AC Milan Life Cycle Assessment

ENVIRON 180A — Practicum in Environmental Science

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Background

Sport has a vital role to play in tackling climate change. It has an unrivaled capacity to be both an advocate and lead by example. With around five billion fans worldwide, and over 250 million players across 200 countries, soccer is one of the most popular sports in the world. The sheer volume and reach of soccer greatly impacts the environment. It is estimated that the global soccer industry produces more than 30 million tons of carbon dioxide each year, which is equivalent to the total emissions of Denmark (Global Carbon Budget, 2023). San Siro, AC Milan's stadium, hosts around two million spectators each year, with an average attendance of 70,000 (ESPN Enterprises, 2024). In collaboration with the AC Milan team, we seek to understand the environmental impacts that result from individual soccer stadium matches and provide recommendations on strategies for emissions reduction.

We do this in two stages. Firstly, we review other attempts to quantify environmental impacts of soccer matches. Since only a handful such studies are available, we also include in our review studies that focus on other large sporting events with comparable scale to an elite European soccer club. Secondly, we adopt the Life Cycle Assessment (LCA) approach to build a model that takes a holistic view of the impacts of a single sporting event through an analysis of all associated operations and facilities involved. By assessing and clearly outlining which sectors contribute the most to the environmental impacts of an event using methods like LCA, sports organizations, such as AC Milan, can be better informed about hotspots for burdens and undertake directed efforts to mitigate these impacts. This information is therefore crucial for making sports events more environmentally friendly and increasing sustainability in the sporting world overall.

Literature Review

Quantifying Environmental Impact for Large Sport Events: Methods, Data Sources, and Results

For large-scale professional sport events, there remains no consensus among researchers on which method should be used for quantifying the environmental burdens accrued when hosting a matchday. A fully comprehensive quantification of the environmental impact of these massive centralized gatherings requires not only an inventory of on-site operations (e.g., stadium lighting, water use) but also their upstream (e.g., merchandise manufacturing) and downstream (e.g., waste generation, emissions) activities. This holistic “cradle-to-grave” perspective is a crucial step towards quantifying and possibly mitigating operational hotspots identified to be especially harmful to the environment when hosting such large-scale sport events (Dolf, 2017). In our survey of existing literature that has attempted to measure these environmental impacts, a variety of approaches have been applied including:

1. Ecological footprint and environmental input-output tables analysis (Collins et al., 2007, 2009),
2. Carbon footprinting (Econ Pöyry, 2009; FIFA World Cup Organizing Committees, 2006-2018; UNEP 2012), and

3. Unit process-based LCA (Dolf, 2012, 2017; Hedayati et al., 2014; Marucci et al., 2021).

Although quantitative studies relevant to the scale and scope of AC Milan are limited, a sufficient amount of research reports have been generated that, when extrapolated from their existing frameworks, provide the groundwork necessary for constructing a comprehensive inventory of environmental impacts created by the hosting of a soccer match at the San Siro Stadium.

In this literature review, we will undertake a thorough analysis of a selection of the previously mentioned reports and case studies most relevant to this project focus. By comparing the methodologies, data sources, and results of various studies, this literature review intends to present a broad overview of existing studies attempting to quantify the environmental impact of large sport events, thus equipping our team with the knowledge required to take steps towards answering this question in the context of our model stadium. These studies were aggregated through a search of databases provided by the UCLA Library (ProQuest & Web of Science) as well as Google Scholar. Beginning the search from the year 2000, the search terms used were “football”, “soccer”, “life cycle assessment”, “sustainability”, “stadium”, “quantitative”, “environment”, “environmental impact”, “climate change”, “emissions”, “carbon footprint”, “functional unit”, and “system boundary”.

Ecological Footprint & Environmental Input-Output Analysis — 2003/04 FA Cup Final

Collins et al. (2007, 2009) published a landmark study marking one of the first attempts at quantifying the environmental burdens produced by a specific soccer match; in this case, the 2003/04 FA Cup Final between Manchester United and Millwall hosted at the Millennium Stadium in Cardiff, Wales was the focus of the study. Employing and comparing two existing frameworks in the form of the ecological footprint and environmental input-output analysis, Collins et al. (2007, 2009) endeavored to move beyond simple identification of environmental impacts and towards actual quantification of them.

The first of the two methods employed by Collins et al. (2007, 2009) is ecological footprint analysis. This framework seeks to measure the environmental impact of each individual stadium visitor through the standardized unit of a ‘global hectare’ (gha). This unit represents the average productive hectare of land required to support a population, and can be compared to the global average in order to determine whether a specific activity is sustainable. In the case of the FA Cup Final, the ecological footprint of the 71,000 fans in attendance was calculated using primary and secondary data to estimate resource consumption among four measurable categories: travel, food and drink, event venue infrastructure, and waste. The results produced by this method revealed that the total ecological footprint of these four categories for each visitor amounted to 3,051 global hectares per day, an increase of 2,633 global hectares of resource consumption when compared to the scenario in which the individual does not visit the stadium.

The second method used in this case study is the analysis of environmental input-output tables. These tables were calculated using a database of regional and local emissions rates dependent on each industry (e.g., manufacturing, merchandise, transport), coupled with economic data to quantify the magnitude of each category of environmental impact. Using tons of carbon equivalent as the impact indicator unit, this method found the total emissions of the 2003/04 FA Cup Final to be over 560 tons of carbon equivalent over the course of the match in the form of matchday processes such as energy and water use.

Although this case study employed primary and secondary data collection, as well as the defining of specific, measurable environmental impact indicators, both these methods fall short of being able to provide a comprehensive picture of all upstream and downstream environmental impacts of hosting a soccer match. The ecological footprint method relies heavily on a comparison to a global average, and uses unclear algorithms to link production and consumption with global land areas (Collins et al., 2009). Similarly, while the environmental input-output analysis carried out in this study gives a better account of indirect climate impacts as a result of certain activities, the main issue with extrapolating this method to a model stadium similar to AC Milan's is the use of largely static industry input-output tables which do not take into account price changes or industry innovations. Thus, this method is most beneficial when considering the environmental burden incurred by a single match, not a season or more of matches as is the case with the San Siro Stadium. Despite these shortcomings, however, the importance of this study in quantifying the environmental burdens that arise in order to stage a single soccer match cannot be understated. With this initial research, Collins et al. (2007, 2009) set in motion a shift in the world of large-scale professional sports towards becoming active players in tackling climate change and away from being passive emitters.

Carbon Footprinting — FIFA World Cups

With the launch of the Green Goal sustainability initiative by the 2006 FIFA World Cup Organizing Committee (OC) in Germany, a pioneering effort was made to quantify a baseline environmental impact report for comparison to other similar mega-scale global sport events (FIFA, 2006). While the World Cup has a much larger scale in regard to attendance and attributable environmental impact compared to one AC Milan match, the methodology, data sources, and impact hotspots presented in this report and subsequent sustainability reports published by future FIFA OCs can be easily adapted to the research context of hosting a matchday at the San Siro Stadium.

The first step the OC took when conceptualizing Green Goal was to establish their scope, goals, and sphere of control in order to determine quantitative areas for environmental harm mitigation within their influence. To do this, the OC partnered with governmental & independent research organizations (The Federal Environment Ministry, Öko-Institut, and World Wildlife Fund Germany) to pinpoint specific environmental objectives to target for the 2006 FIFA World

Cup, ultimately deciding on four main scopes for the Green Goal initiative: water, waste, energy, and transport.

These four scopes have proven to be areas of repeated environmental concern when assessing the impact that a large-scale sport event has on the environment; these areas' importance is evident as they have been a continued focus in subsequent FIFA World Cup carbon footprinting reports to the present day. The baseline dataset constructed by the OC in order to measure their progress towards reaching the mitigation targets outlined in each scope was made by implementing a two-step process. First, a comprehensive measurement of total heat and electricity demand along with product quantities and transport-kilometers accrued over the course of the World Cup was collected through primary and secondary data sources. Next, greenhouse gas (GHG) emissions values specific to each activity were applied using Öko-Institut's life-cycle analysis software, GEMIS (Global Emissions Model of Integrated Systems), which takes into account all upstream activities in the creation of a specific product in order to capture a comprehensive account of the emissions associated with each step in the production process.

Transport in this report and in subsequent FIFA World Cup sustainability reports is consistently the primary contributor towards GHG emissions (See Figure 1). This is due to the fact that the FIFA World Cup attracts fans from all over the globe, necessitating air travel, which accounts for a massive amount of GHG emissions; for example, 79% of total GHG emissions for the 2006 FIFA World Cup in Germany were due to air travel (FIFA, 2006). One key research area present in this report relevant to AC Milan is intra-city transportation methods. The OC's goal of quantifying the environmental impact of different types of transport started with data collected from sources that included analysis of ticket sales, transport surveys, and data requests from local transport agencies (e.g., the German national railway company Deutsche Bahn). By collecting data that included the number of matches played, stadium capacity, and average distance traveled by transport type, the OC quantified the environmental impact of these activities by applying a GHG emission factor to each means of transport using a special model. These analyses show that, averaged throughout the tournament, around 57% of the 3.4 million spectators used city-rail, underground, trams, and public service buses for journeys to stadiums, accounting for just 1% of total GHG emissions (FIFA, 2006). By contrast, the 23% of people who chose to travel in cars accounted for 43% of total GHG emissions (FIFA, 2006). In total, intra-city transportation produced about 70,500 tons of greenhouse gasses over the course of the 2006 FIFA World Cup in Germany (FIFA, 2006).

The successful quantification of environmental impact indicators during the hosting of the 2006 FIFA World Cup initiated a legacy of environmental advocacy and understanding that has carried on and been improved upon by every subsequent OC since the inception of Green Goal. In the very next edition of the FIFA World Cup, hosted in South Africa in 2010, the South African OC partnered with the independent environmental consulting firm Econ Pöyry to continue the precedent set by the Green Goal initiative in 2006. In their feasibility study, Econ Pöyry (2009) took into account the vast differences between this host country and the previous one when calculating the estimated carbon footprint of the 2010 World Cup. The significant contribution of this study was the implementation of ISO 14064 (2018a) standards provided by the International Organization for Standardization (ISO). These internationally recognized standards provided Econ Pöyry (2009) with an organizational framework for the quantification, reporting, and verification of GHG emissions and removals. Equipped with this framework, Econ Pöyry set out to quantify the environmental impact of hosting the 2010 FIFA World Cup. They set the system boundaries to include only direct and indirect emissions within the scope of control of the OC. In the report released by the OC after the conclusion of the World Cup, results showed that intra-city transportation accounted for a total of 39,577 tons of CO_2 equivalent emissions (UNEP, 2012). The carbon footprint methodology applied by Econ Pöyry (2009) in this feasibility study establishes the ability for international standards such as the GHG accounting standards ISO 14064 and ISO 14067 (2018b) to be applied to studies quantifying GHG emissions data from large-scale sport events.

Building on the previous approaches of the 2006 FIFA World Cup in Germany and 2010 FIFA World Cup in South Africa, the 2014 FIFA World Cup in Brazil quantified the carbon footprint of the event using the international Greenhouse Gas Protocol and ISO 14064 (FIFA, 2014). The 2018 FIFA World Cup in Russia utilized the same framework as previous FIFA World Cup reports to quantify greenhouse gas emissions. The approach utilized by the 2018 World Cup in Russia separated the reporting period for emissions into two periods: the preparation period and the FIFA World Cup period. Since our objective is to quantify emissions for a single match, we focused on the emissions data collected during the FIFA World Cup (FWC) period. During the Russia FWC period, total greenhouse gas emissions were quantified separately for World Cup matches and other FWC activities, such as fan fests and banquets (FIFA, 2018). In Figure 1 and Figure 2, we synthesized available carbon emissions data from the FIFA World Cup Reports and other literature on sport events. In our synthesis of FWC data, we documented the total emissions associated with the 2018 FIFA World Cup matches separately from the total emissions of the entire 2018 FIFA World Cup in Russia. In the creation of Figures 1 and 2, we eliminated emissions categories that were not within our project boundaries and/or relevant to activities associated with a single soccer match at San Siro Stadium. Since international and inter-city transportation accounted for a majority of each FWC emissions total, we eliminated these factors to understand the relative contribution of other source categories. Additionally, we removed emissions associated with accommodation, venue, facility construction, refrigerant leakage, and logistics. Since our research question aims to estimate emissions associated with a single soccer match, these source categories are not relevant. Using tons of CO_2e, new percentages were calculated to represent the updated relative contributions of each category to further aid in the identification of environmental impact hotspots.

