in the absence of detailed consumption data.

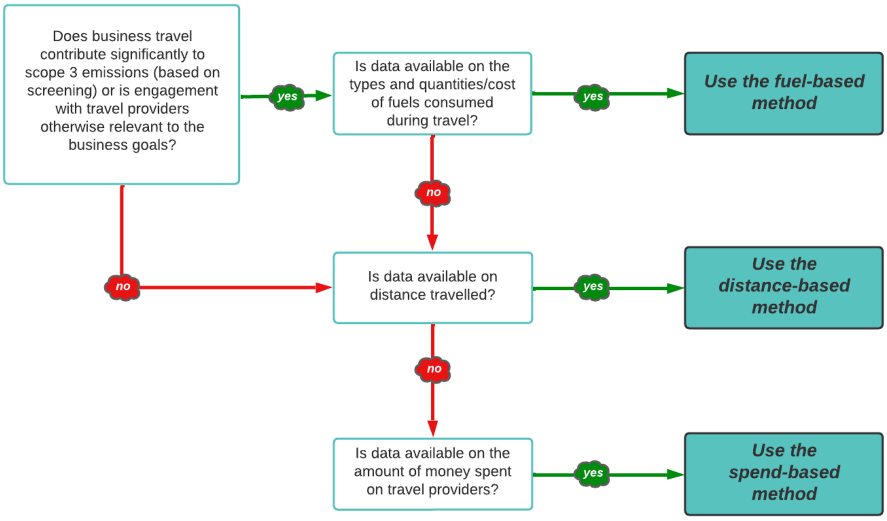

**Figure 5.** Decision tree for selecting a calculation method for emissions from business travel. Graphical representation of the "*Technical Guidance for Calculating Scope 3 Emissions*".

If data on fuel usage are not accessible, companies have the option to utilize the distance-based method. This method entails multiplying the activity data, such as the number of kilometers traveled by vehicle type, by emission factors. These emission factors are typically default national values specific to each vehicle type. It is important to note that vehicle types encompass all categories, including aircraft, rail, subways, buses, automobiles, and more. By employing this approach, companies can estimate the emissions even in the absence of fuel consumption data.

In order to effectively assess and manage transportation emissions, it is crucial for companies to gather accurate and comprehensive activity data. This data should encompass the total distance traveled by each mode of transport, including air, train, bus, and car, among others, throughout the reporting year. To ensure consistency and clarity, the activity data should be expressed in terms of kilometers traveled or kilometers traveled per person for a specific vehicle type, such as passenger kilometers.

The amount of $CO_2e$ emissions resulting from business travel using the distance-based method typically involves the following elements:

$$CO_2e \text{ emissions from business travel} = \Sigma\ (D_v \times E_v) \quad (5)$$

The variable "D" represents the distance traveled by vehicle type [vehicle-km or passenger-km], while "v" belongs to the set V, which represents each type of vehicle used for transportation. Finally, "E" represents the combustion emission factor of each vehicle considered [kg $CO_2e$/vehicle-km or kg $CO_2e$/passenger-km].

To calculate the emissions resulting from business travel, let us consider a group of five employees using hybrid cars for a 50 km trip in the United States. The emission factor for this hybrid car is 1 kg of $CO_2e$ per kilometer per vehicle, resulting in 50 kg of $CO_2e$ per passenger. By multiplying this value by the number of passengers, we obtain a total of 250 kg of $CO_2e$ for the entire trip. Let us now consider an example of air transport. A group of 10 individuals is assumed to embark on a long-haul flight covering a distance of 10,000 km. The emission factor for this flight is 5 kg of $CO_2e$ per passenger kilometer, resulting in a staggering 500,000 kg of $CO_2e$ in total. These examples effectively demonstrate the application of emission factors in quantifying carbon emissions for different modes of business travel.

