ANNEXES

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ANNEX I - COMPOSITION OF RECYCLED RUBBER GRANULES

Recycled rubber granules that are used as infill material in synthetic turf can be produced from end-of-life tyres (ELT) or from other materials. Most of the infill material in Europe is from EU-produced tyres.

Information on substances in recycled rubber granules has been submitted to ECHA by the industry and industry associations and is described here. In addition, the composition of recycled rubber granules has also been published in scientific literature and in studies conducted by different research institutes.

Information on those studies that have analysed samples from stocks (new material, not yet used in the fields) has been separated from the information received from samples taken from the fields. This is because the field samples might have been contaminated from airbourne sources of the substances seen, such as releases from traffic exhausts and industry emissions.

In this annex, emissions of substances measured in the air above the fields or when measured using personal sampling equipment are reported as well as substances that are migrated or that have leached to different media (e.g. water).

The substances and their concentrations are provided in Tables A to D (appendixed to this annex). If it is not specified that the information is from recycled rubber material from tyres and if the other sources of recycled rubber material are known/available, then this is specified.

Some of the studies also included other infill materials (not recycled) in their research: these are discussed under Section 4.3 and Annex VII on alternatives. When metals are discussed, it is not known if they are as metals or as metal compounds in the recycled rubber granules due to the limitations in testing. Different methods to analyse substances have been used, however, these types of details are not included in this report.

Rubber granules used as infill material have been investigated worldwide (this annex mainly provides information from European studies) and many substances have been reported to be linked to the infill materials. Therefore, certain substances were prioritised as they were the most hazardous and on which most of the information exists.

This evaluation report concentrated mainly on polycyclic aromatic hydrocarbons (PAHs), phthalates, and some other substances. The wide variety of substances that have been found in literature can be found in the the US Research Protocol and in their status report (US EPA and Centers for Disease Control and Prevention, 2016)[1].

Composition of rubber granules from European end-of-life tyres (SBR rubber infill) (industry information)

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[1] See: https://www.epa.gov/sites/production/files/2016-08/documents/tcrs_research_protocol_final_08-05-2016.pdf

The European Tyre and Rubber Manufacturers Association (ETRMA) provided information on the substances in rubber granules from end-of-life tyres. Many of the substances used in the production of tyres react during the vulcanisation process, creating a three-dimensional network ('rubber matrix') in which those chemicals are bound.

Passenger car tyres and truck tyres represent the majority of tyres sold on the EU market. Table I.1 provides their respective average composition (pre-vulcanisation).

Table I.1– Main components of new passenger car and truck tyres (average composition)

Material	Car	Trucks	Reacting during vulcanisation?
Rubber/elastomers	43 %	42 %	YES/YES
Carbon black and silica	28 %	24 %	YES
Metal	13 %	25 %	NO
Textile	5 %	-	NO
Zinc oxide	2 %	2 %	YES
Sulphur	1 %	1 %	YES
Accelerators/antidegradants	2.5 %	2.2 %	YES/NO
Stearic acid	1 %	0.7 %	YES
Oils	7 %	1.6 %	NO

Source: ETRMA

Substances used in tyre manufacturing can generally be categorised in different groups:

- Reactive substances, which are involved in chemical reactions that transform these substances:
    - Substances that react during the manufacturing process, by the creation of links with polymers and/or fillers:
        - Peptisers;
        - Bonding agents;
        - Vulcanisation agents and accelerators;
        - Cobalt salts;
        - Some types of tackifiers.
    - Substances that react during the service life:
        - Antioxidants, which react with ozone or ambient oxygen during the service life of tyre and are present at the end-of-life in concentrations lower than the initial concentration.

- Non-reactive substances, like plasticisers (according to ETRMA, no phthalates are used in the manufacturer of tyres).

Some of the previously listed chemicals are associated with transformation products as indicated below:

- Vulcanisation agents (example: benzothiazole compounds, cyclohexylamine, di cyclohexylamine);
- Anti-aging agents and antidegradants (example: aniline, phenylenediamine compounds).

According to the International Carbon Black Association (ICBA, 2017), carbon black is inseparately bound in rubber. This is supported by IARC, 1996.

Carbon black also contains polycyclic aromatic hydrocarbons as impurities. ICBA refers to several scientific studies and concludes that PAHs on the surface of carbon black do not migrate from rubber nor are they bioavailable.

ETRMA provided the following information (Table I.2 and Table I.3) on substances potentially present in ELT–derived rubber granules based on expert judgement.

Table I.2 -Substances possibly present, in ELT-derived rubber granules (expert judgement (ETRMA))

Substance possibly present in ELT-derived rubber granules	CAS number	Estimation in ppm	
		min	max
Diphenyl guanidine	102-06-7	0	150
N-1,3 dimethylbutyl N' phenyl-p-phenylendiamine	793-24-8	0	1 000
Aniline	62-53-3	0	100
Mercapto benzothiazole	149-30-4	0	200
Para ter octyl phenol	140-66-9	0	200
Para ter butyl phenol	98-54-4	0	100

Source: ETRMA

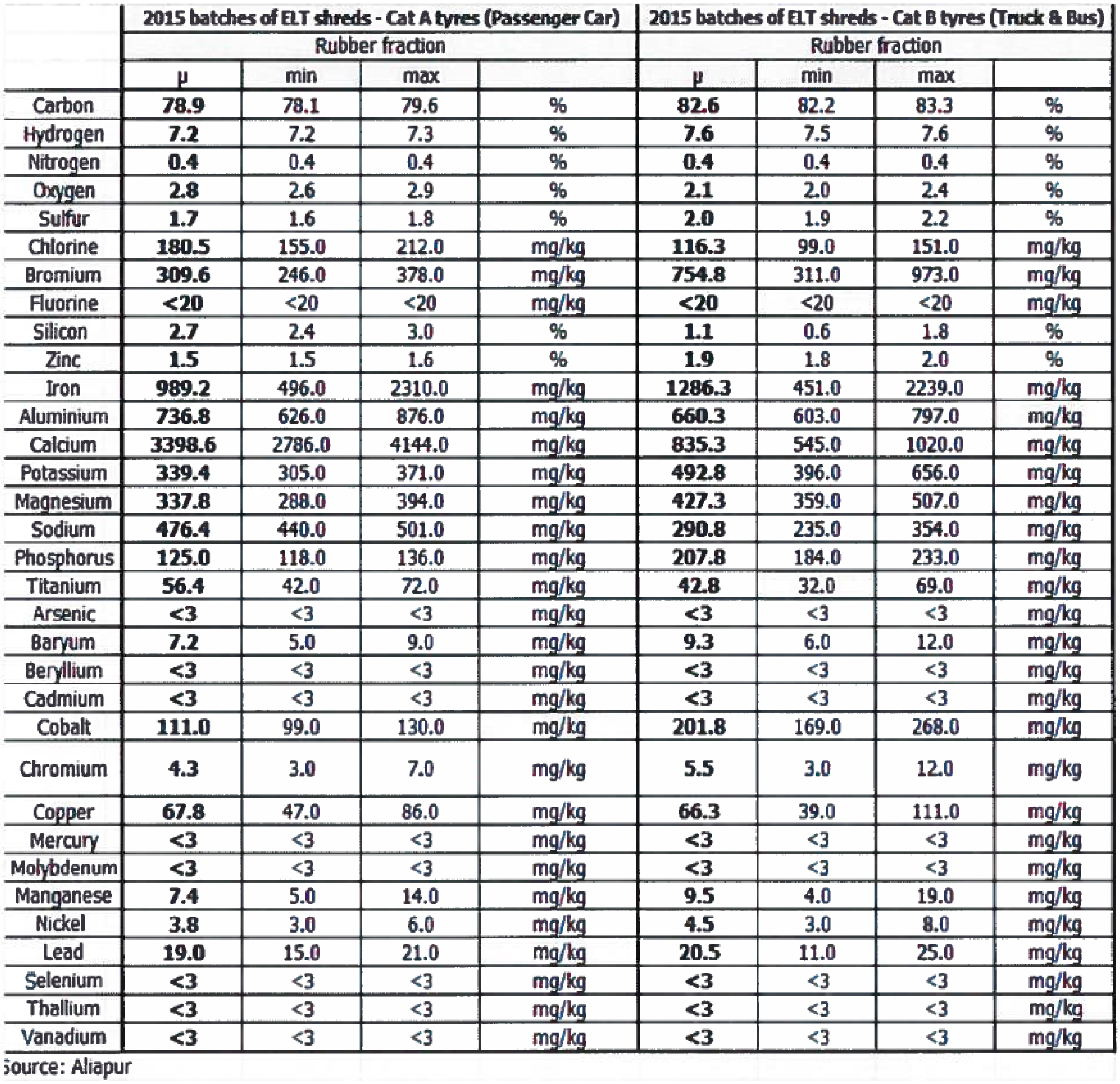
Table I.3 - VOCs potentially emitted by ELT-derived rubber granules (expert judgement (ETRMA))

