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Artificial Turf Pitches

System analysis for Switzerland and Germany

Artificial Turf Pitches – System Analysis for Switzerland and Germany

taking into account microplastic and greenhouse gas emissions, recycling, locations and standards, costs, and player opinions

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Content

Statement on financing, responsibilities, and terms of use

The creation of this report was commissioned as a multi-client study by a consortium of Swiss and German municipalities and one company. The project budget was 70,000 euros. Alongside literature research, data collection/evaluation, and reporting, the multi-client study also included inspections of the artificial turf pitches in the commissioning municipalities with sampling and analysis.

The authors were free to choose their formulation of the report; no influence was exerted by the clients, the surveyed organizations, or any other third parties. Nonetheless, the clients had the opportunity to critically comment on the preliminary versions of the report in two rounds. The results of the report, therefore, do not represent the view of the commissioning organizations or the Fraunhofer Institute UMSICHT in every case, but primarily represent the authors' point of view.

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1 What should be done? – Key results and our recommended actions

The key insights and results from chapters 2 to 16 are summarized below. Recommended actions are then provided based on this. The recommended actions are directed towards the most important actors in relation to artificial turf pitches:

- Manufacturers of artificial turf systems and their components
- Designers of artificial turf pitches (architects and town planning authorities)
- Associations and committees (e.g. sports associations, RAL Quality Assurance Associations, standardization bodies, etc.)
- Operators of artificial turf pitches (municipalities or clubs)
- Users (players, former players, spectators, and fans)
- Science and testing institutions

HOW ARE ARTIFICIAL TURF SYSTEMS CONSTRUCTED?

- An artificial turf system is constructed in layers that have a complex interaction. The implementation of the damping substructure as a combined elastic/asphalt layer or as an elastic base layer distinguishes the examined artificial turf pitches in Switzerland from those in Germany.
- Activities such as brushing, removing, cleaning, and watering are predominantly performed by voluntary or full-time workers from the sports facility. Topping up infill (rubber granulate and sand) is also part of maintenance.
- The service life of an artificial turf pitch is determined by the artificial turf carpet and is generally approx. 12 to 15 years. The artificial turf pitches examined in Germany and Switzerland are used for an average of 1882 hours per year.

- Designers, operators, users: There are a range of variants and different providers for artificial turf pitches today. Preliminary planning and decision-making should therefore largely take place independently of manufacturers.
- Designers, operators, users, manufacturers: The manufacturer (pitch supplier) should be able to provide information about maintenance workload and costs (including topping up infill). Warranties far beyond the statutory warranty should be demanded in terms of the durability and service life of granulates and the artificial turf carpet, as the pitches are subjected to significant effects of the weather.
- Operators, users: It should be assessed whether the need is sufficient to achieve a high intensity of use significantly above that of natural turf.

HOW ARE ARTIFICIAL TURF PITCHES STRUCTURALLY INTEGRATED?

- An artificial turf pitch is surrounded by paved/unpaved and natural/artificial surfaces.
- Location selection, the pitch surroundings, and the sports ground for the artificial turf pitch (ATP) depend on the local conditions, legal regulations, and the preferences of the operators.

- An artificial turf pitch is permeable to water and drains rainwater away. A distinction is made between infiltration (vertical drainage), collection and channeling (horizontal drainage), and (supported) drainage.
- The majority of the water infiltrates into or next to the artificial turf pitch. The rest is collected and channeled away. The channeling primarily takes place using storm sewers, less often directly into receiving waters, even less often into the sewage treatment plant via the wastewater system.

➢ Designers, operators: When selecting the location, water management and ecological conditions on site must be particularly taken into account (including extreme weather events and flooding). To prevent infill loss due to heavy rain, spacious infiltration surfaces should be created around the pitch.

➢ Designers, operators, manufacturers: If rainwater can enter or is introduced into the storm sewer or directly into receiving waters, it is recommended to install filter elements to retain infill. In the event of a mixed sewer system, retention options would need to be checked to avoid combined wastewater discharges.

WHERE ARE THERE ARTIFICIAL TURF PITCHES IN GERMANY AND SWITZERLAND?

- There are no official figures for the number of artificial turf pitches either in Germany or in Switzerland. Satellite data evaluations result in 800 artificial turf pitches or artificial turf-like pitches in Switzerland – outside of private use – and around 9000 in Germany. Official estimates are generally below these figures.[1]
- It is possible for over 50,000 people – or even almost no one – to live within a radius of 1 kilometer around artificial turf pitches. A roughly equal proportion of artificial turf pitches is integrated into an agricultural or forested environment (136 square kilometers) or a residential or commercial environment (129 square kilometers).
- In Germany, 5.8 million m^2 of bodies of water are located within 100 meters of artificial turf locations (corresponding to 2 percent of the space). The mean distance is 330 meters from running and 730 meters from standing water.

➢ Politics, associations: Artificial turf pitches should be recorded in full in an official database according to location, environment, and construction method. The population density and aspects relating to the environment and nature protection within a defined radius should also be recorded as part of monitoring.

➢ Politics, designers, operators: Artificial turf pitches should above all be implemented in densely populated, urban spaces, but not in water protection areas or on flood plains. Any funding should above all be oriented towards the actual needs and not be provided for construction within natural environments that are worthy of protection.

1 According to calculations by the Swiss Institute for Environmental and Process Engineering UMTEC, there are 465 soccer pitches with artificial turf in Switzerland. This primarily differs from the UMSICHT figure as UMSICHT has also taken into account non-soccer pitches.

HOW ECONOMICAL ARE ARTIFICIAL TURF PITCHES?

- The cost differences in detail are significant. Different turf systems require different infrastructures and maintenance approaches. Annual cost considerations even out many differences between natural and artificial turf pitches.
- Clear cost benefits for artificial turf pitches arise based on the hours of use. It is as yet unclear whether these can be maintained as environmental regulations increase.

- ➢ Designers, operators: The cost-effectiveness of artificial turf pitches should be based on a detailed survey of needs in terms of playing hours per year. These needs should be determined over a prolonged period of time before the decision regarding construction is made. External costs caused by unexpected environmental damage should be internalized as far as possible and taken into account in a comprehensible way.
- ➢ Designers, operators: The costs of clean-ups, structural measures such as barriers, boards, walls, additional expenditure in wastewater treatment to reduce emissions, and the end-of-life phase (recycling, thermal utilization, restoring the original condition) are explicitly to be taken into account in the profitability assessment with a view to any requirements that are to be expected in the future.

HOW MUCH INFILL IS ON THE PITCHES AND WHAT DOES IT DO?

- The examined pitches from 2009 to 2019 show no reduction in the amount of performance infill used, regardless of the year of construction.
- Accumulation due to compaction on the pitches was not measured.
- A small number of results on the change in particle size distribution over time indicate that the performance infill is pulverized over time and also disintegrates as brittleness increases.
- The infill is distributed very unevenly over the pitches, this effect increased with the age of the pitches. The relevance of the performance infill with regard to play-related properties may be overestimated.

- ➢ Politics, associations, manufacturers: The innovation efforts regarding infill-free, mineral-only artificial turf systems or those only filled with (unmodified) natural materials should be pushed forward. The systems should be tested in demonstration projects. Play-related performance and the risk of injury to the players on the various systems should be borne in mind when developing new infills.
- ➢ Science, manufacturers: The thesis regarding the extensive accumulation of infill on the pitches as a result of compaction shown in various scientific publications contradicts the experimental results of this study. It should be tested experimentally and in practice with the further use of performance infill in future artificial turf systems.

HOW HIGH IS INFILL LOSS?

- The average loss of performance infill on the examined pitches comes to 2.98 metric tons per year, and is thus above the top-up quantity (2.68 metric tons per year). However, there are significant fluctuations in losses. The 95% confidence interval for losses for all pitches of the same construction type is in the range of 1.29 to 4.67 metric tons per year.
- No correlation with the age of the pitches was found. However, the low density of the infill appears to promote discharge.

- ➢ Manufacturers, science: As there is no correlation between topping up and loss quantities and the experimentally determined loss rates are significantly higher than many figures published recently, experimental evidence about loss rates should be provided based on construction method, maintenance, and upkeep, as well as the type and intensity of use, and be made transparent.
- ➢ Designers, operators, associations, politics: The specifications regarding loss rates should be set down in corresponding calls for tenders and the relevant standards. Compliance can be checked using the method developed as part of this study. Depending on how ambitious these loss rates are, this also favors non-infill or purely sand-filled pitches in the tendering process.

WHAT IS KNOWN ABOUT FIBER LOSS?

- From the perspective of environmental protection, it is necessary to consider not only performance infill but also fiber loss. The few experimental investigations that are available suggest high losses of artificial turf fibers.
- The discharge can vary depending on the fiber use weight and infill type. At the same time, it presumably increases with the age of the pitch. Previous estimates range from around 50 kilograms to over 1 metric ton per year.
- To what extent these losses are discharged, recorded as waste as part of maintenance work, or remain in the artificial turf has not been investigated. It is, however, apparent that discharge via players plays an especially large role for fibers.

- ➢ Manufacturers, designers, operators: Information on the long-term durability of the artificial turf carpet in the form of quantitative fiber losses over the service life and per year (e.g. determined using the Lisport test) should be provided in product data sheets. These requirements should also be included in functional specifications and corresponding warranties should be arranged.
- ➢ Politics: The ECHA or the national environmental authorities should assess whether the abrasion of plastics in applications that are open to the environment, as is the case for fiber loss in artificial turf pitches, can be taken into account in future restriction procedures.

VIA WHICH ROUTES IS THE INFILL DISCHARGED AND WHERE DOES IT GO?

- Rubber granulate is discharged from artificial turf pitches and is found virtually everywhere in the pitch surroundings.
- Strong winds and heavy rain, in particular, cause the emissions to spread beyond the pitch surroundings. This is demonstrated by rubber granulate found in inaccessible points, sometimes very far from the pitch. Further spreading often takes place via waterways.
- Infill can often be found on natural or artificial barriers, e.g. green spaces or buildings that prevent the further mobility of the infill. Very large quantities of granulate can accumulate in the environment without this being visually noticeable in every case. The final fate of the infill depends on the layout of the pitch and the pitch surroundings and the geographical situation on site.

- ➢ Politics, associations, committees, designers, operators: The pitch surroundings are to be designed with barriers so that the infill can be prevented from spreading and unavoidable losses are returned to the pitch or disposed of. Corresponding requirements should flow into standards and quality marks. The requirements should relate not to the design, but to performance in terms of retention in order to give manufacturers the freedom to create innovative and effective solutions.

- Designers, manufacturers, operators, players: To prevent granulate and fibers from being carried away by players, suitable technical and organizational measures should be implemented and the responsibility of the players addressed.

WHAT IS THE STANDARD OF KNOWLEDGE CONCERNING FURTHER ENVIRONMENTAL EFFECTS?

- Artificial turf pitches largely comply with the limit values in relation to various hazardous substances. A small number of studies show that limit values are exceeded for individual heavy metals. Nevertheless, there are differences between various material options, and discussions and studies into hazardous substances are continuing.
- The critical examination should concern performance infills as well as the elastic layers and artificial turf fibers.
- The possible overheating of artificial turf pitches and their relevance for the urban microclimate, as well as the amount of water needed to counteract these effects, should be taken into consideration in advanced planning.

- Designers, operators: As artificial turf pitches achieve a long service life and are ideally recycled at the end of the utilization phase, high demands should be set regarding the materials being free from hazardous substances, and these should go beyond the current statutory requirements (in view of the fact that limit values will be tightened in the future). This requires corresponding specifications in calls for tenders. These should concern not only infills but also the fibers and damping system.
- Designers, operators: It should be assessed whether sufficient quantities of water are available to adequately cool the pitches in summer. This should be included in the ecological and economic evaluation.

WHAT IS THE CURRENT SITUATION REGARDING RECYCLING?

- The artificial turf industry strives to recycle the artificial turf mechanically as fully as possible, as well as the elastic base layer over the medium term. A closed-loop approach for the entire artificial turf or even individual components – with the exception of the infill sand – cannot yet be identified.
- The mechanical recycling will lead to greater end-of-life costs and the recycling of ELT granulate from artificial turf pitches could compete with the direct recycling of end-of-life tire granulate.

- Designers, operators: During planning, sufficient provisions should be taken into account to restore, recycle, or remove the artificial turf at its end of life.
- Manufacturers, operators: The proportion of recycled material and the recyclability of all components should form part of product descriptions and service specifications.
- Politics: A framework is necessary to support the best recycling methods for ELT granulate from an ecological and environmental economic viewpoint in order to prevent disposal bottlenecks for end-of-life tires while, at the same time, not causing problem shifting to occur via a cascading use of the pitch components (e.g. infill in riding arenas).

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WHAT IS THE CARBON FOOTPRINT OF ARTIFICIAL TURF PITCHES?

- Depending on the type of artificial turf, the carbon footprints are between 9.4 and 29.8 kilograms of carbon dioxide equivalents per hour of use.
- The type of infill material plays a major role here. As a biogenic material, cork has a lower carbon footprint compared to fossil-based infill materials. The greenhouse gas emissions associated with disposal are especially relevant for types of infill such as SBR, EPDM, or TPE.
- The use of foamed polyethylene with or without Drainasphalt instead of an elastic wearing layer (EWL) leads to much lower emissions both in the production phase and during disposal.
- High-quality recycling of the components and a longer useful life for infill materials and the damping system can significantly reduce the carbon footprint.

➢ Designers, operators, manufacturers, politics: Permitted carbon footprints over the life cycle or at least the manufacturing phase should be set down in calls for tenders and service specifications. They should be calculated as part of environmental product declarations (type III, EPD) for artificial turf systems. The permitted values should be reduced to below 10 kilograms of carbon dioxide equivalents per square meter.

HOW ARE ENVIRONMENTAL ASPECTS TAKEN INTO ACCOUNT IN STANDARDS?

- The standards and quality marks barely go beyond the minimum statutory requirements in terms of their environmental requirements. Microplastic emissions in the form of fibers and granulates are only marginally addressed without any specified aims.
- Types of construction are specified in the German standard and in the FIFA Quality Programme that, for instance, essentially exclude prefabricated shock pads without an asphalt layer and non-infill pitches from the competition (even for the ecologically best solution), despite these concepts offering advantages.
- Considering that environmental regulations are often tightened over time as knowledge is gained, the standards that are relevant to artificial turf pitches have so far failed to offer sufficient planning security for either manufacturers or operators.

➢ Associations: Quality marks for artificial turf pitches must include ambitious environmental objectives that go beyond the statutory regulations. Only in this way will it be ensured for manufacturers and operators, who rely on these quality marks, that artificial turf pitches will fulfill expectations regarding environmental compatibility in the long term. Alongside the current marks, an environmental label (e.g. the Blue Angel) or an assessment according to a sustainability standard for buildings (e.g. DGNB) would be desirable in the future in order to demonstrate an especially high level of ecological quality.

➢ Politics, associations: In order to prevent environmental technology lock-ins and avoid jeopardizing company competition, it should be ensured that standards and quality marks do not define types of construction, but instead contain ambitious and measurable environmental objectives.

HOW GREAT IS THE NEED FOR ARTIFICIAL TURF PITCHES?

- Hard pitches are no longer considered in keeping with the times by clubs and players and have thus been converted into natural or artificial turf pitches for quite a long time.
- Artificial turf pitches thus enable team sports to be available throughout the year, particularly in densely populated cities and/or in cities with high land prices.

- Associations, politics, operators, users: Alongside the benefits of artificial turf pitches, the operators and users must also be made aware of the responsibility for the ecological and social effects associated with this.
- Politics, operators: Sealed surfaces (including former hard pitches) in urban areas are an option for conversion into artificial turf pitches. Preference should be given to construction in such spaces so as to meet demand.
- Operators: The local needs – taking into account a shift towards new trend sports – should be ascertained in detail.

WHAT DO THE USERS SAY?

- Both active and former soccer players are involved in the debate surrounding the relevance and environmental effects of artificial turf pitches. Artificial turf plays a key role in the everyday reality of many people and makes it possible to play sports outside throughout the year.
- Rubber granulate is still the preferred infill type, yet users still consider cork and non-infill pitches to be alternatives. In general, the majority of those surveyed expect that artificial turf pitches will become more environmentally friendly.

- Operators, users, politics, associations: Soccer and soccer pitches are an important to very important aspect of the everyday reality of many people, but above all young people. This and the desire for more environmentally friendly pitches expressed by users offers an ideal setting for modern participation processes at a municipal level. Interest in sport can serve as a catalyst to test participative democracy and the assumption of societal responsibility for ecologically sensible solutions and establish this as municipal practice.

2 Background and subject of the multi-client study

Due to the emissions of plastic fibers in all versions of artificial turf pitches and of plastic granulate for infill artificial turf pitches (ATP), they have become the focus of society, politics, and the media in the context of the microplastics debate. According to estimates and calculations by Fraunhofer UMSICHT, the quantities of microplastics released from infill artificial turf pitches come to several thousand metric tons a year in Germany alone. These figures are so far primarily based on freely available data and a study assessing the overall situation for plastic emissions published in 2018.[2] However, the previous estimates were uncertain due to the vague data situation. The manufacturing companies, for instance, replied that the artificial turf construction methods that dominate in Germany and Switzerland in accordance with DIN 18035-7 require smaller quantities of infill and thus cause significantly lower emissions than the construction types established in other countries.[3] However, these statements have so far been exclusively based on qualitative arguments. At the same time, exemplary inspections of pitches showed that the emissions can vary significantly depending on the condition of the pitch, the construction method, and local constraints. In addition, microplastic emissions only represent one possible environmental effect of artificial turf pitches.

In order to conduct a comprehensive evaluation, it is thus urgently necessary to improve the data situation and to include further aspects, also outside the microplastic problem. We want to make a contribution towards this with this multi-client study together with the commissioning partners. The aim of the study is to create as objective an evaluation basis as possible for the various options for artificial turf in sports field construction and to provide recommendations for an environmentally sound, economical, and socially responsible approach.

2.1 Information about methods and data uncertainties

This report is based on a methodologically heterogeneous approach. Data collections and surveys of pitch operators were carried out for certain aspects, while, for others, scientific literature, product information, rules, standards, and position papers were evaluated or satellite data used and life-cycle assessments (carbon footprints) created. Empirical investigations into granulate loss were also carried out.

This range of methods was necessary to fulfill the aim of gaining as comprehensive a view of the complex artificial turf system as possible. Further empirical analyses could not be represented with the limited project budget. As a result, the presentation of various system aspects inevitably does not always display the same processing depth and the same level of detail.

The assessments in this report also include subjective elements as it involves weighing many different aspects against each other, which is fundamentally a normative process. It is ultimately the task of politics to assess the benefits and risks of the artificial turf system according to a socially accepted weighting and make decisions based on this. This report provides new data, arguments, and viewpoints for these decision-making processes along with new findings obtained by other actors.

2 Bertling et al. 2018a; Bertling et al. 2018c.

3 https://www.ral-ggk.eu/de/news/49-news/220-microplastik-in-kunstrasen.html; last accessed: June 23, 2021.

2.2 Which pitches were examined?

A total of 19 artificial turf pitches (ATP) were examined in the present study. Of these,

- 15 were filled with a performance infill (1 of which was cork) and sand
- 2 were only filled with sand, and
- 2 were non-infill (1 of which was a hockey pitch)

Of the pitches examined,

- 13 were in Switzerland and
- 6 were in Germany

Table 1 shows a summary of the outline data such as the year of construction, manufacturer/type designation, the FIFA quality standard achieved for the pitch, pile height, fiber weight, infill type used, and playing hours for the various artificial turf pitches.[4] Samples were taken from a total of 17 ATPs, 15 were examined with regard to infill.

Table 1: Overview of the examined pitches (information from pitch operators)

No.	Year of construction	Quality standard	Manufacturer/type	Pile height [mm]	Fiber weight [g/m²]	Infill	Playing hours [h/year]
A	2013		Fieldturf Tarkett SAS	45	n.s.	EPDM	1,600
B	2012		Domo Sports Grass	42	n.s.	TPE	1080
C	2014		Fieldturf 360 42-20	42	n.s.	SBR+PU	1920
D	2016		Fieldturf 360 XL 42-17	42	n.s.	TPE	2420
E	2009		Polytan LigaTurf 240 RS+ 22/4	40	n.s.	SBR+PU	2420
F	2013		Limonta Qualifloor Soccerpro MaX S 40	42	n.s.	TPE	1920
G	2018		Fieldturf 360 XL 42-14	42	1338	EPDM	2150
H	2013	FIFA Q Pro	Greenfields REAL FT 40 Slide pro xt	40	1010	EPDM	1584
I	2013	FIFA Q Pro	Polytan Liga Turf 240 RS+ 22/4	40	1365	EPDM	1580
J	2018	FIFA Q Pro	Fieldturf Core 42/17 FG/OG	42	1550	EPDM	2000
K	2009		Greenfields REAL FT 46 V -Slide	n.s.	n.s.	SBR+PU	2500
L	2018		Limonta Sport	40	n.s.	EPDM	1800
M	2013		Polytan	40	n.s.	EPDM	2000
N	2011		JUTA	40	n.s.	EPDM	2000
O	2019		Polytan Liga Turf RS+ CoolPlus	40	1000	Cork	2000
P	2020		Fieldturf Purefield MF 30-17	30	2690	Only sand	1750
Q	2013		Greenfields REAL FT V-Slide nf	32	2970	Non-infill	1584
R	n.s.		Polytan N.N.	30	n.s.	Only sand	1500
S	n.s.		Polytan N.N. (Hockey)	12	n.s.	Non-infill	1400

[4] Glossary of various technical terms (→ Chapter 20).

3 How are artificial turf systems constructed?

“An artificial turf system is constructed in layers that have a complex interaction. The implementation of the damping substructure as a combined elastic/asphalt layer and as an elastic base layer distinguishes the examined artificial turf pitches in Switzerland from those in Germany.

Activities such as brushing, removing, cleaning, and watering are predominantly performed by full-time workers from the sports facility. Topping up infill (rubber granulate and sand) is also part of maintenance.

The service life of an artificial turf pitch is determined by the artificial turf carpet and is approx. 12 to 15 years. The artificial turf pitches examined in Germany and Switzerland are used for an average of 1882 hours per year.”

3.1 Fundamental structure

In many cases, an artificial turf system consists of a damping substructure and the actual artificial turf including infill. These are installed on a water-permeable, load-bearing layer of asphalt or crushed gravel (base layer, finished grade). While damping often used to be avoided due to the substructure and artificial turf with longer fibers was used instead, it has now largely become standard in Germany and Switzerland today. Three different versions have become established as the damping layer:

A) Elastic base layer (EBL)

B) Drainasphalt layer with elastic layer (EL) on top

C) Elastic layer directly on a leveling layer

Above all version A has so far become established in Germany, which was confirmed by inspections of the German pitches as part of the study. The EBL usually consists of ELT granulate[5] (produced from end-of-life tires), a binding agent (generally PUR), and mineral aggregates. The EBL is implemented on site. It represents a solid construction element that usually outlasts the service life of the artificial turf. The EBL is dismantled or removed at the end of the service life using heavy equipment. The on-site installation places the highest demands on the base layer (finished grade) so that a consistent thickness and even damping properties are ensured for the entire pitch.

Version B dominates at the Swiss pitches that were inspected. It is the most expensive version due to the additional asphalt layer. Here, the EL, which, like the EBL, consists of ELT granulate plus a polyurethane binder but without mineral aggregates, is created on site. *Shock pad* refers to the elastic layer. The asphalt layer underneath enables the thickness of the EL to be controlled particularly well in comparison to the EBL. Elastic layers made from foamed polyethylene or foamed polyurethane are an alternative to those made from ELT and PUR. Foamed polyurethane is above all used for heated

[5] ELT = end-of-life tires.

pitches (mainly commonplace in Scandinavia). Polyethylene foams, which, in contrast to ELT solutions, are not open-pored, generally have a macroscopic structure (holes, grooves), which ensures the drainage of rainwater. The foamed elastic layers are generally prefabricated. There are applications in which they are placed on a Drainasphalt layer and also those in which they are applied directly to the finished grade (version C). The latter is considered to be a particularly cost-effective and easily dismantled construction method for artificial turf pitches.

Construction methods A and B are described in DIN 18035-7 (fig. 1). The fact that construction method C has not found its way into the German standard, despite being included e.g. in the DFB handbook for sports ground construction, is particularly criticized as interference in the free market by international competitors. However, work is currently underway on a European standard, which could eliminate this deficit.[6]

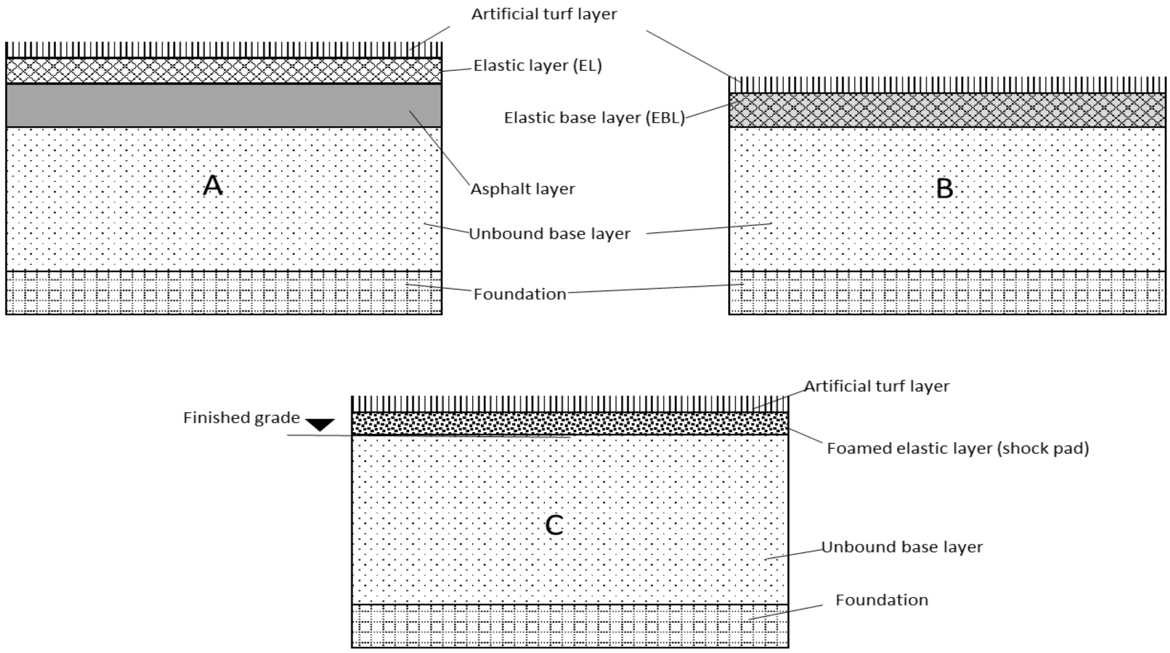

Figure 1: Structure of an artificial turf pitch, construction method A and B, in accordance with DIN 18035-7, and construction method C with finished grade (authors' diagram)

The artificial turf fibers from the artificial turf carpet consist of polyethylene or polypropylene fibers, which are embedded into a carpet backing made from polypropylene woven fabric or a polypropylene or polyamide mesh. A polymer dispersion (latex) based on styrene-butadiene elastomers is usually used to fix the fibers into the fabric or mesh. The artificial turf carpets differ according to pile weight or fiber weight – the yarn mass in the back of the carpet. It varies between 1000 and approx. 3000 grams per square meter.

The artificial turf carpet is applied in strips that are affixed to each other. To statically fix the artificial turf in place, e.g. against wind loads, sand is generally added on top of the carpet as a stabilizing infill material (approx. 20 kilograms per square meter).

6 EN 15330-4:2020-08 – Draft

Round-grained marble sand[7] or odor-minimizing zeolites[8] are also offered in addition to quartz sand.

Alongside sand, a second infill is added to the majority of the pitches, which determines the play-related and safety-relevant properties of the pitch. It is referred to as performance infill. The performance infill is usually an elastomer, a thermoplastic elastomer, or a natural substance. The most commonly used materials in Switzerland and Germany are ELT granulates with or without a polyurethane coating, EPDM, TPE, and cork. However, in Germany and Switzerland, granulates from end-of-life tires tend to be in the minority according to statements from manufacturers and cannot be found in large quantities. EPDM and TPE granulates are often filled with talc. Fiber-reinforced variants of infill (generally with hemp or flax) have also become established. ELT granulates, which are produced from end-of-life tires, have the typical composition of tire rubber (including natural rubber, synthetic rubber, soot, silica, plasticizer oils, and possibly textile scraps). The granulates are black, brown, or green.

There are also non-infill pitches that dispense with performance infill. In this case, the significantly higher fiber weights of three kilograms per square meter are required to achieve a dense and load-bearing playing surface. If the stabilizing sand should also be dispensed with, metal profile rails are needed at the edges to prevent the artificial turf from being lifted by the wind.

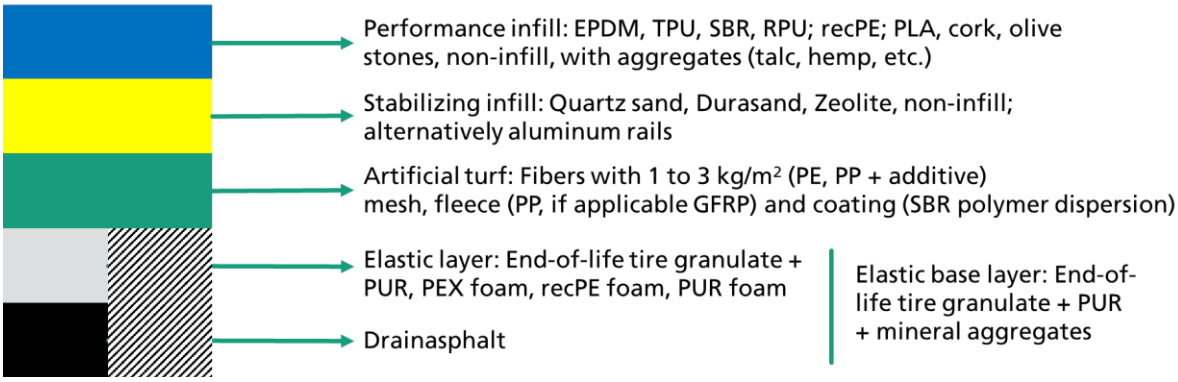

Figure 2: Schematic presentation of the layer-by-layer structure of artificial turf pitches

3.2 Maintenance and upkeep

The survey of pitch operators in Switzerland and Germany found that regular maintenance and upkeep are necessary when artificial turf pitches are used intensively. Alongside the mechanical stress caused by the use of the pitch, precipitation, strong winds, sunlight, impurities such as leaves, waste, or traffic dust, and other environmental influences also put a strain on the artificial turf pitch. The aim of maintaining an artificial turf pitch is to ensure consistent pitch and playing properties and keep the artificial turf pitch in a good condition for as long as possible. The maintenance and upkeep of an artificial turf pitch are organized by municipalities or clubs as the pitch operators and are performed in the majority of cases by permanently employed or volunteer groundskeepers who work at the sports facility. Less often, maintenance agreements exist with

[7] https://sperl.riedau.info/naturKunstrasenNb20200714TbA4.pdf; last accessed: July 8, 2021.

[8] https://www.rymargrass.ca/zeolite; last accessed: July 8, 2021.

external service providers. In this case, the contractors are pitch builders and artificial turf suppliers as well as specialized cleaning service providers, who often perform the maintenance using machines. Pitch operators in Switzerland and Germany cited annual maintenance costs of around 10,000 euros. Topping up infill causes costs to fluctuate significantly and should be viewed separately (cf. Chapter 5)

The maintenance and upkeep of infill and non-infill[9] artificial turf pitches include, in particular, the activities listed in Table 2, which were supplemented with data on scope and frequency from the survey. It should be noted that the artificial turf pitches considered were predominantly infill pitches.

Table 2: Maintenance and upkeep of artificial turf pitches – evaluation of the survey

Activity	Quantifications and cycles
Infill and non-infill artificial turf pitches	
Regular brushing to realign the blades of artificial grass	Between 1x per week and 1x per month.
Cleaning the pitch of leaves, dirt, and waste	Partly achieved by brushing/removing. Usually takes place as required. Occasional use of leaf blowers.
Pitch irrigation	To cool the pitch and reduce abrasion. Predominantly in the event of heat, sometimes also before each match. On hot days before the pitch is used, e.g. before training. The water needed is approx. 6-8 l/sqm for non-infill ATPs and approx. 3 l/sqm for infill ATPs.[10]
Snow clearance	Between 2x and 50x per year, depending on the weather. Stated much more often in Switzerland than in Germany.
Surface cleaning	Usually by workers from the sports facility when required. Performed with brooms/brushes, street sweepers, suction devices.
Deep cleaning	Usually with machines (sit-on machines) as an external service, between 1-3x per year.
Minor repairs (holes, tears)	Where required. According to information, seldom necessary in practice.
Only infill artificial turf pitches	
Topping up granulate and sand	The stated quantities to top up rubber granulate were between 0.5 and 10 metric tons per year. Topping up took place acyclically and where required. Only one statement regarding topping up sand (approx. 250 kilograms per year).
Removal of the pitch to redistribute the granulate evenly	Results from brushing the pitch. Between 1x per week and 1x per month.

Regularly *loosening the filling* is not explicitly stated but, according to expert statements, is an important maintenance activity for infill artificial turf pitches in order to counteract pitch compaction. To do this, strips of steel tines are pulled across the ATP using machines, which often takes place in combination with brushing.[11] When surveying those responsible for pitch maintenance,

[9] "Non-infill" in the context of the study means 4th-generation ATPs without sand and rubber granulate, which do not need stabilizing infill due to a denser fiber mix (straight, crimped, textured).

[10] https://www.polytan.de/blog/sportplatzbau/kunstrasen-sportplatzbau-richtig-planen/; last accessed April 16, 2021.

[11] https://kalinke.de/produkte/kunstrasen/verti-groom/; last accessed March 11, 2021.

the maintenance workload for an artificial turf pitch was stated as being "low" to "the same as a natural turf pitch". One explanation for this could be that many activities for artificial turf pitches are performed by machine and often as external services. In general, pitch builders and pitch suppliers offer the refilling, cleaning, maintenance, and repair of the artificial turf pitch as a service. The service also includes training and seminars for groundskeepers.

Garden designers and landscapers state three activities as being necessary as basic maintenance for natural turf: mowing, fertilizing, and watering. There are also recurring activities such as weed control, scarifying, dragging, loosening, reseeding, and harrowing. To ensure the theoretical maximum utilization of the natural turf pitch of 800 h per year in the long term, other operations are often added, e.g. aeration, perforation, sanding, or reseeding.[12]

3.3 Useful life and service life

Artificial turf pitches in Germany and Switzerland are primarily used to practice soccer. Other sports played on artificial turf pitches include hockey, tennis, American football, and rugby. The artificial turf pitches are also used for school gym classes and are accessible to the general public during free times in certain municipalities.

The annual playing hours on a natural turf pitch for soccer are around 800 hours a year.[13] This relatively low number of hours when viewed over a year is because playing sports is dependent on the weather. Natural turf cannot be used, or can only be used to a limited extent, in snow, frost, and heavy rain, as the condition of the pitch does not allow it to be played on or else the pitch would be damaged. In contrast to natural turf pitches, artificial turf pitches are used throughout the year, largely independently of the weather. The operators of the examined artificial turf pitches confirm their use almost all year round and thus a higher annual number of playing hours. During the surveys conducted as part of the study, the pitch operators stated between 1080 and 2500 playing hours per year (Figure 3). The mean of 1882 hours is thus close to the value of 1800 hours per year that is often stated in the literature.[14,15] An artificial turf pitch can therefore be played on two to three times more often than a natural turf pitch. Nevertheless, the intensity of use appears to differ widely. Whether this is due to different requirements or restrictions in effect at the respective pitches could not be ascertained.

The entire service life of artificial turf pitches is significantly dependent on the manufacturing quality of the components, the construction quality, weather influences, frequency of use, and, last but not least, pitch maintenance. The service life of the actual artificial turf carpet is generally the factor that determines the service life of an artificial turf pitch. The artificial turf carpet is directly subjected to high mechanical stress due to play as well as various environmental influences. The service life of the elastic layer underneath the artificial turf surface is quantified by manufacturers at over 30 years. The DFB even states a service life of up to 40 years. The elastic layer or elastic base layer thus usually outlasts the actual artificial turf. The service lives stated for artificial

12 Information on maintaining NTPs can also be found on the FLL and DRG websites: https://www.fll.de/ and https://www.rasengesellschaft.de/; last accessed April 26, 2021.

13 https://www.sportstaettenkonzepte.de/wissen/details/kunstrasen-vs-naturrasen; last accessed: July 8, 2021.

14 http://www.hergiswil.ch/dl.php/de/5e74dddbe8f35/Sportplatz_Grossmatt_Prasentation_Fussballplatz_02.03.2020.pdf; last accessed April 15, 2021.

15 https://www.jfv-varel.com/startseite/zukunft/; last accessed April 15, 2021.

turf by manufacturers and in the literature differ widely.[16,17,18,19] On average, the service life of an artificial turf carpet is 12 to 15 years.

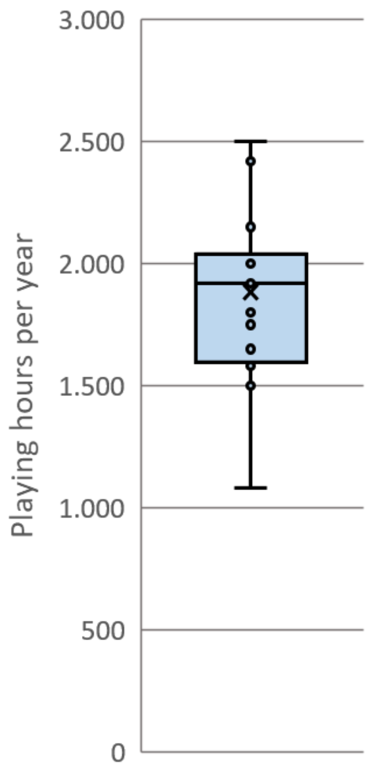

Figure 3: Box plot showing playing hours per year (n = 17)

[16] Private Greens & FiberGrass International GmbH 2017.

