Author(s): Uusitalo, Ville; Halonen, Vilma; Koljonen, Heidi; Heikkinen, Suvi; Claudelin, Anna

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Research article

In search for climate neutrality in ice hockey: A case of carbon footprint reduction in a Finnish professional team

Ville Uusitalo [a,*], Vilma Halonen [a], Heidi Koljonen [a], Suvi Heikkinen [b], Anna Claudelin [a]

[a] Department of Sustainability Science, Lappeenranta-Lahti University of Technology LUT, Lahti, Finland
[b] School of Business and Economics, University of Jyväskylä, Jyväskylä, Finland

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ABSTRACT

Mitigation actions in all sectors of society, including sports, to limit global warming have become an increasingly hot topic in public discussions and sports management. However, so far, there has been a lack of understanding and practical examples of how these organizations, especially in team sports, can holistically assess and reduce their climate impacts to achieve carbon neutrality. This paper presents a carbon footprint assessment, implemented actions for GHG emission reduction, and offers the example of a professional Finnish ice hockey team that achieved carbon neutrality. The study is based on a life cycle assessment method. The Results show that the team's carbon footprint was reduced from 350 tCO_{2eq} by more than 50% between seasons 2018–2019 and 2021–2022 in the assessed categories. The most GHG emission reductions were achieved in the team's and spectators' mobility and ice hall energy consumption. Furthermore, the team compensated for their remaining emissions to achieve carbon neutrality. Multiple possibilities for further GHG emission reductions were recognized. The majority of the GHG emissions were linked to the Scope 3 category, indicating that co-operation with partners and stakeholders was a key to success in attaining carbon neutrality. This paper also discusses the possible limitations and challenges that sport organizations face in assessing climate impacts and reducing GHG emissions, as well as the prospects of overcoming them. Since there are many opportunities for sports to contribute to climate change mitigation, relevant targets and actions to reduce GHG emissions should be integrated into all sport organizations' management.

1. Introduction

Sustainability in sports is a hot topic, in academic and public discussions and in sports. The impacts of human-induced climate change can already be observed in the form of extreme weather events as well as losses and damages caused to nature and humans. Moreover, around 3.3 to 3.6 billion people live in places that are highly vulnerable to climate change. However, the magnitude of such impacts can be lowered by rapidly reducing greenhouse gas (GHG) emissions in all sectors of society (IPCC, 2022).

Climate change has a significant impact on winter sports, as it signals high uncertainty for their future (Cury et al., 2022; Orr and Inoue, 2019; McCullough, 2023). It is evident that climate change will decrease snow-reliable areas worldwide (Schneider and Mücke, 2021). In this context, Scott et al. (2022) found that if GHG emissions continue to grow on the current trajectory, only one out of 21 previous Winter Olympic host cities would be able to safely host winter sport events by the end of this century. However, if emissions could be lowered according to the 1.5-degree Celsius trajectory, eight possible locations would remain eligible (Scott et al., 2022). Furthermore, while the ski season can be prolonged using snowmaking technology, it has been estimated that in Tyrol, Austria, for example, the current snowmaking technology would not be sufficient to ensure a viable and snow-reliable ski season within the next 10–30 years due to climate change (Steiger, 2010).

There is no clear overarching picture of the role of sports in intensifying climate change. The current literature on this issue has mainly focused on megaevents, such as the Olympics and the soccer World Cup and the Euro Cup (Goldblatt, 2020) and to some smaller sport events such as ultra trail event (Grofelnik et al., 2023) and varsity sport events (Dolf and Teehan, 2015). Specifically, the majority of GHG emissions in these events can be linked to new infrastructure construction and spectators' mobility. However, despite huge emissions from these events (1–4 million tons of CO_{2eq}), it is more likely that the majority of GHG emissions related to global sports are linked to national leagues and

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* Corresponding author. Mukkulankatu 19, 15210 Lahti, Finland.
E-mail address: ville.uusitalo@lut.fi (V. Uusitalo).

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everyday sports.

Earlier research has shown some examples of sport event related GHG emissions such as FA Cup finals (Collins et al., 2007), UK stages of the Tour de France (Collins et al., 2012), and the UK round of the 2004 World Rally Championship (Jones, 2008). Some studies have also focus on sports related travel e.g. football spectators' in Germany (Thormann et al., 2022), snow-sport-related travel (Wicker, 2018), and sport travel in Germany (Wicker, 2019).

Many sport organizations and teams have already initiated efforts to mitigate their climate impacts. However, these actions remain scattered, while a holistic understanding and strategic approach largely remains missing from this context (Cury et al., 2022). In 2021, the United Nations announced new targets for climate action in sports, which include 50% GHG emission reduction by 2030 and achieving carbon neutrality by 2040 (United Nations Climate Change, 2021). The United Nations recommended that sport teams should follow a systematic approach toward climate action, which includes conducting measurement, actionable, educational, promotional, and reporting activities.

Some interesting measures and actions to reduce the climate impact of sports have been reported in non-scientific literature. Forest Green Rovers, a football club in the UK has been calculating its CF since 2011 and for the 2020–2021 season it was 32.7 tCO_{2eq}. It is the first sports club to be certified as carbon neutral by the United Nations. Nowadays, the club uses 100% renewable energy, has solar panels installed on the stadium roof, encourages sustainable travel to games and are a 100% vegan football club (Forest Green Rovers Football Club, 2021). The National Hockey League (NHL) in North America, which has been calculating its league's CF, reported that its overall CF was 182,355 tCO_{2eg} in 2016 (Green, 2018). The Finnish ice hockey league published its CF for the 2017–2018 season, showing that its total CF was approximately 6400 tCO_{2eq}, primarily resulting from spectators' mobility, followed by energy production for ice halls (Hepo-Oja, 2018). The Seattle Sounders football club in the U.S. calculated its CF in 2018 (1847 tCO_{2eq}) and pledged to become carbon neutral by 2019 by compensating its GHG emissions (Sounders FC Communications, 2019). Apart from these organizations, the American basketball league NBA franchise Portland Trail Blazers have launched sustainability to reduce their environmental impact (NBA, 2019). The International Biathlon Union (IBU) adopted a sustainability strategy for 2020–2030, aiming to reduce its CF by 50% and become climate neutral by 2030. For the 2020–2021 season, their emissions were 4203 tCO_{2eq} (IBU, 2022).

Some athletes have taken an active role in enhancing sustainable development by acting as role models to motivate their fans to pursue similar goals (Triantafyllidis and Mallen, 2022). There is sufficient indication that sports fans support the sustainability actions of sport teams. According to Daddi et al. (2020), 86% of soccer fans agree or strongly agree that the sport should pay heed to environmental protection in the same way that it tackles other issues, e.g., racism. In addition, 69% of fans claimed they would be happier to attend a match if they knew it was environmentally friendly. According to Thormann and Wicker (2021b) 64.3 % of German sport club members would be willing to pay for environmental measures on average 14.5 € per year. McCullough et al. (2021) studied the environmental attitudes of external stakeholders (sport fans, non-sport fans/community members) in sports to find that sport fans and local community members believe that sport organizations have a platform and a responsibility for supporting pro-environmental issues.

