Scientific and technical support on the possible risks related to the use of materials derived from the recycling of used tyres in synthetic sports grounds and similar uses

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Scientific and technical report

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Key words

End of life Tyre (ELT), recycling, granules, PAH, artificial sports pitches, playgrounds

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Acronyms and abbreviations

CDC	Center for Disease Control and Prevention
ECHA	European Chemical Agency
EHHI	Environment and Human Health, Inc
ELT	End-of-life Tyres
EPA	Environmental Protection Agency
EPR	Extended Producter Responsibility
EU	European Union
FIFA	International Federation of Football Association
NGO	Non Governmental Organization
NYC	New York City
PAH	Polycyclic aromatic hydrocarbons
REACH	'Registration Evaluation and Authorization of Chemicals', Regulation (EC) n° 1907/2006
RIVM	Netherlands Institute for Public Health and Environment
SBR	Styrene Butadiene Rubber
TPE	Thermoplastic elastomer
VOC	Volatile Organic Compound
TVOC	Total Volatile Organic Compound
USA	United States of America
WSDH	Washington State Department of Health

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1 Request context and objectives of the scientific and technical support

The upcycling of used tyres (ELT – End of life Tyres) in the form of granules and other materials used in the production of synthetic grounds is one of the main ways for developing the economy of of the French tyre waste management system. Concerns have emerged over recent years with regards to the potential impacts of synthetic grounds on human (and animal) health as well as the environment, especially in the context of their use as articicial sports pitches and children playgrounds.

These materials are used *inter alia* for outdoor and indoor fields, for team sports and individual sports. According to the Ministry of Sports, the number of major sports areas with artificial grounds is estimated at around 3,000 in France (7% of the total number of major play fields). Exposure situations may be numerous, for example: professional or amateur sportsmen, schoolchildren, operating or maintenance professionals, via the dispersion of unsecured materials into the environment. Other more specific uses are cited such constituents of animal litter or in the equestrian floors.

For several months, the French media have reported concerns related to such reuse of used tyres in particular for synthetic football fields. This strong concern has given rise to numerous requests to Anses from representatives of civil society, local authorities and industry. The "Robin des Bois" association, the cities of Nantes and Paris have in particular contacted Anses on this subject. The request for scientific and technical support, dated February 21, 2018, comes from six signatory Ministries and covers the exposure of the general population and workers. The issue around occupational exposures includes the use of other potentially toxic chemicals at different stages of manufacture, installation and maintenance.

Potential risks to the environment, as well as to the health of animals likely to be in contact with these materials, are also discussed. However, after discussions with the representatives of the Directorate-General for Food and representatives of the industrial sector, it appears that the uses that can expose animals are very rare uses. This issue is therefore not addressed in this report.

2 Means implemented and organization

The French Agency for Food, Environmental and Occupational Health & Safety (Anses) was mandated on 21 February 2018 to document the possible risks related to the use of materials from the recycling of used tyres. This request for scientific and technical support comes from six ministries, illustrating the diversity of issues associated with the re-use of these materials for the health of humans and their environment. Within the given timelines, the Agency focused on carrying out a contextualized analysis of published data and works in progress, identifying knowledge needs to guide action and research priorities. The analysis performed does not therefore constitute a health or environmental risks assessment and does not therefore provide any final conclusions from the agency on the existence or absence of risks. Beyond this, it has focused on identifying knowledge needs to guide action and research priorities in line with health and environmental risk assessment questions related to tyre aggregates.

In addition to the analysis of academic publications, the consultation of gray literature and media sources, the presented work relied on the hearing of the following organizations:

- Youth and Sports Directorate and Parisian Department of Environmental Health of the City of Paris, auditioned on 6 April 2018;

- “Robin des Bois” Association, whose representative was interviewed on May 3, 2018;

- Representatives of the industrial sector, including French actors in the manufacture, installation and testing of the grounds and artificial pitches concerned by this expertise, auditioned on 3 May 2018;

- The European Union of the Tire and Rubber Industry (ETRMA), contacted by telephone on 25 May 2018;

- ‘France Pneumatic Recycling’ Group, contacted by telephone on 21 June 2018.

This expertise was carried out in compliance with standard NF X 50-110 "Qualité en expertise – Prescriptions générales de compétence pour une expertise (Mai 2003)".

This expertise was supported by the Anses’ experts committee (CES) on ‘Assessment of chemical risks of consumer items and products’.

Anses analyzed the links of interests declared by the experts before their appointment and throughout the expertise, in order to avoid the risks of conflicts of interest with regard to the points dealt with in the framework of the expertise.

The declarations of interests of the experts are published on the Anses website (www.anses.fr).

Ms Mélanie NICOLAS, expert from CSTB french institute, did not participate to the discussion within the CES on “Assessment of chemical risks of consumer items and products”, as Anses had decided to contact CSTB to perform tests in a near future on those materials.

3 Regulations and standards applicable to uses of ELT-derived rubber granules

3.1 Waste management and circular economy

First, in the European Union, landfilling ELTs have been prohibited since 2006 following the European Directive 1999/31/EC. The French law also precises the hierarchy of used tyres processing: reuse, recycling, and finally recovery, especially the energy one.[1]

In France, the original manufacturer has a duty of care to ensure that the waste from the products it has created is disposed of responsibly, in an environmentally sound manner. This makes the producer responsible for the waste that the consumer generates (Extended Producer Responsibility - EPR). Under the EPR, ELTs have to be managed by their manufacturers and importers. They may fulfil the required obligations by setting up an eco-organization, which is a corporate structure, such as a consortium, which takes care of all activities related to the ELT management, including communication and reporting obligations to the national authorities.

These eco-organizations are mandated by law to collect and organise the treatment of an equivalent amount of the volumes of tyres sold individually or collectively by affiliated companies on the same year or the year before. The process is financed through an environmental contribution charged upfront by ELT companies to its affiliated tyre manufacturers and importers on tyre sales. The fee is passed on by producers and distributors throughout the value chain to the end user.

Aliapur is the leader company in the field of recovering used tyres in France. It is a Public Limited Company whose founding members are Bridgestone, Continental, Dunlop Goodyear, Kléber, Michelin and Pirelli. The founding manufacturers make up approximately 70% of the annual yearly circulation of used tyres. Since December 2003, Aliapur has been chosen by more than 300 producers, as defined by the French Environmental Code, to collect and recover the quantities of used tyres they are bringing on to the French market. Besides, EPR - as waste management - takes part of a broader frame of action that is circular economy. This recently became a global topic of public intervention, framed by sustainable development and green growth. Thus an *ad hoc* European Union (EU) Package was adopted since 2018, as a French Roadmap. These public policies emphazise the limited resources of the planet, therefore the necessity to “do more and better with less” for economic development and environmental protection.The French policy specifically underlines the outcome of social change. Dedicated to consumers, industries as public authorities, it notably targets waste management and planned obsolescence.

3.2 Regulation for ELT-derived rubber granules

In the European Union, used tyres are banned from landfilling since the entry into force of Directive 1999/31/EC of 26 April 1999 on the landfill of waste. Tyre manufacturers are responsible for the collection and recovery of used tyres (in line with the "extended producer responsibility" principle).

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[1]. Article R543-140, Code de l’environnement (modifié par le Décret n°2015-1003 du 18 août 2015 - art. 4)

In this organization, the manufacturers have therefore created a recycling sector for used tyres, represented by one or more eco-organizations (the main French actors are Aliapur and France Recyclage Pneumatiques) in metropolitan France.

Article R543-140 of the French Environmental Code (amended by Decree No. 2015-1003 of 18 August 2015 - Article 4) states that any collected used tyres must be treated according to the following modes, with priority given to priority order:

1- Preparation for reuse (retreading);

2- Recycling;

3- Other methods of recovery, including energy recovery.

These practices are part of a larger framework of a European policy on the circular economy. Thus, in line with the European circular economy package of Spring 2018, France also adopted in April 2018 an *ad hoc* roadmap.

Currently, there is no specific regulation on the ELT-derived rubber granules used as infill material in artificial sport pitches or as shock-absorbing pavements used in children's playgrounds.

However, regarding the PAHs and the tyre itself, entry 50 of Annex XVII to REACH prohibits the production or import into the EU of tyres produced with non-complying oils since 1 January 2010, as followed:

From 1 January 2010, extender oils shall not be placed on the market, or used for the production of tyres or parts of tyres if they contain:

- *more than 1 mg/kg (0,0001 % by weight) BaP, or,*
- *more than 10 mg/kg (0,001 % by weight) of the sum of all listed PAH.*

This restriction affects the composition of ELT-derived rubber granules used as infill material. Indeed some granules may contain tyres produced before 2010. Furthermore, as far as imports of tyres could be also concerned, it may be complicated to check what types of oils have been used in the production of tyres.

The current level of compliance with entry 50 of Annex XVII to REACH for all different types of imported tyres, from different worldwide countries, is not available. The Netherlands (NL) consider the need to address all ELT-derived rubber granules used in the European Union (produced also with tyres put on the market before 2010 or imported) (RIVM 2017) via a new restriction proposal in the framework of REACH.

New restriction proposal:

NL, in cooperation with ECHA, proposed to restrict "placing on the market of plastic, rubber and other granules containing PAHs above a set concentration limit for use as infill material on synthetic turf pitches or for use as loose granules or mulch on playgrounds and sport applications". The restriction intention includes 8 PAHs (the same that listed in Entry 50). The justification of NL to restrict the granules is the following: granules as infill material are characterised as mixtures. If the concentrations of carcinogenic PAHs are as high as the generic limit for mixtures supplied to the general public defined in REACH, there is a concern. To ensure that no plastic and rubber granulate is placed on the market with such high PAH concentrations, a lower limit needs to be set (dossier submitted in July 2018).

3.3 Standards for synthetic turf

There are **several standards for synthetic turf**. Most of these standards focus on the game quality offered by synthetic turf. These include:

- The French standard **NF P90-112** that defines the conditions of realization of the ground of big sized fields made of synthetic turf. Regarding the infill material, the only 'toxicological' requirements of this standard are for the environment and in particular the quantities of certain metals found by leaching. The standard sets the limit concentrations not to be exceeded in leachates or residual waters for lead (Pb), cadmium (Cd), chromium (Cr total and Cr VI), mercury (Hg), tin (Sn) and zinc (Zn).

- The standard **EN 15330-1:2013** gives specification for synthetic turf outdoor surfaces for football, hockey, rugby union training, tennis and multi-sports use. These specifications are related to performance, durability, wear resistance, anti-slip surfaces, mechanical properties of materials.

- The International Federation of Football Association (FIFA) quality standard proposes a battery of tests (in the laboratory or in the field) concerning the durability of the field, the absorption of shocks, the rebound and the rolling of the ball, the permeability of the grass to the water, etc.

- World Rugby has also produced the Rugby Turf Performance Specification to set a minimum standard for artificial playing surfaces which may be used in rugby (World Rugby, 2018). The specification relates to the suitability of an artificial playing surface for rugby regarding Ball/Surface Interaction, Player/Surface Interaction and Durability of the playing surface.

- The Synthetic Turf Council published a report "Suggested Environmental Guidelines for Infill" which advocates environmental standards to be followed by industry to limit heavy metal levels in artificial turf (Synthetic Turf Council, August 2015). The STC suggests that any toxicological test and analysis of infill for synthetic turf fields be performed according to European Standard **EN 71-3** – Safety of Toys Part 3: Migration of certain elements. The EN 71-3 protocol specifies maximum migration limits for three categories of (toy) materials. The limits for the migration of certain elements are expressed in milligrams per kilogram (parts per million) of the tested material and should be detailed in the testing report. The purpose of the limits of the European protocol is to minimize children's exposure to certain potentially toxic elements. EN 71-3 concerns all toys and materials that might be ingested. While the STC does not consider synthetic turf infill as a toy or children's product, pieces of infill can be ingested. The STC has identified Category III of EN 71-3 to be the closest definition to infill materials[2].

Substances commonly present in recycled rubber granules are polycyclic aromatic hydrocarbons (PAHs), metals, volatile organic hydrocarbons (VOCs) and semi-volatile organic hydrocarbons (SVOCs). However, the existant quality standards do not explicitly consider the limitation of such potential harmful substances.

Regarding toxicology, the FIFA Quality Programme[3] considers in its requirements that the manufacturer should be asked to supply to the purchaser an assurance that the sports surface

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[2] https://c.ymcdn.com/sites/www.syntheticturfcouncil.org/resource/resmgr/guidelines/STC_Environmental_Guidelines.pdf

[3] FIFA. Handbook of Requirement. October 2015 Edition.

together with its supporting layers, does not contain in its finished state any substance which is known to be toxic, mutagenic, teratogenic or carcinogenic when in contact with the skin. Furthermore, it is stated that no such substances will be released as a vapour or dust during normal use. However, there is no information on the test or analytical method needed to comply with this requirement.

Some producers of synthetic turf propose as a voluntary action to certify their products according to indoor air quality guidelines: for instance the GREENGUARD Gold standard includes health based criteria for different chemicals and also requires lower total VOC emissions levels to ensure that products are acceptable for use in environments such as schools and healthcare facilities (source: Mondo DUAL AS EF product description, 30/05/2018. www.mondoworldwide.com).

3.4 Standards for shock-absorbing pavements used in children's playgrounds

The following standards focus on children safety due to the likeliness to fall during playing:

- In France, the **Decree No. 96-1136** of 18 December 1996 lays down safety requirements for playground surfaces. The decree specifies in its annex 2 that the areas on which children are likely to fall must be lined with appropriate absorbing materials and must meet 'the conditions of hygiene and cleanliness to prevent any contamination or stain'.
- The **BS EN 1177:2018** standard also applies to synthetic coatings, of which granules are part. This standard makes it possible to measure the absorbing capacities of a soil by the HIC (Head Injury Criterium) test. In fact, this test makes it possible to determine the critical drop height by taking into account the distance between the ground and the highest point that can be used by the child during a normal use. Depending on the determined critical drop height, the thickness of the coating may be more or less important.
- Regarding the human health, the **NF EN 1176-1** standard (October 2008) specifies the general safety requirements for permanently installed public playground equipment and floors. It is stated that no harmful substances must be used in such equipment if they constitute a risk for the user health. In particular, asbestos, lead, formaldehyde, coal tar oils, carbonyls and polychlorinated biphenyls (PCBs) are listed (non-exhaustive list).

To sum up, it emerges from this regulatory and normative identification work that existing texts are mainly oriented towards sports performance and damping qualities (especially for playgrounds), without any requirements relating to chemical composition or health / environmental risks (with the exception of some heavy metal leaching thresholds in the standard NF P90-112).

4 The market of recovery used tyres

A review was conducted in order to draw a picture of the End of life Tyres (ELT) recycling into granules that can be used for synthetic turf fields and playgrounds.To that extend, a state of play was done by reading reports available and by doing hearings of French stakeholders.The following Aliapur scheme describes how ELT can be recycled.

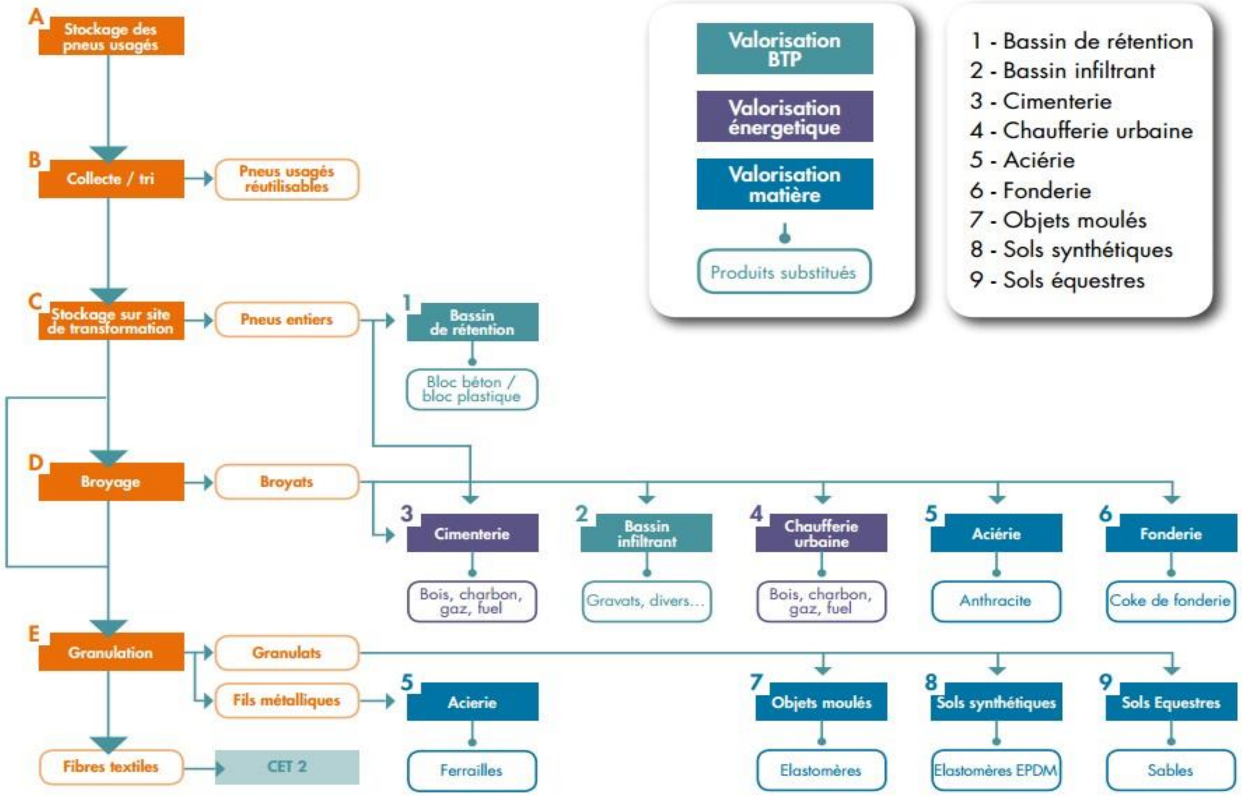


Figure 1: Overview of ELT treatment (source: Aliapur, in French)

ELT can be:

- Re-used into two ways (re-treading or second hand market),
- Transformed into material recovery that will be employed into granules or powders,
- Mixed into energetic recovery and material recovery,
- Only used for energetic recovery.

As an example, the Table below presents the different profiles of tyres recycling in the EU.

Figure 2: EU tyres recycling profiles (Ademe 2015)

ELT-derived rubber granules are used in many applications. According to ETRMA, ELT-derived rubber granules and powders are currently used for:

- Synthetic turf field: ELT-derived rubber granules are used as an infill material that provides proper resilience and shock absorbance to the artificial turf fields.
- Sport surfaces/athletic tracks: ELT-derived rubber (non-granules) is used in many outdoor sport areas (primarily for athletics, multi-use sports) to dissipate the vibrations and impacts that otherwise would lead to muscular-skeletal effects in athletes. ELT-derived rubber is also used in indoor surfaces (e.g. for volleyball and basketball courts), generally with a polyurethane (PU) top coating but this represents a smaller volume compared to outdoor surfaces.
- Shock-absorbing pavements: ELT-derived rubber is typically used to produce shock-absorbing floorings (in-situ floors or mats) that are durable in outdoor conditions, weather-resistant, permeable to water, etc.
- Moulded rubber goods: ELT rubber granules and powders can be mixed with polyurethane binders to produce re-moulded rubber articles such as wheels for trolleys (e.g. caddies, dustbins wheelbarrows, etc.), urban furniture, safety corners, rail filler block systems, etc.
- Other applications: Asphalt rubber, equestrian floor, etc. (ECHA, annex XV dossier 2017).

The following sections focus on material recovery into granules or powder that can be used especially for synthetic turf fields or playgrounds.

4.1 Volumes of ELT used in material recovery

In 2016, 432 655 tonnes of used old tyres were treated in France (Aliapur annual report, 2017).

Between 2005 and 2016, 41% of the recycled tyres were used for material recovery whose 30.9% where dedicated to granulates and powered rubber (plaquette ACV, Aliapur, 2017) while in 2012, 40% of the granules were dedicated to synthetic turf fields (Ademe 'observatoire des filières', 2013). In 2017, 41 % of the ELT were recycled into raw valorisation. In these 41%, 23.8% were recycled into granules and powder which can be re-used for synthetic turf fields. These 23.8% represent in France around 36,000 tons of ELT (Aliapur annual report, 2017).

These figures are confirmed in the ECHA annex XV report, in 2017, which explains that the market for ELT granules and powder is decreasing for the use in synthetic field including infill from 43% in 2011 to 30% in 2014.

Two tyres collectors exist in continental France. Aliapur gathered around 350 000 tons of tyres in 2017 while France Pneumatique Recyclage gathers around 70 000 tons. In the French overseas departments, around 17 000 tons of ELT were collected.

ETRMA figures show that, in France, ELT recovery represents 161 000 tons in 2016. The recycling includes granulation (around 90 000 tons), use of ELT in steel mills and foundries as well as docks fenders, blasting mats, pyrolysis and the incorporation of the inorganic content of ELTs in cement manufacturing."

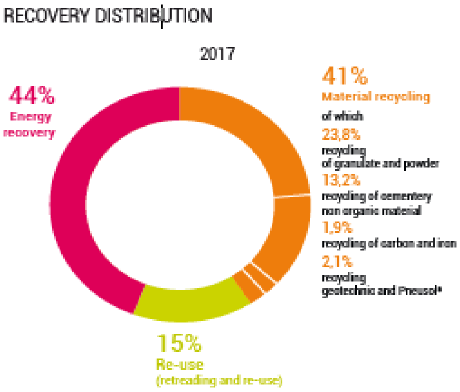


Figure 3: Recovery distribution in 2017(Aliapur annual report, 2017)

Based on industry estimates (ETRMA, 2016), the quantity of ELT rubber infill that is used on European synthetic turf fields is about 80,000 to 130,000 tonnes per year.

In terms of tonnages, Belgium, the Netherlands, Denmark, Hungary, Portugal and Spain have used more material recovery than energy one for tyres. At the international level, Canada seems to be the spearhead of granulation. There are a lot of market opportunities for recycled raw materials, including sport playground but also roofs, automotive equipment, hiking paths etc. over there. In most European countries, the tonnage dedicated to granulation tends to decrease, except in Italy. In terms of proportion compared with global recovery, this is more ambivalent. Material recovery is stagnating in Germany, United-Kingdom, Spain and Portugal, whereas it is increasing in Denmark, Italy, Belgium and the Netherlands (ADEME, 2015).

4.2 Playground/ paving slabs/ soft ground sports

In playgrounds, ELT can be used in granules as their damping properties allow to absorb shocks and guarantee safety. The rubber of ELT is transformed into granules within a diameter of 1 to 4 mm. Then these granules are melt with resin and casted into a mold so that they will take the shape of slabs (source: Aliapur website).

Usually, athletic tracks/soft grounds are made of coloured EPDM (ethylene propylene diene monomer) granules and polyurethane. ELT granules are used as an under layer due to their irregular shape. But athletic tracks can now be made of ELT granules linked by polyurethane resins (source: Aliapur website) because it is claimed that this type of material can ensure comfort and performance, absorb shocks etc... At least, in France, one athletic soft ground in the City of Clermont Ferrand is made of these granules linked by polyurethane and represents the valorisation of 9,000 ELT.

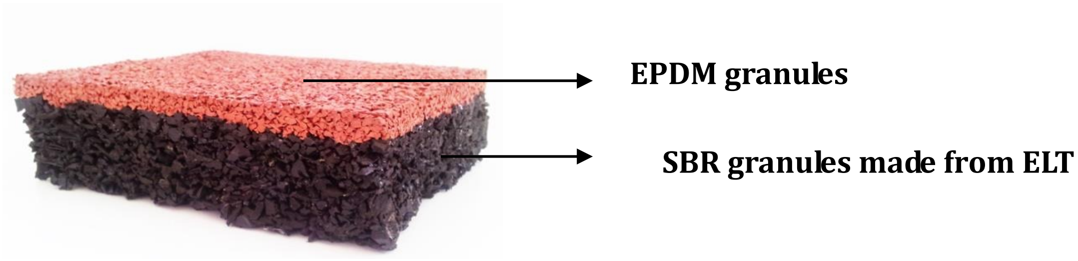


Figure 4: Playground composition scheme

4.3 Synthetic turf fields

Synthetic turf fields are made of a synthetic grass carpet within a sand ballast covered by free ELT derived rubber granules.

The synthetic grass carpets are usually made of coloured polypropylene or polyethylene and sometimes polyamide or polyester under the shape of filament. These filaments are attached in a strip mat of polypropylene coated by latex (source: Aliapur website). The sand provides weight and holds the plastic mat in place, while the rubber provides elasticity. Other infill materials than rubber granules are available.

Fields / sports pitches can be infilled with material in a few different ways. Sand is often used as lower layer infill material to act as a ballast for the turf component. On top of this lower layer either will be tyre crumb rubber or a sand/tyre crumb rubber mix, topped by additional tyre crumb rubber. Other fields can use an infill exclusively comprised of tire crumb rubber. On a smaller number of fields, tyre crumb rubber could be coated with paint, typically green, either for aesthetic purposes or heat control. To a much lesser extent, natural materials (e.g., ground coconut husk), EPDM, or thermoplastic elastomers (TPE) granules are used as the complete infill. These materials also can be used as the uppermost layer of infill. Infill material is spread using small utility vehicles that make multiple passes across entire fields, laying the material down in thin layers that are placed one on top of the other until the appropriate height is reached. Additional machinery can be used to drag or brush the blades upright to allow the material to fall between the blades (US EPA, 2016).

There may also be antioxidants added to the grass made of plastic to improve weather resistance (organic phenolic structures), UV stabilisers to protect against light degradation and also colourants to make the artificial grass green (ECHA, 2017).

The fibres are coloured green. Some of the green colourants can be based on metallic complexes (copper), or they can be of the azo colourant type, of 18 which some, e.g. yellow, are known to be potentially carcinogenic. The green colour is produced by mixing yellow and blue colours (Danish EPA, 2008).

The most commonly used filaments height is 60 mm and between 110 and 120 tonnes of infill on a full size football field are used. If the system incorporates a shockpad, the pile height may be lower and the infill quantity could be as low as 40 tonnes.

During the hearing, Aliapur mentioned that the ELT granules used in synthetic turf field come from tyres that are 5 years old maximum and collected in France.

Outdoor synthetic turf fields are more common than indoor fields (US EPA, 2016). The differences in the construction between outdoor and indoor fields are the use of a more durable fiber in indoor fields and the use of adhesives to glue down the fiber carpet to the floor of indoor facilities (US EPA, 2016).

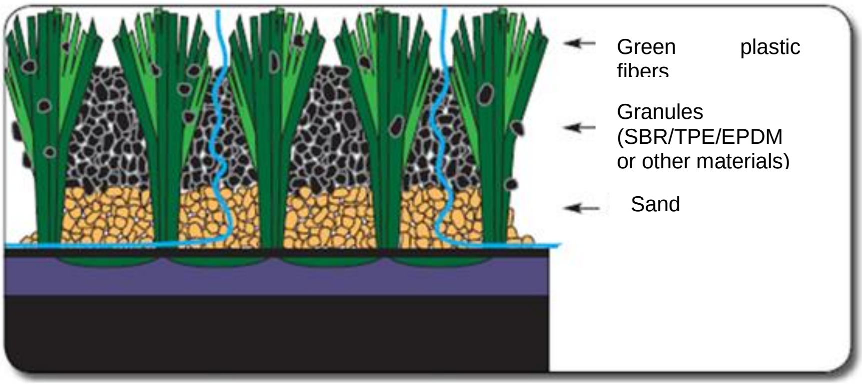


Figure 5: Typical synthetic turf field composition

4.4 Synthetic turf fields in France and Europe: estimation of the number of pitches

The European Synthetic Turf Organisation (ESTO, 2016) states in its Market Report Vision 2020, that there are over 13,000 synthetic turf football fields within the EU and over 47,000 minipitches used for football. Data from the major synthetic turf manufacturers and the ELT granulators operating in the EU indicate that around 1,200 - 1,400 new football fields are nowadays installed every year in the EU. This includes the replacement of old fields. According to ESTO, the number of fields is expected to continue to grow, e.g. by 2020 the number of football fields with synthetic turf is expected to be about 21,000 and the number of minipitches around 72,000.

In France, there are around 180 artificial football fields installed annually and in 2017, around 2,497 fields with synthetic turf were installed in France. (ECHA Annex XV report, 2017). ESTO estimates that 95% of the synthetic turf installations are currently located outdoor.

4.5 Synthetic turf fields maintenance

In a similar way than with natural fields, synthetic turf fields need also to be maintained through a set of routine maintenance practices. Routine synthetic turf field maintenance is conducted to maintain a safe playing surface, improve its appearance, and extend the life of the field. Recommended maintenance practices include brushing the field for infill redistribution, raking to rejuvenate the fibers and to level the top portion of the infill, and sweeping for debris removal. It is recommended that some of these practices be performed more frequently than others, depending on the frequency with which the field is used and specific guidelines for the sport played on the field. There are also guidelines that recommend using surfactants, such as liquid laundry fabric softener or static conditioner, to help reduce static electricity that builds up during maintenance. Water also is used to reduce the static electricity in synthetic turf fields. It is important to maintain an appropriate amount of infill in the field for proper cushioning and firmness. Tyre crumb rubber granules can be lost for a number of reasons, such as migration in the shoes and clothing of athletes, in weather events such as rain or snow, and through routine maintenance practices. Because of tyre crumb rubber migration, new infill material sometimes is added to existing fields to refresh or replace the tyre crumb rubber that is lost over time. Infill material also can be added to modify the sponginess of a field. Certain high-use locations on a field might require replacement material more often than others (CPSC Research Federal Action Plan, 2016).

According to ECHA Annex XV report published in 2017, refilling of infill material happens each year: on average 0.5 to 1 ton of refill per year has to be supplemented for each field and for winter service 3-5 tons is used.

In an Australian report (Government of Western Australi, 2011), the authors claimed that various steps of maintenance are required to guarantee the synthetic turf optimum performances. Here under are listed the various types of maintenance:

- Cleaning: Sweeping of leaves and other debris from the surface generally needs to be done weekly. If leaves, tree flowers, pine needles and other debris are left on the surface for any length of time they rapidly rot down and form a drainage-inhibiting skin within the surface which can encourage the growth of algae and moss.

- Grooming the surface is a crucial operation aimed at keeping the mat and texture of the synthetic turf as even and uniform as possible, so as to prevent the deterioration of play characteristics, appearance and drainage properties. Grooming the surface through brushing and/or drag matting lifts the fibres at the surface. It redistributes evenly any sand or rubber that has been disturbed, and counteracts any compaction of the sand and any tendency to form an impervious surface skin which might impair drainage (filled surfaces only).

- Moss and Algae: In certain situations and in some seasons, algae or moss can occur on the surface. Prevention is more effective than cure, therefore, an annual application of moss-killer and/or algaecide is recommended (by the Government of Western Australi).

- Weed Removal: Weeds are not as prevalent in synthetic turf as they are with natural grass but, they do still appear from time to time. It is important to remove weeds as soon as they are noticed to prevent them from spreading. They can either be removed by hand or local areas of infestation can usually be treated with domestic weed killer, however, always check with the manufacturer before using any chemical sprays on the surface.

- Stain Removal: Most stains can be removed easily with a solution of warm (not boiling) water and a household detergent such as dishwashing liquid. Before attempting to remove heavy soiling and stubborn stains it is important to seek the surface supplier‘s advice.

- Joints and Seams: It is important to check all joints and seams on a regular basis and repair any failures promptly, before loss of any synthetic surface pile or risk to users.

- Check and Top-up Infill Levels (filled surfaces only): High traffic areas such as penalty spots and short corners should be checked daily or weekly, but other areas of the ground infill levels should be checked monthly.

- Power Brushing: Many (but not all) manufacturers of third generation rubber-filled surfaces now recommend the use of powered brushing machines to ensure that the rubber particles remain mobile and the carpet fibres upright. This operation is recommended at least every 6 months.

- Deep Cleaning: Both sand filled, dressed and rubber filled surfaces may in time require a degree of deep cleaning. This will depend largely on the environment and usage levels and should only be performed if surface contamination is suspected, and then only by specialist contractors.

4.6 Uncertainty within the chain

ADEME notes also several constraints affecting the chain of tyres recovery (ADEME, 2015). In France as in some European countries, the financial resources coming from eco-contributions tend to decrease. Globally, production costs (investment, energy, workforce) are pretty high. Moreover, the price of granulate has been globally reduced, but an upturn is noticeable since 2014. In France in particular, the number of production facilities and capacities of management are pretty small. The producers of granules in particular suffer from a fierce European concurrence, as they can lack of price-related and quality-related competitiveness. Nevertheless, the French chain gets also some advantages, such as circular economy public policies, low price of energy, technical efficiency, efforts of R&D - even if all the projects have not been completed yet. As in other countries, these R&D projects deal more with civil works, more with concrete uses of infill material than the specific uses for playgrounds.

This context of economic uncertainty is notably complemented by the uncertainty of the implementation of the end-of-waste process, the public incentive to energy recovery as the debates about synthetic fields in France. Considering this situation, sport and children playgrounds may be not the main economic opportunity of the recycled tyres sector; especially for the specialized manufacturers of artificial grounds as the installers of these fields. Thus these actors are now questioning the necessary adaptation and other possible outlets.