[17] Rasenprojekt.de 2019.

[18] Melos GmbH 2019.

[19] https://www.aargauerzeitung.ch/panorama/vermischtes/wenn-der-kunstrasen-zur-kostenfalle-wird-ld.1992424; last accessed: July 8, 2021.

4 How are artificial turf pitches structurally integrated?

"An artificial turf pitch is surrounded by paved/unpaved, natural/artificial surfaces.

Location selection, the pitch surroundings, and the sports ground for the ATP depend on the local conditions, legal regulations, and the preferences of the operators.

An artificial turf pitch is permeable to water and drains rainwater away. A distinction is made between infiltration (vertical drainage), collection and channeling (horizontal drainage), and (supported) drainage.

The majority of the water infiltrates into or next to the artificial turf pitch. The rest is collected and channeled away. The channeling primarily takes place using storm sewers, less often directly into receiving waters, even less often into the sewage treatment plant via the wastewater system."

4.1 Designing of the pitch surroundings

An artificial turf pitch is a structure that is embedded into a settlement's infrastructure. The selection of the site and the designing of the pitch surroundings and the sports ground result from the possibilities available in the municipality (urban, extra-urban), legal regulations (e.g. nature or water protection areas), and the preferences of the operators. Like a natural turf pitch, an artificial turf pitch is also surrounded by paved and unpaved surfaces: paths, paving, stands, grass verges, embankments, or trenches.

The pitch inspections in Germany and Switzerland led to a heterogeneous picture of the installation of an artificial turf pitch. There is no prototype of an artificial turf pitch or artificial turf pitch installation. The pitch surroundings in Switzerland and Germany were individually designed in each case with natural surfaces such as earth walls, lawns, trees, shrubs, and flower beds. Without exception, all of the pitches were enclosed by a fence and thus demarcated from the outside. Some of the pitches were elevated. In Germany, almost all of the inspected pitches were fitted with paving directly next to the turf surface. This paving was installed with different widths (Figure 4 l.). In Switzerland, some of the pitches were also surrounded by concrete slabs or asphalt as well as paving. Curbs and channels were mainly installed between the artificial turf area and the paving. In Switzerland, some of the pitches had edging stones and ball catchers in the form of barriers or fences. Some of the pitches had stands at the edge of the pitch. None of the examined pitches were artificial turf pitches surrounded by a running track. One inspected artificial turf pitch in Switzerland had a surrounding zinc plate strip that was intended to keep the infill on the pitch (Figure 4 r.).

Figure 4: Paving around an artificial turf pitch (l.), surrounding metal strip to retain infill (r.)

4.2 Drainage of artificial turf pitches

Pitch drainage takes place vertically by means of infiltration and horizontally by means of channeling and infiltration next to the pitch if water-permeable surfaces are present there. Horizontal drainage supports water discharge, particularly in the event of heavy rain, by discharging excess water. The type of water discharge for artificial turf pitches primarily depends on whether the water lands on or next to the pitch. The rainwater that lands on the pitch infiltrates through the pitch towards the drainage and groundwater. The water that lands next to the pitch is collected and channeled by corresponding drainage elements such as channels or drains, and discharged via wastewater or rainwater channels. Figure 5 shows the routes of the water and the possibilities of drainage for artificial turf pitches.

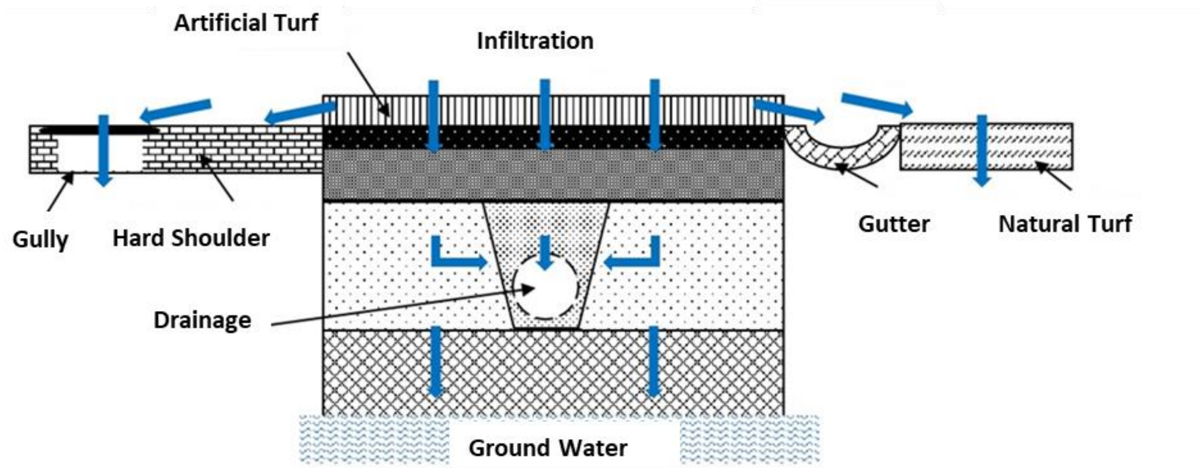

Figure 5: Possibilities of drainage for artificial turf pitches

For vertical drainage, an artificial turf pitch, like a natural turf pitch, must be able to absorb and discharge rainwater. Sufficient water permeability is necessary for this. Guide values exist for the water permeability of an artificial turf pitch in Switzerland and Germany. According to DIN 18035-7, depending on the layer of an artificial turf pitch, 720 millimeters per hour (unbound base layer) to 72 millimeters per hour (subgrade) of rainwater must be able to infiltrate through

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the pitch.[20] The permeability must increase from the top layer to the last layer before the subgrade. Both for the asphalted base layer and for the elastic base layer and the elastic layer, water permeability (water infiltration rate) of 360 millimeters per hour is specified according to DIN 18035-7. EN 15330-1 and FIFA QUALITY specify water permeability of at least 180 millimeters per hour for artificial turf. As a result, there are higher standards on artificial turf than on natural turf with regard to permeability (cf. Table 3). For natural turf, the turf base layer must absorb at least 60 millimeters per hour of water, the drainage layer underneath between 180 and 1800 millimeters per hour, and the foundation at least 30 millimeters per hour (≥ 30 mm/h ≤ 1800 mm/h).[21] The relevant standard for natural turf pitches is DIN 18035-4.

Table 3: Water permeability requirements for artificial and natural turf pitches

Layer	Infiltration rate	Standard
Artificial turf pitch		
Artificial turf	≥ 180 mm/h	DIN EN 15330-1
Elastic layer	≥ 360 mm/h	DIN EN 18035-7
Bound elastic base layer	≥ 360 mm/h	DIN EN 18035-7
Asphalt layer	≥ 360 mm/h	DIN EN 18035-7
Base layer without binding agent	≥ 720 mm/h	DIN EN 18035-7
Subgrade	≥ 72 mm/h	DIN EN 18035-7
Foundation	≥ 72 mm/h	DIN EN 18035-7
Natural turf pitch		
Turf base layer	≥ 60 mm/h	DIN EN 18035-4
Drainage layer	≥ 180 mm/h to ≤ 1800 mm/h	DIN EN 18035-4
Foundation	≥ 30 mm/h to ≤ 1800 mm/h	DIN EN 18035-4

The requirements for water permeability would fundamentally have to be sufficient to also achieve reliable infiltration with heavy rain. Heavy rain is considered to be over 25 millimeters per hour. In terms of the German average, this occurs around four to six times over the 10 to 15-year service life of an artificial turf pitch.[22] Nevertheless, depending on the location of the pitch, floods are also conceivable, especially if the artificial turf pitch is lower than the surrounding area, the surrounding area is sealed, or the pitch is located on a flood plain.[23, 24] The water permeability of

20 A rainwater height of 1 mm corresponds to 1 liter per square meter of rainwater.

21 https://rasenlabor.ch/tag/din-18035/; last accessed: March 11, 2021.

22 https://www.dwd.de/DE/leistungen/unwetterklima/starkregen/starkregen_node.html; last accessed: June 16, 2021.

23 https://www.suedkurier.de/regionalsport/regionalsport-hochrhein/wasserschaden-nach-wolkenbruch-beim-sv-waldhaus-mit-video;art3111,10578486; last accessed: June 16, 2021.

24 https://www.lz.de/lippe/lemgo/3322635_Neuer-Kunstrasen-fuer-den-Jahnplatz.html; last accessed: June 16, 2021.

an artificial turf carpet can also significantly decrease over the years due to soiling, which can cause perforations in the carpet backing to become blocked. Additional lateral drainage systems are thus installed for the surface water in order to discharge rainwater. The surface water is, for instance, collected and discharged via channels, drains, and gullies surrounding the artificial turf pitch. Alongside the artificial turf pitch, there are also often sealed surfaces such as paving or concrete slabs to discharge rainwater or open surfaces such as lawns or planted soil to absorb and infiltrate rainwater (Figure 6). In the event of floods, sediments can be deposited or massive displacements and losses of the infill can occur, depending on the type of infill and the flow velocity. Particularly in the case of cork infill, which is especially lightweight and buoyant, this has also been documented in individual cases.[23]

Figure 6: Different drainage elements: Drainage channel bordering the pitch, trough channel with gully shaft, trough channel with grating shaft, open drainage channel, open dry well, smaller grating shaft (from top left counterclockwise).

The drainage of artificial turf pitches is usually supported by a drainage system that is located underneath the pitch. The drainage consists of slit pipes (suction) distributed over the pitch surface, which receive the water from outside to inside and discharge it via a main pipe (collector) (Figure 7). Apart from one exception, all of the examined artificial turf pitches have this kind of pitch drainage.

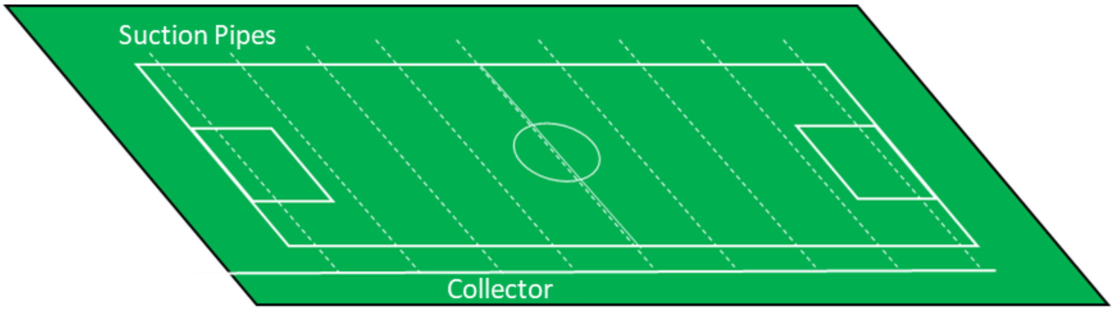

Figure 7: Drainage system for artificial turf pitches

There are different routes for discharging the collected rainwater and drainage water. For instance, the water is introduced directly into a nearby stream or river. Alternatively, the collected water is transported via wastewater or storm sewers in the combined or separate sewer system. Depending on the system, the water is thus fed into the sewage treatment plant or the receiving waters. The location of the artificial turf pitch determines where the rainwater ultimately ends up. If an artificial turf pitch is located in the city or near to a city, it is common for water to be transported via wastewater/combined wastewater sewers and introduced into the sewage treatment plant. If an artificial turf pitch is located in the outlying districts of a municipality or in a rural region, direct or indirect discharge into receiving waters via the storm sewer is the dominating practice. [25]

The drainage situation at the examined pitches was presented in many different ways. Almost all of the pitches were equipped with drainage under the pitch, implemented as a suction-collector system. In addition, some artificial turf pitches were equipped with dry wells (infiltration ditches). The draining water collects in the dry wells and infiltrates over time. Trough channels and/or gullies were predominantly installed next to the pitches to collect the surface water. Less often, pitch drainage solely took place by guiding the water into planting areas, where it could infiltrate. The collected water was discharged in the combined and separate sewer system, sometimes with an emergency spillway to the receiving waters. No artificial turf pitches were fitted with drainage filters to retain rubber granulate.

Alongside this, in terms of sustainability, there is a trend towards saving rainwater and, for instance, using it for subsequent pitch irrigation.[26,27] This concept was also applied at one of the inspected artificial turf pitches in Switzerland. The water was fed into a cycle and used to irrigate the pitch. Solids were separated via a filter system to protect the nozzles. This also separated out infill and fibers. Insofar as filter residues are disposed of as solid waste during regular filter cleaning, rubber infill and fibers are prevented from entering the urban water management system or aquatic environment via the wastewater route.

The discharged water contains dirt, sand, and leaves as well as infill and fibers that come from the artificial turf pitch. Nevertheless, except for mud buckets in gullies, special filter elements, such as to retain particulate matter, are rarely used.

The inspections of the artificial turf pitches in Switzerland and Germany have shown that artificial turf pitches differ significantly, despite valid and applied standards. Especially with regard to the design of the drainage, it makes a difference whether the artificial turf pitch is, for instance, filled with rubber or cork or non-infill, as the emitted amount of granulate significantly exceeds the emitted quantity of fibers. As a result, the following suggestions for designing the drainage relate above all to infill artificial turf pitches:

- Sufficient distance from bodies of water. Suitable site location based on the municipality size (village – city, extra-urban – urban). An ATP in the city has, for instance, the ad-

[25] It should be noted here that e.g. DIN 18035-3 *Drainage* recommends discharging the surface water and drainage water into receiving waters.

[26] https://www.hallertauer-landschaft.de/referenzen/sportplatzbau/8844-neubiberg-erstellung-kunstrasenplatz-im-sportzentrum/; last accessed: April 16, 2021.

[27] https://www.stb-hsos.de/fileadmin/HSOS/Homepages/ILOS/pdf/2017-07-Wassersparkonzepte_auf_Sportanlagen-Osnabrueck_Rasentage.pdf; last accessed April 16, 2021.

vantage that, due to the increased surface sealing in the area surrounding the pitch, emitted infill tends to be fed into the sewage treatment plant and more rarely ends up in nature

- However, do not install the pitch as a trough in low-lying areas and/or surround it by walls and dense vegetation in order to give the wind and rain a smaller target and also keep the emitted infill near to the pitch
- Surrounding of the ATP e.g. with edging stones and other barriers to retain infill. Align possible collection points for infill according to the pitch gradient
- For horizontal drainage via channels, gullies, or troughs, it is sensible to install filter elements to retain any rubber granulates and plastic fibers that are carried away
- For vertical drainage towards groundwater, fit filter layers to retain particles. This could be coarse to fine aggregates, e.g. 0/32 filter gravel. The requirements regarding water permeability are to be noted here
- Fit drainage pipes with drainage filters where applicable. This not only prevents the diffusion of fine infill, but also protects the slits of the drainage pipe from becoming blocked. Nonwoven material, for instance, is available to sheathe the drainage pipes
- Drainage elements such as channels, drains, and troughs should not – without installed filter elements – be connected directly to the artificial turf so that the infill still has a "run-off area" and is not discharged directly with the water. Sweeping the lying infill back onto the artificial turf pitch also reduces the need to top up the granulate
- Do not discharge drainage water contaminated with infill into bodies of water via separated rainwater discharge, but instead into the local sewage treatment plant via the wastewater or combined wastewater route. This measure ensures that emitted infill does not end up in the aquatic environment. If the local sewage treatment plant works the sewage sludge into the soil, it is, however, to be expected that the pollution of the aquatic environment would be replaced by the pollution of agricultural soils. An inspection of the situation on site – application of sewage sludge or incineration of sewage sludge? – is sensible here. It is also recommended to check the locally applicable drainage regulations[28] (drainage statute, urban drainage) with regard to permission and costs

[28] In the applicable municipal regulations, the introduction of drainage water into sewage plants is often prohibited.

5 Where are there artificial turf pitches in Germany and Switzer-

“There are no official figures for the number of artificial turf pitches either in Germany or in Switzerland. Satellite data evaluations result in 800 artificial turf pitches or artificial turf-like pitches in Switzerland – outside of private use – and around 9000 in Germany. Official estimates are generally below these figures.

It is possible for over 50,000 people – or even almost no one – to live within a radius of 1 kilometer around artificial turf pitches. A roughly equal proportion of artificial turf pitches is integrated into an agricultural or forested environment (136 square kilometers) or a residential or commercial environment (129 square kilometers).

There are 5.8 million square meters of bodies of water located within 100 meters of artificial turf locations with a mean distance of 330 meters from running and 730 meters from standing water.”

In Germany and Switzerland, there are no official figures regarding the number, surface area, and location of artificial turf pitches. Estimates and investigations exist from a small number of organizations. [29,30,31,32,33,34] The numbers indicate between 6,000 and 13,000 pitches in Germany depending on the year of collection, counting method, recorded sports, and uses, as well as across all size classes. At the beginning of 2019, the number of reported large playing fields, which only represent a proportion of the artificial turf pitches, was stated by the DFB[35] as 5,109.

In order to also be able to make further statements on the location and environment of the artificial turf pitch locations and surrounding areas, a satellite data evaluation was conducted to identify the locations. With the help of the globally available Sentinel-2 satellite data, it was possible to distinguish between artificial and natural constituents in the surface coverings of the sports pitches. Multispectral image data were used for this, which enable the vegetation index NDVI (Normalized Difference Vegetation Index) to be calculated with a geographical resolution of 10 meters. In addition to this, the “red value” provides information about the color of the surface. The results in Table 4 and Figure 8 have been achieved in combination with official data on digital landscape models, which include information on the location of sports and leisure facilities in general. Non-natural, non-red-colored sports pitches were identified using this methodology. Artificial turf pitches are largely identified in this way. Within this, other non-natural surface coverings on sports and leisure areas are also recorded for smaller spaces, causing misdetection and making the number of artificial turf pitches shown somewhat larger than the actual figure. As geodata is classified in more detail in Switzerland, the robustness and reliability of the results for Switzerland

29 German Bundestag 2020.

30 DFB 2020.

31 Frias and Nash 2019.

32 DIN Standards Committee Building and Civil Engineering (NABau) 2019.

33 Bertling et al. 2018b.

34 DOSB and German Federal Institute of Sport Science 2020.

35 DFB 2019.

are also somewhat greater than for Germany. The number of pitches shown here includes a combination of artificial turf pitches along with pitches that provide similar data in the spectral analysis.

The analysis nevertheless provides valid data.[36] Particularly for the following statements on incorporating the pitches into their surrounding area, which no other available data set can currently make.

The comparison of the number of pitches based on the satellite data analysis in Table 4 shows that the proportion of pitches with artificial turf and artificial turf-like material, in relation to all sports and leisure areas, is higher in Germany than in Switzerland. This relates both to small and large pitches. The greater prevalence also becomes apparent if the number of artificial turf pitches is related to the population figure. In terms of figures, regardless of the pitch size, 8,725 people share an artificial turf pitch in Germany, while the figure in Switzerland is 10,680.

Table 4: The number of identified artificial turf pitches and artificial turf-like surfaces in Germany and Switzerland based on a satellite evaluation

Pitch type	Size (m²)	Quantity Germany		Quantity Switzerland	
		All locations	of which artificial turf	All locations	of which artificial turf
Small pitch	< 5,000	37,934	2,661 (7%)	13,841	447 (3%)
Large pitch	> 5,000	34,455	6,852 (20%)	2,304	356 (15%)
Total number of pitches		72,389	9,513 (13%)	16,145	803 (5%)

Figure 8 shows that the macroscopic distribution of ATPs largely corresponds to population density. It can also be determined that there are comparatively more small pitches in Switzerland and southeast Germany.

[36] This data could be further improved with a supplementary aerial photograph evaluation, during which the RGB values of the identified pitches would once again be inspected. This was not possible as part of this study for time and cost reasons. In Switzerland, a corresponding method is currently being applied by the Eastern Switzerland University of Applied Sciences within the KuSIM project. Results are expected by the end of 2021.

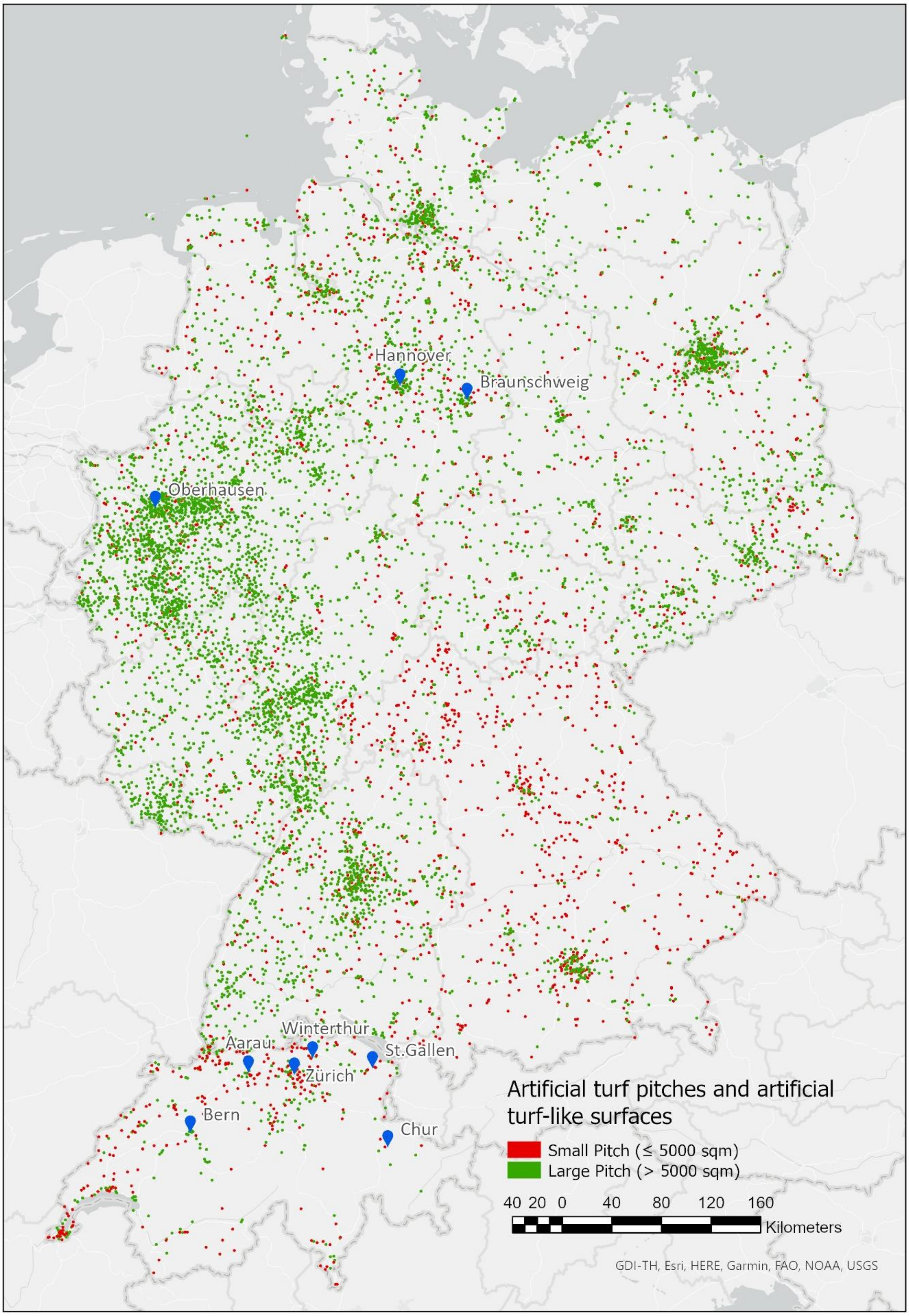

Figure 8: Location of surfaces identified as artificial turf and artificial turf-like in Germany and Switzerland; locations of on-site analyses are marked in blue

5.1 How are the spaces integrated geographically?

Artificial turf pitches can be found in sports and leisure facilities in all parts of Germany and Switzerland. Open spaces immediately neighboring settlements are predominantly characterized by sport, recreation, and leisure areas, which can be either sealed or feature green spaces (Figure 9). The distance analyses in Chapter 5.2 show that they can often be found near flowing waters. Flood plains offer suitable space for sport and leisure facilities, especially in hilly areas, but also in densely populated municipalities.

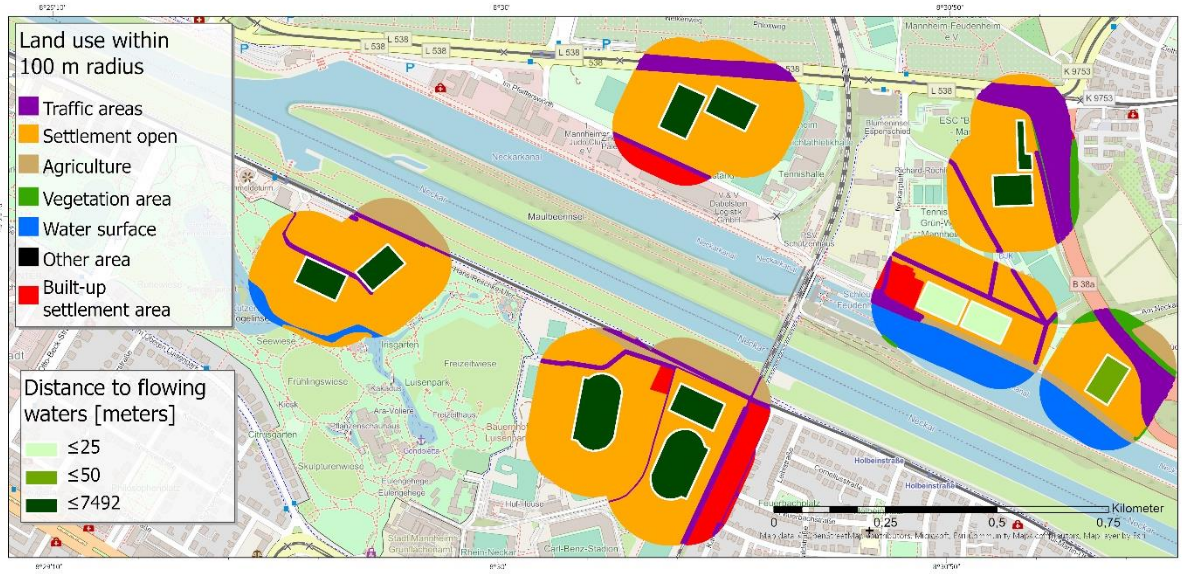

Figure 9: Example map: Use of space in the area surrounding artificial turf pitches

Aside from the actual sports, leisure, and recreation areas, the further area surrounding the artificial turf pitches displays various types of use (Figure 10). A distinction can generally be made between two types: Sports facilities in a generally rural environment with a high proportion of agricultural space or forested surroundings, and sports facilities in a generally urban environment characterized by residential areas or other types of development. Fifty-one percent of the surrounding area of artificial turf pitches is vegetal (agricultural space, forests, and woods) or aquatic space (flowing and standing water).

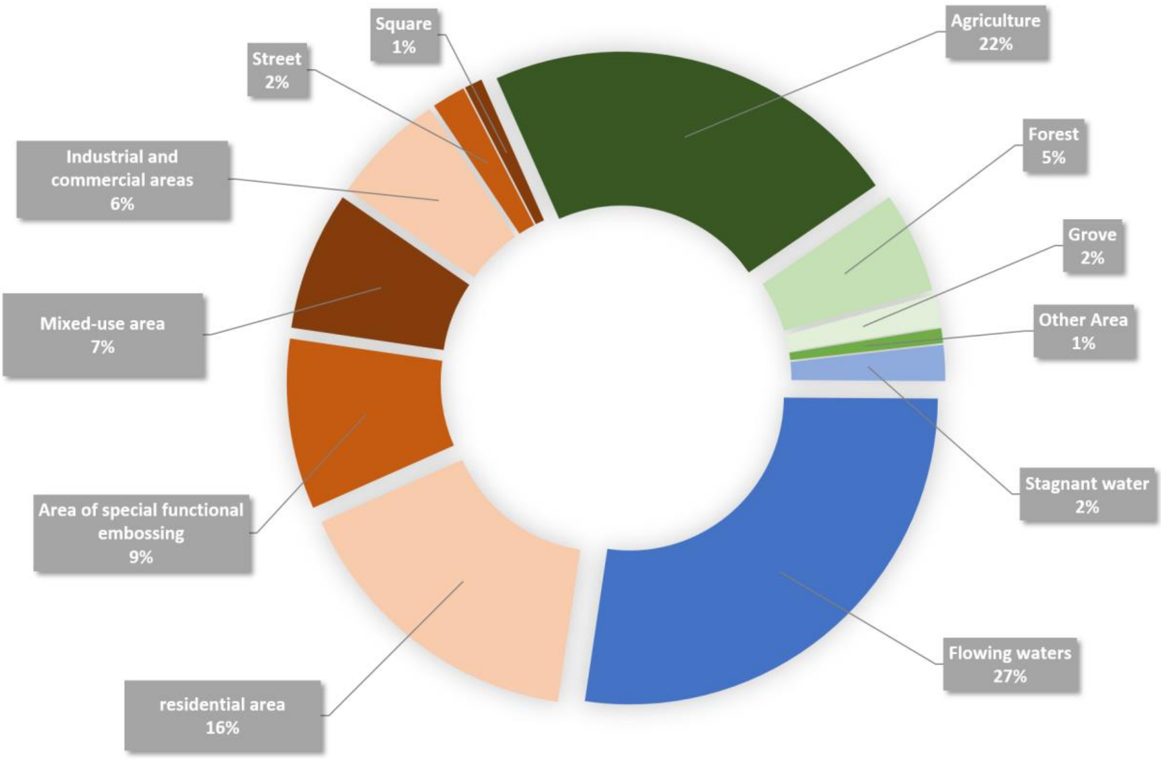

Figure 10: Average space composition within a 100 m radius of artificial turf pitches in Germany

The greatest inhabitant density within a one-kilometer radius of an artificial turf pitch can be found in Berlin-Neukölln with 23,379 inhabitants (Figure 11). Particularly in rural regions, there are also locations without a residential population.

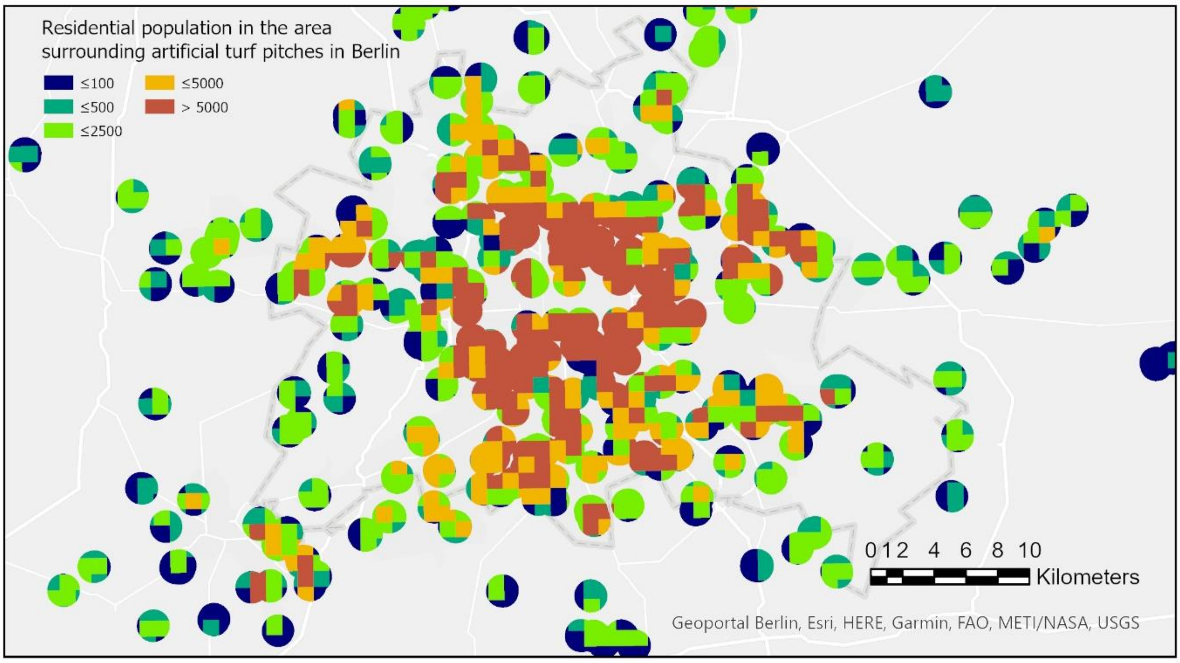

Figure 11: Example of Berlin: Residential population in the area surrounding artificial turf pitches (GIS analysis)

5.2 How far away can open bodies of water be found?

To estimate how likely it is that plastic granulate or fibers could enter the surrounding bodies of water, a geographical evaluation was conducted for Germany based on data from the digital landscape model (Basis-DLM). The neighborhood analyses conducted place artificial turf pitches with surface water in a geographical context to identify how important bodies of water are for the potential spread of microplastics from artificial turf pitches into the environment. Figure 12 shows the frequency distribution of the distances from flowing water. Almost 100 percent of the artificial turf pitches have a body of water within a distance of 1 kilometer, but around 25 percent of the pitches (2,311 pitches) also have flowing water within a smaller distance of up to 50 meters.

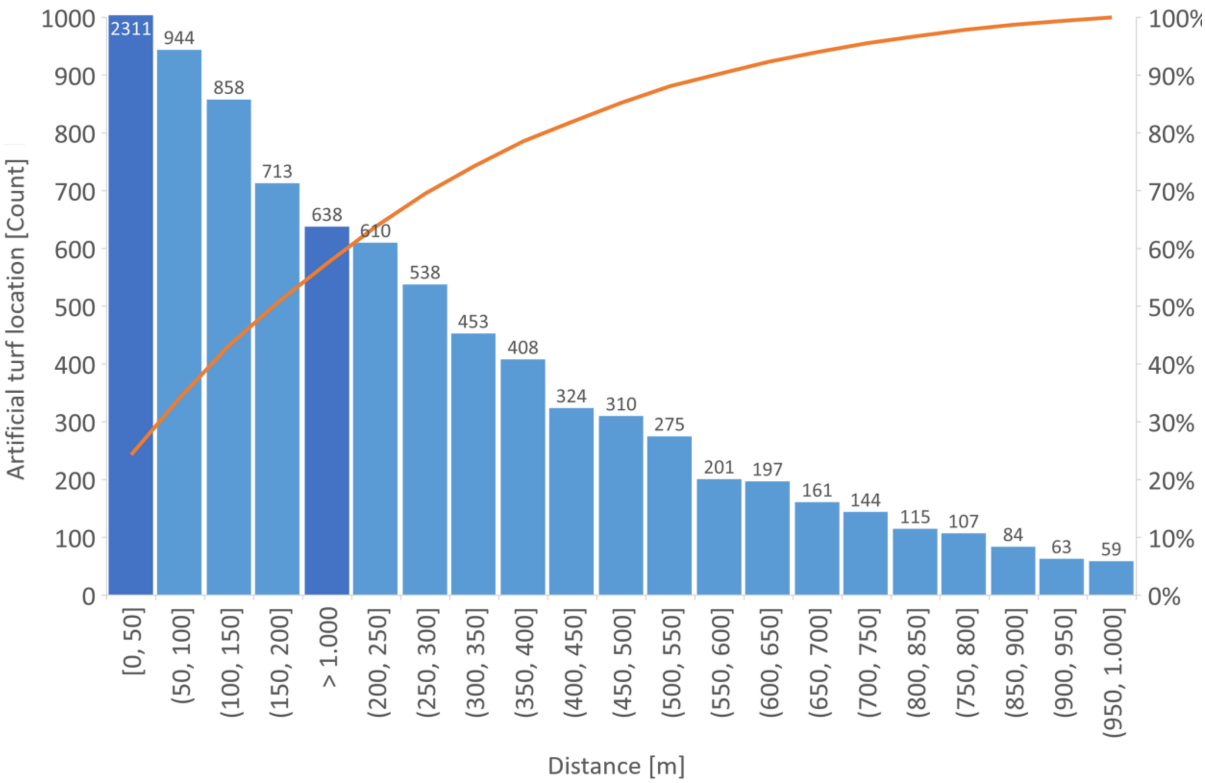

Figure 12: Frequency distribution of the distances of artificial turf locations from larger bodies of flowing water

There are generally no specific statutory regulations or recommendations in Germany and Switzerland that specify the distance of artificial turf spaces from permanently or periodically flowing bodies of water. The regulations from the German construction and agriculture sector were used for representation in Figure 13 for comparison purposes. According to the German Federal Nature Conservation Act, it is prohibited (exceptions possible) to erect structural facilities in an outdoor area within a distance of up to 50 meters from the shore line of federal waterways, first-order bodies of water (bodies of water with significant importance for the water economy), and at standing bodies of water measuring more than 1 hectare. Around 25 percent of the locations are within this area, which is not a problem from a legal viewpoint as long as the artificial turf spaces are located at smaller bodies of water or “the impairments to the ecosystem or landscape created by the structural facility, particularly with regard to the function of the bodies of water and their shore areas, are minor or this can be ensured by taking corresponding measures".[37]

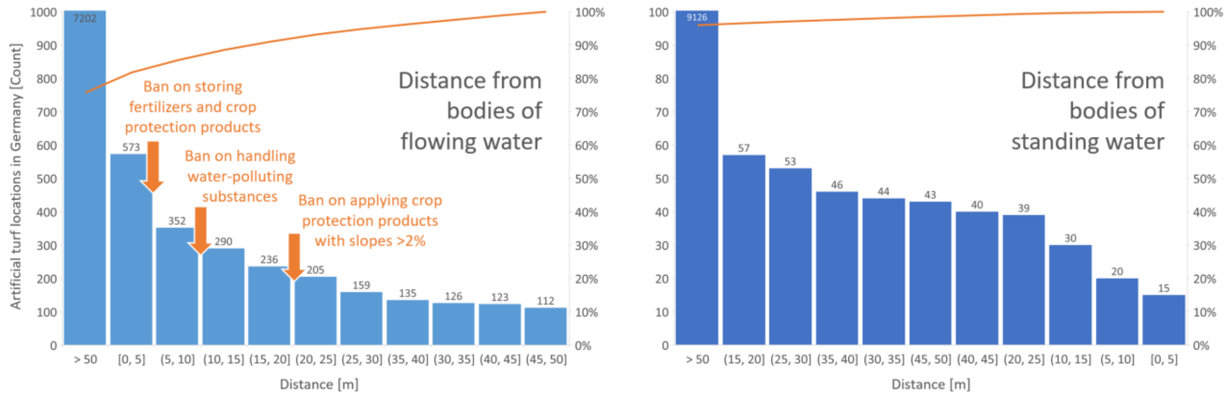

Figure 13: Frequency distribution of the distances from larger bodies of flowing and standing water

As a comparison: in Switzerland, water corridors[38] are defined that are primarily reserved for the bodies of water and within which other uses are significantly restricted. These corridors are at least 11 m wide and become larger depending on the bed width of the body of water.