Despite growing interest and reported examples of case studies, we still lack sufficient knowledge on GHG emissions and the possibilities for their reduction in sports, especially in team sports. Wicker (2018) has also highlighted the need for sport team related assessments in addition to events. In particular, understanding the need for a holistic approach toward CF assessment and possible reduction actions, as recommended by the United Nations Climate Change (2021), requires practical examples of how sport organizations can reduce their climate impacts and achieve carbon neutrality. McCullough et al. (2020A) call for next advancement concerning the assessment and measurement of environmental sustainability efforts in sport organizations.

This paper therefore focuses on addressing some of these gaps in our knowledge. The aim of this paper is to holistically assess and demonstrate changes in the CF of a professional ice hockey team (PIHT) operating in the Lahti subregion in Finland. The team is called Pelicans, and they have committed to finding their way to achieving carbon neutrality between seasons 2018–2019 and 2021–2022. To our knowledge, this is the first scientific publication related to a sports team's CF and carbon neutrality assessment. This paper also describes the kinds of challenges and uncertainties related to regulating CF in sports and suggests methods to overcome and manage them in the future. It provides a few general recommendations on ways in which sport organizations can assess their climate impacts and presents the kinds of actions required to reduce their GHG emissions.

2. Materials and methods

2.1. Background information

Ice hockey is the most popular sport in Finland (Sponsor Insight Finland, 2022). Before the COVID-19 pandemic, the Finnish professional ice hockey league "Liiga" with it's 15 teams had more than 2.1 million spectators in 2018–2019, with an average of 4200 spectators per match (Liiga, 2022).

The Pelicans, from the city of Lahti, are one of the teams playing in the Liiga. Lahti is the 9th largest city in Finland, with 120,033 inhabitants as of July 2022 (Lahti, 2022). Their audience average, in which the Pelicans rank 7th in the Liiga, is approximately 4000 spectators with 75% arena occupancy. The combined turnover for the Pelicans and their subsidiary restaurant business, was 8.3 million euros (season 2018–2019) (Grönroos and Aalto, 2019). In 2018, they announced an ambitious target to be the first carbon-neutral ice hockey team in the world.

2.2. Carbon footprint (CF) assessments

CF assessments reflect the global warming impacts of a product, a process, or an organization in terms of kilograms of carbon dioxide equivalents ($kgCO_{2eq}$) (ISO 14067, 2018). CF assessment is based on the methodology and procedure of life cycle assessment, which is generally based on ISO 14040 and 14044 standards (ISO 14040, 2006). CF-specific instructions are provided by the ISO 14067 standard. Likewise, this study implemented the instructions of the Greenhouse Gas Protocol for conducting organization level CF assessments and for the scope classification of GHG emissions.

According to ISO 14021, carbon neutrality indicates that all GHG emissions from all stages of the product life cycle have been reduced, removed, or accounted for through a system of offsetting to zero (ISO 14021, 2016). Meanwhile, the IEMA (2020) established a framework for achieving carbon neutrality, which includes the following steps: 1) eliminating or preventing GHG emissions across the life cycle, 2) reducing GHG emissions within operations, 3) substituting processes with lower embodied emissions, and 4) compensating unavoidable emissions. Therefore, the first step to becoming carbon neutral is to understand the current CF based on localized and up to date data, followed by carrying out various emission reduction actions to decrease the CF. Furthermore, although all emissions cannot be avoided, they can be compensated for to achieve carbon neutrality. Nevertheless, the primary focus should always be on reduction actions.

2.3. Goal and scope of the assessment

The goal of this study is to assess the CF for a PIHT (the Pelicans) and to evaluate the impact of the actions undertaken between the 2018–2019 and 2021–2022 seasons on their CF. Therefore, the focus of

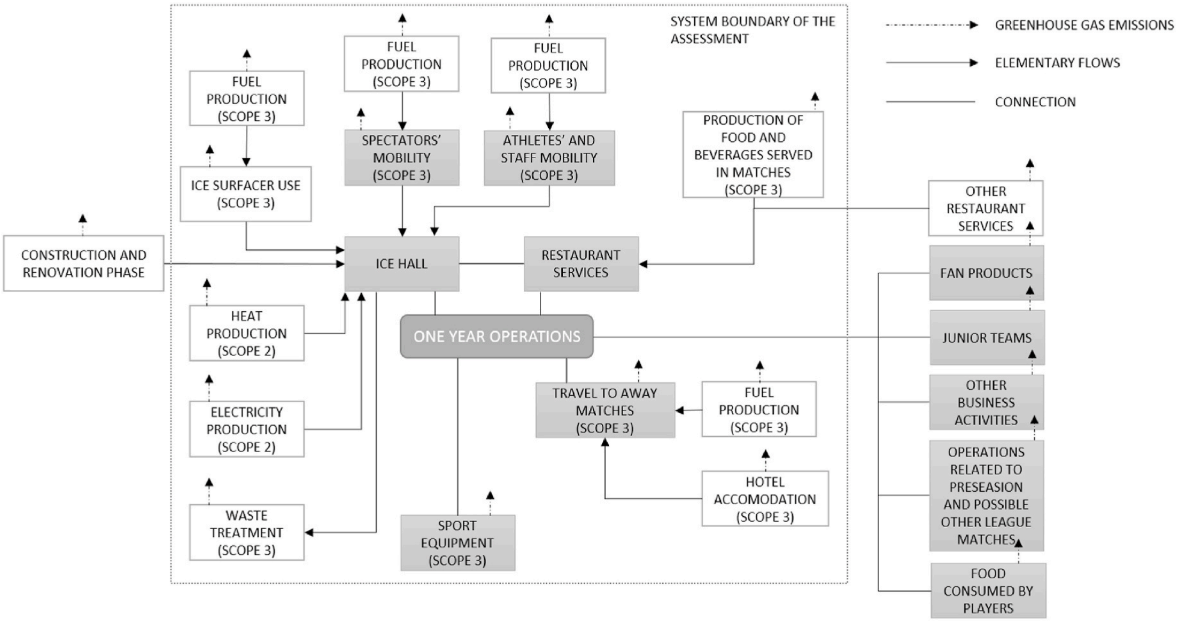

Fig. 1. System boundaries of carbon footprint assessment for the professional ice hockey team applied in this paper.

Table 1
Number of matches, total traveled distance (in kms) by mobility modes and spectator amount at home matches of the PIHT for different seasons within the scope of this study. "H" and "A" refer to home and away, respectively. Differences in total traveling are observed due to the different number of play-off matches.