Figure 1

Carbon Emission Data from Existing Literature on Sport Events

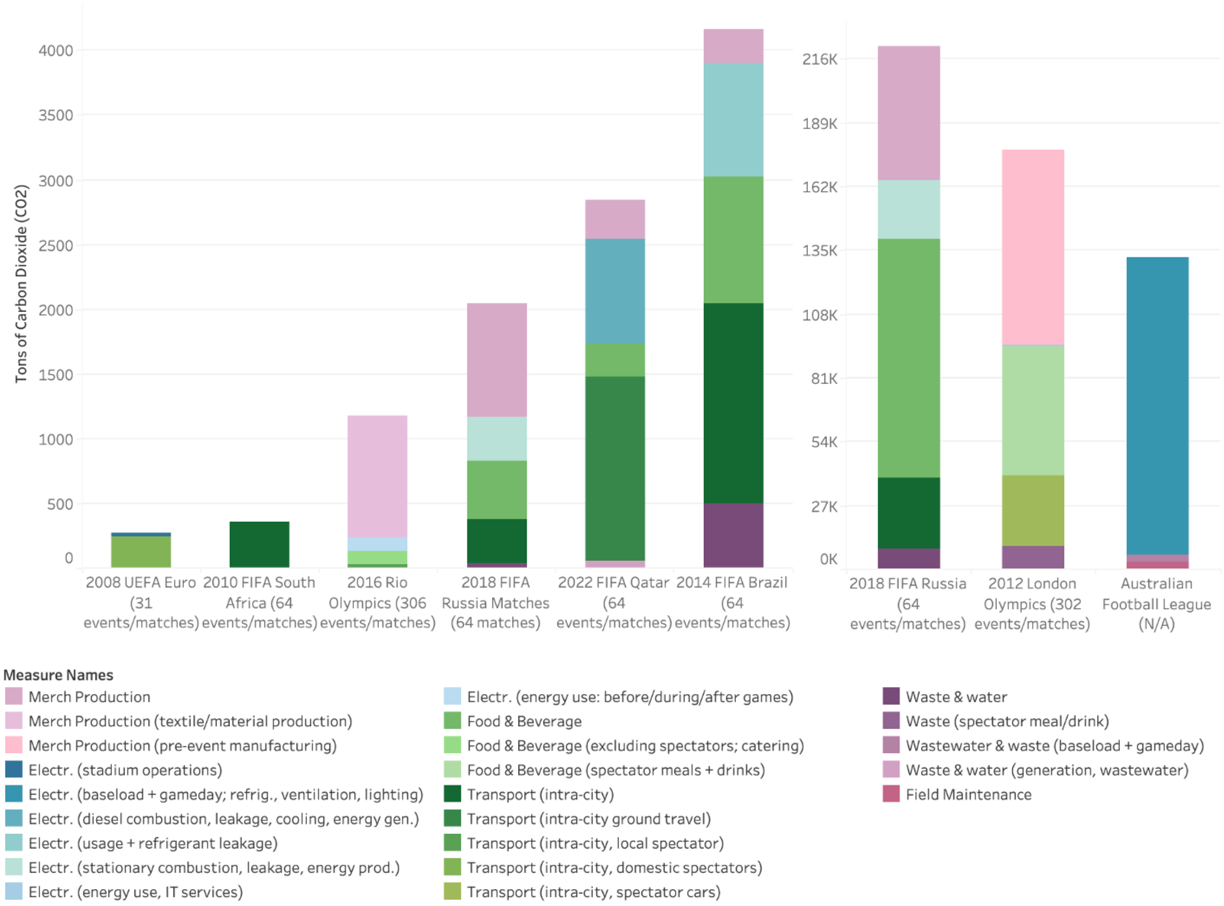
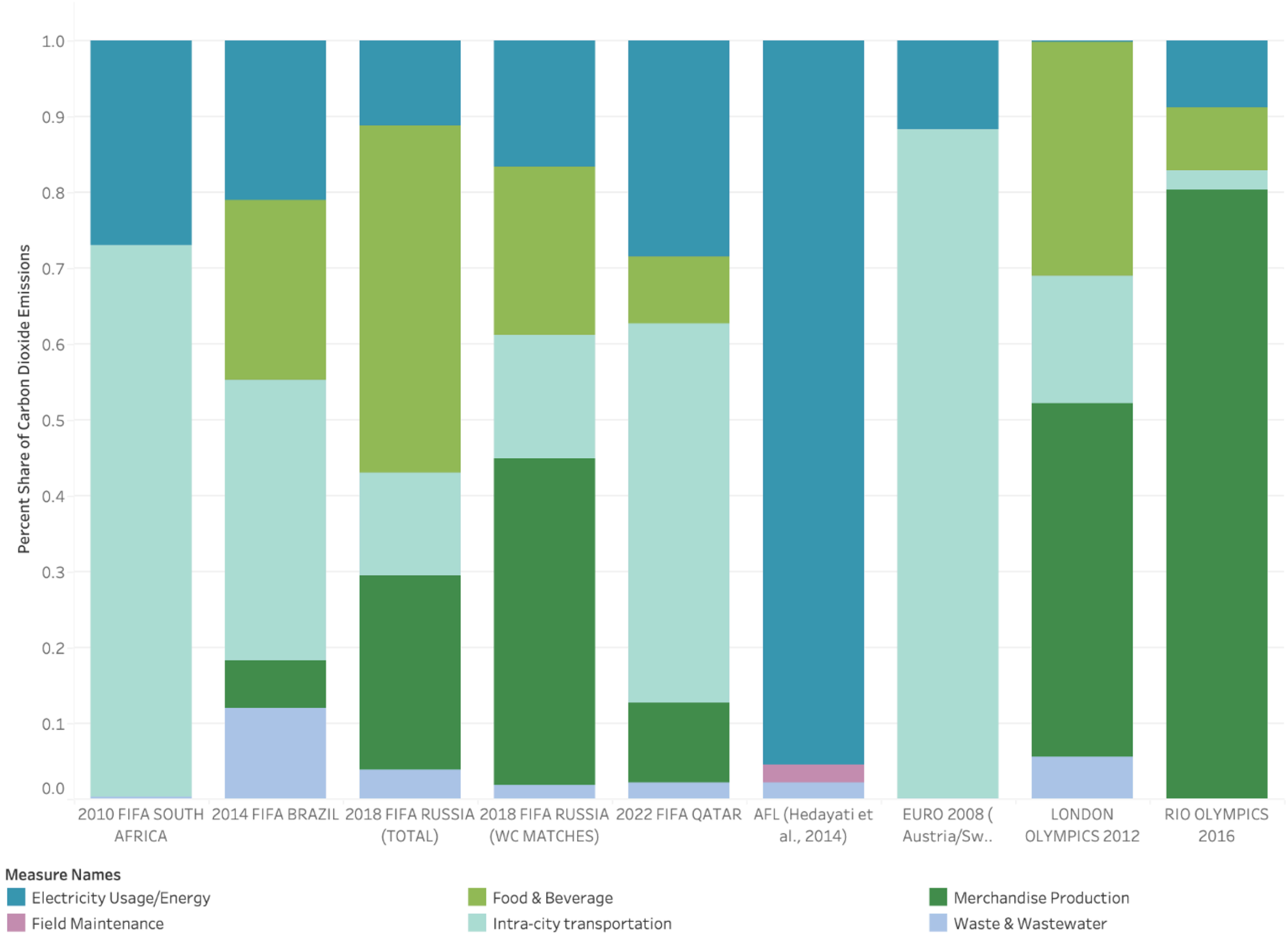


Figure 2

Carbon Emission Data from Existing Literature on Sport Events, Normalized by Percent Share



Unit Process-Based LCA — University of British Columbia, Australian Football League

The most recent studies in this field have all converged on LCA as the most comprehensive methodology to quantify the environmental impact of large-scale sport events. Specifically employing a unit process-based LCA, this methodology is considered a bottom-up approach that provides the most detailed understanding of each individual unit process going into matchday activities (Dolf, 2017). Given this, the potential for unit process-based LCA to cover the scope and scale of the environmental impact of a matchday at AC Milan's San Siro Stadium is highly promising. In accordance with ISO 14044 (2006), this LCA standard consists of four iterative phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. These four stages serve to inform both decision-making and further data collection, and together have been employed by the following studies to quantify the environmental impact of sport events of various scales.

The first relevant study to conduct a comprehensive unit process-based LCA was carried out by Dolf (2012) in his exhaustive LCA of each of the athletic facilities that host sporting events on the University of British Columbia (UBC) campus. Although the scale of this study is much smaller compared to AC Milan's context (spectator capacity of UBC's soccer venue is 300), the LCA methodology can be easily adapted to the San Siro Stadium. The LCA employed by Dolf (2012) utilized environmental impact data factors from existing LCA databases, studies, and other reports in order to quantify the total impact of the activities that occur both from the UBC soccer field and their team. These processes were categorized into specific hotspots which included travel, waste, and electricity use. The primary and secondary data collected for this study was analyzed using Quantis to quantify the environmental impact of each activity. While the results of this study are not applicable to the San Siro Stadium's potential environmental impact, the methodology used in this study may be adapted to our research question.

A subsequent unit process-based LCA study was conducted by Hedayati et al. (2014) assessing the GHG emissions and environmental impact of events at the 27,500 person capacity Heritage Bank Stadium, an Australian rules football stadium that hosts a variety of large-scale events. Following the LCA process established by ISO 14044, Hedayati et al. (2014) established their functional unit of "the provision of entertainment services for attendance of one person at one AFL (Australian Football League) event in a stadium with a capacity between 20,000 and 30,000 people." The system boundaries took into account electricity, natural gas, water, and waste. Additionally, Hedayati et al. (2014) took into account the different environmental impact of daytime versus evening events, the latter of which were found to have an increase in electricity consumption. The results of this LCA found that the average impact of one individual at each event is 14.74 kilograms CO_2 equivalent, amounting to approximately 405,000 total kilograms CO_2 equivalent emissions for a single matchday when considering the capacity of the stadium (Hedayati et al., 2014).

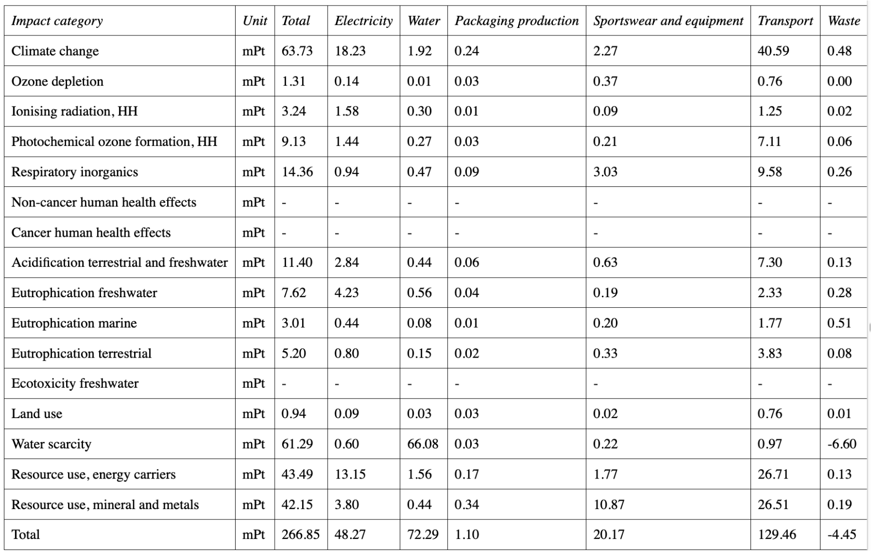
Unit Process-Based LCA — "Sustainable Football"

The book "Sustainable Football: Environmental Management in Practice" (2021) by Luca Marrucci, Tiberio Daddi, and Fabio Iraldo includes a unit process-based LCA of 31 grassroots soccer organizations across eight European countries. While the scale of a "grassroots" or amateur soccer match is much smaller than the scale of an AC Milan home match, the study still presents meaningful data, as the functional unit and system boundaries used are very similar to our selected assessment parameters. The functional unit of this study was one match played. The system boundaries for the study were: energy and water consumption associated with the soccer match processes (i.e., irrigation of the pitch, lighting, showers of the players, heating of the locker rooms); production and end-of-life of the apparel and equipment (i.e., sport leather shoes, T-shirts, shorts, sports suits, balls, sports bags, goalkeeper pants, etc.); production and end-of-life of waste materials associated with the soccer match, and related production of the corresponding materials (i.e., paper, plastic, glass, metal, household waste, plus wastewater treatment); transport of the players to the soccer pitch (home team and away team); and transport of the public attending the soccer match (home team and away team) (Marucci et al., 2021)

Data was collected through questionnaires distributed to each team. In cases where data was omitted by a team, national averages were used instead. The study used the PEF (Environmental Performance Indicators) default list to choose environmental impact categories relating to emissions into the air, emissions into water, consumption of natural resources, toxicity, and land use. After the life-cycle assessment was completed, the results were weighted to select the most relevant impact categories, and each single score was expressed in eco-points (Table 1).

