Artificial turf pitch of the future

Test- and development project on Silkeborgbanen

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1. Project description

At the Søholt Sports Facility on Ansvej in Silkeborg, Silkeborg Municipality has installed two new, third-generation artificial turf pitches next to an existing artificial turf pitch and the JYSK Park football stadium.

The new artificial turf facility at Søholt was designed according to the recommendations described in the joint European guide for the construction of artificial turf pitches – CEN report (DS/CEN/TR 17519 – "Surfaces for sports areas – Synthetic turf sports facilities – Guidance on how to minimize infill dispersion into the environment").

The purpose of the project in Silkeborg was to verify whether the recommendations described in the CEN report are sufficient to keep the spreading of microplastics below a 7 g/m^2/year limit. This corresponds to maximum 50 kg a year per 11-a-side football pitch. Furthermore, the project builds on experience from the test project finalised by the Swedish environmental consultancy company Ecoloop in Kalmar, Sweden, in 2019. In connection with the "Ecoloop"- project, the conclusion was that the dispersal of rubber granules can be kept at an absolute minimum if pitches are constructed with simple containment measures – so called Risk Management Measures (RMM) – including fencing with barriers along the perimeter of the pitch as well as specially designed clean-down points at entrance/exit areas.

In the Silkeborgproject, the effects of Risk Management Measures such as the pitch design, including fences and barriers, entry and exit points, along with maintenance, on the dispersion of microplastics will be measured, estimated and documented following the practises and methodology from similar studies.

1.1. Background for the study

Previous studies have been made for the establishment of the potential rubber granulate discharge from artificial turf pitches. In Figure 1 the breakdown of the mass balance for rubber granulate discharge from artificial turf pitches without risk management measured is illustrated based on current studies from Germany, The Netherlands, Norway, Sweden and Denmark.[1]

[1] Løkkegaard, Malmgren-Hansen, Nilsson: Mass balance of rubber granulate lost from artificial turf fields, focusing on discharge to the aquatic environment, Teknologisk Institut, 2019

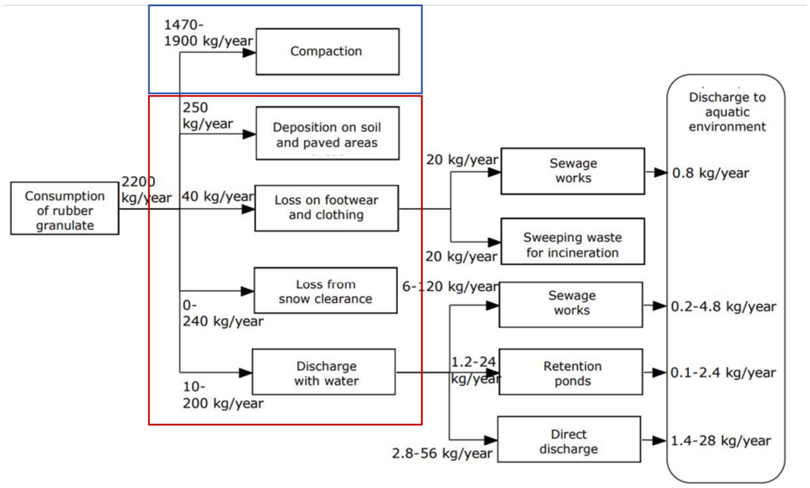

Figure 1: Breakdown of mass balance for rubber from artificial turf pitches

Here, it is seen that the majority of the consumption of rubber granulate is due to compaction. However, this mass balance also illustrates the need for analyse and document the effects of different RMM, as new CEN report measures aim for a release to the environment of less than 50 kg/year.
This mass balance overview also underlines that on an artificial turf pitch with granulate infill, the main pathways of emissions are:

- Over fences and barriers
- At player entry and exit points
- Transport with maintenance equipment
- Drainage water

To assess the total emissions from the pitches, monitoring of the individual pathways are essential.

1.2. Pitch design and risk management measures

The artificial turf pitch in Silkeborg was designed and installed according to the recommendations described in the joint European guide for the construction of artificial turf pitches (DS/CEN/TR 17519), aiming at a total discharge of rubber granulates below 7g/m^2/year or up to 50kg/year for the pitch area.

An illustration of the layout and installed risk management measures are illustrated in Figure 2 below.