5 An overview of costs and benefits of synthetic vs. natural turf

The aim of this section is to provide a brief and descriptive overview of the costs and benefits of synthetic turf and natural grass, focusing only from the buyer's perspective. Data from studies and reports on France, Europe and some Anglo-saxons countries (the USA and Australia whose the fields'composition are pretty closed to the European ones) were gathered, based on the publicly available literature from 2000. The purpose is only to draw up an illustrative comparison between the two types of fields; hence the information and data gathered have not been subject to in-depth scrutiny at this stage. Moreover, the quantity as the quality of sources may be limited to some extent.

In this section, the costs related to the implementation of a synthetic turf are presented, focusing on soccer fields and crumb rubber infills, compared to a natural field.

Before exploring the data found on different countries/world regions, a brief explanation about what the different costs are (associated with the choice of using a synthetic turf or a natural grass), and what they stand for, is provided.

5.1 Typology of costs

5.1.1 Typology of fields

The classification of the type of fields that exist is the following:

- ✓ The natural with native soil field
- ✓ The natural with on-side native soil field: no added top soil or sod
- ✓ The natural with sand and drainage field: same as native soil but with no topsoil, 8"-12" sand rootzone, 4"-6" perforated piping trenched below a 3"-4" gravel layer (STMA, no date).
- ✓ The natural with sand cap field: same as native soil but with no topsoil and a 4"-6" sand layer.
- ✓ The synthetic (crumb rubber infill) field: described in the previous section

5.1.2 Construction costs

This category of costs groups together costs from the capital that should be invested to the design phase (manufacturing of the materials composing the field, preparation of the soil to be built on, etc.) to the layout of the field (transport cost, installation, etc.).

5.1.3 Maintenance costs

For natural grass, these costs can be decomposed as follows:

- ✓ Mowing: the grass should be cut weekly during the spring and summer seasons and fortnightly during the colder months.
- ✓ De-compaction: this maintenance action is required in order to sustain the soil structure.
- ✓ Sodding: when there is an excessive wear, sodding is necessary to preserve a good turf and surface quality.
- ✓ Top-dressing: used to maintain surface levels.
- ✓ Weed/pest/disease control: this maintenance action consists in treating the grass with specific phyto-pharmaceutical products
- ✓ Irrigation: the grass must be irrigated on a regular basis to keep it alive (depending on the geographical and weather conditions)
- ✓ Thatch control: thatch should be minimised otherwise it would be harmful for the grass health
- ✓ Fertilisers: they represent the nutrition the grass need. It is recommended that laboratory soil tests are done annually.

The maintenance costs for synthetic turf are related to the different maintenance steps such as described in section 3.5 (Cleaning, grooming, moss and algae prevention, weed removal, stain removal joints and seams , check and top-up infill levels, power brushing and deep cleaning).

5.1.4 End of life costs

The last category of costs concerns only the synthetic turfs whose lifespan is considered to be between 8 and 10 years. Whereas natural grass, thanks to its regenerative properties, has theorically an indefinite lifespan. The removal costs include costs such as resurfacing, disposal, transportation, and landfill. It has to be born in mind that the longevity of a field, synthetic or natural grass, depends on the wear and maintenance.

5.2 Data on costs

5.2.1 Costs data for France

For this section, data from two different sources were gathered. The figures in the first table were published by "Société française des gazons", second data have been collected for the city of Paris, after the audition of "Direction de la Jeunesse des Sport (DJS)" hold by Anses in May 2018.

	Natural grass	**Synthetic turf**
Average cost of the field created	140,000€	380,000€

	Natural grass	**Synthetic turf**
Average maintenance cost (over 10 years)	110,000€	80,000€
Total 1 : total cost over 10 years	250,000€	460,000€
Weighted cost over 1 year	25,000€	46,000€
Number of hours of annual usage	450h	850h
Total 2 : total weighted hour cost of usage over 10 years	55.56 €	54.12 €

Table 1: Costs comparison of a synthetic turf and a natural grass in France (Source: Société française des gazons, 2006)

Notably, a synthetic turf has a higher investment value than a natural grass field (see Table 1). Although the maintenance costs for a synthetic turf are lower the orders of magnitude are similar. This refutes the common assumption that maintenance costs between the two types of fields are very different. The third notion to take out from this table is that a synthetic field can be used far more intensively than a natural grass. Given the above figures, a synthetic turf can be considered as more cost-effective than a natural grass. Indeed, as regards the last line of the table above, the total cost per hour of usage, over a 10 year period is comparable for a synthetic turf than for a natural grass (54.12 € versus 55.56€ respectively).

The Hearing of the “Direction de la Jeunesse des Sport” (Youth and Sports Directorate) of the city of Paris gave the opportunity to collect some general costings which are of the same magnitude as compared to the figures in Table 1. There are 39 football fields in Paris. According to the Directorate, the installation cost of a synthetic field is about 400,000€ per unit. The replacement of a synthetic turf costs 250,000€. The maintenance cost for a natural grass would be about 30,000€ per year.

These two sources do not give any figures on the end-of-life (or so called disposal) costs. Some indications about disposal costs for France are however provided in the Eunomia Research & Consulting Ltd 2017 report, presented in the next section.

5.2.2 Costs Data for Europe

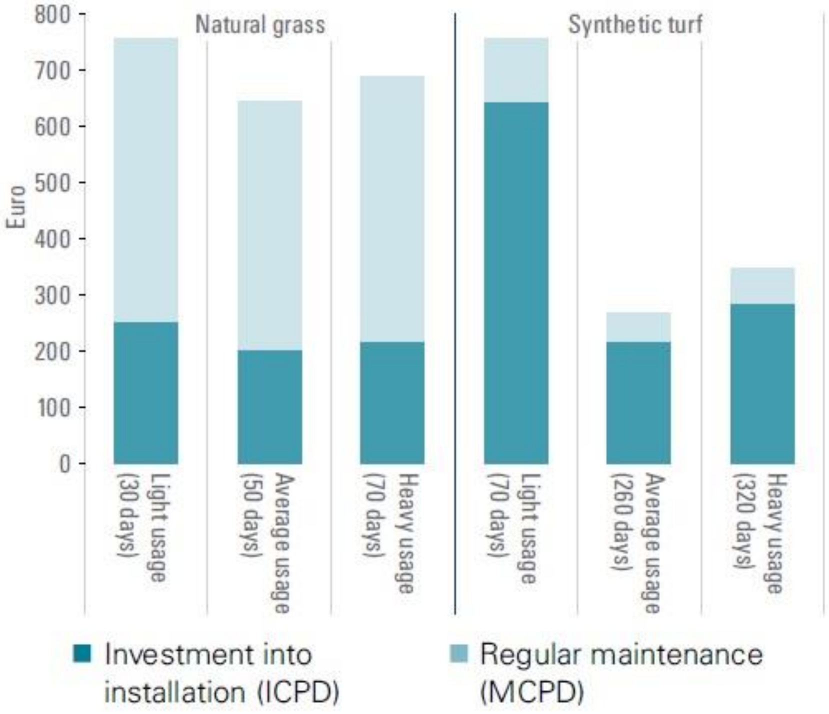
Concerning Europe, the main source of data is a study done by the KPMG in 2012, commissioned by the European Synthetic Turf Organization (ESTO). The study comes to the same conclusions as for the French case presented above. Mainly that the construction of synthetic field requires a large capital investment (300,000€ to more than 1 million euros, depending on the quality of the field) and that the maintenance costs are higher for the natural grass (5-15,000€ versus more than 20,000€), but the difference is not significant.

The study enlightened also the fact that synthetic fields can be more used: 20-40 hours per week compared to 5 to 10 hours per week for a natural grass. Unfortunately, the study does not give any indication on the end-of-life (or so called disposal) costs.

In the graph below (included in the study by KPMG on synthetic turf in Europe), the total costs per playing days are divided into the investment costs per playing day (ICPD) in darker blue, and the maintenance costs per playing day (MCPD) in lighter blue, for natural grass and synthetic turf.

What comes out of the graph is:

- The total cost per playing day is higher for any kind of use for natural grass compared to synthetic turf.
- For natural grass, the maintenance cost per playing day represents the most important part of the total cost per playing day. Indeed e.g. for heavy usage, maintenance cost is approximately equal to 71.4% of the total cost per playing day.
- For synthetic turf, the investment cost per playing day is the most important part of the total cost per playing day. Indeed for heavy usage, the investment cost per playing day represents approximately 85.7% of the total cost per playing day.
- In any kind of usage (light, medium or heavy), synthetic turf can be more intensively used than a natural grass field. For example, the heavy usage of the natural grass is equal to 70 playing days, whereas it is equal to 320 playing days for the synthetic turf.



Source: KPMG research
Note: Time value of money was not considered because of the significant variations in the rate across different countries.
Assuming the construction and the installation of the turf was delivered properly.
Assuming the turf is maintained properly to provide a quality playing surface continuously.

Figure 6: Total costs per playing day (TCPD) of synthetic vs natural turfs in Europe (Source: KPMG, 2012)

In the "Environmental impact study on artificial football turf" report, published by the Eunomia Research & Consulting Ltd for FIFA in 2017, it is said that in Europe, the method of disposal that is the most preferred is landfill. For example, the cost of disposal per ton for France is around $85, whereas it is around $145 in Sweden.

5.2.3 Costs data at the international level

It seems that the different problems emerging from the use of synthetic turf came into the light sooner in the United States. Hence the economic analyse trying to compare the costs of both fields are more numerous for the US than for Europe or France. Therefore, in this section, data for the USA and Australia are presented.

As one can see, the same conclusions as developed in the precedent section for Europe will be drawn.

5.2.3.1 USA

5.2.3.1.1 Construction costs

The data presented below are extracted from a guide written by Sportsturf Managers Association, which is a non-profit association of managers of outdoor sports, which tries through its published guide, to help managers to choose between natural grass and synthetic field.

As already shown above for other geographical areas, a synthetic field is more expensive to install than a natural grass field. Indeed, according to the figures provided in Table 2, a synthetic turf would cost, on average, approximately five times more than a natural with on-side soil field.

	Costs range for construction (in US $ such as provided in the study)	Costs range for construction (converted in euros[4])
natural with on-side native soil	\$0.60-\$0.90 per sq. ft.	€0.52-€0.78 per sq. ft.
natural with native soils	\$1.25-\$2.50 per sq. ft.	€0.87-€1.73 per sq. ft.
natural with sand cap	\$2.60-\$3.85 per sq. ft.	€1.73-€2,6 per sq. ft.
natural with sand and drainage	\$4.25-\$5.00 per sq. ft.	€3.46-€4.32 per sq. ft.
synthetic infill	\$4.50-\$10.25 per sq. ft.	€3.46-€8.66 per sq. ft.

Table 2: Construction costs for different types of fields in the USA (Source: Sportsturf Managers Association, no date)

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[4] Conversion rate of June 2018: 1 US$=0.86412€

5.2.3.1.2 Maintenance costs

The data collected on maintenance costs and provided herein come from Massachusetts Toxic Use Reduction Institute, 2016. The costs presented below in the different graphs concern a field of 85,000 square feet, which approximately corresponds to a soccer field. The figures are averages (see Appendix for the full ranges).

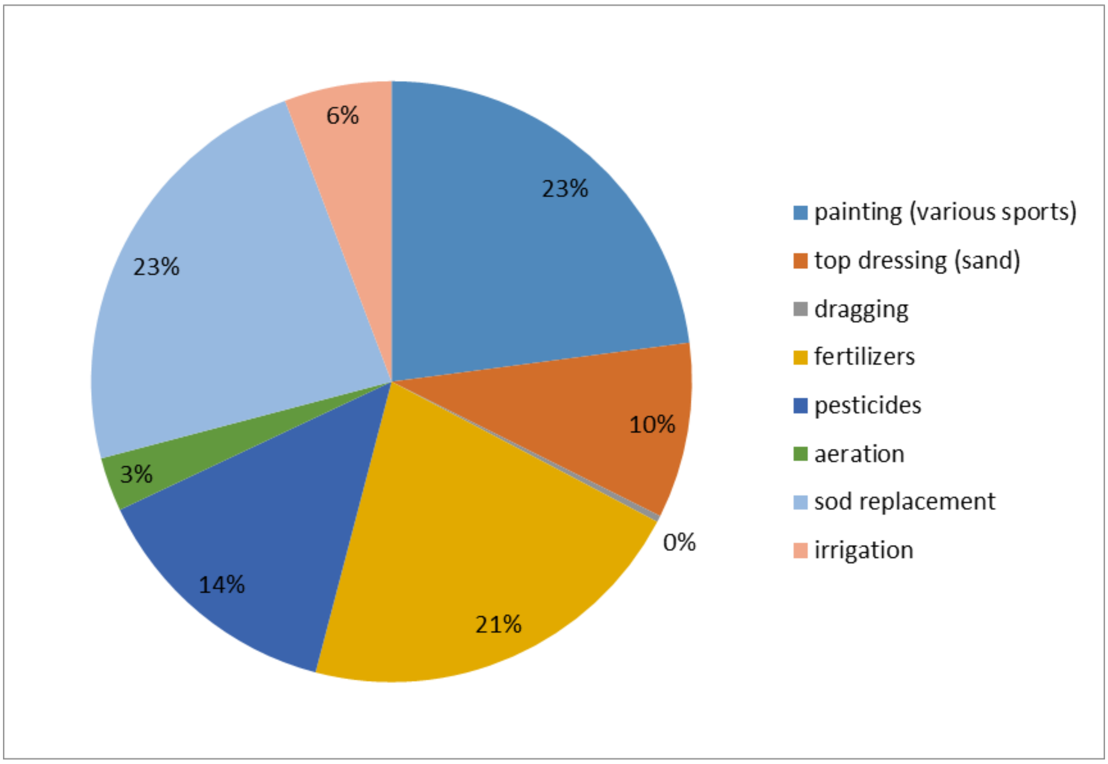

Figure 7: Average annual maintenance costs for natural grass in the USA (Source: Massachusetts Toxics Use Reduction Institute, 2016)

The total annual maintenance total costs range from $8,133 to $48,960 (€7,034 to €42,347). From the Figure 6, the biggest maintenance costs components are:

- painting, if different sports are played on the same field and sod replacement, which count for 23% of the total cost each
- fertilisers, which represent 21% of the total cost

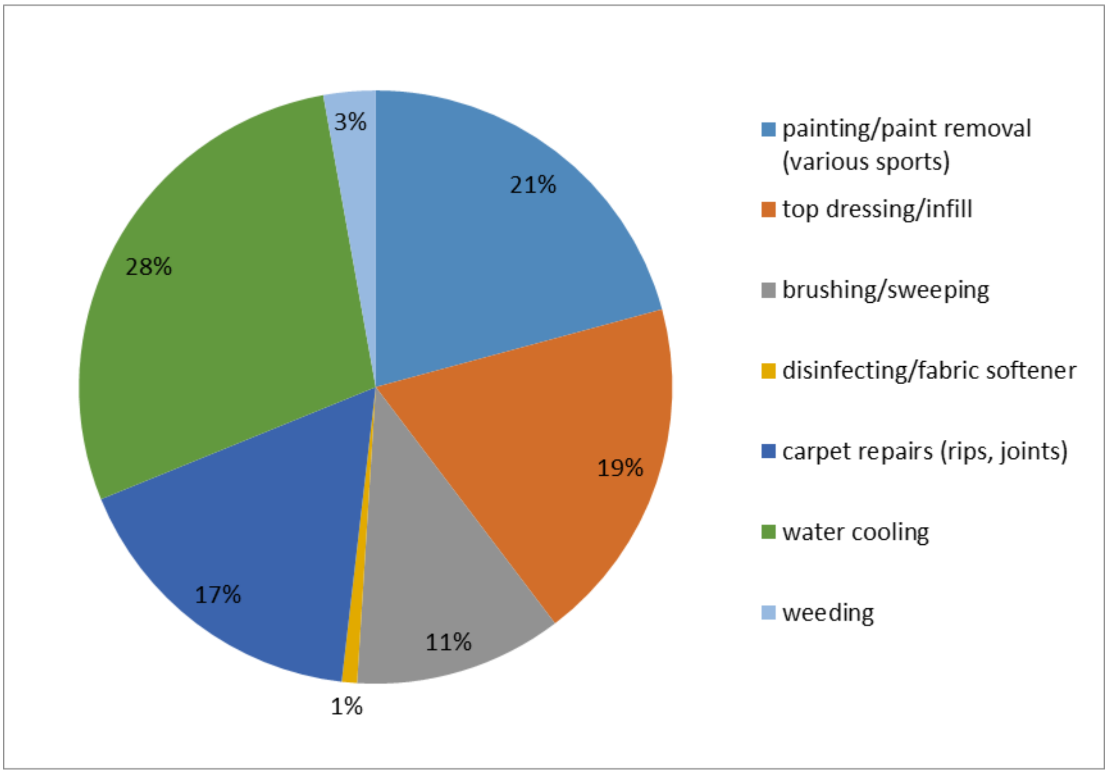

Figure 8: Average annual maintenance costs for synthetic turf in the USA (Source: Massachusetts Toxic Use Reduction Institute, 2016)

The total annual maintenance total costs range from $13,720 to $39,220 (€11,870 to €33,923). From this graph, it can be seen that:

- as a whole painting/paint removal, water cooling, carpet repairs and top dressing represent 85% of the total maintenance cost
- Water cooling amounts for 28% of the total cost. Indeed, it is reported that synthetic turfs generate a lot of heat under cold or hot days; therefore in order to control the temperature water is sprayed across the field.

From these two graphs, two conclusions can be drawn: mainly that the range of total maintenance costs is wider for natural grass; but on average the difference between the total costs is not significant ($28,547 (€24,698) for natural grass versus $26,470 (€22,899) for synthetic field).

5.2.3.1.3 End of life costs

As already mentioned, end of life costs (or so called disposal costs) concern only synthetic turfs.

The figures of Table 7 below are reported in Massachusetts Toxics Use Reduction Institute, 2016 and come from two different sources:

- The Sportsturf Managers association (STMA)
- The Turfgrass Resource Center (TRC) is a non-profit association that promotes the use of natural grass.

	Disposal cost summary for synthetic turf of 85,000 sq. ft. (in US $ such as provided in the study)	Disposal costs summary for synthetic turf of 85,000 sq. ft. (converted in euros[5])
Removal and disposal (TRC)	**\$149,000-\$191,000**	**€128,908-€165,274**
Disposal and resurfacing (STMA)	\$553,000-\$663,000	€478,560-€573,799
Transportation and landfill (STMA)	\$130,000	€112,490
Total (STMA) (disposal&resurfacing+ transportation&landfill)	**\$683,000-\$793,000**	**€591,006-€686,254**

Table 3: End of life costs for synthetic turf in the USA (Source: Massachusetts Toxics Use Reduction Institute, 2016)

For the TRC, removal and disposal of a synthetic turf would cost between \$149,000 and \$191,000 and for the STMA the total cost related to the end of life of a synthetic turf would cost between \$683,000 and \$793,000.The studies thus provide very large ranges from one to another. However, the removal costs are significant. Any life-cycle costs analysis (including the whole costs of a field from construction to end-of-life over more or less long timeframes; see next section) performed could then turn the scales in favour of the natural grass.

Finally, in the report “Environmental impact study on artificial football turf”, published by the Eunomia Research & Consulting Ltd for FIFA in 2017, some costs concerning recycling, landfill and incineration and costs of disposal are given. Indeed, this report enlightens the fact that the cost of disposal is source of great pressure for managers who wish to install a synthetic turf. According to this report, the cost of disposal can range from \$10,000 to \$50,000 for one pitch. The cost of disposal also depends on the gate fee (price charged by incinerators) or the landfill taxes to be paid for this type of material. Therefore the cost of disposal varies greatly between countries.

The transport costs for Trans-Atlantic shipment by 40ft container ranges from \$50 to \$80 per ton.

5.2.3.2 Australia

In 2011, the Department of Sport and Recreation of the government of Western Australia published a study report entitled “Natural grass v synthetic turf”. This report analyzed different types of sports fields and a life-cycle cost analysis is performed.

Compared to other reports already presented, this study adds new information: it distinguishes between elite (competition) and community (leisure) level. This distinction is interesting, because at the competition level, natural of synthetic fields have to comply with some general rules, like for example FIFA requirements, which can be found in “FIFA Quality Programme for Football Handbook of Test Methods”. These requirements are stricter than for community fields and may

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[5] Conversion rate of June 2018: 1 US\$=0.86412€

increase the costs of compliant synthetic fields. Here below, data for soccer fields only are considered.

Type of costs	Natural field	Synthetic field
Construction costs	\$212,000 (€135,458[6])	\$705,000 (€450,333[3])
Maintenance costs for a "community sport field"	\$27,250 (€17,406[3])	\$25,000 (€15,967[3])
Maintenance costs for a "elite sport field"	\$34,400 (21,973€[3])	\$25,000 (€15,967[3])

Table 4: **Construction, Maintenance costs for community and elite sport field in Australia (Source: Government of Western Australia, 2011)**

The conclusions from this table are in line with all previous studies. Indeed, a natural grass field requires a lower investment than a synthetic pitch (whatever is the elite or community level of the field); maintenance costs for a community sport field are not very different either this is a synthetic or a natural field. However, the maintenance costs for an elite sport field are larger for a natural field than for a synthetic turf. What is worth noticing is that the maintenance costs for a synthetic field is the same at the community level and at the elite level. It illustrates the idea that a synthetic field deals better with wear than natural field.

<u>Life-cycle cost analysis for a "community sport field"</u>

The Department of Sport and Recreation of the government of Western Australia also reports life cycle costs for a community sport field. A life cycle costs analysis includes the whole costs of a field from construction to end-of-life.

Table 5 below shows the total cost for a community sport field of both types, over 25 years and 50 years.

Sport	Natural grass over 25 years	Natural grass over 50 years	Synthetic turf over 25 years	Synthetic turf over 50 years
Soccer	\$1,004,917	\$1,797,833	\$2,517,500	\$4,330,000
Soccer (in euros[3])	€641,851[3]	€1,148,312[3]	€1,607,978[3]	€2,765,874[3]

Table 5: Life cycle cost for a community sport field in Australia (Source: Government of Western Australia, 2011)

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[6] Conversion rate on June 2018: 1 AU\$ = 0.639€

A natural grass field seems to have a lower life cycle cost over 25 years and 50 years. But it has the benefit to enlighten the fact that synthetic turf can be more costly than natural grass, and also the importance to weight the pros and cons when installing a natural grass or synthetic field over the whole lifespan of the field and even over longer timeframes.

5.3 A comparison of the benefits of synthetic turf and natural grass

The benefits for both types of fields hereafter, focus on the following issues: playing capacities, safety of the field, economic perspectives, preference of the players and environmental impact. They are qualitative and do not address some issues such as disposal costs of synthetic turfs, environmental impacts...

Benefits of synthetic turf	**Benefits of natural grass**
Occupancy rate: Synthetic turfs have begun to be very popular especially for big cities as for example Paris, because there is a lack of space for recreational activities. Indeed, five natural grass fields will provide the same supply as one synthetic field (IRDS, 2011). A synthetic field can be more intensively used: 30 hours per week compared to 6 hours per week for natural grass (*IRDS, 2008*).	**Less heat:** a natural grass is a living organism therefore it regulates itself, whereas a synthetic turf attracts more sunbeams and so becomes hotter. A case study done at the University of Missouri enlightened this fact. Dr. Brad Fresenburg compared two fields: the MU's Faurot Field, a synthetic field and a natural grass field near by the latter field. He found that under a 98°F (37°C) day, the artificial field was 173°F (78°C) and the natural grass was 105°F (41°C) (*TRC, no date*). In order to decrease the temperature, the synthetic field has to be watered. A case study of the Brigham Young University exposed the fact water application could decrease the temperature from 178°F (79°C) to 85°F (29°C). But five minutes later, the temperature will increase to 120°F (49°C) and twenty minutes after water application, the field will be 164°F (73°C) (*TRC, no date*).
Water saving: can save 4,000,000L of water per year for one field (Aigueperse, 2017)	**Softness**: greater shock absorption (Yasamin Alipour Ataabadi *et al.*, 2017).
More resistant to changes in weather: less training cancellations or rescheduling or the necessity of renting another field to train.	**Biodiversity and ecosystem services:** "carbon sinks". Indeed a natural grass can capture carbon whereas synthetic turf cannot (Toronto Public Health, 2015).
New revenues: other events than sport competitions can be organised on the field, as for example fireworks or concerts…, because the turf suffers less than a natural one	**Clear preference of professional players to play on natural turfs:** In 2010, the NFL players association conducted a survey (*NFL players association, 2010*). A total of 1619 players, coming from 32 different teams filled the

Benefits of synthetic turf	Benefits of natural grass
	survey. For more details see below.
Easy to install: synthetic turf can be install on any surface, indoor and outdoor (Aigueperse, 2017)	Produces smaller peak push-off force and do not slow down changes in acceleration during sport practice. (Yasamin Alipour Ataabadi *et al.*, 2017).

Table 6: Compared benefits of synthetic turf and natural grass

Such as indicated in Table 6, the following graphs illustrate the players' preference to play on natural grass than on synthetic turf field.

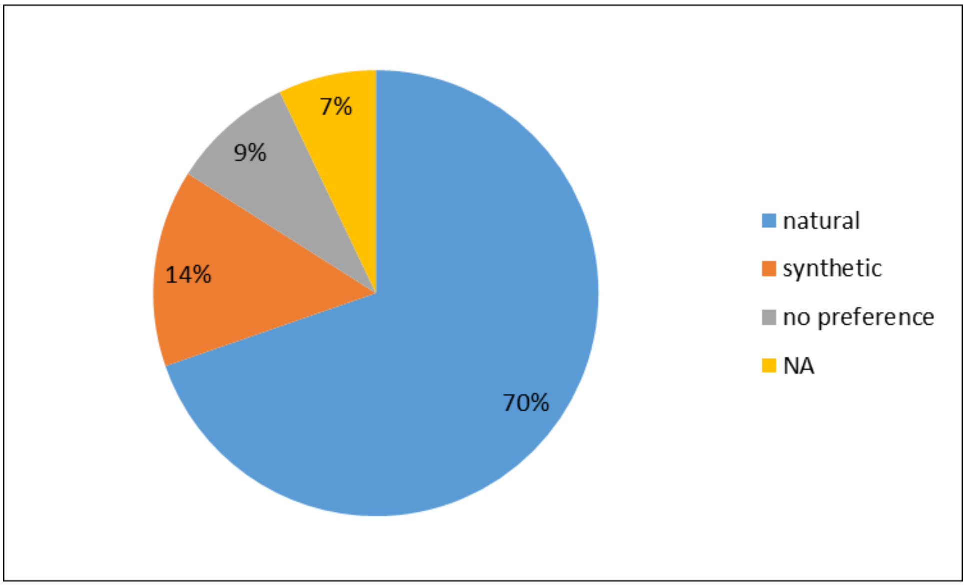

Figure 9: What type of field do you prefer to play on? (Source: NFL Players Association, 2010)

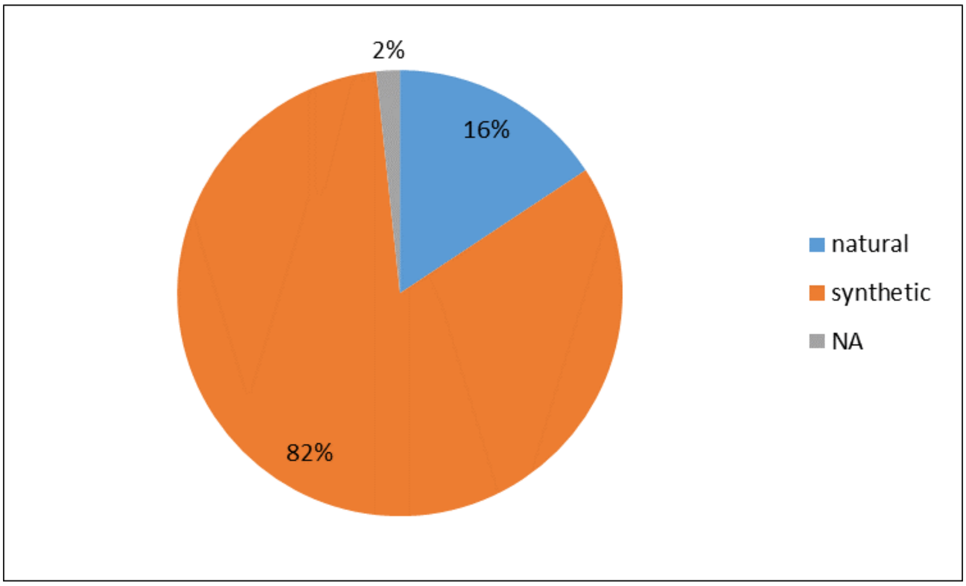

Figure 10: Which surface do you think is more likely to contribute to injury? (Source: NFL Players Association, 2010)

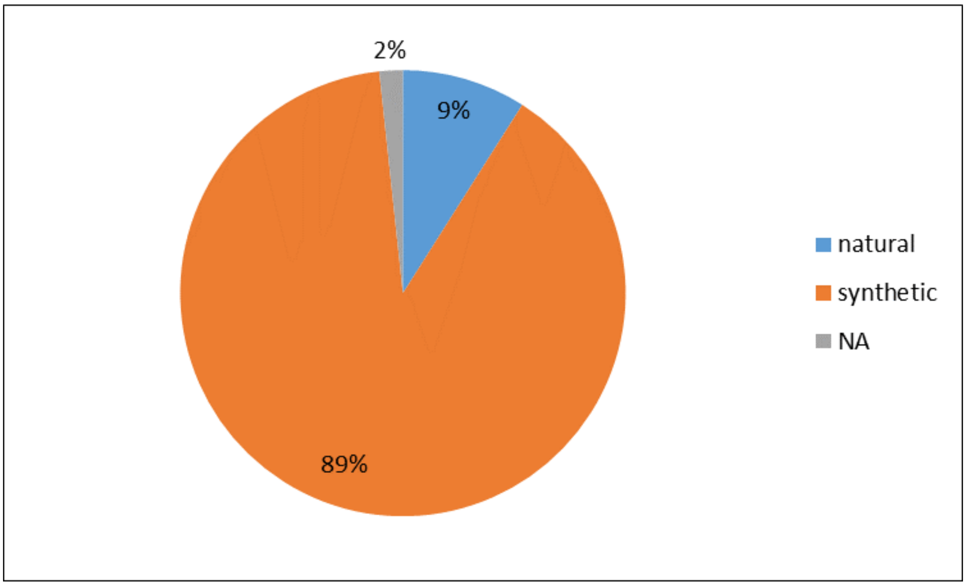

Figure 11: Which surface do you think causes more soreness and fatigue to play on? (Source: NFL Players Association, 2010)

As it can be seen, 70% of the players that responded to the survey, prefer to play on natural grass field (Figure 8). To questions related to pain and injuries, players answered that synthetic field contributes more to injury and causes more soreness and fatigue than natural grass (Figures 9 and 10).

5.4 Conclusion

The choice between synthetic and natural grass should be very carefully thought considering costs and benefits. **The different costs related to the two types of fields were described, based on the available literature. However, no final recommendation can be drawn at this stage**. Indeed, the pros and cons listed above should be closely studied prior to any decision, based on the local conditions and constraints.

Overall three key points should be borne in mind:

- Synthetic turf has a higher investment value than natural grass.
- The maintenance costs of both types of fields are not significantly different, the synthetic being overall cheaper to maintain.
- Opting for synthetic turf will generate additional costs, mainly disposal (end-of-life) costs.

6 Sociopolitical dynamics. Actors and ideas of the debates about artificial fields: Characteristics, shifts, and persistence

6.1 Contexts and topic

The sociopolitical debates about synthetic grounds based on ELT-derived rubber granules from recycled tyres, are deeply multidimensional, heterogeneous and evolving in time and space. However, there is also persistence.

Before considering recycled tyres, let us say a few words about artificial fields. The first synthetic grounds were developed by Ford and Monsanto in the 1960s (Claudio, 2008). At that time, these were based on nylon plastic. They were strongly developed the following years, in particular for professional sport arenas. In the 1980s, first concerns and questions emerged, notably about physical shocks and injuries for sport players, in England as in the United States of America (USA). This contestation has grown during the 1990s. However, natural grass also shew its limits for professional sport. Anyway, the competition between these two types of fields and their advocates was launched at that time.

Besides, the new and so-called third generation of artificial grounds, *i.e.* based on infill material from recycled tyres, was born in this very period of 1990s. It has been first used for sport pitches, then for children playgrounds in the end of 2000s at the international level. It is still used nowadays. In particular, since 2004 (FIFA, 2004), the installation of synthetic turfs has fostered a perennial international debate within football communities. Nevertheless, there have been other actors and areas of controversies. Precisely, this third generation of artificial grounds has generated several types of concerns: environmental concerns (release; end-of-life pitches management; loss of green spaces), sport concerns (performance, rebound, speed) and health concerns (abrasion, injuries, linked with bacteriological contamination or not; chemical exposures; cancers; annoyance and uncomfortable smell…).

6.2 Goals and approaches

This chapter aims to provide a quick overview of the various debates about synthetic fields. It suggests notably putting the French situation into perspective. This chapter is based on a review of different sources, such as grey literature (scientific and technical reports; industrials and NGO’s documents); generalist press (national, local) and specialized press (sport; economy; investigation). There is indeed no specific academic literature in social sciences which deals with sociopolitical contexts and debates about artificial grounds. However, some elements about them can be integrated into natural sciences publications, even if this is not developed so much and lacks precision about the evolutions or the types of actors. Considering the huge range and density of controversies and sources at all levels, as the correlated difficulty of “chicken-and-egg situations”, this presentation cannot be exhaustive. Therefore, the salient facts are here synthetized.

6.3 The cross-cutting aspects of multidimensional debates

Despite of the variety of national and local dynamics of debates, several constant features can be detailed.