Table 1

Weighted and Normalized Results of PEF (single score)



Impact category	*Unit*	*Total*	*Electricity*	*Water*	*Packaging production*	*Sportswear and equipment*	*Transport*	*Waste*
Climate change	mPt	63.73	18.23	1.92	0.24	2.27	40.59	0.48
Ozone depletion	mPt	1.31	0.14	0.01	0.03	0.37	0.76	0.00
Ionising radiation, HH	mPt	3.24	1.58	0.30	0.01	0.09	1.25	0.02
Photochemical ozone formation, HH	mPt	9.13	1.44	0.27	0.03	0.21	7.11	0.06
Respiratory inorganics	mPt	14.36	0.94	0.47	0.09	3.03	9.58	0.26
Non-cancer human health effects	mPt	-	-	-	-	-	-	-
Cancer human health effects	mPt	-	-	-	-	-	-	-
Acidification terrestrial and freshwater	mPt	11.40	2.84	0.44	0.06	0.63	7.30	0.13
Eutrophication freshwater	mPt	7.62	4.23	0.56	0.04	0.19	2.33	0.28
Eutrophication marine	mPt	3.01	0.44	0.08	0.01	0.20	1.77	0.51
Eutrophication terrestrial	mPt	5.20	0.80	0.15	0.02	0.33	3.83	0.08
Ecotoxicity freshwater	mPt	-	-	-	-	-	-	-
Land use	mPt	0.94	0.09	0.03	0.03	0.02	0.76	0.01
Water scarcity	mPt	61.29	0.60	66.08	0.03	0.22	0.97	-6.60
Resource use, energy carriers	mPt	43.49	13.15	1.56	0.17	1.77	26.71	0.13
Resource use, mineral and metals	mPt	42.15	3.80	0.44	0.34	10.87	26.51	0.19
Total	mPt	266.85	48.27	72.29	1.10	20.17	129.46	-4.45

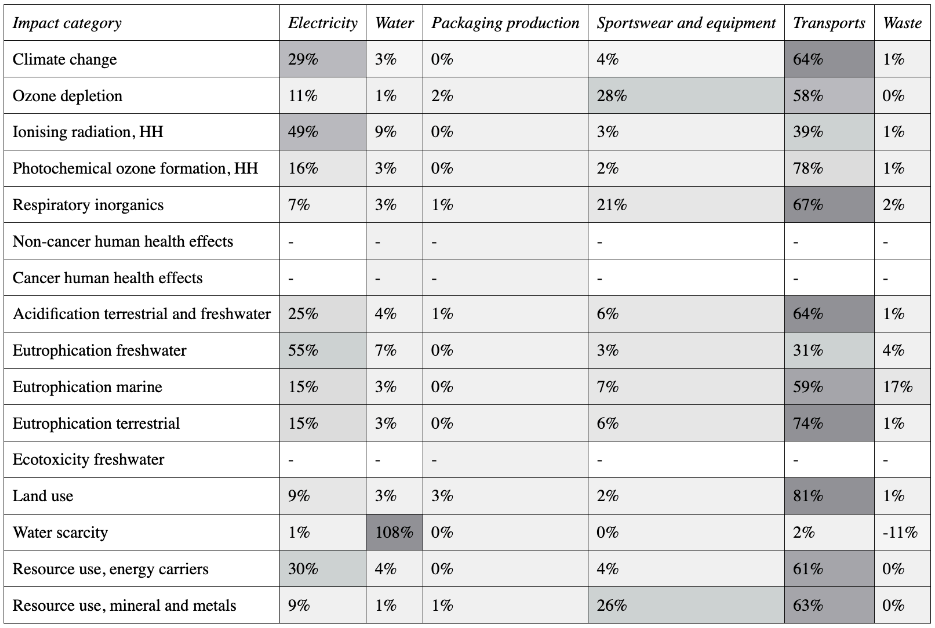
Based on these results, the four categories with the greatest impacts were:

1. Climate change
2. Water scarcity
3. Resource use (energy carriers)
4. Resource use (minerals and metals)

Next, the data was weighted by impact category so that each impact had a total of 100%, split between the six sectors of electricity, water, packaging production, sportswear and equipment, transports, and waste (Table 2).

Table 2

Weighted Results of PEF (life cycle phases contribution) - 16 Impact Categories

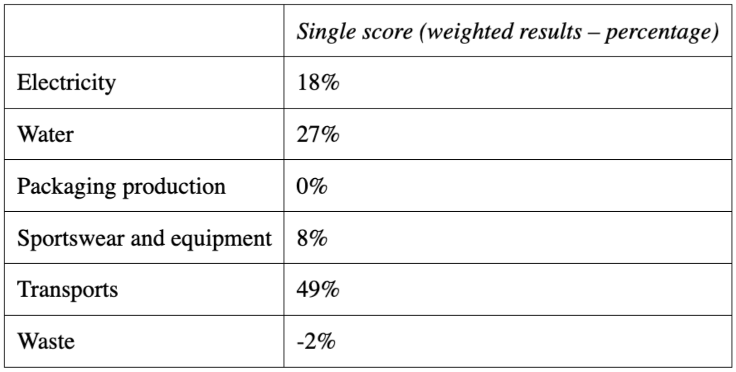


Impact category	*Electricity*	*Water*	*Packaging production*	*Sportswear and equipment*	*Transports*	*Waste*
Climate change	29%	3%	0%	4%	64%	1%
Ozone depletion	11%	1%	2%	28%	58%	0%
Ionising radiation, HH	49%	9%	0%	3%	39%	1%
Photochemical ozone formation, HH	16%	3%	0%	2%	78%	1%
Respiratory inorganics	7%	3%	1%	21%	67%	2%
Non-cancer human health effects	-	-	-	-	-	-
Cancer human health effects	-	-	-	-	-	-
Acidification terrestrial and freshwater	25%	4%	1%	6%	64%	1%
Eutrophication freshwater	55%	7%	0%	3%	31%	4%
Eutrophication marine	15%	3%	0%	7%	59%	17%
Eutrophication terrestrial	15%	3%	0%	6%	74%	1%
Ecotoxicity freshwater	-	-	-	-	-	-
Land use	9%	3%	3%	2%	81%	1%
Water scarcity	1%	108%	0%	0%	2%	-11%
Resource use, energy carriers	30%	4%	0%	4%	61%	0%
Resource use, mineral and metals	9%	1%	1%	26%	63%	0%

Finally, each sector was given a single weighted percentage score based on their total environmental impact across all categories (see Table 3 below).

Table 3

Weighted Results of PEF (life-cycle phases contribution) - single score



	Single score (weighted results – percentage)
Electricity	18%
Water	27%
Packaging production	0%
Sportswear and equipment	8%
Transports	49%
Waste	-2%

These results are consistent with the other results from our literature review, with transportation having the largest environmental impact. In this study, transportation accounted for almost half of the total environmental impact of a single soccer match, making up 66% of the impact of climate change, 81% of land use, 61% of resource use (energy carriers), and 63% of resource use (minerals and metals); therefore, transportation was found to be the greatest contributor to 3 of the 4 largest impact categories mentioned above (Marucci et al., 2021). However, it is important to note that in most cases, including AC Milan, transportation is out of the organization’s control. Water was the second largest contributor, making up 27% of the total environmental impact, while only having a considerable contribution to the water scarcity impact category (108%) (Marucci et al., 2021). Electricity was the next greatest contributor, making up 18% of the total environmental impact, with large contributions to climate change (29%), ionizing radiation (49%), freshwater eutrophication (55%), and resource use (energy carriers) (30%) (Marucci et al., 2021). Sportswear and equipment were responsible for 8% of the total environmental impact, and packaging production and waste had negligible impacts compared to the other sectors measured (Marucci et al., 2021). As mentioned previously, one limitation of this study is the size of a single “grassroots” match being much smaller than a single AC Milan Serie A match; however, this LCA and the data produced still provides a helpful framework for our project, as we can use the functional unit, system boundaries, and the results to help formulate our life-cycle assessment to target different aspects of a single soccer match that we will expect to have the greatest environmental impacts.

Although there have been a number of applicable and useful case studies and papers conducting life cycle assessments on sports matches, there has not been a study comparable to the life cycle assessment conducted at a club level. As seen in prior paragraphs, there have been sport game life cycle assessments conducted at varying scales, ranging from smaller mini series matches (Marucci et al., 2021) to large, global scale soccer matches at the FIFA World Cup. Both scales utilize widely different parameters compared to what AC Milan would use. Thus, our current life cycle analysis can contribute to sports event database knowledge, and fill in data gaps, as there has not been a study conducted at this scale on a professional club sports level. Thus, our report builds a hypothetical baseline of the carbon footprint of a single soccer match at a stadium loosely resembling San Siro Stadium. As interest and importance in life cycle assessment and corporate sustainability grows, this study can provide crucial insights into a new scale of club sports, and can act as a baseline and example for future life cycle assessments of other club sports.

Methodology

I. General LCA Methodology

For this project, we decide to utilize a lifecycle approach for all of our calculations. An LCA is a systematic method used to evaluate the environmental impacts associated with all stages of a product's life, from raw material extraction through production, use, and disposal. Thus, the first step for our project is determining a specific functional unit and scope to define the system boundaries of our LCA. Our functional unit is one match played at a stadium similar in scale to AC Milan's San Siro Stadium. The scope of our project includes six different sectors that contribute to a matchday's carbon footprint: intra-city transportation, electricity, heating, food and beverage, merchandising, and lighting for field growth (referred to simply as "Field" in this report).

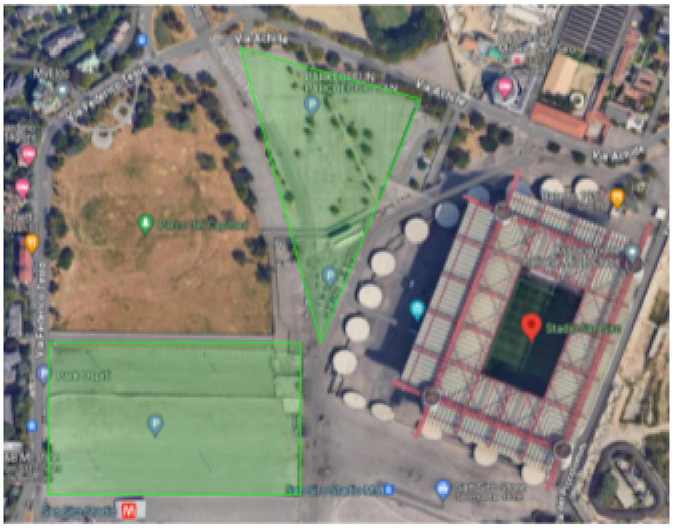
Each sector requires an inventory analysis, impact assessment, and interpretation. An inventory analysis includes a compilation of all materials or activities that are associated with the specific sector being examined. Once a compilation of all materials and activities is complete, an impact analysis can be conducted to determine the total tons of CO_2 equivalent that are associated with all matchday materials and activities. This impact analysis includes a compilation of knowledge from foreground and background data. Depending on the sector, certain statistics were provided by the clients and could be utilized as data. For the sector parts that are not as clearly defined, data from the literature is utilized and scaled to a single soccer match in order to provide a meaningful statistical analysis. Finally, after calculating the total tons of CO_2e released for each sector, we can interpret the results and use them to determine the most sustainable course of action for future soccer matches. This is largely done through sensitivity analysis where specific materials or activities are reduced by a certain percentage in order to understand their individual impact on the total matchday emissions per sector. In this report we focus only on the greenhouse gas emissions and use the terms "carbon emissions" and "greenhouse gas emissions" interchangeably. We will discuss the individual methodology for each of the chosen sectors in the following sections.

II. Transportation

For this sector, the goal is to determine the share of carbon dioxide emissions resulting from transportation to San Siro Stadium, and to assess the relative contribution of different modes of transportation. This sub-sector accounts for emissions from spectator transportation, and includes transportation by car, urban rail, bus, and train. Only spectator travel is considered in this report because we found that it accounted for the largest share of the transportation emissions total. We do not assess transportation by air travel. For the transportation sector, the standardized unit for each emission factor is kilograms of carbon dioxide equivalent produced per passenger kilometer. In order to determine the emission factors for each mode of transportation, an analysis of existing literature on transportation LCA's was conducted to identify what emission values were commonly used. Our analysis focused on emission values for modes of transportation in Italy specifically, and then was expanded to Europe in general; we further expanded to global emission factors depending on data availability and quality.

As previously established, the functional unit of this life cycle assessment is a single match played at San Siro Stadium. The capacity of San Siro is 85,000, with an average attendance of 70,000. The average distance traveled by spectators, to and from the match, is assumed to be 20 kilometers. This value is based on the fact that Milan city's longest span is 15 km. This estimate implicitly assumes that the majority of fans are local and does not account for fans traveling from outside of Milan, an assumption that might be worth questioning. A survey conducted by another research team with a different focus included questions regarding the respondents' mode of transportation and distance traveled. This survey indicated greater distances; however, the respondents were exclusively members of the 'fan club' of AC Milan and are unlikely to be a representative sample of stadium attendees. We recommend that a survey should be conducted at the stadium during a matchday to help refine these estimates of travel behavior.

Anecdotal evidence supports the assumption that many spectators take public transportation. The availability of public parking at San Siro Stadium is relatively low compared to the proximity of public transport around the stadium. A look at satellite imagery shows the massive size difference between public parking at San Siro Stadium, and that of the similarly sized SoFi Stadium in Los Angeles. The survey, conducted by the UCLA Practicum team, revealed that around 60% of spectators traveled by car; however, as previously mentioned, the survey was not a representative sample of spectators traveling to San Siro because the respondents were considered to be "super fans" and were not randomly sampled. In order to reconcile the differences in the number of spectators traveling by different modes of transportation, we assume a larger share, around 70%, of spectators would travel by public transportation. Based on these assumptions of travel behavior, we account for 30% of spectators traveling by car, 40% by urban rail, 20% by bus, and 10% by train. Based on analyses of



matchday mobility, we find that the average number of passengers per vehicle is 2.5 for sport events. The final value for number of spectators traveling by car accounts for 30% of the average attendance and an average occupancy of 2.5, significantly reducing the number of vehicles we account for in the emissions total.