Substance possibly emitted from ELT-derived rubber granules	CAS	Remark
Phenol	108-95-2	Impurity
Formaldehyde	50-00-0	Impurity
Ethanol	64-17-5	
Methanol	67-56-1	
Methyl isobutyl ketone	108-10-1	
Amines coming from sulfenamides	n/a	Cyclohexamine, dicyclohexylamine, terbutylamine
Benzothiazole	95-16-9	
Nitrosamines	n/a	On EU manufactured tyres: guarantee of the absence of volative nitrosmines and no guarantee in imported tyres

Source: ETRMA

One ELT management company (Aliapur, the main French ELT management company) has made an elemental analysis of ELT rubber granules (studies from 2015), both from passenger car and from truck and bus tyres. Table I.4 provides this information as submitted by ETRMA (2016).

Table I.4 - Elemental composition of ELT-derived rubber fraction



	2015 batches of ELT shreds - Cat A tyres (Passenger Car)				2015 batches of ELT shreds - Cat B tyres (Truck & Bus)			
	Rubber fraction				Rubber fraction			
	μ	min	max		μ	min	max	
Carbon	**78.9**	78.1	79.6	%	**82.6**	82.2	83.3	%
Hydrogen	**7.2**	7.2	7.3	%	**7.6**	7.5	7.6	%
Nitrogen	**0.4**	0.4	0.4	%	**0.4**	0.4	0.4	%
Oxygen	**2.8**	2.6	2.9	%	**2.1**	2.0	2.4	%
Sulfur	**1.7**	1.6	1.8	%	**2.0**	1.9	2.2	%
Chlorine	**180.5**	155.0	212.0	mg/kg	**116.3**	99.0	151.0	mg/kg
Bromium	**309.6**	246.0	378.0	mg/kg	**754.8**	311.0	973.0	mg/kg
Fluorine	**<20**	<20	<20	mg/kg	**<20**	<20	<20	mg/kg
Silicon	**2.7**	2.4	3.0	%	**1.1**	0.6	1.8	%
Zinc	**1.5**	1.5	1.6	%	**1.9**	1.8	2.0	%
Iron	**989.2**	496.0	2310.0	mg/kg	**1286.3**	451.0	2239.0	mg/kg
Aluminium	**736.8**	626.0	876.0	mg/kg	**660.3**	603.0	797.0	mg/kg
Calcium	**3398.6**	2786.0	4144.0	mg/kg	**835.3**	545.0	1020.0	mg/kg
Potassium	**339.4**	305.0	371.0	mg/kg	**492.8**	396.0	656.0	mg/kg
Magnesium	**337.8**	288.0	394.0	mg/kg	**427.3**	359.0	507.0	mg/kg
Sodium	**476.4**	440.0	501.0	mg/kg	**290.8**	235.0	354.0	mg/kg
Phosphorus	**125.0**	118.0	136.0	mg/kg	**207.8**	184.0	233.0	mg/kg
Titanium	**56.4**	42.0	72.0	mg/kg	**42.8**	32.0	69.0	mg/kg
Arsenic	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Baryum	**7.2**	5.0	9.0	mg/kg	**9.3**	6.0	12.0	mg/kg
Beryllium	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Cadmium	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Cobalt	**111.0**	99.0	130.0	mg/kg	**201.8**	169.0	268.0	mg/kg
Chromium	**4.3**	3.0	7.0	mg/kg	**5.5**	3.0	12.0	mg/kg
Copper	**67.8**	47.0	86.0	mg/kg	**66.3**	39.0	111.0	mg/kg
Mercury	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Molybdenum	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Manganese	**7.4**	5.0	14.0	mg/kg	**9.5**	4.0	19.0	mg/kg
Nickel	**3.8**	3.0	6.0	mg/kg	**4.5**	3.0	8.0	mg/kg
Lead	**19.0**	15.0	21.0	mg/kg	**20.5**	11.0	25.0	mg/kg
Selenium	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Thallium	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg
Vanadium	**<3**	<3	<3	mg/kg	**<3**	<3	<3	mg/kg

Source: Aliapur

Based on the elemental study, carbon, hydrogen and oxygen represents 90 % of the ELT rubber granulates mass. Adding the mass of zinc, sulphur and silicon provides 96 % of the total mass of ELT rubber granulates. Carbon black and silica which are used in the manufacturer of the tyres (28 % for car tyres) and 24 % for truck tyres) are assumed to be reacting during vulcanisation.

ETRMA notes that the results show the presence of chemical elements not attributable to typical tyre recipes. ETRMA's assumption is that some elements can come from road dust, asphalt, as well as brake pad dust on the sidewall. However, as they are present in the rubber granules, they are regarded as composites/impurities of the rubber granules even though the composition may vary due to different environmental conditions (asphalt may be different in different areas etc.).

Ecopneus (2016, unpublished) has investigated the composition (sum of 8 restricted PAHs, bentzo(a)pyrene (BaP) and aromaticity index of plasticising oils (H-Bay%)) of specific batches of infill material. For the purpose of the study, sampling was done at five ELT recycling facilities operating in different Italian regions. The ELTs were separated into batches by production date (ante-2010 and post-2010, due to the entry into force of restriction entry 50 to REACH on PAHs in extender oils used to produce tyres on 1 January 2010) and by place of origin of production (EU and non-EU).

The reason for separation was to investigate the effectiveness of the restriction in entry 50 and possible problems of compliance concerning imported tyres after 2010. The verification of the separation and sampling was done by Bureau Veritas.

Two methods were used to measure the sum of 8 PAHs and BaP: the Grimmer method and a method developed by the Mario Negri Institute. The concentration of BaP was below 2 mg/kg, except for non-EU tyres produced before and after 2010, where the concentrations were slightly above 2 mg/kg with the Grimmer method.

The sum of 8 PAHs varied from around 5 mg/kg to around 13 mg/kg, the highest being for non-EU tyres produced before 2010 and the lowest for EU batches after 2010. Based on the studies, Ecopneus defined a 'fingerprint' of PAH concentrations in ELT rubber from the rubber of the tyres recycled between October 2014 and January 2015 covering specific concentration limits for 8 PAHs (Figure 1).