First of all, the locations and uses of synthetic fields are plural. They include indoor and outdoor sport pitches, children playgrounds in cities and schools, and urban parks. The first ones stay at the core of the debates at the French and international levels. Secondly, the discussions about this type of grounds have been including various private and public actors. Behind the "public" or "private" labels, there is definitely a wide range of figures: individuals and groups, organizations and institutions, sectors, spheres of socialization and work, existing in different scales (local, national), mostly in industrialized countries.

PUBLIC ACTORS	PRIVATE ACTORS	HYBRID ACTORS
State, national and local administrations	Producers of artificial fields	Whistleblowers
Local authorities	Installers	Schools
Environment, health agencies	Eco-organization	Academics
Legal institutions	Leisure companies	
Public advocates	Amateur sport associations	
Elected officials	Professional sport federations	
Scientific and technical institutes	Civic groups	
Cabinets	Environmental associations	
	Families	
	Media	

Table 7: The various categories of actors of the controversies[7]

Specifically, the controversies about synthetic fields illustrate the everydayness and the familiarity of this tool of leisure and sport. They have indeed emerged with direct sensitive experiences, as visual (tactile, olfactory sensations (for instance, children coming back home infill material in shoes after playing sport): in other words, "questioning by feeling" or "contesting by doing". This is exemplified by the significant presence of individual citizens as parents into the debates. These are notably preoccupied for their children playing on artificial grounds and coming back home with rubber crumb in their shoes. In the same time, these logics of debates have been deeply interconnected with several technical and scientific publications and reports since the middle of the 2000s. These can be separated in two groups. The first scientific works have been dedicated to physical issues as injuries (Dragoo et *al.*, 2012) and bacteria (Kazakova, et *al.* , 2005), then to considerations regarding chemical characterization, exposures, and impacts. Even the first aspect is currently less disputed in public debates than the second one, it has not disappeared (Rennie et *al.*, 2016). Moreover, in several industrialized countries, there have been plenty of technical and

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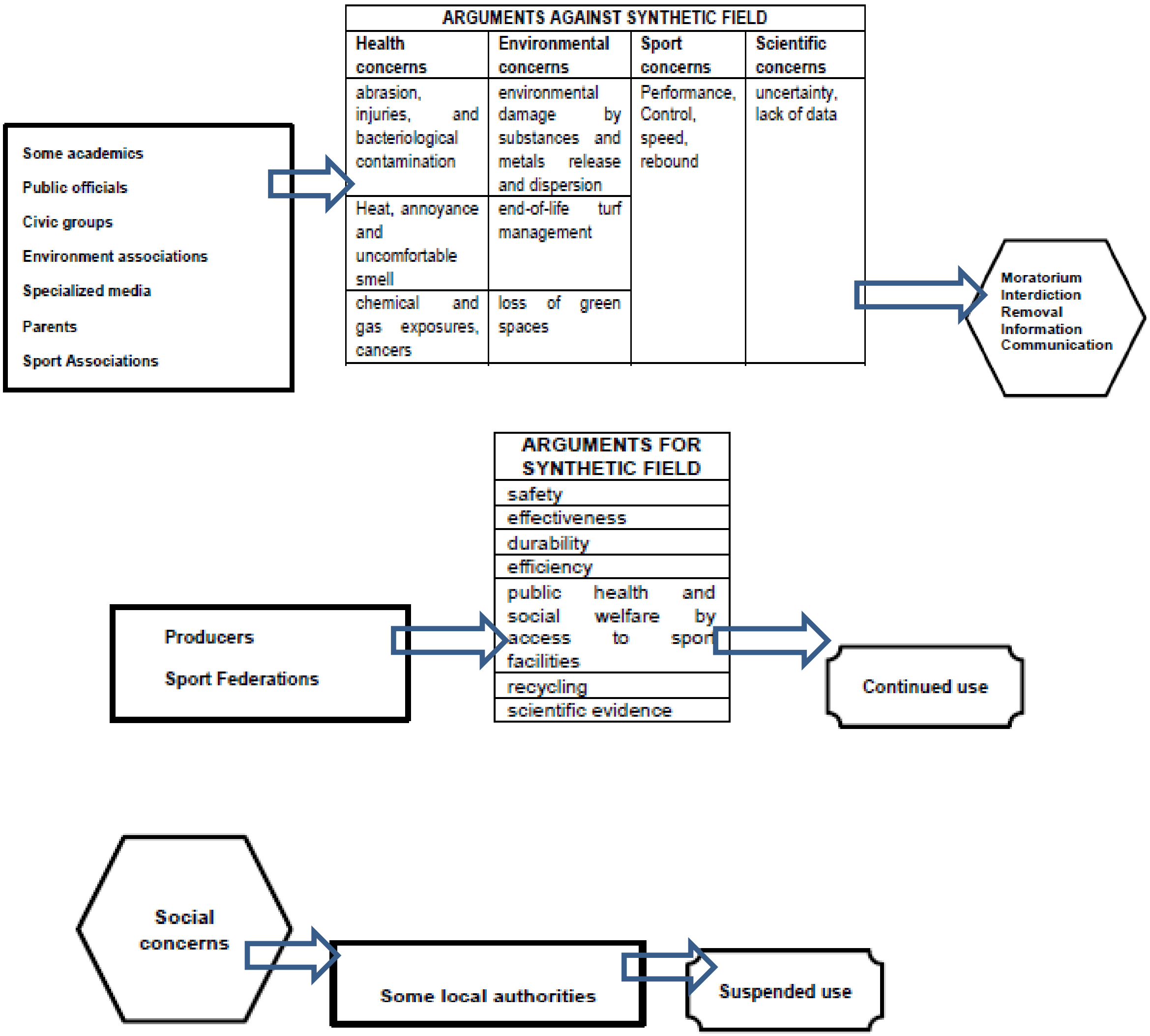
[7] The homogeneity of each subgroup cannot be overstated. In the same time, convergence between these various actors is sometimes possible, but varies in function of ideas and situations. Consequently, different concerns and responses have been linked with various artificial grounds made from recycled tyres.

scientific studies which have shown the weak or negligible risk of artificial fields for many years[8]. However, some analyses do not share this viewpoint. Indeed, some are more qualified even alarming, whether this is the quality and conditions of scientific research (lack of data, of global approach or case studies; industrial funding; uncertainty…) (Watterson, 2017 ; Llompart et *al.*, 2013 ; Devitt et *al.*, 2007 ; Willimans et *al.*, 2006), or the presence of substances (Zhang et *al.*, 2008 : Mattina et *al.*, 2007 ; EHHI, 2017 ; TRC, 2008) or risks (Crain, Zhang, 2007), or the need of additional public information (ECHA, 2017).



ARGUMENTS AGAINST SYNTHETIC FIELD			
Health concerns	Environmental concerns	Sport concerns	Scientific concerns
abrasion, injuries, and bacteriological contamination	environmental damage by substances and metals release and dispersion	Performance, Control, speed, rebound	uncertainty, lack of data
Heat, annoyance and uncomfortable smell	end-of-life turf management		
chemical and gas exposures, cancers	loss of green spaces		

ARGUMENTS FOR SYNTHETIC FIELD
safety
effectiveness
durability
efficiency
public health and social welfare by access to sport facilities
recycling
scientific evidence

Figure 12: Actors, ideas and claims of the controversies on synthetic grounds

Finally, these debates about artificial fields based on recycled tyres remind us the possibility of perverse effects of practices and logics positively supported by public action and society. One key issue is at stake with artificial grounds: the potential negative effects of environmental-friendly practices as recycling and more broadly circular economy. These dynamics have only been foreseen as virtuous so far.

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[8] See *supra.*

6.4 Synthetic fields: the discussions at international level in and out of football communities

The international level of controversies about synthetic grounds can be detailed. In this report, this is justified by the following reasons:

- the relative similarity of the manufacturing of French, European and American artificial fields
- the strength of the international discussions about synthetic grounds (relayed in France), contrary to what is perceived by some French producers[9]

Briefly, the debates about artificial grounds have begun in the middle of the 2000s in England, North America, Northern Europe, then continental Europe, most recently in China. To sum up, a basis process and timeline of the discussions can be drawn.

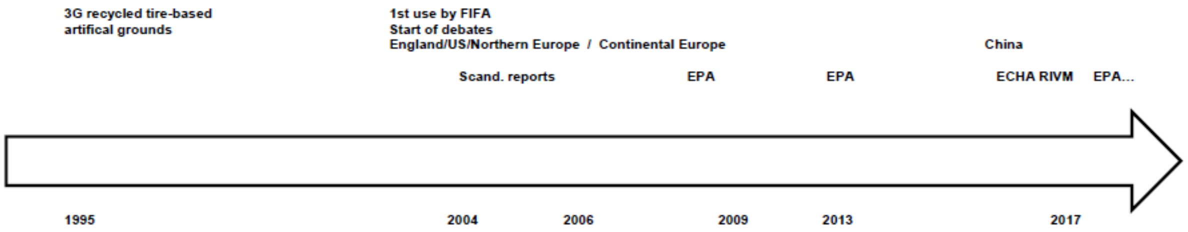

Figure 13: Basis timeline of international debates

More precisely, since the middle of the 2000’s, the international level is thus characterized by:

-the first steps of public questioning about synthetic grounds made from recycled tyres, notably in North America and Europe, and within football communities

-the noticeable role of some whistleblowers recensing sick sport players as media coverage, both echoing and fostering new scientific studies

-the mix of health (physical, chemical, welfare aspects ; risks of cancers), environmental, sport considerations, linked to the principle, texture, composition, and situation of artificial grounds

6.4.1 Football, a first and perennial area of international debates with various preoccupations

The amateur and professional football communities (players, supporters, managers…) at the international level represent a first and major area of discussions about artificial grounds based on recycled tyres, notably in USA, England, Canada, and Northern Europe. The physical, chemical, and sport dimensions of the controversies have also grown in Northern Europe (Norway, the Netherlands, Sweden, Denmark, and Great-Britain).

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[9] Hearing, economic actors of the infill material chain, Anses, 3rd May 2018.

Physical injury on artificial fields is one of the health aspects of the debates. In 2005, a Swedish football association published a study on the player attitudes on synthetic fields (Johansson, Nilsson, 2005). It underlines these are reluctant to play on artificial grounds, notably in Holland, Germany and Slovenia. The risk of injury is indeed perceived higher for the majority of respondents in Germany and Norway, not in Italy and Slovenia. In that context, FIFA and UEFA (Union of European Football Associations) have developed studies on physical injuries on synthetic grounds since the beginning of their use in the middle of 2000s. In 2006, a study these organizations mandated shew that there was globally no more risk of injury on artificial grounds than on natural turfs, except in the case of ankle injuries (FIFA, 2018). In the same time, a literature review noticed in 2015 that none research can prove the correlation between natural turfs and risk of injury within football (Rennie et *al.* 2016). Finally, the scientific data on the link between type of pitches and risk of injury are pretty ambiguous.

In the meantime, the chemical dimensions of the controversies about artificial grounds have quickly emerged.

Since 2009, the American ex-players and soccer coaches Julie Foudy and Amy Griffin have warned about leukemia affecting their players, especially the goalkeepers. They have made a list of ill players. Nevertheless, their investigation did not directly correlate cancer and artificial turfs. The Washington State Department of Health (WSDH), and several researchers responded and expanded the coaches'approach. Their work confirms that the number of ill players of the list is lower than the cancer rate among all Washington residents of similar ages. They also confirm the safety of artificial turfs (WSDH, 2017). In the meantime, the number of ill players, playing in both natural and synthetic grounds, has been growing on the list of J.Foudy and A.Griffin (now 237). Another response to the coaches' initiative came from the Synthetic Turf Council, a forum and trade association of producers promoting artificial grounds. It echoed the WSDH report, recalling the importance of the healthiness of sport. Other producers underlined the similarity of the levels PAHs and VOCs found in artificial fields and in natural soils, as Center of Disease Control (CDC) and Environmental Protection Agency (EPA) have already noticed (EPA/CDC/ATS, 2016). However, this very report of WSHD has been challenged, notably by Environment and Human Health, Inc. (EHHI). This organization is an advocacy group of Connecticut composed by scientists. It is notably involved in the artificial grounds debate and very quoted by the American press. In 2017, EHHI published a report underlining the lack of data on synthetic fields and consideration for cocktail effects in a group of publications. It also published in 2015 the inventory of chemicals in the artificial grounds of Yale University, whose part turns out to be carcinogenic (EHHI, 2017).

Recently, In Great-Britain, the debates about artificial fields have notably been expanding with the alert of a National Health Service director, Niguel MacGuire, whose son got cancer. He wants to stop the installation of synthetic fields and have been studying the various researches, notably about the new chemical components added in fields (The Telegraph, 2016). About these aspects, in Holland, in 2016 a TV report Zembla named “Dangerous Play” was broadcasted. It showed children’s leukemia playing football on artificial pitches. It also underlined that scientific research about artificial pitches was limited, and safety not absolutely guaranteed. It notably targeted a study of the Netherlands National Institute for Public Health and the Environment (RIVM) of 2007 which has indirectly taken part in the boom of artificial fields in the country by concluding to the safety of synthetic fields. More broadly, the TV show raised questions from parents, public authorities, as sport associations. This has led to a new publication of RIVM in December 2016 (RIVM, 2017). This has tested substances existing in ELT-derived rubber granules of 100 sport fields, and made an international scientific review on these substances and impacts. It concluded to health negligible risks, and no correlation with leukemia or lymphoma. In the same time, it confirmed the possible environment effect of metal release[10]. In this European context, the European Chemicals Agency (ECHA) confirmed in 2017 the low risk of cancer in regards of PAHs concentration, and more globally the negligeable characters of health concerns (ECHA, 2017). Currently supported by the Netherlands, the concentration limit of PAHs in infill material is intended to be restricted in a near future in the framework of REACH Regulation. In the meantime, the precautionary principle is applied by several local public authorities while several synthetic fields have been removed.

Finally, another aspect of concern has emerged at the international level in the professional football sphere. It is the decrease of sport performance on artificial grounds. Some teams connected low scores, loss of speed and control, rebound problems (Johansson, Nilsson, 2005) with artificial pitches, even if there are counter-examples, like the German team. In 2015, a petition gathered more than 23 000 signatures of professional football players. This has been led by the American player Amy Wambach to make natural grass come back for the Women Football World Cup in Canada in 2015 (The Guardian, 2014, 2015). A lawsuit was filed against FIFA and the Canadian Soccer Association, arguing gender discrimination because men players can play on natural grass. This kind of initiative was repeated by the Women US soccer team (New York Times, 2015), but in a broader context of demand to improve the work conditions (the New York Post, 2017). Despite a first agreement with the US Soccer association, the players are regretting the slowness of the change.

6.4.2 Within and beyond football: the North American case

Nevertheless, the importance of the debates on artificial fields within football communities is not exclusive. The American situation illustrates that. At federal, federated, municipal levels of the USA, they have been plenty of debates and mobilizations about synthetic grounds. New York City (NYC) exemplifies the variety of discussions about this topic. It also concentrates a large part of artificial fields among the US municipalities (Katz, 2007), and its local debates are deeply publicized. The first public concerns have emerged in the late 2000's. In 2008, the NYC Health Department found a high level of lead in infill material of a park of Manhattan. Other tests were performed on other fields, but all of them showed acceptable lead levels according the EPA standards, quoted by the NYC Department of Parks and Recreation). In the same time, since 2008, various actors (parents, public local officials, public advocates, environmental associations, civic groups of NYC) demanded the end of artificial grounds. Chemical exposures but also heat, excessive use of water, loss of green areas and connection with nature were denounced. Considering particularly the first issues, a specific elected official has notably asked for a moratorium until new scientific conclusions (the Gotham Gazette, 2008). So did the NGO NYC Parks Advocates preoccupied by the absence of any environmental impact assessment of artificial grounds. On the opposite, the NYC Health administration as the NYC Parks administration insisted on the safety of these turfs. In the same time, the NYC Health and Environment Departments sponsored a new study on chemical release in 2008-2009 (NYSDEC/NYSDOH, 2009). This concluded to none significant environmental and health risks, and underlined that the heat conditions must be very high to affect human health. At the federal level in 2009, the US EPA also worked on the safety of synthetic pitches and playground. On the first place, it concluded to a weak level of concern (EPA, 2009). As this study was not considered comprehensive, adjustments were made in 2013, and a new global analysis has been launching with the Center of Disease Control (EPA/CDC/CPSC, 2016). This latter finally explained the impossibility to get sound conclusions on health risks, due to the lack of data and knowledge on chemical expositions. Finally, NYC has stopped to install new grounds based on ELT-derived rubber granules, and informed public about precaution linked to the preexisting artificial grounds. Some local authorities have made different

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[10]. See *supra.*

arrangements. For instance, the State of Connecticut keeps on using them by giving priority to encapsulated infill material since 2017.

To finish about the international level, we must note that the controversies can also oppose the manufacturers of artificial and natural grounds, but they are more discrete. They thus deal with the advantages and drawbacks of the different types of fields. For instance in the USA, the leading producer of artificial turf, the Tarkett group, notably its division FieldTurf (outdoor sports) has underlined the quality of this type of ground, as the absence of health or environmental risks. On the contrary, some producers of natural grass like the European Seed Association have challenged the resistance, the safety of synthetic fields, and its environmental impacts (ESA, 2006) in order to promote the natural ones[11].

6.5 What about France?

Since the middle of 2000s, two steps of discussions about artificial grounds have been significant in France:

1) 2005-2011: confined discussions at the national level with public authorities, economic actors, and the environmental association Robin des Bois. The latter has been calling for the end of synthetic grounds based on infill material.

2) 2012-…: growing public and local discussions and strong media coverage. They have notably involved local authorities as families, in addition to the aforesaid actors, demanding new scientific studies on health risks.

- There have not been so many NGOs which have been mobilized on the artificial grounds topic at the national level. Robin des Bois has been the only one since the middle of 2000s, with an global, environmental as much as sanitary understanding of the issue of used tyres.
- The formulation of artificial grounds, and exposures to chemical compounds and sanitary risks, notably for children, represent the main and persistent concerns.
- Occupational health and professional exposures considerations have recently emerged, notably supported by Robin des Bois as the Ministry of Labour
- Refering to some European reports, the producers of artificial fields have put social concerns in questions

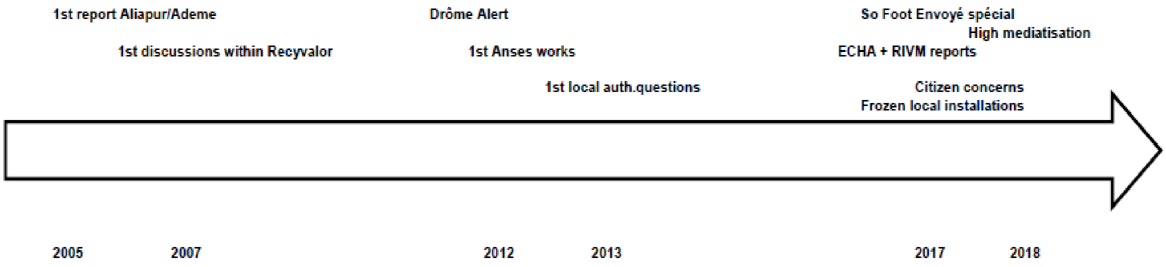

Figure 14. Basis timelines of the debates in France

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[11] About a comparison between natural and artificial fields, see *infra.*

6.5.1 Children and environment exposures to chemical compounds: the first debates (2005-2011)

The French debates have notably begun in confined spaces at the national level since 2007. They have been notably fed by the environmental NGO Robin des Bois, when this used to be a member of Recyvalor, a pluralist network with public and private actors dealing with the management of abandoned tyres. An important issue is that this association has been tackling the broad topic of tyres from environmental and sanitary viewpoints, and not only those related to synthetic fields.

On the sanitary aspects, the possible toxic emissions in case of fire in sport rooms, the exposure of children playing indoor football (also coming back home with rubber crumb in shoes), the possible air pollution, the unpleasant smell and the residues of infill material in children shoes have been the first drivers of its mobilization. In environmental terms, Robin des Bois has also denounced the issue of dispersion and water pollution. In parallel, the uncertainty of substances of concern in tyres as on roads, the long-term effects, the traceability of infill material[12], and the use of end-of-live grounds have constituted other core preoccupations of the NGO. Consequently, Robin des Bois has primarily been demanding the exclusive use of ELT-derived rubber granules for energy recovery, and the end of their use for artificial pitches due to huge uncertainties on potential risks.

In the first instance, this claim has been opposed to a first national private-public agreement on the continuation of granulation. There are several reasons for that. On one side, this process represents an economy, with jobs. On the other side, it takes part into the growing ideology of circular economy, and its growing place into political agenda at various levels of public action since the end of 2000’s. These justifications gathered economical actors (tyre recycling) and political actors (Environment Cabinet). This illustrates the difficulty to foresee the potential negative externalities of green dynamics as recycling and circular economy. These dynamics are only described as essentially virtuous until now.

6.5.2 Expansion in public spaces, with new actors and concerns (2012-…)

Since 2012, the discussions about artificial grounds have become more and more public but also local, involving new actors, scientific references and demands, and occupational health considerations.

In 2012, some local preoccupations emerged in Drôme. The benzene levels in a children playground were higher than the authorized standards. Nevertheless, the alert came from employees of the nursery located closed to the playground. Physical effects of nausea, headache, and harmful odors were reported to the Health administration. It has also led Anses to examine the health impacts of artificial fields for the first time (Judille, 2015). A year later in 2013, the first official parliamentary questions about the safety of synthetic fields were addressed to the Minister of Sports from local officials. Afterwards, in 2015, the work (not publicized) realized under the auspices of Anses has concluded to the impossibility to determine some health risks. However, it has called for vigilance. It has also led economic actors to pay attention to rubber components and materials and taken part in scientific studies[13].

Nevertheless, the concerns of local authorities have been persistent. The city of Nantes for instance has asked the Health and Sport administrations clear and sound scientific studies on health (toxicological, physical; biological) risks, as the assistance of Anses. It has considered the

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[12]. It is one of the limits of normalization: synthetic grounds are standardized and get technical files attesting the respect of norms, but still can lack of traceability of the sources of tyres (imported or not). *Idem* about the recuperation of end-of life grounds.

[13] Hearing, Economic actors of the infill material chain, Anses, 3rd May 2018.

ECHA report of 2017 insufficient and still imprecise, even if the conclusions are reassuring.Two media events have amplified these debates in France. Both of them have been widely relayed by generalist national and local press, as they have concerned numerous families, local authorities, and Robin des Bois. The first one is a special report of the magazine *So Foot* published in November 2017 (So Foot, 2017). It has alerted on the health and environmental risks of sport artificial pitches. It has notably echoed the aforesaid international controversies, especially on cancer risks and chemical exposures. In this line, there is also the TV show *Envoyé Spécial* in the 22th of February 2018 sharing the same concerns.

The articles of *So Foot* have definitely been a springboard for Robin des Bois. It has precisely alarmed it about quantity of tyres used for artificial playground, and it has motivated it to engage Anses to work on them. Moreover, several local officials (Nantes, Paris, Bordeaux, Poitiers etc.) interested in environmental health, have been alerted by the publication of *So Foot*. They have asked to the government the application of precautionary principle by referring to growing international studies underlining potential risks (but without specific quotations of these studies except for the EHHI study). Meanwhile, they have demanded a new scientific as independent study, and the developed information and communication to the public. Some local officials have already decided the suspension of the installation, public budgets and procurement contracts dedicated to the installation of synthetic pitches. Others have also challenged the arguments of the low cost of artificial grounds compared with natural ones (So Foot, 2017). Some of them sent new questions to the Minister of Sports in 2017 and 2018. Its response invocated the respect of French toxicological standards and norms, the preexistence of protective regulation (REACH), and the reassuring conclusion of several international studies (French Senate, 2017-2018). It also echoed to the reassuring study of ECHA, and mentioned the Anses work in progress. Nevertheless, all local officials do not share the same viewpoint. Some of them have been alerting on the risks of “ultra-precautionism” (ANDES, 2017), and the need of actualized scientific studies before taking any decision.

In this context, the economic actors of the artificial fields sector have been receiving growing questions from citizens and local authorities. They have understood them as “ “emotions” widely generated by inappropriate perceptions and excessive media coverage[14]. Some of manufacturers have been trying to fight against the “fake news” by public statements (Aliapur, 2018). To answer them, the economic actors globally have drawn upon the above reports of RIVM and ECHA published in 2017. If they can reassure individually, these scientific references have not be able to eliminate collective controversies yet. The economic actors thus have to deal with the public frozen installations and budget for artificial pitches in several municipalities. 30% of the production of artificial grounds have been frozen and deferred until 2019[15].

To conclude, new interrogations of Robin des Bois as the Ministry of Labour have recently emerged. They are related to workers in Paris parks, breathing particles and dust when they clean the artificial fields.

6.6 Perspectives

Finally, the very different actors of the French debates are converging towards a common expectation: the results of the Anses' Opinion. We can also notice that, the controversies tend to be focused on sport fields and chemical exposures in France and at the international level. Thus

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[14] *ibid.*

[15] *ibid.*

the topic of outdoor children playgrounds is less disputed. *A priori*, this encourages Anses to focus on the first type of fields, *i.e*. the sport grounds, notably their chemical composition and the risks of cancer. In the same time, this report is encouraged to mix the social, scientific and technical considerations, and to insist on the less documented aspects of the topic (children playgrounds especially) and other possible pathological correlations (than cancer risks).

7 Composition of synthetic turf fields and playgrounds

A literature review was conducted in order to gather in a table,the substances that have been quantified or detected in synthetic turf fields and playgrounds. It can be noticed that a great amount of data are available for synthetic turf fields. Polycyclic aromatic hydrocarbons, phthalates and heavy metals are the chemicals that are the most frequently investigated in ELT rubber granules. It has to be pointed out that the analytical methods used to quantify the chemicals are not all the same. An uncertainty can be pointed out regading the quantification/detection limits that are not always known in the identified studies.

On the contrary, few studies are already available regarding the quantification and/or the migration of substances that are present in playgrounds.

The US Environment Protection Agency project will provide information on substances that can be present in synthetic turf fields and playgrounds: more than 200 chemicals are currently investigated. Moreover, the Annex XV report from ECHA (2017) hase been investigated. As it gather some peer review studies and industrial data, only the peer review studies have been considered in the hereunder tables.

Here under are 2 tables that list the various substances that have been quantified or detected in playgrounds and synthetic turf fields.

Substances	Maximum Concentrations	Reference
HAP		
Phenanthrène	7,1 mg/kg 3,3 mg/kg 1,56 mg/kg	RIVM 2017 Celeiro 2018 Marsili, 2014
Anthracene	1,1 mg/kg 0,56 mg/kg 0,28 mg/kg	RIVM 2017 Celeiro 2018 Marsili, 2014
Fluoranthene	20,3 mg/kg 13 mg/kg 3,74 mg/kg	RIVM 2017 Celeiro 2018 Marsili, 2014
Pyrene	28,7 mg/kg 18 mg/kg 10,28 mg/kg 9,74 mg/kg : uncoated granules 15,1 mg/kg : coated granules 25,9 mg/kg	RIVM 2017 Celeiro 2018 Marsili, 2014 Menichini, 2011 Menichini, 2011 Ruffino 2013
Benzo(ghi)perylene	7,7 mg/kg 6,6 mg/kg 0,91 mg/kg 29,2 mg/kg : uncoated granules 28,5 mg/kg : coated granules 4,16 mg/kg	RIVM 2017 Celeiro 2018 Marsili, 2014 Menichini, 2011 Menichini, 2011 Ruffino 2013
Benzo(c)fluroene	0,7 mg/kg	RIVM 2017
Cyclopenta(cd)pyrene	2,5 mg/kg	RIVM 2017
Benzo(a)anthracene	2,2 mg/kg 5,7 mg/kg 1,61 mg/kg 0,43 mg/kg : uncoated granules 0,15 mg/kg : coated granules	RIVM 2017 Celeiro 2018 Marsili, 2014 Menichini, 2011 Menichini, 2011

Substances	Maximum Concentrations	Reference
	15,3 mg/kg	Ruffino 2013
Benzo(b) + Benzo(j)fluorenthene	3 mg/kg	RIVM 2017
Benzo(k)fluorenthene	0,5 mg/kg 1,4 mg/kg 3,61 mg/kg 5,02 mg/kg	RIVM 2017 Celeiro 2018 (Marsili, 2014) Ruffino 2013
benzo(a)pyrene	2,2 mg/kg 1,9 mg/kg 0,66 mg/kg 10,7 mg/kg : uncoated granules 2,3 mg/kg : coated granules	RIVM 2017 Celeiro 2018 Marsili, 2014 Menichini, 2011 Menichini, 2011
Benzo(b)fluoranthene	4 mg/kg 15,71 mg/kg 8,81 mg/kg	Celeiro 2018 Marsili, 2014 Ruffino 2013
benzo(e)pyrene	7,8 mg/kg 3,04 mg/kg	RIVM 2017 Menichini, 2011
chrysene	3,5 mg/kg 4,1 mg/kg 3,42 mg/kg 2,38 mg/kg : uncoated granules 0,99 mg/kg : coated granules 4,21 mg/kg	RIVM 2017 Celeiro 2018 Marsili, 2014 Menichini, 2011 Menichini, 2011 Ruffino 2013
dibenzo(a,h)anthracene	0,57 mg/kg 0,03 mg/kg : coated granules 8,13 mg/kg	Marsili, 2014 Menichini, 2011 Ruffino 2013
Sum PAH (8 regulated by REACH)	19,8 mg/kg	RIVM 2017
Naphtalene	0,089 mg/kg 2,039 mg/kg	Celeiro 2018 Marsili, 2014
Acenaphtylene	0,46 mg/kg	Celeiro 2018
Acenaphtene	0,18 mg/kg 10,15 mg/kg	Celeiro 2018 Marsili, 2014
Fluorene	0,082 mg/kg 10,367 mg/kg	Celeiro 2018 Marsili, 2014
benzo[b]fluoranthene +benzo[k]fluoranthene	1,78 mg/kg : uncoated granules 0,46 mg/kg : : coated granules	Menichini, 2011 Menichini, 2011
Indeno[1,2,3-c,d]pyrene	3,73 mg/kg : uncoated granules 1,08 mg/kg : coated granules	Menichini, 2011 Menichini, 2011
	Benzothiazoles	
Benzothiazole	6,3 mg/kg 5,2 mg/kg	RIVM 2017 Celeiro 2018
2-hydroxybenzothiazole	13,8 mg/kg	RIVM 2017
2-mercaptobenzothiazole	7,6 mg/kg	RIVM 2017
2-methoxybenzothiazole	10,2 mg/kg	RIVM 2017
2-aminobenzothiazole	0,4 mg/kg	RIVM 2017
N-cyclohexyl-1,3-benzothiazole-2-amine	3,9 mg/kg	RIVM 2017
2,2-dithiobis(benzothiazole)	0,3 mg/kg	RIVM 2017
N-cyclohexyl-2-benzothiazole sulphenamide	0,04 mg/kg	RIVM 2017
	Phthalates	
di-2 ethylhexylphthalate	27,2 mg/kg 17 mg/kg	RIVM 2017 Celeiro 2018
di-isobutylphthalate	2,3 mg/kg 7,2 mg/kg	RIVM 2017 Celeiro 2018
di-isononylphthalate	61 mg/kg	RIVM 2017
dicyclohexylphthalate	0,2 mg/kg	RIVM 2017
di-n-nonylphthalate	0,8 mg/kg	RIVM 2017
diphenylphthalate	0,1 mg/kg	RIVM 2017
bis(2-ethylhexyl)adipate	1,1 mg/kg 251 mg/kg 0,47 mg/kg in artifical turf	RIVM 2017 Celeiro 2018 Lim 2012

Substances	Maximum Concentrations	Reference
diethylphtalate	11 mg/kg	Celeiro 2018
dibutylphthalate	16 mg/kg	Celeiro 2018
benzylbutylphthalate	0,19 mg/kg 428 mg/kg in artifical turf	Celeiro 2018 Lim 2012
Metals		
Lead	55,36 mg/kg : rubber chips 19,47 mg/kg : artificial turf 38,99 mg/kg 26 mg/kg : uncoated granules 28 mg/kg : coated granules 46 mg/kg 308 mg/kg	Lim, 2012 Lim, 2012 Marsili, 2014 Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Chromium	18,6 mg/kg : rubber chips 4,49 mg/kg : artificial turf 17,52 mg/kg 4,6 mg/kg : uncoated granules 6,2 mg/kg : coated granules 56 mg/kg	Lim, 2012 Lim, 2012 Marsili, 2014 Menichini, 2011 Menichini, 2011 Bocca, 2009
Cadmium	0,74 mg/kg : rubber chips 2,68 mg/kg 1,9 mg/kg : uncoated granules 1,9 mg/kg : coated granules 1,89 mg/kg	(Lim 2012) (Marsili, 2014) Menichini, 2011 Menichini, 2011 Bocca, 2009
Zinc	4327 mg/kg : rubber chips 3168 mg/kg : artificial turf 13202 mg/kg 17,772mg/kg : uncoated granules 1063 mg/kg : coated granules 19,375 mg/kg 1,53%	(Lim 2012) (Marsili, 2014) Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Mercury	0,37 mg/kg : rubber chips 0,0001mg/kg : artificial turf 0,16 mg/kg : uncoated granules 0,08 mg/kg : coated granules 0,16 mg/kg	Lim 2012 Lim, 2012 Menichini, 2011 Menichini, 2011 Bocca, 2009
Nickel	26,12 mg/kg 26 mg/kg : uncoated granules 5,8 mg/kg : coated granules 5,8 mg/kg	Marsili, 2014 Menichini, 2011 Menichini, 2011 Bocca, 2009
Copper	84,49 mg/kg 2,5 mg/kg : uncoated granules 60 mg/kg : coated granules 60 mg/kg 60,5 mg/kg	Marsili, 2014 Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Iron	7256 mg/kg 620 mg/Kg : uncoated granules 465 mg/kg : coated granules 4318 mg/kg 0,105%	Marsili, 2014 Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Cobalt	116 mg/kg : uncoated granules 234 mg/kg : coated granules 234 mg/kg 125 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Tin	2 mg/kg : uncoated granules 1,74 mg/kg : coated granules 3 mg/kg 0,039%	Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Aluminium	755 mg/kg : uncoated granules 1028 mg/kg : coated granules 6680 mg/kg 0,094%	Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Barium	23 mg/kg : uncoated granules	Menichini, 2011