	2018–2019	2020–2021	2021–2022
Amount of matches			
Regular season matches	30 (H) + 30 (A)	30 (H) + 30 (A)	30 (H) + 30 (A)
Play-off matches	3 (H) + 3 (A) to Helsinki	2 (H) + 3 (A)[a] to Turku	1 (H) + 1 (A) to Kouvola
Travel to away matches			
Plane	2000 km[b]	0 km	0 km
Bus	18,600 km[b]	20,600 km[b]	19,800 km[b]
Service team's van	18,600 km[b]	20,600 km[b]	19,800 km[b]
Spectators at home matches			
Regular season matches	120,554[c]	11,346[c]	65,482[c]
Play-off matches	15,830[c]	0[c]	2929[c]

[a] Required only 2 travels because two consecutive matches were played at home and away due to the COVID-19 pandemic.
[b] Hepo-oja (2018) and measurements using satellite maps.
[c] Liiga (2022).

this study is especially on the 2018–2019, 2020–2021, and 2021–2022 seasons. A functional unit of this assessment, conducted by applying an operational control approach (the GHG Protocol), is one year's operations of the ice hockey team. Although the focus of this study is especially on operations related to the PIHT, identifying the processes that should be considered as part of an ice hockey team's operations is not always clear, because sport organizations may have other operations and businesses, such as restaurants, accommodation services, etc. Although these operations have not been included in this assessment, they could be studied in future research if the scope of the analysis is expanded to cover the whole organization. It is also not clear whether the food consumed by team members should be included in the CF of the team. In this paper, we have excluded GHG emissions related to the food consumed by athletes because these emissions can also be viewed as an integral part of personal CF. However, their inclusion may be considered in future studies.

Fig. 1 presents the system boundaries of the analysis and the life cycle step divisions across Scopes 1–3 according to the GHG Protocol. To understand and measure the level of control of direct and indirect GHG emissions from different operations, the emissions are divided into three scopes. Scope 1 includes all direct GHG emissions of the organization. Indirect GHG emissions from the consumption of purchased electricity and heat are included in Scope 2. Other indirect emissions, such as the production of purchased materials and fuels and transport-related activities that are not owned or controlled by the organization, are covered in Scope 3 (Greenhouse Gas Protocol, 2022).

2.4. *Inventory analysis for carbon footprint assessment*

In this chapter initial data and assumption related to CF assessment have been presented.

2.4.1. *Team's travel to away matches*

Teams travel for 30 away matches during a regular season and to possible addition play-off matches. It should be noted that pre-season matches or other leagues, such as the Champions Hockey League (CHL), in which teams may participate have not been included in this assessment. The number of league matches played by the team during different seasons is presented in Table 1.

The team traveled approximately 18,000 km by bus and 2000 km by plane during the season 2017–2018 to away matches (Hepo-Oja, 2018). We have assumed that there have not been major changes between regular seasons in terms of total traveling because the number of matches and teams have remained the same. The amount of traveling has already been reduced by the league by organizing the season in a way where teams often end up playing a few consecutive away matches during the same trip. The team had previously been flying only to Oulu, which is the furthest away location for their matches, but they decided to quit flying and use the bus instead after the 2018–2019 season. According to the PIHT, on average, 26 people participate in away trips by bus. A leased van for the service team drives separately to each away match. The traveled distances for the seasons are presented in Table 1.

Aviation emissions have been calculated assuming that regional flights lead to 160 gCO$_{2eq}$ pkm^{-1} direct GHG emissions (Graver et al., 2020), while roughly 29% additional emissions from kerosene production are also considered (Claudelin et al., 2022). This is accompanied by

Table 2
Greenhouse gas emissions from mobility (Technical Research Centre of Finland, 2017; Claudelin et al., 2022; Halonen et al., 2023).

Mobility mode	Emissions for 2018–2019 and 2019–2020 [gCO_{2eq} pkm^{-1}]	Emissions for 2021–2022 [gCO_{2eq} pkm^{-1}]	Modal shares for 2018–2019 and 2019–2020 [%]	Modal shares for 2021–2022 [%]	Average two-way distance by mobility modes (all years) [km]
Passenger car (ICE)	94.1 (1.9 people)	84.1 (1.9 people)	64.5	43.8	22.8
Passenger car (electric)	n.a.	9.5 (1.9 people)	n.a.	1.5	22.8
Passenger car (hybrid)	n.a.	41.7 (1.9 people)	n.a.	6.8	22.8
Passenger car (gas)	n.a.	16.6 (1.9 people)	n.a.	0.8	22.8
Bus	61.1	27.6	11.0	14.8	11.8
Train	1.6	1.6	0.6	0.8	157.0
E-scooter	n.a.	1.9	n.a.	3.6	8.7[a]
Cycling	0	0	3.8	3.9	8.7
Walking	0	0	20.2	20.9	5.5
Taxi	n.a.	72.1[b]	n.a.	3.1	22.8

[a] Assumed to be the same as for cycling.

[b] Assumed to be the average of passenger car types.

non-CO_2 radiative forcing effects due to additional emissions from combustion of fuel at high altitudes in aviation. While there is uncertainty regarding the exact magnitude of this impact, this paper has used a factor of 2.0 in comparison to direct emissions (European Commission, 2022).

The PIHT use a EURO 6 bus for their bus travels. Direct emissions and fuel consumption for a EURO 6 bus with 26 passengers for highway drives are approximately 600 gCO_{2eq} km^{-1} and 9.0 MJ km^{-1}, respectively (Technical Research Centre of Finland, 2017). Notably, the bus service provider decided to switch from a regular diesel mix to renewable diesel for the team's travels after the 2018–2019 season. In Finland, it is possible to buy fully renewable diesel, which, according to the vendor, leads to a 90% emission reduction in CF compared to regular diesel mix (Neste, 2020).

Emissions from the service team's van were calculated based on information provided about the relevant van model by the van manufacturer. Direct emissions from this van are 285 gCO_{2eq} km^{-1} and its fuel consumption is 3.8 MJ km^{-1}. An emission factor of 20 gCO_{2eq} MJ^{-1} has been considered for fossil fuel production for transportation in the EU (European Commission, 2015). Similar to the team bus, the van also operated on renewable diesel during the 2021–2022 season.

According to the PIHT, the team stays in hotels for 4–5 nights during a season. Sokos Hotels (2022) is a Finnish hotel chain with 44 hotels in Finland. The chain's calculation of the average CF for a night at the hotel based on guest amounts in 2019 has been considered in this study. According to their estimates, the CF per room is 31 $kgCO_{2eq}$, including GHG emissions related to breakfasts. Since the share of emissions from breakfast is 85% of the total CF, the emission per room excluding breakfast is 4.65 $kgCO_{2eq}$ per night (Sokos Hotels, 2021).

2.4.2. Ice hall

The main ice hall in the city of Lahti is the ISKU Arena, where the PIHT play their home matches and organize majority of their practice sessions. Their office operations, as well as their restaurant, are based in the ISKU Arena. The average heat consumption and average electricity consumption of the ice hall were approximately 961 MWh a^{-1} and 1725 MWh a^{-1}, respectively, for the 2018–2020 duration (Jäähalliportaali, 2018). According to the ice hall operator, the fossil propane-based ice surfacers was changed to electric-based ones in 2021, which slightly increased the annual electricity consumption. The total electricity consumption for 2021 was 1963 MWh a^{-1} and heat consumption 1023 MWh a^{-1}. Propane consumption of ice surfacers before 2021 was approximately 2816 kg a^{-1} and its lower heating value was assumed to be 46.4 MJ kg^{-1}, with a CF of 65 gCO_{2eq} MJ^{-1} (Technical Research Centre of Finland, 2017).