With regard to the handling of substances, requirements on distances from bodies of water when using agricultural crop protection products[39] have been chosen as reference values for the representation as the standard of comparison.

It should be noted that this representation is only illustrative and thus no statements can be made concerning the risks associated with plastic granulate in general and in comparison with fertilizers and crop protection products in particular. Nevertheless, the European Chemicals Agency ECHA considers any emission of a persistent plastic < 5 mm (microplastic) to be an environmental risk. [40]

The neighborhood analyses were performed as bodies of water and, in particular, flowing waters are relevant for the spread of microplastics in the environment. Examples of this are shown in Figure 14. The results show that artificial turf pitches are often located very close to surface waters. Direct pollution due to drift or surface discharge thus appears to be entirely realistic. No reliable quantifiable statements can currently be made regarding the scope of plastic granulate or fiber discharge from artificial turf pitches into surface waters.

Nevertheless, granulate was found a distance of over 10 meters away from almost all of the pitches during the on-site examinations of the artificial turf pitches in Germany and Switzerland. Bodies of water lie within this area for around 10 percent of the pitches. The quantities of plastic granulates and fibers that enter the bodies of water should be the subject of future in-depth investigations.

[37] BNatSchG.

[38] https://www.zh.ch/content/dam/zhweb/bilder-dokumente/themen/planen-bauen/wasserbau/gewaesserraum/merkblatt-und-vorlagen-zur-festlegung-des-gew%C3%A4sserraums/1_merkblatt.pdf; last accessed: July 20, 2021

[39] KTBL 2019.

[40] https://echa.europa.eu/de/registry-of-restriction-intentions/-/dislist/details/0b0236e18244cd73; last accessed: June 25, 2021.

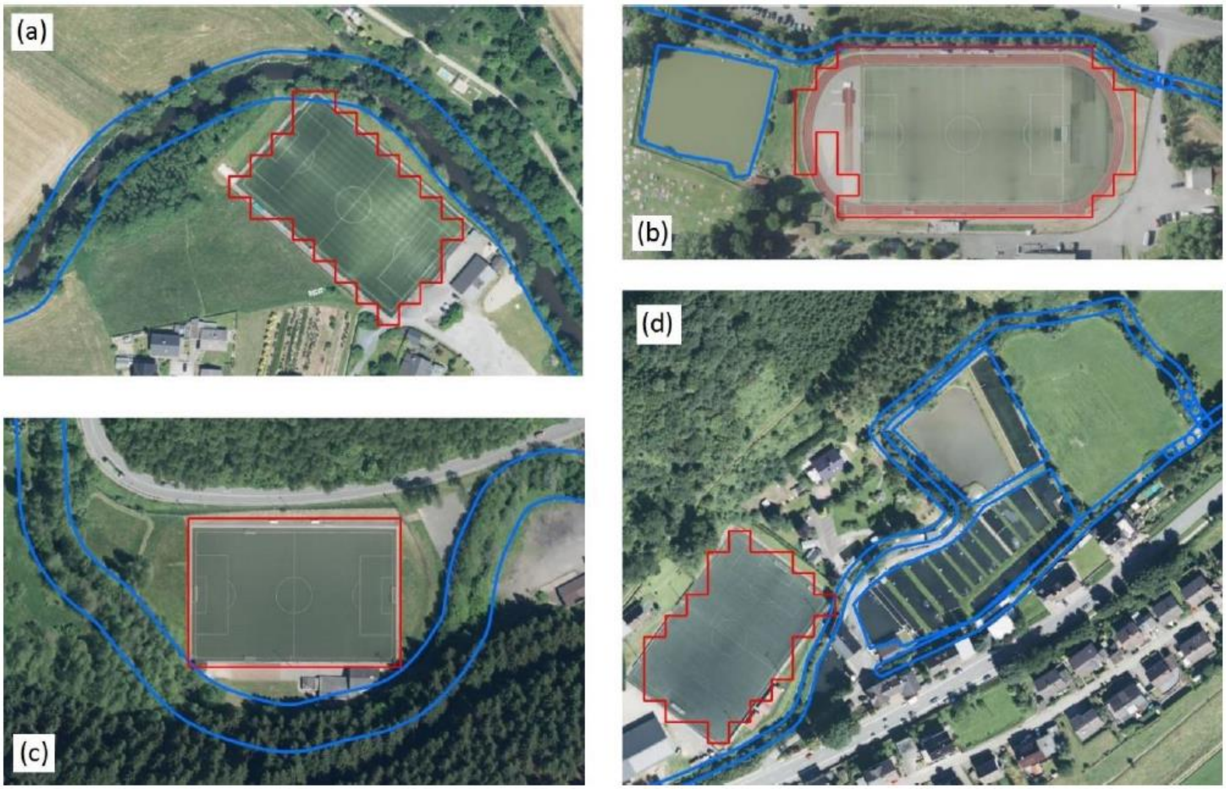

Figure 14: Examples of artificial turf pitches located close to surface waters. Artificial turf pitch in red, nearby surface waters in blue.[41]

41 Osterthun 2020.

6 How economical are artificial turf pitches?

“The cost differences in detail are significant. Different turf systems require different infrastructures and maintenance approaches. Annual cost considerations even out many differences between natural and artificial turf pitches.

Clear cost benefits for artificial turf pitches arise based on the hours of use. It is as yet unclear whether these can be maintained as environmental regulations increase.”

sition that have a corresponding effect on the cost structure for procurement, operation, and disposal, and on the extension of utilization times due to restoration.

The structure of a natural turf pitch can differ based on the local conditions. In all cases, natural turf pitches always have a foundation, a subgrade, a turf base layer, a root zone, and the turf surface layer. Depending on the conditions, drain sections, sand applications, and drainage packing are also required. Artificial turf systems can consist of various materials and material combinations, which have been described in detail in Chapters 3 and 4. For hybrid turf, natural and artificial turf are combined to achieve a qualitative improvement.

Table 5 shows a comparison of the most important economic parameters based on various sources for a usage cycle without restoration costs.[42,43,44,45] The cost overview is based on the conditions in Germany, although the statements can also be applied correspondingly to Switzerland. Compared to the other systems, natural turf has the lowest construction costs, while artificial turf has the lowest operating costs. Significantly higher disposal costs are incurred for the hybrid turf systems if a compostable system – which has only recently become available – has not been chosen. [46,47]

Table 5: Comparison of natural, artificial, and hybrid turf pitches

Type	Natural turf	Artificial turf	Hybrid turf
Construction costs [€]	200,000 – 250,000	420,000 – 550,000	400,000 – 450,000
Maintenance costs [€/a]	25,000 – 35,000	12,000 – 24,000	25,000 – 60,000
End of life and costs [€]	Processing: 22,000	Recycling: 65,000	Composting: 40,000 Disposal: 400,000
Total costs [€]	247,000 – 307,000	507,000 – 649,000	535,000 – 965,000
Hours of use [h/a]	800	1800	1000
Service life	> 15	12 – 15	8 – 10

42 Schneider 2019.

43 Sportstättenrechner 2020.

44 DFB 2017.

45 Sportplatzwelt/Stadionwelt 2020b.

46 Sportplatzwelt/Stadionwelt 2020a.

47 Heiler-Sport 2020.

Restoration costs [€]	65,000	160,000 – 210,000	250,000

As the systems and their components display significant differences in terms of service life and the possible hours of use per year, the annual total costs are shown in Figure 15 for a better system comparison and the annual costs were allocated to the hours of use in Figure 16. To enable these comparisons, the system-specific disposal and restoration costs have been calculated as a 15-year cycle.

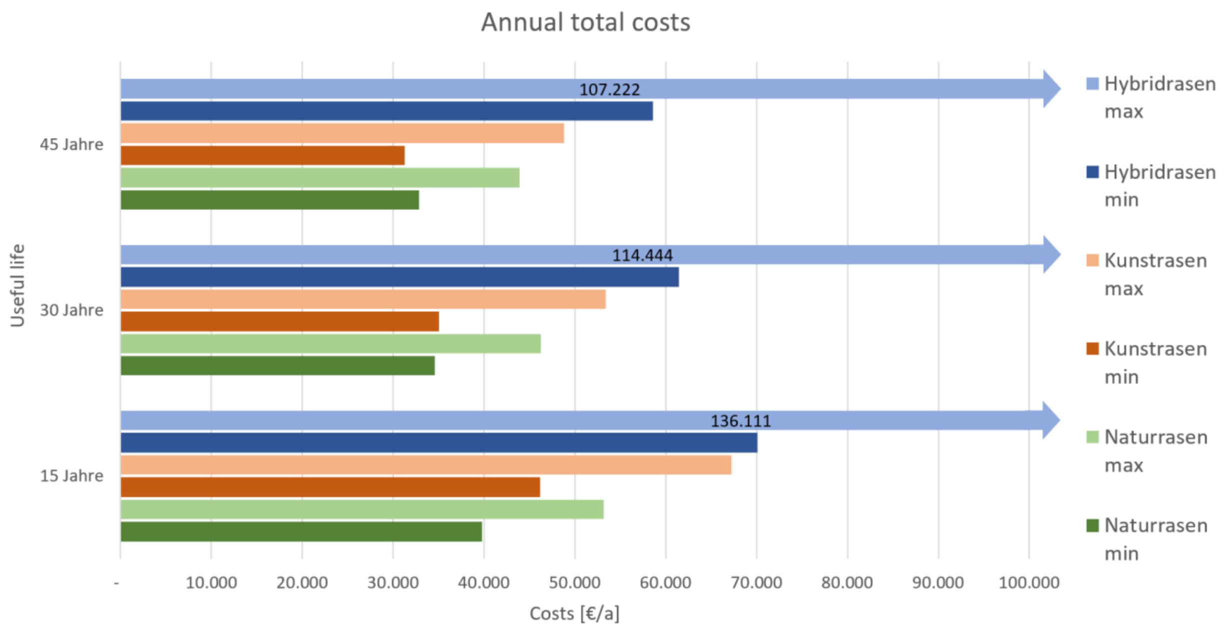

Figure 15: Comparison of the annual total costs for 15, 30, 45 years of useful life

The comparison of the annual total costs shows that conventional (non-compostable) hybrid turf systems represent the most cost-intensive version. The relative cost disadvantage of this will increase even further over time due to the high disposal and processing costs compared to the other systems. The disposal costs fall significantly for compostable systems, although this type of system remains comparatively expensive due to its high restoration costs.

The economic results of the natural and artificial turf systems are relatively close together when considering annual costs. The slight cost advantage of natural turf in the first 15 years equals that of artificial turf over longer periods of time due to the lower maintenance costs despite higher restoration costs (cf. Chapter 2.2).

Furthermore, the costs of regranulation due to granulate loss and compaction are not taken into account appropriately by the maintenance flat rates in every case. There may be a further increase in the running costs for artificial turf pitches if the artificial turf pitches require greater regranulation (cf. Chapter 7). The implementation of future measures to reduce granulate loss, as described in the technical report by the European Committee for Standardization CEN[48], could increase the investment costs for artificial turf pitches, but also reduce running costs by minimizing the need for regranulation (cf. Chapter 8).

48 https://www.estc.info/wp-content/uploads/2020/03/FprCENTR-17519-Public.pdf; last accessed: June 23, 2021.

The achievable hours of use have a great influence when choosing a turf system. They differ significantly between the systems and have a corresponding effect on the total costs per hour of use (cf. Table 5). Widely differing costs per hour of use from €26 (artificial turf minimum) to €113 (hybrid turf maximum) can be recorded after 15 years (Figure 16). The order artificial turf, natural turf, and hybrid turf is still retained after 15, 30, and 45 years with significant cost gaps.

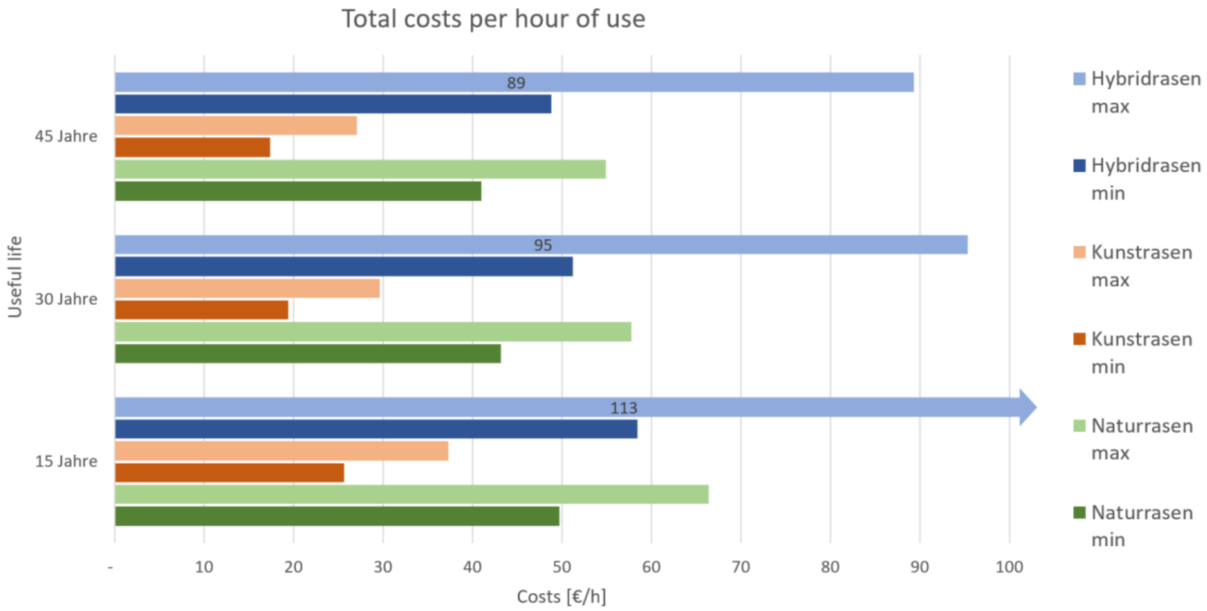

Figure 16: Comparison of the total costs per hour of use for 15, 30, 45 years of service life

The estimated hours of use and service lives are crucial for this comparison of natural and artificial turf.

- In interviews and in the literature,[49] fewer hours of use of around 400 h/a can also be found for natural turf and greater hours of use of 2000 h/a and over for artificial turf. The comparison between these two systems would then be improved towards artificial turf
- On the other hand, statements regarding a longer service life can also be found for natural turf pitches, meaning that the restoration costs would only be incurred at a later time and so the result for natural turf would ultimately be more positive. Statements regarding greater hours of use are sometimes also made, although this would also mean a greater maintenance workload

In addition to the economic parameters, other factors, including in interaction with clubs and players, should be taken into account when selecting a turf system (Table 6).

[49] Schneider 2019.

Table 6: Example of properties that are to be taken into account when deciding to invest in a turf system

Properties	Natural turf	Artificial turf	Hybrid turf
Maintenance workload	average	low	high
Use during frost	inadequate	sufficient (heavily dependent on the infill type)[50]	inadequate
Use in wet conditions	good	very good	good
Playing comfort	very good	good	good

If no artificial turf is used, the question particularly arises as to how training needs can be met in winter or in heavy rain (during which natural turf often cannot be played on in order to prevent damage). The situation is also made more difficult in that space in conurbations is rare and expensive and so a high intensity of use is advantageous. Alternatively, long travel distances may need to be accepted. To what extent indoor sports halls can meet these needs (cold air or warm hall) is not only an acceptance question here (cf. Chapter 16), but it would also raise the question of how the additional costs associated with this are to be assessed in a comparison of the systems. This would produce further benefits in favor of artificial turf compared to a combination of natural turf and sports hall. On the other hand, it should be taken into account that, in particular, the use of artificial turf following snowfall has so far been associated with high granulate losses due to snow clearance. There are also suggestions for improvement in this regard in the CEN technical report.[48] To what extent playing in low temperatures also promotes fiber loss (e.g. due to cold weather embrittlement) is so far unknown.

50 Particularly for pure sand pitches and pitches filled with cork, playability in winter is considered rather poor by experts, personal communication: D. Schockmann May 14, 2021.

7 How much infill is on the pitches and what does it do?

"The examined pitches from 2009 to 2019 show no reduction in the amount of performance infill, regardless of the year of construction.

Accumulation due to compaction on the pitches was not measured.

A small number of results on the change in particle size distribution over time indicate that the performance infill is pulverized over time and also disintegrates as brittleness increases.

The infill is distributed very unevenly over the pitches, this effect increased with the age of the pitches. The relevance of the performance infill with regard to play-related properties is obviously overestimated."

7.1 Quantities used

As part of the study, the infill quantities were determined at five measuring points within a pitch quarter at 15 pitches (Figure 17). To perform the measurement, the infill was completely removed in a defined area and examined using helium pycnometry and sieve analysis (cf. Annex).

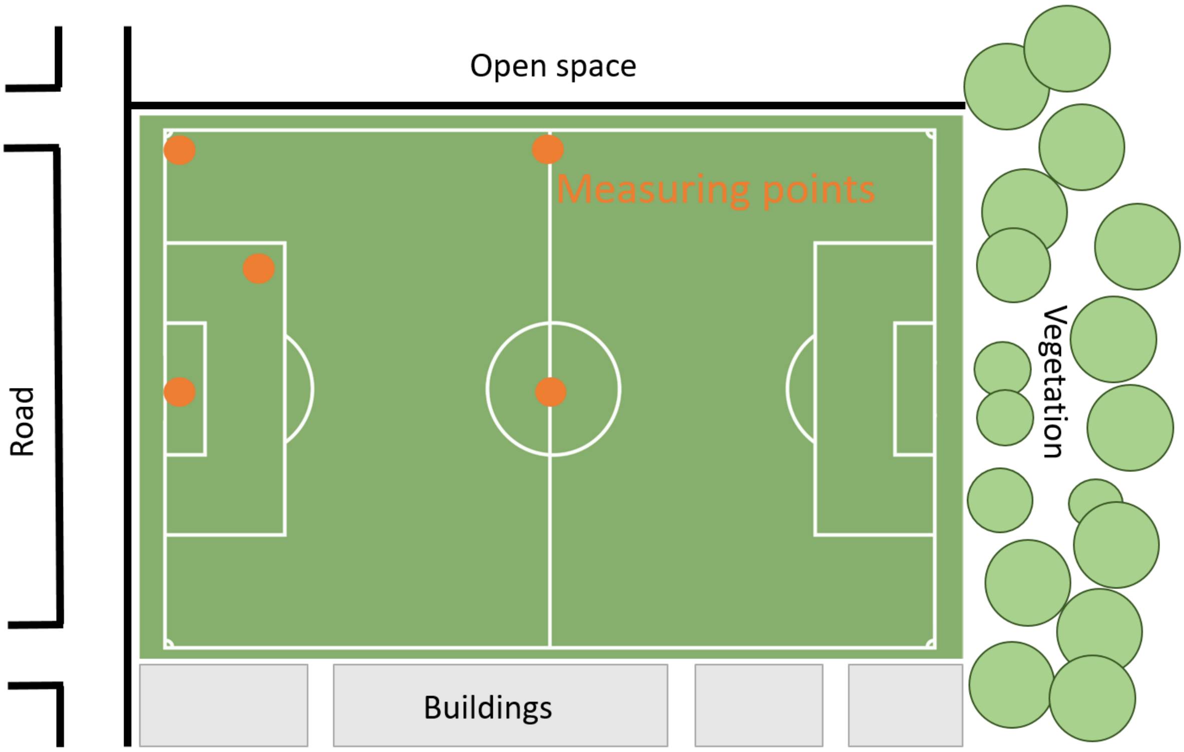

Figure 17: Location of the measuring points within a pitch quarter

The quantity of infill on the pitches varies between 6.4 and 34.4 kilograms of infill per square meter, the quantity of performance infill between 1.2 and 12.3 kilograms per square meter (Figure

18). Taking into account the respective pitch size, the overall quantity of performance infill per pitch varies between 17 and 95 metric tons.

The proportion of the performance infill in the entire infill was between 10 and 86 percent. While this value varied significantly for older pitches, it stabilized at values around 40 percent for newer pitches. A weak positive correlation thus exists between the year of construction and the quantity. The infill quantity increases slightly for the examined pitches as the age of the pitches increases. However, the correlation is not significant ($r = +0.35$, $p = 0.22$). In contrast, the proportion of performance infill in the total infill shows a slightly negative correlation with age; this correlation is also not significant ($r = -0.31$, $p = 0.29$). A frequent assumption that less performance infill is used for newer pitches cannot be confirmed for the examined pitches. On the contrary, it appears that the proportion of sand and thus the entire mass would increase. In addition, no systematic correlations were identified between the infill quantity per pitch and the turf type, infill material, or density of the infill used. The infill quantities instead appear to be determined by manufacturer preferences and the maintenance performed by the pitch operators. By using cork (green column, far right) instead of synthetic elastomers (orange), the mass and mass proportion decrease significantly due to the low density of the cork.

Where data existed, the fiber weights of the infill pitches were between 1000 and 1400 grams per square meter.

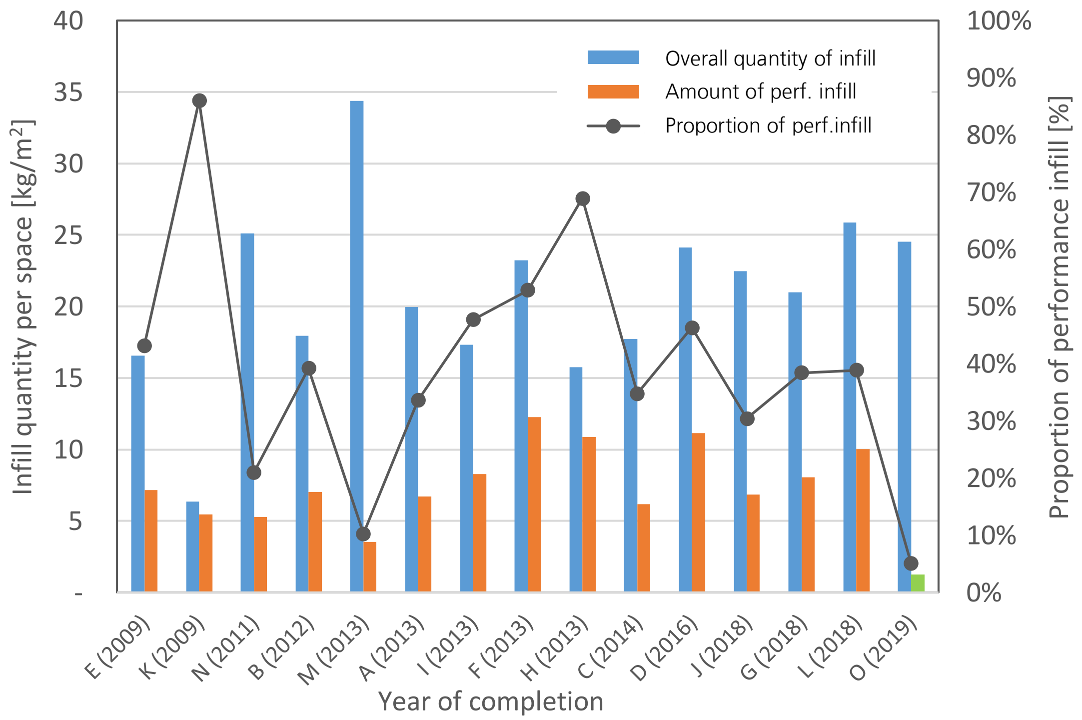

Figure 18: Infill quantity and proportion per pitch and year of completion

7.2 Accumulation of infill

Many artificial turf playing fields become compacted over their life cycle. The turf filaments are bent and broken by playing and the infill becomes compressed. Particularly for elastic infill, laboratory investigations by Fleming et al. measured increases in bulk density of up to 39 percent following mechanical compression. After it was loosened up (decompacted) as part of maintenance activities, the density increase was reduced to 9 percent.[51] This density increase is repeatedly cited as an indicator of granulate accumulation on the pitch.[52,53]

Verschoor et al.[53] additionally mention a field study. This is based on data from a single pitch.[54] The calculation of compaction is also based on the comparison of four points on the pitch at the time of sampling. It is not stated how the rubber granulate and sand mass were separated and quantified. Due to the typically high fluctuations on the field, the selection of the points (penalty spot, goal area, external area), and the unclear methodology, the results of this field study do not appear robust. In the view of the authors of this study, the laboratory investigations and field studies to date are thus unable to provide any verifiable evidence on the accumulation of infill over the service life of the pitch and contradict the authors' own results.

With this in mind, the difference compared to the performance infill quantities directly after the completion of the pitch was determined in this study using the mean values from the measurements taken at 5 measuring points per pitch (Figure 19). It was shown that an accumulation over time tends to occur more rarely (5 out of 15 pitches) and a reduction in the amount of granulate (10 out of 15 pitches) much more often. Averaged over all of the pitches with elastomer performance infill, the quantity of infill reduced by 12 percent; no correlation with the age of the pitches was found (r = +0.08). The pitch with cork displayed a particularly high reduction in infill (green bar). Considering these results, it appears rather unlikely that systematic regranulation takes place to compensate for infill compaction.

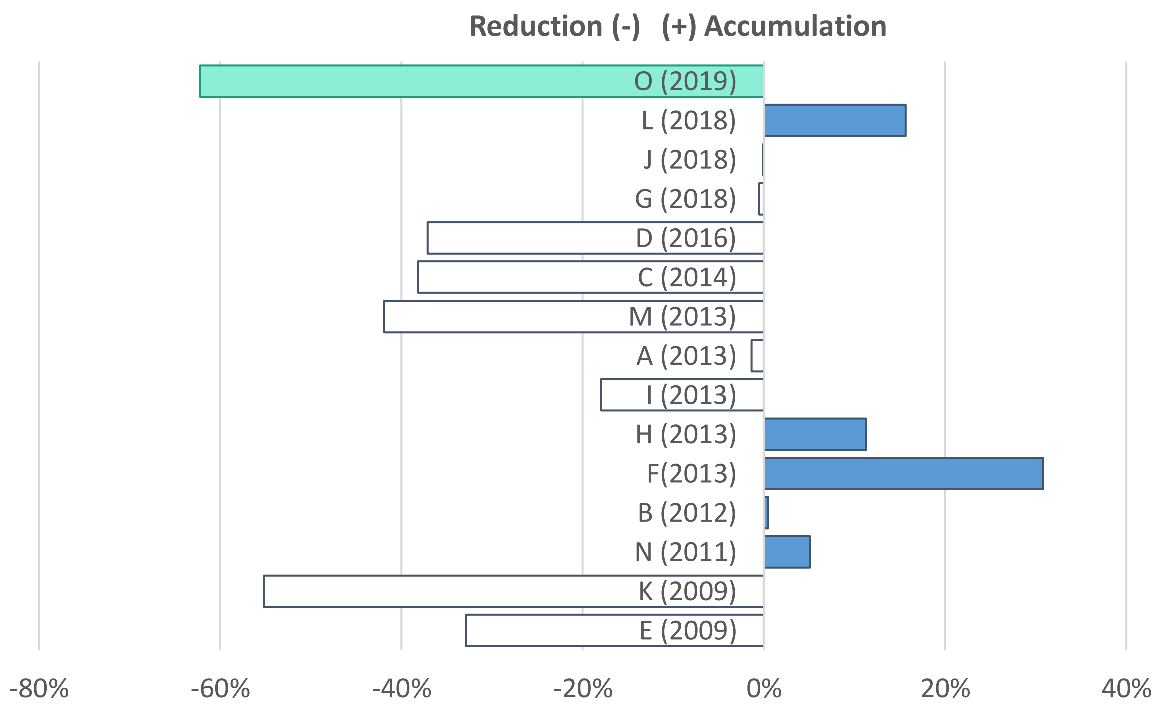

Figure 19: Reduction and accumulation of infill compared to the situation on completion

51 Fleming et al. 2015.

52 Lokkegaard et al. 2019(DTI)

53 Verschoor et al. 2021.

54 A second pitch is mentioned which, it is claimed, would provide the same results on compaction. However, the original source cited did not confirm this.

7.3 Fragmentation of the infill

Samples of the unused infill were available for two of the examined pitches, which were compared with the infill from the pitch sampling (Table 7). For both pitches, an increase in the fine fraction (> 0.1 mm, also in the fraction 0.1 to 0.3 mm for the older pitch) can be ascertained, which indicates abrasion. The significant decrease in the fraction larger than two millimeters with a simultaneous increase in the fraction of more than one millimeter for the older pitch suggests massive fragmentation. The increase in the fraction larger than two millimeters for the newer pitch could indicate that the granulate is both defibered (size increase) and fragmented (size decrease) due to mechanical stress in the first step and pulverized by the abrasive effect of the sand infill. At the same time, it is likely that fragmentation increases as the granulate becomes older and more brittle.

Due to the low number of measurement values, the topping up of fresh granulate over the useful life, and the unknown loss rates per size class, these statements are nevertheless still very uncertain and in-depth investigations into the change in particle size distribution would be useful. It should also be investigated here whether the tendency towards fragmentation and defibration is the same for all infill types.

Table 7: Results of the sieve analyses of the performance infill from two pitches of different ages

Grain sizes	J (2018) – EPDM, 2 years		K (2009) – RPU, 11 years	
	new	used	new	used
> 2 mm	51.67	54.90	22.98	13.56
> 1 mm	42.59	42.11	65.26	76.30
> 0.5 mm	5.54	2.85	11.61	9.61
> 0.3 mm	0.16	0.00	0.15	0.29
> 0.1 mm	0.03	0.14	0.00	0.24

7.4 Infill distribution and play-related properties

The quantities of performance infill fluctuate not only between the different pitches but also between the measuring points on a single pitch. The coefficient of variation (COV = (maximum value - minimum value) / mean) for the infill quantity has values between 36 and 144 percent. The fluctuation range for newer pitches tends to be somewhat lower than for older pitches ($r = -0.51$, $p < 0.05$). This could be a result of deficient or decreasing pitch maintenance or caused by improved fixing of the infill due to different turf fibers used on newer pitches. No systematic correlations were found in terms of certain measuring points having higher and other measuring points lower proportions of performance infill.

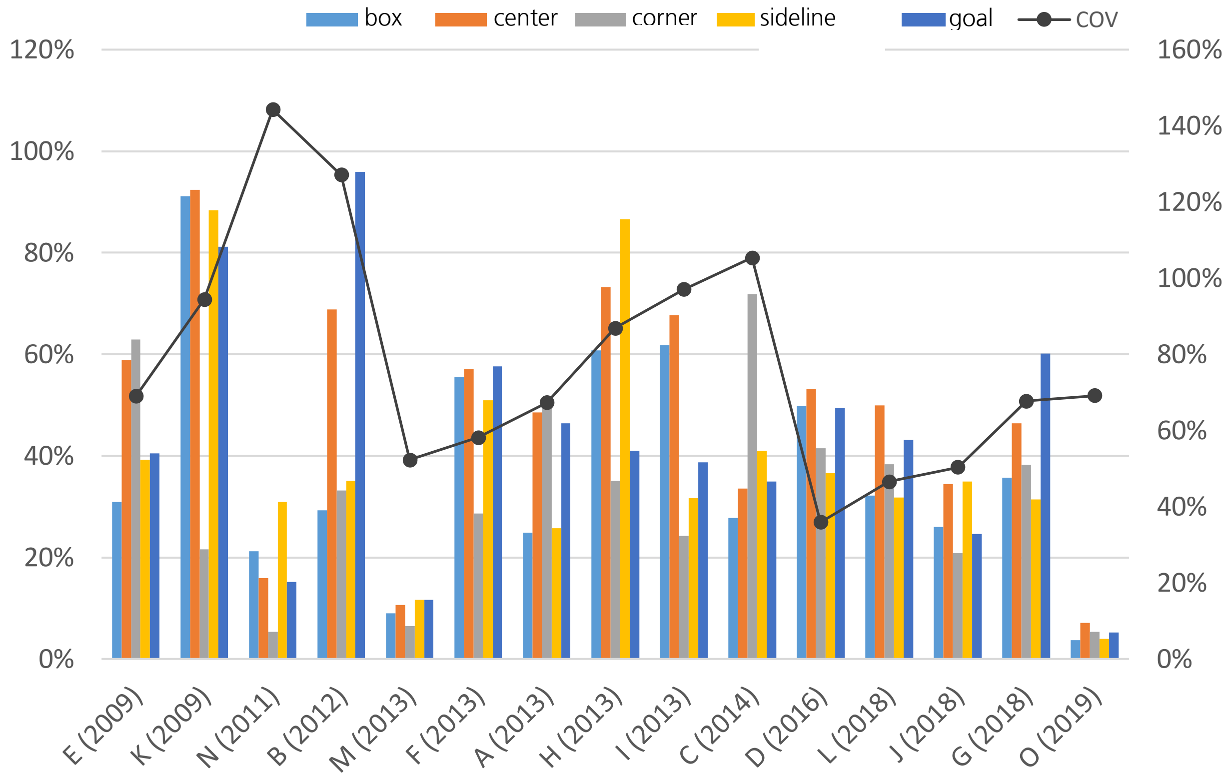

Figure 20: Proportion of performance infill per measuring point and coefficient of variation per pitch

The four most important performance parameters for an artificial turf pitch are ball rebound, ball rolling behavior, force reduction, and rotational resistance. They are specified, for instance, in standard DIN 18035-7 and the FIFA Quality Programme. Three of the artificial turf pitches examined in this study correspond to the "FIFA Quality Pro" standard. For these pitches, the fluctuation range for the performance parameters, which were determined at six measuring points, were compared with the fluctuation range for the performance infill. It could not be confirmed that fluctuations in the infill lead to increased fluctuations in performance. The fluctuation range for the performance parameters was also significantly below that for the quantity of performance infill.

Compared to the fluctuations in fill, performance appears to be extremely robust. The type and quantity of the infill can vary in wide areas without this necessarily being associated with poorer performance. It is possible that the role of the performance infill is overestimated while the role of the shock pad, stabilizing infill, and turf type is underestimated. Corresponding in-depth investigations would be necessary and could open up innovative scope to optimize the artificial turf system both environmentally and economically.

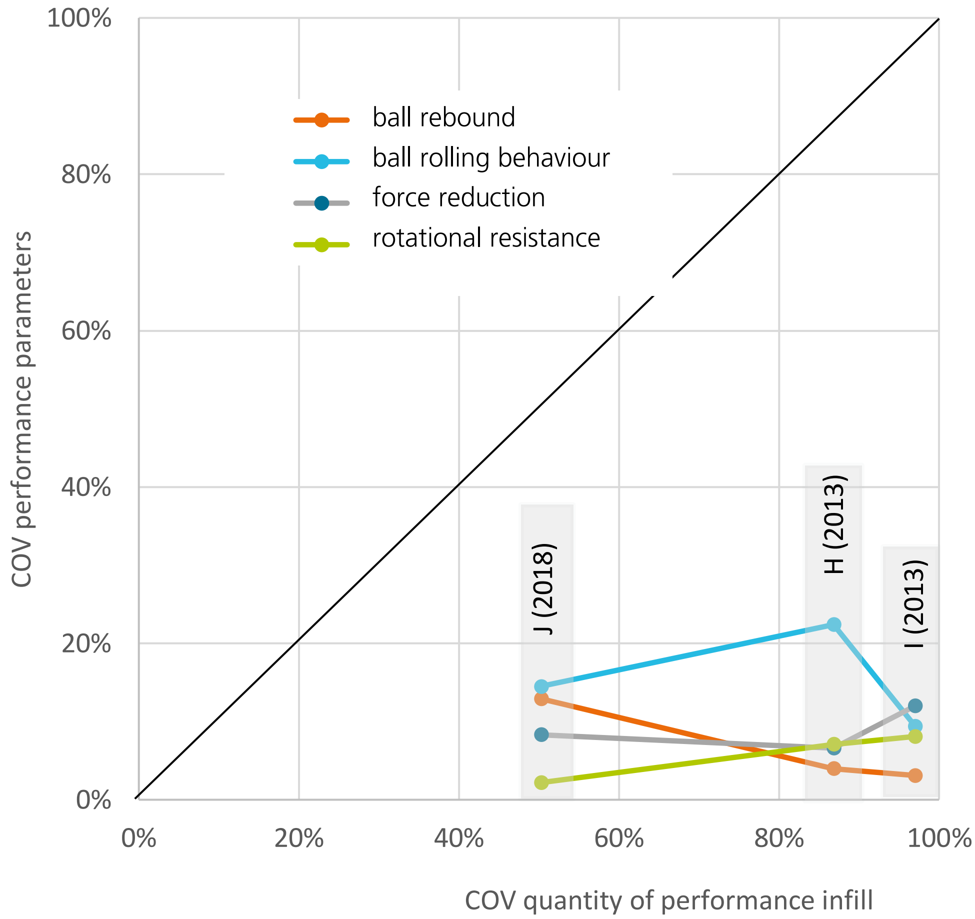

Figure 21: Coefficient of variation (COV) of performance over the coefficients of variation for the infill quantity for three FIFA Quality Pro pitches

7.5 Infill alternatives

In view of the ECHA restriction proposal, alternatives to the current infill types are being sought. The following alternatives are particularly conceivable here:

- Omission of fillers
- Mineral fillers
- Biodegradable materials
- Natural materials

If fillers are not used, significantly higher fiber weights are required in order to produce a stable artificial turf that can be played on. It has not been investigated to date whether and to what extent this would lead to higher fiber emissions compared to infill pitches. At the same time, it would need to be checked how the environmental effects of released fibers are to be assessed compared to released infill. As the ECHA restriction proposal does not address fiber losses (this is

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not an intended addition), there is the risk of an unfavorable steering effect from an environmental viewpoint due to the restriction, should it transpire that the fibers are to be considered more critically than the polymer performance infill.