Substances	Maximum Concentrations	Reference
	741 mg/kg : coated granules 4478 mg/kg 167 mg/kg	Menichini, 2011 Bocca, 2009 Ruffino 2013
Manganese	4,4 mg/kg : uncoated granules 5,2 mg/kg : coated granules 30 mg/kg 5,5 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009 Ruffino 2013
Titanium	0,14 mg/kg : uncoated granules 0,07 mg/kg : coated granules 48,5 mg/kg	Menichini, 2011 Menichini, 2011 Ruffino 2013
Arsenic	0,41 mg/kg : uncoated granules 0,24 mg/kg : coated granules 1,21 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Berrylium	0,04 mg/kg : uincoated granules 0,04 mg/kg : coated granules	Menichini, 2011 Menichini, 2011
Lithium	1,4 mg/kg : uncoated granules 7,4 mg/kg : coated granules 11 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Magnesium	653 mg/kg : uncoated granules 966 mg/kg : coated granules 966 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Molybdene	0,29 mg/kg : uncoated granules 0,13 mg/kg : coated granules	Menichini, 2011 Menichini, 2011
Rubidium	3,1 mg/kg : uncoated granules 3,0 mg/kg : coated granules 26 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Antimony	1,1 mg/kg : uncoated granules 6,4 mg/kg : coated granules 7,7 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Vanadium	3,5 mg/kg : uncoated granules 1,5 mg/kg : coated granules 22 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Strontium	6 mg/kg : uncoated granules 19 mg/kg : coated granules 90 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Tungsten	0,12 mg/kg : uncoated granules 0,36 mg/kg : coated granules 2 mg/kg	Menichini, 2011 Menichini, 2011 Bocca, 2009
Thalium	0,21 mg/kg	Bocca, 2009
Others		
Xylene	975 µg/kg	Ruffino 2013
Toluene	449 µg/kg	Ruffino 2013
Benzene	0,64 µg/kg	Ruffino 2013
Butyl hydroxy toluene	56 µg/g	Celeiro 2018
Phenols		
4-tert-butylphenol	0,076 mg/kg	Celeiro 2018
4-tert-octylphénol	22,4 mg/kg	RIVM 2017
BPA	2,5 mg/kg 1,7 mg/kg	RIVM 2017 Celeiro 2018
PCB		
PCB	0,074 mg/kg	RIVM 2017

Table 8: Composition of rubber granules in synthetic turf field

Substances	Maximum Concentrations	Reference
PAH		
Anthracene	4,72 µg/g	Llompart (2013)
Pyrene	29,5 µg/g	Llompart (2013)
Benzo(ghi)perylene	11,9 µg/g	Llompart (2013)

Substances	Maximum Concentrations	Reference
Benzo(a)anthracene	2,02 µg/g	Llompart (2013)
Benzo(b) fluorenthene	4,32 µg/g	Llompart (2013)
Benzo(k)fluorenthene	1,69 µg/g	Llompart (2013)
benzo(a)pyrene	4,66 µg/g	Llompart (2013)
chrysene	9,16 µg/g	Llompart (2013)
dibenzo(a,h)anthracene	0,97 µg/g	Llompart (2013)
Naphtalene	24,2 µg/g	Llompart (2013)
Acenaphtylene	13,4 µg/g	Llompart (2013)
Acenaphtene	12,8 µg/g	Llompart (2013)
Fluorene	47,7 µg/g	Llompart (2013)
Phenanthene	25,5 µg/g	Llompart (2013)
Fluoranthene	8,24 µg/g	Llompart (2013)
Indeno (1,2,3,c,d)pyrene	2,77 µg/g	Llompart (2013)
Benzothiazoles		
Benzothiazole	39,9 µg/g	Llompart (2013)
4-tertbutylphenol	0,78 µg/g	Llompart (2013)
2-mercaptobenzothiazole	398µg/g	Llompart (2013)
Butyl hydroxytoluene	23,9 µg/g	Llompart (2013)
Diethyl phtalate	1,13 µg/g	Llompart (2013)
Diisobutyl phtalate	2,45 µg/g	Llompart (2013)
Dibutyl phtalate	1,97 µg/g	Llompart (2013)
Metals		
Plomb	146,03 mg/kg	Lim 2012
Chrome	11,71 mg/kg	Lim 2012
Cadmium	0,05 g/kg	Lim 2012
Zinc	2805 mg/kg	Lim 2012
Mercure	0,17 mg/kg	Lim 2012
Phthalates		
DEP	1,13 µg/g	Llompart (2013)
DIBP	2,45 µg/g	Llompart (2013)
DBP	1,97 µg/g	Llompart (2013)
Di-(2-ethylhexylphtalate	63,8 µg/g	Llompart (2013)
Diisononyl phtalate	20615 µg/g	Llompart (2013)
Disodecyl phtalate	1284 µg/g	Llompart (2013)

Table 9: Composition of rubber granules in playground

8 Human health risks assessment

This chapter lists the conclusions from the main reports and scientific studies aiming at assessing human exposure and health risks from rubber granules used in synthetic turfs and children playgrounds. These come from national authorites at a domestic, European or international scale, from peer-reviewed scientific articles and from industrial consultants. These studies have not been peer-reviewed by Anses and are summarised in Annex 2.

More than fifty reports and scientific studies have been published for the last decade. Some have published new data from experimental assays, whereas others have collected existing information in order to issue conclusions on health risk assessment for the general population or for workers. A specific focus is made herein on the RIVM, ECHA and Washington State Department of Health reports as they are the most complete and recent studies considering the purpose of this report. For each of these, Anses identifies a list of theirs their strenghs and limits (the Washington State Department of Health has been reviewed by a scientific expert in epidemiology).

8.1 Synthetic turf fields

8.1.1 RIVM (2017)[16]

In 2017, the RIVM issued a domestic survey on 100 randomly selected synthetic turf fields located in the Netherlands, representing over 5% of the total number of synthetic turf fields with ELT derived Styrene Butadiene Rubber granules (SBR) in the Netherlands. These SBR granules Six samples were collected per field, located in positions required for FIFA regulations (areas subject to intensive and less intensive play), and a questionnaire was filled out for 60% of them in order to complete the knowledge on each field. The sampling method used a vacuum cleaner, and triple samples were taken from fewer synthetic turf fields particularly for migration assays and counterchecks.

Chemical analyses on these samples concerned PAHs, phthalates, volatile compounds and heavy metals, as pre-selected substances based on the RIVM literature review. One laboratory extended its research on additional PAHs, phthalates and on complementary compounds: phenols, PCBs and benzothiazoles. A general screening was included to detect the presence of unknown compounds.

Based on this characterisation, RIVM set up migration assays to determine which substances were released from rubber granules after ingestion, inhalation and skin contact. Three experimental conditions were performed, using a saliva-gastric and intestinal simulants system for 4 hours at 37°C, a heating process up to 60°C for gaseous releases and a sweat simulant for 2 hours at 37°C.

For migration into sweat, three metals (cadmium, cobalt and lead), PAHs and phthalates were selected, as they were considered as relevant for skin contact. From 7 SBR samples, none of the phthalates were detected; no correlation has been made for metals. Only 5 PAHs were detected: naphthalene, fluoranthene, pyrene, chrysene and benzo(g,h,i)perylene. RIVM compared the migration concentrations of these 5 PAHs to the total content in the same SBR samples, to

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[16] RIVM (2017). Evaluation of health risks of playing sport on synthetic turfs pitches with rubber granulate. Scientific background document. Report 2016-2017. Bilthoven.

estimate if the relationship is consistent and reproductible to other SBR samples. As a linear relationship was determined considering the molecular masses of these PAHs, RIVM assumed the migration profile for these 5 PAHs is representative of the other PAHs in this research.

For migration in the gastrointestinal tract, from 5 SBR samples, PAHs and phthalates concentrations were just above the limit of detection. Compared to the total content in these samples, RIVM estimated 20% as the migration rate for phthalates and 9% for PAHs. It could not be estimated for metals as only 2 samples were tested.

For emission in air, in a worst-case situation for Netherlands (60°C with no air dilution of the emitted substances), none of the leukemogen chemical compounds were detected: benzene, styrene and 1,3-butadiene. PAHs concentrations (0.03 $ng.m^{-3}$) were well below the European limit value of 1 $ng.m^{-3}$ and the WHO air quality guideline value of 0.12 $ng.m^{-3}$. RIVM mentioned the average background concentrations of BaP in ambient air in Netherlands varied from 0.04 and 0.11 $ng.m^{-3}$.

Regulatory limit values were selected for relevant chemical compounds found in rubber granules, considering the comparable material or field of application:

- Dutch eco-label certification scheme for rubber granules as infill for synthetic turf fields,
- Dutch Soil Quality Decree (prevent from undesirable release in the environment) for PAHs,
- Toy Safety Directive 2009/48/EC for CMR category 1A/1B/2 with some exceptions,
- European Toy Standard EN 71 for metals, nitrosamines and nitrosables substances
- REACH Annex XVII Restrictions
    - entry 5: toys and mixtures for benzene above a concentration limit,
    - entry 23: mixtures and specific articles for cadmium,
    - entry 27: piercings and jewellery for nickel migration limits,
    - entry 28-30: rubber granules for CMR category 1A/1B above concentration limits,
    - entry 48: adhesives and spray paints for toluene above a concentration limit,
    - entry 50: oils for processing rubber in tyre production and for toys for 8 PAHs,
    - entry 51-52: toys for 6 phthalates above concentration limits,
    - entry 63: jewellery and articles for children for lead above concentration and migration limits.

The risk assessment was then focused on CMR priority substances, selected on literature data given the timeframe. Toxicological reference values were identified from the available literature. Five exposure scenarios were determined, based on recreational sport by children and adult players: children under 6 y.o., goalkeepers aged 7 y.o., children aged 11-18 y.o. with more frequent training on synthetic turf fields, adults and lifelong exposure scenario averaged up to 70 y.o. For each of these scenarios, the maximum migration or content values for the prioritised substances were used.

Considering the 8 regulated PAHs under REACH for consumer products and toys (maximum levels of 1 mg/kg and 0.5 mg/kg respectively), the maximum levels for 5 PAHs measured from SBR samples were 2.2 to 7.75 times and 4.4 to 15.5 times higher to these limits respectively. RIVM considered these exceeding values do not pose a significant additional cancer risk, as these migration concentrations led to a carcinogenic excess risk of $0.8\text{-}1.2.10^{-6}$ for a player, and $2.2\text{-}3.0.10^{-6}$ for a goalkeeper, considered as negligible risk. For phthalates, benzothiazoles, BPA, cadmium, cobalt and lead, the indicative risk assessment suggested no health risk considering the low contents of these compounds from SBR granules.

The RIVM made a specific focus on leukaemia and lymphoma in children and adolescents, as several cases were reported in the United States and being referred to in the Netherlands. Through the literature, the RIVM could not find any new evidence of a relationship between exposure to ruuber granules used in synthetic turf fields and the development of childhood leukaemia or lymphoma. These cancers are well-described as multiple factors diseases linked to benzene, pesticides, cigarette smoke for example, with additional individual genetic factors. In completion, the RIVM analysed the trends in the incidence of leukaemia and lymphoman in children and adolescents from the NKR registry. Data showed that almost 2 300 children under the age of 18 were diagnosed with leukaemia or lymphoma between 2006 and 2015 (40% of all cancer in children under the age of 18). The most common cancer up to 15 y.o. was acute lymphocytic leukaemia, and lymphoma after the age of 15.

An age and sex standardised incidence for leukaemia and lymphoma, from 1989 and 2015, was calculated for children and adolescents between 10 and 29 y.o., which was considered as the most similar group raised at risk in the United States. The incidence rose gradually since 1989 from 6.4 to 8.8 per 100 000 per year (4 cases per year). RIVM concluded that this analysis did not indicate any changes in the trend at any time of the period. Synthetic turf fields with rubber granules were introduced in the Netherlands from 2001, with 30% of synthetic football pitches in 2015. No additional increases in leukaemia nore lymphoma were observed since the introduction of synthetic turf fields in the Netherlands, although the relevance of this conclusion had to be balanced by correcting factors that were not taken into account (e.g. changes in known risk factors for leukaemia and lymphoma, improved diagnostic testing, latency period). Nevertheless, RIVM study did not reveal the presence of the leukemogenic compounds benzene, styrene or 1,3-butadiene in any rubber granules samples. Moreover, the carcinogenic risk from 2-mercaptobenzothiazole was too low to raise any concern.

For all these reasons, RIVM finally considered the resultst of the ongoing study of ECHA (cf. chapter 8.1.2), US EPA (cf. chapter 10.1) and the Washington State Department of Health (cf. chapter 8.1.3) will be of outmost importance, especially for US studies as synthetic turf fields were installed earlier than in the Netherlands.

Strengths:

- *Well-designed, transparent and complete experimental protocole. Good statistical analysis*
- *Representativeness and largest number of synthetic turf fields sampled in the Netherlands*
- *Blinded tests for chemical characterisation (composition and migration) by several laboratories, so the origin of the rubber granules were known only by RIVM*
- *For the skin contact migration assay, stricter experimental conditions compared to the Danish EPA protocol*
- *For the ingestion migration assay, use of a two-compartments active system with gastric and intestinal secretions simulants*
- *Worst-case hypothesis for exposure conditions (sum of all released compounds concentrations, highest values reported)*
- *Discussion of their results compared to other findings from other research publications*

Limits:

- *Details about the type of synthetic turf fields: the Dutch Football association database which is not systemically updated, leading to incomplete data on the type of infill material used in turf fields. As a result, 58% of the selected synthetic turf fields had an unknown infill, which was assumed by RIVM as rubber infill. This was corrected for 91 pitches for which discussions with managers and observations in situ revealed the infill granules were not rubber. Moreover, the dedicated laboratories excluded samples taken from synthetic turf fields not rubber, leading to a reduced number of samples afterwards (91 synthetic turf fields)*
- *General screening highly dependent on the solvent used (hexane) and unfinished (probable identification not confirmed by further research on reference compounds within the time frame of the study)*
- *Most recent date of new infill of rubber granules on each synthetic turf field not known*
- *Limits on the number of SBR samples for migration assays, reducing statistical analysis*
- *Choice of regulatory limit values used for risk assessment, as toxicological reference values may be more relevant*
- *Prioritisation of relevant substances based on literature data given the timeframe*

- *Prioritisation based on the exceeding of one or more regulatory limit values, which do not consider toxicological dose-reponse relationships*
- *Indicative risk assessment based on test methods which did not always correspond to the specific test methods per substance groupe*
- *For the analysis of cancer incidence rate and installations of synthetic turf fields, latency period and possible improved diagnostic techniques were not taken into account*

8.1.2 ECHA (2017)[17]

The European Chemicals Agency (ECHA) was requested on June 2016 by the European Commission to advise them if there was a risk to human health that needed to be better addressed at a European level. In 2017, ECHA published an Annex XV report, including 10 member states and industrials scientific contributions, on the possible health risks of recycled rubber granules used as infill in synthetic turf sports fields.

ECHA screened substances from the list of the US EPA published in 2016 (cf. chapter 10.1) with the Annex VI of the Classification, Labelling and Packaging (CLP) Regulation 1272/2008/EC. Only 20 had a harmonised classification as carcinogenic, mutagenic or toxic to reproduction (CMR) categories 1A or 1B: formaldehyde, some PAHs, some phthalates. ECHA also identified 17 substances classified as skin sensitisers: e.g. formaldehyde, 2-mercaptobenzothiazole (MBT) and cobalt which is also a respiratory sensitiser. For the purpose of health risk assessment, ECHA finally selected:

- the EU-8 carcinogenic PAHs: benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene (BaP), benzo[e]pyrene and dibenzo[a,h]anthracene). This list is considered as benchmark substances for all the PAHs that could be contained or released by rubber granules, in particular BaP often used for HAPs exposure and risk assessment;
- 4 phthalates (di-2-ethylhexylphthalate, diisobutylphthalate, dibutylphthalate, benzylbutylphthalate): in addition of their classification as toxic to reproduction category 1B, these 4 phthalates are considered as endocrine disruptors in humans;
- benzothiazole and MBT: MBT is a skin sensitiser category 1;
- methylisobutylketone (MIBK): it causes serious eye irritation, is harmful if inhaled and may cause respiratory irritation,
- formaldehyde and benzene,
- metals: they were selected if the elemental metal is classified regarding the CLP Regulation.

The limit values of Reach Annex XVII entry 28 for carcinogenic compounds category 1A-1B, and the limit values of Reach Annex XVII entry 50 for PAHs were mentioned, as they are applicable to mixtures for supply to the general public. If available, Derived No-Effect Levels (DNELs) for the selected substances were taken into account for the general public and for workers.

For these substances, ECHA identified the corresponding concentrations in rubber granules from 50 samples from new recycles rubber granules, several hundred of samples taken for more than 100 synthetic turf fields in Europe and different fractions of tyres by industry. The measured PAHs concentrations are comparable to urban levels, with a seasonal influence: higher concentrations were measured in winter explained by external contribution due to heating emissions and traffic exhaust. This was confirmed by an unpublished study from industry, with a maximal level of BaP in

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[17] European Chemicals Agency (ECHA). 2017. An evaluation of the possible health risks of recycled rubber granules used as infill in synthetic turfs sport fields. Annex XV Report. Main report and annexes. 28 February

winter in Portugal. The influence of playing sports on synthetic turf fields on PAHs emissions was unclear as data gathered by ECHA revealed a decrease of the PAHs concentrations without playing, but an increase of BaP values during playing.

Exposure was assessed via skin contact, ingestion and inhalation (gaseous form and dust).

Risks were investigated for the general population playing on synthetic turf fields, professional football players and workers installing or maintaining the fields (this last issue is described in chapter 8.4).

Finally, ECHA recommends basic hygiene rules for sport players to protect them from possible chemical risks from rubber granules skin contact. These recommandations require for example, washing hands after playing and before eating, cleaning cuts or scrapes while playing on synthetic turf fields, or taking off the sport equipment outside their home in order to avoid rubber granules contamination.

Strengths:

- *Risk assessment carried out for general population and workers*
- *High number of samples of rubber granules (> 150)*

Limits:

- *Review of existing studies, unpublished information or uncomplete data given by Member States or industry*
- *Lack of clarity or relevance for some chapters or some paragraphs within a chapter*
- *Selection of relevant compounds for risk assessment based on CLP classifications and not on toxicological profiles*
- *Derivatives compounds of metals (inorganic or organic) classified as CMR 1A-1B were not taken into account if the elemental metal is not classified itself, reducing the number of selected compounds for risk assessment*
- *Selection of DNELs for risk assessment: these values lack of transparency as they do not systematically rely on peer-reviewed or published scientific data*
- *Concerning the carcinogenicity assessment, the comparison between the occupational exposures in the rubber manufacturing industry and the exposure of players on synthetic turf fields is not relevant: the weight of evidence for carcinogenic effects among workers in the rubber manufacturing industry has been assessed for years and relies on sufficient and relevant evidence, on the contrary to exposure to rubber granules used as infill in synthetic turf fields. Moreover, there is an important difference between these two types of exposure issues in terms of substances, concentrations of exposure of these substances and duration of exposure.*

8.1.3 Washington State Department of Health (2017)[18]

The concerns about a relationship between leukaemia or lymphoma and synthetic turf fields came particularly from Amy Griffin, a goalkeeper trainer in Washington State in the USA. Since 2009, she has been identifying people suffering from these cancers, with this specificity they all have played or were playing football on synthetic turf fields (players but mostly goalkeepers). This list was completed by Amy Griffin herself based on her personal relations or after being directly contacted by people diagnosed with these cancers. This collection method suffers from a selection bias and aims not at proposing exhaustive and scientific-based data. But the increasing concern about this

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[18] Washington State Department of Health (2017). Investigation of Reported Cancer among Soccer Players in Washington State. Revised April 2017. DOH Pub 210-091.

list led the Washington State Department of Health to determine how these date had to be interpreted. The purpose was not to determine if football players were at increased risk of cancer due to exposures from crumb rubber in artificial turf.

The list of Amy Griffin was compared to the cancer registry in the state of Washington, to examine whether there was an increased risk for specific types of cancer among football players on synthetic turf fields. Individual data were gathered from the Amy Griffin's list and compared to the Washington State cancer registry (for local cancer incidence) and the National Cancer Institute (for national cancer incidence). One case was defined as a person who lives in Washington State and who has played football for at least 5 months, diagnosed from cancer between 2002 and 2015 and aged 6 to 24 years old when diagnosed. Information regarding playing on synthetic turf was gathered through questionnaires sent to 53 persons from Amy Griffin's list, living in Washington state. Only 35 persons answered these questionnaires and finally, 28 persons were determined as "cases" regarding the above-mentionned definition by the Washington State Department of Health. No restriction on ages was made for goalkeepers in order not to exclude any of the cancers among goalkeepers from the observed number of cancers.

The Annex C of this report documents in details, the calculation of the expected numbers of cancers from the soccer cohort, considering the same interval of age between the observed and the expected numbers of cancers. This annex displays how the person-years at risk were determined, corresponding to all the years spent by people in which they would be considered a case if they had a cancer diagnosis. For each category of age, the person-years at risk was multiplied by the Washington cancer registry rate, in order to provide the expected number of cancers among all soccer players in Washington State if those players had the same cancer rates as all state residents. By summing the expected cases at each age, the total expected number of cancer cases was 1384. Compared to the 28 observed cancers from Amy Griffin's list, the O/E (observed/expected) ratio was 0.02 (cf. **Erreur ! Source du renvoi introuvable.**).

Observed cancers from coach's list	**Expected cancers**		**Ratio of observed to expected**	**95 percent confidence interval**
All soccer players				
All types of cancer	28	1,384	**0.02**	0.01-0.03
Leukemia	6	131	**0.05**	0.02-0.10
Hodgkin lymphoma	5	147	**0.03**	0.01-0.08
Non-Hodgkin lymphoma	6	89	**0.07**	0.02-0.14
Goalkeepers	14	153	**0.09**	0.05-0.15
Select/premier soccer players	15	284	**0.05**	0.03-0.09

Table 10: Observed cancers from coach's list and expected cancers: soccer players ages 6–24 years diagnosed during 2002–2015 (from Washington State Department of Health, 2017)

This epidemiological analysis confirms the list from Amy Griffin is incomplete: it did not include all soccer players ages six to 24 years old who developed cancer during 2002–2015 as she primarily focused on female goalies. Moreover, this analysis excluded people who did not meet the case definition among the observed number of cancers, reducing their total number but reducing the total expected cancers as well, resulinting in even smaller O/Es than those computed.

These results could not be considered as sufficient enough to justifiy further public health actions in Washington State.

Strengths:

- *Robust epidemiologic approach to compare observed cancer ratio with expected one, under identical exposure conditions, as followed in annex C ("cluster investigation")*
- *Transparency and robustness of the calculation of person-years-at-risk, with 4 scenarios of players and 4 scenarios*
- *Transparency in the limits as all the assumptions made during this study were mentioned and as a revision was published 3 months after its first issue*
- *Underestimation of the number of expected cancers: large interval of age for football players*

Limits:

- *Hypothesis of player turnover from 0 to 10%, between the age of 6 and 15, as no existing data were collected*
- *Incorrect estimation of the number of residents ages six to 24 years who played soccer: the WYS data source does not account for all soccer players and may exclude those that do not require a youth soccer "player card" for participation*
- *Lack of interpretation on the wide difference between the observed and the expected number of cancers (28 vs 1384), indicating a lack of consistency in the data collection for the observed cancers*

8.1.4 Other relevant publications

Considering the alert triggered by Amy Griffin, Bleyer and Keegan (2018) tested the relationship between a high density of synthetic turf fields and an increased incidence of lymphoma among adolescents and young adults (14-30 y.o.), using US and Californian cancer registries. The authors analysed the incidences of lymphoma throughout US National Cancer registries by age, race/ethnicity and socio-economic status. Indeed, the incidence of lymphoma is strongly associated with race/ethnicity and raises with the family income. The authors also compared the county-level incidence of lymphoma for the 58 counties of California with race/ethnicity and the density of synthetic turf fields (number of pitches per capita). The incidence of lymphoma was compared to the geographic location or the density of synthetic turf fields. The authors indicated there was no trend between an increased incidence of lymphoma and the highest number of synthetic turf fields, for any of the groups. In California, the incidence of lymphoma from 1974 to 2013 in the two counties with the highest density of synthetic turf fields was not increased over time, nor since 1992 in the eight counties with the highest densitiy of synthetic turf fields. The authors concluded there were no spatial correlation between incidence of lymphoma and the density of synthetic turf fields, considering a large latency period.

Peterson *et al.* (2018), working for the Gradient corporation, realised a multipathway health risk assessment for young soccer players and spectators exposed to rubber granules infill in synthetic turf fields (outdoor and indoor – see chapter 8.2). A literature search compiled the concentrations of rubber granules and the air sampling data from North-American synthetic turf fields. The investigation evaluated accidental ingestion by children, inhalation and dermal exposures for chemicals of potential concern. The upper-bound exposure concentrations were compared to chronic reference values for residential soils and air. As there are no existing dermal reference values, the authors used adjusted oral reference values. Target-organ-specific hazard indices (0.1) and target carcinogenic risks of 10^{-6} were summed for each chemical of potential concern and for each exposure scenario. Results showed cancer risks for all scenarios were below 10^{-6}. The highest identified risk concerned the child spectator scenario with a cancer risk of 9.10^{-7} and a hazard index of 1, for which endocrinous specific hazard index was 0.96. The authors calculated the higher impact came from a potential ingestion of cobalt in recycled rubber. A relative risk assessment in natural soils was also determined as it was considered as an important part of risk communication. Cancer risks from chemicals in natural soils were all superior to cancer risks from rubber infill, with a similar contribution from PAHs and metals at higher levels due to a higher bioaccessibility. This comparative assessment highlighted the uncertainty to interprete health risk assessment from recycled rubber infill, as it was not possible to distinguish wether these compounds came from natural soils or synthetic turf fields. Finally, the authors compared their results with ECHA, RIVM and other published studies for cancer and non-cancer risks, showing they are all consistent given the different datasets and methods used: 9.10^{-7} to 1.10^{-6} for higher cancer risk; 0,008 to 1 for hazard quotient. The authors concluded cancer and systemic risks from chemicals associated with recycled rubber infill were acceptable.

Pavilonis *et al.* (2014) evaluated the bioaccessibility and risk of exposure to metals, PAHs and SVOCs in synthetic turf fields (SBR granules infill and fibres). Migration assays using simulants of lung fluids, sweat and digestive fluids were performed on artificial turf fibres, different types of infill and samples from actual fields. PAHs were not detected and SVOCs were not quantified above soil regulation levels. Metals were measured at low concentrations except for lead for some fields and materials. The authors concluded that the global exposure of the selected synthetic turf fields was minimal.

Marsili *et al.* (2014) determined the release of PAHs and metals from crumb rubber in synthetic turf fields, and assessed the hazard for ahtletes inhaling PAHs. Nine samples were used for metals and PAHs detection (BaP, chrysene, benzo(a)anthracene and benzo(g,h,i)perylene) in emission test chambers. The results showed higher concentrations of PAHs in new synthetic turf fields rubber granules samples compared to the Italian National Amateur League standards, with lower levels in old synthetic turf fields. The emissions profile indicated though that these levels were not decreasing with time, suggesting a possible chronic exposure for players. The analysis revealed that temperature increased the PAH emissions. Zinc and cadmium were also measured at high levels. The hazard index (HI) ranged from $8.94.10^{-7}$ to $1.16.10^{-6}$, considered as negligible by the authors.

Ruffino *et al.* (2013) questionned wether chemicals released from rubber granules pose a risk to sport players. Five Italian synthetic turf fields were sampled for PAHs and metals detection. Pyrene and BaP were the most significant PAHs quantified. Zinc was the most detected metal, with iron, cobalt, manganese, barium and lead. These results were difficult to interprete as steel was not separated from rubber granules during the experiment. A risk assessment was determined for direct skin contact, contaminated rainwater skin contact and inhalation. The cumulative carcinogenic risk was lower than 10^{-6} and the cumulative non-carcinogenic risk lower than 1 for all routes of exposure. Exposure to airborne pollutants was rather implied in the inhalation route than exposure to chemicals emitted from synthetic turf fields.

Schiliro *et al.* (2013) compared synthetic turf fields and urban areas to PM10 and PM2.5 concentrations, PAHs and BTXs levels and mutagenicity activity of organic extracts from PM10 and PM2.5, during 2 sampling periods (warm and cold days). No significant differences were found between PM10 concentrations on urban sites vs synthetic turf fields, both during warm and cold seasons and during on-field or not activity. BTXs concentrations were significantly higher at urban sites than on synthetic turf pitches. PAHs levels were comparable between urban sites and synthetic turf fields, and the contribution of PAHs from rubber granules was considered as negligible by the authors. Mutagenicity activities of PM10 and PM2.5 organic extracts were globally comparable between the two sampling sites (higher for PM10 but lower for PM2.5 for synthetic turf fields air samples). These results showed that synthetic turf fields do not contribute to additional exposure and risks than urban areas.

Menichini *et al.* (2011) searched for the potential risks from 25 metals and 9 PAHs in rubber granules from 13 Italien synthetic turf fields. Air sampling was triggered on 2 turf fields with personal sampling, air sampling located above and outside the turf fields. Among metals, only zinc was quantified in concentrations above Italian soil standards, followed by copper and tin. BaP was the most significant PAH detected in air samples, at higher concentrations on the field compared to measurements done outside the fields. But PAHs concentrations varied widely from one synthetic turf field to another, regardless of the origin of the samples. The authors though noticed PAHs concentrations were lower on older synthetic turf fields. A carcinogenic risk assessment was calculated for BaP, considering an intense 30-year activity on a synthetic turf field. The risk was negligible and considered as less relevant for discontinuous or amateur sport players.

In 2009, the US EPA conducted a multiroute monitoring of two synthetic turf fields in the United States. Air samples were conducted at three differents locations to detect PM10, metals, particle morphology and 56 VOCs above synthetic turf fields, with an additional background location air sample. VOCs samples were collected in the beginning of the afternoon, taking into account the maximal emissions with the highest temperature of the day. Wipe samples and rubber crumb samples were collected at the three different locations of air sampling in order to characterise metal and lead contents. This protocol was carried out for two consecutive days and completed with a few additional synthetic turf samples. PM10 and lead air samples were similar to background location air sample and below National Ambiant Air Quality Standards. VOCs samples were measured at very low concentrations, except for one sample with MIBK measurement. Total lead concentrations in the rubber infill were below the EPA standard for soil or EPA standard for lead in residential floor dust. The overall concentrations of measured substances led to a low concern for health risks. However, considering the limited number of synthetic turf fields and samples in this preliminary study, US EPA concluded the need for additional data.

In 2009, the OEHHA determined the chemicals and particulates emissions from synthetic turf pitches by a literature review up to 2008. Inhalation exposures of soccer players were estimated for five carcinogens: formaldehyde, benzene, naphthalene, nitromethane and styrene. A theoretical increased risk could be calculated (> risk level of 10^{-6}) but this was overestimated for two reasons: indoor air samples were used to determinate these risks for outdoor synthetic turf fields and the lifetime exposure for playing soccer was always considered on synthetic turf fields. This first assessment was followed by the determination of VOCs, PM2.5 and metals released from four synthetic turf fields, on eight samples per field (OEHHA, 2010). Measurements were carried out during periods of activity (for PM2.5 emissions) and during the summer (for VOCs maximal release), with a background measurement for each field. PM2.5 and metals were either not detected nore quantified at the same level as background measurements. VOCs were not detected as well or inconsistently among samples and among fields, with no correlation with the surface temperature. For 7 quantified VOCs, risk assessment for acute and chronic inhalation exposure concluded in the absence of health concerns. The OEHHA concluded that there were no reasons for restricting playing sports on synthetic turf fields during cool mornings in the summer as there was no increase in VOCs release at higher temperature.

In 2008, the Danish EPA investigated chemical substances contained in synthetic turf fields in the Danish market. After a literature survey gathering studies from Norway, Sweden, the Netherlands, Switzerland and France, an analysis of samples was carried out in order to characterise composition, emissions of volatile substances and leaching potential. Four substances were detected after leaching assays, considered as representative toxic compounds from rubber synthetic turf fields: benzothiazole, dicyclohexylamine, cyclohexylamine and dibutylphthalate. The worst case exposure scenario determined by the Norwegian studies (cf. chapter 8.2) led to the calculation of MoS for these 4 substances. MoS were all above 100 indicating no health risks for exposure to the selected substances from synthetic turf fields. However, the Danish EPA underscored the possible skin allergic risk from the sensitising compounds.