The average GHG emission intensities from the production of purchased electricity, were 160 gCO_{2eq} kWh^{-1}, 193 gCO_{2eq} kWh^{-1}, and 165 gCO_{2eq} kWh^{-1} for 2018, 2020, and 2021, respectively (Lahti Energia, 2021; Oomi, 2020). Heat usage in the ice hall has generally been covered by locally produced district heat. There was a significant drop in district heat-related GHG emissions when a local energy company quit using fossil coal and shifted to renewables in 2019 (Lahti Energia, 2021). The ice hall owner started to purchase fully renewable district heat for the establishment in the beginning of 2022. Emission intensities, as reported by the local district heat provider, were 181 gCO_{2eq} kWh^{-1}, 59 gCO_{2eq} kWh^{-1}, 30 gCO_{2eq} kWh^{-1}, and 0 gCO_{2eq} kWh^{-1} for 2018, 2020, 2021, and 2022, respectively (Lahti Energia, 2021).

Cooling processes in ice halls require refrigerants, which, in some cases, can act as strong GHGs if they leak into the environment (Li et al., 2019). The ISKU arena uses an ammonium-based refrigerant (R717), which has zero GWP (Abas et al., 2018; Jäähalliportaali, 2018). Because ammonium is circulated in a closed loop and is not typically added to the process in high proportions, its contribution to total GHG emissions has assumed to be marginal.

The main waste fractions from the ISKU Arena were 17.3 t (2018) and 9.2 t (2021) for biowaste, 19.5 t (2018) and 24.0 t (2021) for energy waste, and 25.9 t (2018) and 29.0 t (2021) for mixed waste. GHG emissions linked to waste handling have been calculated using waste fraction-specific emission factors, which were 69 gCO_{2eq} kg^{-1} for biowaste, 410 gCO_{2eq} kg^{-1} for energy waste, and 506 gCO_{2eq} kg^{-1} for mixed waste (Green Office, 2021). These emission factors may be assumed to represent conventional waste handling in Finland. Waste management systems are complex, and there can often be variations in the emission factors of different waste handling options. Therefore, the uncertainty related to these emissions is rather high. The waste amounts refer to the total annual waste from the ice hall, with no detailed information available on their exact origins. However, it is likely that most of the waste originates from restaurant services, and it is not necessarily related to the team's sports operations. Due to the lack of exact data, we used a precautionary principle and allocated all the waste-related emissions of the ice hockey team during a season. A season lasts approximately 7 months; therefore, waste-related GHG emissions of the PIHT and other ice hall users were allocated in terms of a 7:5 correlation.

A key question that arises in this context concerns the accurate allocation of emissions related to energy consumption in the ice hall between the PIHT and other ice hall users. In this paper, this allocation was made based on the ice hall's utilization rate. According to Hepo-Oja (2018), Pelicans account for approximately 15% of the total utilization rate of the ISKU Arena. However, this rate seems to vary widely, from 5% to 60%, with a typical rate of 20%, between teams in Finland (Hepo-Oja, 2018). It could also be argued that larger ice halls are

Table 3
Modal shares for athletes', coaches', and staff members' commuting.

Mobility mode	Modal shares (2018–2019) [%]	Modal shares (2021–2022) [%]
Passenger car (ICE)	75	32
Passenger car (hybrid)	0	19
Public transportation	17	25
Active mobility modes	8	24

primarily built for professional teams and, therefore, a higher share should be allocated for the team. We use a high 30% allocation for the team in a sensitivity analysis to evaluate the magnitude of this assumption in the results.

2.4.3. *Spectators' mobility*

Data related to spectators' mobility for home matches were collected using two electronic surveys distributed via email-list of the Pelicans' team followers. The first survey was sent out in spring 2019, and the second in autumn 2022. The main goal of the surveys was to collect information on modal shares (both surveys) and travel distances (the first survey) to matches. Around 346 answers were collected for the first survey, while the second survey garnered 854 answers, based on which mobility-related emissions of the respondents were assessed and scaled to represent the total spectator amounts for home matches. It should be noted that the COVID-19 pandemic and related restrictions had a major impact on spectator amounts for the 2020–2021 and 2021–2022 seasons, as well as on mobility in the city of Lahti (Kareinen et al., 2021). The total number of spectators for the seasons considered within the scope of this study is presented in Table 1.

The modal shares and average travel distances of spectators are presented in Table 2. GHG emissions from mobility modes for the 2018–2019 season were mainly obtained from the Lipasto database (Technical Research Centre of Finland, 2017). For passenger cars with an internal combustion engine (ICE), the average direct GHG emissions were assumed to be 159 gCO_{2eq} km^{-1} for 2018–2019 and 2020–2021 and 142 gCO_{2eq} km^{-1} for 2021–2022 (Technical Research Centre of Finland, 2017). Meanwhile, fuel consumption in a passenger car (ICE) is 2.30 MJ km^{-1} for 2018–2019 and 2020–2021 and 2.05 MJ km^{-1} for 2021–2022 (Technical Research Centre of Finland, 2017). The 15% biofuel blend is assumed to be ethanol acquired from waste feedstocks, which have 12 gCO_{2eq} MJ^{-1} production-related emissions (Jääskeläinen, 2017; Directive 2018/2001, 2018). According to the answers collected from the surveys, each passenger car carries 1.9 people on average. GHG emissions for local buses operating with diesel have been assumed to be 61.1 gCO_{2eq} pkm^{-1} for the 2018–2019 and 2020–2021 seasons (Technical Research Centre of Finland, 2017). Notably, a significant drop in bus emissions was observed during the 2021–2022 season because the majority of the buses operated using electricity and renewable diesel (Halonen et al., 2023). Although emissions from trains are mainly linked to electricity production, the minor diesel usage involved in this context leads to 1.4 gCO_{2eq} pkm^{-1} emissions. Finnish trains use 0.3 MJ pkm^{-1} electricity on average, which is again produced by renewables (Technical Research Centre of Finland, 2017; VR Group, 2019). For the 2021–2022 season, electric scooters appeared on the streets of Lahti. GHG emissions for an e-scooter operating in Finland are assumed to be 1.9 gCO_{2eq} km^{-1} (Claudelin et al., 2022).

2.4.4. *Athletes', coaches', and staff members' commuting*

Information on the commutes of athletes, coaches and staff members were collected in 2019 and 2022. A basic assumption in this context was that, on average, 37 people commute to the ice hall for 150 days per year. In 2019, data were collected using the same electric survey as for spectators from 12 persons, while it was collected from all commuters in 2022. The average one-way commuting distance was 8.0 km for passenger cars and 5.0 km for public transportation. In addition, there were a few people who commuted over 100 km from the capital region—they have been included in the assessment separately. Modal shares for the 2018–2019 and 2020–2021 seasons are presented in Table 3. It should be noted that there is higher uncertainty related to the 2018–2019 shares due to the low number of responses. The same GHG emissions