The use of mineral infills was practiced for a long time with sand in the form of 2G pitches and is still established today. The main reason for the transition to pitches with supplementary performance infill (3G) was the reduction in injuries (grazes). The performance of pitches with a pure sand infill is the subject of controversial debate.[55] Evaluations by Fleming et al. (2017)[56] also show that abrasion significantly increases. A comparative investigation is necessary here, which takes into account the overall emissions of various infill and non-infill versions (granulate and fibers). Potential innovations can be found in optimizing grain shape for mineral bedding materials in order to prevent abrasion and an increase in hardness during frost. Improvements could be achieved with modified or alternative mineral fillers. Zeolites and rounded sands (trade names: Zeolite, Durafill, Envirofill) are offered as an alternative to conventional quartz sand. They are said to offer various benefits (water permeability, water storage capability, reduction in abrasion, etc.).[57] However, no experimental comparisons are currently available.

The criteria for biodegradability and natural polymers are very narrow as part of the planned ECHA restriction. Natural polymers are only considered to be those that have not undergone any chemical transformation (except for hydrolysis). Even polymers that experience an intermediate transformation such as viscose or cellophane are not usually classified as natural, while lyocell, which is chemically identical and only treated mechanically, is considered natural. Materials such as cork, fibers or shells from coconuts, rice husks, walnut shells, olive stones, or wood (fibers, bark) come into consideration as natural polymers. There is little experience so far regarding the long-term stability of these materials. While, for instance, freshly filled cork is very mobile and displays high loss rates (pitch D in this study), the inspection of an older cork pitch in Dortmund showed that the cork has a humous, soil-like consistency after many years. To what extent, for example, maintenance and upkeep work counteracts this or this presents disadvantages for EoL recycling is still unknown. The use of natural materials often has advantages in relation to carbon footprint and reduces the overheating of the pitches, while it may also require the use of fungicides or antimicrobial additives.[57]

The requirements for biodegradability in the ECHA restriction proposal are oriented towards the requirements in various standards. The requirement for a 90 percent degradation in soils within 24 months (EN ISO 17556:2012) appears best-suited to the assessment of infill types. However, it is questionable whether a material can be found that is not or not appreciably degraded on the pitch within 10 to 15 years, is sufficiently resistant to fungi and microorganisms, and also – once it enters the surrounding soils – is largely completely broken down within 2 years. It would also have to be assessed whether biodegradable polymers also withstand the high temperatures that sometimes occur on pitches without melting and agglomerating. In this regard, there has been negative long-term experience with various infill types in the past. The first biodegradable infill types based on polyesters are already being introduced on the market.[58]

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55 https://www.bisp-surf.de/Record/PU201812008952; last accessed: July 7, 2021.

56 Sharma et al. 2016b.

57 As an example: https://www.artificialgrassliquidators.com/sand-infill-for-artificial-grass/; last accessed: July 8, 2021.

58 https://www.senbis.com/products/products-by-industry/sport-fields-landscape/biodegradable-grass-infill-greenfill; last accessed: July 7, 2021.

8 How high is infill loss?

"The average loss of performance infill on the examined pitches comes to 2.98 metric tons per year, and is thus above the top-up quantity (2.68 metric tons per year).

However, there are significant fluctuations in losses. The 95 percent confidence interval for losses for all pitches of the same construction type is in the range of 1.29 to 4.67 metric tons per year.

No correlation with the age of the pitches was found. However, the low density of the infill appears to promote discharge."

8.1 Previous insights

It has long been known that above all performance infill is lost from artificial turf pitches. The previous estimates of infill losses by almost all authors are based on theoretical estimates. They are based above all on expert statements and the assumption that the top-up requirement equates to the quantity of dispersed infill. Table 8 offers an overview of the estimates/calculations of various authors for various geographic frames of reference. It should be taken into account that this concerns losses but not discharges into certain environmental compartments (e.g. the sea). In some of the studies, estimations are made about discharges, particularly in the aquatic environment.

The equation of the top-up amount and loss, which has been used as the basis for estimation on numerous occasions to date, has been criticized by manufacturers many times as they considered a large proportion of the top-up requirement to be compensating for compaction. More recent studies have attempted to take this effect of compaction into account and obtain significantly lower loss quantities (the corresponding studies are marked with *; (cf. Chapter 10.3). The fact that topping up is needed to compensate for infill compaction could not be confirmed as part of the experimental investigations for the present study (cf. Chapter 7.2).

The study by Regenell et al. (2019) aimed to investigate at a single pitch how relevant the sewage system is for discharge and what measures can be used to significantly reduce the discharge.[59] The study provides little information on infill losses in the past and over the total number of pitches.

Table 8: Information about infill losses in the literature (*compaction was taken into account; **Study into the specific minimization of emissions at a model pitch, discharges onto surrounding surfaces via the wind and rain were not considered)

Region	Loss [t/(pitch x year)]	Source
Germany	1.2 to 4.8	FEDERAL GOVERNMENT 2019
Germany	0.25 to 0.5	DFB/DOSB 2019
Germany	approx. 3.1	Bertling et al 2018
Norway	approx. 3	Sundt et al 2016
Netherlands*	< 0.3	Weijer et al. 2017
Sweden	3.0 to 5.0	Magnusson et al 2016

59 Regnell 2019.

Sweden	2.0 to 3.0	Magnusson et al. 2017
Sweden*	0.55	IVL 2019
Denmark*	0.3 to 0.7	Lokkegard et al. 2019 (DTI)
Denmark	1.5 to 2.5	Lassen et al 2015
Europe	1.2 to 4.8	Hann et al 2018
FIFA pitches (world)	1.3 to 5.0	Eunomia 2017
Individual pitch**	< 0.1	Regnell 2019 (Ecoloop)

8.2 Infill losses and regranulation on the examined pitches

It is possible to determine the loss quantities from a balance. The infill quantities at the time of completion and the quantities of infill used for topping up are added together for this and then subtracted from the current infill quantities determined in calculations. The difference is then the loss quantity.

Figure 22 shows the average top-up quantities per pitch and the calculated annual losses per examined pitch. The average top-up quantity is 2.68 metric tons per year (median: 1.75 metric tons per year) with a fluctuation range of 0.25 to 8.25 metric tons per year. The average losses per year are 2.98 metric tons per year (median: 1.78 metric tons per year) with a fluctuation range of 0.27 to 10.12 metric tons per year.

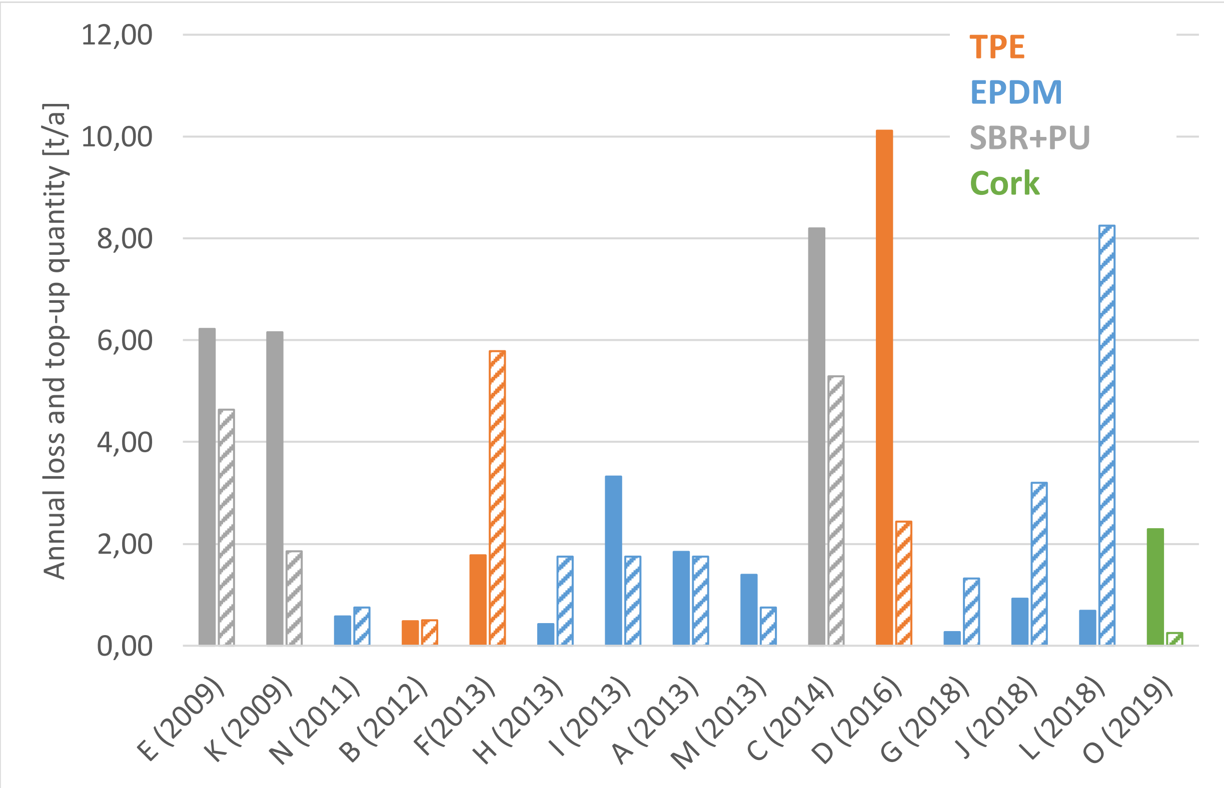

Figure 22: Infill losses (filled) and top-up quantities (hatched) per pitch, according to age and infill type

The significant differences between the top-up quantity and loss show that targeted tracking of the infill level as part of groundskeeping is difficult and hard to control. There are both pitches at which the top-up quantity is less than the losses, as well as those that are filled to a greater extent. Interestingly, the top-up quantity is generally much lower, especially at pitches that lose a great deal of infill. The high losses are thus presumably not caused by excessive topping up.

The 96 percent confidence interval for the mean loss of pitches that are similar to the examined pitches is 1.29 to 4.67 metric tons per year, for the top-up quantity 1.45 to 3.92 metric tons per year.

8.3 Pitch parameters with an influence on infill losses

High infill losses occur at pitches where SBR+PU is used as infill. In contrast to this, there tends to be less infill loss when using EPDM. One reason for this could be the significantly lower density of the SBR+PU (approx. 1.2 kg/l) compared to EPDM (approx. 1.6 kg/l). The lower densities can lead to greater mobility, such as during rainfall. The comparison with TPE infill, which has a similarly high density as EPDM, is heterogeneous as one pitch (D) displays especially high losses.

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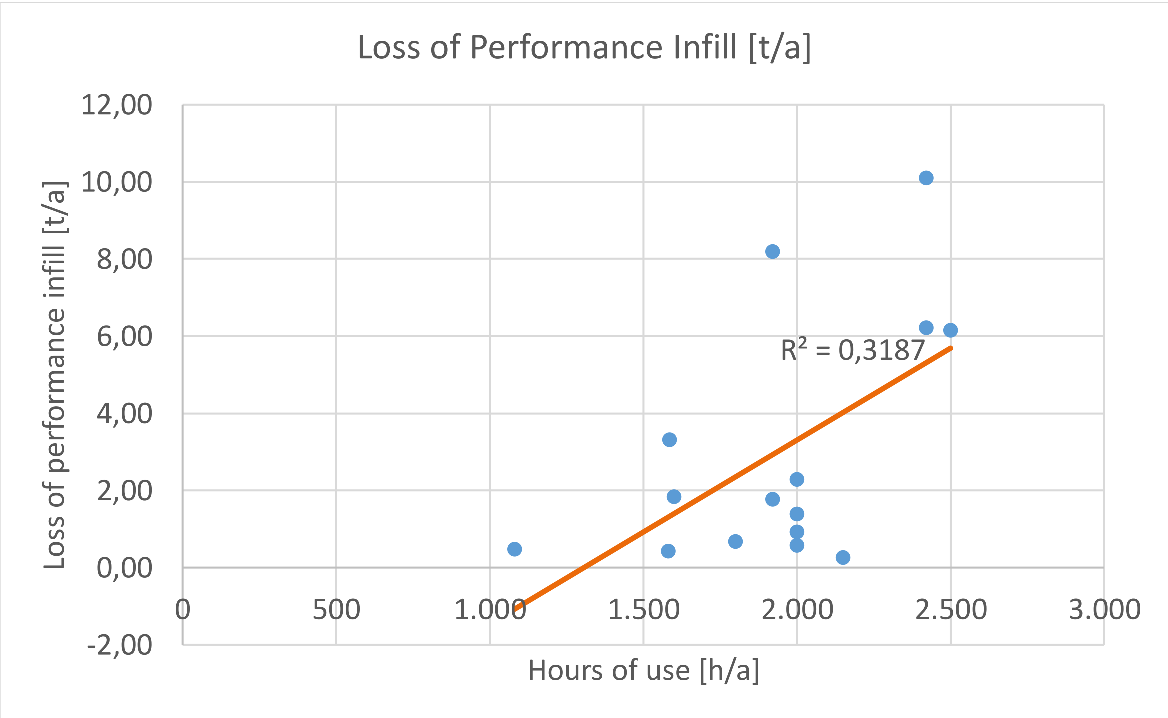

Figure 23: Infill losses as a function of hours of use

When calculating the mass losses in terms of volume or the reduction in infill height, cork would display the greatest losses with its very low density of just 0.3 kg/l. When inspecting a pitch freshly filled with cork, there was also the impression that the fresh cork had a high level of mobility. For older pitches filled with cork, however, cork has a soil-like, humous consistency and its mobility tends to be lower than that of granulate.

No correlation can be identified with the age of the pitch (r = -0.21, p = 0.43). The argumentation often given by manufacturers that the quantity of infill on the pitch correlates with the infill losses has not been confirmed (r = 0.11, p = 0.85). However, the latter also appears understandable as the infill losses are likely to be caused by superficial effects (playing, wind). In contrast to this, the loss correlates very well with the number of hours of use (r = 0.56; p = 0.03; Figure 23: Infill losses as a function of hours of use). Further investigations into the relevance of playing and the specific mechanisms that lead to infill loss would be helpful here.

9 What is known about fiber loss?

"From the perspective of environmental protection, it is necessary to consider not only performance infill but also fiber loss. The few experimental investigations that are available suggest high losses of artificial turf fibers.

The discharge can vary depending on the fiber use weight and infill type. At the same time, it presumably increases with the age of the pitch. Previous estimates range from around 50 kilograms to over 1 metric ton per year.

To what extent these losses are discharged, recorded as waste as part of maintenance work, or remain in the artificial turf has not been investigated. It is, however, apparent that discharge via players plays an especially large role for fibers."

As a result of the planned restriction proposal by ECHA, above all the polymer performance infill, which, according to the ECHA definition, is an intentionally added microplastic, is currently at the center of the societal debate and scientific analyses. However, from an environmental viewpoint, it is largely insignificant whether discharge takes place due to intentional addition or abrasion. It is thus to be expected that fiber losses will also increasingly gain public attention in the future. This is particularly true as they lead to much smaller particles, which may also be more of a toxicological concern.

The following figure shows how fiber abrasion is presented and how this can be carried away, for instance, by the clothing and shoes of the players. According to player statements, adhesion differs widely on different days. Electrostatic effects and moisture could be relevant parameters here that influence adhesion.

Figure 24: Fiber adhesion to clothing and shoes. [Source: Zimmermann, Ökopool 2021]

In a long-term study of maintenance and performance at 450 artificial turf pitches, Fleming et al. investigated, among other things, the abrasion behavior of the artificial turf carpet.[60] In relation to

60 Sharma et al. 2016b.

fiber length, they found an average reduction of 0.32 millimeters per year for 3G pitches. Purely sand-filled pitches (2G) displayed higher abrasion rates (0.42 millimeters per year). The loss rate increases with the age of the pitches (year 0 to 5: 0.2 millimeters per year, year 5 to 10: 0.5 millimeter per year), which is an indication of aging and the brittleness of the fibers.

The pitches in the present study have fiber weights of 1000 grams per square meter for infill pitches (pile height: 40 millimeters), 2,690 grams per square meter for purely sand-filled pitches (pile height: 30 mm), and 2,970 grams per square meter for non-infill pitches. If one were to assume that the average annual fiber length losses determined by Fleming et al. are proportionate to the mass losses, this would result in the figures shown in Table 9.

Table 9: Estimate of fiber losses per year

Region	Pitch code	Year of construction	Pile height [mm]	Surface weights of artificial turf [g/m²]	Loss according to Fleming et al.		Loss according to Thieme-Hack	
					Length decrease [mm/a]	*Calculated fiber losses[61] [kg/a]*	Weight decrease [%/a]	*Calculated fiber losses[62] [kg/a]*
with performance infill	J	2018	42	1,550	0.2	55	1.9	218
	H	2013	40	1010	0.5	94	5.7	427
Only sand	P	2020	30	2690	0.42	280	1.9	380
Non-infill	J	2013	32	2970	0.2	138	5.7	1256

Newer systematic investigations into abrasion were conducted by Thieme-Hack et al.[63] These not only determined the length decrease but also a thickness and weight decrease in the fibers. Here, too, there was found to be an increase in abrasion with the age of the pitches as well as intensified abrasion from the fourth year. However, the measurements are only based on analyses at a small number of pitches, meaning that other influencing factors alongside age could also have widely differing effects. An application of the loss rates by Fleming and Thieme-Hack to the pitches investigated in this study (last and third-last column in Table 9) is thus uncertain. Nevertheless, the results offer an important indicator that fiber abrasion can have high values, even on the same scale as granulate losses. In-depth experimental investigations are urgently required here.

The investigations above suggest that fiber abrasion is presented evenly over the fiber in the form of the finest abrasion particles or takes place by the fiber breaking horizontally to the longitudinal axis. However, these are not the only mechanisms that lead to fiber losses. Previous studies by a client and the inspection showed that the fibers can be spliced or entire fibers pulled out of the backing (Figure 25). Splicing can particularly be found in fibers with complex shapes, such as a

61 Fiber loss per year = surface weight of artificial turf x loss rate according to Fleming/pile height x 7,420 sqm.

62 Fiber loss per year = surface weight of artificial turf x loss rate according to Thieme-Hack x 7,420 sqm.

63 Bußmann et al.

double S cross-section. The fibers that had been pulled out could not be identified to the same degree at all of the pitches and indicate insufficient fixing in the latex coating in the back of the artificial turf carpet. However, both appear to be defects that occur at many pitches and thus may substantially contribute towards microplastic discharge.

The forms of fiber losses described above should not be considered equal to the emitted quantity. It is to be expected that large quantities of infill are bound or removed during cleaning measures. There is no data currently available on this. Nevertheless, discharge via the players and their clothing appears especially relevant for fibers. Investigations would be helpful here.

Figure 25: Splicing of fibers (pitch F) (l.), pulled-out fibers (pitch H; white fibers from the pitch marking can be identified, indicated with the yellow circles) (r.)

10 Via which routes is the infill discharged and where does it go?

"Rubber granulate is discharged from artificial turf pitches and is found virtually everywhere in the pitch surroundings.

Strong winds and heavy rain, in particular, cause the emissions to spread beyond the pitch surroundings. This is demonstrated by rubber granulate found in inaccessible points, sometimes very far from the pitch. Further spreading often takes place via waterways.

Locations where infill can be found are often natural or artificial barriers, e.g. green spaces or buildings that prevent the further mobility of the infill. Very large quantities of granulate can accumulate in the environment without this being visually noticeable in every case. The final fate of the infill depends on the layout of the pitch and the pitch surroundings and on the geographical situation on site."

In order to gain knowledge concerning the transfer and fate of pitch infill, an on-site inspection of all pitches was conducted by the study partners. The acquired knowledge is based on survey results and qualitative observations as well as the evaluation of current studies on the same topic. A quantitative record of the infill emitted into the environment or systematic tracking and balancing of individual transfer routes was not part of the study.

10.1 Observations from the pitch inspections

During the inspections of 20 artificial turf pitches in Switzerland and Germany, it was clearly shown that infill on the artificial turf pitch is above all emitted into the immediate vicinity of the pitch and beyond. Emissions of artificial pitch fibers take place more rarely, but still occur. This raises the question of what routes the emitted infill takes where it ultimately ends up. For the infill losses determined in Chapter 7, a distinction can fundamentally be made via the following scenarios concerning the fate of the infill:

a) The infill is collected and disposed of as solid waste

b) It enters urban water management via drainage

c) It is transported into the surrounding area

Infill, granulate, and fibers were found in the immediate vicinity and extended environment around the pitch for all infill pitches. Due to the green, brown, or black color of the infill, it is not immediately easy to identify. However, once the eye has been trained somewhat, granulate can be identified in many points in the surrounding area of the pitches. How the rubber granulate and turf fibers are transported into the environment and where they go depends on a variety of factors. Alongside natural influences such as the wind and rain, the geographic location, the usage frequency of the pitch, cleaning and maintenance cycles, the type of pitch irrigation, and the structural design (neighboring paved surfaces, paving stones, barriers, stands, walls) all play an important role. Part of the infill takes the water route, which was confirmed by inspections of channels, drains, and gullies during the pitch instructions (Figure 26).

Figure 26: Rubber granulate in drains and channels

Rubber granulate and turf fibers often remain lying next to the pitch. In the surveys, distances of up to 20 meters from the end of the playing field were stated for emitted infill. Depending on whether granulate and fibers are located on a turf or paved surface, the infill remains there, is moved on by the wind and rain, or removed by cleaning measures (Figure 27).

Figure 27: Infill next to the pitch on paved and unpaved surfaces

Enclosing the artificial turf pitch can reduce infill transfer. The retaining effect of barriers was obvious (Figure 28). However, at the same time, particles were found in elevated positions such as in gutters, which raises the question of a sensible design and, in particular, the necessary height of barriers to retain infill and fibers.

Figure 28: Barriers around an artificial turf pitch (l.), granulate in the gutter of a garage around 15 meters away from the artificial turf pitch (r.)

Unfortunately, there are currently no comprehensive investigations into the collection and disposal of granulate and artificial turf fibers as solid waste, meaning that, although the losses were ultimately determined in Chapter 7, it has not yet been possible to quantify the transfer and fate in the environment.

An estimate should serve as a comparison of the visual impression in the pitch environment and the quantitative infill loss determined in Chapter 7. It is assumed that a quantity of 2.9 metric tons per year is emitted, although only part of this is transported into the areas surrounding the pitch. The remaining proportions are collected directly as waste (e.g. after cleaning or snow clearance), immediately enters the drainage system, or is carried away by the players and their clothing. The relevant surrounding surface is estimated at around 8,640 square meters (corresponding to a distance of around 20 meters from the edge of the playing field). A density of 1.5 kilograms per liter and a particle size of 2.5 millimeters are assumed for the infill. Taking into account various cleaning intervals and a variation in the proportion that is transported into surrounding areas, this results in an average particle allocation (particles per square meter) according to Table 10. It should be taken into account that the particles can be subsequently transported by the wind and rain and that the stated particle allocations represent maximum values immediately before a cleaning measure. The particle allocations on paving stones and boards as well as in grooves and joints are significantly higher than average, while those on smooth surfaces are generally lower than the average values. According to information from the pitch operators, typical cleaning intervals range from weekly to monthly. Based on a visual impression during the inspection, average particle allocations (number of particles per square meter) of several hundred particles per square meter appear realistic. This supports the idea that relevant proportions of the losses are collected as waste, but also further transported by wind and water. However, on the other hand, it is also clear that noteworthy quantities can be emitted without the pitch surroundings appearing significantly soiled.

Table 10: Average particle allocation (= number of particles per square meter) based on the proportion transported into the surrounding areas and the frequency of cleaning with a loss quantity of 2.9 metric tons per year

Particle allocation [Particles/m2]		**Proportion transported into the surrounding areas**		
		5%	25%	100%
Cleaning interval	Weekly	26	132	526
	Monthly	114	570	2,280
	Quarterly	342	1,710	6,841

10.2 Standard of knowledge from current studies

The results from studies for Denmark, the Netherlands, and Sweden, which have also discussed the fate of microplastics, are discussed below. The studies were also used by the BIR Tyre&Rubber Committee for a position paper.[64,65,66] A more recent overview article by Verschoor et al. is also evaluated.[67]

All studies assume a need for topping up in their estimate of infill losses. The present study instead analyzes the original infill quantity on completion, the total topped-up quantity, and the current status of the infill quantity (cf. Chapter 8.2). This takes into account the fact that infill on pitches can both accumulate and become depleted. In the previous studies, only accumulation by compaction is assumed. For instance, in the study by the DTI, it is argued that the quantity of infill can fluctuate in wide areas without this necessarily being noticed by the groundskeeper. However, this argumentation is only used in relation to accumulation due to compaction, but not in relation to possible losses.

Compaction

The studies consider a significant proportion of the need for topping up to be a result of compaction (DTI: 67 to 87 percent, Weijer: 51 to 94 percent, IVL 20 percent to over 50 percent). This estimate is based on theoretical assumptions, laboratory investigations, and a field study at an individual pitch. Our own experimental investigations allow an accumulation of performance infill due to compaction to appear rather unlikely. Even if this is actually possible for individual pitches, no general trend towards accumulation could be identified – on the contrary, it appears as though

64 BIR Tyre & Rubber Committee 2019; the Swedish study is only available in Swedish. The data were thus taken from this secondary source.

65 Regnell 2019.

66 Weijer and Knol 2017.

67 Verschoor et al. 2021.

the quantity of infill on the pitch decreases on average over the service life of the pitch. This point was already discussed in Chapter 6.3.

Quantities collected as waste

Weijer et al. determined the infill quantities that occur during maintenance and cleaning measures.[68] They analyzed the frequency, quantity volume, and composition of the waste and came to the result that the quantities collected as waste can amount to up to 250 kilograms per year. A statement on what proportion of the granulate is collected as waste cannot be derived from the investigations. As the proportion of granulate in the amount of waste is viewed as constant, it increases with the total amount of waste collected.

Discharge via players

Experimental data concerning discharge via players are available from the Ecoloop study for Sweden,[69] an evaluation from Norway,[70] and the study by Weijer et al. Shoes and socks were examined. Discharge via other items of clothing is, however, also conceivable. The studies show that discharge is dependent on the playing time and the ambient humidity. Above all with high humidity or rain, the discharges per player were significantly higher. The Norwegian evaluation was stated as the most reliable source both in the DTI study[71] and in the publication by Verschoor. On average, there was found to be approx. 0.9 g per person with a playing time of approx. 30 minutes. The Norwegian study also showed that the discharged quantity increases with the playing time. The Ecoloop study showed discharges on the same scale: 0.7 grams per player in dry conditions and 2.2 grams in wet conditions. Overall, average discharges of 1 to 1.5 grams per person and training and playing time appear realistic. With an intensity of use of approx. 1,900 hours per year and an average number of 30 players per 120 minutes (during a match: 23 people, sometimes significantly more during training), this results in an average discharge of 28 to 43 kilograms per pitch and year. Regular moistening of the pitch in summer and more intensive use (more playing hours, more people) can significantly increase the discharged quantity. It is to be expected that most of the discharged quantity ends up on paved surfaces and in the sewage system or is disposed of as waste.

Maintenance and upkeep work

Snow clearance work is often cited as a possible cause of infill losses. Especially if great masses of snow need to be removed or the snow is only removed after a thaw-frost cycle, large quantities of infill are also removed. If this is stored outside of the pitch or on unpaved surfaces or is soiled (e.g. with leaves or grass), this can prevent the infill from being transported back onto the pitch (Figure 29). The infill can end up in the drains or on neighboring surfaces due to melting, rain, and the wind.

[68] Weijer and Knol 2017.

[69] Regnell 2019.

[70] Verschoor et al. 2021.

[71] Lokkegaard et al. 2019.

Figure 29: Accumulation of granulate masses at the edge of the playing field with greater masses of snow (l.),[72] impurities with leaves (r.)[73]

Alongside snow clearance, the removal of leaves, which particularly land on the playing fields in fall, also forms part of maintenance work. Leaf blowers are often used, which achieve flow velocities of over 400 km/h or over 100 m/s. Wind erosion of soil particles occurs from a flow velocity of just 5 m/s.[74] The density of soil particles (clay, silt, sand) ranges between 1.8 and 3.8 kilograms per liter and is thus higher than that of the performance infill (1.1 to 1.7 kilograms per liter). It can therefore be assumed that, despite the significantly larger particle size, large quantities of granulate can still be discharged by the leaf blowers. Especially when the pitch is dry and thus low cohesive forces act on the granulate. Furthermore, losses are particularly to be expected if the leaves, and thus also the granulate, are moved to the edges of the pitch by the leaf blowers. There are currently no detailed investigations into the influence and scope of discharge using leaf blowers that also take into account product properties such as particle size, shape, and density. The granulate could end up being processed as organic waste alongside the leaves, and thus be composted and subsequently used in agriculture or horticulture.

Granulate losses can also arise due to cleaning and brushing of the pitch. It is to be assumed that the majority of the quantity of infill collected ends up in waste disposal (see above). Furthermore, the Ecoloop study[75] investigated how much infill adheres to the work machines themselves and is discharged by them. The quantity was determined as approx. 24 kilograms per pitch and year. This does, however, significantly depend on whether and how often maintenance and upkeep measures are performed in wet conditions and whether and how the machines are cleaned before leaving the pitch.

Discharge via rainfall

Weijer et al. examined silt for granulate in one rainwater collection chamber per pitch. The annual losses were estimated using the infill residue contained in the silt. However, this can hardly lead to usable results as it is unclear what proportion of the infill has passed into the silt and whether

72 https://www.safehealthyplayingfields.org/maintenance-synthetic-turf; last accessed: July 5, 2021.

73 https://eu.northjersey.com/story/news/local/2018/12/05/new-milford-nj-working-toward-reopening-field-closed-snow-removal/1862591002/; last accessed: July 5, 2021.

74 Cf. here: https://www.bmel.de/DE/themen/landwirtschaft/pflanzenbau/bodenschutz/bodenerosion-durch-wind.html; last accessed: July 5, 2021.

75 Regnell 2019.

large quantities of silt have been discharged due to heavy rain. The stated values of less than 1 kilogram per pitch and year appear too low – including in comparison with the quantities identified during the inspections of shafts and channels when inspecting the pitches – especially at pitches surrounded by drainage channels. In addition, Weijer et al. ascertained the amount of infill in the silt from drainage channels, which they estimated at 4 to 6 kilograms per year. Here, too, it is questionable whether the assumption that the granulate sediments completely in the drainage channels represents reality with sufficient accuracy.

In the study by Regnell, filters with a pore size of 200 micrometers were installed in the collection shafts to achieve almost complete retention from a quantitative perspective. The quantities of microplastics were determined at approx. 15.5 kilograms per year. However, the proportion of rubber in all of the identified polymers should only be 26 percent. Instead, large proportions of PUR (it could be the coating of the ELT) and polyolefins (these are likely to be artificial turf fibers) were identified. For the pitch investigated by Regnell, it is unclear precisely how the channels were designed and where the shafts were positioned.

Discharge via the wind

Discharge via the wind is largely considered irrelevant in various studies. This statement is likely to apply to wind conditions within the normal range. The critical wind speed at which particles begin to bounce along (saltation) is approx. 9 meters per second for particles with a diameter of 0.5 millimeters and approx. 13 meters per second for particles with a diameter of 1 millimeter.[76] This corresponds to around 6 on the Beaufort scale. In Germany and Switzerland, at least one gust of wind with speeds of over 25 meters per second must be expected over a period of 5 years on all surfaces[77] – speeds that are far above the speed necessary for soil erosion. Three such events are likely during the service life of an artificial turf pitch. Gusts with speeds of over 11 meters per second (6 on the Beaufort scale) occur much more often.[78]

Whether and to what extent the wind can move infill also depends on the moisture of the pitch or granulate. As winter storms are prevalent in central Europe, it is to be assumed that the high level of moisture on the pitch that this creates hampers movement by the wind in many cases. The wind will particularly contribute towards distribution if the infill has already been loosened up by playing or maintenance activities or lies on top of condensed artificial turf with snapped fibers. Granulate that has already been deposited on paved surfaces due to cleaning and playing can also be transported further by the wind. Open bigbags or an accumulation of granulate (e.g. following snow clearance) also offer the wind a good target, enabling larger quantities to easily be discharged.

Fate on paved spaces and surrounding green spaces

Verschorr et al. determine the quantities of infill on paved surfaces based on visual comparisons with reference surfaces known to be contaminated with granulate. By extrapolating to the entire paved surface, it is estimated that around 60 kilograms end up on these surfaces each year. Our own photo documentation of the pitch inspections clearly shows that granulate and fibers are deposited very heterogeneously. Large quantities accumulate on paving stones, barriers, and in

76 Rijn 2019 (the values stated in the source apply to particles with a density of approx. 2.6 kg/L. The density of the performance infill is much lower, meaning that the critical wind speeds with an assumed even particle size should tend to be even lower).

77 https://www.klimanavigator.eu/dossier/artikel/030136/index.php; last accessed: July 8, 2021.

78 Depending on the location, this is the case 0.1 to 10 percent of the time; cf. here: Lefebre et al. 1983

grooves and holes, while only a small amount of granulate and fibers can be found on smooth surfaces. A visual determination of the quantities is thus difficult (cf. Chapter 10.1).

Both Verschoor et al. and Weijer et al. took samples from green spaces around artificial turf pitches. Weijer et al. took 4 samples in each case at a width of 0.5 meters next to paved surfaces and determined the content of rubber granulate. It was ascertained here that the granulate is above all found in the top two centimeters. Only at older pitches does it also reach depths of up to 7 centimeters. Starting with the total area and the volume resulting from the depth of sampling, they calculate discharge of 15 to 260 kilograms per year and pitch. No lateral spatially resolved measurements were taken. This would have made it possible to estimate statements on the size of the areas contaminated with granulate. Verschoor et al. took samples at a width of 2 meters from the edge of the paved surfaces and a depth of up to 10 centimeters, and determined average contents of up to 1.3 percent rubber granulate. This makes it possible to estimate discharges of approx. 175 kilograms per year, provided that the area is also limited to the sampled area in this case. The high proportion of rubber granulate found in the surrounding green spaces by Weijer and Verschoor independently of each other is an indicator of high mobility and noteworthy discharges from the playing fields. In the future, samples should be taken of the surrounding area of playing fields to determine how much rubber granulate accumulates on which surfaces and in which local conditions (barriers, walls, boards, etc.).

10.3 Mass balances

The Danish Technological Institute DTI in Copenhagen created a literature-based mass balance on the transfer and fate of rubber granulate from artificial turf pitches for Denmark (Figure 30).[79] The DTI assumes an average infill consumption of 2.2 metric tons per pitch.

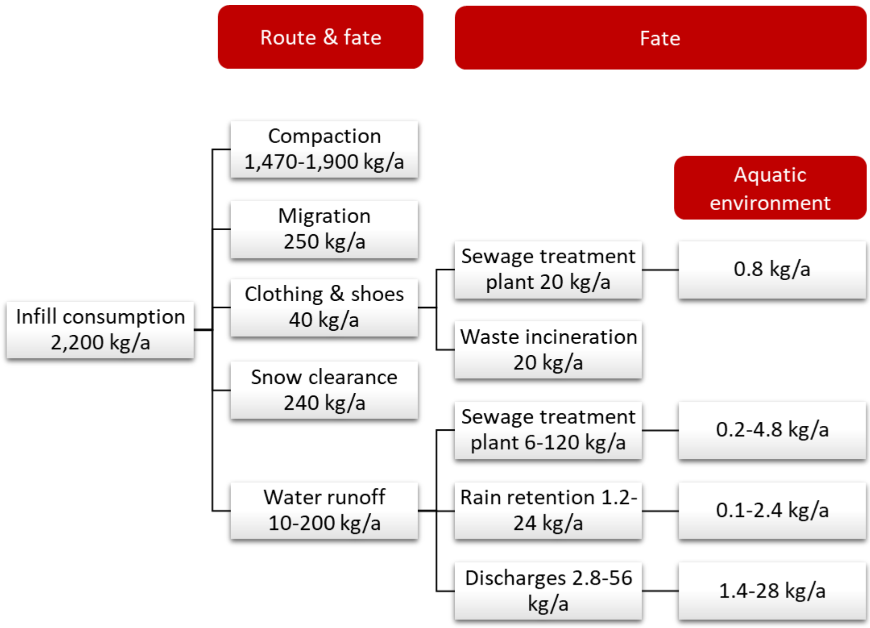

Figure 30: Mass balance on the consumption, transfer, and fate of infill – case study by DTI for Denmark

79 Lokkegaard et al. 2019.

According to the mass balance, between 1,470 and 1,900 kg/a (67 to 86 percent) of the infill consumption each year is used to compensate for the effects of pitch compaction. 250 kg/a (11 percent) of infill migrates and thus reaches surfaces and soils in the immediate vicinity of the pitch, e.g. paving or green spaces. Between 0 and 240 kg/a (0 to 11 percent) of infill is removed from the pitch by snow clearance. 10 to 200 kg/a (9 percent) of infill leaves with water draining away from the pitch. Only 40 kg/a (1.8 percent) is carried away from the pitch by shoes and clothing due to playing. Of the infill that adheres to shoes and clothing, it is assumed that half ends up as refuse in waste incineration and the other half ends in up sewage treatment plants, for instance via washing machines. Due to the high cleaning performance of sewage treatment plants (96 percent retention), DTI estimates that only 0.8 kg/a enters the aquatic environment. According to estimates by the DTI, up to 60 percent of the draining granulate flows into a sewage treatment plant, a maximum of 12 percent ends up in rainwater retention systems, and a maximum of 28 percent directly enters bodies of water. According to the balance by DTI, this means that between 0.11 and 1.64 percent of the annually required infill amount ends up in the aquatic environment. The DTI assumes here that approx. 39 percent of the examined pitches have shock pads, i.e. much less than in Switzerland or Germany, but nevertheless a relevant proportion.