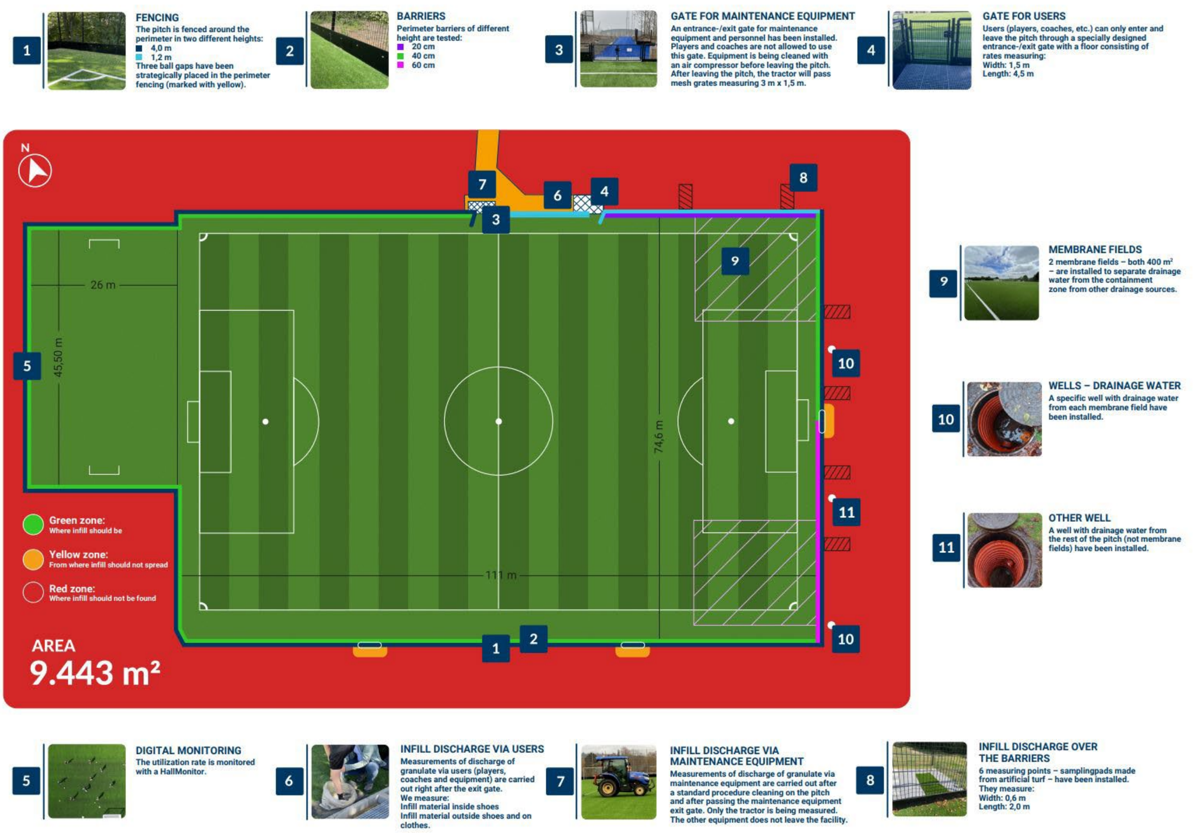

Figure 2: Pitch layout and risk management measures of the artificial turf pitch

In summary, the pitch is designed with

- Barriers and fencing along the sides of the pitch (1-2). In this case, these are in varying heights to evaluate the effects of barrier of an approximated height of 20cm, 40cm and 60cm.
- Gate for maintenance equipment (3) allowing maintenance equipment to leave the pitch. There is subsequent cleaning of the maintenance equipment before leaving the facility (where rubber granulates are allowed).
- Gates for users (4), forcing the players to leave the pitch through this exit, which leads them over a grate to help remove of rubber granulates from the outside of shoes before entering the "red" zones
- Digital monitoring of the use of the pitch (5)
- Membrane fields that cover approximately 10 % of the pitch. The membranes drain the pitch and isolate the drain water from the surrounding materials. This enables an accurate analysis of contributions of contaminants solely from the materials that form the pitch (9)
- Wells separating the drainage water from the membrane fields and from the rest of the pitch (10-11).

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2. Main Conclusion of the study

The four main pathways of infill dispersion were studied, i.e. the dispersion of materials over fences and barriers, along with the effect of barrier heights; the emission of materials via players and equipment; the dispersion of material via maintenance equipment; and the dispersion of materials via drainage.

The collective emission from these pathways is illustrated in Figure 3 below. Overall, these studies show, that the major pathway for of the infill materials is over fences and barriers. This dispersion pathway can however be substantially reduced by increasing the height of the barriers. Furthermore, large seasonal variations are observed, where significantly larger emissions are observed in winter periods compared to summer periods. A large amount of this observed difference can however be attributed to winter maintenance of the pitch (see results and discussions in section 4.1 - Fences and barriers).
These results illustrate, that with barrier height of 60cm, the total dispersion of rubber infill material can be kept below 30kg/pitch/year, and with focus on winter maintenance a barrier height of 40cm is expected to be sufficient for keeping the total dispersion below 50kg/pitch/year. Further elaboration of the main findings on the individual pathways are discussed below.

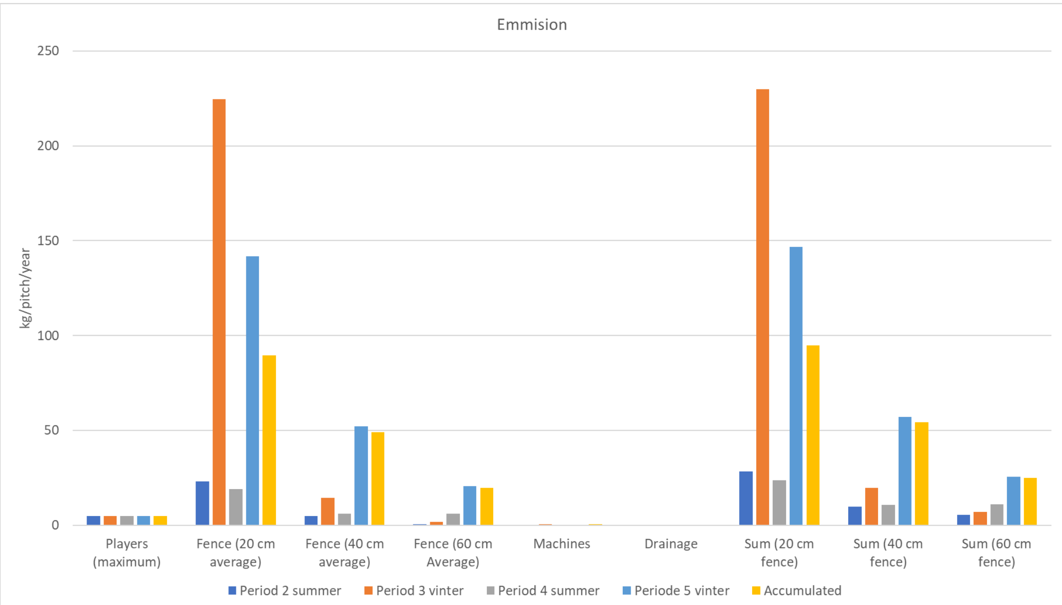

Figure 3: Individual emissions and total emission based on average fence height (all seasons)

Fences and barriers

As already stated, dispersion over pitch barriers are the main pathway of infill dispersion from the pitch area if good practices are maintained for players and maintenance equipment leaving the pitch area. When considering the summer periods, emission over the barriers can however be kept under 10-12 kg/pitch/year by using barrier heights of 40cm or above. However, in the current study, emissions over the barriers seems to depend highly on the maintenance during winter periods with snow clearance. On Søholt in Silkeborg, snow piles have been observed melting near the sides of the pitch area (and close to the fences) on numerous occasions, leading to the possible conclusion, that cleaning for and melting of snow can contribute significantly to the emissions, if not handled carefully and not along the fences of the pitch. Design with an extra safety zone where removed snow from maintenance can be kept (as exists partly in Silkeborg) can be a solution.

Players

Emission from players and their equipment (footballs, cones, vests) was rather low but comparable to other studies in grammes per player. The emission was less than 5 kg/pitch per year but will increase with increased use of the pitch (at Søholt, the pitch is used by an average of appr. 255 players per week).

Maintenance equipment

Emission from maintenance equipment which leaves the field areas are low as they are cleaned with compressed air inside the field. The amount left on tractors was estimated to <0,4 kg/pitch/year However, as mentioned above, the maintenance routines are an important factor to consider, especially during the winter season, where the placement of snow removed from the pitch can have a large impact on the total yearly dispersions. Snow piles should be kept away from the pitch barriers, or be removed to dedicated zones, that does not allow the collected infill material in the snow to escape these zones.