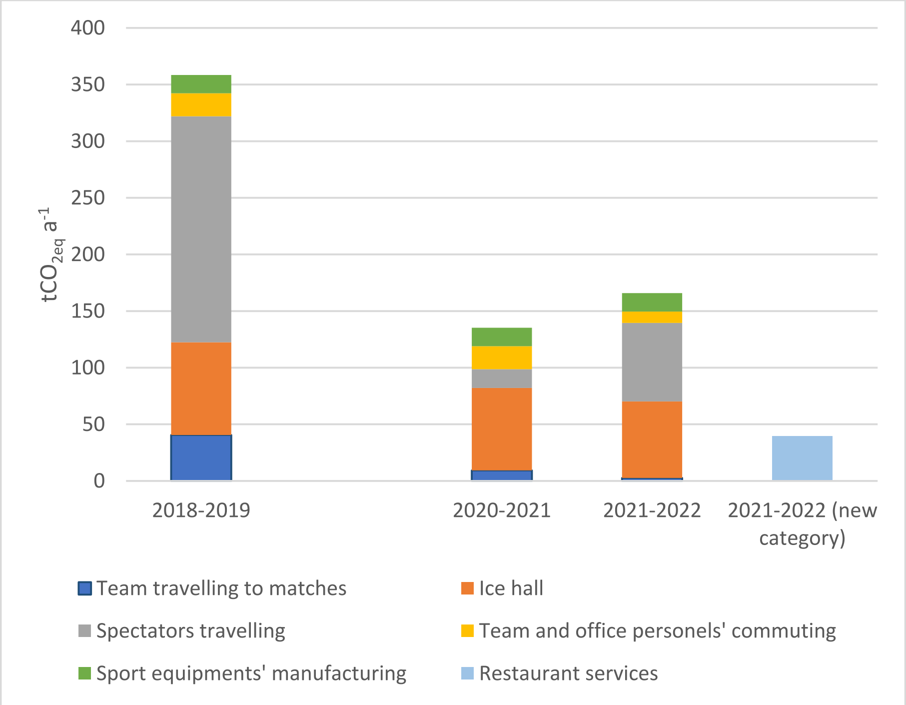

Fig. 2. Total GHG emissions related to the teams' operations for the season within the scope of this study.

Table 4
Break down off GHG emissions from team's traveling to away matches, from ice hall, from athletes,' coaches', and staff members' commuting and from spectators' mobility. All numbers are in tCO$_{2eq}$ a^{-1}.

Category of CF	2018–2019	2020–2021	2021–2022
Team's traveling to away matches	**40.6**	**9.4**	**2.6**
Airplane (direct)	10.7	0	0
Airplane (indirect, non CO$_2$)	8.3	0	0
Service team's van	6.7	7.4	0.7
Bus	14.5	1.6	1.5
Hotel accommodation	0.3	0.3	0.3
Ice hall	**81.8**	**72.7**	**67.6**
Electricity consumption	41.5	49.9	48.6
Heat consumption	26.1	8.5	4.3
Ice surfacer	1.3	1.3	-[a]
Waste handling	13.0	13.0	15.0
Athletes,' coaches', and staff members' commuting	**20.3**	**20.3**	**10.1**
Passenger car (ICE)	16.0	16.0	6.6
Passenger car (hybrid)	–	–	1.3
Public transportation	0.2	0.2	0.4
Shared passenger car and van	4.1	4.1	1.7
Spectators' mobility	**199.5**	**16.6**[b]	**69.4**[b]
Passenger car (ICE)	188.5	15.7	57.5
Passenger car (Electric)	-[c]	-[c]	0.2
Passenger car (hybrid)	-[c]	-[c]	4.4
Passenger car (gas)	-[c]	-[c]	0.2
Taxi	-[c]	-[c]	3.6
Bus	10.8	0.9	3.3
Train	0.2	0.0	0.1
E-scooter	–	–	0.04

[a] Included in "electricity consumption" emissions.
[b] COVID-19 pandemic had a high impact on spectators-mobility.
[c] All passenger cars were assumed to be internal combustion engine (ICE) cars.

Table 5
Annual average, minimum and maximum GHG emissions for each product category in the Pelicans' restaurant services and minimum and maxim.

Category at the restaurant	Average GHG emissions of food	Minimum GHG emissions of food	Maximum GHG emissions of food	Share of food service related GHG emissions
	tCO$_{2eq}$ a^{-1}	tCO$_{2eq}$ a^{-1}	tCO$_{2eq}$ a^{-1}	%
Meat products	16.1	9.7	22.5	41 (33–45)
Alcohol beverages	13.7	12.1	15.3	35 (31–41)
Coffee etc.	3.2	1.5	5.0	8 (5–10)
Other food products	2.5	2.5	2.5	6 (5–9)
Snacks	1.7	1.6	1.8	4 (4–5)
Soft drinks	1.6	1.5	1.7	4 (3–5)
Disposal plates & cutlery	0.6	0.4	0.7	2 (1–2)
Total	39.5	29.3	49.5	100

intensities as for the spectators were used in this assessment.

A total of 11 leased passenger cars were used for commuting in 2022. There was one fully electric passenger car and a diesel-operated van leased for shared use, both of which operated approximately 10,000 km a^{-1}. The passenger car was previously operated using fossil fuels. Emissions related to leased cars have been categorized as Scope 3, as they fall under operating lease rather than financial or capital lease (the GHG Protocol). Notably, although we have allocated 100% of emissions from staff mobility to the PIHT due to the precautionary principle, some share of these GHG emissions is most likely linked to other business activities.

2.4.5. *Sport equipment manufacturing*

So far, there is no available information related to GHG emissions from ice hockey equipment manufacturing. The CF of annual sport equipment purchases can be roughly estimated using an emission factor of 0.491 kgCO$_{2eq}$ USD$^{-1}_{2004}$, as noted in the International Olympic Committee (2018) guide to calculate the CF of equipment used in the Olympic Games. The guide instructs to consider exchange and inflation rates while using the factor. On considering the average USD-EUR exchange rate in 2004 to be 0.80 (Fxtop.com, n.d.) and accounting for the inflation rate between December 2004–2020 (Inflation.eu, 2022), the emission factor for sport equipment is found to be 0.314 kgCO$_{2eq}$ €$^{-1}$. According to the PIHT, the equipment for a field player and a goaltender cost approximately 4000 € a^{-1} and 5750 € a^{-1}, respectively, while the team comprises 23 field players and 2 goaltenders. Some of the sport equipment, such as hockey sticks, are typically fully consumed during a season. However, several kinds of equipment can also be used afterwards, e.g., by junior teams. Although we do not have exact data on this, we have assumed that an equipment can be used for two years on average. Manufacturing-related GHG emissions have, therefore, been allocated accordingly.

2.4.6. *Restaurant services*

The CF of the Pelicans' restaurant services is primarily related to the restaurant and snack products served during matches in the home arena. Therefore, the consumption for one match was calculated considering the average number of spectators before the COVID-19 pandemic, which was then multiplied with the number of home matches. Other restaurant services owned by the Pelicans, such as their lunch restaurant, catering services, summer terrace, and the food provided to the players, were not considered in this study. Product information and consumption quantities for the products were obtained from the Pelicans restaurant services. The CF of the foods and beverages, as well as single-use serving dishes, have been considered based on information about specific products provided by producers or similar products from available databases (Appendix 1). This method of measurement created some uncertainties, which were addressed in a sensitivity analysis that included the possible minimum and maximum GHG emissions (Appendix 1). For CF assessment, the products were divided into seven categories—meat products, other food products, snacks, alcohol beverages, soft drinks, coffee products, and disposable plates and cutlery. Meanwhile, the energy used for food production and the waste generated have both been included in estimations of the total emissions from ice halls.