Figure 31 shows the mass balance on the transport and fate of pitch infill for Sweden, conducted by the Swedish Environmental Research Institute (IVL). Like the DTI balance, the proportion of compaction in infill consumption is the greatest driver of infill consumption.

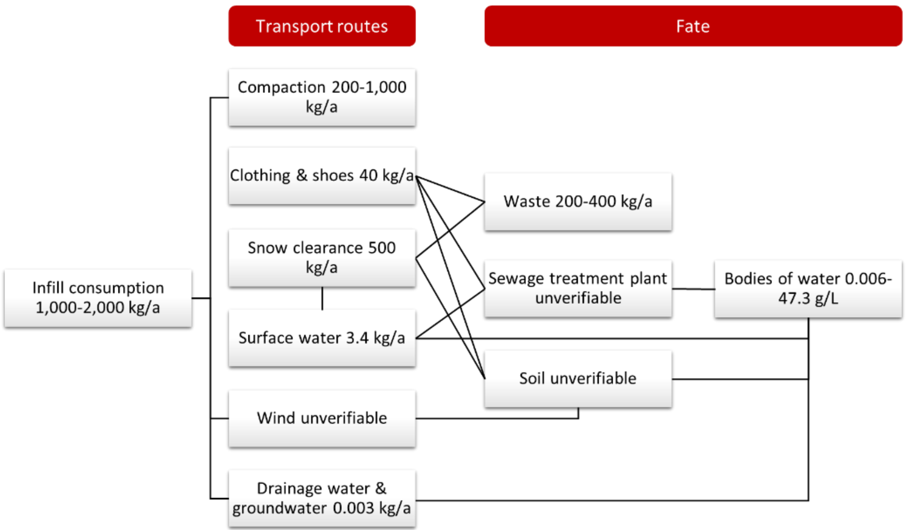

Figure 31: Mass balance on the consumption, transfer, and fate of infill – case study by IVL for Sweden[80]

Both DTI, IVL, the study by Weijer et al., and the overview publication by Verschoor assume that large proportions of the top-up requirement serve to compensate for compaction. The quantities that enter the terrestrial environment are based on the work by Weijer et al. and Verschoor in all of the studies. Astoundingly, Verschoor et al. no longer mention this route in their own rough mass balance, although they discuss the experimental data in their publication.

In contrast to the studies mentioned above, IAKS Germany omits the compaction route in its mass balance, which is based on a member survey. Nevertheless, the top-up requirement and losses are equated here, too. The top-up requirement is stated as approx. 300 kilograms per pitch. Figure 32

80 BIR Tyre & Rubber Committee 2019 (primary source is only available in Swedish).

shows a mass balance for Germany, based on the information from IAKS.[81] According to estimates by IAKS, rainfall and wind events are the main discharge routes or main drivers of infill loss. The rest of the infill leaves the pitch via drainage, snow clearance, and adhesion to clothing and shoes.

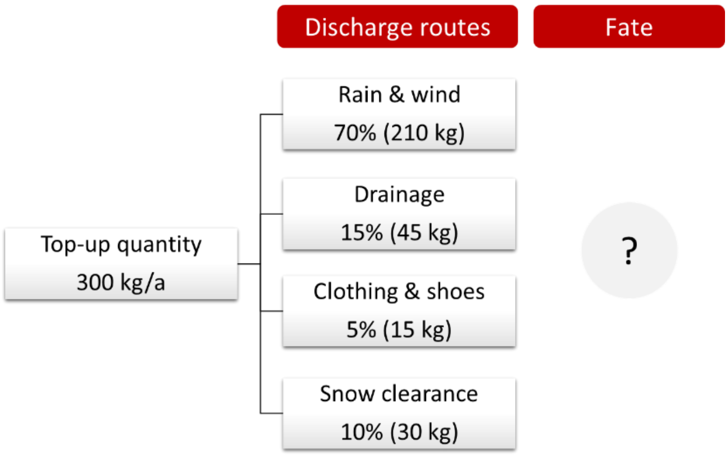

Figure 32: Mass balance on the consumption and transfer of infill for artificial turf pitches in Germany

None of the mass balances presented in the studies are already sufficiently validated in the view of the authors of this study. There are still many knowledge gaps, and the individual differences between the pitches also make it difficult to make generalized statements and would require a significant expansion in the number of examined pitches in order to make statistically reliable statements. The current state of knowledge can be summarized as follows:

- In view of the analyses conducted in Chapters 6 and 7, it is evident that the top-up requirements cannot be the starting point for a mass balance. The infill is lost from the granulate present on the pitch and such losses are largely independent of the top-up amount
- Too much focus has so far been placed on discharge via rainwater drainage. The quantities for most pitches only correspond to a small proportion of the expected overall emissions and can also be largely quantitatively retained using very simple measures (filter installation). However, it should be investigated here whether finer particles or fibers can make their way into bodies of water through the filters or even the substructure of the pitch
- Conversely, discharge into the nearby terrestrial environment appears to be of great importance. If open bodies of water are located within close proximity to the pitch, direct discharge is also to be expected here. However, it is still unclear whether the discharge into soils or nearby open bodies of water tends to be caused by the wind, players, or maintenance and upkeep measures, and this would have to be investigated in the future. The same applies to the temporal and spatial spread of the granulate in the soil. The investigations by Weijer et al. and Verschoor provide initial indications here
- Maintenance and upkeep measures will then lead to massive discharges if the granulate and fiber masses are not deposited onto the pitch and worked back into the artificial turf

[81] IAKS 2019.

or, alternatively, immediately transferred into waste disposal. In general, the usual maintenance and upkeep measures for the pitch are not designed to reduce infill and fiber losses. Conversely, however, incorrectly performed maintenance can – from an environmental perspective – significantly increase the discharge of granulate into the environment

- A good initial database exists for discharge via players, and this should be further improved. The total amount purely via this route is likely to be approx. 280 metric tons for Germany and approx. 16 metric tons for Switzerland per year.
- Future investigations also need to address fiber losses. The fact that fibers adhere better to the skin and clothing in wet conditions, with sweat or due to electrostatic charges, and as a result of the significantly smaller particle size should be taken into account here.

The following graphic (Figure 33) on infill transfer and fate was created on the basis of the collected data and the pitch inspections, as well as based on the studies by Ecoloop, IAKS, DTI, and IVL. It serves as the basis for the discussion on transfer routes and should form the framework for future mass balances. In order to realistically assess the weighting of the individual routes, long-term infill monitoring with measurements and sampling is required in the opinion of Fraunhofer UMSICHT. Fraunhofer UMSICHT considers an in-depth understanding of the interactions between the discharge routes, transport routes, and fates to be more important than specific figures. For drainage, a distinction is made between drainage for surface water (channels, gullies, etc.) and drainage for seepage. Although snow clearance is part of pitch maintenance, it is listed separately due to its relevance for infill discharge and the country-specific variation in snowfall. It is apparent that the pitch surroundings and the sewer system are places where infill accumulates. These are temporary, as the infill continues to be moved from these starting points to its ultimate place of depositing (sink) or is transported back onto the pitch.

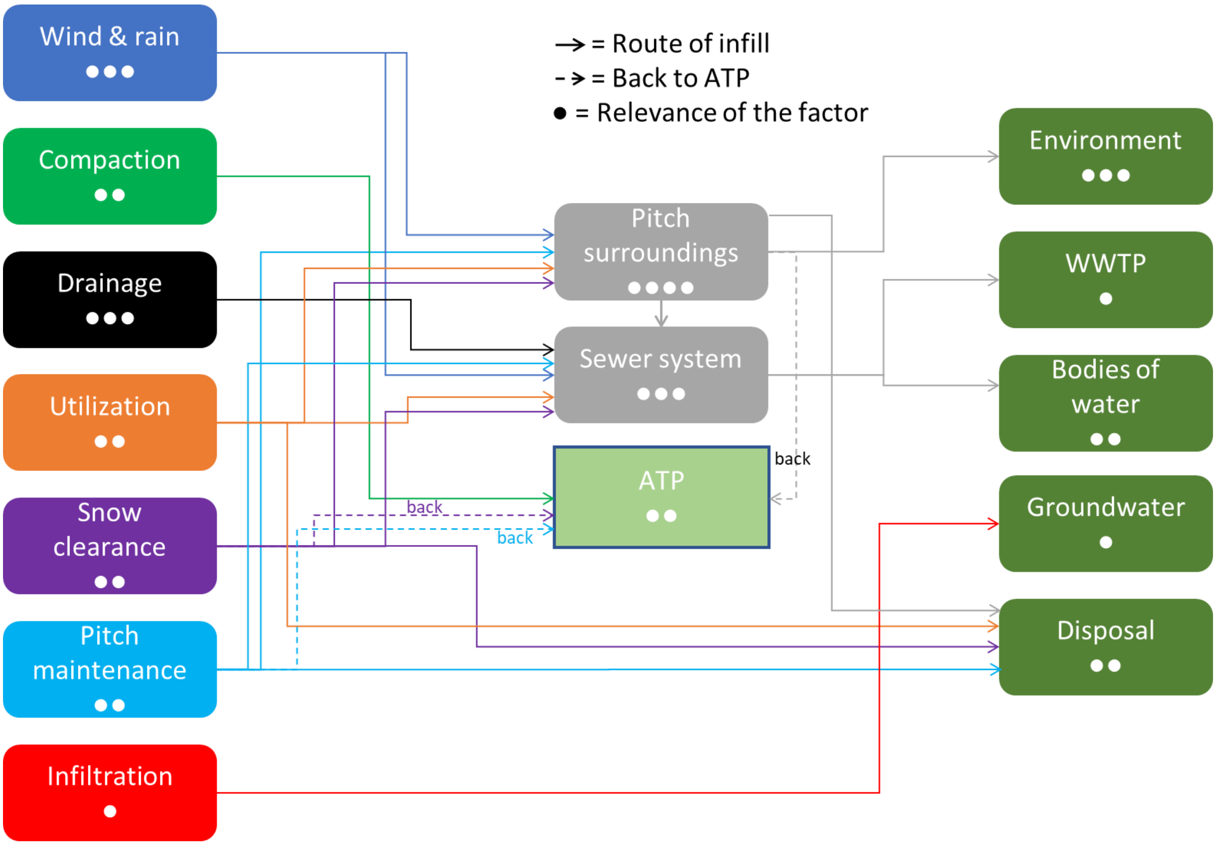

Figure 33: Transfer routes and fates of infill, schematic diagram [Fraunhofer UMSICHT]

11 What is the standard of knowledge concerning other hazardous substances and the effects on health?

"Artificial turf pitches largely comply with the limit values in relation to various hazardous substances. A small number of studies show that limit values are exceeded for individual heavy metals. Nevertheless, there are differences between various material options, and discussions and studies into hazardous substances are continuing.

The critical examination should concern performance infills as well as the elastic layers and artificial turf fibers.

The possible overheating of artificial turf pitches and their relevance for the urban microclimate, as well as the amount of water needed to counteract these effects, should be taken into consideration in advanced planning."

11.1 Critical substances in the artificial turf system

Plastics that are used for artificial turf and its components are usually equipped with stabilizing additives so that they can meet requirements resulting from environmental influences (sunlight, temperature changes, rainfall, playing, maintenance, and cleaning). The raw materials also include secondary materials that have inherited certain additives and hazardous substances from their primary application ("legacy additives"). Some of them contain substances that have harmful effects on people and the environment (e.g. PAH, heavy metals, VOC, and more). However, the quantities released are often below the actually applicable limit values. In addition, artificial turf also contains numerous substances for which further research findings are still missing.[82] Experience shows that limit values often become stricter over time. Especially with the long service lives that are strived for with artificial turf pitches, it is possible that impurities and additive concentrations that are acceptable today will be restricted to such an extent in the future that further use or recycling of the artificial turf will not be possible.

Rubber granulate and a binding agent are usually mixed together to produce elastic layers in situ. There are also additional mineral aggregates for elastic base layers. The rubber granulate (primarily styrene-butadiene rubber) predominantly comes from shredded end-of-life tires. Polyurethane-based one- (1c) and/or two-component adhesives (2c) are used as binding agents for elastic base layers and elastic layers, as well as to affix the artificial turf strips. Commonly used PUR adhesives are often based on MDI (methylene diphenyl diisocyanate), HDI (hexamethylene-1,6-diisocyanate), or TDI (toluene-2,4-diisocyanate).

Isocyanates are highly reactive, but also toxic, have a sensitizing effect on the airways, and are (partly) suspected of being carcinogenic (MDI and TDI).[83,84] As health problems and above all allergic reactions occur without any prior warning signs and even at minimal concentrations below the MAC limit value of 0.005 ppm, isocyanates are considered substances of very high concern

82 Perkins et al. 2019.

83 GMBl 2009.

84 Senthilkumar et al. 2012.

(SVHC).[85,86] Despite the strict limit values for the maximum allowable concentration [87,88] (MAC value for TDI), there is still an unacceptably high number of occupational illnesses due to isocyanates according to estimates by the European Commission.[89] They have thus been regulated by the REACH regulation since August 3, 2020. According to this, only products that do not exceed a diisocyanate content of 0.1% by weight can be used from August 24, 2023.[90,91,92,93,94,95,96,97,98,99] There is also a comprehensive training obligation for employees.

The adhesives for artificial turf pitches are usually processed on-site outdoors. Although certain protective measures are specified according to TRGS 430 when handling isocyanates (such as wearing protective clothing: respiratory protection, eye and face protection, hand and skin protection, body protection), the MAC values only apply to indoor spaces. [100] How high the concentrations are in practice when working outdoors and whether these concentrations can pose a risk has not been investigated scientifically to date. When hardening the isocyanates, the hazardous substance in the plastic is chemically bonded and thus immobilized. For a complete, emission-free implementation, it is important to precisely adhere to the mixing ratios and processing conditions for 2C systems. Special care is thus required throughout the entire process cycle when using such substances. However, according to current knowledge, the application of isocyanates is mainly a question of occupational health and safety and less a matter of environmental protection. In the event of a fire, however, critical products such as hydrocyanic acid, cyanate, carbon monoxide, or nitrile can be created from isocyanates.[101]

The artificial turf carpet lies on top of the elastic layer/elastic base layer or on the shock pad. The fibers are fixed on the back of the mat with latex or a polyurethane-based adhesive. Allergic reactions (latex allergy) can occur when in contact with the turf and/or the infill granulate.[102] However,

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85 Brandt et al. 2013.

86 WECOBIS 2021.

87 GMBl 2009.

88 GMBl 2021.

89 European Commission 2020.

90 European Commission 2000.

91 European Commission (EC) 2004.

92 European Commission (EC).

93 European Commission (EC) 2014.

94 EU Commission; EU Parliament May 8, 2019.

95 European Commission (EC) 2004.

96 European Commission (EC) 2014.

97 European Commission (EC) 2019.

98 EU Commission; EU Parliament May 8, 2019.

99 European Commission 2020.

100 GMBl 2009.

101 Hensler 1995.

102 FOPH 2017.

there has been no known increase or accumulation of cases due to the use of artificial turf surfaces. Nevertheless, latex allergies with frequent close contact are a relevant health risk, although this also occurs in many other areas of daily life (protective gloves, sportswear, condoms, etc.).[103]

PFAS can be contained in most artificial turf fibers consisting of polyethylene (PE) or polypropylene (PP) as they are sometimes used as a processing aid when manufacturing fibers.[104] Perfluoroalkyl and polyfluoroalkyl substances can produce neurotoxic effects, cause endocrine conditions, and damage the immune system.[105] The decomposition products are also extremely persistent and accumulate in the environment, such as in bodies of water. This can make it difficult to acquire drinking water and keep it clean.[106,107] They can also accumulate in humans and animals via the airways.[108] Due to the high number of various compounds that belong to this substance group, they have not all been tested for potential harmful effects to date. However, according to current knowledge, they are considered to be of very high concern. In addition, investigations into fibers found traces of potentially harmful heavy metals, although only in concentrations that were not considered a danger.[109]

Additives are added to artificial turf fibers to increase mechanical resistance. Alongside coloring agents, these are mainly UV stabilizers, which are intended to protect the plastic from becoming brittle and breaking. Some of the organic UV stabilizers such as benzophenone, which has been found in performance infill, are considered to be endocrine disruptors, i.e. hormonally active substances.[110] Light stabilizers, such as hindered amine light stabilizers (HALS), are toxic and can cause irritation upon contact.[111] In the context of artificial turf, however, the additives used in the fibers have not been shown to have any negative effects on people so far.

Scientific hazardous substance analyses of the infill granulate are currently heavily focused on ELT granulate, as this is used most worldwide and has been criticized for several years. ELT granulate, which is produced from a complex, high-performance elastomer and additive mix from end-of-life tires, contains numerous hazardous substances, including twenty-five different heavy metals, polycyclic aromatic hydrocarbons, phenols such as bisphenol A, phthalates, volatile organic compounds (VOC), and semi-volatile organic compounds (SVOC), various chlorine compounds, furans, and many others. [112,113,114,115]

Polycyclic aromatic hydrocarbons and other organic compounds (VOC) are outgassed during the service life (to a much greater extent at the beginning than towards the end), especially in the

103 www.allergieinformationsdienst.de/krankheitsbilder/weitere-krankheitsbilder/latexallergie/verbreitung.html

104 TURI 2020.

105 Grandjean and Clapp 2015.

106 Sharma et al. 2016a.

107 TURI 2020.

108 Grandjean and Clapp 2015.

109 FOPH 2017.

110 Schlumpf et al. 2004.

111 ChemBK 2021.

112 Bocca et al. 2009.

113 Marsili et al. 2014.

114 Schneider et al. 2020.

115 Perkins et al. 2019.

event of a temperature increase (e.g. in summer).[116,117] This can lead to unpleasant odors on the pitch.[118] In addition, the hazardous substances can enter the air and thus cause hazardous substance emissions that are inhaled.[109,114,116,119,120] However, previous studies were unable to find any negative effects on human health as the concentrations were below the permitted limit values.[109,113,121] The pollution level roughly corresponds to the typical background pollution in a city.

Hazardous substances contained in granulate can also be absorbed through contact with the skin. The contact times studied so far do not, however, indicate any health risks.[122] Various authors nevertheless consider harmful effects to be possible with prolonged and regular skin contact times (e.g. due to granulate dust that adheres to the skin) or through ingestion (e.g. dust, resuspension, or due to infants).[113,123] More precise scientific investigations into this do not currently exist. Other studies assume that oral intake routes are fundamentally insignificant.[124]

It is to be expected that critical discussions surrounding ingredients will continue. In a review of a total of 43 scientific investigations, 306 different substances and chemicals were identified in SBR granulate.[125] These were investigated with regard to their potential carcinogenicity using the software ADMET-Predictor[126]. The abbreviation **ADMET** (ADME-Tox) stands for **a**bsorption, **d**istribution, **m**etabolism, **e**xcretion, and **t**oxicity. The program serves to predict the potential harmful effects of individual substances on people on the basis of the properties of previously known hazardous substances. The result of the review was that 197 out of the 306 identified substances were classified as presumably carcinogenic. 61 percent and 80 percent of these probably hazardous substances are not yet classified by the U.S. Environmental Protection Agency (EPA) and the European Chemicals Agency (ECHA), respectively, as substances that could be potentially harmful and thus would need to undergo more rigorous scientific investigations.[125]

There are so far hardly any scientific investigations for EPDM and TPE granulate with regard to possible health or environmental risks. The consideration of potential risks is made more difficult by the fact that manufacturers only need to provide limited information on the composition of their products. In terms of an evaluative comparison of the infill options, these materials should be investigated in detail in the future and biodegradable or natural alternatives should also be included, provided that performance infill continues to be used.

EPDM is often considered less harmful compared to ELT granulate. However, initial investigations show that it contains a large proportion of the same hazardous substances as ELT granulate.[127] Some manufacturers state concentrations for 15 verifiable carcinogenic PAHs on product data

[116] Menichini et al. 2011.

[117] Watterson 2017.

[118] However, during a survey of pitch operators conducted as part of this study, negative odor formation was not cited as a problem.

[119] Cheng et al. 2014.

[120] Claudio 2008.

[121] Pronk et al. 2020.

[122] Schlummer et al. 2018.

[123] Hibbert et al. 2017.

[124] FOPH 2017.

[125] Perkins et al. 2019.

[126] www.simulations-plus.com/software/admetpredictor/.

[127] Massey et al. 2020.

sheets.[128] The granulates are usually certified according to category 1 (products intended to be put into the mouth or with prolonged skin contact) in the hazardous substance specification from the Product Safety Commission (AfPS). This means that the concentration of the individual PAHs is below 0.2 mg/kg and less than 1mg/kg in total (PAH 15), which corresponds to the limit values recommended by the German Federal Institute for Risk Assessment. The same applies to TPE, PU, and other plastic granulates. These also contain a large proportion of the same hazardous substances as SBR granulates, although lower in number and concentration.[129] As a result, these granulates are so far considered non-hazardous in the industry.

The assessment in many studies (see above) that no negative effects are to be expected due to hazardous substances in plastic granulates is sometimes criticized in other scientific publications as there are still many gaps in knowledge and data with regard to the real situation on the pitches, which would reduce the significance of previous findings.[130,131] At the same time, previous investigations regarding the mobility of the hazardous substances do not illustrate all of the dangers, as eluate tests were mainly carried out. It should be clarified here to what extent microplastic emissions represent a discharge route for hazardous substances and whether this would lead to a different assessment of the hazard potential, especially for the environment. The abrasion and crushing process that occurs for all granulate types with long utilization times, regardless of the type of plastic used, and the increasing mobility of hazardous substances resulting from this should be investigated in more detail.

An overview of the hazardous substances found in artificial turf pitches is shown in Table 11. The colored ticks show whether a certain hazardous substance can occur in the respective component because it is part of the product or part of manufacturing and/or has been detected in scientific experiments. The information does not allow any conclusions to be made reading the precise likelihood with which the stated hazardous substances can actually occur in the product. As the information is based on scientific studies of products on the market, it is, however, to be assumed that the listed compounds can occur in corresponding products. The state of knowledge is still unsatisfactory, especially for newer products and materials that are currently offered as a solution to environmental problems.

The classification represents a qualitative comparison of the products with each other. It makes no statements regarding the concentration of the hazardous substances or potential risk. The statutory limit values for substances of concern were complied with in most scientific investigations. Only the limit values for individual heavy metals (Cd, Co, Se, Zn) were exceeded in two investigations.[132,133] Nonetheless, the list shows which product versions tend to contain more or less hazardous substances than others. Due to the variety of hazardous substances investigated and detected in various studies, it was not possible to show all of them. The most well-known that were detected most often and/or that have the most harmful effects according to current knowledge were shown. The list, therefore, does not claim to be exhaustive and must be expanded by further studies.

128 Gezolan AG 2015.

129 Massey et al. 2020.

130 Massey et al. 2020.

131 Watterson 2017.

132 Bocca et al. 2009.

133 Marsili et al. 2014.

Despite compliance with statutory limit values, some researchers in their investigations consider the use of products with lower concentrations to be "safer"[134].

134 Massey et al. 2020.

Table 11: Detected and released hazardous substances in various artificial turf components[135,136,137,138,139,140,141,142,143]

	HM[1]	PAH[2]	VOC[3]	PM10[4]	Phe-nols	Phthalates	Fu-rans	PFAS[5]	CL[6]	Iso[7]	Phe-nones	HALS[8]	PCB[9]	Other[10]
Elastic layer/elastic base layer														
EL/EBL (SBR)	✓	✓	✓	?	✓	✓	✓	X	✓	✓	✓	X	✓	✓
EL/EBL (EPDM)	✓	✓	✓	?	✓	✓	?	X	X	✓	X	X	X	?
PE shock pad	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Turf carpet														
Backing	?	?	?	X	?	?	?	✓	X	?	?	X	X	?
Fibers PE	✓	X	X	X	X	X	X	✓	X	X	X	✓	X	✓
Fibers PA	✓	X	X	X	X	X	X	✓	X	X	X	✓	X	✓
Infill														
SBR	✓	✓	✓	✓	✓	✓	✓	X	✓	X	✓	X	✓	✓
SBR with PU	✓	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	?	✓	✓
EPDM	✓	✓	✓	✓	✓	✓	?	X	X	X	X	X	X	?
TPE	✓	✓	✓	✓	?	✓	?	?	?	?	?	?	?	?
TPU	?	?	✓	✓	?	?	?	?	?	✓	?	?	?	?
Cork	X	X	✓	?	X	X	X	X	X	X	X	X	X	X
Sand	X	X	X	✓	X	X	X	X	X	X	X	X	X	X

✓ contained
? not yet scientifically investigated
X not contained

[1] HM = Heavy metals	[6] CL = Chlorine and chlorine compounds
[2] PAH = Polycyclic aromatic hydrocarbons	[7] Iso = Isocyanates, diisocyanates, and isocyanate compounds
[3] VOC = Volatile organic compounds	[8] HALS = Hindered amine light stabilizers
[4] PM_{10} = Particulate matter	[9] PCB = Polychlorinated biphenyl
[5] PFAS = Perfluoroalkyl and polyfluoroalkyl substances	[10] Other hazardous substances and substances of very high concern that do not belong to one of the stated groups

In terms of environmental history, the regulation of hazardous substances is constantly increasing. Limit values tend to be tightened rather than eased. This may be due to new findings on their occurrence in certain products, the hazards associated with them, or better analytical methods to

135 Bocca et al. 2009.

136 Menichini et al. 2011.

137 FOPH 2017.

138 Massey et al. 2020.

139 Norwegian Institute for Air Research 2005.

140 Gomes et al. 2021.

141 Marsili et al. 2014.

142 Perkins et al. 2019.

143 TURI 2020.

detect them. Nevertheless, it is quite likely that hazardous substance concentrations that have previously been considered safe may be assessed differently in a few years. Many substances that are suspected of having harmful effects require further scientific investigations. Current regulation and declaration systems may not be sufficient to show all detected and potentially possible harmful effects.[144] The uncertainty regarding future requirements also represents an obstacle in view of the circular economy, as hazardous substances become increasingly concentrated in the cycle ("legacy additives") or new findings lead to stricter limit values.[145,146] In order to be able to conduct more in-depth investigations, more information and data on the compositions of individual artificial turf components are required, including outside of ELT granulate used as performance infill and as a component of elastic layers.

Fires also represent a particular risk. The higher the fire temperature, the greater the release of hazardous substances due to firefighting water entering the soils, particle emissions, and above all volatile components such as VOC. The plastics and elastomers used for artificial turf surfaces are fundamentally flammable. The quantities used also give rise to a critical evaluation of the fire.[147] Flame retardants based on halogen compounds are thus sometimes added.[148] They are considered toxic, which is why the use of many flame retardants is already banned. However, the required fire protection is generally ensured exclusively by adding sand. This means that artificial turf surfaces fall under fire protection class "fire retardant (Cfl-s1)" according to EN 13501-1 for floorings. Products of combustion for the plastics used in artificial turf pitches PE, PP, EPDM, SBR, TPE, and PU include many alkanes, alkenes, alcohols, aldehydes (e.g. formaldehyde), ketones, carboxylic acid derivatives (e.g. formic acid, acetic acid), aromatic hydrocarbons (e.g. benzol, toluol), phenols, hydrogen cyanide, ammonia, urea, etc.[149] There has not yet been a detailed scientific discussion of the release of hazardous substances in the event of a fire.[150]

11.2 Heating of the pitches

Artificial turf pitches have an influence on the microclimate in their surrounding area. They are heated by direct sunlight, especially in summer, far beyond the temperature level of the surrounding area.[151,152,153] This is due to the low reflectivity of the artificial turf. It is lower than any other surface in an urban area, which means that a large proportion of the solar radiation is absorbed and the surface temperature can even increase above that of asphalt. [154,155]

144 Perkins et al. 2019.

145 Wagner and Schlummer 2020.

146 Onyshko and Hewlett.

147 MUEEF 2019.

148 Clercq et al. 2019.

149 Hensler 1995.

150 Clercq et al. 2019.

151 Watterson 2017.

152 Jim 2016.

153 Jim 2017.

154 Yaghoobian et al. 2010.

155 Williams and Pulley 2002.

Emissivity is influenced by the material, morphology, and color of the individual turf components. Among the different granulates used, SBR granulate has the lowest reflectivity. Temperatures up to 10 °C higher than TPE granulate were measured. Fibrillated fibers heat up more than non-fibrillated fibers.[156,157] White granulates and fibers were an average of 5–6 °C cooler than components of other colors during measurements. It is assumed that the type of elastic layer also has an influence on the surface temperature of the pitch.[158] Aspects of thermal insulation relating to the ground may also play a role here. However, this has not yet been sufficiently researched.

Various studies measured temperature increases of 35–65 °C on average compared to the surrounding area, with peak temperatures of up to 93 °C.[159,160,161,162,163,164] Artificial turf surfaces thus heat up significantly more than natural turf surfaces. In a direct comparison, the surface temperature of artificial turf, at 74.6 °C, was 38 °C higher than that of natural turf under the same conditions.

In Germany, the high summer temperatures regularly led to cases in which performance infill granulates stuck together on numerous artificial turf pitches due to thermal softening.[165,166,167,168] This causes the granulate to clump together, stick to the users' shoes (Figure 34), stick to the fibers, and form a continuous rubber layer, which meant that pitches sometimes had to be milled off and renovated at great cost. The clumping usually happens with peroxide cross-linked granulates (particularly EPDM); this effect did not occur for sulfur cross-linked ELT granulates. For TPE granulates, which are not chemically cross-linked, thermal stabilization is very complex. [169,170]

[156] Villacañas et al. 2017.

[157] Penn State's Center for Sports Surface Research 2012.

[158] Petrass et al. 2014.

[159] Buskirk et al. 1971.

[160] Jim 2016.

[161] Jim 2017.

[162] McNitt et al. 2006.

[163] Williams and Pulley 2002.

[164] Brakeman 2004.

[165] Sturm 2019.

[166] RP online 2018.

[167] Borowski 2020.

[168] WDR 2020.

[169] https://rasencoach.ch/2018/02/11/verklumpung-granulat/; last accessed: July 27, 2021

[170] https://www.stadionwelt.de/fachwissen/19287/einfuehrung-alles-ueber-einstreugranulat-fuer-kunstrasensysteme; last accessed: July 27, 2021


Figure 34 - Adhered granulate under the shoes of a user (WDR 2020)

The performance of the players is also influenced – sometimes positively – by the increased temperatures on artificial turf pitches.[171,172] However, it is unclear whether this causes health risks. There has so far been hardly any research into the direct effects of overheated artificial turf pitches on users.

The increased temperatures put greater pressure on the cardiovascular system and make the users increasingly dehydrated. This can trigger heat-related illnesses.[173,174] Some researchers thus consider playing on overheated artificial turf pitches to represent a health risk and fear negative effects on health.[175]

However, artificial turf pitches not only influence those playing sport and spectators, but also the microclimate of the surrounding area, specifically in urban areas. Modeling shows that artificial turf pitches heat the surrounding area in urban spaces by up to 4 °C.[176] In the context of climate change and the already existing problem of overheated cities in summer, artificial turf pitches represent an exacerbating factor. Heat waves have been a massive problem, especially in urban regions, for many years.[177] A negative assessment of the artificial turf system due to overheating would, however, also have to sufficiently acknowledge the health benefits of playing sport on ATPs.

Natural turf surfaces cool due to evaporation. The evaporation of water causes a cooling effect and the surface temperature is reduced. Artificial turf pitches are watered in order to achieve this

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171 Calderón-Pellegrino et al. 2020.

172 Mohr and Krustrup 2013.

173 Rikkert et al. 2009.

174 Keatinge 2003.

175 Jim 2017.

176 Yaghoobian et al. 2010.

177 Rikkert et al. 2009.

effect. However, the water consumption for infill artificial turf pitches at approx. 2-4 and for non-infill at 3–8 l/m² is significantly below the amount of water required for watering natural turf at approx. 15-25 l/m².[178,179,180] Watering also serves to bind dust and reduce abrasion of artificial turf. Cork as an alternative infill also requires watering; it is as yet unknown to what extent the water requirement is higher or lower than for conventional performance infills.[181]

To reinforce the cooling effect by evaporation, granulates with increased hygroscopy have been offered for many years (e.g. by adding hygroscopic materials). These absorb more water and should therefore cause evaporative cooling over a longer period of time and to a greater extent. However, studies show that these granulates do not lead to a permanent reduction in the surface temperature of artificial turf in practice.[182] The evaporative effect only occurs as long as the granulate is wet. Once it dries, there is no further cooling effect (as no further evaporation can take place) and granulates with increased hygroscopy heat up just as much as conventional granulates. Once dried, heating takes place very quickly. Temperature increases of 20 °C were measured in a period of just five minutes.[183] The granulates dry out as the pitch is not watered throughout the day. Especially at the height of summer, the water consumption would otherwise be too great, so the pitches are usually watered in the morning, evening, or shortly before use. In particular, artificial turf pitches are often even only watered immediately before use.[184] To achieve a permanent cooling effect and thus limit extreme heating, an artificial turf pitch would thus have to be watered throughout the entire day on hot days. Watering took place before every training session or match in summer at some of the pitches investigated as part of this study.

11.3 Sports accidents and germ loads

The emergence of artificial turf pitches also marked the start of the discussion over whether artificial substrates pose a greater risk of injury than natural substrates. Surveys show that users expect there to be a greater risk of injury on artificial turf surfaces than on natural turf surfaces.[185,186,187]

To date, scientific investigations do not show any clear picture, even if an overall consideration clearly shows a trend indicating an increased risk of injury on artificial turf pitches. Williams et al. state that the risk of ankle injuries on third-generation artificial turf pitches is around seven times higher and the risk of knee injuries around eight times higher than on natural turf. The proportion of grazes is also significantly higher.[188] It is still not possible to make a clear statement for fourth-

178 Klapproth 2017.

179 Sportstättenrechner 2020.

180 DIN 18037-2

181 https://www.salzburg24.at/news/salzburg/kunstrasen-zwei-salzburger-sportplaetze-verzichten-auf-plastikgranulat-73903663; last accessed: July 27, 2021

182 Jim 2016.

183 McNitt et al. 2006.

184 Klapproth 2017.

185 Twomey et al. 2019.

186 Roberts et al. 2014.

187 Zanetti 2009.

188 Williams et al. 2011.

generation pitches, as the results to date vary greatly and are based on a low number of investigations. The studies also do not distinguish sufficiently between the substrate type, use type, and constitution of the users.[185]

Analyses of the microbiology of artificial turf pitches found significant differences compared to natural turf pitches. Although the germ concentration found was comparable between both substrate types, the relative proportion of pathogenic germs was higher on artificial turf surfaces. [189] Scientific investigations assume that there is a significantly higher risk of infection in general and of infections with multidrug-resistant germs on artificial turf pitches due to grazes.[190,191,192] Similar findings have also recently been published for other plastics in the environment.[193]

189 Valeriani et al. 2019.

190 Cohen 2008.

191 Meyers 2013.

192 Bass and Hintze 2013.

193 Gkoutselis et al. 2021.

12 What is the current situation regarding recycling?

"The artificial turf industry strives to recycle the artificial turf mechanically as fully as possible, as well as the elastic base layer over the medium term. A closed-loop approach for the entire artificial turf or even individual components – with the exception of the infill sand – cannot yet be identified.

The mechanical recycling will lead to greater EoL costs and the recycling of ELT granulate from artificial turf pitches could compete with the direct recycling of end-of-life tire granulate."

12.1 EoL options

The European Synthetic Turf Organization (ESTO) has recommended the energetic utilization of artificial turf pitches since 2009.[194] The following were given as reasons:

- High costs and energy expenditure for the separation, cleaning, and processing of the components, and
- Chemical decomposition and oxidative damage of the components (artificial turf, infill, shock pad)

In 2019, the successor organization ESTC changed its assessment and now refers to the five-stage waste hierarchy.[195] This means that artificial turf systems should firstly be created in such a way that they have as long a service life as possible, that they should secondly be re-used, and thirdly recycled well. Only once these options have been fully exploited should energetic utilization or – if this should not be possible – disposal be considered.

Ten years ago, the service life of artificial turf was still stated as 10 to 12 years at 1,300 to 1,400 hours per year.[196] In a comprehensive examination of artificial turf pitches in Spain, Burillo et al. (2012) identified that the age of the pitches is a particularly relevant value in relation to mechanical and functional sport-related properties.[197] The properties worsened significantly for the five-to-ten-year-old pitches in contrast to the pitches that were up to five years old. The authors thus assume that most pitches are overused and a service life of 6 to 7 years would be sensible. Especially in regard to safety-relevant shock absorption, they identified a significant reduction for older pitches. A study of artificial turf pitches in Switzerland also came to similar results. There are no detailed analyzes concerning which measures and construction methods allow the service life to be improved.

The pitches examined as part of this study were used on average for 1,830 hours. Three of the 17 pitches were more than 10 years old. For the "FIFA Quality" or "FIFA Quality Pro" pitches, it was possible to retain functional sports-related properties within the first four years of use. For one of the pitches, however, additional maintenance was required for this, as the pitch was unable to

194 ESTO 2009.

195 ESTC 2019.

196 Sportrasen GmbH.

197 Burillo 2012.

meet two out of the five parameters in the specifications required by FIFA during the first inspection.