Focusing on nitrosamines emissions from rubber infill, RIVM surveyed in 2007 an experimental assay in order to characterise nitrosamines emissions above football pitches. Air samples were taken above 4 synthetic turf fields. Several measurements were done during a football match, at 30 and 100 cm height. In addition, pieces of rubber and loose crumb from various parts of six football pitches were analysed at 70°C. None of the air samples nore the materials analysis showed the presence of nitrosamines (all below the detection limit). They were only released in two migration tests at a limited extent (4,5 $\mu g.kg^{-1}$). RIVM concluded nitrosamines did not pose a health issue from synthetic turf fields.

The Swedish institute for chemicals (KEMI) run a literature survey in 2006 in order to facilitate local decisions and assessments when installing new synthetic rubber fields. The review included previous reports from Sweden and European guidelines and standards, focusing on the respiratory route. The KEMI concluded at that time that exposure data were too poorly studied to highlight any health risks. Existing synthetic turf fields could remain in place, but new ones shoud not contain any SVHC.

8.2 Indoor synthetic turf fields

There is globally very few studies assessing exposure and risks associated with indoor synthetic turf fields.

Peterson *et al.* (2018) (see above) also considered soccer players exposure in indoor synthetic turf fields. The same methodological approach was followed on the composition of rubber granules and the list of chemicals of potential concern. But there was a lack of indoor facilities data as only two studies were assessed by the authors. In this issue, the exposure duration for a young soccer player was determined at 3 hours for 1 day per week, 4 months a year (winter and spring). This hypothesis was considered maximalist as the typical game length is 60 minutes. The cancer risk for youth indoor soccer player was 2.10^{-7} and the global hazard index was 0.05. The target-organ-specific hazard indices were well below 0.1, with the highest value of 0.018 for endocrine effects. Benzothiazole was identified as a risk-driver but needed further assessment as its identification was based on a surrogate. 3-Phenyl-2-propenal (cinnamaldehyde) was also found in indoor air samples but is unlikely emitted by synthetic turf. Its presence was linked to the occurrence of many VOCs detected in the air of indoor synthetic turf fields. Many factors influence the quality of chemicals evaluations such as air exchange rates, suggesting strengthening more-detailed studies on this issue.

The ECHA report on Annex XV (2017) mentioned the rubber granules from outdoor fields seemed to have higher levels of PAHs than rubber granules collected from indoor synthetic turf fields. On the contrary, VOCs levels are higher in indoor pitches than in outdoor ones: up to 716 $\mu g.m^{-3}$ in one measurement in an indoor pitch without ventilation with high concentrations of ketones and aldehydes (111 $\mu g.m^{-3}$). Some of them are skin sensitisers (e.g. formaldehyde and MBT) or local irritants (e.g. MIBK, formaldehyde, acetone) linked to sore throat, runny nose, eye and skin irritation. In one indoor pitch with a deficient ventilation system, a benzene concentration was measured at 7 $\mu g.m^{-3}$ (compared to 0.5 $\mu g.m^{-3}$ in ambient air). This high concentration was concomitant with toluene and xylene elevated concentrations.

The University of Connecticut (2010) drawed an exposure characterisation on 1 indoor artificial turf field located in Connecticut. This facility had four air extraction devices at each end of the building that were not operating during samples. Running electrical devices were located in this indoor facility (e.g. electric motorized carts, ice machine and gym equipements). Personal air samplings were collected on young children playing on synthetic turf fields under simulated active conditions, for nitrosamine, VOCs and 5 targeted rubber-related SVOCs: benzothiazole, 4-tert-octylphenol, 2-mercaptobenzothiazole, butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT). Area samplings were realised for the 22 US EPA PAHs, nitrosamines, VOCs and PM for 2 hours, at high temperatures (26°C). Globally, the highest air concentrations on the selected turf fields in this study (including outdoor ones) were found at the indoor field. Concentrations of benzothiazole and BHT were 10 to 100 fold higher than the outdoor facilities, with the highest concentration of benzothiazole from all measurements (14 $\mu g.m^{-3}$). Toluene personal sampling concentrations were greater than 127 $\mu g.m^{-3}$ and MIBK was also found for personal and area measures at 35.98 $\mu g.m^{-3}$ which was the highest VOC detected in area sample, all types of turf fields included. Five PAHs were ten fold higher on indoor synthetic turf than background measurements: 1-methylnaphthalene, 2-methylnaphthalene, fluorene, naphthalene and pyrene. Nitrosamines concentrations were below the detection limit. Finally, PM_{10} concentrations were foung at the same level as background locations and futher analyses were inconclusive. The report concluded that more research is needed to better understand chemical exposures in indoor facilities as these results relied on one dataset.

One of the most comprehensive reports on indoor synthetic turf fields comes from the Norwegian Institute for Air Research and the Norwegian Institute of Public Health (2006). Measurements of air contaminants were realised in 3 indoor synthetic turf fields in Norway, focusing on PM10, PM2.5, phthtalates, PAHs, PCBs, additive compounds and VOCs. PM10 measurements were comparable to urban outdoor levels. Low concentrations of PAHs, phthalates, SVOCs, benzothiazoles and aromatic amines were quantified, but high concentrations of VOCs were measured in two halls. These air concentrations were used afterwards for carcinogenic and genotoxic risk assessment for football players. Several exposure scenarios were determined: inhalation and skin exposure for children 7-11 y.o., 12-15 y.o., 16-19 y.o. and adults. Oral exposure was only considered for children, taking into account an estimation of rubber granules swallowed during a match. Data on duration and frequency of exposure were provided by two managers of the three investigated indoor halls. Finally, a worst case exposure scenario was determined for each category of age, considering a 100% absorption rate. The measured values were compared to NOAELs[19] for relevant critical toxicological effects for each substance category (carcinogenicity, reprotoxicity, systemic effects). The calculated margin of safety (MoS) for VOCs indicated a possible risk of irritation for formaldehyde and limonene (MoS < 100). The MoS for benzene showed negligible risks, with a cancer risk of 2.10^{-6}, as well as for PAHs. No risk assessment was done for PCBs, PAHs, phthalates and phenols for skin contact as exposure concentrations for these substances were very low. The report concluded that the use of indoor synthetic turf fields do not cause any elevated risks for human health, but was not able to assess neither the risk of dermatitis linked to latex allergy nore the development of asthma and respiratory allergies.

8.3 Children playgrounds

Celeiro *et al.* (2014) carried out an assay on a restaurant playground in a indoor shopping centre, aiming at detecting and quantifying PAHs and other toxic compounds. A leaching study on runoff water was also realised, showing 9 PAHs at the ppm level. Extracts from the rubber playground revealed the content of 14 PAHs and the emission of 9 PAHs. No risk assessment was investigated but the authors considered these carcinogenic compounds as a reason for concern, expecially for children playing on these rubber playgrounds.

Llompart *et al.* (2013) investigated the hazardous chemical content and release in rubber recycled tyre playgrounds and pavers. Seventeen samples of floor tiles and carpets were sampled from 9 Spanish urban playgrounds. Seven commercial pavers and tiles of different colours were also sampled in commercial retails. PAHs, vulcanization additives, antioxidants and plasticizers were analysed in these samples. All contained PAHs up to 178 µg/g for one urban playground sample. Commercial rubber tiles showed considerably higher levels of PAHs (up to 18.699 µg/g) and phthalates. These authors concluded the use of these materials intended to children should be reconsidered or restricted for some samples, at least more carefully controlled.

In completion to the US EPA study on synthetic turf fields (2009), the same protocol as mentioned in chapter 8.1 was carried out on one synthetic playground, with a sample of tire crumb material of the playground and additional samples in another playground. Concentrations of PM10 and metals at the playground site with high play activity were higher than the background levels. But considering the very limited number of samples, US EPA concluded to the need of additional data.

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[19] No Observed Adverse Effect Level

The Californian EPA and the OEHHA assessed health effects for children exposed to recycled waste tyres used for outdoor playgrounds and track surfaces (2007). Chronic exposure to 13 metals by ingestion of 10g of rubber tire shreds (larger than rubber granules) and hand-to-mouth contact were evaluated after migration assays in a gastric fluid simulant. VOCs exposure was also assessed as well as skin sensitisation by direct contact. All 13 metals were at higher concentrations than in the control sample, but for arsenic, cadmium and lead, the increased cancer risk was below 10^{-6} considered as the acceptable level for cancer risk. Three VOCs were detected: benzothiazole, 2(3H)benzothiazolone and aniline for which the increased cancer risk was also below the acceptable cancer risk level.

In 2005, the Danish EPA assessed health risks from PAHs and aromatic amines from tyres commonly used for playgrounds. Twenty tires and 2 rubber tiles were analysed for a composition characterisation and migration assays using artificial sweat. All samples contained high concentrations of PAHs and aromatic amines (e.g. para-phenylene diamines (PPDs)), with a certain degree of variability between samples. Migration studies quantified fluoranthene, pyrene, 6-PPD and isopropyl-PPD. For these 4 substances, a risk assessment was carried out considering several exposure scenarios: 200 cm² skin contact for a child for 1 hour, 5 times a week for one year; ingestion of 10g of sand contamined with substances from tyres, 5 times a week for 6 months with 100% oral absorption. NOAELs/LOAELs[20] and reference doses from literature were identified for the selected substances, leading to MoS superior to 10 000. Moreover, a migration test conducted from a tractor tyre to sand revealed that PAHs migration mainly comes from atmospheric deposition rather than tyre migration. The Danish EPA considered that health risks from tyres or rubber tiles used for playgrounds are insignificant.

8.4 Risks for workers on synthetic turf fields

A specific focus is made herein concerning occupational risk assessment while installing or maintening synthetic turf fields. Few data were published on this issue, in particular on dust and particulate matters exposure. Moreover, none of the consulted studies have assessed occupational risks for workers on children playground.

In its Annex XV report, ECHA investigated risks for workers installing or maintaining synthetic turf fields (ECHA, 2017; cf. chapter 8.1.2). First, ECHA discussed about the carcinogenicity in rubber industry, based on the International Agency for Research on Cancer (IARC) on occupational exposures in the rubber-manufacturing industry in 2012. IARC concluded there was sufficient evidence for leukaemia, lymphoma, cancers of the urinary bladder, lung and stomach in humans. In comparison to the investigations carried out by the RIVM and the Washington State Department of Health in 2017 (cf. chapters 8.1.1 and 8.1.3), no increased rates of cancers among players were found. But concentrations of exposure for workers in the rubber-manufacturing industry are much higher than on synthetic turf fields.

According to the literature review, ECHA considered that the exposure to inhalable and respirable dust can be moderate during the installation and the maintenance of synthetic turf fields: the respirable dust in the breathing zone for installers of synthetic turf fields is globally below 1 mg.m^{-3}, especially if risk management measures are implemented. BaP exposure varied widely, from 0 to 26.7 ng.m^{-3} during installation of a football field. Workers were not exposed to VOCs as these chemicals were not detected in the breathing zone.

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[20] Lowest Observed Adverse Effect Level

8.5 Conclusions

The above-mentioned expertise reports on the risks related to the exposure of athletes and children using synthetic grounds, as well as the risks related to the exposure of workers involved in the installation and maintenance of these fields, mostly conclude that health risk is negligible.

The characterizations carried out for the assessment of emissions on the one hand, and migration simulations on the other hand, indicate low concentrations of heavy metals, plasticizers, additives or VOCs, which are below reference toxicological values retained by the authors of the studies reviewed. In particular, given the low concentrations of carcinogens emitted or released by tyre granules, the identified studies consider the risk of carcinogenicity as low or negligible, given that PAHs are the carcinogenic substances most frequently evaluated in the studies analyzed.

In addition, the epidemiological studies identified in this report do not show an increased incidence of cancers, in particular lymphoma and leukemia, related to the installation and use of synthetic sports fields. They state, in their conclusions, the possible existence of cofactors that could be at the origin of leukemias or lymphomas observed in children or young athletes.

Anses identified sources of uncertainties and methodological limitations in the publications and reports consulted:

- Some substances likely to be emitted by tyre granules may not have been searched: in fact, the risk assessments examined mainly substances with proven carcinogenicity such as PAHs. However, the variety of substances used in the composition of tyre granules deserves a broader analysis and without *a priori* pollutants contained or emitted by these materials. This is particularly true for the nanometric fractions of the dust likely to be emitted by tyre granules, considering the nanocarbon and nanosilica charges used in their manufacture;
- In the composition and emission measurements carried out on synthetic sports field, the representativity of sampling among each field and the number of grounds which have been tested may be questionned. This limit does not allow to characterize finely the variability of the composition of the tyre granules, highly dependent on the nature and the age of the tyres that have been recycled and which could vary from one country to another. The variability of emissions from these synthetic fields is also poorly taken into account; this requires consolidation of data to extend the robustness of the conclusions. The results of the North American study, the California joint study and the European study conducted by ETRMA would provide more data and a better characterization of the variability from one field to another (see chapter 10). Such information would consolidate the assumptions to be taken into account in an comprehensive risk assessment (based on a worst-case scenario);
- Exposure from synthetic grounds in confined space is little or poorly documented, especially concerning the air quality of these sports grounds in confined space. A better characterization of the exposure according to the different routes of exposure (inhalation and cutaneous) to the materials of these grounds appears necessary;
- Compared to synthetic sports fields, few studies have focused on the exposures and risks associated with the use of synthetic playgrounds. These playgrounds use specific chemicals for their design and implementation (glues, dyes, binders, smoothing agents), complexifying the potential chemicals emissions. The results of the North American study (see chapter 10) would be useful for assessing the risks associated with these playgrounds.

9 Environmental risks assessment

A non-exhaustive review of the literature was conducted in order to identify sources of information about the potential environmental risk associated to the use of ELT derived rubber granulates on children's playground and as infill on artificial turf fields. The aim of this literature review was to achieve a comprehensive overview of the issues raised by the use of recycled rubber and other petroleum infill, formulate conclusions and propose some further research to improve our comprehension of the potential risk of these materials for the environment.

The artificial surface for sports tracks usually consists of elastomers while artificial turf is mostly made from polypropylene (PP) or polyethylene (PE). Granulates used as infill material are mostly produced from ethylene propylene diene monomer rubber (EPDM), thermoplastic elastomers (TPE) or ELT-derived rubber granulates. This last is mostly produced from discarded car tyres and the material was initially only made of natural rubber derived from rubber tree (Hevea brasiliensis). Nowadays, a mixture of natural and synthetic rubbers is used. Synthetic rubbers are polymers made from petroleum containing about 1–4% of sulphur for vulcanization, and approximatively 1% of zinc oxide as catalyst. As filler and UV-resistant material, 22–40% carbon black is added to the composition (Kole et al. 2017). From recent research and improvement, carbon may sometimes be replaced by silica and nanosilica (nanoscale glass sphere) (Okel and Rueby 2016). To improve the mechanical properties of tyres, different oils are added, and to protect them for their life-service, different additives are added such as antidegradants, antioxidants, antiozonants, waxes and flex-crack inhibitors.

Due to the complex matrix and chemical mixture entering the composition of tyres, and their uses as infill on artificial turf fields and on children's playgrounds, concerns have been raised regarding potential environmental risks specially associated with the release of chemicals substances in the environment and their effects on living organisms.

9.1 Potential release of substances into the environment

The complex matrix and chemical mixture composition of tires, and their uses as recycle infill material on artificial turf fields and on children's playgrounds raised concerns due to the potential environmental risks associated with the release of substances and their distribution in the environment. Indeed, when surfaces are located outdoor, the infill material is subjected to a number of environmental conditions (such as rain, sun, wind, and variable UV irradiation), mechanical stress (by the use of these surfaces) as well as regular maintenance practices (watering). These conditions can led to the release of substances composing these infills materials in the surrounding environment. The main potential risk identified was the release of hazardous substances from infill materials by leaching after their contact with water. The released chemicals can ultimately end up in terrestrial and/or aquatic systems by runoff, leaching or percolation.

9.1.1 Findings from European studies

Most of the studies found in the literature have been focused on analyzing the composition of recycled rubber granulates and explored the potential release of substances into the environment from leachates studies. Furthermore, most of the leachate studies have been conducted on laboratory conditions and few of them on real field conditions (from artificial turf fields and/or playgrounds surfaces).

In Europe, studies of artificial turf pitches related to environmental risks have been conducted by research institutes and/or National Agencies of Norway, the Netherlands, Switzerland, France, and Sweden.

In 2003, The Norwegian Building Research Institute (NBI) was commissioned by the Norwegian Football Association (NFF) in order to carry out a study of the potential health and environmental effects linked to artificial turf systems. The study covered leaching studies in laboratory from two samples of artificial turf fiber and three different recycled rubbers granulates samples and EPDM. The chemical analyses in the leachate were focused on the detection of some metals (zinc and chromium), organic substances as PCBs (7), PAHs (16), phthalates (8), and phenols as 4-t-Octylphenol, 4-n-Nonylphenol and iso-Nonylphenol. Besides metals analyzed, Zn was found in highest concentrations specially in leachates from rubber granulates, it was reported up to 2290 µg/L, no concentrations of Cr were reported in the leachates from rubber granulates, and fibers, however in the case of EPDM, it was reported the presence of Cr, but the concentration was lower than the quantification limit (<2 µg/L). Regarding organic substances, the group which exhibited the most concentrations was the phenols; it was reported concentrations especially for 4-t-Octylphenols up to 3600 µg/L followed by iso-Nonylphenols (up to 1120 µg/L). Concentrations of phthalates also were found in the leachates up to 5.6 µg/L for diethylhexylphthalate (DEHP), and among the PHAs analyzed, the most highest concentrations detected was for acenaphthylene (0.27 µg/L) (Plesser and Lund 2004).

On the basis of these results, an environmental risk assessment was conducted by the Norwegian Institute for Water Research (NIVA). Their assessment was based on a local scenario, assuming that run-off from an artificial turf pitch is drained to a nearby stream. Furthermore, they assessed the effects on aquatic organisms, including the sediment compartment. The assessment shows that the main contributor to the environmental risk is zinc, but alkylphenols, and octylphenol were also predicted to exceed the limits for environmental effects. The leaching of chemicals from the materials in the artificial turf system is expected to decrease only slowly, so that environmental effects could occur over many years. The total quantities of pollution components which are leached out into water from a normal artificial turf pitch are however relatively small, so that only local effects can be anticipated (Källqvist 2005).

The Swedish Chemicals Agency, also interested in the issue, published on 2006 a status report “Artificial turf from a chemical perspective”. The report was focuses on health and environmental aspects on artificial turf football pitches with an infill made by only granulate from recycled tyres. The assessment did not include other uses of recycled tyres, such as playgrounds horse-riding surfaces and other sporting activities. Regarding environmental issues, the information analysis was mainly focused in the work conducted by research institutions in Norway during 2004-2005, which is reported in lines above of this document. The agency concluded that synthetic turf that contains rubber from recycled tyres may give rise to local environmental risks. Investigations have shown that zinc and phenols can leach from the rubber granulate, and these substances can affect aquatic and sediment dwelling organisms, if they reach neighboring water courses. The total amount of these substances that leaches from synthetic turf is small, and thus any effect on the environment that they have is expected to be local (KEMI 2006).

The Netherlands National Institute for Public Health and the Environment (RIVM) (Verschoor 2007) published a report which estimated the release of zinc from rubber infill and the distribution between the soil, groundwater and surface water. Regarding zinc leaching, the authors conclude that ageing of the rubber crumbs is an important factor that contributes to zinc releases into the environment. Estimations of zinc concentrations in drainage water, soil, surface water and groundwater and the comparison with ecotoxicological risk limits, allowed identifying ecotoxicological risk in surface water, groundwater and soil.

The Danish environmental protection agency published a report on 2008 (Nilsson, Malmgren-Hansen, and Sognstrup Thomsen 2008) which provide valuable information about leaching of substances from infill materials, artificial turf mats and pads. The leachate studies were conducted also with sodium chloride and calcium chloride solutions, in order to evaluate the contribution of salt on leachate substances, especially during the winter season. The leachates studies were conducted with 16 different infills materials (ex: granulated car tyres black, EPDM granules, SBR rubber granules, SBR granules dyed brown, TPE…etc), 8 samples of artificial turf mats from 6 different supplies and two types of pads. The results showed that high amounts of phthalates leachate were detected from infill materials and artificial turf, the concentrations found were significantly higher than those found from the Norwegian study (Plesser, 2004). For SBR granulates, it was reported concentrations of DEHP comprised between 14 to 114 µg/L, total of phtalates (without DEHP) between 162 to 428 µg/L. Regarding zinc, concentrations in leachate from elastic infill material were in the range of 600-2300 µg/L. Furthermore, others substances such as 6PPD (degradation product of 1,4-Benzenediamine, N(1,3-dimethylbutyl)-N'phenyl) and benzothiazole were detected in some samples in a concentration range of 266 to 687 µg/L and 293 to 574µg/L respectively. Regarding the leachates experiments from artificial turf, significate concentrations of phtalates were found, especially for DEP (302-359 µg/L) followed by DEHP (5-183µg/L) and DIBP(10-144), concentrations of nonylphenol were also detected in the range of 143-384 µg/L. The substance Bis-(2,2,6,6-tetramethyl-4-piperidinyl)sebacate was found in a very high concentration (35000 µg/L) in the leachate from one sample of artificial turf.

In order to assess the transfer of substances to drainage water in nearby watercourse, especially those found in significant concentrations from the leachate studies, an environmental risk assessment was conducted with the followed substances: zinc and its salts, 6 PPD, Dicyclohexylamine, Diisobutyl phthalate, Nonylphenol, 2,4-Di-tert-butylphenol, bis(2,2,6,6-tetramethyl-4- piperidinyl)sebacate. A worst case scenario was considered in the calculation of PEC in water. It was assumed that the drainage water concentrations of substances correspond to those found in the leachates experiments. From the data obtained in the leachate experiments with the infill materials assessed, the results showed significate high risk ratios for zinc, phthalates, Cyclohexanamine and cyclohexanamine,N-cyclohexyl, Phenol 2,4-bis (1.1-dimethylethyl)- and from artificial turf mats the highest risk ratio were found for phatalates, nonylphenol and for Bis-(2,2,6,6- tetramethyl-4-piperidinyl) sebacate.

ALIAPUR with Fieldturf Tarkett and the ADEME (French Environment & Energy Management Agency), published a report on 2007 regarding the results of experimental studies conducted in order to evaluate the environmental and health impact of the different material used as filling in artificial turf (Moretto 2007). The studies were focused in the evaluation of possible environmental effects linked principally to the substances presents in percolates from artificial turf surfaces. Volumes of percolates were recovered during 11 months of monitoring period from pilot's scenario as well as an in situ football pitch surfaces. Three types of sports surfaces produced from 3 distinct types of granulates were assessed, PUNR (SBR), EPDM and ETP granulates. The chemical analysis of substances included total cyanide, phenolic index, 16 PAHs, TOC, Al, As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, Zn, fluorides, nitrates, ammonium, chlorides and sulphates. In order to evaluate possible enrichments of the percolates, the rainwater and supply network drinking water of the pilots was also characterised. In addition, acute toxicity tests with the percolates recovered were conducted with *Daphnia magna* and the algae *Pseudokichneriella subcapitata*. Over time and irrespective of the type of filling material, the cyanide, phenol and total hydrocarbon concentrations were very low (cyanide < 60 µg/l, phenol < 20 µg/l and total hydrocarbon < 50 µg/l, mainly < LOD in most of time). The metal Sn, As, Mo and Sb presented slight fluctuations but always remains below the reference guide values. In all the experiments, the metals analysed Al, Ba, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sn and Zn showed a drop in their concentrations over time reaching values close to the controls and they were below reference guide values and sometimes even below the LOD. The authors indicate that the essential part of the release of substances takes place in the 1st month after the deployment of granulates in the artificial turf. Regarding the Ecotoxicity results for the 4 pilots studies on percolates collected 15 days after the launch of the experiments show a slight toxicity for daphnia and algae (CE50 was never reached). No toxicity was recorded with the percolates recovered after 3 and 8 months. For in situ football pitch, the Ecotoxicity assessment do not highlighted any toxicity except after 7.5 month for algae with a growth inhibition rate of 57.5%. The authors attributed this results to external pollution linked to the environment of the pitch.

The RIVM published a scientific background document dealing with the evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate (Oomen AG and GM 2017). This report assess the substances in rubber granulate from 100 sports pitches and to what extent they may be released. They found that the main chemical released from rubber granulate was Zn in concentration as high as 129 mg/kg dry matter and that may have adverse consequences for organisms in soil or water. Leaching of organic compound in runoff water was not assess during this evaluation.

The RIVM published a scientific background document dealing with the evaluation of the environmental impact of rubber infill near synthetic turf fields (Verschoor, Bodar, and Baumann 2018). This document report that leaching of substances from rubber granulate is possible and can enter in soil in the field borders and in the ditches. They conclude that ditch water and groundwater in the natural soil are not contaminated by rubber granulate on the fields. They report that concentrations of zinc, cobalt and mineral oil exceed the environmental quality standards for soil and sediment at various locations. This could be a problem because the environment is particularly sensitive to high concentrations of zinc; however, zinc is not a health issue for humans. At one of the studied locations, RIVM detected a very significant zinc levels exceeded the limit value by more than 250 times, and the concentration was more than 15 times higher for cobalt.

The report highlighted that in the measured ditch water samples, the concentrations were diluted causing no harmful effects. However, most substances have the ability to bind to particles that can precipitate into the sediment, resulting in effects for the sediment organisms. The technical sublayers of the synthetic turf can accumulate cobalt, zinc and mineral oil that leached from rubber granulate possibly leaching latter in the environment. This was shown by studies by various municipalities, which RIVM additionally evaluated as part of this study. The conclusion from this report was that some effects on living organisms were found in a part of the samples of drainage water and sediment. The uses of rubber granulate infill on synthetic turf pitches may lead to local contamination of soil borders around sports pitches and of sludge at the bottom of ditches. This contamination consists of rubber particles and substances that leach out of rubber granulate. Groundwater and surface water seem to be uncontaminated, so the risk of more widespread dispersal of the substances appears minimal

RIVM recommends to prevent the spreading of rubber granulate to the field borders and to limit the emission of substances via the drainage water.

9.1.2 Findings from others sources

Several metallic elements were identified in leachates from synthetic turf infill made with recycled granulate (Bocca et al. 2009). Significant concentrations of Zn (2300 µg/l) and Mg (2460 µg/l) were found followed by other metallic elements like Fe (300 µg/l), Sr (77.0 µg/l), Al (67 µg/l), Mn (33.0 µg/l) and Ba (27 µg/l). Very little or undetectable leaching levels were observed for the other elements analyzed. In particular, toxic metals such as As, Hg, Cd and Pb or other severely allergenic metals as Co, Cr and Ni had non-significant releases.

Synthetic rain water applied for 24h to automobile tyre powder sampled in the United States was able to leach a mean concentration of 3400 mg/ kg of Zn, 17 mg/kg of Pb, 5 mg/kg of Cu, and 1 mg/kg of Cd (Davis, Shokouhian, and Ni 2001). In leaching studies with tyres collected from two different tyre retailers concentrations of Zn between 110 to 590 µg/L were reported (Wik and Dave 2006).

Different to the classic methods of leaching, (Canepari et al. 2018), studied the release of particles, organic compounds, and metals from infill materials used in synthetic turf under chemical and physical stress. The results highlighted that materials can engender leachate from SBR with concentration of 246 to 251 mg/kg for Zn, 82 to 112 mg/kg for Ca, 10 to 30 mg/kg for Si, 11 mg/kg for Mg, 2.5 to 3.4 mg/kg for Cu depending on the leaching method (mechanical agitation, microwave-assisted extraction and ultrasonic-assisted extraction). The use of MAE (temperature and pressure conditions) on thermoplastic and natural rubber highlighted that the main released chemicals were Mg (2 to 91 mg/kg) and Ca (265 to 6905 mg/kg)

In other study, five samples of crumb rubber and one sample of natural soil from sports facilities were characterized and the release of chemicals when they were in contact with water was assessed according to the EN 12457/2 compliance test. It was highlighted that metallic chemicals were principally released. Zn exhibit concentration comprised between 1143 to 2729 µg/L, Mg between 12.3 to 42.4 µg/L, Cu between 6.62 to 22.1 µg/Land Co between 9.03 and 11.9 µg/L. Toluene and xylene were also detected, with concentration ranging from 0.29 to 0.43 µg/L and 0.34 to 0.45 µg/L, respectively (Ruffino, Fiore, and Zanetti 2013).

With the perspective of re-using material for cycle economy, it was demonstrated that the use of recycle-EPDM from cables and automotive mats may engender large amount of leaching of some chemicals, such as 5000 µg/l of Zn after a single stage of the shaking test at L/S 10 according to EN 12457-2 standard (Magnusson and Mácsik 2017).

Regarding zinc, the metallic element can be used on the production of tyres under different chemical forms but mainly as ZnO (Fauser et al. 1999, Degaffe and Turner 2011, Councell et al. 2004). It has been estimated that a typical soccer pitch can contain a total load of 1.2 tons of zinc and can potentially release 10 to 40 % of his Zn content within one year depending of the size of the granulates and debris (Cheng, Hu, and Reinhard 2014, Smolders and Degryse 2002). Cheng et al., 2014, estimated that, if the maximum concentration for Zn in water is 120 µg/L (US EPA recommendation), 10% of ZnO released from tyre crumb rubber for 10 to 20 years, can ultimately contaminate 1 million of m3 of water, having in mind that Zn can adversely affects the growth, survival, and reproduction of aquatic plants, protozoans, sponges, molluscs, crustaceans, echinoderms, fish, and amphibians at concentrations as low as 10 to 25 µg/L and NOEC starting at 10 µg/L . Tyre rubber also contains PAHs originating from aromatic oil, carbon black as reinforcing agent. Due to their physico-chemical parameters, and especially hydrophobicity, these chemicals were not expected to be released easily from the tyre matrix.

Besides tyre rubber crumb, plastic fibers composing the artificial turf are also a potential source for the release of chemical. In the early years of artificial turf, plastic fibers made of nylon or polyethylene/nylon blends where colored with some lead chromate pigment that can possibly leachates and generates lead containing dust from the fibers when they are submitted to aging and degradation (Van Ulirsch et al. 2010, Cheng, Hu, and Reinhard 2014, Highsmith, Thomas k. W. , and W. 2009). Moreover, the coloring pigments often served as UV inhibitors in polymers, explaining why fibers contains relatively high concentration of metals, such as Zn, Fe, Al, Ti, Sn, Cu, Co, and Ni (between 0.1 to 17 mg/g) (Cheng, Hu, and Reinhard 2014, Krüger et al. 2012, Zhang et al. 2008).

9.1.3 Factors affecting the release of substances

The cross-linked polymer matrix of rubber granulates is susceptible to aging, due to exposition to a number of environmental external factors such as weather conditions, the fluctuations of oxygen, ozone, temperature, heat, sunlight, diurnal cycle ,liquids, etc and also to the mechanical action exerted on granulates (ex; abrassion). All these external factors led to physical and chemical modifications of the properties of tyre rubber crumb then allowing the release of contaminants from the degraded rubber matrix.

The aging process is triggered by the oxygen present in the air that permeates into tyre rubber leading to oxidative degradation of the vulcanizates. In parallel, ozone attacks the surface causing cracks in the rubber. The temperature also plays an important role on the kinetics of these reactions by accelerating oxygen diffusion. UV radiation and sunlight also intervene in the oxidative degradation of the rubber surface whereas water and mud cause leaching of the soluble components from the rubber surface (Baldwin and Bauer 2008, Stevenson, Stallwood, and Hart 2008, Cheng, Hu, and Reinhard 2014).

A wide range of additives are used by tyre manufacturers to inhibit the attacks degradation of tyre, such as antidegradants, antioxidants, antiozonants, waxes and flex-crack inhibitors. During the tyre used life, antidegradants are gradually lost leading tyres to have drastically reduced resistance to cracks and weather effects compared to new ones. When decreasing size of tyre crumb rubber, the specific surface to area ratio increases and, as a result, the volatilization of organic contaminants into air, and the leaching of heavy metals and organic contaminants into water were increasing. The small particle sizes of the tyre rubber crumb also facilitate the aging process, leading to circle event reactions (Cheng, Hu, and Reinhard 2014). To a very lesser extent, biodegradation may also contribute to degrade crumb rubber granulates, but this pathway is very negligible (Stevenson, Stallwood, and Hart 2008, Li, Zhao, and Wang 2012, Rose and Steinbüchel 2005, Ali Shah et al. 2013).

Ruffino et al. (2013) studied four sports fields with derived rubber granulate of two ages: 1.5 years or 3 years. The authors observed that the youngest infills were those releasing more PAHs in the leachate. Others studies also observed the same tendency (Day et al. 1993, Gualtieri et al. 2005). It seems that the levels of PAHs tend to decrease with time. Zhang et al., 2008, attributed this tendency to the semi-volatility character of PAHs, photolysis and thermolysis reactions. Regarding metals, the tendency is not really clear, some studies have shown a decrease of metals concentrations in leachates over the time (Aoki 2008, Moretto 2007), whereas other studies have highlighted an opposite tendency (Kalbe et al. 2013, Rhodes, Ren, and Mays 2012, Li et al. 2010, Verschoor 2007). Based on results of previous studies on laboratory and field conditions, the RIVM (Verschoor 2007) highlighted that the aging of rubber material lead to an increase of zinc emissions. The RIVM (2007) showed an increase of zinc emission from the measurements in field-aged ELT-derivated granulates rubber and on laboratory aging conditions. The increase was explained by the ageing of ELT derivate granulates.