Drainage

In the drainage analysis, limited contamination exceeding the Danish environmental objectives for Danish freshwater environments were found. Generally, most values are around or below Danish requirements in relation to drinking water. No micro rubber was detected – i.e. rubber granules or rubber granulate residue – in the drainage water, however a very small amount of microplastic was detected: 0,4kg/pitch/year.

Rainwater and drainage water was tested for PFAS contamination. Results show PFAS values below the Danish limit values for aquatic environments and around or below the Danish requirements in relation to drinking water. In respect to PFAS, both rainwater and drainage water from Silkeborgbanen with rubber granulate as infill and rainwater and drainage water from an artificial turf pitch with sand as infill ("Gødvad-banen2 by Dybkjærskolen) was analysed. Data did not indicate that rubber granulate as infill material should be a significant source of PFAS contamination.

3. Recommendations from the study

Based on these studies, our main recommendations for RMM in relation to artificial turf pitches are:

- The height of the pitch barriers are very important, and in summer periods (or periods without snow), the infill dispersion can be kept below 10-12 kg/pitch/year with barriers of 40cm height.
- In areas with snow, maintenance routines are very important, and snow piles should not be left near the pitch barriers. Either these should be far from the barriers, or dedicated zones should be established to ensure that infill materials will not leave the areas with melting snow.
- For maintenance equipment, this should be left inside the dedicated area, or good cleaning routines should be established (fx pressurised air cleaning). With these measures in place, emissions from maintenance equipment can be kept under 0,4 kg/pitch/year.
- Gates should be established for players and other users of the pitch area, forcing them to exit the pitch through dedicated exit point, where grates are installed ensuring the removal of the majority of infill material from the outsides of shoes can limit the dispersion via players to below 5kg/pith/year (at Søholt in Silkeborg). Further, instructions on how to empty shoes for remaining infill materials or collection of these materials in changing facilities could further limit the dispersion of materials.

On the basis on the knowledge gained through this project, we have two recommendations for further studies:

1. A study with a focus on maintenance during winter condition (snow)
2. A study on how new alternative infill materials will behave and spread from pitch areas.

4. Documentation of emissions from artificial turf pitches

4.1. Fences and barriers

As most artificial turf pitches are symmetrical with barriers on the side and ends of the pitches, it will typically be representative to measure the emission to the environment of rubber granulates over the sides of the pitch on one quarter of the pitch. However, to study the effect of barrier hights, there are three different barrier hights at Silkeborgbanen and measurement fields installed as described below and as illustrated in Figure 5.

- Along the top side of the pitch, the barrier hight is 20 cm. Here two measurement fields are installed, one is near the corner flag, where a higher emission is often observed, and one in the middle of the top quadrant
- At the end of the pitch, there is a 40 cm barrier from the top to the centre of the pitch (behind the goal), where two measurement fields are installed
- At the end of the pitch, from the centre and down and along the bottom side, the barrier hight is 60 cm. Here two measurement fields are also installed symmetrical to the sampling fields for the 40 cm barrier.

In a short pretest of 26 days, sampling on 2 meter wide geotextile was performed to make an overview of where the emission was worst. After this it was decided to sample using a special method developed at DTI.

Sampling on a measuring point was done on sampling areas 60 cm wide and 200 cm long perpendicular to the fence as shown in Figure 4. In this study, sampling pads made from artificial turf (see Figure 4) was used. This ensures capture of the particles emitted and limits removal of particles from the sampling area caused by fx wind. The sampling areas are fixed by using proper fixation. The sampling positions for fences is shown Figure 5.

Figure 4: Sampling pads for granulate emitted over fences and barriers.

Figure 5: Illustration of Silkeborgbanen, with sampling positions and fence-heights

The results are presented for each sampling position recalculated to emission in kg/pitch/year in Table 1 and Figure 6. For calculation a total circumference of the pitch of 360 m has been used.

Table 1 Emission over barriers (kg/pitch/year)

Sampling Position		Period 1 summer [2]	Period 2 summer	Period 3 winter	Period 4 summer	Period 5 winter	Accumulated
1	Long side middle 20 cm	1.18	6.05	53.3	8.17	253	107
1x	Long side middle 35 cm					132	132
2	Long side at corner 20 cm	1.59	40.2	396	29.8	0.00	342
2	Long side at corner 60 cm					53.5	53.5
3	Goal side towards corner 40 cm	0.14	1.51	25.3	3.82	10.5	15.6
3y	Goal side towards corner 0 cm					30.6	30.6
4	Behind goal 40 cm	0.64	8.13	3.52	8.06	13.8	10.0
5	Behind goal 60 cm	0.42	0.62	1.68	6.56	5.23	3.83
6	Goal side towards corner 60 cm		0.14	1.59	5.44	3.20	3.05
7	Long side (near lake) at corner 20 cm					6.33	6.33

Period 1: 10/6-22 to 6/7-22 (26 days)
Period 2: 6/7-22 to 2/12-22 (149 days)
Period 3: 1/12-22 to 22/3-23 (111 days)
Period 4: 22/3-23 to 6/7-23 (106 days)
Period 5: 11/8-23 to 14/3-24 (215 days)

[2] Period 1 was a very short sampling period in summer in a pre-campaign using 1 month and sampling on geotextile. It is not expected to be as representative as the longer sampling periods.