### 4.6. Accommodations

The calculation of the impact of accommodations in assessing the $CO_2$ impact at a major sporting event holds immense significance for several key reasons. To begin with, hospitality facilities, such as hotels, resorts, and lodging establishments, play a pivotal role in the ecosystem of a major sporting event. These venues not only cater to the athletes and staff involved in the organization but also accommodate thousands of spectators from across the globe. Hence, the $CO_2$ emissions associated with the operation of these accommodation facilities can be substantial. When determining the country in which a hotel is situated, it becomes crucial to accurately calculate the carbon emissions linked to hospitality. This is primarily due to various factors, including the energy sources utilized, domestic energy production, environmental policies, and available technologies. Emission coefficients can vary significantly from one country to another, making it imperative to consider the specific location. Consequently, when tallying the activities, it is essential to account for the number of hotel nights for each individual participant. This ensures a comprehensive assessment of the carbon footprint generated by the event. By meticulously calculating the impact of accommodation, we gain valuable insights into the environmental implications of a major sporting event. This information enables us to develop effective strategies and implement sustainable practices to mitigate the $CO_2$ emissions associated with hospitality. Ultimately, this contributes to the overall success and positive reputation of the event while also promoting environmental responsibility on a global scale.

The amount of $CO_2e$ emissions resulting from the overnight stay in the users' hotel typically involves the following elements:

$$CO_2e \text{ emissions from the overnight stay in the users' hotel} = \Sigma\ (H_p \times E_p) \quad (6)$$

The variable "H" represents the hotel nights for each individual person participating in the event [nights], while "p" belongs to the set P that represents each individual person. Finally, "E" represents the combustion emission factor for each hotel in individual nations [kg $CO_2e$/night].

To calculate the $CO_2e$ emissions resulting from a five-person stay at a generic hotel in Italy for two nights, we simply multiply the number of nights by the emission factor for each person. With a conversion factor of 26.2 kg of $CO_2e$ per night, the total emissions for the five-person stay over two nights would amount to 261.2 kg of $CO_2e$.

## 5. Discussion

Current scientific research demonstrates remarkable expertise in categories related to transportation and accommodation in sports events. The analysis of waste and food and beverages is also emerging as a research theme. However, it is essential to highlight that the entire sports industry has experienced significant growth in recent years, introducing new variables to consider.

There is a tendency to focus on traditional categories, such as transportation and accommodation, while the increasing complexity of sports events requires the inclusion of other variables in the environmental assessment. For example, branded goods spending represents an important aspect, considering that many teams use specific materials for event sponsorship, such as center circles, club crests, and giant carpets. These elements require accurate reporting in terms of quantity ($m_2$ or kg) and disposal methods.

It should be emphasized that some teams take advantage of sports events to market their own sports materials, such as shirts, sweatshirts, and hats. Proper reporting requires an evaluation of the quantities sold and a detailed composition of the items.

The evaluation method for elements such as merchandising and ceremonial objects can be attributed to Category 1. Regarding specific evaluation methodologies, as previously mentioned, there are several approaches, including the supplier-specific method, the hybrid method, the average-data method, and the spend-based method. The choice between these methodologies depends on the availability and coverage of the data at hand.

In Table 3, the activities that need to be accounted for are listed. These activities have been added by this methodology, which has not been previously considered within an evaluation of emissions in a large sports event.

**Table 3.** Secondary activities during a large sports event.

| Activity | Description |
|---|---|
| Branded items | The expenditure is dedicated to specific items used for event sponsorship and promotion. |
| Ceremonies and signage | The evaluation of brand expenditure in sports events considers costs, quantity, and types of materials such as center circle, club crest, and giant carpet. |
| Merchandising | The purchase of merchandise by fans, including hats, jerseys, sweatshirts, and scarves, is evaluated based on the number of units sold per category and the overall weight. |

The elements presented in Table 3 represent a step forward in evaluating the greenhouse gas emissions of an event, aiming to always account for all the variables within the evolution of a sports event. This progress is crucial in understanding and addressing the environmental impact of such events.

### *5.1. Limitations of the Methodology*

The development of the research in this area is hindered by several limitations. One major challenge is the need for a large and reliable dataset to effectively utilize tools for the Carbon Footprint Report. This is a common issue faced by many studies, which often leads to increased assumptions.

Unfortunately, gathering information on all event-related consumption items is currently impossible. Specifically, data quality for the items tied to an event or region is often lacking, resulting in what is known as gray data.