Assessing the aging of recycled rubber granulates and their contribution to the release of substances under real environmental conditions is difficult to evaluate, especially for synthetic turf due to their regular maintenance (addition of new infill material) which could contribute to a continuous releases of substances (Zhang et al. 2008)

Furthermore, maintenance practices, such as the application of salt in winter may result in change on leachate composition. In the study conducted by the Danish Ministry of the Environment (Nilsson, Malmgren-Hansen, and Sognstrup Thomsen 2008) the effect of the use of $CaCl_2$ salt on the leaching of infill material substances was analyzed. The results showed a significant decrease especially of leached phtalates and other organic substances. Regarding zinc no significant change on the concentrations were found.

Another factor that contributes to the variability of the releases of substances on leachates is the origin of the ELT-derived rubber granules. Differences in formulation between car and truck tyres may partly explain the differences in the composition of rubber granules commercialized by a company or between company (Plesser and Lund 2004). Indeed, according to Verschoor (2007) truck tyres contains more zinc than car tyres, which can explain disparities in zinc concentrations measured on rubber granulates. Moreover, it was highlighted that truck tires release more substances than car ones (Lim and Walker 2009). On the other hand, the type of tyre (winter or summer) could also contribute to the variability of the composition of granulates especially concerning the content of high aromatic oils (HA oils), which are still present on summer tyres (Wik and Dave 2005). Moreover, tyres or granules imported from countries outside the EU can be used, possibly containing other compounds or different concentrations in chemicals composing the tyres, leading to different leaching concentration (Re Depaolini et al. 2017).

Coated granulates with polyurethane (PUR) as infill material on synthetic turf and playground surfaces can be used. Some studies have shown a decrease of leachate substances for coated granulates. Gomes et al. 2010, compared the concentrations of substances (PAHs and metals) released from leaching experiments with two types of coating applied on ELT rubber granulates (Gomes et al. 2010). Their results showed a decrease of the concentrations of PAHs and metals for one type of coating compared to the non-coated ELT-derivated rubber granulates. Another study showed also a decrease of concentrations, especially for some PAHs and phtalates during leachates experiments with green coated ELT rubber granulates compared to uncoated ELT rubber granulates (Celeiro et al. 2014). Although, the presumably effectiveness of coated rubber granulates to limit leaching of substances, this would be decreased by the weathering (UV radiation, temperature, ozone) (Kalbe et al. 2013).

The size of the aggregates can also change the amount of substance that can be released from granulates. In fact, reducing the size of aggregates leads to an increase in their specific surface area, making these aggregates more capable of releasing chemical compounds than whole tyres (Rhodes, Ren, and Mays 2012, Wik and Dave 2009).

9.1.4 Potential environmental risk by the release of chemical substances

According to the studies summarized on the previous sections leachates can contain elevated concentrations of zinc and other metals such as Cd, Cu Cr, Cu, Fe, Mg at relative low concentrations. Regarding organic substances a wide range of substances were also detected, being the following families of substances such as phtalates (dibutyl phthalate (DBP), diethyl phthalate (DEP), diisobutyl phthalate (DIBP), et diethylhexyl phthalate (DEHP)), phenols (4-tert-octylphénol (4-t-OP), 4-nonylphénol (4-NP)), amines, BTX (Benzène, Toluène, Xylène) et benzothiazoles.

Regarding zinc, as indicated previously in this document, numerous studies have found the presence of the zinc element in ELT-derivated rubber granulates (Källqvist 2005, Gomes et al. 2010, Nilsson, Malmgren-Hansen, and Sognstrup Thomsen 2008, Ruffino, Fiore, and Zanetti 2013, Bocca et al. 2009, Menichini et al. 2011, Zhang et al. 2008, Price and Beausoleil 2015, Marsili et al. 2015, Llompart et al. 2013, Plesser and Lund 2004, Milone and MacBroom 2008). However none of these studies were able to distinguish between the zinc compounds used in the composition of the aggregates. Concentrations of zinc in granulates were ranging between 174 mg/kg and 27,000 mg/k, and between 0.59 µg/L up to 5,000 µg/L in the leachate.

Zinc can be used as various chemical compounds during tyre production (see section 7). The main form used is zinc oxide which acts as a vulcanization activator. More rarely, zinc can be used as a vulcanization accelerator as thiocarbamates: ZDMC (zinc dimethyldithiocarbamate), ZDEC (zinc diithyldithiocarbamate), ZDBC (zinc dibutyldithiocarbamate), ZBEC (zinc dibenzyldithiocarbamate) (ChemRisk and DIK 2008).

Chemical name	**CAS No**	**Classification**	**PNEC$_{freshwater}$**
Zinc (Zn)	7440-66-6	Water-react. 1, Aquatic Acute 1, Aquatic Chronic 1	20,6 µg/L
Oxyde de Zinc (ZnO)	1314-13-2	Aquatic Acute 1, Aquatic Chronic 1	20,6 µg/L
Diméthyldithiocarbamate de zinc (ZDMC)	137-30-4	Acute Tox.4 (H302), Acute Tox. 2 (H330), Eye Dam. 1, Skin Sens. 1, STOT SE 3, STOT RE 2, Aquatic Acute 1, Aquatic Chronic 1	5.34 µg/L

Chemical name	**CAS No**	**Classification**	**PNEC$_{freshwater}$**
Diéthyldithiocarbamate de zinc (ZDEC)	14324-55-1	Acute Tox.4, Eye Irrit. 2, Skin Irrit. 2, Skin Sens. 1, STOT SE 3, Aquatic Acute 1, Aquatic Chronic 1	0,064 µg/L
Dibutyldithiocarbamate de zinc (ZDBC)	136-23-2	Eye Irrit. 2, Skin Irrit. 2, Skin Sens. 1, STOT SE 3, Aquatic Acute 1, Aquatic Chronic 1	0,32 µg/L
Dibenzyldithiocarbamate de zinc (ZBEC)	14726-36-4	Not in CLP.*	0,32 µg/L

Table 11: Chemical forms of zinc used in tyre production

Furthermore, Zinc is the second most abundant heavy metal that exists in living cells and is an essential metal required for the survival of many organisms (INERIS 2014). Nevertheless, it is known that high levels of zinc can cause adverse effects on aquatic, terrestrial organisms and plants (Rhodes, Ren, and Mays 2012, Eisler 1993, Bodar 2007).

In order to determine the risk presented by zinc for aquatic environments, the concentrations identified in the leachate were compared with the PNECfreshwater (20.6 µg/L) (ECHA 2018a). The majority of available studies show concentrations exceeding the PNECfreshwater. In addition, the risk assessment conducted by the Norwegian Institute (Källqvist 2005) shows that zinc is the component which represents the greatest risk for environmental effects. The risk quotient calculated for the water and sediment compartment were 40 and 341 respectively, which indicates a risk of environmental effects for both compartments. Moreover, it was estimated that the leaching of zinc from artificial turf pitches were originate from both turf synthetic fiber (30%) and rubber granulate (70%). The RIVM (Verschoor 2007) also showed in their environmental risk assessment for zinc in ELT derived rubber granulates infill on football pitches that potential ecotoxicological risk in surface water, groundwater and soil may occur.

Phthalates have been detected in recycled tyre aggregates, their leachate and in dust present over indoor artificial turf (Plesser and Lund 2004, Llompart et al. 2013, Dye et al. 2006). Phthalates are derived from phthalic acid and are used for their plasticizing properties mainly in the rubber industry. They are banned from use in several sectors such as cosmetics, children's articles, toys, textiles and hygiene products because of their identification as endocrine disruptors (ED). Phthalates are not chemically bonded to the matrix, so they can migrate into plastic and be released into the environment (Nilsson et al. 2016).Among the phthalates detected in the composition and leachates from ELT derivate rubber granulates and synthetic turf, dibutyl phthalate (DBP), diethyl phthalate (DEP), diisobutyl phthalate (DIBP), and diethylhexyl phthalate (DEHP) where those which presented the highest concentrations. These substances have been identified as SVHC (substance of very high concern) by their endocrine disruptor properties and list in the annex XIV of REACh (ECHA 2018b). The Danish Environmental Protection Agency (Nilsson, Malmgren-Hansen, and Sognstrup Thomsen 2008) showed risk ratio for water around 10 for phtalates, based on the leachate tests conducted and the calculations of discharge for leached substance from infills to watercourses, which implies that infill materials and artificial turf may engender a potential environmental risk for these substances.

Regarding the detection of alkylphenols in leachates from ELT-derivated granulates and synthetic artificial turf, the substances 4-tert-Octylphenol (4-t-OP) and 4-n-Nonylphenol (4-NP) were principally identified. Both substances are known to be highly toxic to aquatic organisms, they have been identified as endocrine disruptors for the environnement (ECHA 2018b) and they are identified as priority substances in the Water Framework Directive (2011/0429/EC 2011). The risk ratio calculated for water and sediments by the Norwegian Pollution Control Authority (Källqvist 2005) during their assessment highlighted a potential risk for the aquatic environments. For alkylphenols, 4-tert-octylphenol alone represents a risk; the nonylphenols contribute to the risk quotient for water and sediment of 3.3. The Danish EPA (Nilsson, Malmgren-Hansen, and Sognstrup Thomsen 2008) reported a high risk ratio of 115 for nonylphenol in leaching originating from artificial turf mats.

Relative to PAHs group, in the assessment of Källqvist 2005, the risk quotients for the individual substances is less than 1, however the sum of the risk quotients for water is 1.13, indicating that the collective effect of PAHs could represent a risk for the biota in aquatic compartment. It is expected a decrease of concentrations of PHAs on ETL-derivated rubber granules due to the PAH-rich extender oils restriction in uses set by European Commission since 2010 (Krüger et al. 2012, Wachtendorf et al. 2017, European Commission 2009).

9.2 Ecotoxicity studies with leachates

Some ecotoxicity studies have attempted to identify the potential risks to aquatic and terrestrial organisms. Most of them have been conducted on laboratory conditions in which organisms have been exposed by short term exposition to leachates generated from ELT-derivated rubber granulates and others infill materials (EPDM and NR).

Gomes et al.. 2010 in their experiments of leaching with coated and non-coated ELT-derivated rubber granulate studied also the toxic effect of leachates with the aquatic marine bacteria *Vibrio fischeri*. The experiments showed that leachates from coated and non-coated ELT rubber granulates exerted a toxic effect, although a significant decrease of toxicity was observed for the coated aggregates. The authors suggest that the coating of aggregates would significantly reduce the released substances and therefore their toxicity. Another study with aquatic organisms, *Daphnia magna* (48 hours of exposition) and *Selenastrum capricornutum* (72 hours of exposition), respectively, highlighted no toxic effects of the leachates (Gomes et al. 2011).

Toxicity effects with leaching from EDPM granulates and ELT-derivated rubber granulates were observed by Krüger et al., 2013. They results from short term experiments with *Daphnia magna* and *P.subcapitata* showed that EPDM leachate exerted the highest effect on *Daphnia magna* (EC50 < 0.4% leachate) and the highest effects with ELT granulates were observed with *P. subcapitata* (EC10 = 4.2% leachate; EC50 = 15.6% leachate) (Kruger et al. 2013).

Birkholz, et al (2003) investigated the toxicity of leachates of ELT-derived rubber granulates samples by short term test on aquatic organisms representing four trophic levels: *Vibrio fisheri*, *Daphnia magna*, *Selenastrum capricornutum* and *Pimephales promelas*. According to their results, all the leachates tested exerted a toxic effect on the organisms. The toxic effects were higher on S. Selenastrum capricornutum which present the highest toxicity potential according to the Potential Ecotoxic Effects Probe (PEEP) index. The authors also observed that toxicity is significantly reduced with the aging of aggregates (59% decreased). They conclude that, despite the observed toxicity, the method used has the worst case scenario, so under more realistic conditions (where the leachate would be diluted), it seems unlikely that the aggregates pose a risk to aquatic environments (Birkholz, Belton, and Guidotti 2003).

Regarding the potential effect on terrestrial organisms, two studies were identified in the literature. Pochron et al. (2017) investigated the sublethal and lethal effects of ELT-derivated rubber granulates on the worm *Eisena fetida*, as well as the effects on soil microbial populations. Worms were exposed to a mix of soil and ELT granulates during approximately one month. The authors did not observe any effects of contaminated soil on microbial populations and worm mortality. However, a decrease was observed in the growth of worms compared to controls. The authors indicate that a decrease in the weight of worms could be followed by a decrease in fertility and more studies are needed to conclude on the effects on worms' reproduction (Pochron et al. 2017). Effects on nematode populations were observed in the experiments conducted by Zhao, He, and Duo (2011). The authors studied the impact of natural grass fill with ELT granulates on several nematode populations. The nematodes were exposed to a mix of fresh soil and dry soil to which aggregates and seeds of the herbaceous *Lolium perenne* were added. The authors observed, on one hand, a significant decrease in the dry weight of L. perenne shoots in contaminated soils, and on the other hand, a decline in the number of nematodes in contaminated soils. However, they were unable to conclude on the reason for this decrease. They hypothesized that the effects observed could be resulting to the presence of zinc, which is known to exert toxicity to some nematode species (Zhao, Deng, and Chen 2011).

Ecotoxicity studies with percolates collected from a lysimetric system from pilot scenarios and field from a football artificial turf surface (infilled with ELT-derivated rubber granulates) were investigated by Alliapur and ADEME (Moretto 2007). In their experiments, *Daphnia magna* and *Pseudokirchneriella subcapitata* were exposed to the collected percolates after 48 hours and 72 hours respectively. According to their results, no toxicity was observed with the percolates from the field on *Daphnia magna*. However, a growth inhibition of algae of 57.5% (based on an 80% inhibition threshold) was observed with the last percolate recovered (approximately 7.5 months). The authors attributed this toxicity to external pollution. Results from pilot's scenarios showed slight toxicity to the organisms on the percolates recovered after 15 days of watering. The highest toxicity was observed with the *P. subcapitata* (Moretto 2007). Another study conducted also with percolates recovered from field synthetic turf (infilled with ELT-derivate rubber granules) showed no lethal effects with *Daphnia pulex* after 48 hours of exposition to the percolates (Milone and MacBroom 2008).

In view of the limited number of references concerning the ecotoxicological effects of ELT-derivated rubber granules, the toxic effect on living organisms cannot be exclude. Several studies with chips, rubber particles or whole tyres have been conducted on species belonging to different taxa. Acute toxicity was observed in most of the studies, especially on test with smaller particles (from pulverized rubber/ tyre tread particles) (Wik and Dave 2009).

In order to decrease the discharge of pollutants from drainage to receiving water bodies, optimized treatement systems and management strategies are needed. The treatment of drainage would be necessary also to prevent potential synergistic impacts of the contaminants, specially for those found at low concentrations (Cheng, Hu, and Reinhard 2014). In some artificial turf fields, it is used crushed rock that possesses the ability to retain some heavy metals through sorption/coprecipitation process. The same type of active filtration could be achieved for hydrophobic substances with the use of sorbent such as activated carbon (Cheng, Hu, and Reinhard 2014, Cheng and Reinhard 2010, Milone and MacBroom 2008). This type of system could help to prevent the release of hazardous material from artificial synthetic turf and playgrounds.

9.3 Others sources of pollution

9.3.1 Microplastics

Infill materials, comprising the whole family of synthetic polymers, thermoplastics, thermosets, elastomers and ELT-derivated rubber granulated, but also including modified natural bio-polymers, are considered to be a potential source of pollution as microplastics from an environmental point of view (Verschoor 2007). During their uses and lifetime, car and truck tyres can release wear particles through mechanical abrasion and may be an important source of microplastics in the environment (Kole et al. 2017). The same type of mechanical interaction (with players and mechanical tools for maintenance) may occur in artificial turf, leading to the release of microplastics from these infills to the surrounding environment.

ELT-derivated rubber granulated, which are between 0.5 and 4 mm in size in synthetic turfs and playgrounds, can be described as microplastics (Magnusson and Mácsik 2017). There are primary microplastics, which are manufactured to be of microscopic size (microbeads) and so-called secondary microplastics which are particles resulting from the wear of plastic waste. According to that definition, tyres aggregates can be considered as primary and secondary microplastics (Lassen et al. 2015).

Nowadays, few studies have investigated the "microplastic" nature of ELT derivated rubber granulates. Taking into account the recommendations for maintenance of synthetic turf (infill), the Danish Environmental Protection Agency has estimated that synthetic turf refilling could be comprised between 380 and 640 tons / year in Denmark. Moreover, apart from synthetic football fields, tyres are also used for rugby-tennis-and golf fields, running lanes, rubber mats for playgrounds, etc. Therefore, the same amount of infill material is estimated to enter the environment, leading to a total amount of microplastics in the environment of 760 to 1280 tons/year (Lassen et al. 2015). Another report by Magnusson et al. (2017) concluded that aggregates were the second largest source of microplastics in environment and that the loss of tyre granulates from artificial turfs is estimated to be about 2300–3900 tons/year in Sweden (Magnusson and Mácsik 2017). According to these estimations, the loss of infill material to the environment is significant when compared to the amount of wear and tear from tyres and could represent 18 to 50 % of the materials (Kole et al. 2017).

These studies also highlighted the difficulty of estimating the quantity of granulates that can be released into the environment, and more particularly, coated granulates. Indeed, these studies have mainly focused on infill material from artificial turf in the free form, however playground coatings or athletic tracks could also be a source of microplastics. This case has been observed in the Lomma’s school playground in Sweden where coated infill material were found in river located several meter away from the playground location (Andersen Hörman 2017).

The specific gravity of microplastics will influences their floating ability in water (Besseling et al. 2017) and will determine their distribution in water compartment, as part of the flow or, most likely, as sinking and settling down particles onto sediment. The specific gravity of tyre rubber is comprised between 1.15 and 1.18 indicating a high possibility for those particles to settle down in water compartment (e.g. average density of ocean waters at the surface of 1.025) (Kole et al. 2017).

Regarding the efficiency to remove microplastics on the effluent of Waste Water Treatment Plants (WWTP), it was evaluated in different studies in the Netherlands, Sweden and Denmark that, 5.3% to 28% of microplastics with a size comprised between 10 to 5000 µm were still present at the end of the filtration process, remaining in the water flow and ending in the environment (Magnusson and Wahlberg 2014, Leslie et al. 2017, Magnusson and Norén 2014).

For sludge produced in WWTP in Europe and North America, Nizzetto and colleagues (2016), estimated that 50% of them is used as a fertilizer on farmland. They used the INCA-contaminants model and estimated that 16 to 38% of the microplastics spread with the WWTP sludge on the land remain in the soil indicating a possible source of pollution for soil compartment (Nizzetto et al. 2016, Nizzetto, Langaas, and Futter 2016).

The hazardous effects associated by microplastics, arise from the ingestion of degraded particles by organisms, fixation of these particles on organisms, modifying their locomotion and thus, impacting the predatory-prey relationships. These microplastics may also be retained and fixed in the respiratory systems of organisms, such as gills, thus limiting the respiration (Scherer et al. 2017, 2008, Rist and Hartmann 2018, Rist et al. 2016, Anderson, Park, and Palace 2016, Setälä, Norkko, and Lehtiniemi 2016, Browne et al. 2013, Nobre et al. 2015). Moreover, the adverse effects inside the organisms may then arise when the release of substances occurs after being continuously or periodically submitted to the fluctuations of the local physico-chemistry, especially in environment such as stomach fluids.

9.3.2 Nanoparticles

Nanomaterials (NMs) have long been used in the production of tyres and it continues to grow as they significantly improve the performance of tyres, reduce their wear and thus increase their service life (ChemRisk 2011, Price and Beausoleil 2015, OCDE 2014). The most used NMs are carbon black, carbon nanotubes (CNTs) and silica nanoparticles (SiO2-NPs). However, the use of other NMs is possible and increasing, such as nano clays including both natural clays (phyllosilicates e.g., montmorillonite, hectorite and saponite) and synthesized clays (e.g., fluorohectorite, laponite and magadiite), ZnO, polyhedral oligomeric silsesquioxane (POSS), nanodiamonds, carbon nano fibers, etc. (OCDE 2014, Giftson Felix and Sivakumar 2014). For example, the Lanxess Group developed nanoprene, a new technology that uses 50 nm polymerized styrene and butadiene to reduce tyre wear. In addition, the zinc oxide currently used in its micro form could be replaced by its NPs form, which would reduce the amount of ZnO used in tyre production (Suchismita et al. 2007).

Carbon black and SiO_2-NPs are used as reinforcing filler and have long been used in the tyre industry, averaging 20 to 35% of the weight of a car tyre (Wik and Dave 2009). It is assumed that those NMs may be found in SBR released materials. Moreover, with recent research and improvement, carbon black may sometimes be replaced by silica and nanosilica (nanoscale glass sphere) (Okel and Rueby 2016). When used in tyre, CNT improved mechanical properties, such as tensile strength, tear strength and hardness of the composites by almost 600%, 250% and 70% respectively, comparing with those of the pure SBR composites (Giftson Felix and Sivakumar 2014).

Due to their particular properties, carbon black and CNT may adsorb other compounds such as PAHs, metal oxides or other organic substances resulting from the decomposition of tyre aggregates. SiO_2-NPs can be in individual form (2 to 40 nm), aggregates (100 to 500 nm) or agglomerates (1 to 40 µm).

Moreover, besides the uses of NMs inside the tyre matrix, nanoparticles are increasingly added into the polymer used for the generation of turf fibers. NPs were added into the polymer matrix in order to improve their wear resistance, decreased their infrared adsorption, strengthen their structure and increased their mechanical and thermal properties. SiO_2-NPs can improve mechanical properties of artificial turf fibers when SiO_2-NPs content is 6 wt.% (Hongling et al. 2014, Weishan et al. 2011).

Consequently, as nanotechnology is increasingly used in technological products and undergoes larger and larger scale production, it is inevitable that nanoscale by-products and will end up in the environment possibly engendering a contamination and a risk for the organisms living in those different environmental compartments.

9.3.3 Heat effect

Synthetic turf surface temperatures have become a factor of growing interest and concern, particularly in warmer regions. Indeed, one major drawback of synthetic turf is elevated surface temperatures compared to natural turf grass (Lim and Walker 2009). The crumb rubber granulates infill and the hydrophobic dry plastic (polyethylene) pile-fibers materials have low specific heat, moisture and present no evapotranspiration (Jim 2017, 2016). These specificities induce a little time lag to synchronize with insolation rhythm and led to a fast warming and cooling events. On sunny day, intense incoming short- and longwave radiation corresponding to a high net solar irradiance are absorbed readily by synthetic materials composing the artificial turf field leading to a cascading warming effect conducting to rapidly increased turf surface temperature. Then, heat is dissipates by strong ground-thermal emission and by conduction and convection phenomenon to near-ground air (Jim 2017). It was suggested that level of solar radiation, ambient temperature and relative humidity were the environmental variables that significantly influenced surface temperature on infilled synthetic turf (Petrass, Twomey, and Harvey 2014, Petrass et al. 2015). Moreover, electromagnetic radiation will affects infilled synthetic turf surface temperature more than ambient air temperature. Indeed, after irradiation of infilled synthetic turf surface at ambient air temperatures of 36.7°C, surface temperature were highlighted to be higher than 90°C. Moreover, the difference in pigment coloration of the playground (generally in green) and the white lines areas delimitating the surfaces were shown to generate different temperatures reflecting variability in light reflectance and solar radiation intensity (Williams and Pulley 2002, 2006). Thus, high temperature were frequently recorded on infilled synthetic turf fields (Jim 2017, 2016, Villacañas et al. 2017, Thoms et al. 2014, Petrass, Twomey, and Harvey 2014, Petrass et al. 2015) and also on non-infilled synthetic turf (Buskirk, McLaughlin, and Loomis 1971), with temperature exceeded by 30°C to 65°C those of natural turf fields.

The irrigation system is the main system implemented to try to cool the synthetic turf playing surfaces (Thoms et al. 2014). Irrigation was reported to cool infilled synthetic turf surface temperature to reach the temperature of natural turf grass after 30 minutes. Nevertheless, the decreased in temperature surface was lasting only for 5 minutes after the end of irrigation before increasing again (Williams and Pulley 2002). In another case, the irrigation leads to decreasing the temperature for 3 hours (McNitt, Petrunak, and Serensits 2008). It was suggested that duration of synthetic turf surface cooling from irrigation is dependent on environmental conditions such as wind speed, ambient temperature, and solar radiation (Thoms et al. 2014). Moreover, experimental investigation of infilled synthetic turf fields highlighted that turf fields built with styrene–butadiene rubber and fibrillated fibers present the highest temperature and that thermoplastic rubber and the monofilament fibers contribute to a lesser extent to the increased of temperature (Villacañas et al. 2017, Petrass, Twomey, and Harvey 2014, Petrass et al. 2015).

The high temperature that can be found near infilled synthetic turf could engender a localized hot spot that could lead to disturb the fauna and flora and disrupt the functioning of the ecosystems by a burning effect of the most sensitive species.

9.4 Discussion

The recycling of end life tyres in the form of granules for the production of synthetic grounds is one of the main ways for valorising material in the French tyre waste management system.

The use of ELT-derivated rubber granulates on children’s playground and as infill material on artificial turf fields raises questions about the potential impact on the environment. These concerns are the result of the extensive variety of hazardous substances that are composing the tyres matrix and that could potentially be released into the environment. The available studies highlighted that a large number of chemical substances are able to leachate from the recycled rubber and synthetic turf. Rainwater as well as watering practices may favour the leaching of hazardous organic and metallic compounds, transporting them on sewage waters, groundwater and surface waters and potentially reach the soil and sediment compartment of the surrounding environment.

The main groups of substances found in leaching studies with infill materials, especially with ELT-derivated rubber granulates used in synthetic turf were PAHs, phthalates (DBP, DEP, DEHP, and DIBP), metals (mainly zinc), phenols (4-t-OP, 4-NP), amines, BTX (Benzene, Toluene, Xylene) and benzothiazoles.

Regarding the exposition of living organisms to hazardous substances, the available studies agreed and highlighted that local exposure, i.e. in the close vicinity of artificial playgrounds and fields, is more likely to arise. Nevertheless, an occasional exposure at a larger scale is possible due to the dispersion of rubber granulates, for example in case of heavy precipitation, wind, transport by users, etc. The risks for the environment are driven by the release of metalic and organic compounds, but, despite the available literature, the environmental risks estimated from punctual leaching evaluation could still be underestimated. Indeed, the leaching experiments and estimations do not often consider the release of substances throughout the functional lifetime of ELT-derivated rubber granulates. It was highlighted that ageing of rubber granulates could favor the increase of emissions of Zn over time, whereas for organic substances it seems that emissions could decrease over time. Furthermore, the analysis of leachates from different studies performed with ELT-derivated rubber granulates showed that the chemicals substances were present at varying concentrations ranging from very high for Zn, to very low for organic substances such as PAHs. These organic substances may concentrate in the environmental compartments receiving these leachates and could possibly lead to long-term adverse effects for living organisms.

Under natural conditions, determination of chemical substances released from artificial synthetic fields infilled with ELT-derivated rubber granulates could be a huge and complicated task, especially when taking into account the fate and transport of these substances in the different environmental compartments. The long-term evolution of the substances is difficult to predict locally when focusing on the released kinetics only. Indeed, the amount of substances available on the surface of the ELT-derivated rubber granulates to undergo leaching and dilution in water is decreasing among time, but, at the same time, the ageing process increases the degradation of crumb rubber granulates, exposing new surfaces possibly leading to more leaching of chemicals.

Moreover, the available studies in the literature highlighted that the main groups of chemical substances identified (zinc, phtalates, PHAs and phenols) after leaching experiments can be released at concentrations higher than environmental quality standards or $\text{PNEC}_{\text{freshwater}}$, potentially leading to adverse effects for organisms living in the environmental receptors of these leachates. The main chemical released from ELT-derivated rubber granulates was zinc with most of the reported concentrations in the literature being higher than the $\text{PNEC}_{\text{freshwater}}$. Furthermore, environmental risk assessments using exposure scenarios also showed an environmental risk for the aquatic compartment. In addition, the French norm NF P90-112 regarding sports surfaces express that leaching concentrations below the threshold of 0.5 mg/L have to be respected for artificial sport pitches. The concentrations reported in the literature exceed this threshold value (up to several mg/L). Thus, the exposition to significant zinc concentrations could potentially lead to adverse effects for living organisms.

Furthermore, some of the chemical substances released from ELT-derivated rubber granules have been identified as substances of very high concern due to their endocrine disruptor properties (eg DBP, DEHP, DEP, 4-t-OP, 4-NP). It has been demonstrated that these substances can cause adverse effects even at very low concentrations. It may be pertinent to consider the risk related to organism's exposure to multiple endocrine disruptors, and their potential interactive effects. Moreover, little is known on the “cocktail effect” of these chemical substances, possibly enhancing effects of each substance.

Another point that has been noted is that nanomaterials are used in the manufacture of tyres and fibers making up synthetic sports grounds (OCDE 2014). These nanomaterials can potentially be released into the environment. However, currently there are not sufficient available data on their release to assess their environmental risks.

Ecotoxicological studies conducted with aquatic or terrestrial organisms exposed to leachates generated from ELT-derivated granulates are not substantial. Some of these studies have demonstrated effects, mainly on aquatic organisms. However, the results of these studies do not allow drawing conclusions about the risks for the living organisms. Indeed, these studies have been conducted on short-term exposures using very high concentrations in order to reflect a worst case scenario. Moreover, the exposure conditions used are often unrealistic, not taking into account dilution and competitions with other molecules with respect to biological receptors or adsorption of these substances.

Other identified risks for the environment:

In addition to the release of hazards substances, the generation of hot spots, or the microplastics and their subsequent dispersion in the environment may be hazards associated with the installation of synthetic turf fields with ELT-derivated granulate infill. In the case of urban heat islands, high temperatures could, for example, limit the development of vegetation, disrupt ascending air currents and change the flight of birds or affect the presence of organisms in the vicinity of the grounds, deeply impacting the local ecosystems generating risks for the environment. This kind of pollution is important to take into account and can be lowered, particularly as organic infill has been introduced and marketed in several countries for this purpose. Further studies should consider measuring different types of organic infill advantages/disadvantages so that manufacturing companies can maintain their effort to work and market products with a more neutral impact. The uses of natural infill can also have an impact on the level of chemicals potentially released from synthetic turf infill, lowering the risks and preventing the long term effects of the ELT-derivated granulate infill.

The use of ELT-derivated granulate infill can lead to the generation of microplastics as a result of mechanicals constraints applied to the granulates from the users or by maintenance practices on synthetic turf fields and playgrounds. The generation of microplastics and their dispersion can be amplified by environmental conditions such us the variation of temperature, humidity, rain, etc. The microplastics generated can give rise to a serial of hazardous effects on aquatic and terrestrial organisms.

Finally, the maintenance of synthetic turf fields with/without ELT-derivated granulates infill could be a source of localized pollution. Indeed, from the analysis of the maintenance guides for these artificial turfs, the need to apply, under specific situations, some pesticides, detergents or other cleaning products on the surface came out. By their nature and what they are meant to be, some of these products may pose a risk to surrounding ecosystems.

9.5 Conclusions and recommendations

The present overview of the literature attempted to identify sources of information about the potential environmental risk associated to the use of recycled rubber granulates as infill material on artificial turf fields and children's playground. The aim of this literature review was to achieve a comprehensive overview of the issue raised by the use of recycled rubber and other petroleum infill and propose some further research to improve our comprehension of the potential risks of these materials for the environment.

The available literature shows that ELT-derivated rubber granulates has the potential to release some hazardous substances to the environment. Furthermore, the available data suggest a potential risks to the environment, mainly related to the release of zinc but also to organic substances such as some phthalates or phenols with endocrine disrupting properties. However, given the current state of knowledge, these data are insufficient to draw a definitive conclusion on the environmental risks associated to synthetic turf and/or playgrounds surfaces for children.

There is a need to conduct further research on the leaching behaviour that operates in artificial turf fields and surface playgrounds under realistic environmental conditions. Special effort must be placed on the tracking of substances and their environmental fate. This monitoring need to be conducted for a long period of time at differents locations, to ascertain that the potential release of substance will not engender a risk for the surrounding environment during the time.

Moreover, research need to be carried out to develop mitigate measurements for lowering the amount of chemical released from leachates by achieving new designs in field's construction and/or using new materials to ascertain that the potential release of substance will not engender a risk for the surrounding environment.

10 On-going projects

Three major projects should be published soon, gathering some new and interesting evidence regarding rubber granules characterisation, exposure and risk assessment for human health linked to rubber infills in synthetic turfs. Anses will stay focus on the publications of these on-going projects as their conclusions could enhance our expertise on these issues.

10.1 US EPA “FRAP”

In 2009, the US EPA released a report on the safety of tyre granules following measurements in two synthetic turfs and a children's play area. The results indicated that levels of concern were low with respect to potential health risks from exposure to toxic chemicals in these granules. The Public Employees for Environmental Responsibility (PEER) considered that these risks were underestimated and that the risk assessment was unreliable, in particular because of the limited number of measurement sites.

The US-EPA therefore reversed its conclusions in 2013, stating that given the limited scope of its study and the wide variety of materials used in tyre granules, it was not possible to conclude with respect to the health risks associated with these materials without review of additional data, especially for children and athletes.

A challenging project has been launched at the end of 2016 by the U.S. Environmental Protection Agency (US EPA) with the Centers for Disease Control and Prevention (CDC), the Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Consumer Product Safety Commission (CPSC). This Federal Research Action Plan (FRAP) on Recycled Tire Crumb used on Playing fields and Playgrounds aims at investigating the risks to human health from recycled granules manufactured from tyres.

The research protocol was published in 2016, identifying a list of more than 200 substances in rubber granules based on research studies, information from potential tyre manufacturing chemicals and analytical laboratories.

The comprehensive report, after peer-review, should be submitted for public consultation. A final version would be published by the end of 2018.