There is no clear answer to the question of what service life is ecologically sensible. On the one hand, a longer service life has a positive effect on the carbon footprint (cf. Chapter 13). However, the investigations in this study have shown that losses of performance infill are largely independent of the age of the pitch (cf. Chapter 8.3). It is nevertheless likely that increasing quantities of finer particles are emitted due to fragmentation, and fiber loss also increases (cf. Chapter 9). Furthermore, as the useful life increases or when the artificial turf is dismantled, the elastic base layer or the shock pads may be damaged and fragmented, thus hampering emission-free dismantling.[198] The re-use of artificial turf systems often takes place in the form that pitches that no longer fulfill the quality standards (e.g. according to the FIFA Quality Programme) are used for applications with lower quality standards (e.g. as training or recreational pitches). To what extent recirculation is actually achieved by this or whether this approach causes a further overall increase in the number of artificial turf pitches has so far not been investigated. In general, however, criteria should be applied to re-use. This is because the argumentation of the ESTO in 2009 that the components degrade and are subject to oxidative damage is likely to still apply. The corresponding damage could mean that the embrittlement and fragmentation of granulate and artificial turf fibers would increase during a second or even third utilization phase and emissions would grow significantly. According to the ESTC, however, a possible further use should also be investigated based on play-related properties six months before the pitch is dismantled.

A further EoL strategy would be the use of non-infill pitches. This would do away with the workload involved in separation and the separate processing of the components. However, the ESTC has so far assumed a shorter service life. [199] This would be counterproductive in terms of a circular economy. However, there are so far no systematic investigations into this and the statement does not correspond to the experiences at one of the pitches examined as part of this study. A foamed monomaterial as a shock pad in place of an elastic base layer or a combination of Drainasphalt with SBR/PUR shock pads is also a promising option. Systems of this kind use considerably fewer resources, which, for instance, also has a positive effect on the carbon footprint (cf. Chapter 13). It would also be easier to dismantle such systems. Shock pads based on foamed polyethylene are available today both as new products and as production waste.[200, 201] EoL shock pads are not currently recycled. As the foamed shock pads consist of cross-linked polyethylene, it is questionable whether they can undergo further thermoplastic processing and be foamed. Avoiding using end-of-life tire-based rubber granulate as infill or as a constituent of shock pads or elastic base layers would end this important reuse path for scrap tires.[202] To what extent avoiding using end-of-life tire granulate in artificial turf systems would have a positive or negative effect overall on the environment is thus difficult to assess. The lack of ecologically beneficial reuse alternatives, in particular, could speak in favor of the use of such granulates in artificial turf construction.

198 Cf. here e.g.: https://www.svburgsteinfurt.de/die-arbeiten-am-kunstrasenplatz-im-volksbank-stadion-wurden-wieder-aufgenommen/; last accessed: July 9, 2021

199 ESTC 2019.

200 https://progame-shockpads.com/; last accessed: July 8, 2021.

201 https://www.schmitzfoam.com/; last accessed: July 8, 2021

202 EuRIC 2020.

Approx. 98 percent of EoL artificial turf pitches are replaced by new artificial turf areas. Genuine recycling (re-use for the same purpose) would thus be sensible. In particular, the elastic base layers (composite of mineral gravel, end-of-life tire granulate, and polyurethane) and the back of the artificial turf (PE/PP fiber, PP fabric, and SBR latex) as well as the PE shock pads, which are partly cross-linked with electron beams, represent problematic fractions for recycling. The stabilizers used in the performance infill and the artificial turf fibers to protect against photooxidative damage are also likely to be used up. Above all for non-thermoplastic components (such as EPDM, end-of-life tire granulate, or SBR backing, electron beam cross-linked shock pads), adding more stabilizer is technically complex and re-use in the same application is rather unlikely.

In general, recycling the sand should be the easiest element. However, it is questionable whether the value creation that can be achieved from the sand content would be enough to compensate for the costs of a recycling process. In order to reduce the costs of separating performance infill and sand, it is recommended to use cork or another biogenic or biodegradable performance infill. As these would not be affected by the ECHA restriction proposal, they could be reused.[203] Depending on the envisaged re-use, however, it should be assessed whether the mixture guarantees sufficient performance or – in the case of secondary utilization – whether the requirements on a permitted total carbon content can be met.

Regardless of whether they involve downcycling or upcycling from the viewpoint of the operators, utilization solutions in which the plastic components are re-used in an application other than the original one are generally only sensible if they replace an existing, less environmentally-friendly resource. The use of the granulate in industrial flooring or as panels for green roofs, for instance, is currently being discussed.[204] In these applications, the granulate would be competing against the direct use of end-of-life tire granulate. As the quantities of end-of-life tire granulate that are generated are considerable and the disposal pressure is high, there is competition for sinks here.[205] The fibers of the artificial turf carpet should be used in elastic layers or elastic base layers. A positive effect on the recyclability of the elastic base layer would then arise if mineral aggregates could be avoided without impairing the elastic properties of the base layer.[204] It is, however, questionable whether the PUR-bound elastic base layers can really be recycled as a material once again after up to 45 years.

12.2 Situation regarding recycling

A total of around 60 million square meters of artificial turf pitches exist in Germany and Switzerland. If it is assumed that the service life of artificial turf is an average of 12 years and 24 years for the elastic layer, from today's perspective, around 5 million square meters of artificial turf including infill and 2.5 million square meters of elastic base layer or shock pads with or without a Drainasphalt layer should be generated each year (Table 12).

Table 12: Amounts at the end of life of artificial turf per year in D and CH

Component	Total area for disposal/recycling in D+CH	Material surface weights	Mass
Artificial turf			

[203] https://www.heiler-sport.de/de/rueckbau-recycling.html: Last accessed: July 8, 2021

[204] Weitzel 2020.

[205] EuRIC - Position papers - EuRIC Factsheet - LCA Tyre Recycling Environmental Benefits (euric-aisbl.eu)

Artificial turf carpet	5,000,000 (100%)	PO: 1.4 kg/sqm PP: 0.3 kg/sqm Latex: 1.0 kg/sqm	7,000 t/a 1,500 t/a 5,000 t/a
Synthetic performance in-fill (EPDM, TPE, SBR(/PUR))	4,750,000 (95%)	7.5 kg/sqm	35,600 t/a
Sand	5,000,000 (100%)	20.0 kg/sqm	100,000 t/a
Damping layer			
Elastic base layer (crushed gravel, SBR granulate+PUR)	2,000,000 (80%)	SBR: 15.0 kg/sqm PUR: 2.3 kg/sqm Crushed gravel: 13.0 kg/sqm	SBR+PUR: 34,600 t/a Crushed gravel: 26,000 t/a
Shock pad elastic (SBR+PUR)	375,000 (15%)	SBR: 9.8 kg/sqm PUR: 1.2 kg/sqm	SBR+PUR: 4,100 t/a
Shock pads – foamed (PE-X)	125,000 (5%)	PE-X: 0.6 kg/sqm	PE-X: 750 t/a
Total quantities of waste from artificial turf in D+CH per year		**Plastic/rubber: 88,500 t/a** **Sand/crushed gravel: 126,000 t/a**	

Based on the current disposal costs, this results in approx. 5.35 euros per square meter for the removal, disposal, and recycling of the elastic base layer and approx. 3.13 euros per square meter for the artificial turf.[206] The total costs per pitch for a reference period of twelve years are approx. 45,000 euros for disposal (the costs for the base layer were estimated as half due to the longer service life).

The total costs for the disposal of approx. 88,500 metric tons of rubber and mixed plastic and 126,000 metric tons of sand and crushed gravel are around 29.1 million euros per year or 135 euros per metric ton. In the best-case scenario, the achievable prices can be estimated at around 200 euros per metric ton[207] for the rubber/plastic fraction and at approx. 5 euros per metric ton for the sand/crushed gravel fraction. Overall, this would result in approx. 18.3 million euros or €85 per metric ton of income from the sale of the material. The total resulting from acceptance remuneration and the sale of recycled material of approx. 220 euros per metric ton is hardly sufficient to finance the transport, separation, sorting, and processing of the artificial turf waste as secondary raw materials. At the same time, it is hard to imagine that secondary raw materials that achieve higher prices on the market compared to end-of-life tire granulate can be produced from artificial turf systems – especially as end-of-life tire granulate is often already used as a starting material for artificial turf pitches. It can thus be assumed that future mechanical (instead of the current energetic) recycling will lead to significantly higher EoL costs. To what extent ecological benefits arise from the recycling depends on whether the recycled material would substitute primary raw materials.

206 Calculation with the Sportstättenrechner sports pitch calculator

207 Corresponds to the price for rubber granulate from end-of-life tires

At present, four companies offer the recycling of artificial turf playing fields or have announced that they will offer this in the near future: the Danish company Re-Match[208], the Dutch company GBN[209], FormaTurf[210], which belongs to the German Sport-Group-Holding, and the south German company PR-Recycling[211]. The companies advertise various secondary raw materials. However, there are no life-cycle assessments of specific applications and products in which these secondary raw materials are used, or material flow analyses that offer information about the routes taken by the recycled material. PR-Recycling announced a procedure to recycle the elastic base layer on site, which would be a considerable advancement.

208 https://www.re-match.dk/; last accessed: July 8, 2021

209 https://www.gbn-agr.nl/de/; last accessed: July 8, 2021

210 https://www.formaturf.com/; last accessed: July 8, 2021

211 http://www.pr-recycling.com/de/; last accessed: July 8, 2021

13 What is the carbon footprint of artificial turf pitches?

"Depending on the type of artificial turf, the carbon footprints vary between 9.4 and 29.8 kilograms of carbon dioxide equivalents per hour of use.

The type of infill material plays a major role here. As a biogenic product, cork has a lower carbon footprint compared to fossil-based infill materials. The greenhouse gas emissions associated with disposal are especially relevant for types of infill such as SBR, EPDM, or TPE.

The use of a foamed polyethylene with or without Drainasphalt instead of an elastic wearing layer leads to much lower emissions both in the production phase and during disposal.

High-quality recycling of the components and a longer useful life for infill materials and the damping system can significantly reduce the carbon footprint."

13.1 Aims and functional unit

This chapter offers a brief overview of the carbon footprint of various artificial turf systems. In general, a life-cycle assessment (LCA) comprises a definition of the goal and scope of the system, an inventory analysis, an impact assessment, and the interpretation of the results in accordance with standard DIN EN ISO 14040/44.[212,213] The aim of the life-cycle assessment conducted here was to calculate and compare the greenhouse gas emissions of seven different versions of artificial turf systems. The reference value for the life-cycle assessment (functional unit, FU) is defined in this study as follows: "Playing time of one hour on the respective artificial turf system with a playing field size of 7,500 square meters."

The artificial turf systems in this analysis were distinguished according to the following criteria:

- Type of filling (non-infill vs. infill, type and quantity of the infill material)
- Fiber density of the artificial turf mats
- Nature and type of damping layer (elastic wearing layer, elastic layer with Drainasphalt, foamed shock pad)

The substructure of the artificial turf was not varied, but instead a typical type of construction was determined for all versions. Table 13 shows the fixed parameters and Table 14 the free parameters for the artificial turf systems that were examined. The fact that the height of the unbound wearing layer could be slightly reduced when using an asphalt layer was ignored here.

[212] ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework

[213] ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines

Table 13: An overview of the examined fixed parameters (EWL: elastic wearing layer; EL: elastic layer; AT: artificial turf)

Component	Unit	Version 1-7	Source
Functional unit	[Hours of use]	1	214
System boundaries	[-]	Cradle-to-grave	214
Intensity of use	[Hours/year]	1600	214
Space	[m²]	7500	214
Service life (EWL, EL)	[Years]	30	214
Service life (artificial turf mat)	[Years]	10	214
Service life of sand infill	[Years]	10	214
Service life of performance infill	[Years]	10	215
Service life of cork infill	[Years]	4	215
Substructure & subgrade	[m]	0.53	216
Drainage	[kg/m²]	0.11	216
Geotextile	[kg/m²]	0.25	216

A consideration of multifunctionality is an important aspect in the LCA. This is necessary if a system produces several product outputs or uses inputs that come from another product life cycle. For instance, infill materials produced from recycled end-of-life tires are used in certain artificial turf systems. The by-products (steel, textile) generated when processing end-of-life tires are not considered any further. All process loads associated with the production of the rubber granulate from end-of-life tires are also assigned to them as a percentage by weight. However, the secondary raw material end-of-life tires is assumed to be load-free. The carbon dioxide emissions saved by avoiding thermal utilization in the primary process can nevertheless also only be taken into account in the primary process (called the cut-off approach). The life-cycle assessment makes no statements as to, for instance, how the non-use of end-of-life tire granulate in artificial turf systems would affect greenhouse gas emissions in the upstream primary applications. Comprehensive system analyses of whole usage cascades for all material components would be required here, and cannot be performed as part of this study.

13.2 Examined systems

The assessment consisted of a "cradle-to-grave analysis" including end-of-life treatment. Figure 35 shows an illustration of the examined systems.

214 Own estimate/calculation

215 [Johansson 2018]: Life cycle assessment of two end-of-life tyre applications: artificial turfs and asphalt rubber, Ragn-Sells AB, https://www.sdab.se/media/1323/2018-1511-sdabs-annex-4-lca-granulat-foer-konstgraesplaner-ragn-sells.pdf

216 [Magnusson 2016]: Environmental perspectives on urban material stocks used in construction – Granular materials https://www.diva-portal.org/smash/get/diva2:1045893/FULLTEXT02

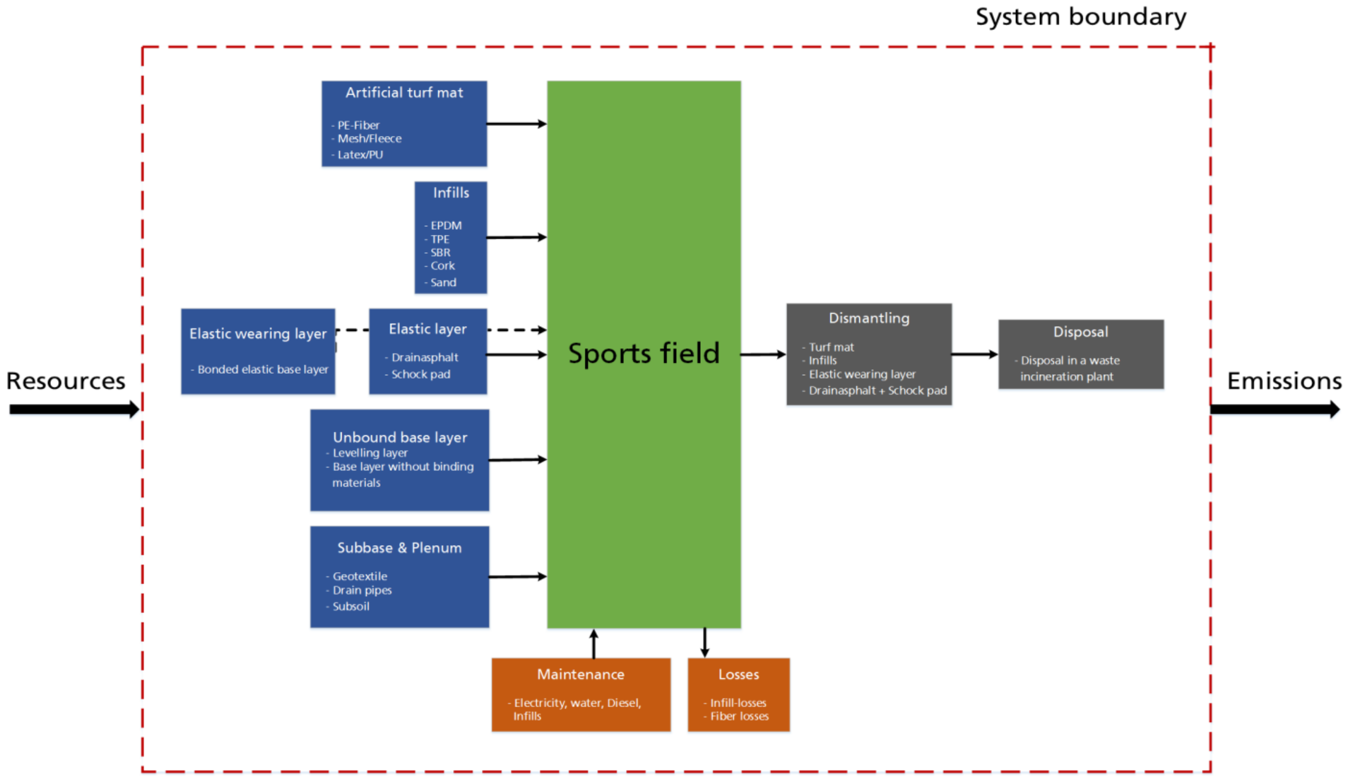


Figure 35: System boundaries of the artificial sport pitch

Production, construction, maintenance, and disposal of the artificial pitch components were taken into account. Aspects of the utilization phase that related to the players, such as arrival routes, the cleaning of transported artificial turf fibers or granulate, etc., were not modeled. More specifically, the production of the following components was taken into account:

- Pipes for drainage
- Geotextile
- Elastic wearing layer (EWL)
- Elastic layer (shock pad)
- Drainasphalt
- Infill material
- Artificial turf mat

A range of materials was examined for the performance infill: EPDM, SBR, TPE, cork, and sand. The artificial turf carpet itself, alongside different pile heights (fiber length above the carpet backing), can also consist of the materials polyethylene, polypropylene, or polyamide (nylon). The elastic wearing layer (EWL) can either be produced in situ or prefabricated. The EWL is typically produced by binding a mixture of SBR and crushed gravel using polyurethane. The elastic layer (EL) can also consist of SBR with a polyurethane binding agent or of foamed PE.

The construction phase comprises excavating the playing field, installing a drainage pipe system, and applying the base layer of crushed gravel and a leveling layer of fine gravel. It also includes laying geotextile, the EWL, or Drainasphalt layer with shock pad. It finally also comprises laying the artificial turf mat and filling with corresponding infill material.

The annual amount of electricity, diesel, and water required for the maintenance and upkeep of the artificial turf surfaces was estimated. Topping up the corresponding infill material was also taken into account in order to compensate for the loss of the infill. In addition, the maintenance phase also includes the disposal of damaged artificial turf and infill material that cannot be reused. Due to a lack of better-differentiated data, water consumption of 400 cubic meters per year was estimated for the maintenance of all of the pitches. This corresponds to approximately 10 percent of the value for natural turf surfaces.[217]

In relation to the infill, the median values of 1.75 metric tons per year for topping up and 1.78 metric tons for the granulate losses determined in Chapter 7.2 were used regardless of the infill type. The lower value of 1.9 percent per year determined by Thieme-Hack for newer pitches was used for the fiber losses, as the higher value appears unrealistic according to expert surveys. Finally, it was assumed that most materials (including cork) are thermally treated in a waste incineration plant at the end of their service life (cf.Table 13 for the service life of the respective components). It was assumed that sand infill is reused as a material (e.g. at a horse-riding facility).

[217] [Klapproth 2015]

Table 14: An overview of the examined free parameters

Component		Unit	Version 1	Version 2	Version 3	Version 4	Version 5	Version 6	Version 7
Elastic wearing layer	SBR	[kg/m²]	15	15	-	-	-	-	-
	PUR	[kg/m²]	2.25	2.25	-	-	-	-	-
	Crushed gravel	[kg/m²]	13	13	-	-	-	-	-
Drainasphalt		[kg/m²]	-	-	-	-	-	101.5	-
Elastic layer	PE foam (*recycled PE)	[kg/m²]	-	-	0.5	0.6	-	-	*2.3
	SBR	[kg/m²]	-	-	-	-	-	9.8	-
	PUR	[kg/m²]	-	-	-	-	-	1.2	-
Artificial turf mat	PP pile fibers	[kg/m²]	1.38	1.22	1.22	2.06	2	1.4	2.85
	PP mesh	[kg/m²]	0.27	0.27	0.27	0.27	0.2	0.27	0.3
	Latex	[kg/m²]	1	1	1	1	1	1	1
Infills	EPDM	[kg/m²]	-	6	-	-	-	-	-
	SBR	[kg/m²]	-	-	-	-	14.9	-	-
	TPE	[kg/m²]	-	-	-	-	-	8.45	-
	Cork	[kg/m²]	2.52	-	2.52	-	-	-	-
	Sand	[kg/m²]	22	25	22	22	25	15	13
Maintenance/upkeep	Diesel consumption	[L/year]	1850	1850	925	580	1850	1850	1850
	Water consumption	[m³/year]	400	400	400	400	400	400	400
Infill top-up	EPDM	[kg/year]	-	1750	-	-	-	-	-
	SBR	[kg/year]	-	-	-	-	1750	-	-
	TPE	[kg/year]	-	-	-	-	-	1750	-
	Cork	[kg/year]	1750	-	1750	-	-	-	-
	Sand	[kg/year]	5000	5000	5000	5000	5000	5000	5000
Fiber loss		[%/year]	1.9	1.9	1.9	1.9	1.9	1.9	1.9

13.3 Impact category

In this study, the impact category greenhouse gas emissions and the global warming impact (GWI) are exclusively considered as an indicator of environmental impact.[218] The result produces an estimate of all greenhouse gas emissions (e.g. carbon dioxide, nitrous oxide, methane, halogenated hydrocarbons) that can occur for each of the examined processes within the system boundaries. They are identified as carbon dioxide equivalents in order to allow the different emissions to be compared.

13.4 Results

As shown in Table 13, the parameters field size and service life (artificial turf mat, EBL, or EL with Drainasphalt) were the same across all seven versions. The dimensions and the design of the substructure and subgrade were also assumed to be the same across all of the artificial turf versions.

218 IPCC, 2007a

They exclusively serve to enable the relevance of certain components to be assessed in relation to the overall system and conduct a (careful) comparison with other studies (cf. Chapter 13.5).

In general, it can be seen that the annual playing hours are inversely proportionate to the greenhouse gas emissions. This means that an increase in the intensity of use (within the limits specified by the manufacturers) considerably reduces the carbon footprint. In this study, an average playing time of 1,600 hours per year was assumed.

Figure 36 shows the comparison of the greenhouse gas emissions of the various artificial turf system versions. It should be noted that version 3 (EL/sand+cork infill) and version 4 (EL/only sand infill) exhibited the lowest emissions at 9.4 kg CO_2 eq/hour and 10.5 kg CO_2 eq/hour, respectively. Version 6 (EL+Drainasphalt/TPE+sand infill) showed environmental effects that were over two times higher (approx. 29.8 kg CO_2 eq/hour). The greenhouse gas emissions of versions 2 (ET/EPDM+sand infill) and 5 (-/SBR+sand infill) lie in a similar range at approx. 26.9 and 22.3 kg CO_2 eq/hour. The greenhouse gas emissions for the cork-filled version 1 with an elastic wearing layer (EWL/sand+cork infill) are only slightly lower at 20.7 kg CO_2 eq/hour. However, the non-infill version 7 (EL/non-infill) scores significantly better at 11.9 kg CO_2 eq/hour.

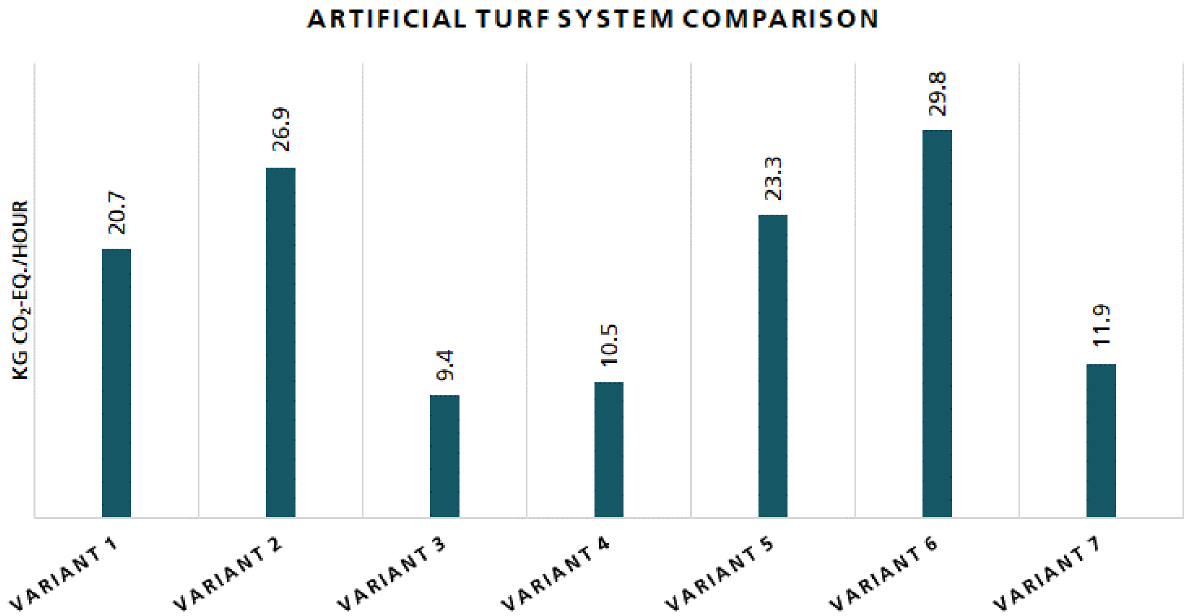
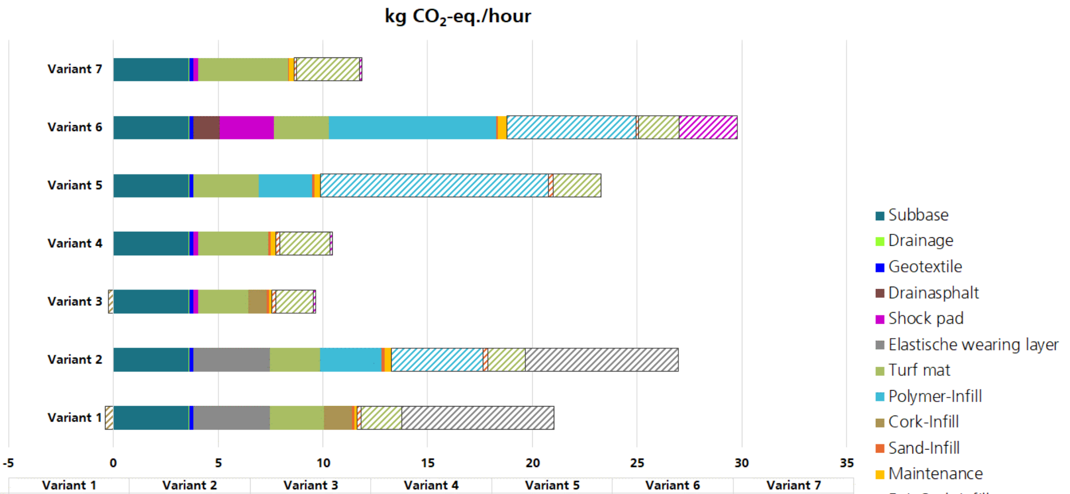


Figure 36: Comparison of the greenhouse gas emissions of various artificial turf system versions

Figure 37 shows a detailed contribution analysis of various artificial turf versions for every component within the life-cycle phase.



	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5	Variant 6	Variant 7
Subbase	3.58	3.58	3.58	3.58	3.58	3.58	3.58
Drainage	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Geotextile	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Drainasphalt	0.00	0.00	0.00	0.00	0.00	1.25	0.00
Shock pad	0.00	0.00	0.21	0.21	0.00	2.57	0.21
Elastische wearing layer	3.63	3.63	0.00	0.00	0.00	0.00	0.00
Turf mat	2.60	2.42	2.42	3.35	3.11	2.62	4.29
Polymer-Infill		2.94			2.55	7.99	
Cork-Infill	1.34	0.00	0.85	0.00	0.00	0.00	0.00
Sand-Infill	0.11	0.12	0.11	0.11	0.12	0.07	0.06
Maintenance	0.15	0.35	0.14	0.24	0.29	0.46	0.24
EoL Cork-Infill	-0.37		-0.24				
EoL Polymer-Infills		4.36			10.87	6.13	
EoL Sand-Infill	0.19	0.21	0.19	0.19	0.21	0.13	0.11
EoL Turf mat	1.92	1.80	1.80	2.41	2.31	1.93	3.00
EoL Shock pad	0.00	0.00	0.12	0.12	0.00	2.77	0.12
EoL Elastic wearing layer	7.29	7.29	0.00	0.00	0.00	0.00	0.00

Figure 37: Comparison of contribution analyses from various artificial turf system versions

For version 1 (EWL/sand + cork infill) and version 2 (EWL/EPDM+sand infill), the disposal of the elastic wearing layer makes the greatest contribution to the carbon footprint. For version 3 (EL/sand+cork infill), version 4 (EL/sand infill), and version 7 (EL/non-infill), the greatest contributions come from the manufacture of the artificial turf mat. For version 5 (-/SBR+sand infill), the biggest contribution is due to the thermal disposal of the infill. For version 6 (EL/DA/TPE+sand infill), the manufacture of the TPE infill makes the greatest contribution.

Figure 38 shows a comparison of the manufacturing-related greenhouse gas emissions of various damping systems per functional unit (the conversion to 1 square meter would lead to an identical result in relation to the comparison). In comparison to an EWL or a combination of Drainasphalt combined with a pure polymer elastic layer (EL) made from SBR, the PE-based EL layers (shock pads) display a lower carbon footprint. It has also recently become possible to use recycled PE foams in the artificial turf system. However, due to the lack of availability of suitable data sets for the life-cycle assessment software, the modeling of PE foam in this study is based on virgin materials. As it concerns production waste and not post-consumer recycled material, this approach – regardless of whether it concerns new or recycled foam – appears justified. The recycled foam would presumably achieve a somewhat worse result, as the second processing requires additional workload and significantly higher foam densities are present, increasing the mass used. It should be taken into account that the comparison only relates to the manufacturing phase due to the current high degree of uncertainty regarding future EoL options. However, generally speaking, it can be expected that the trend from the manufacturing phase will also continue over the entire life cycle.

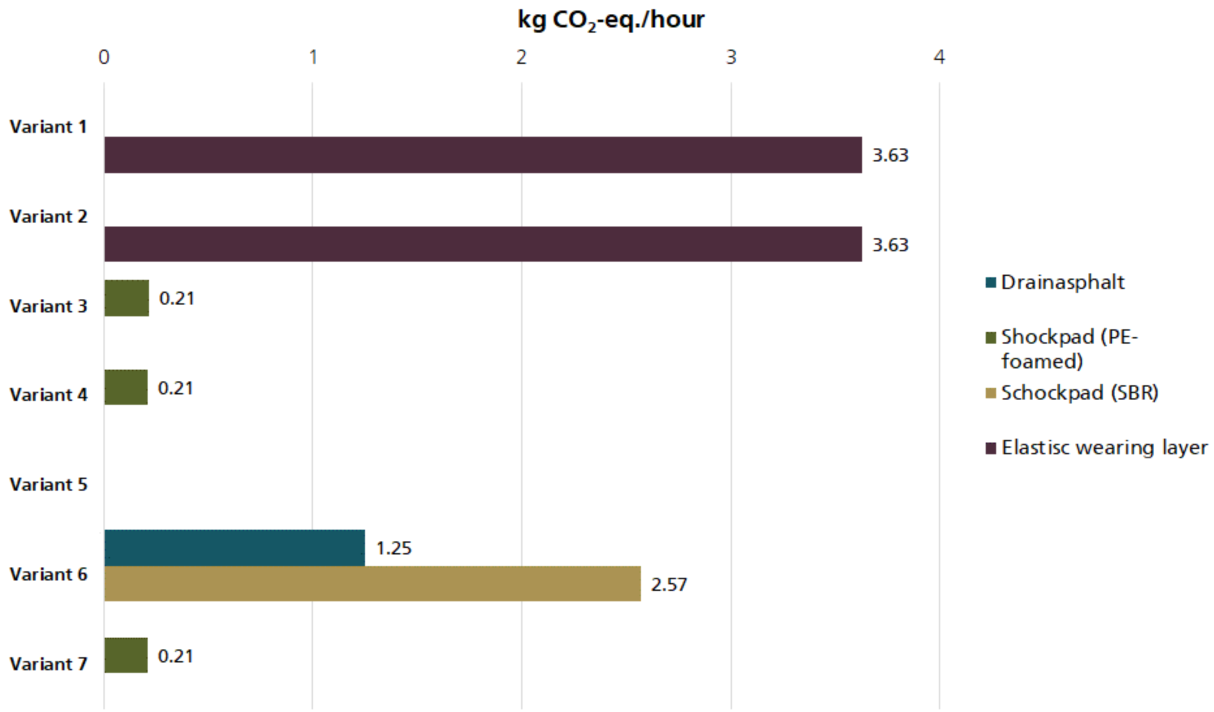


Figure 38: Comparison of the greenhouse gas emissions of various damping layers from the manufacturing phase

Figure 39 shows a comparison of the greenhouse gas emissions of various infill materials. In order to show the effects of various infill materials regardless of the quantity used, which can vary significantly based on the overall system and operator preferences, the greenhouse gas emissions are shown per kilogram. The infill quantity for each version can be seen in Table 14; Figures 35 and 36 take these different infill quantities into account.

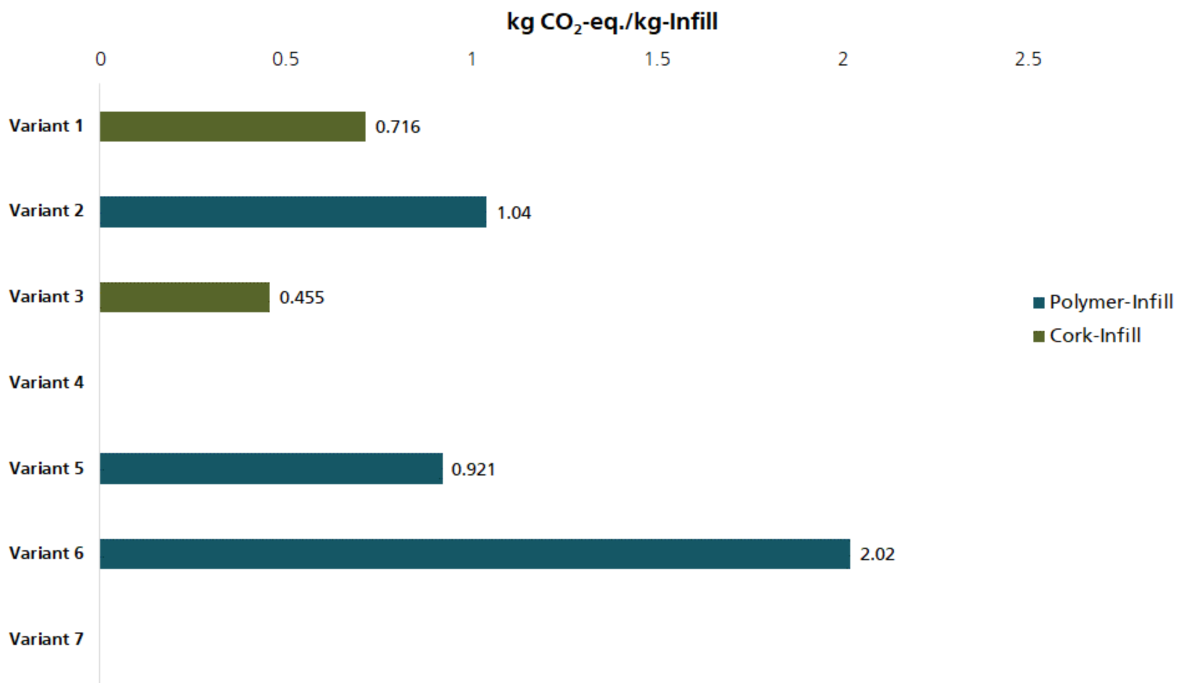


Figure 39: Comparison of the greenhouse gas emissions of various infill versions from the manufacturing phase

It is clear that cork infill (version 1 and 3) has the lowest carbon footprint (0.455 to 0.716 kg CO_2 eq/kg infill), as it is produced from biogenic materials. When comparing plastic infills, SBR-based infills (version 5), at 0.921 kg CO_2 eq/kg infill, have the lowest and TPE-based infills (version 6), at 2.02 kg CO_2 eq/kg infill, have the highest carbon footprint. EPDM-based infills, at 1.04 kg CO_2 eq/kg infill (version 2), only have a slightly larger carbon footprint than SBR granulate.

Taking into account the points stated above, the key results of this analysis can be summarized as follows:

1. Depending on the type of artificial turf, the carbon footprints are between 9.4 and 29.8 kilograms CO_2 eq/hour
2. The type of infill material plays a role, e.g. as a biogenic product, cork infills have a lower carbon footprint compared to fossil-based infill materials
3. The use of foamed polyethylene with or without Drainasphalt instead of an EWL has much lower effects both during the production phase and during disposal.
4. The greenhouse gas emissions associated with disposal are especially relevant for types of infill such as SBR, EPDM, or TPE.
5. High-quality recycling of the components and a longer useful life for infill materials and the damping system can significantly reduce the carbon footprint.

The analysis conducted was limited to the carbon footprint of the various artificial turf systems.

It must, however, be mentioned that there are many other, equally important impact categories (acidification, eutrophication, fine particulate matter, etc.) that were not investigated as part of this analysis. In addition, "playing time of one hour on the respective artificial turf with a playing field size of 7,500 m^2" was used as the functional unit in this study. The functional unit does not take into account any play-related differences between the versions such as ball rebound, damping of ball rolling behavior, rotational resistance, playability in bad weather, surface heating, etc. It is also not currently possible to depict the microplastics problem in life-cycle assessments. It must therefore be additionally taken into account in a comprehensive assessment – as in this study.