The impact of each mode of transportation is determined based on values from EcoInvent and existing literature. The emission factors for car, bus, and train are determined based on values from EcoInvent 3.9, using the impact method, ReCiPe 2016 v1.03, midpoint (H) and a physical allocation method with no cutoffs. We utilized the climate change impact category to determine the global warming potential for each mode of transportation in kilograms of carbon dioxide equivalent (CO_2e). For transportation by passenger cars, the emission factor is based on the market for transportation in Europe and was determined to be 0.364291 kg of CO_2e per kilometer. This emission factor was not represented in terms of passenger kilometers. However, our methodology for passenger cars accounts for the distance traveled by each passenger and the emission value was normalized to passenger-kilometers based on the share of spectators traveling by car, and the average occupancy of a vehicle. For transportation by passenger train, the emission factor is based on Italy. It was determined to be 0.047726 kg of CO_2e per passenger-kilometer. For transportation by regular bus, the emission factor is based on the global market for transportation. It was determined to be 0.120756 kg of CO_2e per passenger kilometer. For transportation by urban rail, the emission factor is based on data from the International Energy Agency (IEA) on the well-to-wheel greenhouse gas intensity of motorized passenger transport modes in 2022. The value was determined using the average intensity of regular buses, and was found to be 0.04921 kg CO_2e per passenger kilometer. This emission factor value is supported by the findings of a predictive LCA of a heavy metro train that will operate in the urban area of Rome. In this assessment, the global warming potential for the heavy rail was 10.4 kg of CO_2e per kilometer traveled. An assessment of the Brussels metro, used by Del Pero et al., indicated that the average capacity of a rail car was 223 passengers. Combining assessments of the metro train in Rome and the metro train in Brussels, the emission factor was determined to be 0.0466 kg CO_2e per passenger kilometer. The difference between this emission factor value and the emission factor from the International Energy Agency is 0.00261 kg CO_2e per passenger kilometer, suggesting that the value calculated by the IEA is somewhat representative of urban rail travel in Italy.

We address sensitivity around our estimated emissions number by altering the percentage of spectators traveling by passenger car to San Siro Stadium. Our baseline assumption is that 30% of spectators traveled by passenger car on matchdays. In our sensitivity assessment we vary the percentage of spectators traveling by car by steps of 5, with a range from 50% to 10%. For each scenario, we determine the change in the percentage of car emissions in the transportation sector emissions total and the change in the percent share of transportation in the total match emissions. As the percentage of spectators traveling by car is changed, the difference in percentage is spread evenly across the other modes of transportation. All other values remained unchanged in this sensitivity analysis. We did not conduct sensitivity analysis for emission factors or distance traveled. The results of transportation sector emissions could be strengthened by undertaking this type of analysis.

III. Field

For this sector, the goal is to quantify the share of environmental impact attributed to the model stadium's grass playing field. The LCA method employed for this task aims to sum the greenhouse gas emissions from the manufacturing, use, and disposal stages of a standardized unit of the grass field. In this case, the standardized unit measured against the emissions factor is 1 square meter of grass playing field. The emissions factor used in the calculations is the same as the other sectors: metric tons of CO_2 equivalent (tons CO_2e). The scope of this sector includes the production stage of each square meter of grass playing field as well as the lighting needed to maintain the surface throughout the season. The production stage encompasses the raw material supply, transportation of raw materials to a factory, and the manufacturing of the final product.

The model stadium's total field size is assumed to be 7,140 square meters (105 meters long, 68 meters wide) with a total of 54 soccer matches being played on it over the course of one full season. It is also critical to note the type of grass field being considered in this calculation, as professional sports fields are typically equipped with fully natural, artificial, or hybrid turf. The model stadium's playing field in this study is hybrid turf, specifically a surface made of seeded natural grass reinforced by polypropylene artificial grass fibers.

Given this preliminary data for the dimensions and playing surface type used in the model stadium, an estimate of emissions is calculated using the standardized unit of 1 square meter of hybrid grass. The background emissions data necessary for this calculation is acquired from an environmental product declaration (EPD) published by artificial grass manufacturer Hatko (2023) in collaboration with EPD Turkey and in accordance with LCA and EPD processes established by ISO standards 14040:2021, 14044: 2021, 14025:2006, and 14020:2000. According to this EPD, the total emissions attributed to the supply of raw material, transport, and manufacturing of 1 square meter of hybrid grass is 0.00315 tons CO_2e.

A final emissions estimate can be calculated taking into account the halogen lighting structure used for grass growth as well as the dimensions and extent of use of the model stadium. The background data used for consideration of the halogen lighting system in the final emissions calculation is acquired from an LCA carried out by the U.S. Department of Energy (2012). This LCA compared the kg CO_2e emitted between different lamp types, including halogen (incandescent) and LED lamps. At the same light intensity and over the same length of time, LEDs were found to emit nearly a tenth of the kg CO_2e compared to halogen lights.

To account for any possible uncertainties in the background data we gathered, we performed a sensitivity analysis on the estimate for the per match metric tons CO_2e emissions that arise from using the playing field's growth lighting systems. This sensitivity also doubles as an emission reduction scenario that could be feasibly achieved by switching to more electrically and thermally efficient grass grow lighting systems. These scenarios are calculated by altering the magnitude of metric tons CO_2e emitted per match by varying percentages in both negative and positive directions from the baseline, which represents the final emissions estimate calculated in this sector. This analysis also allows us to examine the impact that making changes to the efficiency of field maintenance systems has on the total metric tons CO_2e emitted per match across all sectors of the model stadium.

Due to a lack of available data pertaining to the use and end-of-life stages for a hybrid grass playing field, the final calculation for this sector can be considered the low-range estimate of emissions from the grass playing field. However, the end-of-life stage for the playing field can be disregarded as the scope of this study is limited to the emissions occurring during a single match.

IV. Electricity & Heating

The goal for these two sectors is to determine the share of matchday carbon emissions resulting from electricity and heating consumption at a large-scale stadium similar to AC Milan's San Siro Stadium. The matchday emissions for both sectors are assumed to only be attributable to any matchday activities that use electricity or heating within the stadium itself, so any areas outside of the stadium that may use additional energy on matchdays (such as the parking lot) are excluded from the system boundary. The standardized unit for the electricity and natural gas emission factors used for the electricity and heating sectors is kilograms of carbon dioxide equivalent (kg CO_2e) produced per kilowatt-hour (kWh).

All calculations done for the electricity and heating sectors' baseline emissions estimates utilize San Siro's average attendance of 70,000 spectators as a rough estimate for the capacity of the model stadium. The roof size of San Siro is used as an approximation for the model stadium as well since the electricity and heating estimate values taken from the literature are given as per square meter values; the roof size is assumed to be approximately 40,000 m^2 (Structurae, n.d.). Only the AC Milan electricity and heating burden is considered when calculating the annual energy consumption of the model stadium; since AC Milan plays 19 matches during its regular season and 8 matches during its non-regular season, it can be determined that a single year's electricity and heating consumption is equal to the total electricity and heating consumption of 27 matches. We rely on the Smulders (2012) source for estimation of emissions in these sectors since it provides an activity wise breakdown of the emissions for annual heating and electricity consumption in a stadium. Based on anecdotal evidence, the same breakdown is assumed for the model stadium.

Annual electricity and heating estimate values used for creating the baseline model are taken from a report by Smulders (2012), which discussed case studies of 5 different stadiums' annual energy use and gave a breakdown of activities that contribute to a stadium's yearly energy use (along with the relative proportions of each activity's contribution based on data from Sleegers (2009)). Our research revealed multiple other relevant sources that provided useful information for electricity and heating consumption at stadiums (Alcade, 2007; Hedayati et al., 2014; Murray, 2021). However, the stadium specific parameters and scope of activities in these sources didn’t match our model stadium and were thus not useful for the final calculations in this study. For the electricity sector, Allianz Arena serves as a reference stadium since its capacity of 69,000 is the closest in size to our model stadium; Allianz Arena’s estimated annual electricity consumption is 0.179 MWh/m^2/year (Smulders, 2012). For the heating sector, Commerzbank Arena is chosen as the reference stadium since its location in Frankfurt, Germany makes its average annual climate the most similar to that of our model stadium; Commerzbank Arena’s estimated annual heating consumption is 0.126 MWh/m^2/year (Smulders, 2012). Based on the information given in the study, per matchday energy usage is calculated by assuming that roughly 20% of a stadium’s yearly energy usage is associated with matchday activities (Smulders, 2012).

The emission factor used for all electricity sector calculations is 0.2679 kg CO_2e/kWh (ISPRA, 2023). This value is representative of Italy’s national electrical grid. The heating sector calculations used the same factor for the electrical portion and a factor of 0.202 kg CO_2e/kWh for the natural gas portion, which represents an average emissions factor for natural gas production across the entire European Union (Bastos et al., 2024b).

We examine reduction scenarios and address sensitivity around several key factors for the heating and electricity sectors by performing separate sensitivity analyses. These factors include the 20% event energy usage assumption, electricity emissions factor, air conditioning systems emissions, natural gas emissions factor, and space heating emissions. An additional sensitivity analysis is done to examine reduction scenarios for the combined impacts of decreasing the electricity emissions factor and air conditioning systems emissions.

V. Food & Beverage

The food and beverage analysis of a stadium similar in size to San Siro began with a literature analysis of both stadium food systems in the US and EU, and a carbon footprint analysis of individual food and beverage offerings in such stadiums. We created a baseline model with a carbon footprint calculator based on the menu items offered at stadiums similar to that of San Siro and large scale sporting events, including the London 2012 Olympics (LOCOG, 2010). We also created a secondary model that analyzes the greenhouse gas emissions of restaurants comparable in size and scope to the lounge dining options at stadiums similar in size to San Siro.

There is currently no complete comprehensive analysis of food and beverage consumption at a stadium similar in scale to San Siro Stadium. Similarly, there is a limitation of literature and studies conducted in Italy, and our research includes additional US and EU data to provide information where otherwise unavailable. The greenhouse gas emissions values of individual food and beverage items are consistently debated in the scientific community, and thus our analysis is based on current estimates in both the US and EU. The baseline food and beverage emissions estimates include emissions from production, transportation, cooking (where applicable) and packaging. Baseline emissions numbers are sourced from reputable carbon footprint calculator databases, academic research, and previous carbon footprint studies (Espinoza-Orias & Azapagic, 2018; FoodFootPrint; Poore, J. & Nemecek, T., 2018). In the case of uncertainty and discrepancy in study results, averages are calculated based on the most recent and reputable data. To account for regional differences in food and beverage items due to sourcing, production, and transportation methods, emphasis is placed on studies in Italy and the EU.

Our current carbon footprint baseline is created using secondary data from comparable sized restaurants and individual greenhouse gas emissions of food offerings. These estimations are based on the current survey percentage of fans who always consume food and/or beverages at a stadium event. These estimates stand at 27% of fans always purchasing food and 34% of fans always purchasing a beverage (Oracle Food and Beverage, 2019). With these standardized consumption figures, we evaluate the emissions impact of food offerings (excluding lounges) at a model stadium given the number of attendees. Sensitivity analyses are conducted to account for uncertainty in our data as well. In order to estimate food and beverage emissions from stadium lounges, we treat lounge operations as a separate variable, comparable to that of restaurants.

The baseline catering system that has been chosen to model a lounge and average meal served in a lounge is located in northern Italy, specifically in the Lombardy region. The baseline catering service serves around 6,900 meals per day and serves mostly primary and secondary schools. Accounting for various factors like transportation of food, food storage and cooking, and food processing, an average meal served by the catering service had a carbon footprint of 4.1 kg CO_2e. Total carbon emissions for lounges are then calculated by multiplying the average carbon footprint of a meal served by the total number of visitors estimated to visit the stadium on a matchday. This overall strategy assumes that the average carbon footprint for a meal served is comparable to a meal served at a lounge during a matchday. However, both catering services may have varied food ingredients, cooking equipment, and portion sizes. Thus, the carbon footprint of lounges may be an overestimation or underestimation of the actual footprint, but provides a comprehensive and holistic understanding of carbon emissions nonetheless. The total carbon footprint for lounges is then added to the carbon footprint generated by food stalls to obtain the total carbon footprint of the food and beverage sector.

To calculate the greenhouse gas emissions generated by the stadium lounges, an extensive literature research was conducted. The calculations of the greenhouse gas emissions of the stadium lounges are based on primary data, secondary data, and prior studies. Based on primary data, it is assumed that there are a range of 2,800 to 3,500 visitors who are served in lounges on an average matchday. Utilizing primary data, lounges at a stadium adjacent to San Siro's system are assumed to use a catering business and system to deliver and serve food.

After creating our baseline model for estimated carbon emissions, we conducted a sensitivity analysis to address uncertainty and variability in our findings. Variability and uncertainty arose from the estimation of visitors that would visit food lounges, as primary data gave us a fairly wide range of food lounge attendees. Additionally, there was uncertainty associated with the subsectors of agricultural production, operation of canteen, processing food items, transport of food from the canteen, and packaging. More specifically, there is uncertainty within transportation of food, as carbon emission results can vary depending on what truck type and form of transportation is used. As seen in prior studies, trucking emissions can vary from 57-307 g CO_2/t-km in the wider European region (Ragon, 2021), and the data provided by the secondary source had a transportation emissions of 147 kg CO_2/t-km. Although the baseline trucking emission fits within the overall range of trucking emissions, there is much variability within the range; this variability can affect the overall food lounge baseline carbon footprint estimation depending on the different styles and configurations of the trucks.

From our baseline, we address sensitivity around our estimated emissions numbers and consumption variables. A sensitivity analysis is conducted separately for both food stalls and stadium lounges, as both are calculated with different methodologies. The baseline model assumption of stadium visitors is altered by 10%, -10%, -20%, and -30% to include the lower boundary of visitors provided by the primary source. Similarly, the baseline model value of an average meal served by the catering service is broken down into its various components of agricultural production, operation of canteen, processing food items, transportation of food from canteen, and packaging. The agricultural production sector contributes to 58% of the carbon footprint of a catered meal, operation of canteen comprises 24% of the entire footprint, processing food items contribute 8%, transportation from farm to canteen is 6%, and packaging consists of 4% of the catered meal footprint. Because the agricultural production sector comprises such a large fraction of the catered meal footprint, the agricultural production component is altered by 30%, 20%, 10%, -10%, and -20% in the sensitivity analysis.