For more information: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=336195

10.2 OEHHA / CalEPA Project

A similar project is being processed by the Californian Environmental Protection Agency (CalEPA) in order to generate Californian data on rubber infills characterisation, sport players exposure and risk assessment. For this project, the OEHHA Office initiated in 2015 a large-scale study supervised by a group of experts from the scientific community. The third meeting of this expert group was held on May 25, 2018. Results are expected by mid-2019.

10.3 European study from ETRMA

In 2016, European industry launched a major study in a joint initiative of tyre manufacturers, ELT management companies, recyclers, artificial turf installers. This European research program aims to remove doubts about the safety of these materials for human health. The protocol of this study, which has several components (composition, exposure), has been presented to ECHA. The first results are expected in 2019.

11 Discussion and general conclusions

11.1 Summary and findings

The French Agency for Food, Environmental and Occupational Health & Safety (Anses) was mandated on 21 February 2018 to document the possible risks related to the use of materials from the recycling of used tyres. This request for scientific and technical support comes from six ministries, illustrating the diversity of issues associated with the re-use of these materials for the health of humans and their environment. Within the given timelines, the Agency focused on carrying out a contextualized analysis of published data and works in progress, identifying knowledge needs to guide action and research priorities. **The analysis performed does not therefore constitute a health or environmental risks assessment and does not therefore provide any final conclusions from the agency on the existence or absence of risks.** Beyond this, it has focused on identifying knowledge needs to guide action and research priorities in line with health and environmental risk assessment questions related to tyre aggregates.

Following the hearings conducted and the analysis of available (and in production) data, the Agency noted the following points for each identified area:

- Regarding regulations and standards governing the chemical composition of tyre aggregates for recycling, especially when used as filling material in artificial sports grounds or playgrounds:

Existing texts are mainly focused towards sports performance (especially for sports pitches), without requirements relating to chemical composition and health or environmental risks related to materials (with the exception of the leaching thresholds for some heavy metals in standard NF P90-112).

- Regarding the market analysis of the industry, the conditions of use of ELT and associated debates:

The data shows that tyre granules represent, in volume, more than a quarter of the volume of recycled tyres. When used in artificial sports pitches, these granules are present in the surface accessible to direct cutaneous contact for synthetic turf, and rather in case of degradation of the surface layer in the case of other synthetic grounds. As far as playgrounds are concerned, ELT granules can be used as a damping layer, but can also be used in mixtures of molded materials.

Comparative qualitative elements concerning the costs and benefits of synthetic and natural turf have also been presented. The construction choice between a synthetic or natural grass field should be very carefully thought considering costs and benefits. The different costs related to these two types of fields have been described, based on the available literature, but the aim is not to make any recommendation at this stage. Indeed, the pros and cons listed in the dedicated chapter should be closely studied prior any decision, based on the local conditions and constraints.

In addition, the socio-political analysis highlights the durability and dynamism of the debates on this topic, starting in North America and Northern Europe. These are primarily focused on the chemical composition of synthetic sports pitches and health aspects, including children and risks of cancer.These debates have later gained France, progressively becoming public, and including environmental and occupational health concerns, not only public health preoccupations An environmental NGO, local authorities, families as economic actors are the main actors of these public debates. These are widely reported by local and national media. More generally, the debates on synthetic grounds also raise the question of identifying negative externalities (including risks to humans and the environment) to be included in the development of the circular economy. This aspect is not really adressed within the new public policies of circular economy.

- Regarding the composition of used tyre granules:

Available studies have shown the presence of a wide variety of chemicals present in granules. Regarding playgrounds, these substances are also associated with other compounds (dyes, resins, smoothing agents, anti-UV ...) but there are fewer studies on this subject.

- Polycyclic aromatic hydrocarbons (PAHs) are a family of chemicals of concern because of their carcinogenic potential. Ongoing regulatory actions (intention to restrict the content of 8 PAHs in granules under the REACH regulation) have to be supported in order to ensure the control of human health risk. The content of the restriction dossier that will be submitted jointly by RIVM and ECHA is not yet known (scope, proposed concentration limit) but should cover the risks for athletes, children (with risk of ingestion), installers and professionals responsible for maintenance.
- There is a lack of knowledge of the chemical constituents of used tyre granules related to the manufacturing secrets of the industry and the diversity of the origin of used tyres. The analysis of the literature shows several classes of chemical substances used due to their properties (vulcanizing agents, filler, anti-oxidants...). Nevertheless the presence of these substances may vary according to the origin of the tyre, even if the industry indicates a close composition profile among the European manufacturers. Uncertainties appear to be greater for imported tyres, particularly from Asia. The volume of tyres imported into the European Union for pelleting is also uncertain.
- Fillers (or reinforcers) are an important part of the tyre's composition. It is basically carbon black or silica. These substances, in a (nano)particulate form, raise a concern about their hazardous properties. France plans to evaluate carbon black in 2019 under the REACH regulation, in order to clarify its hazardous properties. The characterization of the emissions of these (nano)particles is poorly documented.
- Phthalates are also found in granules analyzes, while tyre manufacturers indicate that they are not used in their manufacturing processes. Several hypotheses are advanced to explain their presence: equipment used for granulation, worn tyres loaded with pollutants on the road, external contamination of synthetic turf by the environment. Current researches on composition and emission include this family of substances because of their toxicological properties.
- Some synthetic turf producers offer encapsulated granules. If the objective is to limit the emission of pollutants, it appears necessary to ensure that this encapsulation is sustainable and does not generate additional pollution of (micro)plastics or other substances added to those that are present in the agranules.

- Regarding other chemicals used in the manufacture, the installation and the maintenance of these synthetic grounds:

- Recycled tyre granules are the cushioning part of synthetic grounds (for shock absorption and filling). Users and professionals responsible for installation and maintenance may be exposed to substances from the other components of these materials: fibers, playground finishing surfaces with coloring agents, granules binders, ‘smoothing’ agents, etc. Ongoing exposure studies (cited in Section 10 above) will measure the atmospheric concentration levels of the various pollutants of interest, with the possible difficulty of determining their origin (tyre granules or other sources?). Current North American studies cover playgrounds, while the European ETRMA-funded study covers only artificial grass pitches. Overall, there are few studies on playground in the existing literature.

- The installation of synthetic grounds uses different chemicals that may pose health risks for professionals. Targeted hearings conducted by the Agency suggest that the hygiene and safety measures recommended by suppliers are not systematically applied during installation and especially maintenance.

➢ Regarding the exposures and potential risks presented by these materials:

- Risk assessments performed by national or international institutes related to the exposure of athletes or children to synthetic grounds containing tyre granules all conclude to a negligible risk to human health. Some uncertainties and methodological limitations remain in the consulted publications and reports.
- Exposure measurements are limited in the available studies. As a result, the data do not allow a fine characterization of the variability of the composition of tyre granules and the variability of emissions from these synthetic grounds. The results of the on-going international studies should provide access to more data needed to characterize the variability of the tyre granules and their emissions from one site to another.
- There is limited data on indoor air quality in enclosed grounds or playgrounds.
- The encapsulation of the granules represents an increasing new market on rubber granules, having the capacity to retain VOCs and certain heavy metals by sorption / co-precipitation. Anses did not have access to any published or scientific industrial data on this issue and remains cautious regarding the benefits presented by the manufacturers of these encapsuled granules.
- The effects of ‘urban heat islands’ appear little studied.
- For playgrounds, very little information is available to assess health and environmental risks. Thus, in addition to the substances found in the granules, other chemicals are involved in the composition of these playgrounds. These substances are also likely to be released into the environment.
- Regarding environmental contamination, available characterization data (on composition and emission) indicate the existence of potential risks to the environment. These potential risks are mainly related to the release of metals (in particular zinc) but also organic chemicals such as some phthalates or phenols with endocrine disrupting properties. However, in the current state of knowledge, these data are insufficient to characterize the potential risks to the environment and living organisms.

11.2 Recommandations

Taking into account the uncertainties identified during the assessment made from the various sources of information made available today, Anses recommends the continuation of the work in order to assess the potential risks for health and for the environment related to granules derived from the recycling of tyres for their use in synthetic grounds. In all these respects, Anses recommends in particular:

1/ To initiate actions in order to clarify specific aspects to carry out a risk assessment for human health:

- To acquire, as a priority, more composition, emission and exposure data for the different constituents of playground materials;

- To assess the representativeness of the ELT-granules composition, given the wide variability of the composition of the tyres entering the recycling channels;

- To carry out a broader analysis of the substances emitted by these granules, in particular for the (nanometric) fraction of the dust likely to be emitted (considering the nanocarbon and nanosilica charges), with a view to specifying the occupational exposures;

- To increase the knowledge concerning the levels of exposure in the indoor air of buildings in which are installed synthetic grounds incorporating ELT-granules (in particular VOC known as respiratory sensitizers);

2/ To support the proposal to restrict the PAH content in granules under the REACH Regulation;

3/ To propose some parameters that could be included in an environmental risk assessment, to be carried out locally before any implementation of this type of artificial grounds.

The research and priority action arising from this report findings and recommendations are intended to be discussed with the French ministries that signed the request for support, with the consultation of the various stakeholders. They can also be re-evaluated in the light of the results of on-going works in Europe and the United States.

More generally, this data analysis on the risks associated with artificial grounds integrating recycled tyres raises the question of the identification of negative externalities (including risks to human health and the environment) to be included in the development of the circular economy.

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12.6 Regulation

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ANNEXES

Annex 1: Request of scientific and technical support

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

Ministère de la Transition écologique et solidaire
Direction générale de la prévention des risques

Ministère des Solidarités et de la Santé
Direction générale de la santé

Ministère de l'Économie et des Finances
Direction générale de la concurrence, de la consommation et de la répression des fraudes

Ministère du Travail
Direction générale du travail

Ministère de l'Agriculture et de l'Alimentation
Direction générale de l'Alimentation

Ministère des Sports
Direction des sports

Monsieur le Directeur général
Agence Nationale de Sécurité Sanitaire de l'Alimentation,
de l'Environnement et du Travail
14 rue Pierre et Marie Curie
94701 MAISONS ALFORT CEDEX

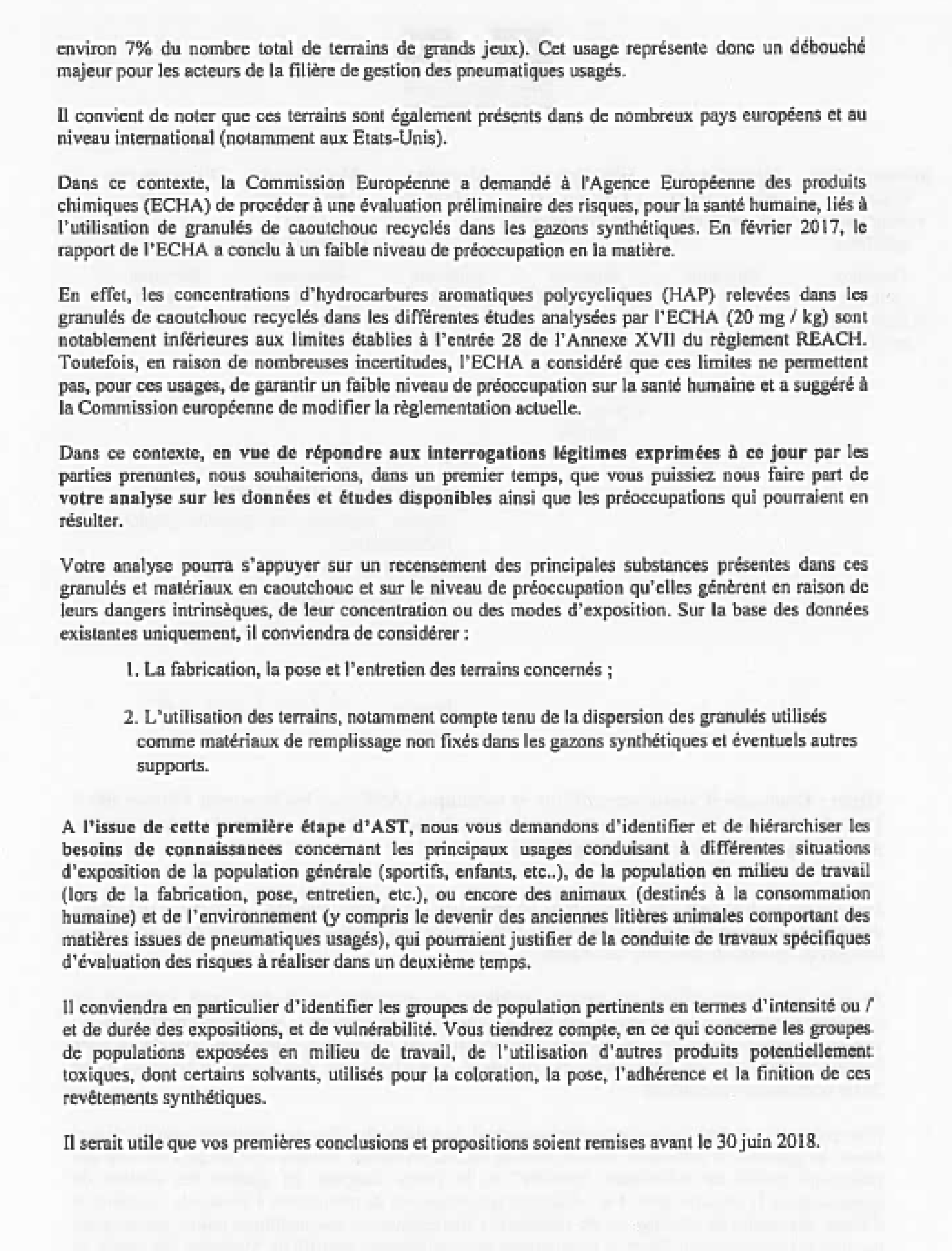
Paris, le 21/02/2018

Objet : Demande d'appui scientifique et technique (AST) sur les éventuels risques liés à l'emploi de matériaux issus de la valorisation de pneumatiques usagés dans les terrains de sport synthétiques et usages similaires

Les terrains synthétiques constitués à base de pneumatiques usagés soulèvent, de manière récurrente, des interrogations quant à leur impact sur la santé et l'environnement, en particulier pour les terrains de sport et les aires de jeux pour les enfants...

Ils sont notamment utilisés en terrains intérieurs ou extérieurs, pour des sports collectifs ou individuels. Les situations d'exposition sont nombreuses, par exemple : sportifs professionnels ou amateurs, enfants scolarisés, personnels d'exploitation ou d'entretien, dispersion éventuelle dans l'environnement de matériaux non fixés. Un usage particulier a été relevé comme constituants de litière pour animaux (équidés).

D'un point de vue économique et environnemental, la valorisation des pneumatiques usagés sous la forme de granulés et matériaux utilisés dans la réalisation de ces terrains synthétiques est l'un des principaux modes de valorisation "matière" de la filière française de gestion des déchets de pneumatiques. Il participe donc à la volonté du gouvernement de promouvoir l'économie circulaire et d'éviter des modes de stockage ou de valorisation énergétique des pneumatiques moins vertueux sur un plan environnemental. Selon le recensement des équipements sportifs du Ministère des sports, le nombre de terrains de grands jeux avec un revêtement synthétique est estimé à 3 049 en France (soit



environ 7% du nombre total de terrains de grands jeux). Cet usage représente donc un débouché majeur pour les acteurs de la filière de gestion des pneumatiques usagés.

Il convient de noter que ces terrains sont également présents dans de nombreux pays européens et au niveau international (notamment aux Etats-Unis).

Dans ce contexte, la Commission Européenne a demandé à l'Agence Européenne des produits chimiques (ECHA) de procéder à une évaluation préliminaire des risques, pour la santé humaine, liés à l'utilisation de granulés de caoutchouc recyclés dans les gazons synthétiques. En février 2017, le rapport de l'ECHA a conclu à un faible niveau de préoccupation en la matière.

En effet, les concentrations d'hydrocarbures aromatiques polycycliques (HAP) relevées dans les granulés de caoutchouc recyclés dans les différentes études analysées par l'ECHA (20 mg / kg) sont notablement inférieures aux limites établies à l'entrée 28 de l'Annexe XVII du règlement REACH. Toutefois, en raison de nombreuses incertitudes, l'ECHA a considéré que ces limites ne permettent pas, pour ces usages, de garantir un faible niveau de préoccupation sur la santé humaine et a suggéré à la Commission européenne de modifier la règlementation actuelle.

Dans ce contexte, **en vue de répondre aux interrogations légitimes exprimées à ce jour** par les parties prenantes, nous souhaiterions, dans un premier temps, que vous puissiez nous faire part de **votre analyse sur les données et études disponibles** ainsi que les préoccupations qui pourraient en résulter.

Votre analyse pourra s'appuyer sur un recensement des principales substances présentes dans ces granulés et matériaux en caoutchouc et sur le niveau de préoccupation qu'elles génèrent en raison de leurs dangers intrinsèques, de leur concentration ou des modes d'exposition. Sur la base des données existantes uniquement, il conviendra de considérer :

1. La fabrication, la pose et l'entretien des terrains concernés ;

2. L'utilisation des terrains, notamment compte tenu de la dispersion des granulés utilisés comme matériaux de remplissage non fixés dans les gazons synthétiques et éventuels autres supports.

A **l'issue de cette première étape d'AST**, nous vous demandons d'identifier et de hiérarchiser les **besoins de connaissances** concernant les principaux usages conduisant à différentes situations d'exposition de la population générale (sportifs, enfants, etc..), de la population en milieu de travail (lors de la fabrication, pose, entretien, etc.), ou encore des animaux (destinés à la consommation humaine) et de l'environnement (y compris le devenir des anciennes litières animales comportant des matières issues de pneumatiques usagés), qui pourraient justifier de la conduite de travaux spécifiques d'évaluation des risques à réaliser dans un deuxième temps.

Il conviendra en particulier d'identifier les groupes de population pertinents en termes d'intensité ou / et de durée des expositions, et de vulnérabilité. Vous tiendrez compte, en ce qui concerne les groupes de populations exposées en milieu de travail, de l'utilisation d'autres produits potentiellement toxiques, dont certains solvants, utilisés pour la coloration, la pose, l'adhérence et la finition de ces revêtements synthétiques.

Il serait utile que vos premières conclusions et propositions soient remises avant le 30 juin 2018.

Le Directeur général de la
prévention des risques

Marc Mortureux

Le Directeur général de la santé

Jérôme Salomon

La Directrice générale de la
concurrence, de la
consommation et de la
répression des fraudes

Virginie Beaumeunier

Le Directeur général du
travail

Yves Struillou

Le Directeur général
de l'Alimentation

Patrick Dehaumont

La Directrice des sports

Laurence Lefèvre

Annex 2 : Litterature on health effects and risk assessment of synthetic turf

Year	Reference	Methodology / Experimental protocol	Population of study	Exposure pathway	Substances analysis	Conclusions	Conflict of interest	Anses Comments
	French studies							
	European studies							
2017	**ECHA** **ANNEX XV report – An Evaluation of the Possible Health Risks of Recycled Rubber Granules Used as Infill in Synthetic Turf Sports Fields**	Compilation of list of US EPA (2016) CLP Regulation selection for CMR and Skin or Resp Sens Exposure scenarios and DNELs for RCR	Players (children to professional goalkeepers) Workers (installation, maintenance by infill, maintenance by brushing	Oral Dermal Inhalation	PAHs : benzo(a)pyrene, benzo(e)pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene and dibenz(a,h)anthracene (total PAHs Phthalates : DEHP, DIBP, DBP, BBP Formaldehyde Benzothiazole, benzothiazole-2-thiol, methylisobutylketone, benzene	Prioritisation of substances No concerns as RCRs < 1 or < 10^{-6} Identification of uncertainties and knowledge gaps	Concentration data of substances in tyres by ETRMA	Risk assessment conducted by ECHA following the EC request in response to the US EPA project Data from ETRMA are not representative and maybe not the most critical
2017	**RIVM** **Evaluation of health risks of playing sports**	100 synthetic turf sampled in NL (n=6)	Children Players (children		PAHs Bisphenol A	Negligible risk for PAHs though calculation of	None	

Year	Reference	Methodology / Experimental protocol	Population of study	Exposure pathway	Substances analysis	Conclusions	Conflict of interest	Anses Comments
	on synthetic turf pitches with rubber granulate	Assays on composition, migration to artificial gastric fluid and sweat and emissions Highest values selected for risk assessment	including goalkeepers, adults and veterans)		Cadmium, cobalt, lead Phthalates MBT	cancer risks in young children remains questionable Below safe limits for other compounds		
2008	**Danish EPA** **Mapping, emissions and environmental and health assessment of chemical substances in artificial turf**	Environmental assays : leaching tests ➪ 4 substances in high concentrations Questionnaires to players on indoor synthetic turf	Adults > 20y Juniors 16-19y Children 12-15y Children 7-12y	Dermal Oral	Benzothiazole Dicyclohexylamine Cyclohexylamine DBP	No health effects by oral route Risk ok skin sensitization for benzothiazole, DCH and CH – especially for sensitive subjects	None	One of the most leached substances is the DBP, which is still controversial Focus on indoor synthetic turf
2006	**Norwegian Institute for Air Pollution** **Measurement of air pollution in indoor artificial turf halls**	3 indoor synthetic turf : 2 with crumb rubber from ELT and 1 with TPE Exposure characterisation: questionnaires to managers of indoor synthetic turf Determination of worst case exposure	Adults > 20y Juniors 16-19y Children (matches and tournaments)	Inhalation Dermal Oral for children	Dust VOCs and TVOC PAHs PCBs Phthalates Alkylphenols	Less emissions from TPE No elevated health risks for all chemicals		Focus on indoor air quality of indoor synthetic turf Comparison of SBR granules and TPE

Year	Reference	Methodology / Experimental protocol	Population of study	Exposure pathway	Substances analysis	Conclusions	Conflict of interest	Anses Comments
		scenarios (highest concentrations and longest duration of exposure) Comparison of exposure concentrations and reference values: margin of safety						
2006	**KEMI**							
	International studies							
Preliminary resultst mid-2018 ***To be published mid-2019***	**CalEPA Research Program**	Hazard identification by screening and characterisation on rubber crumb Data collection on exposure : sampling on synthetic turf, biomonitoring samples		Dermal Inhalation	Particle size		None	
To be published mid-2018	**US EPA / CDC / ATSDR / CPSC** **Federal Research Action Plan (FRAP) on Recycled Tire Crumb**	Multi-agency action plan Data collection on frequency and duration of	Adults Children					

Year	Reference	Methodology / Experimental protocol	Population of study	Exposure pathway	Substances analysis	Conclusions	Conflict of interest	Anses Comments
	Used on Playing Fields and Playgrounfd	synthetic turf activity (during 2017) : questionnaires, individual exposure assessment (personal, biomonitoring and air samples)						
2016	**US EPA / CDC / ATSDR / CPSC** **Status Report**	Establishment of a list of substances contained in tyres Sampling of rubber crumb from 9 recycling plants and 40 synthetic turf (indoor and outdoor) Analysis of rubber crumb Chamber experiments for VOCs and SVOCs			VOCs and SVOCs in chamber experiments		Data collected from industry and NGOs on manufacture of tyres et rubber crumb, and installation and maintenance of synthetic turf	
	Washington							
2010	**OEHHA** **Safety Study of Artificial Turf**	Air sampling of 4 synthetic turfs : measurements of $PM_{2.5}$ and	Soccer players	Inhalation Dermal	$PM_{2.5}$ and VOCs Microbial characterisation	$PM_{2.5}$, metals and VOCs < DL or similar to natural grass	None	One rare study assessing the microbial impact of

Year	Reference	Methodology / Experimental protocol	Population of study	Exposure pathway	Substances analysis	Conclusions	Conflict of interest	Anses Comments
	Containing Crumb Rubber Infill Made From Recycled Tyres	VOCs Analysis of the composition in bacteria in natural grass vs synthetic turf Numbers of skin abrasions for soccer players on natural grass vs synthetic turf				7 VOCs detected < reference values No influence of T° on VOCs emissions Fewer bacteria on synthetic turf Two to 3-fold higher number of skin abrasions on synthetic turf but same severity		synthetic turf
2009	**US EPA**							

Annex 3: Annual maintenance costs for a synthetic and a natural grass field in the USA

	Cost for a 85,000 square feet field	Cost per square feet
painting/paint removal (various sports)	$1,000-$10,000	$0.012-$0.118
top dressing/infill	$5,000	$0.059
brushing/sweeping	$1,000-$5,000	$0.012-$0.059
disinfecting/fabric softener	$220	$0.003
carpet repairs (rips, joints)	$1,000-$8,000	$0.012-$0.094
water cooling	$5,000-$10,000	$0.059-$0.118
weeding	$500-$1,000	$0.006-$0.012
total	$13,720-$39,220	$0.164-$0.461

Table 1: Annual maintenance costs for a synthetic turf in the USA (Source: Massachusetts Toxics Use Reduction Institute, 2016)

	Cost for a 85,000 square feet field	Cost per square feet
painting (various sports)	$800-$12,300	$0.009-$0.145
top dressing (sand)	$0-$5,400	$0-$0.064
dragging	$0-$200	$0-$0.002
fertilisers	$1,200-$11,000	$0.014-$0.129

	Cost for a 85,000 square feet field	Cost per square feet
pesticides	\$1650-\$6,300	\$0.019-\$0.074
aeration	\$700-\$960	\$0.008-\$0.011
sod replacement	\$833-\$12,500	\$0.001-\$0.147
irrigation	\$300-\$3,000	\$0.004-\$0.035
total	\$8,133-\$48,960	\$0.096-\$0.576

Table 2: Annual maintenance costs for a natural grass field in the USA (Source: Massachusetts Toxics Use Reduction Institute, 2016)

Annex 4: Hearing of DJS Ville de Paris – SPSE - 6 April 2018 – Minutes of the meeting (in French)

Participants extérieurs

- SPSE (Service parisien de santé environnementale) : Juliette Larbre
- DJS (Direction de la jeunesse et des sports) : Jean-Christophe Savidan, Jean-Pierre Bobot et Stanislas Robert
-

Participants Anses : Pierre Lecoq, Cécilia Solal

1. Terrains de football et de rugby synthétiques de la ville de Paris

La Ville de Paris possède environ 43 terrains de football synthétiques extérieurs et 1 terrain intérieur en sous-sol. Les premiers terrains synthétiques installés par la Ville de Paris datent de 1986-1987. Ils comportaient, comme matériaux de remplissage, soit de l'EPDM soit du SBR. Après constatation de la mauvaise efficacité (colmatage des granulats d'EPDM rendant trop dur et impraticable le terrain) et du coût plus élevé de l'EPDM, la Ville De Paris a poursuivi avec principalement du SBR. La Ville de Paris possède également une vingtaine de terrains de football en plaine de jeu, c'est-à-dire non homologués par la Fédération française de football (FFF), en pelouse naturelle dans les bois de Boulogne et Vincennes. La fréquence des contrôles des tests *in situ* (mesurant la performance des pelouses) est de 2 ans pour les terrains classés en catégorie 1 et 2 et de 5 ans pour les autres terrains classés.

La Ville de Paris possède également 6 terrains synthétiques de rugby. La fréquence des contrôles des performances des terrains est de 2 ans pour tous les terrains. La Ville de Paris a effectué un essai de remplissage avec des matériaux naturels (liège et fibres de noix de coco) sur le terrain de rugby de la pelouse d'Auteuil. Cet essai fut un échec car les granulats se sont rapidement effrités, de l'herbe est apparue et les granulats se sont transformés en terreau. Ils ont également rapidement moisi.

Ainsi, tous les terrains de football et rugby synthétiques contiennent des granulats de SBR (environ entre 23 et 27 kg/m² de sable selon les gazons, la proportion de billes de SBR est approximativement la même en unité de masse par surface).

La Ville de Paris a différents fournisseurs de billes de SBR comme Genan ou Delta Gom en fonction des marchés passés. Lors de ces marchés, une petite quantité de billes de SBR (1 ou 2 big bags de 1 m^3 soit environ 2 tonnes) est prévue pour stockage, pour recharger le terrain après l'installation en régie (surtout pendant la première année). La Ville de Paris ne reçoit pas de gazons synthétiques en provenance de Chine, probablement à cause des conditions de transport délicates (le transport par bateau écrase les rouleaux et les rend inutilisables).

Les fabricants les plus fréquents de fibres synthétiques sont Eurofield, Polytan, Tarkett et Mondo. Les principaux installateurs (poseurs) sont Artdan Polytan et Mondo. Le coût est de 400 000 euros. Le coût d'un remplacement de gazon synthétique avec les billes de SBR et du sable s'élève environ à 250 000 €. Le port des EPI est obligatoire lors de la pose ou du remplacement d'un terrain mais n'est pas systématiquement appliqué. Les granulats neufs sont enrobés d'une quantité infime d'huile pour éviter l'agglomération des billes de SBR lors de la fabrication et faciliter la pose. Juste après une nouvelle installation, il peut y avoir des inondations lors de forte pluie car la présence d'huile favorise la rétention d'eau. L'huile disparait au bout de quelques semaines ou mois. La pose de terrains neufs se fait généralement entre juin et septembre pendant les vacances d'été, toujours en dehors du froid et de la pluie.

La Ville de Paris reçoit des fiches techniques indiquant le respect des normes NF P90-111 et NF P90-112 mais il est difficile de s'assurer de la provenance des billes de SBR réellement déposées le jour de l'installation. Les laboratoires chargés des contrôles *in* situ (tests de rebond, d'amorti et de sécurité) permettent d'obtenir un classement d'homologation (Labosport, C2S, Sportlabs et Novarea). Cette norme exige également une mesure d'EOX (espèces oxygénées oxydantes) sur des granulats secs.

L'entretien des terrains est assuré par des agents de la Ville de Paris. Ils ne portent pas de masques pendant cette opération mais la Ville de Paris projette un suivi avec la mise en place d'un carnet d'entretien. Selon leur qualité, leur utilisation et la régularité de leur entretien, les terrains synthétiques peuvent être annuellement rechargés par de billes de SBR, soit par la régie avec des sacs neufs stockés, soit par une entreprise privée. Ces rechargements relèvent du cas par cas. Aucun produit phytosanitaire n'est utilisé (politique du zéro phyto à Paris). Des agents ramassent quotidiennement les saletés présentes sur les terrains synthétiques et utilisent fréquemment (toutes les semaines) un tracteur pour homogénéiser la répartition des granulats sur tout le terrain (décompactage) : tous les 5 ans pour le foot, tous les 2 ans pour le rugby, délais nécessaires aux homologations par les fédérations nationales. Aujourd'hui, les terrains synthétiques ne sont pas arrosés (les systèmes d'arrosage sont d'ailleurs systématiquement retirés lors de la pose des terrains synthétiques à la place de gazon naturel). Ils l'étaient sur les terrains anciens lorsque les fibres étaient en nylon ou en polypropylène pour limiter les risques de brûlures. L'évacuation des eaux de pluie des terrains se fait par des systèmes de drainage en direction des égouts ou dans un puisard vers un réseau d'épandage sur la parcelle. Des billes de SBR sont parfois transportées du terrain jusqu'aux vestiaires et aux douches où ils peuvent colmater des canalisations sur les douches ne sont pas fréquemment nettoyées.

Les terrains sont remplacés tous les 8 à 12 ans (durée de vie d'un terrain synthétique). Les terrains synthétiques retirés, comprenant les fibres, les billes de SBR et le sable, sont soit déposés dans une décharge contrôlée, soit déposés dans une usine de recyclage (dont Vink en Hollande). Actuellement, la fibre de gazon est en PE (polyéthylène), le dossier (c'est-à-dire le support des fibres) est en PP (polypropylène) et l'enduit est en latex ou PU (polyuréthane), ce qui rend difficile le recyclage. Il consiste actuellement à le réutiliser en occasion ou en tapis pour les manèges ou pour stabiliser des accotements ou talus. L'entreprise Mondo étudie un produit entièrement en PE pour qu'il soit entièrement recyclable en billes de PE pour créer de nouveaux produits.

Les personnes auditionnées de la Ville de Paris indiquent qu'aucun moratoire n'a été émis sur la pose ou le remplacement des terrains synthétiques. Un remplacement est d'ailleurs prévu cet été sur un terrain dans le XIII^{ème}. Il n'y a pas de projets de construction de nouveaux terrains synthétiques de football pour les JO de 2024.

En moyenne, un terrain synthétique est utilisé pendant 10 à 12 heures par jour. Les demandes d'obtention de créneaux horaires pour utiliser les terrains sont très nombreuses. Les terrains sont pratiquement toujours occupés durant les heures ouvrées par les clubs et les structures scolaires.

Un gazon naturel est utilisable de 10 à 12h maximum par semaine pour conserver son intégrité et rester dans les critères de classement d'homologation. Par conséquent, en heures d'utilisation, un terrain en gazon synthétique équivaut à 7 terrains en gazon naturel. Le coût d'entretien d'un terrain en gazon naturel est d'environ 30 000 euros par an. L'utilisation de terrains stabilisés, c'est-à-dire uniquement sablé, n'est pas possible pour respecter les critères de performance des terrains homologués (souplesse, rebond, sécurité, surtout pour la pratique du rugby). L'entreprise MONDO, entre autre, propose un matériau de remplissage alternatif nommé Ecofill®.

2. Actions engagées par le SPSE

Le SPSE a été sollicité par Jean-François Martins (élu parisien aux sports) pour réaliser une étude d'impact sanitaire d'ici novembre 2018 sur les expositions cutanées et l'exposition environnementale (en cas de pluie).