13.5 Results of other studies

To date, there are comparatively few studies that concern the life-cycle assessment of artificial turf systems.[219,220,221,222] Schüler & Stahl (2008) compared synthetic turf systems with natural turf.[203] Magnusson (2017) analyzed a typical artificial turf system in Scandinavia. [204] Itten et al. (2020) compared various artificial turf systems and natural turf in the Zurich region.[205] Johansson (2018) investigated the effects of various infill types on greenhouse gas emissions.[206]

Table 15 provides a brief overview of the parameters and results of other similar studies in the literature. It should be noted that a one-to-one comparison of the results is hardly possible as the

219 [Öko-Institut 2008]: Ökobilanz für den Vergleich der Umweltauswirkungen von Natur und Kunstrasenspielfeldern

220 [Magnusson 2017]: Analysis of energy use and emissions of greenhouse gases, metals and organic substances from construction materials used for artificial turf, https://doi.org/10.1016/j.resconrec.2017.03.007

221 [ZHAW 2020]: Ökobilanzierung von Rasensportfeldern: Natur-, Kunststoff- und Hybridrasen der Stadt Zürich im Vergleich, https://digitalcollection.zhaw.ch/handle/11475/20774

222 [Johansson 2018]: Life cycle assessment of two end-of-life tyre applications: artificial turfs and asphalt rubber, Ragn-Sells AB, https://www.sdab.se/media/1323/2018-1511-sdabs-annex-4-lca-granulat-foer-konstgraesplaner-ragn-sells.pdf

studies use different parameters (surface, intensity of use, artificial turf components, etc.). Alongside the deviations in the inventory analysis, there are also methodological differences between the studies and the data sets used.

In general, the results show that the greenhouse gas emissions from an artificial turf pitch correlate to a high degree with the material selection, maintenance, and recycling of the materials from the turf system at the end of their service life. In addition, the type of infill material also contributes to the higher greenhouse gas emissions. Studies show that TPE-based infills display the highest emissions, followed by EPDM-based infills. SBR infills from end-of-life tires display the lowest emissions among synthetic infills. These results correspond to the findings of this study.

In summary, the use of natural materials, the recycling of the materials used, and an on-site re-use of soil and stone could reduce greenhouse gas emissions. The solidity of the damping systems made from asphalt or crushed gravel, and ELT granulate and polyurethane binding agent has a considerably negative effect on the result in all life-cycle assessments.

Table 15: Comparison with literature

Component	Öko-Institut 2008 [219]	ZHAW 2020 [221]	This study
Functional unit [hours of use]	1	1	1
System boundaries	Cradle-to-grave	Cradle-to-grave	Cradle-to-grave
Intensity of use, [hours/year]	1500	1600	1600
Space, [m^2]	7650	7420	7500
Service life (EWL, EL), [years]	30	30	30
Service life (artificial turf mat), [years]	10	10	10
Substructure & subgrade	✓	✓	✓
Drainage	✓	✓	✓
Geotextile	-	-	✓
Elastic wearing layer	✓	✓	✓
Drainasphalt	-	✓	✓
Elastic layer	-	✓	✓
Artificial turf mat	✓	✓	✓
Infills	✓	✓	✓
Concrete borders, fence, lighting system	-	✓	-
Maintenance/upkeep	✓	✓	✓
Infill top-up	✓	✓	✓
Dismantling & end-of-life consideration	✓	✓	✓
Greenhouse gas emissions, [kg CO_2 eq/hour]	15	32 to 52	9.4 to 29.8

14 How are environmental aspects taken into account in standards?

"The standards and quality marks barely go beyond the minimum statutory requirements in terms of their environmental requirements. Microplastic emissions in the form of fibers and granulates are only marginally addressed without any specified aims.

Types of construction are specified in the German standard and in the FIFA Quality Programme that, for instance, essentially exclude prefabricated shock pads without an asphalt layer and non-infill pitches from the competition (even for the ecologically best solution), despite these concepts offering advantages.

Considering that environmental regulations are often tightened over time as knowledge is gained, the standards that are relevant to artificial turf pitches have so far failed to offer sufficient planning security for either manufacturers or operators."

14.1 EN 15330-1 and DIN 18035-7

Various standards exist for artificial turf pitches. The European EN 15330-1 and the German DIN 18035-7 are particularly relevant here in Germany and Switzerland. Standard 15330-1 primarily addresses the artificial turf system: turf layer plus infill and elastic layer/elastic wearing layer. Standard 18035-7 additionally comprises earthwork and the associated layers, i.e. the complete system. Standard 18035-7 generally forms the basis for calls for tenders in Germany. EN 15330 is currently undergoing revision. A part 4 is particularly being created, which explicitly looks at the elastic layers. This could mean that the German standard 18035-7 needs to be adapted (harmonized) or withdrawn.[223] Switzerland also orients itself towards both standards. Switzerland does not currently have its own standards for artificial turf pitches.[224] In Germany, a RAL quality mark is also applied in addition to the standards. The quality mark is based on a catalog of criteria that follows the standards. The FIFA Quality Programme is very important for artificial turf pitches on which UEFA or FIFA matches are played. In addition, technical report CEN/TR 17519 from the European Committee for Standardization was published in 2020 to minimize infill losses and has made its way into the ECHA restriction project.[225]

[223] www.beuth.de/de/erweiterte-suche/272754!search?alx.searchType=complex&searchAreaId=1&query=DIN+EN+15330-4+&facets[276612]=&hitsPerPage=10: Last accessed: July 8, 2021

[224] BASPO 111- Kunststoffrasen: Übersicht

[225] https://www.estc.info/wp-content/uploads/2020/03/FprCENTR-17519-Public.pdf; last accessed: July 9, 2021

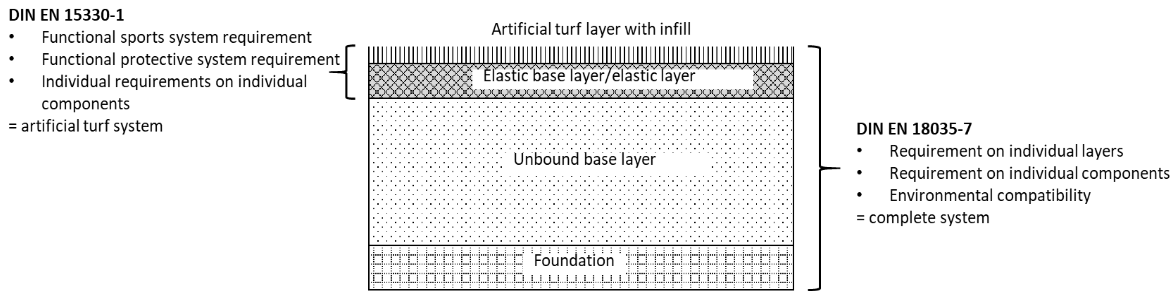


Figure 40: Scope of validity of the standards (authors' diagram according to https://fixgreen.de/kunstrasen-abc-din-normen.html)

The European standards EN 15330-1/-2 and, in the future, also EN 15330-4 most notably specify requirements for the sport-related performance, material properties, and durability of artificial turf systems for mass sports. Environmental aspects are not addressed. In relation to the elastic layer, the aforementioned standards only specify tensile strength; whether this is also applicable and sensible for elastic base layers is not stated. Infill materials are not looked at. Artificial turf pitch designs are recommended in Annex A, which has an exclusively informative character. According to this, artificial turf systems partially filled with rubber and sand with a pile height of 35 to 70 millimeters and a low to moderate fiber weight offer medium to high suitability for soccer; the elastic layer is optional here. Purely sand-filled or non-infill systems are only considered to have limited suitability.

With regard to construction types, it should be assessed whether the standard adequately takes into account the state of the art and the best technology from an environmental perspective, as non-infill and purely sand-filled pitches absolutely have practical relevance in soccer. In the context of a procurement procedure with a reference to the standard, the informative character of the annex should thus be taken into account and, where applicable, should not be used as an exclusionary awarding criterion.

The criterion of long-term durability is also discussed in the revision of the European standard. It is questionable how this criterion will affect the possible use of natural and above all biodegradable plastics.[226]

In addition to the European standard, **DIN 18035-7** also exists in Germany for infill and non-infill artificial turf systems**.** The standard addresses technical and sport-related properties as well as environmental compatibility. Due to the current revision of EN 15330-4, no updates to this standard are currently taking place as this must be harmonized with the overarching European standards. From an expert viewpoint, it thus no longer represents the state of the art.[226] At the very start of the standard, only two construction methods are listed in the general requirements: a) a combination of asphalt layer and elastic layer, and b) with an elastic base layer (cf. Figure 40).[227] Outside of Germany and Switzerland, however, pitches without an asphalt/elastic layer combination or without an elastic base layer and pitches where the (foamed) elastic layer is applied directly onto the finished grade (leveling layer) or in which elastic layers are not used at all are absolutely also relevant and widespread on the market (e.g. in Scandinavia and the United Kingdom). For elastic layers and elastic base layers, the standard continues to only take into account systems consisting of rubber granulate and binding agent. Foamed elastic layers are not taken into account at all. Tensile strength, elongation at break, and abrasion, among other things, are specified for synthetic fillers. These are parameters that can hardly be complied with for natural infill materials such as

226 Personal communication: D. Schockmann (Genan); May 23, 2021

227 In contrast to this, the representation of the construction methods in the annex is characterized as "informative".

cork, recycled material, or future biodegradable infill materials or cannot be measured using established measuring methods. Nevertheless, the application of these values is also recommended for alternative infill materials in the standard. In particular, the specification of tensile strength and elongation at break tends to be superfluous, as the system properties of the overall artificial turf system with regard to ball rebound, ball rolling behavior, force reduction, and rotational resistance are what matter and these may be achievable with very different combinations of materials.

The representation of designs in the standard described above may actually only have an informative character, but it is often used as an exclusion criterion for procurement in practice. A design with a combined asphalt/elastic layer or with an elastic base layer, and the selection of infill materials have a great influence on the release of hazardous substances and microplastics as well as the carbon footprint (cf. Chapter 8 and 13). As a result, the standard prevents potentially more environmentally friendly solutions. In DIN 820-2_2020-03, which governs the creation of standards as a meta-standard, it is explicitly demanded that requirements, whenever possible, need to be expressed with the help of performance characteristics rather than with design or descriptive characteristics.[228] If reference is made to DIN 18035-7 in procurement procedures, it should be stated explicitly in the announcement that, where designs are described in the standard, these are not used as an assessment benchmark. Otherwise, it is not ensured that the most cost-effective and most environmentally compatible solution according to the state of the art can be offered.

In relation to environmental compatibility, the standard stipulates analyses of the seepage water. The recommendation for the values to be complied with is based on the test values stipulated in Annex 2 of the German Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV) for the soil-groundwater exposure pathway. According to the standard, phthalates and chlorinated paraffins should be determined, but no limit values are stipulated. For polycyclic aromatic hydrocarbons (PAHs), which are often a reason why artificial turf systems are criticized, no specifications have so far been made (so as to not contradict a planned supplement to the EU REACH directive). Volatile hazardous substances are also not quantitatively determined, but instead the standard requires information about odors. There are so far no specifications for microplastic emissions.

In general, this raises the question of whether it is sufficient to exclusively make an assessment on the basis of eluate analyses. The artificial turf system is sometimes used in an open environment for decades. According to the current state of knowledge and the investigations and inspections carried out within this study, losses of microplastics (fibers and granulate) are commonplace and an incomplete recovery of the elastic base layer cannot be ruled out. In addition to or as an alternative to the concentrations in seepage water, the total content of the installed system could thus be taken into consideration, as is the case when spreading materials onto soil. This would better satisfy the precautionary principle.[229] This could also take into account any increasing release due to intensified weathering of the polymer binding agents at the end of the service life or during a second utilization phase [230], or the application of new material[231].

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228 Email from L. Bornmann, Deutsches Institut für Normung DIN e. V. from December 9, 2020

229 The precautionary principle can be found in Art. 191 AEUV and was introduced into European law by the Maastricht Treaty. The EU Chemicals Policy states in Regulation (EC) No. 1907/2006 (REACH Regulation) in Art. 1 (Aim and Scope) that the provisions of the REACH Regulation are underpinned by the precautionary principle.

230 Kalbe 2013.

231 Kalbe et al. 2016.

14.2 RAL quality mark RAL-GZ 944

In addition to the aforementioned standards, there is also the quality mark **RAL-GZ 944 (05/2018).** The purpose of determining quality is to demonstrate the quality, environmental compatibility, and professional manufacture of modules, the creation of artificial turf systems, and the maintenance of artificial turf surfaces by means of an initial test. Continuous assurance should take place using continuous self-monitoring measures and regular annual external monitoring. Quality mark 944 primarily summarizes the requirements of the European and German standards. Particularly in reference to environmental compatibility, the quality criteria replicate the recommendations according to DIN 18035-7.

In 2017, the RAL Quality Assurance Associations announced that it would immediately add a mandatory PAH analysis as part of quality assurance in view of the ECHA activities on polycyclic aromatic hydrocarbons in infill granulate[232]. As a target criterion, a limit value of 20 milligrams per kilogram is specified as a cumulative parameter for 8 particularly relevant PAHs.[233] The requirements are thus, for instance, higher than those for toys (100 milligrams per kilogram), which are specified in Directive 2009/48/EC. However, the latter are criticized by the German Environment Agency as requiring correction. In addition, the announced update was not included in the revision of the quality criteria in 05/2018. As the restriction on PAH content according to the restriction proposal of ECHA has so far not entered into force, a regulatory gap exists.[234] Further investigations into environmental effects are not provided in the quality mark. There are no particular requirements for the EoL (end of life), especially for the recycling or at least the recycling capability of artificial turf, in the quality criteria. They should, however, be taken into account as part of a revision of the quality mark in the future.[235]

In relation to abrasion and weathering, the RAL quality mark includes tests that go beyond the requirements in the standards. What is known as the Lisport test, an abrasion test for artificial turf, which is also described in a European standard (EN 15306), is used to simulate play-related abrasion. During the test, the artificial turf undergoes rolling stress using a roller fitted with studs.[236] However, transfer functions between the tests and laboratory conditions and real abrasion behavior are currently lacking. Long-term field studies are required for this. As a result, although a comparative assessment of various artificial turf carpets is possible, it is difficult to forecast the abrasion that occurs in practice. A more realistic test (Lisport XL) is currently being introduced and should also become part of standards. Whether the test only makes the abrasion test faster and more realistic or whether transfer functions relating to the prediction of service life will also be developed is as yet unknown.[237] In addition, the influence of contact diffusion on aging for infill artificial turf systems is investigated via simulated sun exposure before the Lisport test is carried out. It is hoped that this will provide information about negative interactions between fibers and infill materials.

All in all, the first and repeat tests, in particular, are organized as part of the RAL quality mark 944. The quality mark goes slightly beyond the requirements of both standards. The key benefits

232 https://echa.europa.eu/de/hot-topics/granules-mulches-on-pitches-playgrounds; last accessed: July 22, 2021

233 https://www.ral-ggk.eu/en/news-2/49-news/199-aktuelle-informationen-zu-moeglichen-gesundheitsrisiken-auf-kunstrasenplaetzen-in-sportfreianlagen.html; last accessed: April 14, 2021

234 https://echa.europa.eu/de/hot-topics/granules-mulches-on-pitches-playgrounds; last accessed: July 22, 2021

235 Personal communication: D. Schockmann, Genan; May 3, 2021

236 https://labosport.com/reference/lisport-xl-designed-by-labosport last accessed April 16, 2021

237 https://labosport.com/innovation/lisport-xl; last accessed: July 22, 2021

of the quality mark lie in continuous external monitoring that makes sure that assured product properties are also actually implemented. RAL's self-imposed demand to represent particularly high quality ("far-reaching promise of quality") and allow current requirements to flow into quality assurance is only beginning to become apparent in the case of artificial turf systems.[238] However, initial considerations are currently taking place concerning an environmental label (Blue Angel) that could offer a solution here.

14.3 BASPO recommendations

Recommendations on artificial turf systems are issued in Switzerland by the Federal Office for Sport. Recommendations on environmental compatibility are summarized in the document **BASPO 112**, which was published in 2008. In general, no environmental risk is expected due to artificial turf. The infill losses are viewed in relation to tire and road wear particles and characterized as unproblematic. As regards polyurethane as a binding agent for elastic layers and elastic base layers and as a coating for end-of-life tire granulate, the reduction of mercury content over recent decades is considered to be a sufficient improvement. The authors consider the use of tire granulate to be acceptable with continuous monitoring for hazardous substances. In addition, certain materials, such as cadmium or lead, are completely excluded as constituents of artificial turf systems. However, as these metals are associated with other metals (such as zinc), they cannot be completely ruled out, especially when end-of-life tire granulate is used as part of the elastic layer or as a filling material. Instead, limit values can be specified. Infill granulates made from halogenated elastomers (fluorinated rubber and chloroprene rubber) are explicitly ruled out. In a lysimeter test series on various artificial turf systems, which was conducted in Bern from 2006 to 2008 (**BASPO 113**), a critical concentration could not be determined in any of the examined systems. BASPO, therefore, recommends completely dispensing with eluate tests and instead establishing simple decision-making aids for the selection of systems or materials.

14.4 FIFA Quality Programme

The **FIFA Quality Programme**[239] above all focuses on the suitability of artificial turf systems for playing soccer. Sport-related properties take priority here. FIFA and UEFA soccer matches require mandatory certification of the pitches according to this program. A basic requirement here is that the manufacturer of the pitch has been licensed by FIFA. FIFA also indicates preferred manufacturers. FIFA has accredited suitable institutions to conduct testing. Tests on the pull-out force of the artificial turf fibers from the coated carpet backing and the change in breaking force following artificial aging of the fibers are environmentally relevant in the standards. In this way, specifications concerning the reduction of fiber losses are also made indirectly. To what extent specifications on infill splash affect granulate losses is unclear.[240] Regular repeat tests serve to monitor the free pile height, the infill height, and the status of measures to prevent infill losses for information purposes (so far without any specification of target values). The measures for avoiding infill are based on the technical report from CEN (cf. following chapter). Implementing provisions, as in the German DIN, are not included in the FIFA Quality Programme in relation to the damping layer. However, non-infill systems are not considered at all within the FIFA Quality Programme, meaning

238 https://www.ral-guetezeichen.de/; last accessed: April 13, 2021

239 FIFA 2018.

240 It is generally expected that low infill mobility and thus a lower splash value reduces granulate losses. It is, however, conceivable that, with low splash values, fallback within the carpet fibers is prevented and so granulate would leave the artificial turf pitch more easily.

that these systems cannot fulfill the corresponding standard. Greater system openness would be desirable here.

14.5 Technical report on how to minimize infill dispersion CEN/TR 17519

The European Committee for Standardization published technical report **CEN/TR 17519** to minimize infill dispersion at the end of 2020.[241] On the basis of this report, the European Chemicals Agency ECHA asked the Committee for Risk Assessment (RAC) to review and, if necessary, revise its statement on the restriction proposal, which stipulates a ban on placing infill on the market after a transitional period of six years.[242] In the minutes for the relevant RAC meeting, it is noted that, in the submitted technical report, supplemented with a current study on the efficiency of measures by Magnusson et al.[243], no reason is seen to change the previous restriction proposal, which stipulates a ban on placing infill on the market after a six-year transitional period.[244] The CEN report, which essentially agrees with the requirements from the FIFA Quality Programme from 2020, addresses the problem of infill granulate, motivated by the recommended restriction on bringing infill granulate onto the market by the European Chemicals Agency ECHA. Plastic emissions in the form of secondary macroplastics and microplastics (e.g. due to abrasion, weathering of fibers, and a conceivable incomplete recovery of elastic layers or elastic base layers), which are not addressed by ECHA, are also not looked at in the technical report.

Optimizing fiber density and fiber type is seen as a way of better fixing the reduction of infill losses. However, it is currently unclear as to whether a greater fiber density following infill splash (resuspension of granulate due to playing) may even prevent the infill from falling back into the artificial turf carpet and the infill may actually display greater mobility until the next maintenance interval. Snapped fibers and pitches compacted by playing could exacerbate this effect. An infill splash of 1.5 percent is recommended in the technical report. This corresponds to the established standard for FIFA Quality Pro artificial turf pitches.[245] The use of shock pads, which allow lower artificial turf heights and thus a lower infill content, is also cited in the technical report. It is, however, unclear and in dispute to date whether the total amount of infill on the pitch, the surface, or the infill mobility of an artificial turf pitch determine infill discharge (analogy with evaporation). The technical report provides individual indicators regarding the effectiveness of shock pads against infill discharge ("anecdotal evidence").

The infill shape and proportion of particulate matter are relevant parameters for infill losses. Aspects such as low density or a specific surface, which particularly promote mobility via water and wind, are not discussed. Fine particular matter should be reduced in the infill granulate. What requirements are in place to reduce weathering and abrasion and thus the continuous development of new fine particulate matter over the long service life remains unclear.

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241 https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT,FSP_ORG_ID:70580,6198&cs=13A5071A2FBA0B20C87852C3572E4230A; last accessed: September 23, 2021

242 https://echa.europa.eu/documents/10162/13579/rac_mandate_follow_up_microplastics_en.pdf/c3a72330-8eca-3872-49ed-d10ea1a74843; last accessed: April 14, 2021

243 Magnusson et al. 2020.

244 5618cedf-c4b2-becf-968d-bf7a5a1493c8 (europa.eu); last accessed: July 23, 2021

245 https://football-technology.fifa.com/en/media-tiles/football-turf-handbook-of-requirements-2015/

The installation of filter systems in surrounding pitch irrigation systems is suggested as a specific measure. In addition, suggestions are made for board systems that connect directly to the artificial turf pitch or the surrounding paths. Corresponding solutions are certainly sensible, but here, too, there have not yet been any investigations that confirm the suitability of the 200 to 500-millimeter heights suggested in the technical report. Extensive entrance matting and shoe cleaning areas are provided for the entrance areas. It will be challenging to implement these solutions for pitches that are accessible to the general public.

In addition, maintenance practices such as cleaning and snow clearance are also mentioned. The use of leaf blowers, which are often recommended and used for cleaning, is assessed critically in the report. With regard to snow clearance, it is stated that complete snow clearance should be avoided where possible. At least 5 to 10 millimeters should remain on the artificial turf. This means that it will only be possible to play in the event of snow if the remaining covering of snow is melted by sufficiently high ambient temperatures or pitch heating. In other cases, the cleared snow should always remain within the boards and the granulate transported back onto the pitch after melting.

The technical measures for designing the pitch environment suggested in the technical report by Committee 217 of the European Committee for Standardization appear sensible as a first suggestion. However, requirements concerning reliable discharge rates and their verifiability should also be added in the future. In addition, the report's expansion to non-intentional plastic emissions would be recommended as a foresighted measure.

15 How great is the need for artificial turf pitches?

"Hard pitches are no longer considered in keeping with the times by clubs and players and have thus been converted into natural or artificial turf pitches for quite a long time.

Artificial turf pitches thus enable team sports to be available throughout the year, particularly in densely populated cities and/or in cities with high land prices."

The continuing trends towards individualization in society lead us to expect that self-organized sport will continue to record strong growth rates in the future. In view of this and to improve the sports available to recreational sportspeople, especially for families and children, additional exercise areas have been created outside of classic sports facilities for years, which encourage citizens to participate in sport with relevant offers. This is also reflected in the number of members: For many clubs, member numbers for non-profit sport are stagnating, while, at the same time, the number of memberships for commercial sports providers is continuously increasing, especially in conurbations. Nevertheless, the public interest functions of non-profit sport in clubs continue to be undisputed.[246] This is also reflected in the still high numbers of clubs and members (Table 16).

Table 16: Use, needs analysis: Numbers of clubs in Germany and Switzerland

Sport	Country	Clubs	Members	Teams	Matches/games
Soccer	D	25,544	7,131,936	149,735	1.45 million
	S	1,440	281,521	14,593	
Tennis	D	8,946	1,370,801	Usually individual	
	S	900	165,000	Usually individual	330,000
Rugby	D	137	16,500		
	S	47	4750	72	470
Hockey	D	376	85,950		
	S	22	1773	111	388
Riding	D	6,963	682,348	Usually individual	68,000
	S	568	39,275	Usually individual	5515
Golf	D	852	642,240	460	460
	S	96	89,579		

The altered demand structure for sporting activities in combination with demographic changes has also caused the sporting infrastructure to be adjusted and modernized in many cities. In municipalities with a tight budget, a reduction in sports pitches with simultaneous optimization of sports facility provision has been observed in recent years. A similar trend can be identified in eco-

[246] Non-profit status is legally defined in Germany in Section 52 (1) of the Fiscal Code of Germany (AO). It states: "A corporation shall serve public-benefit purposes if its activity is dedicated to the altruistic advancement of the general public in material, spiritual or moral respects."

nomically prospering cities, although not primarily from a budgetary perspective, but also triggered by pressure to develop new residential space at former sports facilities and also cater to new demands on space, including those resulting from individual and trend sports.

For more than a decade, it is under these conditions that assessments have been made regarding the extent to which it makes sense to close, relocate, or convert artificial turf pitches, especially for hard pitches that are due for restoration. In comparison with older sports facilities, modern sports facilities with an artificial turf surface can cover greater capacities and allow for a greater intensity of use. Clubs that previously played on their own pitches have thus often been brought together at a new pitch equipped with artificial turf. The advantages of artificial turf were already recognized by the DFB[247] 15 years ago, for example, in the fact that artificial turf pitches impress with

- Their highly stimulative nature
- High usage intensity
- Low maintenance requirements compared to other surfaces
- Consistent playing properties across the entire pitch
- Use largely throughout the year, regardless of the weather conditions (no problem during alternating freeze/thaw periods and periods of heavy rain, and thus minimization of canceled matches, pitch closures, and training restrictions)
- Hardly any soiling of sports clothing
- Increase in attractiveness through multifunctional use.

A comparatively high intensity of use can be achieved on artificial turf pitches, regardless of local climatic conditions, exceeding the utilization times of natural turf surfaces by a factor of 2-3. As a result, the space needed to perform sport can be reduced elsewhere. Creating artificial turf pitches thus opens up the possibility of recycling space as, by constructing the artificial turf pitches, areas previously used as natural turf playing fields are freed up for other ecologically higher-value uses.

These advantages and the reduced risks of accidents and injuries, above all in comparison with the old hard pitches, led to a boom in artificial turf pitches in many countries in combination with urban development framework conditions. The development described above and the associated abandonment or conversion of pitches is at an advanced stage in many places. So, do we need artificial turf? The contexts described above show that, in most municipalities, this question has already been answered with "yes". Without artificial turf, the developments would not have been possible or have taken place in this form. The high number of hours of use per year appears to have been an especially crucial factor.

At present, more and more municipalities are asking themselves whether older artificial turf pitches should be renewed or natural turf pitches converted into artificial turf pitches in order to develop further inner-city space. However, the latter often meets with displeasure from local residents. In some municipalities, there are also countertendencies within administration[248] and at a

247 DFB 2006

248 Verbal communication from the municipalities involved in the study

political level[249], which aim to counteract a further increase in artificial turf locations. If no restriction in club sports is to be expected, at least the conversion of artificial into natural turf space should be investigated due to ecological (cf. Chapter 10) and urban climatic benefits.

[249] Numerous public statements documented, as an example: www.westfalen-blatt.de/owl/kreis-minden-luebbecke/luebbecke/kunstrasen-grune-wollen-mikroplastik-verhindern-1104567

16 What do the users say?

"Both active and former soccer players are involved in the debate surrounding the relevance and environmental effects of artificial turf pitches. Artificial turf plays a key role in the everyday reality of many people and makes it possible for them to play their sport outside throughout the year.

Rubber granulate is still the preferred infill type, yet players still consider cork and non-infill pitches to be alternatives. In general, the majority of those surveyed expect that artificial turf pitches will become more environmentally friendly."

A survey of soccer players was carried out as part of the study. A total of 105 active or former players took part in the survey. The former players dominate among the over-30-year-olds, most 19-to-30-year-olds play 3 to 6 hours a week, most of those up to 18 years of age even play 6 to 9 hours a week (Figure 41). Unsurprisingly, soccer is above all the sport of youth and growing up. Nevertheless, debates in soccer are also determined by former players, who continue to feel connected to the sport.

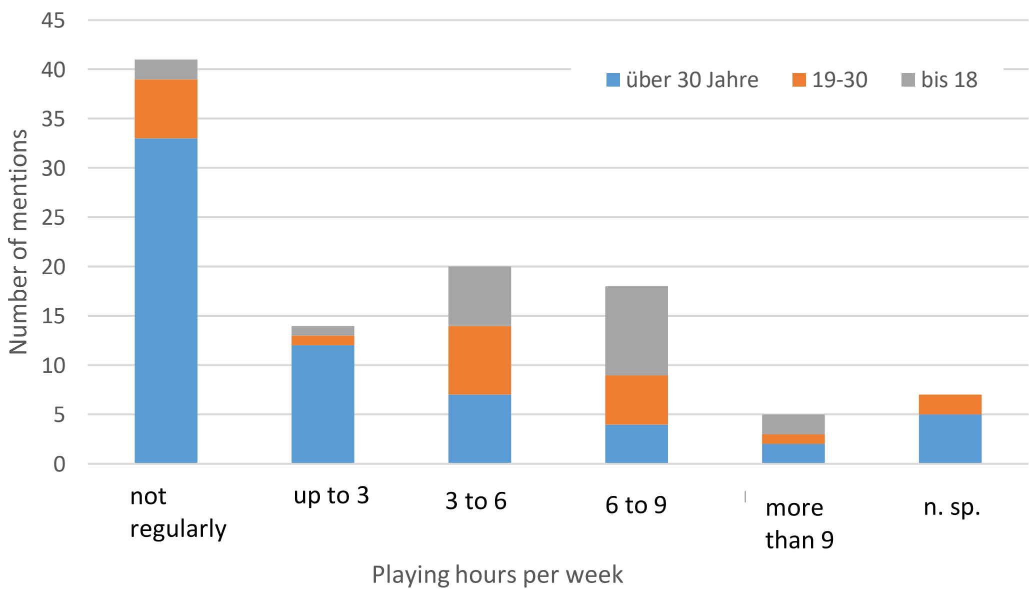

Figure 41: Frequency of activity level (playing hours per week) based on age (n = 95)

One astounding result of the survey is the degree of indispensability assigned to the various microplastic-emitting activities (Figure 42). It transpired here that artificial turf (2.69) is rated by active or former soccer players as considerably more indispensable than cosmetics (4.07) and particularly also fleece clothing (3.60), and somewhat less indispensable than driving a car (1.97). For those who play more than 9 hours a week, artificial turf was equally as indispensable as driving a car. The small difference compared to driving a car shows the high relevance that artificial turf pitches have in the everyday realities of the respondents. Players who are no longer active – i.e. predominantly the group of over-30-year-olds – tend to be able to imagine doing without artificial turf. Astoundingly, however, they can also imagine doing without in all other activities.

In response to the question of what the players would prefer if a natural turf pitch could not be played on in winter, not playing was only an option for around 3 percent and only around 7 percent could imagine playing in a hall. In contrast, over 90 percent gave a clear preference to artificial turf. "Playing through" regardless of the weather is clearly part of the self-image of the soccer players, meaning that it is one of the few sports that can be played outside all year round if artificial turf is available.

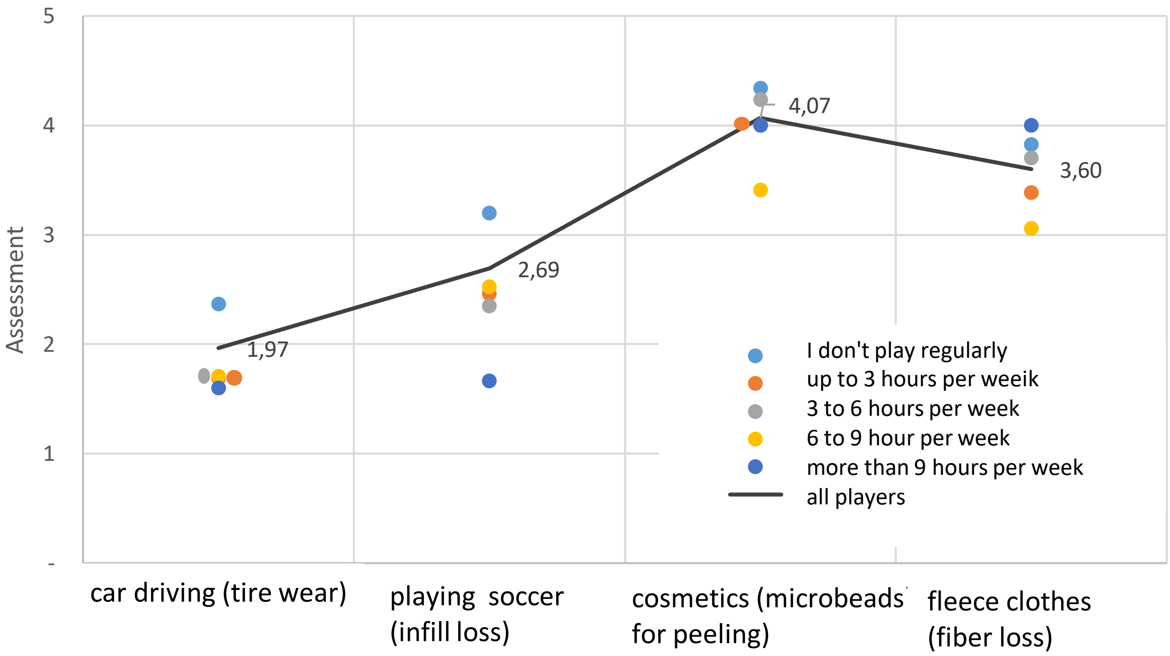

Figure 42: Assessment of indispensability for certain activities (1 = indispensable, 5 = easily expendable; n = 87)

The opinion of the respondents on the preferred infill type is relatively balanced (Figure 43). Overall, there is a slight preference for rubber granulate (28 percent), but cork+sand (13 percent) or non-infill artificial turf (20 percent) is also considered an alternative for the players. Nevertheless, the undecided group represents the largest at 29 percent. This shows that rubber granulate is preferred as infill, but is not without alternatives. If the data is differentiated according to the activity level of the players, the preference for rubber granulate among active players becomes somewhat clearer (29 to 41 percent), yet here, too, the alternatives hold significant shares. It can thus be assumed that both cork and non-infill artificial turf would be accepted by the players. However, there is no acceptance for pitches only filled with sand.

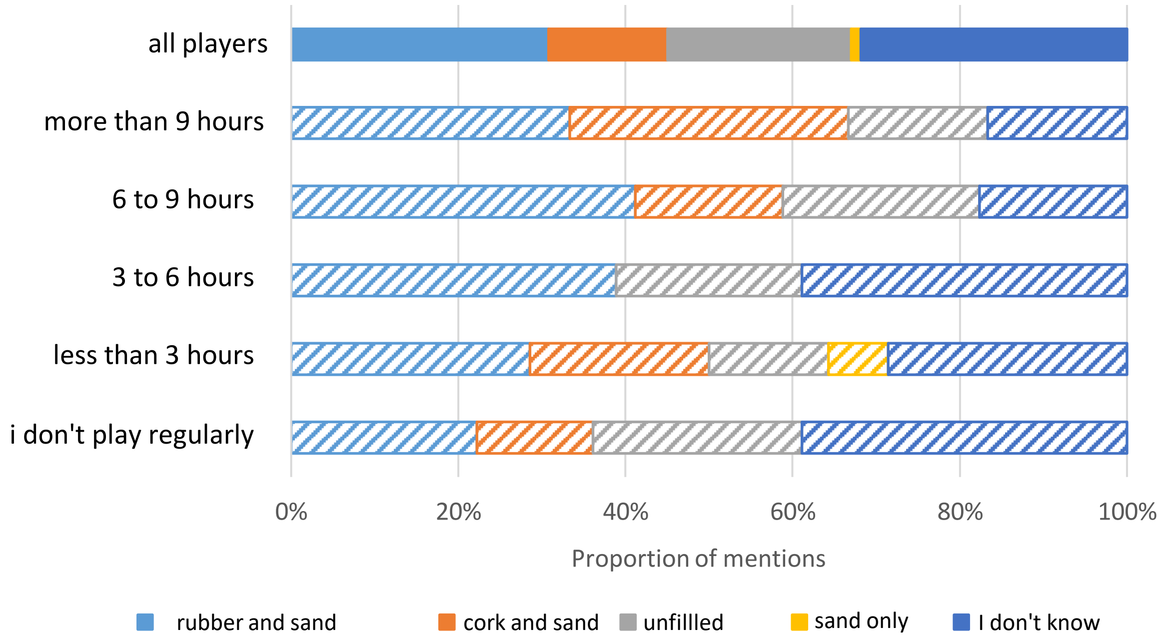

Figure 43: Preferred infill type of the players, taking into account their activity level (n = 91)

Even if artificial turf is rated as indispensable to a high degree by the respondents and the rubber granulate is currently the preferred type, this does not mean that ecological issues are not important to the players (Figure 44). Over 57 percent of respondents support the statement that artificial turf pitches must become more environmentally friendly, only around 2 percent actually speak in favor of a ban. Only the group of people up to 18 years of age agrees more strongly with the statement that artificial turf is not a relevant problem than with the statement that it needs to become more environmentally friendly.