However, with collaborations from teams or organizations, data retrieval could be facilitated, and many data points can be estimated based on the technical parameters of the event. For instance, waste production can be correlated with the number of participants and energy consumption can be estimated based on the size of the stadium. While we acknowledge these challenges, we see collaboration and data estimation as a means to overcome some of the current limitations, enabling a more comprehensive understanding and assessment of the environmental impact of events.

Another concern is the vagueness in reporting participant travel, which is a significant contributor to an event's carbon footprint. To address this, standardization within the methodology could greatly enhance data accuracy. Providing detailed breakdowns of participant travel by transport type or utilizing participant registration data for impact calculations would strengthen reporting.

However, it is important to note that the calculated footprint does not take into account the displacement effects. For example, it fails to consider the reduced consumption by local residents in establishments during the event period. The complexity of carbon accounting and emissions inventories, without proper training, can lead to poor-quality data, underestimation of an event's carbon footprint, and limitations in making direct comparisons across different categories.

Furthermore, the method used does not account for all visitor consumption during the event, such as water or hospital services. Additionally, it overlooks any displacement effects caused by the event, which further complicates the comprehensive assessment of its environmental impact.

These inherent limitations present significant challenges in accurately capturing and comparing the carbon footprint of events.

### 5.2. Possible Future Research Developments

Future research offers potential avenues to enhance our understanding and address the limitations identified in this study. One crucial area of focus could involve the development of specific emission factors for various accommodation categories. Recognizing the influence of participants' chosen accommodations on the overall category impact would provide valuable insights. Educating participants about these impacts could potentially mitigate emissions from sporting events.

Furthermore, efforts to extend research initiatives are essential in equipping event managers with the necessary tools and insights to achieve potential GHG and energy savings. Replicating data collection efforts becomes pivotal in reducing uncertainties and strengthening the foundation of these initiatives.

The identified limitations present opportunities for future studies. Comparing carbon footprints across similar events held in diverse geographical locations could offer valuable insights. Exploring whether host cities with robust public transport systems influence low-carbon travel decisions and, subsequently, lower carbon footprints could be a compelling research avenue.

Additionally, exploring the influence on transportation choices can provide valuable insights. Investigating the efficacy of different incentives, such as free public transit or initiatives aimed at reducing individual emissions, in encouraging the adoption of sustainable transportation options stands as a promising area for future research.

Moreover, delving into participant and spectator profiles represents an essential shift in research focus. Previous studies have primarily focused on the separate environmental impacts of either participants or spectators, lacking an integrated approach that considers both groups simultaneously. Examining the profiles of both segments, particularly in large-scale events like running races, is crucial for a comprehensive understanding of their collective impacts.

We are nearing the completion of our preparations for validating our methodology for calculating greenhouse gas emissions in large sports events. This will be done through a case study involving a Serie A Italian football team in collaboration with a prominent

European sports organization. This real-world application is aimed at refining and enhancing our approach, with the ultimate goal of creating a more sustainable sports industry.

## 6. Conclusions

The assessment of the environmental impact of major sporting events is crucial as sustainability becomes increasingly important for sports organizations and the supporting public sectors. Despite the challenges in collecting comprehensive data, there is a growing number of studies that reflect a rising concern for environmental sustainability.

We also emphasize the significance of waste mitigation strategies, particularly zero-waste approaches. By focusing on food waste, especially from animal-based foods, our study suggests significant ecological benefits that align with the broader sustainability goals of these events.

The examination of carbon emissions from large sports events, particularly in colossal events like the World Cup, underscores the need for robust waste management and sustainability frameworks. Our study identifies key areas, such as predicting food demand and considering fan behavior, to enhance sustainability practices. This not only reduces expenses but also aligns with the growing public awareness of the importance of environmentally friendly events.

This article provides a dual contribution to the understanding of sustainability in major sporting events. Firstly, it offers a clear and comprehensive methodology for environmental assessment, outlining the necessary input data and corresponding reference emission factors. Secondly, it introduces previously overlooked categories, such as merchandise and ceremonial objects for event sponsorship, ensuring a thorough and accurate evaluation. These contributions represent a significant step towards a more comprehensive and inclusive assessment of the environmental impact of major sporting events.

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