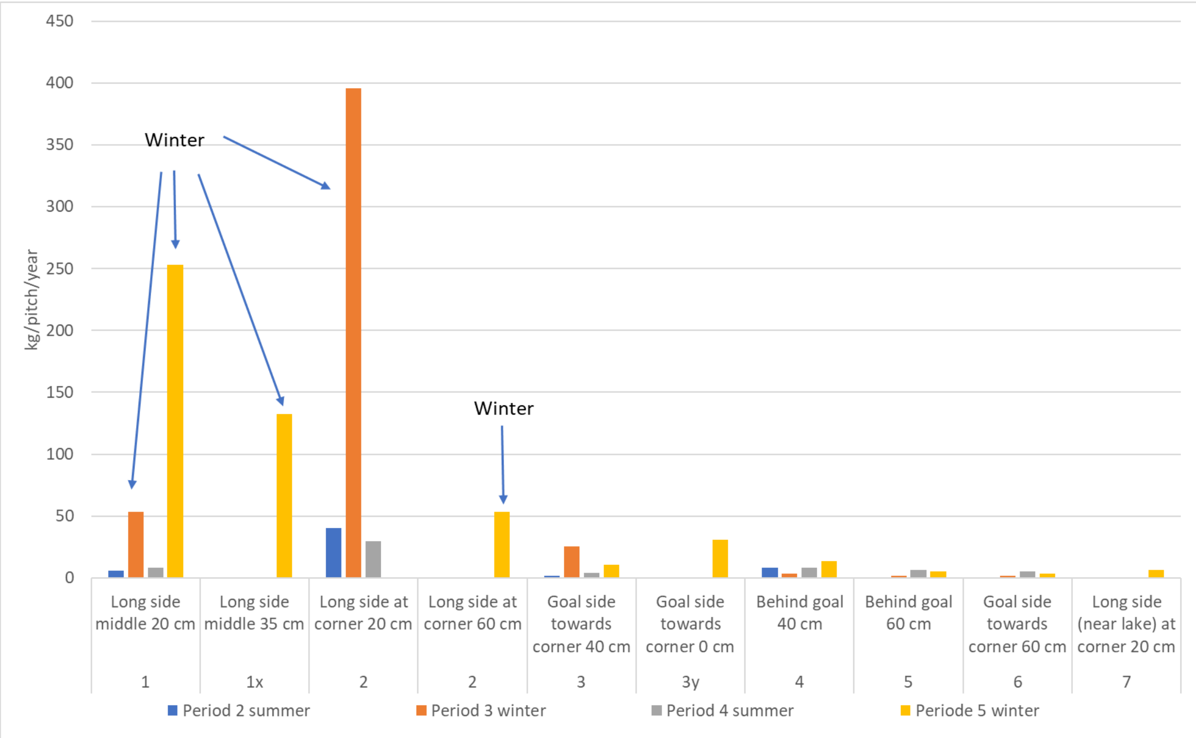

Figure 6 Emission over barriers (all heights)

When comparing the results obtained at different barrier heights and different periods (Table 1 Emission over barriers (kg/pitch/year), there are some observations to be made:

1. The emissions vary extensively with the seasonal variations and show a much higher emission during winter periods (periods 3 and 5) compared to summer periods (periods 2 and 4). This is especially evident at sampling areas 1, 1x, 2 and 3
2. Emissions vary (as expected) with barrier height moving from 20cm through 40cm to 60cm
3. Emissions are particularly high at sample position 2 – "long side corner". This is also evident when comparing this position to position 1 – "long side middle" and, there is a significant difference between the two "symmetrical" positions "2 – Long side corner" and "7 – long side (near lake) corner"

When comparing the results in Figure 6 on specific (comparable) locations we also see that emissions vary as expected with height of fence at the following locations and seasons:

- Summer period 2,4: Emission is higher for 40 cm (4) than for 60 cm (5) on goal side
- Winter period 5: Emission at 0 cm (3y) is higher than at 40 cm (3)
- Winter period 5: Emission at long side 20 cm (7) is higher than the nearby goal side 60 cm (6)
- Winter period 5: Emission is higher for 20 cm (1) than for 35 cm (1x) on long side

Ad 1: These very high seasonal variations at positions 1, 1x and 2 indicates that operations that is seasonal dependent has a significant influence on the emissions over the barriers. In Silkeborg, snow piles melting near the sides of the pitch have been observed on numerous occasions, leading to the possible conclusion, that cleaning for and melting of snow can contribute significantly to the emissions, if not handled carefully and not along the fences of the pitch.

Ad 2: The variation of emissions as a function of barrier height is modelled [3]and shown in Figure 7. for the entire winter and summer periods as well as the accumulated emission over the complete campaign duration. This clearly illustrates the importance of fence height for reducing the emission.

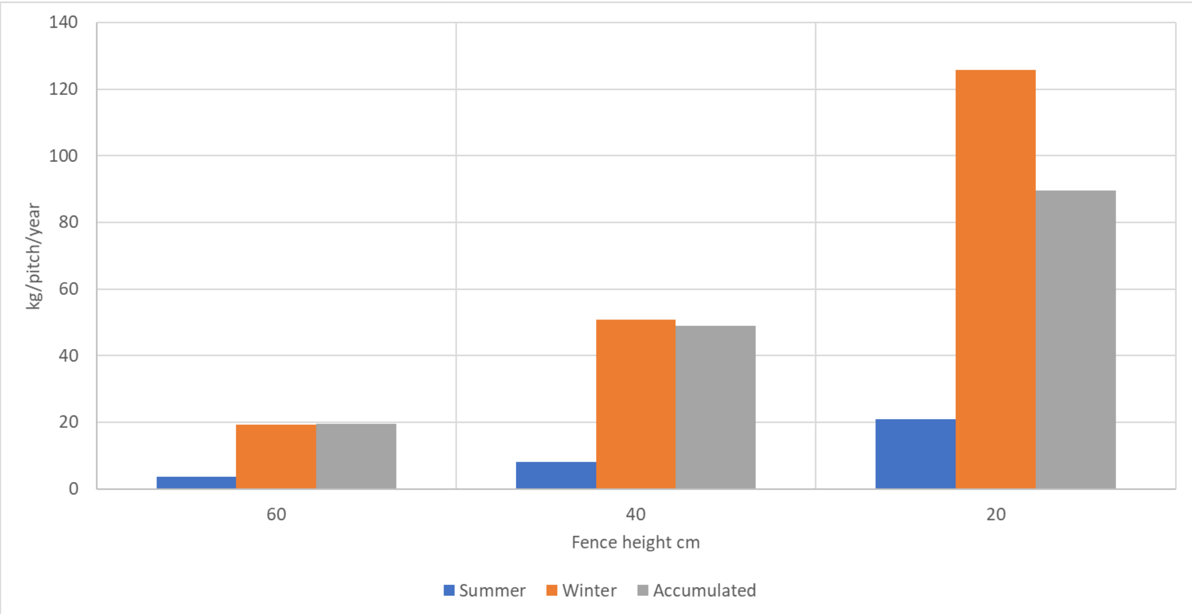

Figure 7 Estimate of emission over fence vs. Height of fence

Ad 3: It is observed that there is a much higher emission on long side at the corner (pos.2) in the summer period 2,4 than on the long side middle (pos.1). Furthermore, the emission in pos. 2 in summer is also higher than the emission on the lake side (winter period 5). This could indicate that a higher amount of rubber is spread towards the entrance side caused by maintenance procedures. This is further substantiated in Figure 8, where it is seen that there is a higher concentration near the fence at left side (entrance side) than in the middle of the field. This inhomogeneity can likely be attributed to maintenance procedures and will increases the risk of spill over the fence. It must be mentioned that the emissions

[3] The model uses the measured emissions for all long sides and goal side sampling points for emission for calculating an emission for the complete field.

on the left side was caught in the zone running from inner fence to an outer fence, which is expected to be used as spectator area classified as a yellow zone.

Figure 8 Drone picture. Left is entrance side where increased emissions has been observed at corner and in winter conditions.