VI. Merchandise

The calculation of environmental impact of merchandise sold during a match at a stadium of similar size to San Siro Stadium begins with a literature review of preexisting LCAs of typical clothing items. Merchandise items assumed to be popular selling items are selected from the AC Milan Store web page. The merchandise items selected are polyester jersey, polyester shorts, cotton hoodie, cotton t-shirt, cotton sweatpants, and cap. A literature review is conducted to find life cycle analysis data for each item, specifically the global warming potential or kg CO_2e produced from the production of one unit. When available, the use stage of the life cycle is omitted, as the use phase is not a responsibility of the team, but of the consumer. Once a number of kg CO_2e is obtained for each item, a model is created to simulate the total carbon footprint from merchandise sold at a typical home match. In a data request from AC Milan, it was determined that, on average, about 1.5% of fans purchase merchandise in the stadium during a match. Supposing that the average attendance of a home soccer match in a stadium of similar size to San Siro is 70,000 fans, it is assumed that 1,050 units of merchandise are sold each match in the baseline model. With no other data to build the model, this number is divided evenly by each of the six merchandise items included in the model, resulting in 175 units of each merchandise type. This value is multiplied by the LCA carbon emissions of each corresponding item to provide an estimate of the total CO_2e emissions produced for each of the item types.

Once the model has produced a total kg CO_2e sum for the merchandise sector, this emissions value is included in the sum of all sectors to determine the percentage of total emissions associated with merchandise sales. Additionally, several scenarios and sensitivities are conducted. The use of recycled polyester and cotton are considered in 4 different scenarios. For each scenario, the model is updated by reducing the previous kg CO_2e value by an amount found in pre-existing LCAs of these recycled materials. The model then produces a new total for each scenario, which is used to determine reduction in kg CO_2e for merchandise, reduction in total kg CO_2e of all sectors, and percent change in total kg CO_2e for all sectors. For sensitivity analysis, base values of kg CO_2e are returned to the model for each merchandise item. The base model assumption of 1.5% fans in attendance is manipulated by -20%, -10%, 10%, and 20%. Similarly to the scenarios mentioned above, these new CO_2e totals for the merchandise sector are used to determine change in kg CO_2e for merchandise, change in total kg CO_2e of all sectors, and percent change in total kg CO_2e for all sectors.

Results and Discussion

This section summarizes the findings of our life cycle assessment. The results are presented in the following seven sections: baseline, transportation, electricity, heating, food & beverage, merchandise, and field maintenance. The findings contain a breakdown of emissions from different activities within each sector, identifying major sources of CO_2 emissions. In addition, we perform sensitivity analyses to understand the variability in emissions, address uncertainty in our data and model assumptions, and to examine the impact of alternative mitigation techniques. The sections on individual sectors include a discussion of emission hotspots within that sector i.e. the most important contributing activities. They also include discussion on emission reduction strategies for that sector which is supported by scenario analysis.

I. Baseline Scenarios

In this section, we present the results from the baseline model[1]. We find that the total lifecycle carbon emissions per soccer match are 214 metric tons of CO_2e, distributed across various sectors. As shown in Figure 3, transportation and food and beverage sectors account for the largest shares of total march emissions, with the transportation sector accounting for 60.3% of and the food & beverage sector accounting for 23.4% respectively. After these two, merchandise, electricity, and heating were the next largest sectors, lastly followed by field operations as the lowest contributor. In existing literature reviewed earlier, transportation and food and beverage sectors generally account for larger shares of the emissions total, which is consistent with our findings here. Heating, electricity, and merchandise are the other sectors that are large contributors in literature as well, however, our percent shares for these sectors appear to be on the lower end of the spectrum. Combined, merchandise, heating, electricity, and field sectors make up 16.3% of the total matchday emissions, while food makes up 23.4% and transportation makes 60.3%. This disparity can be described by variability in the case studies as well differences and limitations in the underlying data. More research is needed to get a better understanding of the relative proportions of these sectors.

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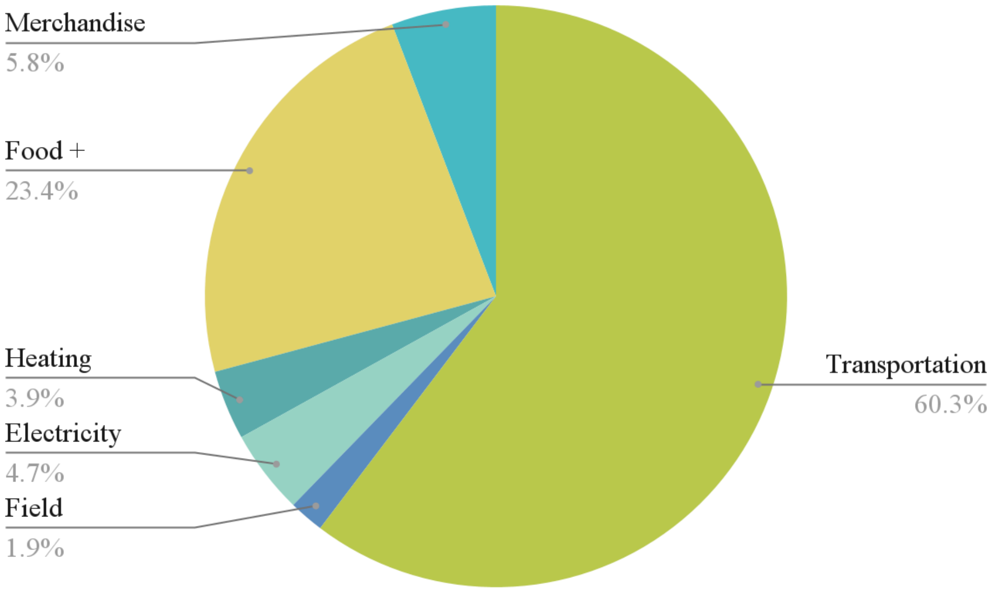
[1] As discussed in the methodology, our baseline model is loosely based on an AC Milan soccer match being played at San Siro Stadium in Milan, Italy. However, it shouldn't be considered an accurate representation of it and thus this analysis is not an accurate representation of AC Milan's emission profile.

Figure 3

Total Emissions per Match by Sector Activity, 214 metric tons of CO_2e

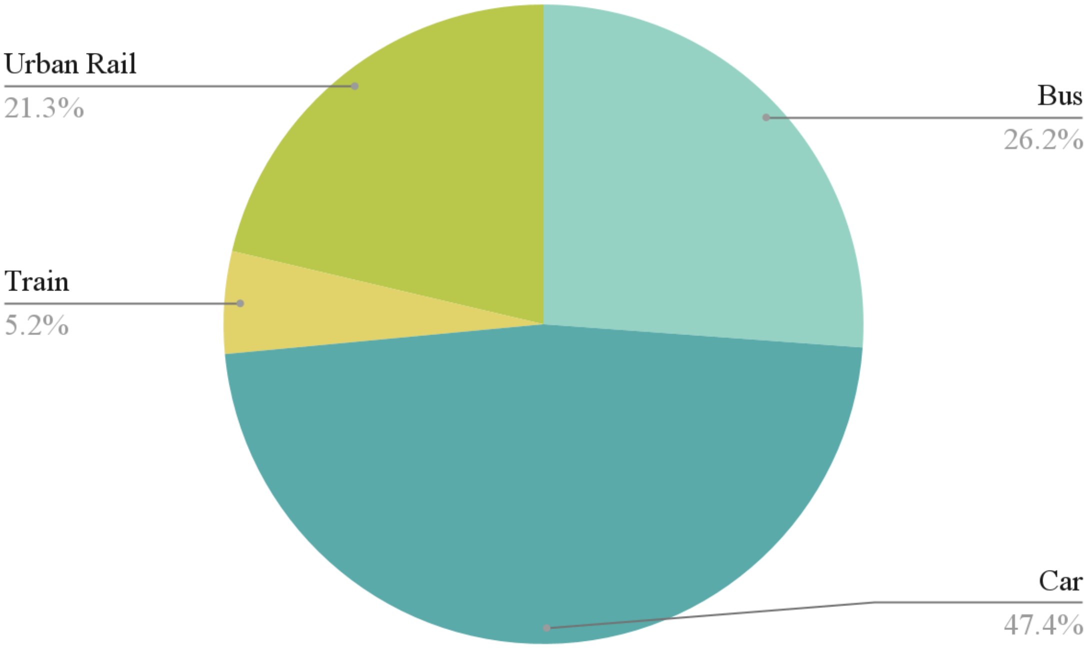


II. Transportation

In the baseline model, the transportation sector has a total carbon footprint of 129 metric tons of CO_2e, accounting for 60.3% of the baseline matchday carbon footprint estimate. Figure 4 shows the breakdown of emissions by mode of transportation.

Figure 4

Share of Emissions by Mode of Transportation for Spectators



Transportation by car has the largest contribution to the transportation sector's footprint, accounting for 47.4% of the greenhouse gas emissions. Transportation by bus accounts for the second highest share of sector emissions, contributing to 26.2% of the transportation sector's footprint. Our findings suggest that these two modes of transportation, car and bus, have significant effects on the environmental impacts of a single matchday, followed by urban rail and train. Although only a third of spectators travel by car in our baseline model, yet this contributes to around half the emissions resulting from transportation. This is expected as public transportation alternatives with higher passenger occupancy have lower per capita emissions.

One of the key assumptions we make when determining the emissions from transportation is that on average 30% of the spectators attending the match travel by car. Due to the uncertainty in this assumption, it is important to conduct a sensitivity analysis to see how the emissions will change by changing that assumption (Table 4).

Table 4

Transportation Sensitivity Analysis

Car	**% of Car Emissions in Transportation Sector Emissions**	**Change in % Share of Transportation in Total Match Emissions**
50%	68.11%	3.47%
45%	63.48%	2.65%
40%	58.49%	1.81%
35%	53.13%	0.93%
Baseline (30%)	47.35%	0.00
25%	41.09%	-0.98%
20%	34.29%	-1.99%
15%	26.87%	-3.06%
10%	**18.76%**	**-4.20%**

The sensitivity analysis reveals that reducing the number of spectators traveling by car can significantly reduce the emissions resulting from a single match. Decreasing the number of spectators traveling by car to 20%, would result in a 2% reduction in the transportation sector's share of total match emissions. On the other hand, increasing the number of spectators traveling by car to 40%, will result in a 1.81% increase in match emissions. These results indicate that the emissions from transportation and thereby total emissions of a match are highly sensitive to the number of spectators traveling by car. Sports stadiums with higher shares of spectators traveling by car will likely see higher greenhouse gas emissions as a result. The maximum reduction in total matchday emissions is achieved by reducing the number of spectators traveling by car to 10%. This change would result in a 4% reduction in the transportation sector's share of total matchday emissions, or approximately 20 metric tons of CO_2e. Thus, in order to effectively reduce carbon emissions from transportation, it is recommended that sport clubs discourage the number of spectators traveling by car to the stadium in favor of public transportation. A number of strategies are available to achieve this transition including implementing incentives for spectators using public transport, working with local transit authorities to increase connectivity, increasing last-mile connectivity to the stadium, higher parking charges, awareness and education campaigns, etc. Although team transportation does not account for a large portion of the emissions total (to the point that it was excluded from the analysis), sport teams should lead by example to demonstrate commitment to sustainable transportation options.

III. Field

We estimate that the model stadium's emissions from the hybrid grass playing field is 4.165 metric tons of CO_2e per match. The important finding to highlight from Table 5 is the -90% emissions reduction scenario, estimated to result in 0.4165 metric tons of CO_2e. This figure represents the estimated total metric tons of CO_2e emitted by this sector given a transition from a halogen to LED field growth lighting system. This change has the potential to result in a drastic reduction in emissions attributed to this sector from 1.94% to 0.19% of the total baseline match emissions.