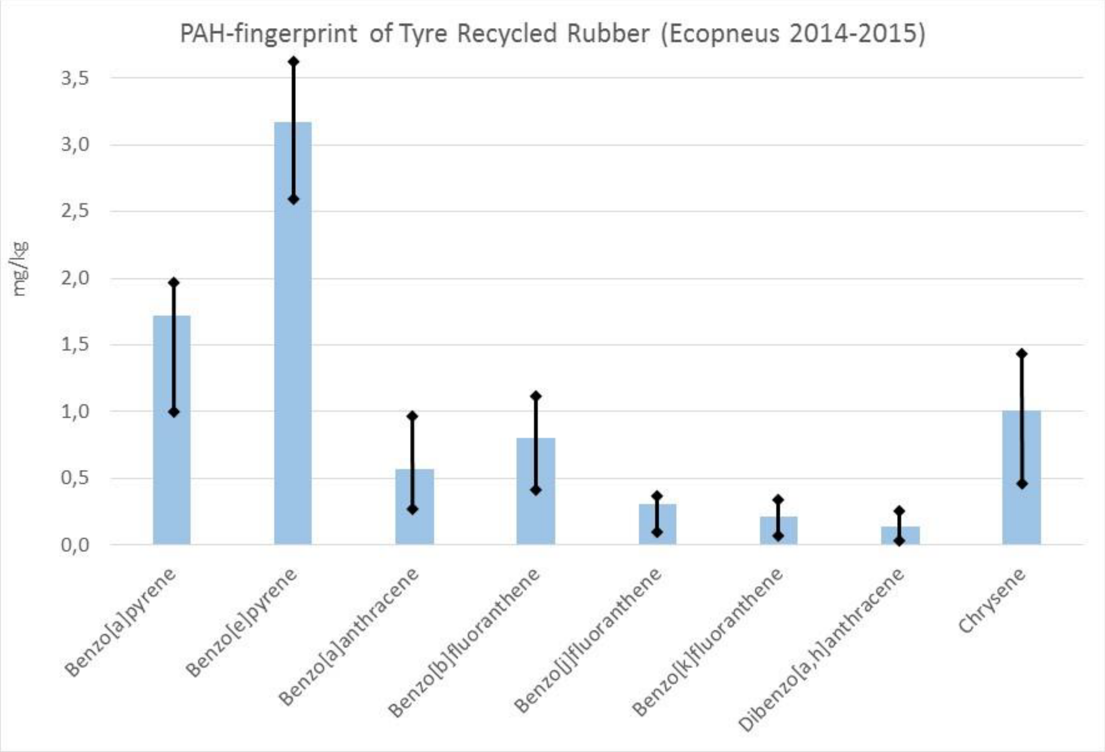


Figure 1– Profile of PAH concentration in recycled ELT rubber

Source: Ecopneus

The comparison was also made with the German measurement method ZEK 01.4.-08 and subsequently on the updated version AfPS GS 2014:01 PAK (valid from 1 July 2015). With this method, Genan (the largest recycler of ELTs in Europe) analysed monthly samples of its production of rubber granules and powder. The results from the same reference period are rather close, which supports the 'fingerprint' definition.

Ecopneus also compared with substance-related information obtained from some scientific literature and concluded that, in some cases, the origin of the recycled rubber did not match with the 'fingerprint' and that the material could not be from recycled tyres. Ecopneus also noted that the sampling methods may vary.

Ecopneus also investigated the aromaticity index of the samples using ISO 21461. With this test it can be ensured, that the tyres placed on the European market fulfil the requirements in entry 50. In all samples, the aromaticity index was (also ante-EU and ante-non-EU) below the limit of 0.35 % bay protons. From 25 samples, it was seen as a reduction of the H-Bay % value when comparing the tyres produced before the restriction on PAHs in extender oil entered into force with the tyres produced after 2010.

Ragn-Sells AB (Sweden) commissioned an analysis of PAHs in different fractions of tyres in 2016 (unpublished, 2016). The conclusions were that tyres produced after 2011 contained less amounts of PAHs compared to tyres produced during 2001-2009 and very little difference was seen in the PAH levels between tyres produced in the EU compared to imported tyres. The concentrations of PAHs (EU-8) were below 12 mg/kg in all cases. According to Ragn-Sells AB, the method of analysis and its sensitivity varies significantly, even when the analysis was performed by the same laboratory in the same sample on two different occasions.

According to the European Synhetic Turf Organisation (ESTO, 2016), when installers of synthetic turf fields are purchasing infill, they should request a material safety data sheet from the supplier. ESTO provided typical examples of safety data sheets and the one from Murfitts Industries, Ltd, UK provides a list of the substances analysed and concentrations measured.

ECHA also received some safety data sheets and other information from stakeholders concerning the content of substances (mainly metals and PAHs) in rubber granules. One of them used the standard for toys (EN 71-3) to estimate migration of metals from recycled rubber granules. Information submitted to ECHA is gathered in the tables in the appendix.

Substances measured from recycled rubber granules (scientific studies)

Several scientific studies report on the analyses of the content of recycled rubber granules. Many of these studies have also measured emissions to air (gas phase and airborne dust), migration to different body fluids and also leachates. These studies are described in more detailed in Annex VI, which provides exposure information. In this part, only a short description of the study is provided. The concentrations measured are summarised in Appendix Tables A.

Norwegian Building Research Institute (2004) studied the content of recycled rubber (three samples) and EPDM obtained from suppliers. Leaching of substances to deionised water and the release of substances to a gas phase after heating to 70 ^{o}C for 30 minutes were also studied.

Van Bruggen, M. *et al.*, (2007) investigated nitrosamines from air samples over the four artificial pitches in the Netherlands. In addition, samples of rubber crumb were taken from six pitches and material was analysed for the presence of nitrosamines in three steps:

1. Heating to 70 °C in a sealed bottle;
2. Extraction with dichloromethane; and
3. Migration to a special fluid, which simulates human saliva.

No nitrosamines were detected when extracting the samples in dichloromethane.

Hofstra U. (unpublished, 2007), commissioned by several companies, studied environmental and health risks of rubber infill. According to the English summary, PAH compounds were found in the rubber granules in amounts of 20-40 mg/kg. The content of heavy metals in rubber granules found in the study complies with the toy legislation in the EU. The same applies to phthalates.

Nilsson N. *et al.* (2008) studied organic substances and zinc from samples of infill material, artificial turf mats and elastic pads. The study included e.g. analysis of dichloromethane extracts for constituents in the actual products. The study found wide variety organic substances in the samples analysed.

Bocca B. *et al.* (2009) analysed samples of rubber granules obtained from 32 playgrounds around Italy. Samples were black, white and coloured rubber granules and the origin of the granules was recycled tyres. The metal content of rubber granules, leaching of metals in acetic acid and leaching of some metals also in water. Rubber granules contained all metals under investigation, zinc being the metal with the highest concentrations.

Gomes J. *et al.* (2010) investigated inhalable dust and PAHs in recycled rubber granules originating from one company (Recipneu, Portugal). The aim was to compare coated material with raw material. Recycled rubber granules were coated with 1) emulsified polyvinyl chloride (PVC) and 2) cross-linked alquidic polymer. Both coating formulations included colour additives and a flame-retarding agent.

Menichini E. *et al.* (2011) studied the content of metals and PAHs from different types of granulates. The samples were collected from playing fields located in Italian towns and the types of granulates were virgin thermoplastic, coated recycled tyres, recycled tyres (uncoated), recycled scrap of vulcanised rubber and recycled ground gaskets. The concentrations of metals were compared to Italian standards for soils to be reclaimed for use as "green areas" and zinc, cobolt and tin exceeded the limit values. Some PAHs exceeded the standard values by up to two orders of magnitude. PCBs, PCDDs and PCDFs were measured from one field. The sums of 30 NDL-PCBs and WHO-TE PCDDs and PCDFs were, respectively, 0.18 mg/kg exceeding the limit in Italian soil legislation and 0.67×10^{-5} mg/kg.

Six artificial turf fields located in the Turin, Italy were the subject of a study by **Ruffino, B. et al. (2013)**. Four fields had infill material made of SBRs from shredded tyres, one had infill material made of TPE and one was a natural turf field (natural soil as infill material). Samples were collected from each of these fields and several substances (metals, PAHs and benzene, toluene and xylenes (BTXs) were analysed from the samples. Benzene, toluene and xylene, including all the PAHs measured were found in almost all samples. The concentration of pyrene was around 20 mg/kg in most of the samples, the concentration of benzo(a)pyrene was around 1-2 mg/kg (one sample was below the detection limit). The results showed that BTX, PAH and zinc contents were higher in the samples of rubber granules made of recycled tyres compared to TPE. The samples from natural turf field contained relatively high concentrations of some metals, like nickel, lead, chromium, tin and arsenic.

Marsili L. *et al.* (2014) studied the quantification of PAHs and heavy metals from rubber crumb from recycled tyres, which were produced before 2010: samples 1 to 5 were new and had not yet been spread on fields, samples 6 to 9 were obtained from fields that had been laid down for 1 to 8 years and sample 5 was virgin rubber and not from recycled tyres (this virgin rubber was not otherways specified). The heavy metals investigated were cadmium, lead, chromium, nickel, copper, zinc and iron. A total of 14 PAH compounds were detected in rubber crumb samples.