As the sampling fields in this campaign was divided into two parts, each of 1m in length, it has been possible to estimate the distribution of emissions over the barriers within the first meter of the pitch and the second meter from the pitch. The results of this is illustrated in Figure 9, where it is observed that approximately 70% of the total emission over the barriers is present within the first meter from the barriers in most cases.

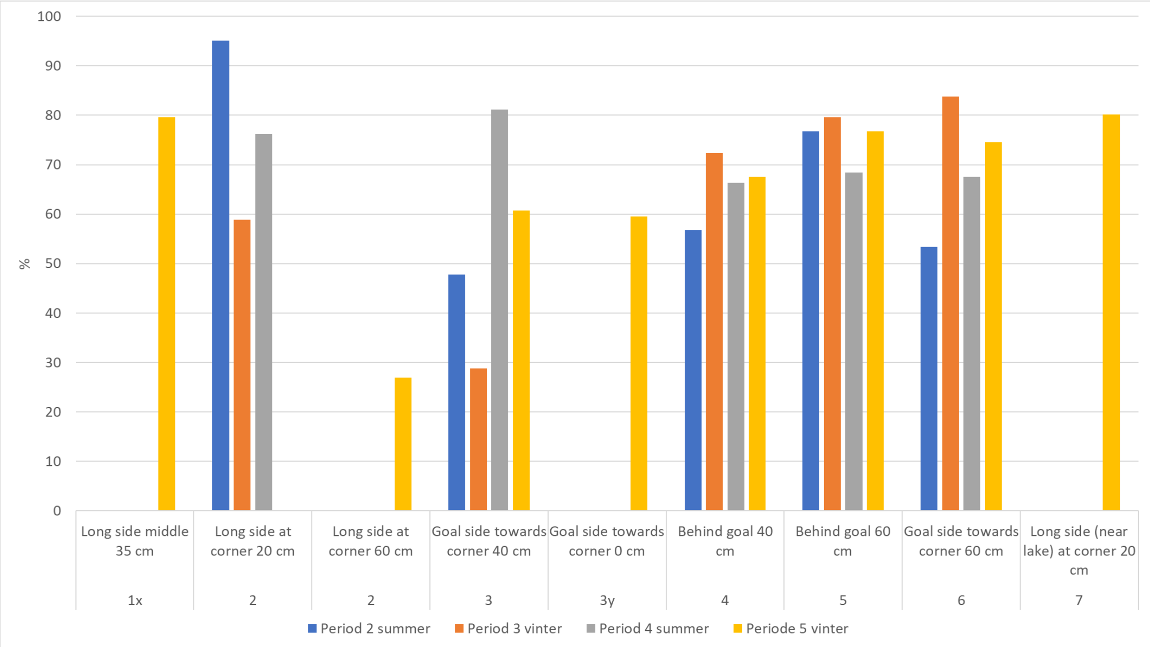

Figure 9 Emission share in % on the first meter of the two meter sampling length

4.2. Players and Equipment

The study of emission of granulate via players have been conducted two times. These measurements have been done in such a way, that they are representative for the use of the pitch area e.g. in dry and wet condition and representative of typical use of the pitch. In Silkeborg, the focus of the sampling from players were in:

1. Infill material inside the shoes of the players
2. The sum of infill material outside shoes and on clothes.

Equipment used on the pitch, such as balls and cones also contain some material which was measured as required in the standard. When performing measurements of emission of granulate via players, it was without instructing the players to behave differently than a normal training/game session, as extra instruction can affect the way the players behave when exiting the pitch area.

The emission of granulates from players and player equipment are shown in Figure 10 recalculated to kg/pitch/year.

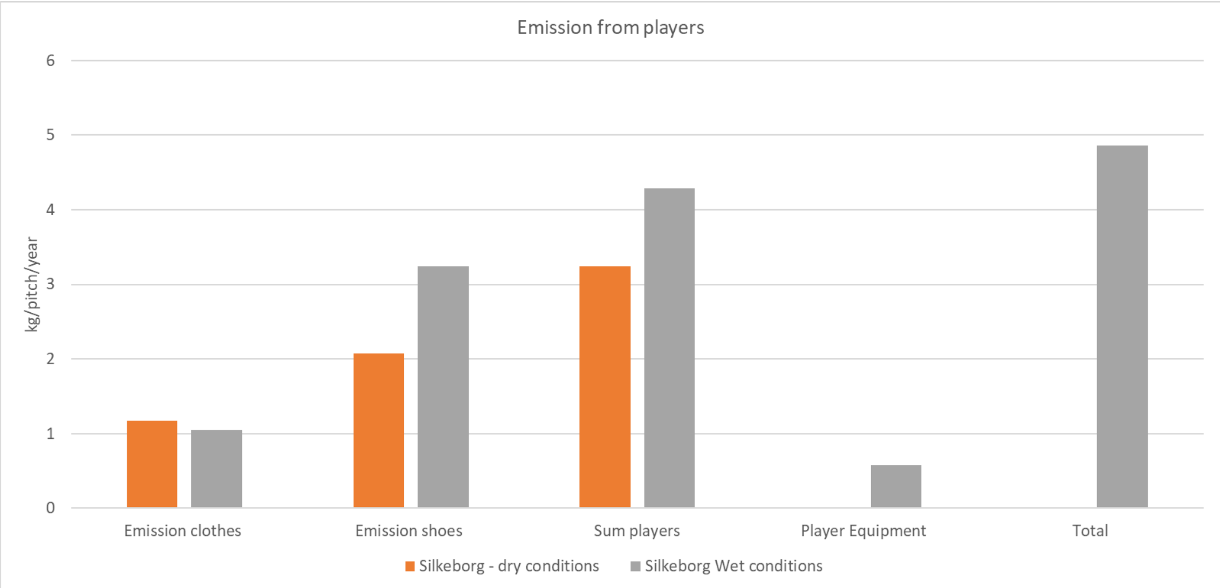

Figure 10 Emission from players and Player equipment

The maximum emission was 4.9 kg/pitch/year from players and player equipment. The figures shows that approximately 66-75% of the emission with players are from granulate in the shoes.

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The measurements performed on granulates from players should be correlated with the actual use of the pitch, meaning the number of players using the pitch during a year and the weather conditions (wet/dry/snow) over the year.

The results can be compared with other studies where a Norwegian study found an emission of approx. 40 kg/year and a Spanish study 5.2 kg/pitch/year. Use of grates when walking out was used at silkeborg. These comparisons can be seen in Table 2.