Table 5

Sensitivity Analysis: Halogen Lighting System for Field Growth

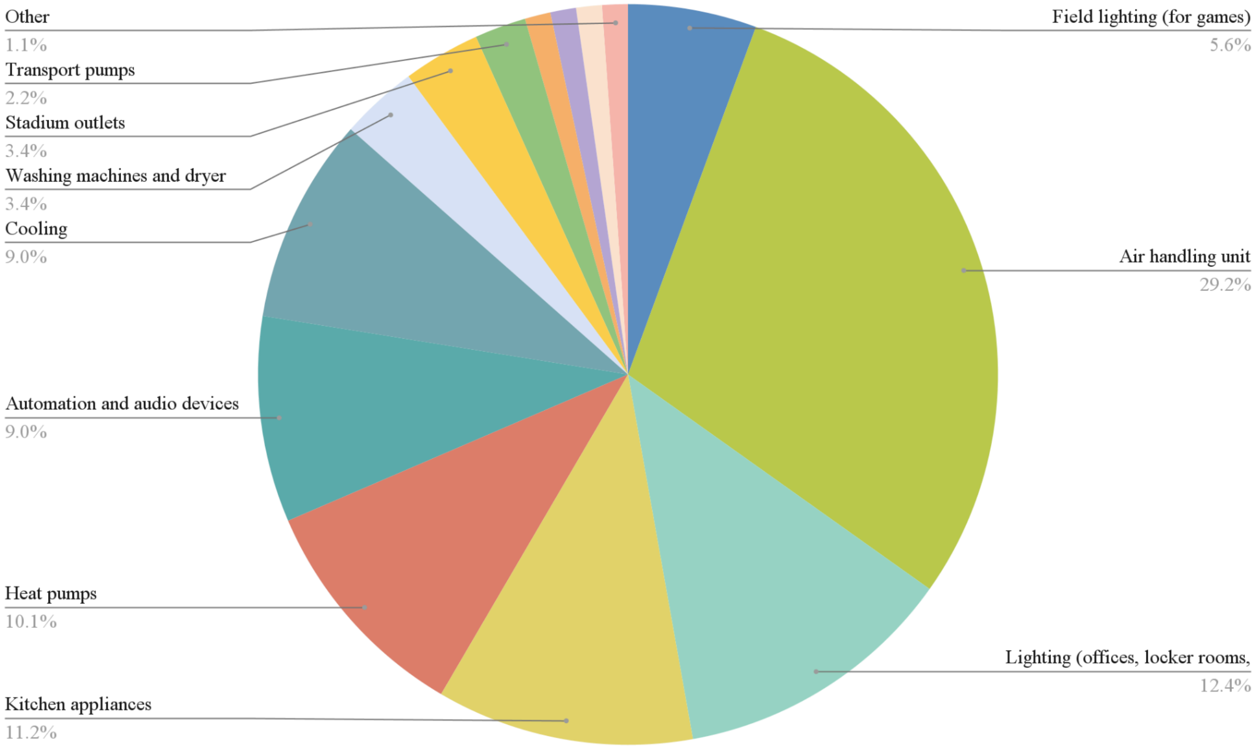
Scenario	**Total Field Sector Emissions of a Soccer Match (Tons CO_2e)**	**% Share of Field Sector in Total Emissions of a Soccer Match**
90%	7.914	3.69%
75%	7.289	3.40%
50%	6.248	2.92%
25%	5.206	2.43%
Baseline	4.165	1.94%
-25%	3.124	1.46%
-50%	2.082	0.97%
-75%	1.041	0.49%
-90%	**0.4162**	**0.19%**

IV. Electricity & Heating

The electricity sector has a total carbon footprint of 10.04 metric tons of CO_2e, making up approximately 4.69% of the overall matchday carbon footprint estimate. Figure 5 shows the breakdown of emissions by activity. The two activities that have the largest contributions to the electricity sector's footprint are air conditioning (made up of the air handling unit, heat pumps, and cooling categories) and lighting (representing the combined contribution of the field lighting and general lighting categories). As the figure below shows, air conditioning systems are responsible for about 48% of the electricity sector's emissions while lighting contributes to about 18% of the sector emissions.

Figure 5

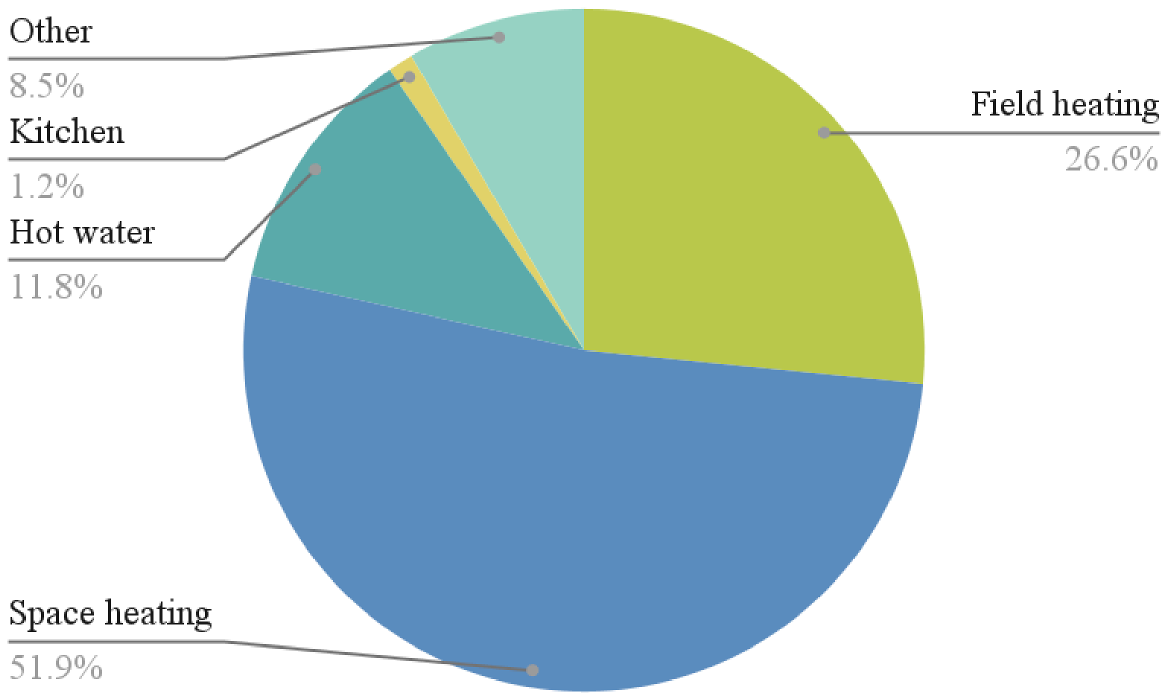
Breakdown of Electricity Sector Emissions



The heating sector has a relatively similar carbon footprint of 8.28 metric tons of CO_2e and makes up about 3.86% of the total matchday footprint. Figure 6 shows the breakdown of heating sector emissions by activity. The two largest contributing activities for heating are space heating and field heating, which are estimated to contribute about 52% and 27% of the sector emissions respectively.

Figure 6

Breakdown of Heating Sector Emissions



One of the key assumptions that we make when determining the emissions from electricity and heating consumption is that the energy used for matchday events represents 20% of the model stadium's annual energy use. To address this uncertainty surrounding this factor, we conduct a sensitivity analysis (Table 6).

Table 6

Sensitivity Analysis for Assumption that 20% of a Stadium's Annual Energy Usage is for Events

Change in 20% event energy usage assumption value	Change in Combined % Share of Electricity and Heating in Total Match Emissions	Absolute Change in Total Match Emissions (Tons CO2-eq)
50%	12.44%	33.73
45%	10.61%	28.11
40%	8.69%	22.49
35%	6.67%	16.87
30%	4.56%	11.24
25%	2.34%	5.62
20% (Baseline)	0.00%	0.00
15%	-2.46%	-5.62
10%	-5.06%	-11.24

As we can see from Table 6, altering the 20% event energy usage assumption changes the share of heating and electricity sector emissions pretty significantly. If we switch this value to 30% instead of 20%, for example, the combined share of the two sectors in the total match emissions increases by 4.56%, which is equivalent to 11.24 metric tons of CO_2e.

Another key parameter in modeling the electricity and heating sector is the lifecycle emission factor for electricity. Table 7 shows the sensitivity of our results to this parameter. This table also serves another purpose by exploring an emissions reduction pathway. The analysis reveals that it is possible to reduce matchday emissions by around 5.22 metric tons of CO_2e if the emission factor is reduced to 40% of its original value. This reduction is comparable to the emissions associated with the daily electricity consumption of around 1,400 people in Italy[2] (Enerdata, n.d.).

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[2] Italy's annual per capita electricity consumption in 2022 was 5,060 kWh. This translates to a daily per capita electricity consumption of 13.86 kWh. To get per capita emissions, we multiply this value by the electricity emissions factor for Italy: 13.86 kWh x 0.2679 kg CO_2e/kWh = 3.71 kg CO_2e. We can then determine an estimate for the number of Italian residents this emissions savings is associated with by converting the emissions savings to kg and dividing by the per capita daily emissions: (5.22 tons CO_2e x 1000 kg/1 ton) / (3.71 kg CO_2e) = 1405 people.

Table 7

Electricity Emissions Factor Reduction Scenario

Change in Electricity Emissions Factor Value	Change in % Share of Electricity in Total Match Emissions	Change in % Share of Heating in Total Match Emissions	Change in Combined Emissions from Electricity and Heating Sectors (Tons CO2-eq)
40%	1.75%	0.54%	5.22
30%	1.32%	0.40%	3.91
20%	0.89%	0.27%	2.61
10%	0.44%	0.13%	1.30
Baseline	0.00%	0.00%	0.00
-10%	-0.45%	-0.13%	-1.30
-20%	-0.90%	-0.27%	-2.61
-30%	-1.36%	-0.41%	-3.91
-40%	-1.82%	-0.54%	-5.22

There are several ways to reduce the electricity emissions factor, including sourcing electricity needed for the stadium operations from cleaner renewable alternatives either through captive generation or through contractual arrangements. Another avenue to be pursued as one of the major consumers of electricity is to advocate for making Italy's national electrical grid cleaner. Other countries in the European region have made major improvements in their national grid emissions factors in recent years by relying more on renewable energy sources for their electricity production. Germany, for example, decreased its electricity emissions factor from 0.508 kg CO_2e/kWh to 0.382 kg CO_2e/kWh between 2016 and 2021 (Bastos et al., 2024a). This decrease "[reflects] a drop in the use of coal and lignite of around 38% and an increase in renewable generation, predominantly in offshore wind and solar PV" (Climate Transparency, 2022a, p. 9). In 2021, fossil fuels accounted for 45% of Germany's electricity generation and renewable energy accounted for 43% (Climate Transparency, 2022a, p. 8); Italy, by contrast, relied on fossil fuels for 58% of its electricity generation and renewable energy for 42% (Climate Transparency, 2022b, p. 8). Thus, there is a lot of potential to reduce the electricity emissions factor simply by investing in more renewable energy at the grid level or at an individual consumer level. Advocacy might be an action that will take time to materialize, but it would be very effective for reducing overall matchday emissions since it would require no change in matchday energy consumption habits.

Table 8 below shows the effects of increasing or decreasing the emissions associated with the air conditioning systems used on matchdays. We look at this sensitivity with two-fold interest- first to address the challenges of not being able to precisely model a specific type of system and second to explore implications of investment in energy efficient upgrades. We find that changing the air conditioning systems emissions value has little to no effect on the total match emissions (Table 8). When reductions to the air conditioning systems emissions are paired with reductions in the electricity emissions factor (as shown in Table 9), however, there is potential for much greater emissions savings. When the electricity emissions factor and air conditioning systems emissions are both decreased by 30%, a reduction of 4.92 metric tons of CO_2e occurs. Therefore, if one were to invest in more efficient air conditioning systems and focus on making Italy's national grid cleaner at the same time, it would be possible to achieve a reduction close to what a 40% decrease in the electricity emissions factor achieves on its own.

Table 8

Air Conditioning Systems Sensitivity Analysis

Change in Air Conditioning Systems Emissions Value	Change in % Share of Electricity in Total Match Emissions	Absolute Change in Total Match Emissions (kg CO2-eq)
30%	0.64%	1,456
20%	0.43%	971
10%	0.22%	485
Baseline	0.00%	0
-10%	-0.22%	-485
-20%	-0.43%	-971
-30%	-0.65%	-1,456

Table 9

Combined Electricity Emissions Factor and Air Conditioning Systems Reduction Scenario

Absolute Change in Total Match Emissions (Tons CO2-eq)	**Change in Electricity Emissions Factor Value**						
Change in Air Conditioning Systems Electricity Use Value	-30%	-25%	-20%	-15%	-10%	-5%	Baseline
-30%	-4.932	-4.353	-3.773	-3.194	-2.615	-2.035	-1.456
-25%	-4.762	-4.171	-3.579	-2.988	-2.396	-1.805	-1.213
-20%	-4.593	-3.989	-3.385	-2.782	-2.178	-1.574	-0.971
-15%	-4.423	-3.807	-3.191	-2.575	-1.960	-1.344	-0.728
-10%	-4.253	-3.625	-2.997	-2.369	-1.741	-1.113	-0.485
-5%	-4.083	-3.443	-2.803	-2.163	-1.523	-0.883	-0.243
Baseline	-3.913	-3.261	-2.609	-1.957	-1.304	-0.652	0.000

Table 10 below provides a sensitivity analysis for the natural gas emissions factor, another key parameter in this sector. The analysis reveals that reducing the natural gas emissions factor does not have as much of an impact on total matchday emissions as reducing the electricity emissions factor does, but it is still possible to reduce total match emissions by approximately 2.1 metric tons of CO_2e if the natural gas emissions factor for the European grid is decreased by 40%.

Table 10

Natural Gas Emissions Factor Sensitivity Analysis, Heating Sector

Change in Natural Gas Emissions Factor Value	Change in % Share of Heating in Total Match Emissions	Absolute Change in Total Match Emissions (kg CO2-eq)
40%	0.94%	2,112
30%	0.71%	1,584
20%	0.47%	1,056
10%	0.24%	528
Baseline	0.00%	0
-10%	-0.24%	-528
-20%	-0.48%	-1,056
-30%	-0.72%	-1,584
-40%	-0.96%	-2,112

Table 11 shows the sensitivity analysis for the stadium's space heating emissions. We felt that it was necessary to do an analysis for this activity because the proportion of the total heating emissions assigned to space heating was estimated based on data from a study done by Sleegers in 2009 (as cited in Smulders, 2012); since this study is over 15 years old and is modeled around a stadium with a capacity of only 22,000, it is possible that the data is outdated and may not represent current stadium operations for large-scale stadiums like San Siro. Therefore, this analysis helps to address the uncertainty in our assumptions while also serving as a resource for recommendations. Based on the results of the analysis, we can conclude that reducing space heating emissions by 30% would lead to total match emissions being 1,290 kg CO_2e lower. A recommendation for reducing emissions would be to increase the efficiency of the stadium's space heating systems.