Le SPSE a déjà réalisé des prélèvements à la main de granulats à plusieurs endroits du terrain au stade Carpentier. Les analyses portent sur :

- la granulométrie : la méthode de prélèvement à la main induit un biais pour les fractions les plus fines (fraction nano par exemple non collectée),
- les éléments traces métalliques (ETM) : du zinc a déjà été détecté de façon majoritaire pour les ETM,
- le plomb,
- les émissions de COV et HAP à 30° et 80° en microchambre : alcools, naphtalène. HAP à tester plus tard.

Le SPSE souhaiterait disposer d'échantillons de granulats neufs afin de comparer les résultats avec les granulats usagés déjà prélevés.

Le SPSE réalisera des mesures *in situ de* COV, HAP et particules en pleine chaleur en été. Le dispositif de mesure ne sera pas installé au milieu du terrain car il finira dans les buts… Les méthodes de mesure et la stratégie d'échantillonnage ne sont pas encore décidées (pompe de prélèvement sur gardien ? sur quel nombre de terrains ?). Le granulomètre mesurera les fractions particulaires pour les relier à la concentration massique et les fractions nanos.

3. Aires de jeux

Certaines aires de jeux sont gérées par la DJS lorsqu'elles sont posées à proximité de terrains sportifs.

Sinon, elles sont principalement gérées par la Direction des espaces verts et de l'environnement (DEVE) et les Services d'exploitation des jardins (SEJ : 10 pour tout Paris : 1 par arrondissement en gros).

4. Autres types de terrains de sport à Paris

Terrains d'athlétisme : SBR collé avec EPDM.

Terrains de tennis synthétique : SBR collé avec EPDM rouge ou vert.

Terrains de hockey sur gazon : en pelouse synthétique très dense mais pas de SBR ni de sable. Les terrains sont souvent arrosés.

Annex 5: Hearing of the Association « Robin des Bois » - 3 May 2018 – Minutes of the meeting (in French)

Participant extérieur : J. Bonnemains, Robin des Bois

Participants Anses : C. Boudergue, K. Burga, F. Debil, V. Lamarca, P. Lecoq, C. Solal.

Contexte

- Saisine Robin des Bois, membre du CA, en décembre 2017
- Programme de travail 2018 Anses – terrains synthétiques à base de pneumatiques recyclés
- Réserves de Robin des Bois vis-à-vis de certains domaines de l'économie circulaire. Témoignages et constats de parents d'enfants faisant l'apprentissage du football sur des terrains à granulés. Témoignages de certains professionnels. Articles dans la revue « So Foot ».

Depuis 2008, l'association Robin des Bois est membre de « Recyvalor » dont la mission qui arrive à son terme a été de résorber et d'éliminer ou de recycler tous les stocks connus de pneus abandonnés sur l'ensemble du territoire, sauf les outre-mer[21].

Concernant la phase aval de l'action Recyvalor, J Bonnemains en tant que représentant de Robin des Bois a constamment exprimé des réserves quant à la réutilisation de ces pneumatiques en granulats pour la fabrication de sols techniques. La position de Robin des Bois s'appuie sur les risques d'émanations toxiques en cas d'incendie dans les endroits publics comme les salles de sport et les effets sanitaires notamment pour les enfants dans les milieux fermés ou par contact répété sur les aires de jeux. La seule méthode pertinente à ce jour pour Robin des Bois est pour les pneus broyables la valorisation énergétique en cimenterie qui aboutit à une destruction irrémédiable. Aliapur (société anonyme comprenant les principaux manufacturiers de pneumatiques) et le ministère de l'Ecologie étaient plutôt en faveur de la granulation pour des raisons économiques et d'image, dans un contexte de valorisation croissante de l'économie circulaire et de mise en valeur du développement durable. 80 à 90% des stocks orphelins ont été sur l'insistance de Robin des Bois et avec l'accord de nombreux partenaires envoyés en cimenterie. Ces chiffres sont confirmés par les comptes-rendus des Assemblées Générales de Recyvalor.

Les réserves de Robin des Bois vis-à-vis de la granulation proviennent aussi des incendies fréquents et polluants qui surviennent dans les entreprises spécialisées. Aujourd'hui ces entreprises sont très peu nombreuses, proches de la faillite dans un secteur ultra compétitif en Europe et dans le monde entier.

Focus sur santé animale

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[21] http://www.recyvalor.fr/

Il y a quelques années, des efforts promotionnels ont été menés par Aliapur sur l'utilisation des « chips » de pneus dans les sols de manège d'équitation sous forme libre et dispersive. Ces matériaux présenteraient de bonnes performances techniques.

L'utilisation en manège est peut-être marginale en tonnage mais Robin des Bois estime même s'il n'y a pas eu de signalements à ce sujet qu'il y a là potentiellement des risques sanitaires importants par inhalation de poussières pour les chevaux, les cavaliers et les entraîneurs. D'autre part, des questions se posent sur ce que deviennent ces broyats usagés quand ils sont remplacés.

En surplus, J. Bonnemains indique et déplore que les traverses de chemins de fer créosotées retirées des voies peuvent être jusqu'à nouvel arrêté réutilisées dans les écuries…

Composition du pneu

Les données de composition des pneus sont à considérer avec attention. Attention à l'importation.. Remarque subsidiaire de J. Bonnemains : les pneumatiques absorbent des polluants pendant leur usage et certains pneus circulent dans des milieux industriels pollués par les hydrocarbures ou même par des marqueurs radioactifs. La traçabilité est insuffisante.

Terrains couverts

Terrains de sport couverts avec des gazons synthétiques utilisant comme substrat des « chips » de pneus.

Comme déjà dit, l'inquiétude est renforcée par les accumulations potentielles de composés organiques volatils et des poussières dans l'atmosphère des salles de sport. L'inquiétude est focalisée sur les enfants, également pour ce qui concerne les broyats de pneus utilisés dans les agglomérats (tapis de sol…).

A noter quelques plaintes liées à des odeurs dans les aires de jeu, ayant suscité une inquiétude il y a 5-6 ans chez des personnels de santé.

Dispersion des granulats

Un travail sur la dispersion des « chips » de pneus dans les milieux aquatiques suite à leur dispersion pendant l'usage aux abords du terrain mais aussi dans les sacs de sport des joueurs est indispensable selon Robin des Bois. Les granulats pourraient être retrouvés à terme au moins dans les estomacs des oiseaux de mer. Robin des Bois est spécialisé dans la connaissance et le comptage des macro-déchets dans l'océan Atlantique. Ce sujet est un enjeu majeur pour la convention OSPAR.

La question du recyclage des terrains en fin de vie est également posée. Existe-t-il une filière de recyclage ? Il n'est pas sûr du tout qu'une filière de recyclage réglementaire existe en France. Les détenteurs essayent de les vendre au m^2 aux supporters, aux familles des joueurs et autres entourages. Exemple du terrain de Lorient. Il existerait une usine spécialisée dans le retraitement aux Pays-Bas. Ce retraitement n'est pas techniquement impossible. D'autres témoignages parlent en France de brûlage à ciel ouvert.

Autres usages : 900,000 tonnes de pneus entiers seraient utilisées pour couvrir les bâches d'ensilage en milieu agricole. Ces stocks ne sont pas concernés par la mission de Recyvalor. Hormis les sols sportifs techniques, il serait important dans le cadre de la saisine de rechercher les autres usages émergents ou existants des broyats de pneus Concernant les récifs artificiels encordés, ils commencent à être retirés car ils sont suspectés de polluer localement les fonds marins et il est constaté que les liens réunissant les pneus se cassent et que les pneus se dispersent.

Santé au travail : témoignage d'un membre du personnel de jardin public passant à la souffleuse les aires de jeu avec un sol de broyats agglomérés et constatant l'envol de particules et l'absence de consignes vis-à-vis des risques pour les professionnels et pour les publics. Le manque d'intégrité du matériau couplé à la puissance de la souffleuse pourrait en effet les exposer à des risques sanitaires. L'exposition de ces personnels est quotidienne.

Annex 6: Hearing of Industry representatives - 3 May 2018 – Minutes of the meeting (in French)

Participants extérieurs :

Mme Claire Rabes – Union Sports et Cycles

Mme Céline Crusson-Rubio, SNCP

M. Jacques Baillet, Président Fedairsport (140 membre actifs)

M. Jean-Marie Geveaux, Fedairsport

M. Frédéric Szablewski, Stockmeier Urethanes France

M. Philippe Prins, Parc et Sports – Constructeur installateur terrains

M. Jean-Philippe Faure, Aliapur

M. Richard Durbiano, Aliapur

M. Eric Daniel, FieldTurf Tarkett

M. Pascal Haxaire, Labosport International, expert au sein du comité de normalisation CEN TC 217 (normalisation sports sportifs)

M. Aurélien Le Blan, Labosport International

Participants Anses :

Mmes Caroline Boudergue, Karen Burga, Fanny Debil, Céline Dubois, Victoire Lamarca, Cécilia Solal et M. Pierre Lecoq

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1- Présentation Aliapur

Un point de situation sur la collecte est présenté par Aliapur : gratuite, les pneus « propres » sont utilisés pour le réusage.

Aliapur est une société anonyme dont les membres fondateurs sont Bridgestone, Continental, Dunlop Goodyear, Kléber, Michelin et Pirelli (actionnaires car société anonyme à but non lucratif – éco-organisme prévu dans le cadre de la REP, avec engagement gouvernemental).

L'âge moyen du pneu récupéré est de 5 ans : collecte dans les garages uniquement, gratuite, uniquement les pneus non souillés sinon rejetés. En terme de volume cela représente plus de 350 000 tonnes annuelles récupérés soit 100% des pneus mis sur le marché.

Un pneu comporte 3 constituants : caoutchouc, métal, textile.

Un schéma sur la granulation est présenté, avec tri des parties textiles et métal. Procédé uniquement mécanique, pas d'ajout chimique. Stockage des granulats en big bag. Les granulateurs sont prestataires mais font des flux c'est-à-dire qu'ils peuvent remonter à l'origine du pneu à l'entrée (numéros de lots), pas de mélange des pneus collectés. Il existe un contrôle qualité sur HAP et COV, ainsi qu'un contrôle de la granulométrie – fibres résiduelles ou métaux résiduels.

Des audits sont réalisés tous les mois par Aliapur chez les prestataires. Il y a 2 prestataires en France (Aisne, Moselle), un troisième le consomme pour lui-même. Aliapur pourra transmettre les coordonnées des granulateurs sur demande.

La taille des granulats produits varie selon les usages ciblés : sur les aire de jeux, les granulats font entre 0,5 et 2 mm.

Il s'agit d'un marché spécialisé : 150 entreprises dans ce domaine dont une cinquantaine spécialisées dans le synthétique. Ce marché impacte également les terrassiers, équipementiers accessoires et cultures, paysagers etc. -> écheveau économique et professionnel très large.

Sur la question des risques présentés par ces matériaux, les professionnels du secteur ont édité une plaquette (Aliapur / SNCP / Fedairsport) qui repose sur les travaux existants d'autres pays tels que ceux du RIVM, de l'ECHA et aux Etats-Unis notamment Washington (sources jugées indépendantes).

2- Données de marché

Historique : marché existant depuis les années 1960. Fieldturf a « révolutionné » l'usage vers la fin des années 1990 (association sable et granulats). 70-80% des terrains synthétiques dans le monde utilisent du matériau SBR (pneu) comme remplissage par rapport à d'autres types de granulats (type EPDM). En France, il reste un gros marché à développer, 90% des terrains actuels sont en SBR.

Environ 200 terrains de grands jeux sont créés par an en France. La France représente un marché peu mature. 90% des terrains synthétiques sont avec du SBR.

L'âge moyen du terrain avant son remplacement est de 10-12 ans.

La répartition des usages en 2017 des pneus recyclés (SBR) est la suivante : 44% en valorisation énergétique, 41% en valorisation matière dont 23% en granulats, 15% de réutilisation (rechapage, réemploi des pneus). Cette distribution a peu varié ces dernières années.

L'objectif est de pouvoir varier les usages et ne pas favoriser une filière seulement. Les granulats en remplissage représentent une voie seulement. Les stocks orphelins de pneus usés ont été tous traités par le biais de **Recyvalor** (le dernier stock a été géré en 2017) : ils sont tous partis en cimenterie (93%) et non en granulation car pas d'historique et pas de traçabilité de l'origine de ces pneus. Ces stocks orphelins représentent environ 100 000T (61 stocks).

Pour les granulateurs français, l'estimation pour 2018 est très mauvaise en raison de la dynamique médiatique et la « psychose » sociale autour de ces revêtements.

Selon Fedairsport : 30% des terrains à construire sont gelés et reportés sur 2019. Une quinzaine de terrains sont planifiés dans les jours à venir mais les collectivités bloquent à cause de la polémique sur les granulats SBR. L'installation est repoussée aux rendus des conclusions sur les risques (en attente des conclusions Anses).

Concernant la polémique : en Espagne, Italie, Allemagne, Autriche, il n'y a aucune inquiétude par rapport à la France, en situation de crise/'psychose sociale'. Il y aurait un effet psychologique sur la couleur noire des granulats.

Par exemple, le Conseil régional d'IDF a décidé de ne plus donner de subventions (Commission d'attribution) en attente des conclusions de l'Anses → si pas d'avis définitif en juin, tout pourrait être repoussé. L'Anses précise que la conclusion définitive ne pourra pas être émise d'ici juin, et sera du ressort du gestionnaire. Il y a une importante **attente d'une position FR** (avis Anses).

En Europe, il existe beaucoup de granulateurs, et peu/pas d'export car coûteux à transporter donc les granulats produits sont utilisés dans un rayon de 400 km du site de production.

Nous sommes actuellement à la 3ème génération de terrains synthétiques, à base de fibres en polyéthylène. Les terrains mixtes (synthétiques / naturels) sont plus chers.

Concernant les salariés poseurs de terrains synthétiques : port de masques car des poussières sont générées lors de la pose. Un entretien est mis en place progressivement pour maintenir une hauteur de remplissage. La fédération a aussi poussé à la maintenance pour la garantie des performances sportives (fibres droites et hauteur de remplissage). Des ‘retests’ ont été imposés après 5 années d’utilisation. Un entretien a donc été mis en place, de deux niveaux : entretien courant et entretien basique. La problématique des approches microbiennes est en cours de développement en ce moment ; il est proposé de nettoyer à l’eau uniquement, pas d’usages de produits biocides même si peuvent être utilisés aux USA. Il y a de l’oxyde de zinc dans le pneu, qui a des propriétés biocides donc il pourrait ne pas avoir besoin d’en rajouter.

Etape de dépose : Fedairsport propose d’envoyer une vidéo descriptive. Concernant la dépose des tapis très usagés : incinération. Si le tapis est revalorisable, les matériaux sont triés : la machine va « vider » le tapis, le sable est récupéré, les granulats SBR aussi pour une troisième « vie » après passage en laboratoire pour retests prouvant que les performances sont assurées. Cette valorisation s’effectue en France, les tapis usagés ne sont pas réutilisés dans d’autres pays (il est interdit de récupérer). Les tapis peuvent être roulés et triés ensuite en centre de retraitement, mais pour éviter de transporter ces tapis c’est souvent fait sur place. Cette dépose dure 1 semaine pour un tapis d’épaisseur de 60 mm, 2 jours en moins si épaisseur de 40 mm. Il y a un enjeu autour des émissions de poussières lors de la dépose.

3- Alternatives

Les alternatives présentent de nombreux inconvénients. A noter toutefois les **granulats encapsulés** par du PU + activateur. Potentiellement ajout de colorants. Globalement plus chers (par exemple les granulats sont à 200 euros la tonne, l’EPDM à 1500 euros).

Les granulats sont jugés bon marché car recyclés, et répond à objectif de l’économie circulaire et durabilité de performance accrue grâce à la gomme qui est vouée à durer pour son côté élastique. Labosport vérifie cette capacité (agréé FIFA) : parfait pour son emploi sur performances sportives. Tous les granulats alternatifs ne répondent pas aux autres critères de qualité/performance. Le TPE et l’EPDM colmatent, le liège flotte avec la pluie avec un potentiel risque d’incendie/parasites, donc pas de solutions miracles pour les remplacer. Les granulats ont moins d’évolution par rapport à d’autres produits avec le temps, leur cycle n’est pas éternel mais peut être réutilisé en 2ème mise en place (en remplissage avec granulats déjà utilisés).

Billes encapsulées : le granulat est encapsulé par du PU. Le procédé de fabrication implique un circuit fermé en usine -> pulvérisation colle PU incolore ou coloré (rouge, verte, brune), solution d’activateur injectée (phase aqueuse avec activateurs aminés par exemple) : attente que bloc se forme et mécanique continue pour déliter bloc et obtenir granulat encapsulé. Les colorants sont micronisés pour améliorer leur intégration (exemple : oxyde de chrome pour vert, titane), des diisocyanates sont ajoutés ensuite. Des additifs sont forme nanométrique ne sont pas déclarés mais proposition d’utiliser un oxyde de fer sous forme nanoparticules (à confirmer). Les émissions seraient réduites par l’encapsulation. La coloration permet de réduire la température par rapport au noir, et permet de réduire les émissions par lixiviation et par rapport aux spécifications de la norme Jouets. Il y a néanmoins une potentielle usure de la capsule dans les aires de jeux car potentiel d’élimination par friction. L’impact couleur serait important sur les ventes (effets psychologique), perception chromatique, et la couleur noir a un impact négatif.

Concernant les pigments poudre (titane, oxyde de chrome vert, pigment rouge…), il y aurait 61 fournisseurs de pigments (1 site en Allemagne, 1 site en Angleterre, 1 site aux USA).

Suite aux « crises » de SBR apparus aux US et NL : les matériaux alternatifs grappillent des parts de marché doucement sur SBR -> de 95% à 70% aujourd'hui pour les granulats.

4- Réglementation / normes

Cahier des charges pour les fournisseurs de granulats : retour d'expérience de Fieldturf, le cahier des charges étant le même en Europe (restriction HAP proposée en NL a été étendue sur tous les autres pays). Les normes pour les COV s'appuient sur le protocole allemand AgBB 2015. Le cahier des charges techniques est donné par FFFootball ou FFRugby selon les spécificités.

Des groupes de travail existent pour améliorer les normes. Le CEN a lancé cette année une norme « TOX infill ». En France, Fedairsport est l'antichambre de préparation des normes NF avec l'Afnor (répliquent et peuvent être plus exigeantes que les normes EU/CEN proposées). La norme NF P 90-112 depuis décembre 2012 a ajouté le volet écotoxicologie pour certains métaux lourds. Des travaux du CEN sur les mesures HAP dans les articles en caoutchouc et plastique sont en cours (SNCP copilote), en lien avec les actions CEN sur les normes toxicologiques. Ce volet avait été proposé en 2012 mais n'avait pas été retenu. La restriction NL sur HAP va de toute façon pousser pour que l'actuelle norme évolue sur ces aspects toxicologiques. Pour les métaux lourds (lixiviation), il y a une référence à la norme Jouets.

Par ailleurs, la FFF pousse à court terme souvent pour des réglementations plus restrictives, donc peut permettre d'aller plus vite.

Cas des pistes et aires de jeux : composés de PU à 12% environ. Primaire en béton le plus souvent. Sous-couche en SBR (laisser sécher 24h), puis couche superficielle qui contient 20% de liants (EPDM) et est souvent colorée. Puis agent lissant visant à compresser l'EPDM pour créer une tension à la surface : utilisation de gasoil, composés aromatiques, white spirit mais préconise plutôt maintenant des produits avec COV réduits à 50% voire des agents lissants n'émettant pas de COV. Certains poseurs chauffent pour lisser. Les FDS (fiches de données de sécurité) sont systématiquement fournies, elles pourront être transmises si nécessaire. La couche SBR peut changer selon l'aire de jeu souhaitée. La durée de vie du revêtement est garantie par le poseur et non par le fabricant : en moyenne elle est de 5 ans mais tout dépend des usages. Le HIC (Head injury criterium ou Hauteur de chute critique) définit l'épaisseur. Pour les pistes d'athlétisme, la durée de vie est de 15 ans mais ce n'est pas le même usage et le HIC souhaité que pour les aires de jeux. Les agents lissants en base aqueuse existent mais font mousser le PU (émissions de CO_2).

Lors de la pose des granulats agglomérés, la communication auprès des poseurs est un gros travail à faire : le cahier des charges fait toujours appel aux règles d'**hygiène et sécurité**. Les entreprises de poseurs nécessitent des formations. Elles sont regroupées à Fedairsport et Union Cycles. Ces informations doivent descendre jusqu'au chantier et les correspondants hygiène et sécurité doivent assurer le suivi.

Le port de masques et gants est préconisé mais nécessite un suivi par le poseur. Les fournisseurs ne le font pas. Les collectivités peuvent le faire. La protection des travailleurs est mal appliquée à priori pour des enjeux économiques (H&S souvent négligés par les collectivités) : si le prix du marché est bas, les conditions de pose seront moindres. Si la collectivité elle-même ne le fait pas, il n'y aura pas de suivi. Ceci constitue un cercle vicieux autour de la baisse des coûts = **externalités sanitaires négatives.**

Les produits phytosanitaires étaient utilisés avant sur les aires de jeux pour lutter contre le développement des algues et la prolifération bactérienne mais maintenant ils sont interdits (entretien à l'eau)…. Le sable peut diminuer le HIC. La charge de **poussières** est importante donc la dépose peut être une situation à risque notamment pour les terrains **indoor** (usure très importante, détérioration de la fibre, endroit peu entretenu car souvent installés dans de vieux entrepôts). Concernant les terrains en extérieur : peu de problèmes de poussières car l'humidité ambiante redépose les particules. L'ECHA recommande dans ses conclusions de mettre en place une ventilation adaptée. La filière n'a pas connaissance du nombre de terrains indoor en France, difficile de recenser car ne relève pas de la fédération et, même si le ministère fait le recensement des équipements sportifs (RES), il n'a pas de visibilité exhaustive.

Importation des pneus valorisés en granulats : concernant la différence de composition des granulats dans le monde, il n'y a pas de différence significative avec les US mais avec la Chine oui. Sur ce marché, il n'y a pas les mêmes contrôles et des manufacturiers différents (en lien avec l'usage huiles aromatiques par exemple). Les importations de pneus existent mais le marché est tenu par les grands manufacturiers « premium » même s'ils ont des sous-marques. Les chinois changent de noms dès qu'une réglementation nouvelle s'applique. Les poids lourds sont mono-vies donc pneus sont souvent asiatiques voire chinois. Les particuliers peuvent acheter sur internet (donc moins bonne traçabilité) et dans ce cas supportent le prix de la monte (un peu moins de 10%) : ces pneus ne sont pas soumis de fait à l'écocontribution.

A noter que la filière est confrontée aux incertitudes sur la réforme sortie de statut des déchets.

5- Travaux en cours

1-Gros rapport du JRC (Joint Research Center) dont la publication est attendue en juin 2018 (Contenu total et biocompatibilité des HAP -> **STANPAH**) : données confidentielles. Travail en commun avec LRCCP, SCL de Massy, RIVM, BfR notamment (liste complète en annexe). Analyses de granulats en plus des formules types et des produits grand public. Les HAP émis seraient les impuretés liées noir de carbone. Les échantillons testés sont neufs (granulats + dalles). Les méthodes d'analyse existantes ont été améliorées par le JRC : diminution du temps d'extraction et LQ notamment. Cette méthode sera présentée au CEN sur dosages HAP dans les articles pour qu'elle soit reprise (application de la restriction dédiée). Parmi les simulants proposés : 20% éthanol qui simulerait la sueur artificielle en pire cas. L'encapsulation a un effet barrière (diminue de moitié les émissions de HAP).

Ces travaux seront probablement pris en compte dans le dossier de restriction NL (et expliquerait le décalage du calendrier de mise en consultation publique… ?). Il est indiqué un seuil probable de **restriction pour les 8 HAPs concernés abaissé à au moins 20 mg/kg**.

2-Une autre étude d'exposition va être publiée prochainement sur les granulats échantillonnés sur plusieurs terrains en Europe (**50 terrains entre 2007 et 2017**) : variation entre 5 et 15 mg/kg sur les teneurs en HAP. Le syndicat européen (ETRMA), avec la chaine de valeur des terrains de grand jeu, l'ECHA et le RIVM ont lancé une étude sur les risques potentiels (ETRMA avec comité exécutif : Fobig, Labosport et Eurofins et un « Advisory scientific board » indépendant désigné par l'ECHA). Les analyses sont effectuées par des laboratoires indépendants. Les HAP mesurés sont les 18 réglementaires. Les premiers résultats sont prévus pour la fin d'année avec une analyse sur la composition et la migration et enfin une analyse de l'exposition (toujours piloté par ETRMA avec ECHA aussi: **prélèvements d'air et sur peau** en utilisation réelle de ces terrains). Ce volet permettra de caractériser l'exposition mais il faudra aussi mesurer les expositions ambiantes. Une sélection de joueurs est prévue pour inclusion dans l'étude.

6- Santé animale

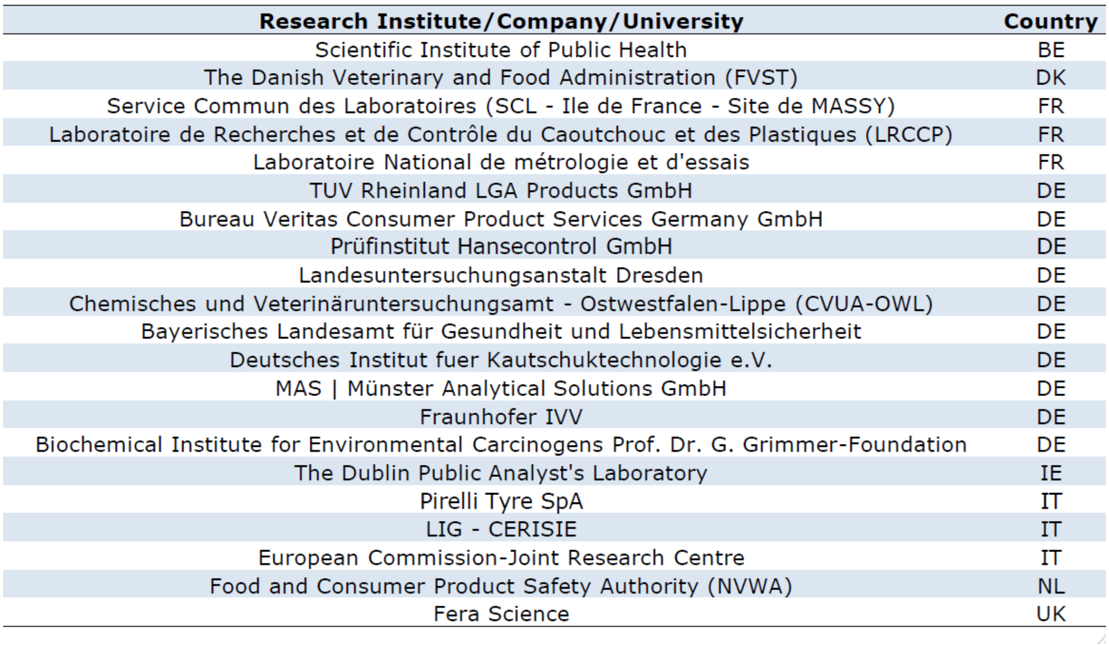
Quelques usages en centres équestres et matériels pour animaux de rente sont connus de la filière. Par exemple les tapis de stabulation pour bovins : agglomérés sans PU, uniquement en pression à chaud. Ces usages représentent un petit marché : 1 prestataire qui en fait un peu. Ces matériaux sont parfois revêtus par une bâche de récupération. Malgré une étude menée en 2006 (avec équipes de l'école vétérinaire sur les amortis et impacts pour cavaliers débutants) cela représente un **marché de niche.** Aliapur n'avait pas d'objectif de commercialisation et pas d'équipe pour le vendre donc cet usage n'a pas été développé malgré de très bons retours.

Sur les autres usages de niche, il existe des tapis préfabriqués aussi avec usage de PU.

7- Environnement

S'agissant des études environnementales : il existe une étude de lixiviation conduite par Aliapur, **finalisée en 2011** et pas de nouvelles études depuis.

Partenaires du projet STANPAH



Research Institute/Company/University	Country
Scientific Institute of Public Health	BE
The Danish Veterinary and Food Administration (FVST)	DK
Service Commun des Laboratoires (SCL - Ile de France - Site de MASSY)	FR
Laboratoire de Recherches et de Contrôle du Caoutchouc et des Plastiques (LRCCP)	FR
Laboratoire National de métrologie et d'essais	FR
TUV Rheinland LGA Products GmbH	DE
Bureau Veritas Consumer Product Services Germany GmbH	DE
Prüfinstitut Hansecontrol GmbH	DE
Landesuntersuchungsanstalt Dresden	DE
Chemisches und Veterinäruntersuchungsamt - Ostwestfalen-Lippe (CVUA-OWL)	DE
Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit	DE
Deutsches Institut fuer Kautschuktechnologie e.V.	DE
MAS | Münster Analytical Solutions GmbH	DE
Fraunhofer IVV	DE
Biochemical Institute for Environmental Carcinogens Prof. Dr. G. Grimmer-Foundation	DE
The Dublin Public Analyst's Laboratory	IE
Pirelli Tyre SpA	IT
LIG - CERISIE	IT
European Commission-Joint Research Centre	IT
Food and Consumer Product Safety Authority (NVWA)	NL
Fera Science	UK

Annex 7: Hearing of GIE France Recyclage Pneumatiques (FRP) – 21 June 2018 – Minutes of the phone conference

Participants

GIE FRP : Nadia Zennache (Responsable des Opérations du GIE FRP), François Dewerdt (Président du GIE, directeur général de SEVIA, Groupe Veolia)

Anses : Céline Dubois, Karine Fiore, Pierre Lecoq, Cécilia Solal

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L'objectif de la filière globale est le suivant : plus de 50% de valorisation matière (dont le réemploi).

En terme de répartition sur le territoire, cela représente environ 10 à 15% pour la réutilisation (50-60 000 tonnes), 40-45% pour le recyclage avec plusieurs applications dont la granulation' sols sportifs) (autour de 100 000 tonnes), les ouvrages travaux publics et bassins drainants (environ 50 000 tonnes). Le restant, en valorisation énergétique

La granulation est marginale pour le GIE FRP. Le GIE a privilégié les solution recyclage Travaux Publics (le GIE FRP compte parmi ses adhérents, une partie importante appartenant au monde du TP).

Mais lors du démarrage de la filière, il existait plus d'une dizaine de granulateurs sur le Marché Français, ce qui offrait la possibilité d'orienter le tonnage en granulation. Aujourd'hui en France, il doit en rester 3 dont deux granulateurs qui fabriquent un produit fini.

Nouveauté : la quote-part pour la valorisation énergétique en cimenterie peut être réincorporée dans le recyclage à hauteur de 25%.

En métropole, Il existe 2 systèmes collectifs : Aliapur et FRP, puis un système Individuel MOBIVIA.

Dans les DROM plusieurs systèmes individuels.

La majorité des pneus collecté en Outre-Mer revient sur la métropole donc ce volume rentre dans les statistiques globales.

Il est précisé pendant l'audition par FRP, que la situation est tendue pour la filière : au-delà de la polémique induite par certains journalistes, les acteurs sont toujours en attente du décret de sortie de statut de déchet depuis 5 ans pour les pneus réutilisables. Cette attente, engendre des complication administratives et financières sur le « terrain ».

Pour le recyclage dans les ouvrages Travaux Publics, les marchés sont « chahutés » pour différentes raisons (activité TP irrégulière).

La granulation reste un débouché important, même si elle faible proportionnellement actuellement pour le GIE.

A noter 2 projets de R&D non aboutis à ce jour :

- Projet d'un manufacturier qui consiste en l'extraction du butadiène pour réinjection dans la fabrication des pneus neufs.Ce projet est activé depuis 3-4 ans mais non opérant.
- Vapothermolyse : projet plus avancé mais non abouti de façon opérationnelle. Pourrait capter quelques dizaines de milliers de tonnes à l'avenir. Objectif : récupération du noir de carbone pour servir à la fabrication caoutchouc.

Le GIE FRP indique que la plupart des adhérents du GIE FRP sont des importateurs divers : importateurs de pneumatiques les importateurs d'engins équipés de pneumatiques comme Caterpillar/John Deere, puis les constructeurs automobiles avec véhicules montés de pneus.

Pour FRP, la granulation représente une faible voie de valorisation (1% en 2017). L'Anses a demandé s'il s'agissait d'un choix ou de la conjoncture ?

Le FRP indique que la granulation est marginale car le choix a été porté sur la valorisation en TP. Mais la granulation est regardée de très près car reste intéressante et entre dans le cadre de l'économie circulaire. Ainsi, si les ouvrages TP ne fonctionnent plus, FRP pourrait activer la valorisation en granulation. Le contexte médiatique actuel pourrait freiner cette voie : si les applications sol sportifs (majoritaire pour les voies de valorisation granulation) sont remises en question, ce serait l'intégralité de la filière qui se retrouverait impactée.

Il existe un rapport de l'ADEME sur granulation en Europe suite à la mise en place d'un groupe de travail auquel a participé FRP. La filière participe aux réunions nationales et européennes sur le sujet.

La valorisation en granulation pour FRP est uniquement en France.

Le GIE présente une phase de croissance de collecte de pneumatiques depuis ces dernières années.

Concernant la traçabilité des pneus collectés, il est mentionné l'obligation réglementaire de collecter tous les pneus, quel que soit leur provenance. Le GIE rappelle que depuis 2010, les pneus entrant sur le territoire sont assujettis à la réglementation REACH.

Les pneus en très mauvais état partent systématiquement en filière cimenterie. En principe la valorisation matière n'est pas alimentée par les pneus très abimés ou altérés.

Pour la granulation, il est utilisé principalement des pneus issus des véhicules légers.