Table 2 Emission from players and their equipment

Test no	Con-ditions	Play-ers+ train-ers	Emis-sion clothes g/player	Emis-sion shoes g/player	Emission players total g/player	Emission /balls , cones other per game (g)	Emis-sion clothes kg/year	Emis-sion shoes kg/year	Sum players kg/year	equip-ment kg/year	Total kg/year
Silkeborg - dry condi-tions	dry, train-ing	17	0.059	0.104	0.163		1.17	2.07	3.24		
Silkeborg Wet condi-tions	wet, train-ing	16	0.056	0.173	0.229	0.4928	1.05	3.24	4.29	0.58	4.86
Norwegean study 2017					0.9				40		
Spanish study may 2022					0.25				5.2		

4.3. Maintenance equipment

Measurement on maintenance equipment was performed two times in such a way that it was representative of typical use. Again, no special instructions were given to the operator of the equipment prior to sampling. The main equipment is a tractor which is used for pulling different tools for maintaining the pitch. All tools are kept within the restricted artificial turf area, except for the tractor, that leaves the area and often commute to other duties.

After the maintenance operation, the tools are left within the artificial turf area, end the tractor was cleaned as the normal procedure by the operating personnel (eg using pressurised air cleaning), the tractor was then transferred on to a plastic film, where remaining granulates were brushed off and collected (see Figure 11).

Figure 11: Sampling from tractor used for maintenance operations was done by thoroughly cleaning the machine while collecting infill material on a plastic sheet.

The results are shown in Table 3

Table 3 Rubber emission with equipment

	Test #1	Test #2
Rubber (grams)	4.64	7.37
Use times/year	50	50
Emission machines kg/pitch/year	0.23	0.37

In the table the emission per pitch per year has been calculated assuming use 50 times per year. It is seen that the cleaning of the tractor is very effective with a calculated emission of only 0.2-0.4 kg/pitch/year.

4.4. Drainage

Drainage water collected from membrane fields were analysed for a set of 30 chemical compounds that have previously been detected and reported on in relation to artificial turf. Of the 30 compounds only 12 were detected in this project.

Table 4 Non-detected compounds. Data from 5 samplings of drainage water found 12 compounds above the analytical detection limit. The remaining 18 compounds are listed in this table. These substances were not found in the tested drainage water.

Metals:	Microrubber:
Cadmium (Cd)	Polybutadiene
PAH:	Polyisoprene
Fluoranthene	Styrene-butadiene rubber (SBR)
Pyrene	Rubber content
Benzo(a)anthracene	Microplastic:
Chrysene/Triphenylene	Polyethylene (PE)
Softeners:	Polystyrene (PS)
Dimethylphtalat (DMP)	Acrylnitrile butadiene styrene (ABS)
Benzylbutylphtalat (BBP)	Polymethyl metacrylate (PMMA)
Alkylphenoles og -ethoxylates:	Polycarbonate (PC)
4-t-octylphenol	Polyvinyl chloride (PVC)

The two main categories of pollutants detected in the samples were metals and microplastic. Lead, Copper, Cobolt and Zinc were detected as part of the metal analyses. Polypropylene (PP) was the most prevalent microplastic detected. In the following tables and figures data is presented for the 5 samplings that were carried out. A comparison to national guidelines for drinking water[4] and the national chemical quality guidelines for freshwater environments[5] shows general compliance for the tested drainage water. The comparison illustrates the relatively small load of the measured pollutants in the drainage water. Table 5 presents data for all compounds that were detected in one or more instances across 5 samplings taken in a 2-year period at Silkeborgbanen.

Table 5 Data from all substances that were detected in drainage samples from Silkeborgbanen. From left to right the columns present detected substances in the drainage water from Silkeborgbanen, units of the presented data, data from sample #1 through #5, detection limits (DL) for the method applied in analysis and the average levels of the detected substances across all samples. Values denoted with lower values than the DL (red text colour) were included in the average as being observed at DL. However, the true value would be between 0 and the DL value. 7 of the 12 detected substances were only detected in a single sample.

		Silkeborgbanen (samplings)							Guide lines (DK)	
		1	2	3	4	5				
Parameter	Unit	01.12.22	17.03.23	25.08.23	04.03.24	28.05.24	DL	Average	Drinking water[1]	Fresh water[2]
Metals:										
Lead (Pb)	µg/l	0.5	0.5	0.5	0.5	1.2	0.5	0.6	5	1.2
Cupper (Cu)		0.5	1.3	0.5	2,0	3.1	0.5	1.5	2000	4.9
Cobolt (Co)		1.9	1.0	2.3	0.5	0.81	0.5	1.3	5	0.28*
Zinc (Zn)		6.4	5.0	5.0	9.7	8.3	5.0	6.9	3000	7.8
PAH:										
Phenanthrene	µg/l	0.01	0.01	0.01	0.017	0.01	0.01	0,0		1.3
Softeners:										
Diethylphtalat (DEP)	µg/l	0.1	0.1	0.1	0.26	0.1	0.1	0.1		
Diethylhexylphtalat (DEHP)		0.1	0.1	0.1	0.63	0.1	0.1	0.2		1.3
Phenoles:										
Bisphenol A		0.01	0.01	0.01	0.08	0.01	0.01	0.02	2.5	0.1
Microplastic:										
Polypropylene (PP)	µg/l	79.8	44.1	65.7	4.6	18.7	0.1	43		
Polyethylene terephtalat (PET)		0.4	0.2	0.2	0.2	0.2	0.2	0.2		
Polyamid 6 (PA6)		0.1	0.1	0.1	0.2	0.1	0.1	0.1		
Polyamid-6.6 (PA 66)		1.0	1.0	1.0	1.0	5.6	1.0	1.9		
Microrubber:										
Rubber content	µg/l	No rubber components detected								

[1]https://www.retsinformation.dk/eli/lta/2024/940

[2]https://www.retsinformation.dk/eli/lta/2023/796

*This number should be added to the natural background concentrations in the recipient

[4] https://www.retsinformation.dk/eli/lta/2024/940
[5] https://www.retsinformation.dk/eli/lta/2023/796

Copper, cobolt and zinc are detected in more than one sample as well as PP. The microplastic PP is the main contributor to overall microplastics emissions as no rubber was found in the drainage water. The measured PP might stem from a single source that is not part of the turf as the lids used for sample equipment are made from PP. It is not optimal for sampling equipment to contain materials also included in the analytical work, but certain types of plastics are so prevalent due to its adverse properties that it can be hard to avoid. The quantified amounts of microplastics when extrapolated to drainage from the entire field with a full year of rain can be seen in Table 6. The microplastics emissions for an entire year are estimated to be less than 0,5 kg and no rubber was detected in the drainage water. The estimate might be somewhat overestimated as parameters such as evaporation has not been considered and the annual precipitation has been set with a margin of safety to include higher averages in the future.