Salonen R. *et al.* (2015) measured concentrations of 16 PAHs from different infill materials (TPO, SBR and EPDM). The infill material samples were collected from six indoor halls using vacuum-cleaning and the analysing method used was the same that is used for PAH measurements from construction materials (extraction to dichloromethane). The highest total amount of PAHs was seen in SBR infill material (38-91 mg/kg), lower with other materials (TPO 0,1 mg/kg, EPDM 1,5 mg/kg). In addition Annex 6 of the study provides information on substances identified qualitatively from infill materials and they are based on GC/MS analysis and substance identity using the MS library.

RIVM (2016) took samples of rubber granules from 100 fields (total of 720 samples) which were using infill material from tyres and analysed the content of certain substances in the granules. In the report, RIVM provides average concentrations from the fields.

Emissions from rubber granules

Several scientific studies have measured different substances in the air above the fields, or using laboratory experiments to measure substances in the gas phase. In addition, airborne dust has been measured in some studies and some substances have been measured from the dust. Similar studies have been conducted for stakeholders and these are reported in this report as well (see Appendix Tables B).

Norwegian Building Research Institute (2004) analysed substances from the gas phase after heating the recycled rubber granule samples to 70 °C for 30 minutes. A large number of alkylated benzenes were observed.

Norwegian Institute for Air Research (NILU, 2006) investigated air quality in three indoor artificial turf pitches. Two of the fields used SBR rubber granulates which were originally from recycled tyres. One field was using thermoplastic elastomer granulates. Stereomicroscope examination revealed that one SBR rubber granulate seemed to be coated or had a film layer. The other one had a drier surface covered with particles. The total VOC concentrations in the two first fields were higher than in the field using TPE. Also, the airborne dust (PM10 and PM2.5 fractions) were higher in the fields using recycled rubber granules from tyres. In all fields, organic materials in dusts were high, even though dust from the fields with SBR granulates contained more rubber.

Moretto R./EEDEMS (2007, unpublished) studied gaseous emissions from artificial turf sport surfaces on behalf of Ademe, Aliapur and FieldTurf Tarkett. Tests were carried out on a laboratory scale using emission test rooms for characterisation of chemical emissions in indoor air of construction products (i.e. artificial turf with rubber granules installed in the test box). Rubber granules from tyres, EPDM and TPE infill materials were tested and samples without infill material were tested as well. The results showed that concentrations of TVOCs and aldehydes decreased rapidly especially between day 1 and day 3 (day 1: TVOC for tyre granules was around 1 600 µg/m^3). At the end of the testing (day 28), TVOCs were 134 µg/m^3 for tyre granules, 118 µg/m^3 for TPE and 490 µg/m^3 for EPDM. For artificial turf, TVOC was 8.3 µg/m^3 on day 28, which was according to the authors comparable to those from other construction products.

Nilsson N. *et al.* (2008) studied organic substances from samples of infill material, artificial turf mats and elastic pads. The study also included analysis of the organic components using headspace analyses of volatile substances. The study found wide variety organic substances in the samples analysed (table includes selected substances).

Institute Fresenius (2008, unpublished study) analysed on behalf of ETRA emissions and immissions on a playing field with artificial turf, filled with recycled rubber granules from car and truck tyres. The measurements were done when sports took place and when matches did not take place. Background measurements were done approximately 100 m away from the playing field. In this measurement, there were no increased dust emissions during sporting activities on the artificial turf. Total volative organic compounds (TVOCs) were slightly increased when playing took place, but without playing the concentration were similar than in the background. Of the TVOCs, alkanes and esters were not detected, the concentrations of aromatic compounds were 38 µg/m^3 when playing and 41 µg/m^3 without playing (background was 11 µg/m^3). No PAHs and benzo(a)pyrene were detected.

Li, X. *et al.* (2010) studied major volatile and semi-volatile organic compounds released from crumb rubber material in laboratory conditions in the US. A specific analythical method was developed. Samples were either recycled tyre rubber or other alternative rubber materials. Recycled rubber samples were never exposed to natural weathering conditions, but the age of the samples were different as some samples were collected from the storage bags at local schools. 10 organic compounds were detected in the vapour phase over the samples. The compounds were:

- vulcanisation accelerator: benzothiazole;
- PAHs: naphthalene, phenanthrene, 1-methylnaphthalene, 2-methylnaphthalene, fluoranthene and pyrene; and
- antioxidants: butylated hydroxyanisole, butylated hydroxytoluene and 4-tert-octylphenol.

The study also investigated the possible reduction of volatile compounds under natural weathering conditions. Virgin rubber material was exposed to the outdoor environment. Six compounds were analysed weekly and concentrations showed generally reduced levels over 70 days.

Simcox N. *et al.* (2011) have studied several substances (volative organic compounds - VOCs, semivolatile organic compounds - SVOCs, nitrosamines as well as particles) in air at synthetic turf fields (using rubber granules, not otherwise specified) in Connecticut, USA. Both personal air sampling and stationary air sampling took place. Personal sampling occurred at waist height, better representing the exposure of children. Samples were collected from six fields, of which four were outdoor, one was an indoor synthetic turf field and one was an outdoor grass area.

The conclusion of the study was that the airborne concentrations of VOC, PAH and targeted SVOC (e.g. benzothiazole) were highest in the indoor facility, benzothiazole being within the same order of magnitude as in the Norwegian study (2006).

Menichini E. *et al.* (2011) studied the content of metals, PAHs, PCBs, PCDDs and PCDFs from different types of granulates. The samples were collected from playing fields located in Italian towns and the types of granulate were virgin thermoplastic, coated recycled tyres, recycled tyres (uncoated), recycled scrap of vulcanised rubber and recycled ground gaskets. In addition to the content of the rubber granules, the PAHs were measured in the field where the granulate had shown the highest PAH content (infill material was from recycled tyres, non-coated) and from another field in which the infill material was recycled tyre rubber granulate. Air samples were measured using a high volume sampler located within the field and using personal air samplers worn by athletes. The concentrations in the first field correspond to those at the background site, but the concentrations in the second field were higher than those in the background.

Schilirò T. *et al.* (2013) has investigated concentrations of particles (PM10 and PM2.5), PAHs, aromatic hydrocarbons (BTXs=benzene, toluene and xylene) and mutagenicity of organic extracts. Sampling sites located in Turin, Italy on six different football fields, five of them being artificial turf fields of which four used rubber granules originated from recycled tyres. The samples were taken in June (temperature ranged from 16-34 °C) without playing activity for at least two weeks and in November during the course of sporting matches (0-18 °C). At all football fields, the measurement of benzene, toluene and BTX levels were taken at approximately 2m height above the street level. PAHs were measured from PM10 and PM2.5 filters. The conclusion of the authors was that no significant differences were found between football fields and urban sites with regard to concentrations of PM, BTX, PAHs and mutagenicity.

Six artificial turf fields located in the Turin, Italy were the subject of a study by **Ruffino, B. *et al.* (2013)**. Four fields had infill material made of SBRs from shredded tyres, one had infill material made of TPE and one was a natural turf field (natural soil as the infill material). Samples of gases and dust were collected above the ground, BTX was measured from gases and PAHs from dusts.

Salonen R. *et al.* (2015) analysed 16 PAH compounds and VOC emissions (including the total VOC (TVOC)) from infill materials. The dustiness of the infill material was also analysed from two halls, where non-used material was available. In addition, PAHs and VOCs were analysed from the air in the halls.

Aldehydes and ketones were seen in nearly all air samples taken from the halls. Benzothiazole was not seen in halls 1 (TPO) and 3 (SBR). Small amounts of formaldehyde and acetone were found in the air of all the halls. PAH concentrations in the air samples were low (sum of all PAHs 0-0.3 µg/m^3).

RIVM/Van Bruggen, M. *et al.* (2007) investigated nitrosamines from air samples over four artificial pitches in the Netherlands. In addition, samples of rubber crumb were taken from six pitches and material was analysed for the presence of nitrosamines in three steps: 1. Heating to 70 °C in a sealed bottle, 2. Extraction with dichloromethane and 3. Migration to a special fluid, which simulates human saliva.