Table 11

Space Heating Sensitivity Analysis

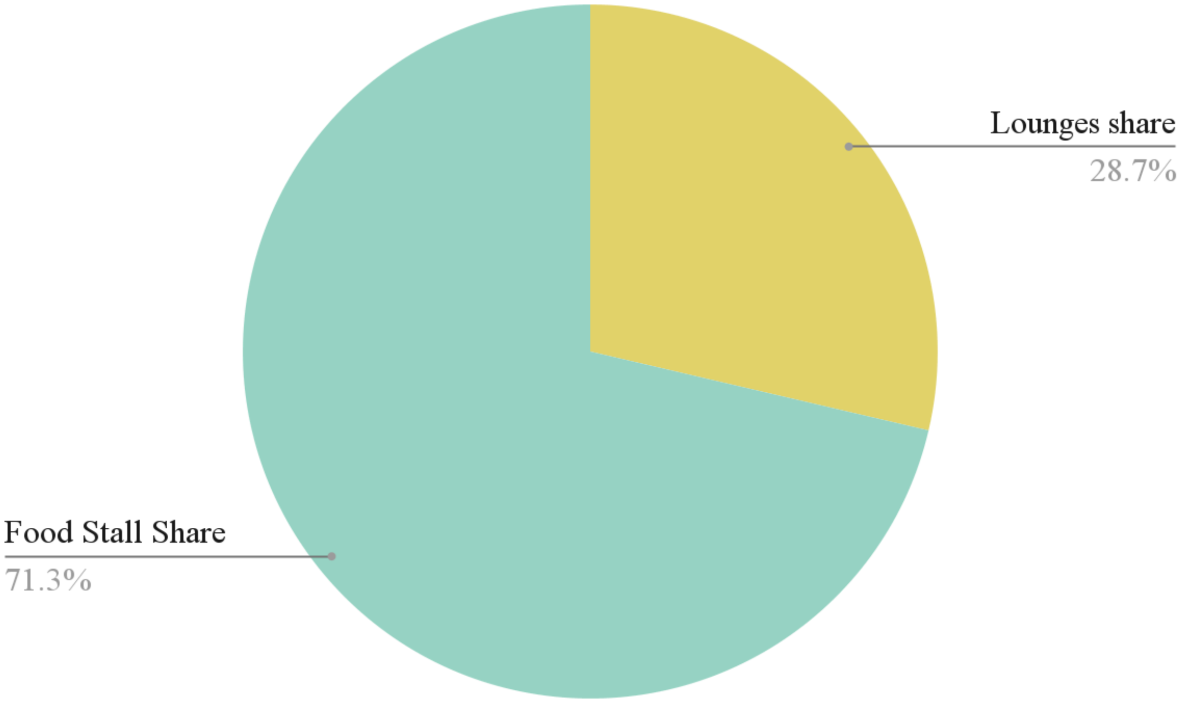
Change in Space Heating Emissions Value	Change in % Share of Heating in Total Match Emissions	Absolute Change in Total Match Emissions (kg CO2-eq)
30%	0.58%	1,290
20%	0.38%	860
10%	0.19%	430
Baseline	0.00%	0
-10%	-0.19%	-430
-20%	-0.39%	-860
-30%	-0.58%	-1,290

V. Food & Beverage

The total carbon footprint of the food and beverage sector is 50.08 metric tons of CO_2e. Food lounges constitute 28.7% of the total footprint while food stalls make up 71.3% of the footprint. The breakdown reflects the estimated large portion of stadium guests purchasing food and beverage through food stalls, rather than from lounges. The most popular food stall purchases as modeled in this study include bottled water, soft drinks, burgers, hot dogs, sandwiches, and fries. From our baseline, we analyze uncertainty in emissions numbers through a sensitivity analysis. To do this, we treat attendee purchasing numbers and carbon emissions of food stall offerings as separate variables, evaluating the impact of incremental changes of 5% and 10% on our total baseline.

Figure 7

Food and Beverage Sub-sector Pie Chart of Carbon Footprint



These sensitivity analyses reveal several key findings. In Table 12, the maximum decrease in attendee purchases studied, which was a 7% decrease in food purchases and 9% decrease in beverage purchases from sector emissions, yields a decrease in total baseline emissions of 4.34%. From this analysis, we see that with less than 10% of a decrease in both food and beverage consumption habits, there is a large reduction in the total baseline emissions. With only a 4% decrease in beverage consumption and 2% decrease in food consumption, it is still possible to achieve a decrease of 1.37% in total baseline emissions, as shown in Table 12.

Table 12

Food Stalls Pivot Table Showing Percent Change in Total Baseline Emissions

% Change in Total Baseline Emissions	**% Fans Purchasing DRINK**				
% Fans Purchasing FOOD	**25%**	**30%**	**34%**	**35%**	**40%**
20%	-4.34%	-3.90%	-3.54%	-3.46%	-3.01%
25%	-1.81%	-1.37%	-1.01%	-0.92%	-0.48%
27%	-0.80%	-0.35%	0%	0.09%	0.53%
30%	0.72%	1.17%	1.52%	1.61%	2.05%
35%	3.26%	3.70%	4.05%	4.14%	4.58%

Within the food and beverage sector specifically, the7% reduction in food purchases and 9% reduction in beverage purchases yields a decrease of sector emissions by 18.57%, as shown in Table 13. With reductions of less than 10% in both food and beverage purchases, there are significant reductions possible within this sector. A smaller reduction of only 4% in beverage purchases and 2% in food purchases correlates to a 5.85% decrease in sector emissions. Thus, even small scale reductions can have a significant impact on both total sector and total baseline emissions.

Alternatively, an evaluation of our emissions factors baseline reveals that a decrease in sector emissions by 20% yields a total decrease of baseline emissions by 3.34%. This number indicates that changes can be made within the food and beverage sector to bring down total baseline emissions. However, this sector is not the top priority in terms of mass reductions on a single matchday level, and should instead be incorporated into plans to reduce the total carbon footprint across the entire sporting operation.

Table 13

Food Stalls Pivot Table Showing Percent Change in Food Sector Emissions

% Change in Total Sector Emissions	% Fans Purchasing DRINK				
% Fans Purchasing FOOD	**25%**	**30%**	**34%**	**35%**	**40%**
20%	-18.57%	-16.68%	-15.16%	-14.79%	-12.90%
25%	-7.74%	-5.85%	-4.33%	-3.95%	-2.06%
27%	-3.40%	-1.51%	0%	0.38%	2.27%
30%	3.10%	4.99%	6.50%	6.88%	8.77%
35%	13.93%	15.82%	17.33%	17.71%	19.60%

There are several methods possible for reducing emissions within the food and beverage sector. While it is not recommended to limit food and beverage consumption and/or guest attendee numbers, it is possible to incorporate lower-emissions food items into the stadium food offerings. Collaborating with local food production facilities is one method for reducing emissions via transportation. Alternatively, it is also recommended to reduce emissions in food packaging and/or food waste through reusable packaging and composting. Incorporating a food packaging or drink cup deposit system is one method that can incentivize fans to contribute to the recirculation of reusable items while significantly reducing the carbon footprint (Obbink, 2023).

The carbon footprint of food lounges was estimated to be 14.35 metric tons of CO_2e, based on a high-volume of visitors scenario. The food lounges consisted of a small fraction of the total food and beverage, because only a small fraction of the total visitor population utilized the food lounges. Given the variation in data and assumptions made from secondary data, a sensitivity analysis was conducted to account for uncertainty.

To account for uncertainties in the model baseline, the number of visitors was altered by 10% increments, starting from -30% and increasing to 10%, as seen in Table 14. This range of sensitivities encompassed the entire range of visitors provided by the primary source, and ensured that fluctuations arising from changes in visitor volume would be accounted for. Similarly those adjustments were combined with results from altering the agricultural production sector by 10% increments starting from -20% and increasing until 30%. The sensitivity analysis revealed that a decrease in 20% of emissions produced from agricultural production combined with a 30% decrease in number of visitors resulted in a maximum reduction of 10.92% of total food and beverage carbon emissions. If not considering decreases in the number of visitors, it can be seen that the largest decrease of emissions of 20% from agricultural production would result in the largest decrease of 3.32% carbon emissions of the food and beverage sector.

Table 14

Food Lounges Pivot Table Showing the Percent Change in Total Sector Emissions

% Change in Sector Emissions	**% Change in Agricultural Production**					
% Change in Fans Visiting	-20%	-10%	0%	10%	20%	30%
-30%	-10.92%	-9.76%	-8.60%	-7.43%	-6%	-5.11%
-20%	-8.39%	-7.06%	-5.73%	-4.40%	-3.07%	-1.74%
-10%	-5.86%	-4.36%	-2.87%	-1.37%	0.13%	1.62%
0%	-3.32%	-1.66%	0.00%	1.66%	3.32%	4.99%
10%	-0.79%	1.04%	2.87%	4.69%	6.52%	8.35%

Regarding the entire baseline scenario of the stadium, a 30% reduction in visitors and a 20% reduction in emissions emitted through agricultural production resulted in a 2.89% reduction in total baseline emissions (Table 15). However, assuming a medium amount of visitors, indicated by a 10% decrease in visitors, combined with a 20% reduction in agricultural production emissions resulted in an overall reduction of 2.89% in total baseline emissions. Thus, through this sensitivity analysis, it can be concluded that there is great potential for carbon emission reductions and sustainability initiatives, especially by reducing agricultural production emissions.

Table 15

Food Lounges Pivot Table Showing Percent Change in Baseline Emissions

% Change in Total Baseline Emissions	**% Change in Agricultural Production**					
% Change in Fans Visiting	-20%	-10%	0%	10%	20%	30%
-30%	-2.55%	-2.28%	-2.01%	-1.74%	-1.47%	-1.19%
-20%	-1.96%	-1.65%	-1.34%	-1.03%	-0.72%	-0.41%
-10%	-1.37%	-1.02%	-0.67%	-0.32%	0.03%	0.38%
0%	-0.78%	-0.39%	0%	0.39%	0.78%	1.17%
10%	-0.18%	0.24%	0.67%	1.10%	1.52%	1.95%

Table 16

Food Lounges Pivot Table Showing the Percent Share of Food Sector in Total Emissions

% Share of Food Sector in Total Emissions	**% Change in Agricultural Production**					
% Change in Fans Visiting	-20%	-10%	0%	10%	20%	30%
-30%	20.82%	21.09%	21.36%	21.64%	21.91%	22.18%
-20%	21.41%	21.72%	22.03%	22.35%	22.66%	22.97%
-10%	22.01%	22.35%	22.70%	23.05%	23.40%	23.75%
0%	22.60%	22.99%	23.37%	23.76%	24.15%	24.54%
10%	23.19%	23.62%	24.04%	24.47%	24.90%	25.33%

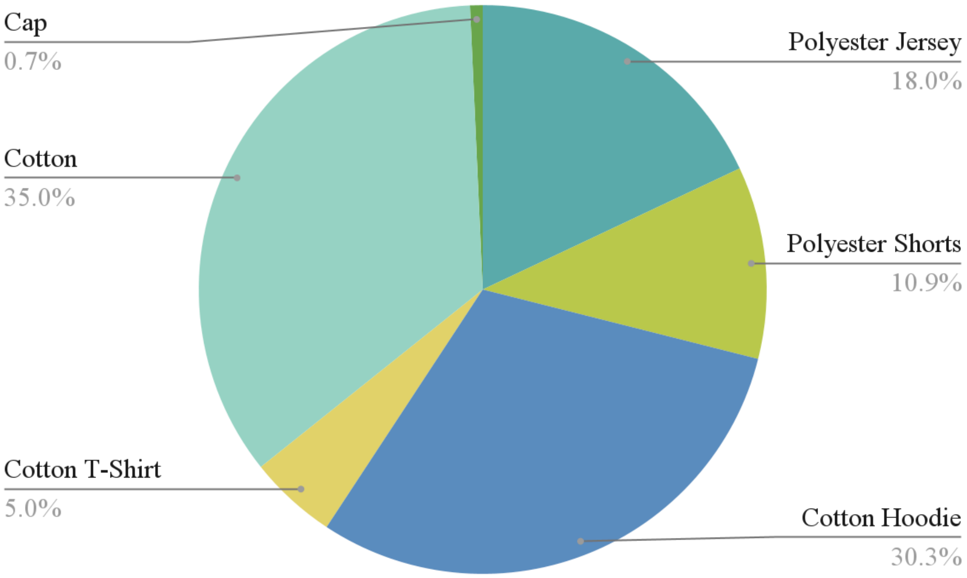
As seen previously in the sensitivity analysis, the maximum 20% reduction in agricultural production resulted in the largest overall reductions in total baseline emissions, especially at a reduced number of visitors. Thus, in order to effectively reduce carbon emissions from food lounges, it is recommended that carbon emissions from agricultural production be decreased. The agricultural production sector holds much potential for sustainability initiatives, and can be reduced by choosing a catering service that sources from farmers who grow crops sustainably and with less chemically-intensive fertilizers. Although transportation of food from canteen comprises only 6% of the carbon footprint of a catered meal, emissions from this subsector can be reduced by sourcing from a catering service closer in distance to the model stadium. Additional other recommendations to reduce food lounge carbon footprint that could be considered include encouraging the catering service to use and purchase more sustainable packaging, or buying sustainable packaging in bulk for the catering service to utilize.

VI. Merchandise

The merchandise sector has a total carbon footprint of 12.45 metric tons of CO_2e, accounting for 5.81% of CO_2e emissions of all sectors in the base model. Of the merchandise items represented in the model, cotton items accounted for approximately 71.1% percent of the total emissions, whereas polyester products accounted for the remaining 28.9% of emissions.