3. Results

As a result of CF assessment in this paper Fig. 2 presents the total GHG emissions of the PIHT for the selected seasons. The total CF in 2018–2019 was 354 tCO$_{2eq}$, which decreased to 164 tCO$_{2eq}$ in 2020–2021. GHG emission reductions were achieved in team traveling, ice hall-related operations, and in athletes' and office members' commuting. Notably, spectators' emissions fluctuated significantly due to the COVID-19 pandemic. Meanwhile, GHG emissions from restaurant services were calculated for the first time for the 2021–2022 season and, therefore, is presented separately. The most significant GHG emission source was spectators' mobility, followed by emissions related to ice hall energy consumption. Therefore, ice hall-related decisions and improvements seem to play a key role in ice hockey teams' GHG emissions. Energy efficiency, utility rate, and energy production methods define the high share of ice hall-related emissions. The location of the ice hall is also crucial for spectators' mobility options, defining the possibility of using public and active transport modes to access it. The PIHT compensated for their remaining GHG emissions of the 2020–2021 season to achieve carbon neutrality.

While there are no direct (Scope 1) GHG emissions from the ice hockey teams' operations (Appendix 2), Scope 2 emissions related to electricity and district heat production, for which the team is dependent

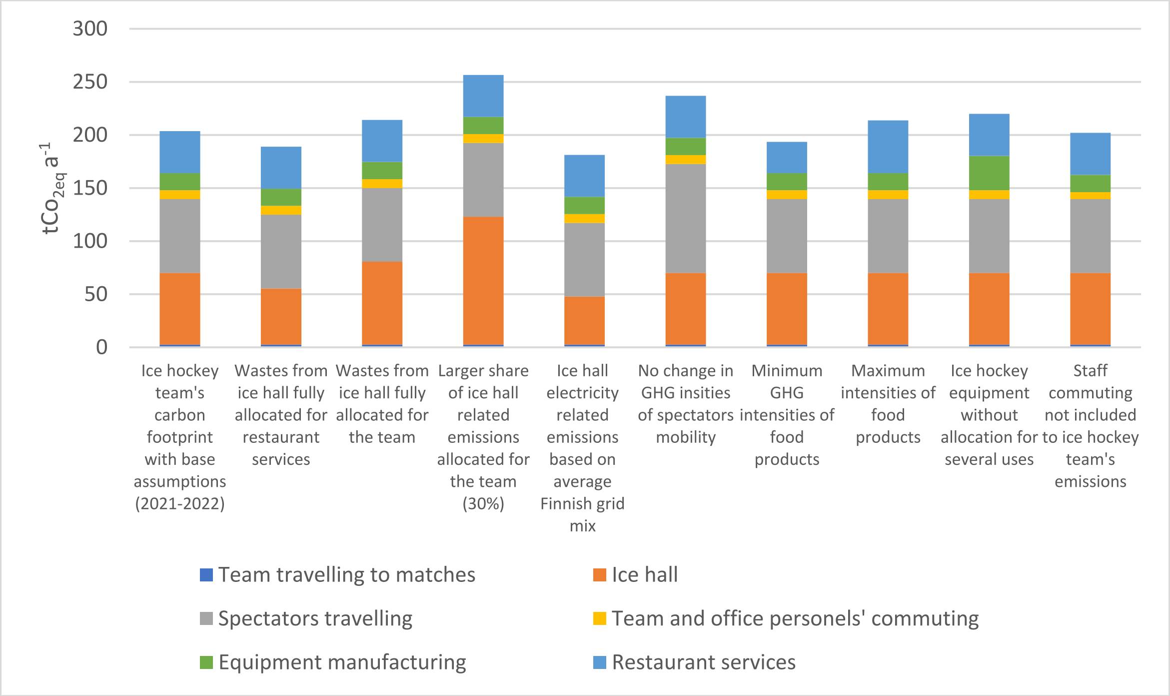

Fig. 3. Sensitivity analysis shows the magnitude of the impact of uncertainties related to the assessment for the season 2021–2022.

on purchased energy production, have been decreasing over time. Since the hockey team is not an owner of the ice hall, it has limited opportunities to impact its energy-related decisions. The majority of the team's GHG emissions belong to the Scope 3 category, which was also concluded previously by McCullough (2023). These emissions have decreased, although spectators' mobility has undergone fluctuations. Moreover, the team has limited prospects of impacting these emissions because they are mainly caused by various stakeholders. This highlights the fact that sport teams and organizations need to actively cooperate with stakeholders to achieve GHG emission reductions because they have limited potential to achieve these reductions by themselves. According to McCullough (2023) scope 3 emissions of sport should be on focus.

Table 4 shows GHG emissions of different categories in more detailed for the study period. GHG emissions related to the team traveling to away matches decreased by 94%, from 40.6 to 2.6 tCO_{2eq} per season. The majority of the reduction was achieved by avoiding flights and shifting to renewable fuels for the team bus and the service team's van. However, the remaining emissions from the team's travels would not be easy to avoid unless new lower carbon intensity energy sources for mobility become available. Moreover, although hotel accommodation plays only a minor role in total emissions, hotels offering accommodation with low CF could be favored in the future.

Dolf and Teehan (2015) recommended to reduce sport event related mobility emissions by reducing long-distance air travel, by increasing vehicle occupancy rates and by encouraging low-emission travel modes and this approach was followed by the case team. An option to further reduce GHG emissions resulting from the team's traveling is to modify the schedules of leagues. According to Wynes (2021), emissions from air travel related to major North American leagues were reduced significantly due to adjustments made for the COVID-19 pandemic. According to the study, leagues could annually reduce 22% of their air travel emissions through schedule adjustments (e.g., cancelling overseas games, geographic sorting, and arranging consecutive games).

A 17% decrease in GHG emissions related to ice hall operations was observed during the study period, (Table 4). This has mainly been caused by changes in local district heat production. Coal usage in district heat production was phased out before the 2020–2021 season. Additionally, carbon-neutral district heat was being purchased from the beginning of 2022. Annual electricity consumption was also affected by changes in weather and in electricity production-related GHG emissions. The fossil propane-based ice surfacer was replaced with an electric one for 2021–2022. Ice hall-related emissions are quite likely to reduce further in the future due to fully carbon-neutral district heat purchasing and changes in electricity production in favor of renewables. By purchasing fully renewable electricity, the ice hall is likely to attain the potential for additional GHG emission reductions. Although some changes have been observed in terms of waste amounts and their related GHG emissions, there may be uncertainties related to accurately estimating this due to ambiguities regarding actual waste handling. Nonetheless, the primary focus for waste management should especially be on waste amount reduction.