The air samples over the artificial pitches were taken in October, when temperatures varied from 11-16 °C to 18-20 °C. One of the pitches was recently (three weeks before) installed (material not mentioned, but explained that there was a clear smell of rubber), one was one-year old (material not mentioned), one two-years old (material not mentioned) and one was a few weeks old (material light-yellow crumb (Thiolon® Infill Pro[2])). Even though the report provides identification for only one rubber crumb material, the report refers to SBR crumb analysis. No detectable nitrosamines were found in the air samples.

The samples of the material were taken from three pitches above and three other pitches, of which one of them was from SBR crumb, material for the other two pitches was not reported. No nitrosamines were detected when the rubber crumb samples were heated.

ETRA has commissioned two emission studies on the artificial turf fields during 2006-2008. The first test report by SGS Institut Fresenius (2007) showed that the total volatile organic compounds (TVOC), sum of n-alkanes, sum of aromatic compounds and sum of esters were higher without playing than with playing in one field and in the second field the concentrations were rather similar with and without playing. The sum of the PAHs (EPA) were with playing 24 and 66 ng/m^3 and without playing 2.7 and 47 ng/m^3 and BaP concentrations were with playing 1.0 and 2.6 ng/m^3 and without playing 1.4 and 7.5 ng/m^3. As the first study was conducted in the wintertime (measurements in December and January), the second was carried out in June on one field. The second test report by SGS Institut Fresenius (2008) shows that PAHs could only be found in the low nanogram range (total EPA PAHs: without playing 5.04 and with playing 9.2 ng/m^3) which was similar compared to the background (8.7 ng/m^3). BaP concentrations were lower than the limit of detection (ng/m^3). The level of TVOC slightly increased while sport was taking place. Without playing, the level was similar compared to the background.

Migration of substances from crumb rubber in biological fluids (e.g. sweat, stomach fluids, pulmonary surfactants) (Tables C in Appendix)

RIVM/Van Bruggen, M. *et al.* (2007) investigated nitrosamines from air samples over the four artificial pitches in the Netherlands. In addition, samples of rubber crumb were taken from six pitches and material was analysed for the presence of nitrosamines in three steps: 1. Heating to 70 °C in a sealed bottle, 2. Extraction with dichloromethane and 3. Migration to a special fluid, which simulates human saliva.

Nitrosamines were detected when rubber crumb was exposed to simulated saliva (method used was NEN-EN 12868, which is used to determine the safety of rubber consumer products such as balloons, however the method was modified slightly because it was found that rubber crumb released smaller amounts of nitrosamines than balloons).

Three nitrosamines were detected: N-nitrosodiethylamine (NDEA), N-nitrosodimethylamine (NDMA) and N-nitrosomorpholine (NMOR). The values obtained were lower compared to the maximum amount of nitrosamines, which may be released from balloons using this method (i.e. 10 µg/kg).

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[2] Thermoplastic infill type. Thiolon I-sport Pro comes as standard in a beige colour, providing a cooling functionality to the pitch. It incorporates flame retardant and anti static agents as standard (patent granted nr. 1026444). (source: http://www.tencate.com/TenCate/Grass/documents/Prodsheet%20Thiolon%20I-sport_final.pdf)

Ecopneus (unpublished, 2016) studied migration of PAHs in artificial sweat using modified test EN 1810 (modification: extending the time of liquid-solid contact from 1 to 24 hours). Based on the results, it was estimated that the migration rate was very limited and always less than 0.007 % of the quantity contained in the rubber analysed.

The most recent study by **RIVM (2016)** measured migration of some substances from rubber granulates from tyres to artificial sweat after two-hours of exposure. Phthalates were not found above the detection limit values. RIVM also studied migration of substances in intestinal fluids after four-hours of exposure.

Leaching of substances from crumb rubber into environment (e.g. water) (Tables D in Appendix)

Leaching of several substances from recycled rubber granules to deionised water was studied by the **Norwegian Building Research Institute (2004).** Zinc and chromium from metals and organic compounds, such as PAHs, PCBs, phthalates and phenols were analysed. The leachates contain zinc, PAHs, phthalates and phenols. PCB levels were below the detection limit values.

The concentrations of anthracene, fluoranthene, pyrene and nonylphenols exceeded the limits for freshwater specified in the Canadian environmental quality guidelines.

The concentration of zinc in leachate would lead it to be placed in the Norwegian Pollution Control Authority's Environmental Quality Class V (very strongly polluted water), but comparing to Canadian drinking water criteria, the authors noted that the concentration would be lower than the criteria.

Leaching of zinc from rubber infill has been investigated in the Netherlands **(RIVM/Verscoor A.J. (2007)).** The emissions of zinc were measured by a column leaching test (NEN 7383). Both rubber granules originating from car tyres and truck tyres were tested taking into account the ageing of the granules. The emissions (at a liquid to solid ratio of 10) varied from 4.6 to 57 mg/kg for granules from car tyres and from 12 to 62 mg/kg for granules from truck tyres. The aging increased the emissions in laboratory conditions, but in the field conditions, the trend was considered more difficult to interpret due to the high variety of the fields. The authors concluded that the zinc load to the environment from the fields was estimated to be 800 mg/m^3/year, and the critical load is exceeded after approximately three years.

Nilsson N. *et al.* (2008) studied organic substances and zinc from samples of infill material, artificial turf mats and elastic pads. The study included e.g. leaching tests using three aqueous contact media. The study found wide variety of organic substances leached from the samples analysed. However, not all of these are listed in this report.

Bocca B. *et al.* (2009) analysed samples of rubber granules obtained from 32 playgrounds around Italy. Samples were black, white and coloured rubber granules and the origin of the granules was recycled tyres. In addition to the metal content analysis, the leaching of metals in acetic acid and leaching of some metals also in water were investigated. The highest leaching in acid was for zinc, followed by iron, strontium, aluminium, manganese and barium. Little amounts of some other metals were leached and some below the limits of quantifications. The percentages of leaching were less than

1 % for most of the elements (Zn included), 1-2 % for barium and iron and ca 10 % for magnesium, manganese and strontium. Leaching of some metals in water was lower than in acid.

Gomes J. *et al.* (2010) investigated inhalable dust and PAHs in recycled rubber granules originating from one company (Recipneu, Portugal). The aim was to compare coated material with raw material. Recycled rubber granules were coated with 1) emulsified polyvinyl chloride (PVC) and 2) cross-linked alquidic polymer. Both coating formulations included colour additives and a flame-retarding agent. In addition to the content measurements, PAHs were measured from the water leachates and heavy metals from acidic water leachates. The authors concluded that the coating materials effectively reduced leaching of PAHs and heavy metals, even though coating material 2) did not hinder tin from being leached.

Six artificial turf fields located in Turin, Italy were the subject of a study by **Ruffino, B. *et al.* (2013)**. Four fields had infill material made of SBRs from shredded tyres, one had infill material made of TPE and one was a natural turf field (natural soil as the infill material). Leaching tests consisted of analysis of in-water extractable compounds according to EN 12457/2.

Kalbe U. *et al*. (2013) particularly studied the feasibility of column tests using complete synthetic surface flooring or turf system assemblies. The release of zinc and polycyclic aromatic hydrocarbons (PAHs) leached from components of sports surfaces containing recycled rubber granules was considered. Additionally, batch tests on coated and uncoated styrene butadiene rubber (SBR) granules aged by artificial weathering were performed to indicate its possible influence on the leaching behaviour of zinc and PAH.

The chosen approach of column tests simulating typical complete synthetic sports surface installations has been proven to be feasible and robust. The time-dependent leaching behaviour and interactions between single components can be evaluated by column tests. Zinc was the most relevant contaminant in the eluates and its leachability was enhanced after accelerated ageing by artificial weathering. Leachable PAHs were found in relatively low but well detectable amounts, which increase by ageing as well.