Values for Copper in the drainage water complies with drinking water standards and with national guidelines for bodies of freshwater. Zinc is generally in compliance as well, but a single measurement exceeded the guideline for bodies of freshwater. However, it should be noted that the guideline for metals in freshwater is not a fixed value as natural background concentrations are to be added to reach the final guideline. Cobolt appears to exceed guidelines for bodies of freshwater on three occasions and the detection limit of the analytical method is too high to validate compliance for the fourth sample.

Table 6 Values for microplastic emissions from Silkeborgbanen via the drainage system. The value is estimated based on extrapolation from the data collected in this project.

	Unit	Result
Microplastic:		
Polypropylene (PP)	µg/l	43
Polyethylene terephtalat (PET)	µg/l	0.2
Polyamid 6 (PA6)	µg/l	0.1
Polyamid-6,6 (PA 66)	µg/l	1.9
Sum af kvantificerede polymerer	µg/l	45
Microrubber:		
Rubber content[1]	µg/l	ND
Yearly load:		
Annual precipitation[2]	mm/year	900
Pitch area	m^2	9500
Precipitation volume	m^3/year	8550
Microplastics	g/m^3	0.04
Microplastic load from Silkeborgbanens drainage[3]	kg/year	0.4

[1]Rubber was not detected in the drainage water.
[2]Rough estimate of precipitation in Silkeborg. Average rainfall in Denmark for the years 1991-2020 was 759 mm/år.
[3]The number is extrapollated from the measurements recorded from approximately 10 % of the total pitch.

A single sampling for rainwater and drainage water was carried out for location "Silkeborgbanen" and location "Gødvadbanen", another local pitch. Gødvadbanen is a pitch with artificial turf and sand infill (no rubber infill). The samples were supposed to evaluate the impact of rubber infill on PFAS emissions. In Figure 12 results show that drainage water contained more PFAS than rainwater collected simultaneously on-site. Furthermore, there is no significant difference between the emissions from the two different artificial pitches. In general, the emissions from both pitches comply with or are close to guidelines for drinking water and bodies of freshwater. There is no indication that the utilized rubber infill at Silkeborgbanen contributes to PFAS-pollution. The test was performed once and should be replicated to verify the results.

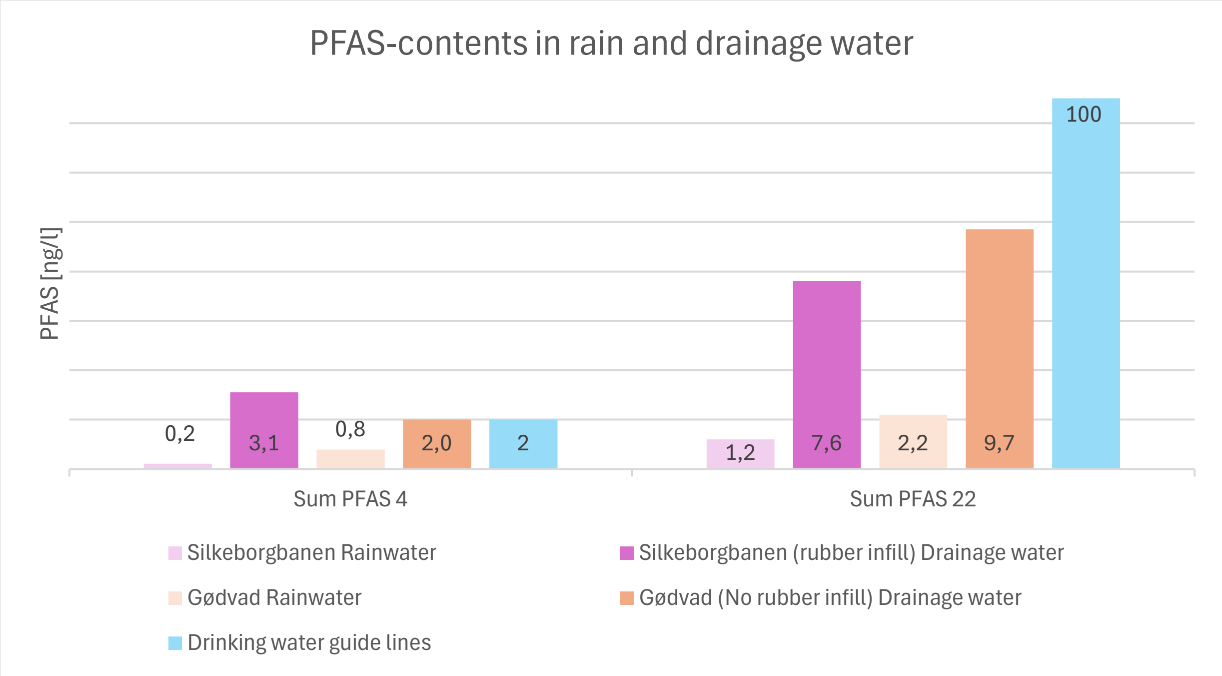

Figure 12 A single replicate of PFAS analyses for drainage water from Silkeborgbanen (rubber infill) and Gødvad artificial pitch (no rubber infill) was performed. PFAS content in rainwater for the two pitches were also determined. Data for Silkeborgbanen is presented in purple columns, data for Gødvadbanen in orange and Danish limits for permitted concentrations in drinking water in blue.

In the drainage analysis, limited contamination exceeding the Danish environmental objectives for Danish freshwater environments were found. Generally, most values are around or below Danish requirements in relation to drinking water. No microrubber was detected – i.e. rubber granules or rubber granulate residue – in the drainage water.

Rainwater and drainage water was tested for PFAS contamination. Results show PFAS values below the Danish limit values for aquatic environments and around or below the Danish requirements in relation to drinking water. In respect to PFAS, both rainwater and drainage water from Silkeborgbanen with rubber granulate as infill and rainwater and drainage water from an artificial turf pitch with sand as infill ("Gødvad-banen2 by Dybkjærskolen) was analyzed. Data did not indicate that rubber granulate as infill material should be a significant source of PFAS contamination.

4.5. Total emission

The total emission has been calculated for use with 20 cm, 40 cm and 60 cm barrier heights. The results are shown in Table 7 and Figure 13 (all seasons) and Figure 14 (only summer).

The figure shows that the majority of the observed emission is from players and over pitch barriers.