There was a huge variation in spectators' mobility-related GHG emissions (Table 4). This has mainly been caused by the COVID-19 pandemic and its impacts on spectator amounts. Our study confirmed the results of Dolf and Teehan (2015) and Cooper and McCullough (2021) that spectators' mobility leads to higher overall GHG emissions than teams' travel to sport events. However, a decrease in spectator-specific GHG emission intensity is also observed from 1.46 to 1.01 $kgCO_{2eq}$ per spectator. This can be explained by the fact that public transport and e-scooter usage have increased, while passenger car usage has decreased slightly. The GHG emission intensities of local buses and passenger cars decreased during this period. Further reduction in emissions could be achieved mainly by replacing passenger car mobility with public transport and active modes of mobility, as well as by reducing the GHG intensity of car usage. This could be done, for example, by increasing carpooling. It should be noted that some uncertainties in the data might have resulted from the timing of the surveys. For example, the share of cycling and e-scooters might be lower during the mid-winter period. This factor could be assessed in future studies.

GHG emissions from athletes', coaches', and staffs' commuting decreased by 55% (Table 4). However, there is a rather high uncertainty related to GHG emissions from commuting in 2018–2019 and

Table 6
Recognized challenges in evaluating and reducing the CF of sport teams and organizations and possibilities to overcome them.

Recognized challenges	Possibilities to overcome challenges
Lack of data on carbon footprints of sport and fan products and equipment	Pressurize sport and fan equipment manufacturers to assess and mitigate their products' carbon footprints. Favor manufacturers who provide carbon footprint information for their products.
Ice hall and sport facility construction-related GHG emissions	When building new sport infrastructure and facilities, carbon footprint assessments should be embedded into the planning and construction phases, and the gathered information should be publicly reported.
Setting system boundaries	Instructions of the GHG Protocol should be recommended and followed in setting system boundaries. Conducting the assessment for the whole organization would solve many of the issues related to system boundaries at the team level.
Allocation of GHG emissions, e.g., ice hall, staff mobility, and waste	Emissions related to a team, a sport, or an organization often must be allocated in terms of other users. The method for implementing this allocation is not always clear. We recommend conducting the allocation based on utilization rates and time. However, a sensitivity analysis of the chosen allocation should be implemented as this would have a high impact on the results.
Origin and actual carbon footprints of food products	Since producer-specific CF information for food products is typically not always available, general CFs for the product categories must be used, although this may cause uncertainties.
Uncertainty regarding whether food consumed by athletes should be included in the assessment	It is not clear whether the food consumed by athletes should be included in the CF of a sport team or remain a part of the athletes' personal CFs. A solution could be to include the food produced in facilities operated by the sport organization in the calculation.
There are typically no or low direct (Scope 1) GHG emissions from sport organizations, while majority of the emissions are linked to Scopes 2 and 3. Therefore, the organization's actions alone have a marginal impact on the total CF.	CF reduction targets and actions should be developed and conducted in co-operation with stakeholders.
Spectators' mobility and commute-related data collection	The initial data on spectators' mobility and commute is typically collected through surveys. However, this is a time-consuming process that cannot be carried out very often. Therefore, this data is accompanied by uncertainties, e.g., related to the timing of a survey (winter vs. spring). Automatic systems to collect mobility data and technological solutions (e.g., measuring the daily number of cars parked by a sport facility) could be implemented in future pilots.
Compensation and selection of compensation mechanism	It can be challenging for sport organizations to recognize reliable and effective ways to compensate their remaining GHG emissions after reduction actions. Compensation mechanisms that involve external verification should be favored. Co-operation among sports should be established to address this matter.

2020–2021 due to the low response rate of the survey. The reduction in GHG emissions has mainly been caused by reduced emission intensity in passenger cars. The share of public transport and active mobility modes seems to have increased, while the GHG emission intensity of shared passenger cars and vans decreased. Similar actions as those taken for spectators' mobility can further reduce commuting related GHG emissions. Increased work-from-home opportunities for office staff would further reduce the total amount of commuting.

Manufacturing ice hockey equipment leads to approximately 16.2 tCO_{2eq} emissions per season. However, there is high uncertainty related to the amount of these emissions due to the lack of ice hockey equipment-specific data. Nonetheless, producers can take concerted steps to reduce GHG emissions related to equipment manufacturing. There are a few examples of sport equipment CFs that have been published by manufacturers, e.g., for polyester sport t-shirts (Fat Pipe, 2022). Extending the life cycle of equipment through repair and second-hand use may help reduce the total emissions linked to sports equipment.

The food services offered to spectators during a game produce average GHG emissions of 1280 $kgCO_{2eq}$. Considering the number of matches during the 2021–2022 season, the yearly GHG emissions were found to be 39.5 tCO_{2eq} (Table 5). The average annual GHG emissions of each product category. Considering possible uncertainties, the estimation of yearly GHG emissions varies between 29.3 and 49.5 tCO_{2eq}. The largest impact comes from meat products, comprising 41% of the average GHG emissions, followed by alcohol beverages with a 35% contribution. Moreover, even after accounting for uncertainties, meat products and alcohol beverages remain the two product categories with the highest impact on GHG emissions. The Pelicans have made improvements with the aim of decreasing the GHG emissions of their restaurant service. During games, drinks are generally served in cans, while cups are provided only on special request.

CF assessments typically suffer from uncertainties related to initial data, system boundaries, assumptions, and methodological selections. Therefore, we performed a sensitivity analysis of nine parameters that we recognized as posing high uncertainty. As shown in Fig. 3, the allocation of emissions is one of the factors that cause relatively high uncertainty. Uncertainty was also recognized in relation to set system boundaries (e.g., inclusion of staff members' commuting), initial data (e.g., use of national or producer-specific emission factors for purchased electricity), and survey data (e.g., modal share change in spectators' mobility).

One of the categories that was not within the scope of this study is fan product manufacturing. The apparel industry is responsible for 10% of all carbon emissions globally (McFall-Johnsen, 2020). Considering the number of sports teams, fan apparel and shipping most likely lead to significant emissions globally. For example, Fanatics, a global sports merchandising manufacturer in charge of licensing production for the NHL, NBA, and NFL, is estimated to reach $5 billion in revenues in 2022 (Azevedo, 2022; Fanatics, 2022).

Since most sport organizations do not have the option to reduce all GHG emissions associated with their activities, carbon neutrality must be achieved using external GHG emission reductions from voluntary carbon offset markets (Broekhoff et al., 2019). Third-party approved compensation projects (e.g., installing renewable energy capacity, energy efficiency improvements, reforestation initiatives) can therefore be used to offset the remaining emissions (International Carbon Reduction and Offset Alliance, 2022). However, there are uncertainties related to the reliability and quality of these compensation projects. To address this, the following criteria presented by Broekhoff et al. (2019) should be followed. McCullough (2023) has highlighted that environmental impacts of sports are inevitable, despite attempts through carbon offsetting and there should be considerations for which environmental impacts are acceptable.