Synthetic turf as a source of microplastic releases

A report by the **Ministry of Environment and Food of Denmark (2015)** on microplastics has identified rubber granules (and artificial grass) as a source of microplastics in the environment. The diameter of the rubber granules from shredded tyres varies between 0.7 and 3 mm (as informed by Genan, 2015), which are regarded as microplastics. In this study, the release pathways of rubber infill granulates and from artificial grass fibres are considered to be the following:

- Release to surrounding soil area;
- Release to paved areas surrounding the field, and subsequently release to sewerage system through grates (includes releases from shoes and clothing);
- Release of infill particles to the indoor environment, as the particles get stuck in sportsbags, shoes, clothing where they are 1) removed by vacuum cleaning, or 2) released to the sewerage system by discharges from washing machines; and

- Release to drainage through drainage water. The fate of the drainage water is: 1) downward seepage; 2) release to sewerage system, or 3) release to nearby streams due to heavy rainfall.

In Denmark, the total release of microplastics from synthetic turf (infill granulate as primary and secondary microplastics[3] and from artificial grassfibres as secondary microplastics due to wear and tear of artificial grass) is estimated to be 450-790 tonnes/year, of which 380-640 tonnes/year is infill granulate.

Releases to the surrounding soil are considered to be the main route for the infill granulates. The study assumes that 5-20 % of the released material ends up in sewege during laundering of the clothes. The study assumes that 94-97 % ends up in sludge, i.e. 20-310 tonnes/year. Assuming that 55% of the sludge goes to agricultural soil, 10-170 tonnes of microplastics from artificial turfs is estimated to end up there annually. It is to be noted that it is estimated that the percentage of rubber granules of total ultimate emissions to aquatic environment is 0.6 % (e.g. releases from tyres as secondary microplastics is estimated to be 60 %).

Magnusson K. *et al.* (2016) commissioned by the Swedish Environment Pollution Agency has made a review of existing data concerning Swedish sources and pathways for microplastics to the marine environment. Plastics in this report are man-made polymers, deriving from petroleum or petroleum by-products, but also non-synthetic polymers like natural rubber and polymer-modified bitumen. The report also states that there is no internationally accepted definition on the size limits for microplastics, but an upper limit of 5 mm has a strong support in the scientific community (GESAMP, 2015).

The lower size seems to be more debatable, but 1 µm is used in the report. It is estimated that around 2 300 – 3 900 tonnes of rubber granulates per year will be lost from the surfaces of the artificial football fields in Sweden. If assuming that 90 % of this material consists of SBR rubber, the yearly release in Sweden would be 2 070 – 3 510 tonnes of SBR rubber, 115-195 tonnes of EPDM rubber and 115 – 195 tonnes of TPA rubber. The authors pointed out knowledge gaps such as actual spill of granulates to the stormwater systems, spills of other artificial turf areas and did not provide any further estimations on the division of releases to different compartments.

In Norway, the sources of microplastic have been investigated as well by **Mepex (2014)** commissioned by the Norwegian Environment Agency[4]. According to the report, annual microplastic emissions from Norwegian primary sources, where figures exist, amounts to above 8 000 tonnes annually. Tyre dust, is by far the most important single source, followed by abrasion and particle shedding from polymer based paint and textiles.

A rough estimation of annual Norwegian macrolittering of the sea would be about 10 000 tonnes, but there is not enough knowledge about the rates and amount of these plastics ending up as microplastics. Another study by Mepex (2016)[5] used the Swedish estimate for annual loss to water (i.e. by run-off) – around 70 kg per year from each turf on average.

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[3] Primary microplastics: intentionally produced as plastic particles. Secondary microplastics: deriving from lare plastics debris fragmenting into smaller pieces

[4] See: http://www.miljodirektoratet.no/Documents/publikasjoner/M321/M321.pdf

[5] See: http://www.miljodirektoratet.no/Documents/publikasjoner/M545/M545.pdf

For Norway, this would amount to above 70 tonnes and hence a significant microplastics source to the sea and waterways. The estimate of the share ending up in waterways, is based on Danish methodology and assumptions in the COWI study, where about 90 % of the losses are captured in the sewage treatment plants. This assumption needs further discussions, both in Norway and Sweden. Due to a rougher climate and poor waste water solutions, losses to waterways may be much higher in Norway.

Appendix to Annex 1 - Concentrations of substances in recycled rubber granules, including emission, migration and leaching information – information from scientific literature and non-published data received from industry or other stakeholders

A: Substances measured from recycled rubber granules, B: Releases to air from recycled rubber granules, C: Migration of substances in artificial sweat etc. from recycled rubber granules and D: Leaching of substances from recycled rubber granules.

These tables contain information from recycled rubber granules that are produced from tyres. Where the study provides information on other recycled material, this is stated, also if it is not known of which material recycled rubber granule is produced. PAHs marked with * are those that are classified as carcinogenic category 1A or 1B. Note that total concentration of PAHs (EU-8): minimum and maximum values are calculated from different samples measured in one study.

Table I.5, Type A - Concentrations of metals in new recycled rubber granules, samples from manufacturer, stocks etc.

	Norwegian Building Research Institute (2004) (three samples of recycled rubber from supplier, origin not known) (mg/kg)	Nilsson N. (2008) (mg/kg) (2 samples)	Marsili et al. (2014) (4 samples) (mg/kg)	Aliapur (2015) (batches of passenger car tyres and truck and bus tyres, elemental composition) (mg/kg)	Murfitts Industries (submitted 2016) (mg/kg) (recycled rubber granules, several products, from consumer tyres)
Aluminium				603.0-876.0	25.7
Antimony					<0.05
Arsenic	<2-<3			<3	<0.05
Barium				5.0-12.0	2.6
Beryllium				<3	
Boron					11.5
Cadmium	1-2		0.47-2.05	<3	<0.5
Chromium	<2-<2		3.34-17.52	3.0-12.0	
Chromium III					<0.5
Chromium VI					<0.004
Cobalt				99.0-268.0	0.7
Copper	20-70		5.59-84.49	39.0-111.0	39.2
Iron			129.12-7256	451.0-2310.0	
Lead	15-20		13.97-33.58	11.0-25.0	<0.5
Lithium					
Magnesium				288.0-507.0	
Manganese				4.0-19.0	2.6
Mercury	<9.93-0.04			<3	<0.5
Molybdenum				<3	
Nickel	<1-<5		4.11-26.12	3.0-8.0	<0.5
Rubidium					
Selenium				<3	<0.5
Strontium					0.6
Tin					<0.5
Titanium				32.0-72.0	
Vanadium				<3	
Wolfram					

	Norwegian Building Research Institute (2004) (three samples of recycled rubber from supplier, origin not known) (mg/kg)	Nilsson N. (2008) (mg/kg) (2 samples)	Marsili et al. (2014) (4 samples) (mg/kg)	Aliapur (2015) (batches of passenger car tyres and truck and bus tyres, elemental composition) (mg/kg)	Murfitts Industries (submitted 2016) (mg/kg) (recycled rubber granules, several products, from consumer tyres)
Zinc	7 300-17 000	16 200, 18 500	3 474-13 202	15 000-20 000	491

Table I.6, Type A - Concentrations of metals in recycled rubber granules, samples taken from the fields