Figure 8

Breakdown of Merchandise Sector Emissions



Surrounding uncertainty around the use of recycled materials, the baseline model used LCA values for newly produced materials. Based on existing literature, rPET (recycled polyester) can reduce global warming potential by 25% to 75% compared to new polyester, based on the technology used. (Periyasamy et al., 2020). For this reason, scenarios of 25%, 50%, and 75% emission reductions were used for the model. Similarly, a blend of 70% recycled cotton and 30% virgin cotton could reduce carbon emissions by 2.2-8.6% (Roy et al., 2023). To simulate the impact of using recycled cotton, reductions of 2.2%, 5.4%, and 8.6% were used in the model.The resulting sums of emissions were then compared to the merchandise emissions of the base model. The following table shows the change in percent share of total emissions across all sectors for each scenario.

Table 17

Change in Percent Share of Total Emissions Across all Sectors for Each Scenario

Change in % Share of Total Emissions	**Recycled Polyester Reduction in Emissions**			
Recycled Cotton Reduction in Emissions	0%	-25%	-50%	-75%
0.00%	0%	-0.51%	-0.95%	-1.32%
-2.20%	-0.13%	-0.64%	-1.08%	-1.44%
-5.40%	-0.31%	-0.82%	-1.26%	-1.63%
-8.60%	-0.49%	-1.00%	-1.44%	**-1.81%**

The findings show that in an ideal scenario with the best technologies (recycled polyester reduces emissions by 75% and recycled cotton reduces emissions by 8.6%), the merchandise sector's share in total emissions can be reduced by 1.81%. The data also finds that the use of recycled polyester alone can reduce the share in total emissions by up to 1.32%, and that the use of recycled cotton alone can reduce the share of total emissions by up to 0.49%, suggesting that the use of recycled polyester will have a larger impact on emissions than the use of recycled cotton.

In the base scenario, it was assumed that 1.5% of fans in attendance purchase merchandise in the stadium during a match. To address the uncertainty in that assumption, we conduct a sensitivity analysis presented in Table 18. This sensitivity was combined with emission reduction scenarios in Table 17 to get a sense of variability along both dimensions together.

Table 18

Uncertainty Analysis Showing Change in Percent Share of Total Emissions

% Change in Share of Total Emissions	**Emission Reduction From Recycled Materials**				
Change in % Fans Purchasing Merchandise	Baseline (-0%)	-0.51%	-1.00%	-1.44%	-1.81%
-20%	-1.11%	-1.53%	-1.93%	-2.29%	-2.59%
-15%	-0.83%	-1.27%	-1.69%	-2.08%	-2.40%
-10%	-0.55%	-1.02%	-1.46%	-1.87%	-2.20%
-5%	-0.27%	-0.76%	-1.23%	-1.66%	-2.01%
Baseline (-0%)	0.00%	-0.51%	-1.00%	-1.44%	-1.81%
5%	0.27%	-0.26%	-0.78%	-1.24%	-1.63%
10%	0.54%	-0.01%	-0.55%	-1.03%	-1.44%
15%	0.81%	0.24%	-0.32%	-0.83%	-1.25%
20%	1.08%	0.48%	-0.10%	-0.62%	-1.06%

The results show that the data from the baseline scenario is quite sensitive to the number of fans who purchase merchandise in the stadium. For example, a reduction in fans of 20% (meaning 1.35% of fans in attendance purchase merchandise instead of 1.5%) would result in a reduction in share of total emissions by 1.08%. This is a considerable reduction, as the scenarios from the baseline 1.5% show that recycled materials can reduce the total share of the merchandise sector by 0.00-1.81%.

Conclusion

Through an analysis of primary and secondary sources, a baseline scenario revealed that one matchday at a stadium similar to AC Milan's San Siro Stadium had a carbon footprint of 214 metric tons of CO_2e. Next, the carbon footprints of the top six sectors contributing to the carbon footprint of a single matchday were then estimated and further analyzed for future recommendations to reduce carbon emissions. From the largest to smallest carbon footprint, transportation had a carbon footprint of 129 metric tons of CO_2e, food and beverage with 50 metric tons of CO_2e, merchandise with 12 metric tons of CO_2e, electricity with 10 metric tons of CO_2e, heating with 8 metric tons of CO_2e, and followed by field operations with 4 metric tons of CO_2e.

The majority of carbon emissions in the transportation sector comes from transportation by car, followed by travel by bus and urban rail. The sensitivity analysis for this sector revealed that emissions produced by car transportation had a large impact on the overall match emissions, and could be drastically reduced. Thus, recommendations for reducing transportation sector emissions would look like an incentive strategy or program to reward spectators who opt for public transportation over car transportation. Additionally, stadium staff could work with local transit authorities to increase connectivity, implement higher parking charges, and create awareness and education campaigns.

For the food and beverage sector, it was shown that food stall emissions consisted of the majority of baseline emissions. A thorough sensitivity analysis reveals high potential for carbon dioxide emission reductions for agricultural production emissions that contribute to the carbon footprint of a catered meal in food lounges. The recommendations derived from the sensitivity analysis for the food lounge subsector is sourcing from farms and suppliers that utilize sustainable farming practices for producing a catering meal. Similarly, recommendations for the food stalls sub-sector involves incorporating low-emission food items into stadium food offerings or implementing a food packaging or drink cup deposit system to incentivize fans to contribute to reusing and recycling items.

Next, it was seen that the production of cotton products contributed largely to the carbon footprint of the merchandise sector. A sensitivity analysis revealed that there was high uncertainty in how much material was recycled throughout the production of merch. Thus, it was seen that the implementation or recycling of materials and fabrics could largely reduce the carbon footprint of the merchandise sector. Specific recommendations within this sector consist of utilizing a more sustainable production method where materials like carbon and polyester are recycled and reused.

The large majority of carbon emissions from the electricity sector comes from air conditioning and lighting. The sensitivity analysis for this sector revealed that the electricity emissions factor is particularly impactful in affecting overall baseline carbon dioxide emissions. Thus, specific recommendations for the electricity sector include sourcing from cleaner renewable alternatives (either through captive generation or through contractual arrangements) or advocating in general for making Italy's electricity cleaner.

Additionally, the two activities that have the largest contributions to the heating sector are space heating and field heating. Given the amount of uncertainty in assuming the proportions of the total heating emissions assigned to space heating, a sensitivity analysis helped us understand potential variations in this sector. A specific recommendation for the heating sector includes increasing the efficiency of the stadium's space heating systems.

Lastly, it is seen that field operations and field upkeep contribute the least to the overall stadium carbon footprint. Although a small sector, a sensitivity analysis revealed that heavy reductions within this had the ability to reduce carbon dioxide emissions of the overall stadium baseline estimation. Specific recommendations for the field sector is transitioning from a halogen to LED field growth lighting system.

We hope this comprehensive analysis of a soccer matchday at a model stadium adjacent to San Siro Stadium in Italy both spreads awareness within fans, sports game participants, and the larger sports industry. It is important to note that water usage and waste was not considered in our baseline emissions analysis, and our current estimation may be an underestimate. However, our estimation, calculations, and recommendations are still a strong estimate and based on strong foreground and background data. Thus, we aim for the proposed recommendations to hopefully be implemented and utilized in the near future to reduce carbon dioxide emissions in sports stadiums.

References

Alcalde, C. (2007). Sustainable Sports Stadia: Potential and Strategies for FC Barcelona's Camp Nou stadium. *Ann Arbor*, *1000*, 48106-1346. https://core.ac.uk/download/pdf/111031252.pdf

Bastos, J., Monforti-Ferrario, F., & Melica, G. (2024a). *GHG emission factors for electricity consumption*. Covenant of Mayors. https://data.jrc.ec.europa.eu/dataset/919df040-0252-4e4e-ad82-c054896e1641

Bastos, J., Monforti-Ferrario, F., & Melica, G. (2024b). *GHG emission factors for local energy use*. Covenant of Mayors. https://data.jrc.ec.europa.eu/dataset/72fac2b2-aa63-4dc1-ade3-4e56b37e4b7c

ISPRA (2023). Efficiency and decarbonization indicators in Italy and in the biggest European countries. Rapporti 386/2023. https://www.isprambiente.gov.it/files2023/pubblicazioni/rapporti/r386-2023.pdf

Climate Transparency. (2022a). Climate Transparency Report 2022: Germany. https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Germany-Web.pdf

Climate Transparency. (2022b). Climate Transparency Report 2022: Italy. https://www.climate-transparency.org/wp-content/uploads/2022/10/CT2022-Italy-Web.pdf

Collins, A., Flynn, A., Munday, M., & Roberts, A. (2007). *Assessing the Environmental Consequences of Major Sporting Events: The 2003/04 FA Cup Final.* Urban Studies, 44(3), 457-476. https://doi.org/10.1080/00420980601131878

Collins, A., Jones, C., & Munday, M., (2009). *Assessing the environmental impacts of mega sporting events: Two options?* Tourism Management, 30(6), 828-837. https://doi.org/10.1016/j.tourman.2008.12.006

Dolf, M. (2012). *Life Cycle Assessment of the UBC Thunderbirds teams, events, and venues*. UBC Center for Sport and Sustainability. https://cfss.sites.olt.ubc.ca/files/2011/01/Life-Cycle-Assessment-of-the-UBC-Thunderbirds-teams-events-and-venues.pdf

Dolf, M. (2017). *A Life Cycle Assessment of the environmental impacts of small to medium sports events*. University of British Columbia. https://open.library.ubc.ca/collections/ubctheses/24/items/1.0362385

Econ Pöyry. (2009). *Feasibility study for a carbon neutral 2010 FIFA World Cup in South Africa*. South Africa Department of Environmental Affairs and Tourism & Norwegian

Government, Stockholm. https://www.dffe.gov.za/sites/default/files/docs/carbonneutralwc_feasibility_study.pdf

Enerdata. (n.d.). Italy Energy Information. https://www.enerdata.net/estore/energy-market/italy/

Espinoza-Orias, N., & Azapagic, A. (2018). Understanding the impact on climate change of convenience food: Carbon footprint of sandwiches. *Sustainable Production and Consumption, 15*, 1-15. https://doi.org/10.1016/j.spc.2017.12.002

ESPN Enterprises. (2024). AC Milan Performance Stats. *ESPN*. https://www.espn.com/soccer/team/stats/_/id/103/league/ITA.1/view/performance

FIFA. (2006). *Green Goal – Legacy Report*. Fédération Internationale de Football Association. https://www.oeko.de/oekodoc/292/2006-011-en.pdf

FIFA. (2018). *Sustainability Report – 2018 FIFA World Cup Russia*. Fédération Internationale de Football Association. https://digitalhub.fifa.com/m/5afd3d89f0e69eb/original/ya7pgcyslxpzlqmjkykg-pdf.pdf

FoodFootPrint. (2022). Find the climate impact of your food. FoodFootPrint.nl. https://foodfootprint.nl/en/

Global Carbon Budget (2023). Annual CO2 emissions - GCB. *Global Carbon Project. https://globalcarbonbudget.org/carbonbudget/*

Hedayati, M., Iyer-Raniga, U., & Crossin, E. (2014). A greenhouse gas assessment of a stadium in Australia. *Building Research & Information*, *42*(5), 602-615. https://doi.org/10.1080/09613218.2014.896141

International Council on Clean Transportation. (2020). CO2 emissions from trucks in the EU: An analysis of the heavy-duty CO2 standards baseline data. https://theicct.org/publication/co2-emissions-from-trucks-in-the-eu-an-analysis-of-the-heavy-duty-co2-standards-baseline-data/

London Organising Committee of the Olympic Games and Paralympic Games (LOCOG). (2010). Carbon footprint study: Methodology and reference footprint. https://library.olympics.com/Default/doc/SYRACUSE/69866/carbon-footprint-study-methodology-and-reference-footprint-london-2012-london-organizing-committee-f?_lg=en-GB

Marrucci, Luca & Daddi, Tiberio & Iraldo, Fabio. (2023). Sustainable Football: Environmental Management in Practice 10.4324/9781003228271.

Murray, W. (2021). Assessing and Reducing the Environmental Impact of the English Premier League. https://www.esru.strath.ac.uk/Documents/MSc_2021/Murray.pdf

Obbink, K. (2023). Encouraging sustainable behaviour in Dutch football stadiums: Perspective of managers and visitors [Bachelor thesis, Breda University of Applied Sciences]. https://bouwstenen.nl/sites/default/files/uploads/Thesis%20Klein%20Obbink%2C%20Job.pdf

Oracle Food and Beverage. (2019). Stadium of the future - The next generation of game day technology. Oracle. https://www.oracle.com/a/ocom/docs/dc/stadium-of-the-future-report-final.pdf

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 360*(6392), 987-992. https://doi.org/10.1126/science.aaq0216

Ragazzi, M., & Rada, E. C. (2018). Municipal solid waste management in a circular economy perspective. *The Science of the Total Environment, 644*, 622-630. https://doi.org/10.1016/j.scitotenv.2018.06.205

Sleegers, M. (2009). RWE energieonderzoek: FC Groningen. Rapportnummer: END-627.

Structurae. (n.d.). Stadio San Siro. https://structurae.net/en/structures/stadio-san-siro

Smulders, T. (2013). Green stadiums: as green as grass [Master thesis, University of Utrecht]. https://studenttheses.uu.nl/bitstream/handle/20.500.12932/17000/Green.stadiums.final.pdf?sequence=1

UNEP. (2012). *FIFA World Cup: South Africa 2010 Report*. United Nations Environment Programme. https://wedocs.unep.org/20.500.11822/31280