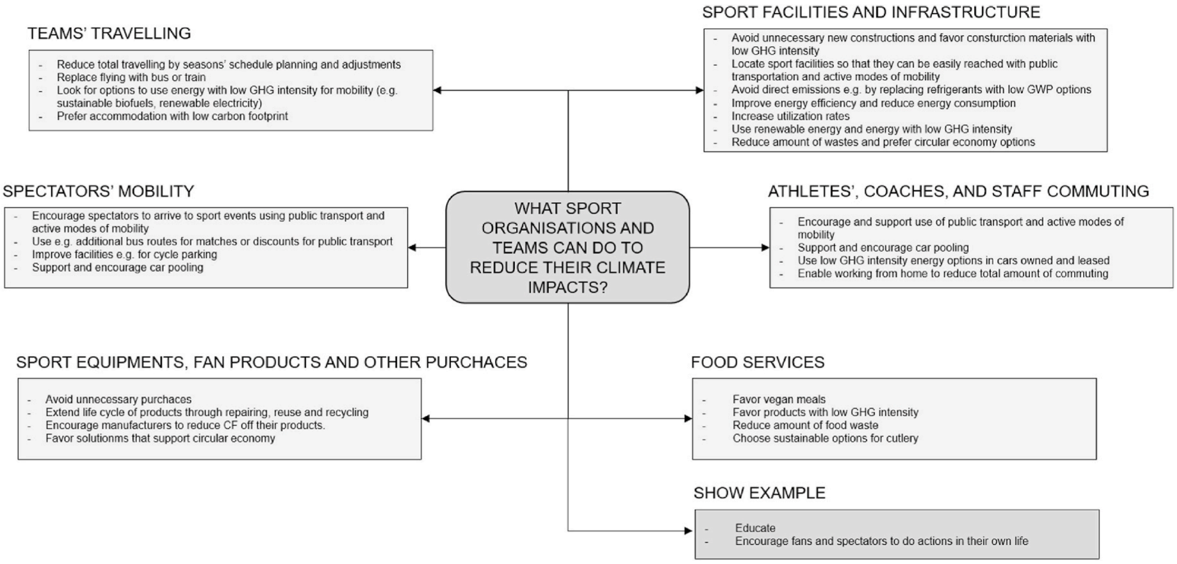

Fig. 4. Framework for actions that sport organizations and teams can undertake to reduce their climate impacts.

4. Discussion

This paper shows that it is possible to assess the CF of sports teams and achieve significant reductions in emissions through various actions. Through this study, we seek to initiate productive conversations on ice hockey, as well as other sports, as a team sport that can take effective steps by planning, executing, and measuring their actions and implementing a holistic plan for environmental management. The scope of research on this topic can be broadened further by evaluating the actions undertaken by other sports and sport organizations (cf. Cury et al., 2022). Sport organizations may face some familiar challenges when conducting similar types of assessments to improve their environmental sustainability through CF actions. These challenges and the possibilities to overcome them are listed in Table 6.

There are uncertainties related to scopes and uncertainties of such studies. It is not always clear which operations should be a part of teams' operations, which are linked to organizations, and which should be considered as a part of athletes', spectators' or stakeholders' carbon footprints. Similar challenge was earlier recognized by Collins et al. (2009). In their environmental analysis for sport events, they concluded that it was difficult to practically consider all the environmental ramifications of event-related consumption.

There exists a knowledge gap regarding how sports can act as a platform for behavioral change and how they, along with athletes, can influence fan behaviors on an everyday basis. Future research should focus on further investigating this topic. A previous study found that even though spectators may engage in sustainability practices at sport venues, they are not likely to adopt these practices as part of their norms and subsequently transfer these pro-environmental efforts to their everyday practices (Casper et al., 2017). Thormann and Wicker (2021a) analyzed active sport club members in Germany and their results revealed that environmentally consciousness members behave more environmentally friendly. In this context, sustainable lifestyles attained through sports could also be a worthwhile topic for future studies in this field. To this end, we believe sport organizations and athletes can play significant exemplary roles in bringing about sustainable change, but more information is required on how this linkage functions. We also know that such a change is always accompanied by its own set of challenges.

Our study offers several key takeaways for managing sport organizations to become more environmentally sustainable in the future. Although our focus in this study is on a rather national level, where it is observed that reduction in CFs can be achieved most often by focusing on practices and strategic decision making, we still need to involve all stakeholders to join the purpose. In the case of ice hockey, collaborative partnerships and international collaborations could play significant roles in this respect. New and innovative ways to engage in stakeholder cooperation could reduce environmental impacts, since environmental sustainability requires collective effort at all levels (local, regional, national, and international). In other words, a complex interplay of negotiations with policymakers and stakeholders at different levels should be encouraged. Apart from this, strategic and well-planned collaborations between practitioners and academic scholars could lead to more efficient use of management functions, such as limited financial and human resources, which could ultimately lead to reduced negative impacts on the environment. Furthermore, maintaining vital and ongoing dialogue between practitioners and academic scholars can not only assist current environmental inputs, but also identify areas for potential collaborative endeavors to steer policymaking. A more thorough understanding of the processes involved in sporting events and seasons, which would offer a long-term perspective for assessing changes, is also recommended. The finding of this paper support to improve understanding on concept of "sport ecology" recommended by McCullough et al. (2020B). Despite actions done in the sport sector Gammelsæter and Loland (2023) concluded in their review that "neither sport's governing bodies, governments, nor the sport industry are currently enforcing effective measures to transform elite sport into an activity that contributes to global cooling". In their analysis they demand degrowth in addition to climate friendly policies. According to McCullough (2023) we should now focus on actions to sustain sport and the natural environments.

Fig. 4. presents a framework based on the assessments of this paper on the possible actions that sport organizations and teams can take to reduce their CFs. This framework can help organizations holistically recognize possibilities to manage improvements in their operations in terms of climate impacts.

5. Conclusions

This was the first study to assess holistically sport team's, especially in ice hockey, carbon footprint and it's changes towards carbon neutrality over three seasons by using life cycle assessment methodology. The study shows that sports teams have multiple opportunities to reduce their climate impacts. In addition to GHG emission reductions, carbon neutrality may also be achieved through compensation.

We observed that the carbon footprint of a Finnish professional ice hockey team was 354 tCO_{2eq} during the 2018–2019 season, which was reduced to 164 tCO_{2eq} in the 2020–2021 season. The majority of these emissions originated from spectators' mobility and ice hall energy consumption. Furthermore, the highest GHG emission reduction was achieved in the case of the team's mobility, ice hall-related emissions, and spectators' mobility.

Since some uncertainties persist in terms of setting system boundaries at the team level, more organizational-level studies need to be conducted in the future to address them. Due to the lack of data related to sport equipment carbon footprints, manufacturers must be addressed by encouraging the collection of more information and to reduce the environmental impacts of production processes.

The majority of the GHG emissions seem to be related to Scope 2 and 3 categories, which indicates that co-operation among stakeholders is crucial for emission reductions. We recommend future research to focus especially on scope 3 emissions of sport teams. It is important to increase understanding on how scope 3 emissions could be measured more easier and perhaps automatically especially related to spectators' mobility and how sport organizations can impact on their scope 3 emissions. We recommend that all sport teams and organizations should take appropriate actions to mitigate their climate impacts in a holistic manner.

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CRediT authorship contribution statement

Ville Uusitalo: Conceptualization, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Vilma Halonen:** Methodology, Writing – original draft. **Heidi Koljonen:** Methodology, Writing – original draft. **Suvi Heikkinen:** Conceptualization, Writing – original draft, Writing – review & editing. **Anna Claudelin:** Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2024.120455.

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