	Nilsson N. (2008) (mg/kg) (1 sample)	Bocca et al. (2009) (mg/kg) (32 samples: black, white and coloured)	Menichini et al. (2011) (mg/kg) (4 samples, uncoated)	Menichini et al. (2011) (mg/kg) (2 samples, coated)	Menichini et al. (2011) (mg/kg) (2 samples, recycled scrap of vulcanised rubber)	Menichini et al. (2011) (mg/kg) (3 samples, recycled ground gaskets)	Ruffino et al. (2013) (4 samples) (mg/kg)	Marsili et al. (2014) (4 samples) (mg/kg)
Aluminium		1.2- 6 680	164-477	490, 1 028	3 260, 311	2 065- 5 922	68-94	
Antimony		0.3-7.7	0.46-1.1	1.6, 6.4	1.2, 3.6	0.65-2.7		
Arsenic		0.10-1.21	0.10-0.41	0.12, 0.24	1.2, 0.11	0.28-0.54	<5.3	
Barium		2.4- 4 778	2.4-23	4.7, 741	31, 10	22- 4 778	10.7-167	
Beryllium		0.001-0.37	0.008-0.04	0.007, 0.04	0.37, 0.006	0.06-0.21		
Cadmium		0.11-1.89	0.62-1.9	0.12, 1.9	0.3, 0.17	0.17-1.1	<0.25	0.47-2.38
Chromium		0.4-56	<0.34.6	1.8, 6.2	6.2, < 0.3	2.5-20	<0.71 (tot)	1.91-5.37
Cobalt		3.5-234	8.8-116	5.0, 234	4.1, 3.5	8.4-21	97-125	
Copper		0.8-60	8.7-22	12, 60	5.9, 13	3.4-11	29-60.5	5.49-65.11
Iron		15- 4 318	199-620	201, 465	637, 183	241-460	37-105	262.2- 1 577.4
Lead		12-46	12-26	<0.7, 28	14, < 0.7	14-35	19.7-308	10.76-38.99
Lithium		0.6-11	0.87-1.4	0.60, 7.4	11, 2.7	1-4.4		
Magnesium		123-966	235-653	668, 966	518, 186	123-286	36-53	
Manganese		3.0-30	3.0-4.4	4.9, 5.2	10, 6.2	3.8-16	4-5.5	
Mercury		0.03-0.16	0.05-0.16	0.07, 0.08	0.06, 0.03	0.07-0.09		
Molybdenum		0.04-6.6	0.12-0.29	0.09, 0.13	0.19, 0.11	0.3-6.6		
Nickel		0.6-5.8	1.3-2.5	0.67, 5.8	4.4, 0.61	2.4-5.5	<1.5	3.9-5.75
Rubidium		0.7-26	0.9-3.1	1.8, 3.0	26, 0.78	1.5-2.2		
Selenium		<0.3-<0-3	<0.3-<0.3	<0.3, <0.3	< 0.3	0-0		
Strontium		3.2-90	3.2-6.0	12, 19	17, 9.9	6.9-86		
Tin		0.1-3.0	0.65-2.4	0.58, 1.74	3, 0.32	0.98-1.4	13-39	
Titanium		0.01-0.21	0.04-0.14	0.03, 0.07	0.21, 0.01	0.03-0.17	36-48.5	
Vanadium		0.4-22	1.3-3.5	1.5, 1.5	9.6, 0.94	9.7-22		
Wolfram		0.02-2.0	0.06-0.12	0.07, 0.36	1.8, 0.13	0.15-0.79		
Zinc	21000	118- 19 375	10 229-17 772	1 063, 19 375	7 611, 1 408	9 488 -14 187	1 220 -1 530	4 168 -6 006

Table I.7, Type A - Concentration of polycyclic aromatic hydrocarbons in new recycled rubber granules, samples from manufacturer, stocks, fields as reference material etc.

	Gomes et al. (2010) (one sample, non-coated) (mg/kg)	Gomes et al. (2010) (two samples, coated) (mg/kg)	Marsili et al. (2014) (4 samples) (mg/kg)	Murfitts Industries (submitted 2016) (recycled rubber granules, several products, from consumer tyres) (mg/kg)	The FA Group (2016) (mg/kg) (SBR, newly constructed artificial pitch, origin not known)	Department for Environment Food & Rural Affairs (UK) (2017) (38 samples, mg/kg)	Department for Environment Food & Rural Affairs (UK) (2017) (2 SBR samples, origin from Asia mg/kg)
Naphthalene	0.16	0.13, 0.35	0.36-2.04	1.43			
Acenaphthalene	0.27	0.27, 0.38		0.735			
Acenaphthene	0.04	<0.08, <0.08	0.35-10.15	nd			
Fluorene	0.12	0.13, 0.18	0.43-11.03	0.293			
Phenanthrene	1.41	1.23, 1.58	0.15-1.56	4.65			
Anthracene	0.13	0.13, 0.19	0.038-0.28	<0.005			
Fluoranthene	4.50	3.74, 5.98	0.87-3.74	7.63			
Pyrene	14.42	13.95, 21.10	3.98-6.73	25.5			
Benzo(a)anthracene*	1.31	0.82, 0.92	0.092-1.61	0.527	0.98	<0.2-2.4	376, 419
Chrysene*	2.83	2.12, 2.70	0.92-3.42	0.825	0.75	<0.2-4.5	1 120, 1 140**
Benzo(b)fluoranthene*	<0.08	<0.08, <0.08	1.15-11.10	0.939	1.37	<0.2-3.1	327, 421
Benzo(j)fluoranthene*				0.517		0.2-2.6	327, 421
Benzo(k)fluoranthene*	<0.08	<0.08, <0.08	0.068-1.20	0.178	<0.2	<0.2-4.5	289, 306
Benzo(a)pyrene*	1.19	<0.08, 0.43	0.12-0.46	1.52	0.75	<0.2-2.8	217, 260**
Benzo(e)pyrene*				2.60	1.21	<0.2-3.6	272, 308
Dibenz(a,h)anthracene*	<0.08	<0.08, <0.08	0.073-0.46	nd	0.27	<0.2-0.3	69.5, 93.4
Indeno(123-c,d)pyrene	<0.08	<0.08, <0.08		0.863			
Benzo(g,h,i)perylene	<0.08	<0.08, <0.08	0.40-0.90	1.98			

	Gomes et al. (2010) (one sample, non-coated) (mg/kg)	Gomes et al. (2010) (two samples, coated) (mg/kg)	Marsili et al. (2014) (4 samples) (mg/kg)	Murfitts Industries (submitted 2016) (recycled rubber granules, several products, from consumer tyres) (mg/kg)	The FA Group (2016) (mg/kg) (SBR, newly constructed artificial pitch, origin not known)	Department for Environment Food & Rural Affairs (UK) (2017) (38 samples, mg/kg)	Department for Environment Food & Rural Affairs (UK) (2017) (2 SBR samples, origin from Asia mg/kg)
Carcinogenic PAHs listed in entry 50 of Annex XVII to REACH*	5.33	2.12, 4.87	2.55-22.78	7.11	5.53	02-23.8	2 997.5- 3 368.4
** above the limit values set in restriction entry 28 in Annex XVII to REACH							

Table I.8, Type A - Concentration of polycyclic aromatic hydrocarbons in recycled rubber granules, samples taken from the fields

	Menichini et al. (2011) (4 samples, uncoated) (mg/kg)	Menichini et al. (2011) (2 samples, coated) (mg/kg)	Menichini et al. (2011) (mg/kg) (2 samples, recycled scrap of vulcanised rubber)	Menichini et al. (2011) (mg/kg) (3 samples, recycled ground gaskets)	Ruffino et al. (2013) (4 samples) (mg/kg)	Marsili et al. (2014) (4 samples) (mg/kg)	Salonen et al. (2015) (4 indoor samples, recycled SBR***) (mg/kg)	RIVM (2016) (mg/kg) (max value from fields' average)
Naphthalene						0.22-1.14	0.1-0.43	<LoD
Acenaphtylene							0.1-1.10	<LoD
Acenaphthene						0.40-6.32	0.07-0.62	1.03
Fluorene						0.53-7.14	0.21-0.87	0.95
Phenanthrene						0.15-1.56	4.35-8.60	7.08
Anthracene						0.04-0.18	<0.40-0.99	1.10
Fluoranthene						0.71-3.25	6.87-14.00	20.3
Pyrene	1.86-9.74	0.42, 15.1	0.44, 0.2	0.75- 11.2	20.0-25.9	1.64-10.28	20.69-37.00	28.7
Benzo(a)anthracene*	0.21-0.43	0.04, 0.15	0.14, 0.21	0.01- 0.18	4.72-15.3	0.005-0.39	<1.41-2.20	2.19
Chrysene*	0.65-2.38	0.97, 0.99	1.34, 0.5	0.03-0.67	1.44-4.21	0.24-0.92	0.82-6.80	3.45
Benzo(b)fluoranthene*	0.27-1.78	0.05, 0.46	0.33, 0.08	0.01-0.44	<0.01-8.81	1.25-10.19	0.16-1.90	2.95
Benzo(k)fluoranthene*					<0.01-5.02	0.13-3.62	<0.16-0.74	0.52
Benzo(a)pyrene*		0.06, 2.30	0.77, 0.07	0.02-2.83	<0.01-1.41	0.52-0.66	<0.94-2.38	2.21
Dibenz(a,h)anthracene*	Nc**	Nc, 0.03	nc	nc	0.72-8.13	0.11-0.57	<0.08-<0.58	<LoD
Indeno(123-c,d)pyrene	3.73 (nc 3 samples)	0.05, 1.08	0.07	0.04-1.26			<0.40-2.75	0.54
Benzo(g,h,i)perylene	29.2	0.25, 8.36	0.46	0.25-9.02	1.70-4.16	0.24-0.54	1.26-8.55	7.70