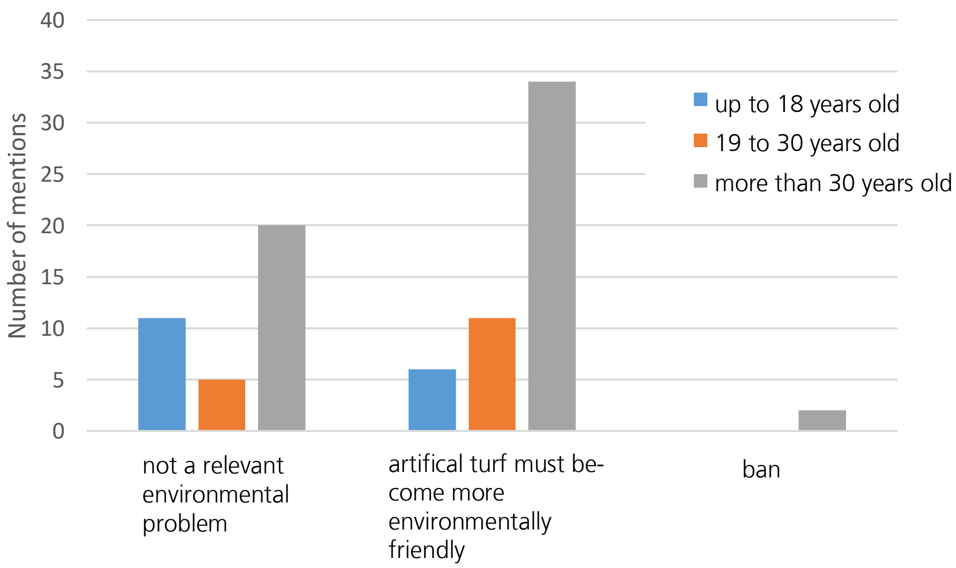

Figure 44: Frequency of mentions in the ecological assessment of artificial turf taking into account age (n = 89)

17 List of figures

18 List of tables

19 List of abbreviations

ADMET	Absorption, distribution, metabolism, extraction, toxicity
AfPS	Product Safety Commission
CEN	European Committee for Standardization
CL	Chlorine and chlorine compounds
DFB	German Football Association
DMI	Digital landscape model
DTI	Danish Technological Institute
ECHA	European Chemicals Agency
EWL	Elastic wearing layer
ELT	End-of-life tire
EPD	Environmental Product Declaration
EPDM	Ethylene Propylene Diene Monomer
ESTO	European Synthetic Turf Organization
EL	Elastic layer/shock pad
FIFA	Fédération Internationale de Football
GFRP	Glass fiber-reinforced plastic
GWI	Global warming impact
HALS	Hindered amine light stabilizers
HDI	Hexamethylene-1,6-diisocyanate
HM	Heavy metals
Iso	Isocyanates, diisocyanates, and isocyanate compounds
IVL	Swedish Environmental Research Institute
ATP	Artificial turf pitch
LCA	Life-cycle assessment
MAC	Maximum allowable concentration
MDI	Methylene diphenyl diisocyanate
NDVI	Normalized difference vegetation index
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyl
PE	Polyethylene
PFAS	Perfluoroalkyl and polyfluoroalkyl substances
PLA	Polylactic acid

PM	Particulate matter
PP	Polypropylene
PUR	Polyurethane
REACH	European chemicals regulation
recPE	Recycled polyethylene
RPU	Rigid polyurethane
SBR	Styrene-butadiene rubber
SVHC	Substances of very high concern
SVOC	Semi-volatile organic compounds
TDI	Toluene-2,4-diisocyanate
GHG	Greenhouse gas
TPE	Thermoplastic elastomers
VOC	volatile organic compounds

20 Glossary

Artificial turf pitch (ATP)	An artificial turf pitch made from synthetic materials with synthetic grass fibers, with or without infill and a substructure for various applications (generally sporting applications).
Artificial turf system	Overall system of an artificial turf pitch usually consisting of artificial turf (fibers and backing), the infill (optional), a substructure (elastic layer/elastic base layer), and, where applicable, a drainage system.
Artificial turf	Generally the colloquial term for the entire artificial turf system. Sometimes the complete system and sometimes only the visible part of the overall system (artificial turf carpet) is referred to as artificial turf. Within this study, the term is used as a synonym for the term artificial turf carpet.
Artificial turf carpet	Consisting of artificial grass fibers, fixed and glued to a backing.
Infill	Filling material filled/brushed into the artificial turf to achieve certain properties. This is usually sand, an elastomer, a thermoplastic elastomer, or a natural substance.
Performance infill	Infill material that determines the safety-relevant properties of the artificial turf. Usually an elastomer, a thermoplastic elastomer, or a natural substance.
Stabilizing infill	Infill material filled/brushed into the artificial turf to stabilize the artificial grass fibers. It is usually sand, an elastomer, a thermoplastic elastomer, or a natural substance.
Artificial turf fiber	Plastic fibers, usually made from PE or PP and various additives, which are intended to imitate natural grass fibers. Various fiber cross-section geometries and fibrillations are used.
Artificial turf backing	Backing fabric to which the artificial turf fibers are attached.
Substructure	Soil structure/layer structure underneath the laid artificial turf carpet.
Elastic layer	Damping layer below the artificial turf carpet, usually consisting of plastic granulate and a binding agent or polyethylene foam.
Shock pad	The international name for the elastic layer.
Elastic base layer	Damping layer below the artificial turf carpet consisting of plastic granulate, a binding agent, and mineral aggregates.
Leveling layer	Finished grade of the foundation.
Asphalt layer	A layer of asphalt below the elastic layer.
Base layer	Prepared mineral layer below the elastic layer/asphalt layer/elastic base layer.

Subgrade	Even surface for the installation of the elastic layer/asphalt layer/elastic base layer.
Pile height	Measured length of the artificial grass fibers above the backing.
Free pile height	Measured protrusion of the artificial grass fibers above the infill.

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22 Annex

22.1 Note about the methods

Table 17: Methods applied in the chapters with specification

Chapter	Method	Specification of data source or measuring instrument
Chapter 3		
Structure of artificial turf systems	Literature and Internet sources, standards	Fraunhofer eLib, Scopus, Google Scholar, Beuth-Verlag, Fraunhofer handouts
	Information about the examined pitches	Documentation and tendering documents handed over by the clients
Maintenance and upkeep	Interviews and pitch inspection	Survey of pitch operators and groundskeepers as part of the pitch inspection; recording of the collected data (→ Chapter 22.2 Inspection report)
Use and service life	Literature and Internet sources	Fraunhofer eLib, Scopus, Google Scholar Information on annual hours of use by the clients
Chapter 4		
Designing of pitch surroundings	Pitch inspections and photo documentation of 20 pitches Recording of the collected data (→ Chapter 22.2 Inspection report)	June 30, 2020, artificial turf pitches in Germany: Hanover and Braunschweig August 24-26, 2020 artificial turf pitches in Switzerland: Aarau, Bern, Chur, St. Gallen, Winterthur, Zurich
Drainage of artificial turf pitches	Pitch inspections and photo documentation of 20 pitches Interviews with pitch operators Recording of the collected data (→ Chapter 22.2 Inspection report)	June 30, 2020, artificial turf pitches in Germany: Hanover and Braunschweig August 24-26, 2020 artificial turf pitches in Switzerland: Aarau, Bern, Chur, St. Gallen, Winterthur, Zurich
Chapter 5		
Geographical integration of ATP	Method: Determination of the vegetation index NDVI and the red values from spectral data Data: ATKIS Basis-DLM, spectral bands from Sentinel-2	Geographical analysis with geographic information system ArcGIS Pro
Distances from bodies of water	ATKIS Basis-DLM	Geographical analysis with geographic information system ArcGIS Pro
Chapter 6		
Profitability	Literature and Internet sources; data from the municipalities involved	Documentation handed over by the clients
Chapter 7		
Quantity of infill on the pitches	Suction of infill at 5 sampling points (cf. Figure 17)	Kärcher industrial vacuum cleaner
	Drying until weight constancy achieved	ED400 drying chamber, Binder; determination of dry matter according to DIN EN 14346

	Determination of density	Helium pycnometry in accordance with DIN 66137-2
	Separation of performance infill, separation of quartz sand and dirt Comparison with literature and product data	AS200 analysis sieving machine, Retsch; sieve analysis according to DIN 66165-2
	Calculation of the masses and the proportion of performance infill and sand for each measuring point Determination of a weighted mean for each pitch	$\frac{m_{Gummi}}{m_{gesamt}} = \frac{1/\rho_{gesamt} - 1/\rho_{Sand}}{1/\rho_{Gummi} - 1/\rho_{Sand}}$
	Determination of correlation and significance with age	Correlation: r value according to Pearson Significance: p value according to Fisher
Accumulation of infill	Comparison of the quantities after completion with the quantities upon measurement	Operator information and awarding documents, documentation of the examined pitches Mass determination: see above
Fragmentation of the infill	Sieve analysis of new and used performance infill, comparison of the mass ratios in the sieve fractions	AS200 analysis sieving machine, Retsch; sieve analysis according to DIN 66165-2
Infill distribution and play-related properties	Comparison of the coefficient of variation (COV = max-min)/mean) of the performance infill quantity at 5 measuring points and the play-related properties at six measuring points for three pitches	Play-related properties from investigation reports on the FIFA Quality Programme for three pitches Mass determination: see above
	Investigation of the correlation between age and COV for the infill quantity	Correlation: r value according to Pearson Significance: p value according to Fisher
Analysis of infill alternatives	Literature evaluation	Fraunhofer eLib, Scopus, Google Scholar, product information from manufacturers
Chapter 8		
Microplastic losses – theoretical	Literature evaluation	Fraunhofer eLib, Scopus, Google Scholar Studies cited by clients and experts
Microplastic losses – experimental	Determination of the total applied quantity of infill (manufacturing and top-up quantity) over the entire duration Determination of the current mass Determination of the difference between the total applied mass and current mass and division by the service life (-annual infill losses)	Operator information and awarding documents, documentation of the examined pitches In-depth survey of the operators, sharing of data by the clients Mass determination: see above
Chapter 9		

Determination of the level of knowledge on fiber losses	Literature evaluation Photo documentation following training units	Fraunhofer eLib, Scopus, Google Scholar Own experience, Till Zimmermann (Ökopol)
Chapter 10		
Identification of discharge routes and accumulation spaces	Pitch inspections and photo documentation of 20 pitches Recording of the collected data (→ Chapter 22.2 Inspection report) Survey of pitch operators, groundskeepers	June 30, 2020, artificial turf pitches in Germany: Hanover and Braunschweig August 24-26, 2020 artificial turf pitches in Switzerland: Aarau, Bern, Chur, St. Gallen, Winterthur, Zurich
	Evaluation of current studies	European studies from Denmark (DTI) and Sweden (IVL)
Creation of own diagram on transfer routes and on infill fate	Based on qualitative observations from the pitch inspections.	
Chapter 11		
Situation regarding hazardous substances	Literature evaluation Compilation of the database	Fraunhofer eLib, Scopus, Google Scholar
Chapter 12		
Situation regarding recycling	Literature evaluation, press releases	Fraunhofer eLib, Scopus, Google Scholar, product information from manufacturers
Chapter 13		
Calculation of the carbon footprint	Literature evaluation to acquire the necessary data	Fraunhofer eLib, Scopus, Google Scholar, product information from manufacturers
	Expert discussions on missing data	Clients, other experts: Oliver Schimmelpfenning, Björn Kuhlmey
	Life-cycle assessment	DIN EN ISO 14040/44 GaBi software and database (Version: 10.5.0.78)
Chapter 14		
Analysis regarding standards	Standard evaluation	Beuth-Verlag, handouts from the Fraunhofer-Gesellschaft, Internet research Expert opinion from DIN e. V. (Lieven Bornmann)
Chapter 15	Literature and Internet sources, surveys	Interviews with representatives from the municipalities involved
Chapter 16		
Player survey	Open online survey of 105 players	Software: Mentimeter Direct contact with players by the authors and clients Advertising via social media (LinkedIn)

22.2 Inspection report

The inspection report was sent to the clients for completion before the pitch inspection. Outstanding issues in the report were discussed and added during the pitch inspection with the pitch operators and other knowledgeable employees. The five-page report contains 7 topic areas: 0) Marginal data, 1) Surroundings, 2) Drainage system, 3) Structure of the artificial turf pitch, 4) Maintenance, 5) Miscellaneous, and 6) Sampling (Fig. 2). The collected data was transferred into an Excel sheet and evaluated together with the analysis data.

Fraunhofer UMSICHT

Protocol for inspecting artificial turf pitches

0 Marginal Data

Location, date, time:

Name and adress of ATP:

Construction year:

New building ( ) Partly new bulding ( ) Redevelopment ( )

ATP generation: 1G ( ) 2G ( ) 3G ( ) 4G ( ) unknown ( )

Standard: EN 15330 ( ) DIN 18035 ( ) None ( )

Costs ATP:

Building-costs:

Total cost:

ATP building company:

ATP delivering company:

ATP dimensions:

Months of use:

Frequency of use (Days of the week and period):

Type & duration of use per week: Soccer ( ) __ h Hockey ( ) ___h Athletics ( ) ___h School sports ( ) ___h Other ( ) ___h ____________ ( ) ___h

Are there hours of unorganized use of sport by the population? Yes ( ) No ( ), if "Yes", ________h/W

Total usage per year: approx. _________h

1 Periphery

ATP enclosure (e.g. fence, wall, etc.): Yes ( ) No ( )

Type of enclosure:

Border: Pavement ( ) Concrete ( ) Gutter ( ) Gully ( ) Running track ( ) tribune ( ) barriers ( ) ___________ ( )

Order of enclosures (viewed from ATP): 1. ___________ 2. ___________ 3. ___________ 4. ___________

Description of the area around the square (trees, open space, river, altitude, etc.):

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22.3 Raw data and operands

Table 18: Infill quantities and top-up quantities on the pitches

Pitch code	D		F		C		E		G		Q		H		I		J		K		A		B		L		M		N		O	
Playing hours per year	2,420		1920		1920		2420		2150		1650		1584		1,580		2000		2500		1600		1080		1800		2000		2000		2000	
Type designation	Fieldturf 360 XL 42-17		Limonta Qualifloor Soccerpro MaX S 40		Fieldturf 360 42-20		Polytan LigaTurf 240 RS+ 22/4		Field Turf 360 XL 42-14		Greenfields REAL FT V-slide nf		Greenfields REAL FT 40 Slide pro xt		Polytan Liga Turf RS+ 240 22/4		Fieldturf Core 42/17 FG/OG		Greenfields REAL FT 46 V - Slide		Fieldturf Tarkett SAS		Domo Sports Grass		Limonta Sport		Polytan		JUTA		Polytan Liga Turf RS+ CoolPlus	
Fiber type	Monofilament straight		straight						Monofilament with cladded yarn		Monofilament PE straight/V and PA crimped		Monofilament, straight				Monofilament										straight		straight		Monofilament, straight	
Fiber weight									1338		2970		1010		1365		1550														*1000*	
Pile height	42		42		42		40		42		32		40		40		42				45		42		40		40		40		40	
Pile protrusion	14		13		12						32		16		15				straight				13		13		11		11		11	
Infill			17	Granulate							0	none		Granulate	15	Granulate							15		15							
Size (gross) [sqm]	7,420		7,420		7,420		7,420		7,420		7,420		7,579		7,420		12,700		7,508		7,208		4,716		7,420		4,930		5,860		5,640	
	Sand	TPE green	Sand	TPE green	Sand	SBR+PU	Sand	?	Sand	EPDM	Non-infill		Sand	EPDM green	Sand	EPDM green	Sand	EPDM gr/br	Sand	RPU	Sand	EPDM brown/green	Sand	TPE green	Sand	EPDM green	Sand	EPDM green	Sand	EPDM green	Sand	Cork
2005																																
2006																																
2007																																
2008																																
2009							15	9.5											15	8.5												
2010								2																								
2011								2																					25	5		
2012								2												8			25	7.0						0.75		
2013			11.5	8.5				2					14.7	9.63	18	9.75				0.2	18.75	6.8		0.5			25	5		0.75		
2014				0	11.5	8.5		2						1.75		1.75				0.2		1.75		0.5				0.75		0.75		
2015				11		10.8		2						1.75		1.75				0.2		1.75		0.5				0.75		0.75		
2016	16.2	15.3		0		0		2						1.75		1.75				0.2		1.75		0.5				0.75		0.75		
2017		0		12.5		8.75		2						1.75		1.75				0.2		1.75		0.5				0.75		0.75		
2018		7.25		7		7.2		30	19.6	8.1				1.75		1.75	20.7	6.3		11.3		1.75		0.5	18	8		0.75		0.75		
2019		2.5	20	10	27	5		5		2.64				1.75		1.75		6.35		0.05		1.75		0.5		4		0.75		0.75	25	2
2020														1.75		1.75		0.05		0.05		1.75		0.5		12.5		0.75		0.75		0.25
2021																																
[kg/sqm]	16.2	15.3	11.5	8.5	11.5	8.5	15	9.5	19.6	8.1			14.7	9.63	18	9.75	20.7	6.3	15	8.5	18.75	6.8	25	7.0	18	8	25	5	25	5	25	2
[t/pitch]	120.2	113.5	85.3	63.1	85.3	63.1	111.3	70.5	145.4	60.1			111.4	73.0	133.6	72.3	262.9	80.0	112.6	63.8	135.2	49.0	117.9	33.0	133.6	59.4	123.3	24.7	146.5	29.3	141.0	11.3
[kg/sqm]	16.2	16.61	14.2	14.0	15.1	12.8	15.0	16.4		8.5			14.7	11.2	18.0	11.4	20.7	6.8	15.0	11.2	18.8	8.50	25.0	7.85	18.0	10.2	25.0	6.1	25.0	6.2	25.0	2.0
[t/pitch]	120.2	123.3	105.3	103.6	112.3	94.8	111.3	121.5		62.7			111.4	85.2	133.6	84.6	262.9	86.4	112.6	84.2	135.2	61.26	117.9	37.0	133.6	75.9	123.3	29.9	146.5	36.1	141.0	11.3
[kg/sqm]	12.96	11.16	10.96	12.28	11.55	6.15	9.42	7.15	12.93	8.06			4.90	10.83	9.07	8.27	15.62	6.83	0.89	5.48	13.27	6.71	10.91	7.03	15.81	10.04	30.88	3.52	19.85	5.27	23.30	1.23
[t/pitch]	96.13	82.81	81.35	91.14	85.74	45.64	69.87	53.04	95.94	59.79			37.17	82.26	67.30	61.34	198.34	86.75	6.71	41.12	95.64	48.36	51.45	33.16	117.33	74.52	152.22	17.37	116.30	30.87	131.41	6.95
[kg/sqm]	3.24	5.45	3.23	1.68	3.58	6.63	5.58	9.22	-12.93	0.40			9.80	0.39	8.93	3.13	5.08	-0.03	14.11	5.74	5.48	1.79	14.09	0.82	2.19	0.18	-5.88	2.54	5.15	0.88	1.70	0.81
[t/pitch]	24.08	40.46	23.98	12.43	26.59	49.18	41.43	68.45	-95.94	2.95			74.24	2.97	66.26	23.26	64.55	-0.34	105.91	43.10	39.51	12.90	66.45	3.85	16.23	1.34	-28.97	12.53	30.20	5.18	9.59	4.58
[kg/sqm]	0.81	1.36	0.46	0.24	0.60	1.10	0.51	0.84	-1.18	0.04			1.40	0.06	1.12	0.45	0.64	0.00	1.76	0.82	0.78	0.26	1.76	0.10	0.27	0.02	0.65	0.28	0.57	0.10	0.19	0.09
[t/pitch]	**6.02**	**10.12**	**3.43**	**1.78**	**4.43**	**8.20**	**3.77**	**6.22**	**-8.72**	**0.27**			**10.61**	**0.42**	9.47	**3.32**	9.22	**-0.05**	15.13	**6.16**	**5.64**	**1.84**	**8.31**	**0.48**	**2.03**	**0.17**	**-3.22**	**1.39**	**3.36**	**0.58**	**4.79**	**2.29**
[t/a]	**6.02**	**10.12**	**3.43**	**1.78**	**4.43**	**8.20**	**3.77**	**6.22**	**-8.72**	**0.27**	**0.00**	**0.00**	**10.61**	**0.42**	**9.47**	**3.32**	**9.22**	**-0.05**	**15.13**	**6.16**	**5.64**	**1.84**	**8.31**	**0.48**	**2.03**	**0.17**	**-3.22**	**1.39**	**3.36**	**0.58**	**4.79**	**2.29**

Table 19: Infill masses and composition at the measuring points

	Total mass [g]				
Pitch code	Box	Center	Corner	Center of side	Goal
A	908.60	892.10	789.90	1207.70	762.90
B	1156.65	485.54	908.70	1096.61	264.20
C	977.20	962.90	571.60	692.90	1004.20
D	1259.88	1094.45	1316.90	1192.24	1067.87
E	836.73	696.26	980.03	885.78	761.84
F	1182.31	1025.39	1523.37	1164.70	1052.76
G	1131.87	777.33	1259.55	1104.35	1253.55
H	828.65	635.72	996.31	786.20	962.99
I	760.48	630.00	1093.03	1114.53	888.14
J	1282.53	994.78	1185.53	1016.30	1079.94
K	320.80	299.85	394.30	324.69	184.93
L	1180.18	1457.8	1015.1	1254.6	1000.55
M	1715.00	1850.00	2005.00	1540.00	1120.00
N	1432.00	1143.00	1760.00	1085.00	924.00
O	1162.00	1297.00	1201.00	1114.00	1434.00

Table 20: Determination of density

	Determination of density [kg/L]						
Pitch code	Sand	Rubber	Box	Center	Corner	S.Center	Goal
A	2.63494	1.58298	2.26	1.99	1.96	2.25	2.01
B	2.60431	1.56467	2.18	1.79	2.13	2.11	1.59
C	2.64471	1.23425	2.01	1.91	1.45	1.80	1.89
D	2.63905	1.52076	1.93	1.90	2.02	2.08	1.94
E	2.60539	1.23	1.94	1.57	1.53	1.81	1.79
F	2.56088	1.53919	1.87	1.86	2.15	1.91	1.85
G	2.64765	1.20346	1.85	1.70	1.82	1.92	1.54
H	2.63597	1.64111	1.93	1.83	2.17	1.73	2.11
I	2.5998	1.68257	1.94	1.90	2.30	2.22	2.15
J	2.63981	1.55851	2.24	2.13	2.31	2.12	2.25
K	2.32478	1.18662	1.24	1.23	1.93	1.26	1.31
L	2.65105	1.57434	2.17	1.98	2.10	2.18	2.05
M	2.64339	1.68485	2.51	2.49	2.55	2.48	2.48
N	2.62853	1.74949	2.38	2.43	2.56	2.27	2.44
O	2.64769	0.32254	2.10	1.75	1.91	2.06	1.93

Table 21: Determination of the proportion of rubber mass

	Determination of the proportion of rubber mass				
Pitch code	**Box**	**Center**	**Corner**	**S.Center**	**Goal**
A	25%	49%	52%	26%	47%
B	29%	69%	33%	35%	96%
C	28%	34%	72%	41%	35%
D	50%	53%	42%	37%	49%
E	31%	59%	63%	39%	41%
F	55%	57%	29%	51%	58%
G	36%	46%	38%	31%	60%
H	61%	73%	35%	87%	41%
I	62%	68%	24%	32%	39%
J	26%	34%	21%	35%	25%
K	91%	92%	22%	88%	81%
L	32%	50%	38%	32%	43%
M	9%	11%	6%	12%	12%
N	21%	16%	5%	31%	15%
O	4%	7%	5%	4%	5%

Table 22: Determination of the performance infill mass per square meter

Determination of the performance infill mass per square meter							
Infill over life cycle	**Box**	**Center**	**Corner**	**S.Center**	**Goal**	**Mean**	**Weighted**
	30%	**30%**	**5%**	**30%**	**5%**		
6.80	4.62	8.87	8.34	6.34	7.28	7.09	**6.73**
7.00	6.90	6.81	6.13	7.85	5.17	6.57	**7.03**
8.50	5.54	6.58	8.38	5.80	7.16	6.69	**6.15**
15.30	12.78	11.86	11.14	8.90	10.76	11.09	**11.16**
9.50	5.26	8.35	12.57	7.07	6.29	7.91	**7.15**
8.50	13.37	11.93	8.88	12.10	12.37	11.73	**12.28**
8.10	8.23	7.36	9.81	7.08	15.37	9.57	**8.06**
9.63	10.27	9.50	7.13	13.89	8.05	9.77	**10.85**
9.75	9.58	8.70	5.40	7.21	7.01	7.58	**8.27**
6.30	6.80	6.98	5.03	7.24	5.42	6.29	**6.83**
8.50	5.96	5.65	1.74	5.85	3.06	4.45	**5.48**
8.00	7.73	14.84	7.94	8.12	8.79	9.48	**10.04**
5.00	3.16	4.03	2.66	3.67	2.67	3.24	**3.52**
5.00	6.19	3.72	1.93	6.85	2.86	4.31	**5.27**
2.00	0.86	1.88	1.30	0.89	1.51	1.29	**1.23**

Table 23: Determination of the sand mass per square meter

Determination of the sand mass per square meter							
Pitch code	Box	Center	Corner	Center of side	Goal	Mean	Weighted
	30%	30%	5%	30%	5%		
A	13.90	9.32	7.76	18.28	8.27	11.50	13.25
B	16.67	3.09	12.39	14.51	0.22	9.37	10.91
C	14.37	13.05	3.27	8.33	13.31	10.47	11.55
D	12.89	10.44	15.70	15.40	11.01	13.09	12.96
E	11.79	5.84	7.41	10.98	9.23	9.05	9.42
F	10.73	8.97	22.17	11.64	9.09	12.52	10.96
G	14.84	8.49	15.86	15.43	10.18	12.96	12.93
H	6.62	3.46	13.18	2.14	11.57	7.40	4.90
I	5.92	4.14	16.88	15.51	11.09	10.71	9.07
J	19.34	13.29	19.14	13.47	16.59	16.37	15.62
K	0.58	0.47	6.30	0.77	0.71	1.76	0.89
L	16.33	14.87	12.75	17.45	11.60	14.60	15.81
M	31.79	33.68	38.21	27.72	20.16	30.31	30.88
N	22.99	19.57	33.95	15.27	15.98	21.55	19.85
O	22.82	24.55	23.17	21.81	27.71	24.01	23.30

22.4 Sieve analysis

Example of a sieve analysis for a given pitch. During the sieve analysis, the sand/performance infill samples were fractioned into different grain sizes in a sieve cascade.

The sieve analysis determined what percentage of different particle size fractions are found at different sampling points. The evaluation includes the values table (Table 24) and a diagram created from this (Figure 45).

This provides additional information about the ratio of sand to performance infill and supplements the analyses on infill quantity and distribution that were made using density measurements. In addition, the particle size analyses offer information about the abrasion and fragmentation of the infill, size-dependent particle movement, and the maintenance condition of the artificial turf pitches.

Table 24: Tabular evaluation of the sieve analyses

Pitch X: Sand + EPDM	**Density EPDM**		**1.6967**	**g/cm³**	
Sample	**X1**	**X2**	**X3**	**X4**	**X5**
Wet weight (in g)	2011.74	1723.28	1860.93	1552.63	1128.26
Dry weight (in g)	2005.00	1715.00	1850.00	1540.00	1120.00
Water content (in g)	6.74	8.28	10.93	12.63	8.26
Water content (in %)	0.34	0.48	0.59	0.82	0.74

Sample	**Corner flag**	**Box**	**Center mark**	**Center line**	**Center goal**
Fraction			**Dry weight (in g)**		
> 2 mm	2.13	2.47	2.41	3.4	1.36
> 1 mm	105.98	145.66	147.37	168.28	167.13
> 0.5 mm	1060.44	657.80	626.53	434.55	383.04
> 0.3 mm	781.24	844.6	986.56	869.82	251.93
> 0.1 mm	47.5	61.47	84.77	61.52	43.1
> 63 µm	1.71	0.36	0.44	0.36	0.22
< 63 µm	0.84	0.09	0.15	0.17	0
Total	1999.84	1712.45	1848.23	1538.1	846.78

Sample	**Corner flag**	**Box**	**Center mark**	**Center line**	**Center goal**
Fraction			**Proportions (in %)**		
> 2 mm	0.11	0.14	0.13	0.22	0.16
> 1 mm	5.30	8.51	7.97	10.94	19.74
> 0.5 mm	53.03	38.41	33.90	28.25	45.23
> 0.3 mm	39.07	49.32	53.38	56.55	29.75
> 0.1 mm	2.38	3.59	4.59	4.00	5.09
> 63 µm	0.09	0.02	0.02	0.02	0.03
< 63 µm	0.04	0.01	0.01	0.01	0.00
Total	100.0	100.0	100.0	100.0	100.0

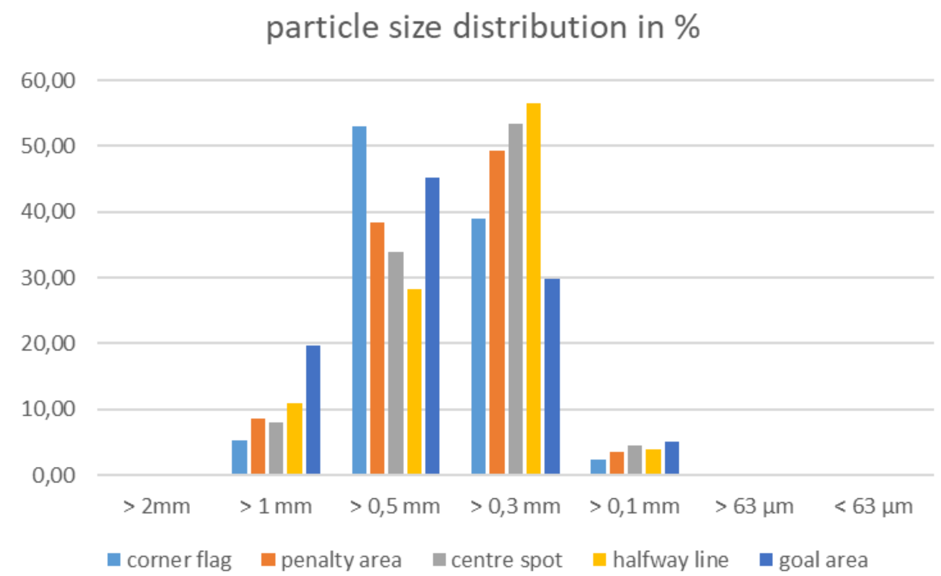

Figure 45: Sieve analysis shown graphically as percentage particle size distribution

Each sample taken from the artificial turf pitch was fractioned using an analysis sieving machine into the grain sizes < 63 µm, > 63 µm, > 100 µm, > 300 µm, > 500 µm, > 1 mm, and > 2 mm (Fig. 45).

Figure 46: Infill samples fractionated via sieve analysis

22.4.1 Photo documentation

Photo selection

Figure 47: Sampling body at corner point (l.); sampling with vacuum cleaner (r.)


Figure 48: Sampling point after sampling (l.); packaged infill samples before fractioning (r.)


Figure 49: Dry well with drainage outlets (l.); strainer with retained performance infill (r.)

Figure 50: Assessment of inspection shaft (l.); taking of a water sample from the inspection shaft (r.)

Figure 51: Performance infill next to the pitch (l.); grid with brush (r.)

22.4.2 Literature evaluation on hazardous substance content

Table 25: Heavy metal concentrations and detection in SBR infill from various scientific studies

	SBR Source: Bocca et al. 2009[250]; Menichini et al. 2011[251]			SBR Source: Marsili et al 2014[252]	
Heavy metal	Median	Min	Max	Min	Max
			[mg/kg]		
Al	755	1.2	6680		
As	0.24	0.1	1.21		
Ba	22	2.4	4778		
Be	2.04	0.001	0.37		
Cd	0.37	0.11	1.89	0.47	2.68
Co	15	3.5	234		
Cr	6.2	0.4	56	1.91	17.52
Cu	12	0.8	60	5.49	84.49
Fe	305	15	4318	129.12	7256
Hg	0.07	0.03	0.16		
Li	1.5	0.6	11		
Mg	456	123	966		
Mn	5.2	3	30		
Mo	0.2	0.04	6.6		
Ni	2	0.6	5.8	3.9	26.12
Pb	22	12	46	10.76	38.99
Rb	1.7	0.7	26		
Sb	1.1	0.3	7.7		
Sn	0.3	0.3	3		
Sr	1.2	3.2	90		
Tl	0.06	0.01	0.21		
V	2.2	0.4	22		
W	0.13	0.02	2		
Zn	12.229	118	19.375	3,474	13,202
Other sources					
Gomes et al. 2021[253]: Zn content measured in SBR granulate at 14.49 mg/kg.					
Massey et al. 2020[254]: Qualitative statement on EPDM granulate: Heavy metals present in comparable concentrations to SBR granulate; qualitative statement on TPE granulate: Heavy metals present in comparable or slightly lower concentrations than SBR granulate;					
FOPH 2017[255]: Safe concentrations of heavy metals detected in SBR, EDPM, TPE granulate, and fibers.					
Packaging Ordinance (VerpackungsV): Lead, cadmium, mercury, and hexavalent chromium concentrations are not permitted to be cumulatively above 100 mg/kg for plastics in the packaging sector.					

[250] Bocca et al. 2009.

[251] Menichini et al. 2011.

[252] Marsili et al. 2014.

[253] Gomes et al. 2021.

[254] Massey et al. 2020.

[255] FOPH 2017.

Table 26: PAH concentrations and detection in artificial turf infill materials from various scientific studies

	SBR Source: Marsili et al 2014[256]		SBR Source: Menichini et al. 2011[257]		SBR Source: Gomes et al. 2021[258]	EPDM Source: GE-ZOFILL product datasheet
	[ng/g]		[mg/kg]			
PAH	Min	Max	Min	Max		
Naphthalene	246.14	2039.61				
Acenaphthene	352.12	11025.47				< 0.1
Fluorene	426.81	11025.47				< 0.1
Phenanthrene	37.92	1560.01				< 0.1
Anthracene	7.64	282.62				< 0.1
Fluoranthene	710.43	3740.04				< 0.1
Pyrene	1643.56	10280.99	0.02	11.2		
Benzo(a)anthracene	5.38	1166.03	0.001	0.43		< 0.1
Chrysene	243.57	3422.21	0.01	2.38		0.1 - 1.6
Benzo(b)fluoranthene	1149.65	15715.42				< 0.1
Benzo(k)fluoranthene	68.25	3615.88				
Benzo(a)pyrene	51.72	662.56	0.001	10.7		
Dibenz(a,h)anthracene	72.75	573.26	0.001	0.03		
Benzo(g,h,i)perylene	239.69	902.89	0.01	8.36		
Total PAHs	8020.6	58211.37	0.04	28.5	1.91 – 14.67	
Carcinogenic PAHs	2545.89	22780.35				
Other sources						
Massey et al. 2020[259]: SBR granulate displays the highest concentrations of PAHs among the examined granulates (SBR, EPDM, TPE). Total concentration of PAHs 51-71 mg/kg. EPDM granulate shows a total PAH concentration of 1 mg/kg.						
FOPH 2017[260]: Qualitative statement: EPDM and TPE granulates have an approx. 50 times lower PAH concentration than SBR granulate.						
German Federal Institute for Risk Assessment: Limit value for category I (products intended to be put into the mouth or materials in toys with intended and long-term skin contact (longer than 30 seconds)): Total PAH < 0.2 mg						

256 Marsili et al. 2014.

257 Menichini et al. 2011.

258 Gomes et al. 2021.

259 Massey et al. 2020.

260 FOPH 2017.

Table 27: VOC detection in artificial turf infill materials from various scientific studies

	SBR Source: Gomes et al. 2021[261]	SBR, EPDM, TPE Source: Massey et al. 2020[262]	Cork
VOC	Only qualitative statement: VOC detected	Only qualitative statement: VOC detected; lower concentration in EPDM and TPE than in SBR	Terpenes are natural components of wood, so cork also contains VOC.

Table 28: PCB concentrations and detection in artificial turf infill materials from various scientific studies

	SBR Source: Gomes et al. 2021[263]	SBR Source: Menichini et al. 2011[264]
PCB	Only qualitative statement: PCB detected	Measured concentration: 0.18 – 0.67 *10^(-5) mg/kg

Table 29: Particulate matter concentrations and detection in artificial turf infill materials from various scientific studies

	SBR Source: Norwegian Institute for Air Research 2005[265]	SBR, TPE Source: Massey et al. 2020[266]
PM_{10}	Particulate matter up to $PM_{2,5}$ detected. Concentration 31.26 – 40.1 µg/m³	Particulate matter up to $PM_{2,5}$ detected.
Other sources:		
Own laboratory tests: Dust >> 2 mm detected, although without detection of the exact size.		
Pitch inspections: Dust >> 2 mm visually identifiable.		

Table 30: Phenol concentrations and detection in artificial turf infill materials from various scientific studies

	SBR Source: Massey et al. 2020[267]	EPDM Source: Massey et al. 2020[268]
Phenols	[µg/kg]	
4-tert-octylphenol	19,600 – 33,700	49.8
Isononylphenol	9,120 – 21,600	1,120
total		Concentration lower than for SBR

261 Gomes et al. 2021.

262 Massey et al. 2020.

263 Gomes et al. 2021.

264 Menichini et al. 2011.

265 Norwegian Institute for Air Research 2005.

266 Massey et al. 2020.

267 Massey et al. 2020.

268 Massey et al. 2020.

Table 31 - Phthalate concentrations and detection in artificial turf infill materials from various scientific studies

	SBR Source: Massey et al. 2020[269]	EMDP Source: Massey et al. 2020	TPE Source: Massey et al. 2020
Phthalates		[mg/kg]	
Dimethyl phthalate	Below the detection limit	3.4 mg/kg	Only qualitative statement: Phthalates detected.
Diethyl phthalate	Below the detection limit	1.5 mg/kg	
Dibutyl phthalate	2.6 – 3.9 mg/kg	1.6 mg/kg	
Benzyl butyl phthalate	1.3 – 2.8 mg/kg	Below the detection limit	
Diethylhexyl phthalate	21-29 mg/kg	3.9 mg/kg	
Di-n-octyl phthalate	Below the detection limit	3.2 mg/kg	
Diisononyl phthalate	57-78 mg/kg		
Total		Detected in lower concentrations than for SBR	

Table 32: Furan detection in artificial turf infill materials from various scientific studies

	SBR Source: Perkins et al. 2019[270]
Furans	Only qualitative statement: Furans detected.

Table 33: PFAS detection in artificial turf components from various scientific studies

	Fibers, backing Source: TURI 2020[271]
PFAS	Only qualitative statement: PFAS detected.

Table 34: Occurrence of HALS in artificial turf fibers

	Fibers Source: Listed as an ingredient in various patents for artificial turf fibers.
HALS	Only qualitative statement: HALS present.

Table 35: Occurrence of isocyanates in artificial turf components

	Elastic layer/elastic base layer
Isocyanates	Present if polyurethane-based binding agents are used.

[269] Massey et al. 2020.

[270] Perkins et al. 2019.

[271] TURI 2020.

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