Table 7 Individual emissions and total emissions (kg/field/year)

Position	Period 2 summer	Period 3 vinter	Period 4 summer	Periode 5 vinter	Estimate for total Period
Players (maximum) [6]	4.86	4.86	4.86	4.86	4.86
Fence (20 cm average)	23.1	224	19.0	142	89.6
Fence (40 cm average)	4.82	14.4	5.94	52.2	49.0
Fence (60 cm Average)	0.38	1.63	6.00	20.6	19.6
Machines	0.23	0.37	0.00		0.36
Drainage [7]	0.40	0.40	0.40	0.40	0.40
Sum (20 cm fence)	28.6	230	24.2	147	95.3
Sum (40 cm fence)	10.3	20.0	11.2	57.5	54.6
Sum (60 cm fence)	5.87	7.26	11.3	25.9	25.2

[6] The emission from players are from period 2
[7] The value is an estimate based on measured emission of microplastics in Table 6. Rubber was not detected.

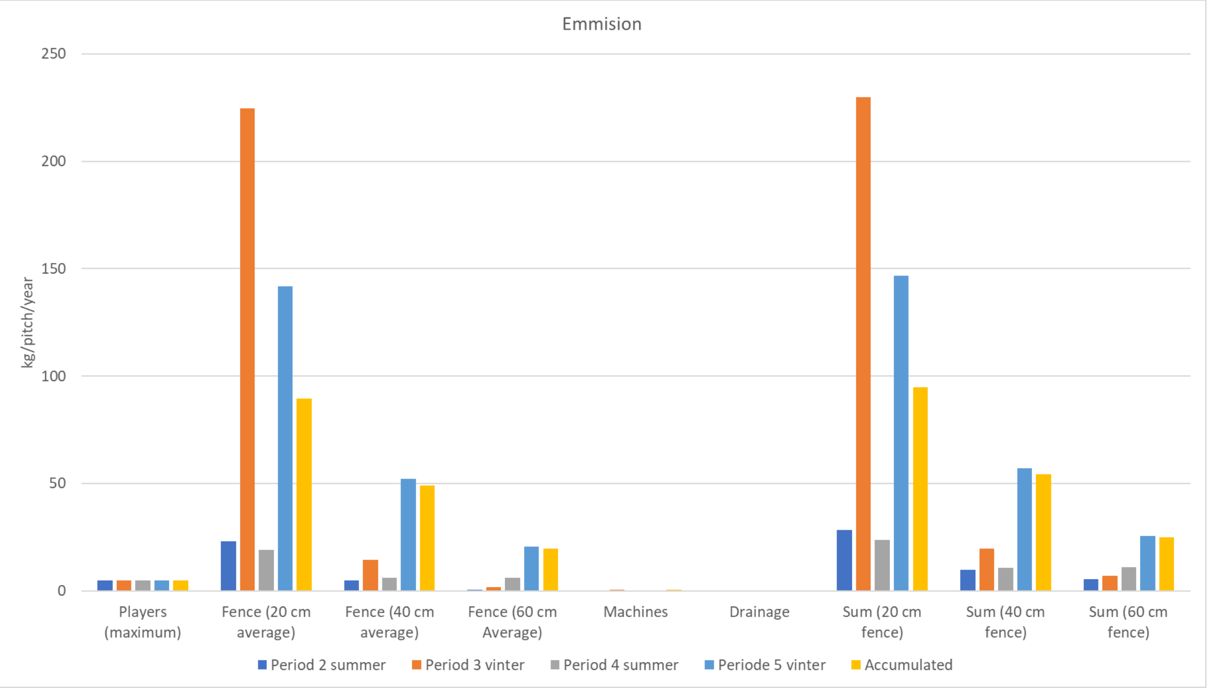

Figure 13 Individual emissions and total emission based on average fence height (all seasons)

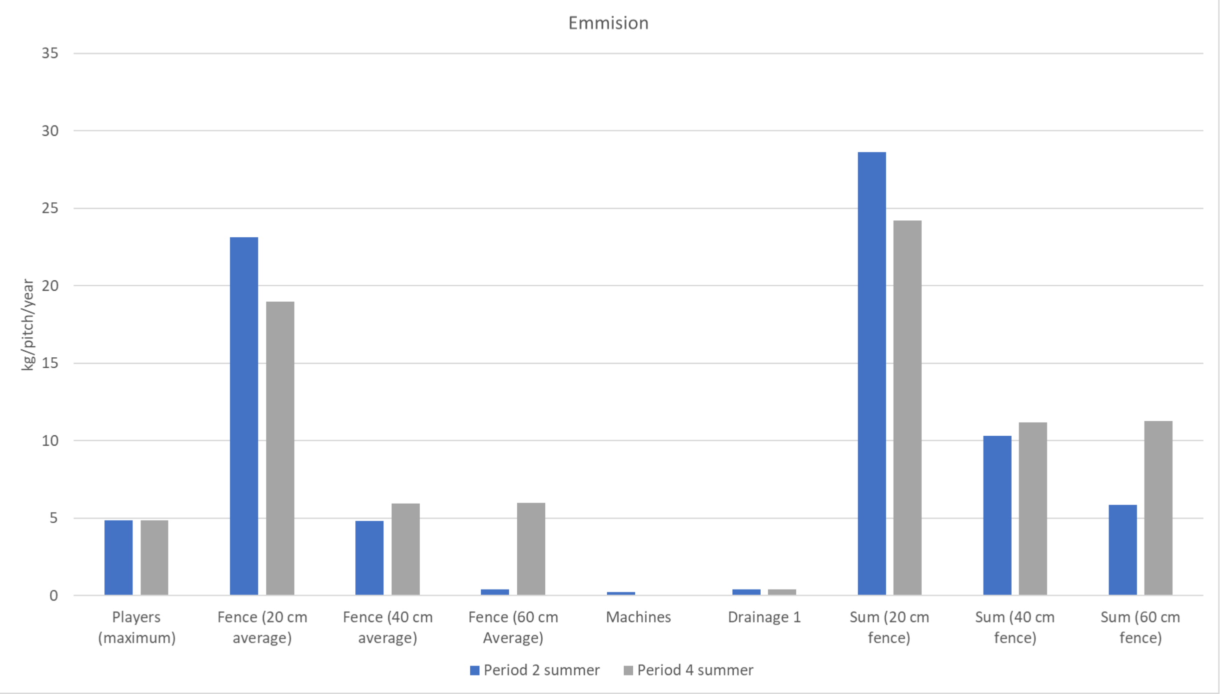

Figure 14 Individual emissions and total emission based on average fence height (summer)

It is observed that the total emission in summer is below 30 kg/pitch/year even when using 20 cm height decreasing to approximately 10 kg/pitch per year at 40-60 cm height.
However, the winter emissions are much higher (up to 230 kg per pitch per year when calculating for 20 cm positions) and seems to depend on maintenance procedures for snow and seems to be higher where snow drift are present (near entrance).

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