	Menichini et al. (2011) (4 samples, uncoated) (mg/kg)	**Menichini et al. (2011) (2 samples, coated) (mg/kg)**	**Menichini et al. (2011) (mg/kg) (2 samples, recycled scrap of vulcanised rubber)**	**Menichini et al. (2011) (mg/kg) (3 samples, recycled ground gaskets)**	**Ruffino et al. (2013) (4 samples) (mg/kg)**	**Marsili et al. (2014) (4 samples) (mg/kg)**	**Salonen et al. (2015) (4 indoor samples, recycled SBR***) (mg/kg)**	**RIVM (2016) (mg/kg) (max value from fields' average)**
	(nc 3 samples)							
Carcinogenic PAHs listed in entry 50 of Annex XVII to REACH* (highest values calculated, even if from different sample)	1.13-4.59	3.93	2.65	0.07-4.12	6.88-42.88	2.60-16.34	0.98-14.02	19.8
**Not calculable due to interference from the laboratory blank sample ***Report does not say if recycled SBR is from tyres								

Table I.9, Type A - Concentration of other substances (other than PAHs and metals) measured from recycled rubber granules, samples from manufacturers, stocks and fields

	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (mg/kg)	Nilsson et al. (2008) (3 new samples from supplies, one coated (co)) (µg/g)	Ruffino et al. (2013) (4 field samples) (µg/kg)	RIVM (2016) (mg/kg) (100 fields, not all measurements from all samples) (max value from fields' average)
Benzene			0.37-0.64	<LoD
Toluene			272-449	0.057
Xylene (o-, m-, p-)			682-975	0.103
Styrene				0.053
Phthalates				
di-2-ethylhexylphthalate (DEHP)	21-29	52	nd-52	27
di-isobutyphthalate			nd-77 (coated)	2.32
di-isononylphthalate (DINP)	57-58			61
Dicyclohexylphthalate				0.21
di-n-nonylphthalate				0.8
Difenylphthalate				0.11
Bis(2-ethylhexyl)phthalate				1.1
Dimethylphthalate (DMP)	<1.0-<1.0			<LoD
Diethylphthalate (DEP)	<1.0-<1.0			2.92
Dibutylphthalate (DBP)	2.6-3.9		nd	?
Benzylbutylphthalate	1.3-2.8			0.99
Di n-octylphthalate	>1.0-<1.0			0.1
di-isodecylphthalate (DIDP)	<1.0			10
dihexylphthalate				<LoD
Bis(2-ethylhexyl)adipate				1.1
Benzothiazols				
Benzothiazol		13, 60, 78 (co)		6.3
2-hydroxybenzothiazol				13.8
2-mercaptobenzothiazol				7.6
2-methoxybenzothiazol				10.2
2-aminobenzothiazole				0.38
N-cyclohexyl-1,3-benzothiazol-2-amine				3.9
2,2-dithiobis-benzothiazol				0.3
N-cyclohexyl-2-benzothiazol sulfenamide				0.04
1-hydroxybenzotrazole				<LoD
benzotriazole				<LoD
tolyltrazole				<LoD
5,6-dimethyl-1H-benzotriazole				<LoD

	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (mg/kg)	Nilsson et al. (2008) (3 new samples from supplies, one coated (co)) (µg/g)	Ruffino et al. (2013) (4 field samples) (µg/kg)	RIVM (2016) (mg/kg) (100 fields, not all measurements from all samples) (max value from fields' average)
Others				
4-tert-octylphenol	19.6-33.7			22.4
4-n-nonylphenol	<5 (µg/kg)			<LoD
Iso-nonylphenol	9.1-21.6			
Bisphenol A				2.5
PCBs	<0.0175-0.202 (PCB7)			0.074

Table B-1

Table I.10, Type B - Concentration of polycyclic aromatic hydrocarbons evaporated from new recycled rubber granules, samples from manufacturers, stocks etc.

	Marsili et al. (2014) (4 samples) (ng/g) (60°C)
Naphthalene	
Acenaphthalene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	
Benzo(a)anthracene*	0.14-0.43
Chrysene*	1.30-5.82
Benzo(b)fluoranthene*	
Benzo(k)fluoranthene*	
Benzo(a)pyrene*	0.11-0.48
Dibenz(a,h)anthracene*	
Indeno(123-c,d)pyrene	
Benzo(g,h,i)perylene	0.42-0.58

Table I.11, Type B - Concentration of polycyclic aromatic hydrocarbons measured above the fields or in laboratory tests from recycled rubber granules, samples from fields (vapour phase or particle phase)

	Norwegian Institute for Air Research (2006) (ng/m^3) (indoor fields, gas phase (g) and airborn dust (PM10) (d); 2 samples from tyres: black and an unknown type (green)) and SBR) (note: some other PAHs measured but not added)	**Menichini et al. (2011) (ng/m^3) (sampler within the field, 2-3 hours, 3 days)**	**Menichini et al. (2011) (ng/m^3) (personal sampler, 1 hour (four samplers), 2 days)****	**Ruffino et al. (2013) (4 samples) (ng/m^3)**	**Schilirò et al. (2013) (ng/m^3) (4 fields, 2 samples, 2 m height from street level) (from PM10 and PM2.5 filters)**	**Marsili et al. (2014) (4 samples) (mg/kg) (laboratory, 60°C)**	**Waste and chemicals (2016) (ng/m^3) (2 samples: before the match, during the match (ambient air); 3 personal samples during the match)**
Naphthalene	20.9, 56.4 (g) 0.13, 0.17 (d)						
Acenaphthalene	32.4, 78.1 (g) 0.04, 0.19 (d)						
Acenaphthene	5.82, 14.2 (g) 0.06, 0.02 (d)						
Fluorene	10.2, 19.2 (g) 0.10, 0.04 (d)						
Phenanthrene	19.7, 25.0 (g) 0.52, 0.33 (d)				<0.09-0.17		
Anthracene	1.86, 1.33 (g) 0.05, 0.04 (d)				<0.09-<0.09		
Fluoranthene	2.81, 2.20 (g) 0.67, 0.48 (d)				<0.09-0.57		
Pyrene	3.54, 3.09 (g)			<0.09	<0.09-0.79		

	Norwegian Institute for Air Research (2006) (ng/m³) (indoor fields, gas phase (g) and airborn dust (PM10) (d); 2 samples from tyres: black and an unknown type (green)) and SBR) (note: some other PAHs measured but not added)	Menichini et al. (2011) (ng/m³) (sampler within the field, 2-3 hours, 3 days)	Menichini et al. (2011) (ng/m³) (personal sampler, 1 hour (four samplers), 2 days)**	Ruffino et al. (2013) (4 samples) (ng/m³)	Schilirò et al. (2013) (ng/m³) (4 fields, 2 samples, 2 m height from street level) (from PM10 and PM2.5 filters)	Marsili et al. (2014) (4 samples) (mg/kg) (laboratory, 60◦C)	Waste and chemicals (2016) (ng/m³) (2 samples: before the match, during the match (ambient air); 3 personal samples during the match)
	0.81, 0.64 (d)						
Benzo(a)anthracene*	0.15, 0.07 (g) 0.56, 0.36 (d)	0.03-0.05		<0.09	<0.09-2.13	0.16-0.49	
Chrysene*	0.19, 0.11 (g) 0.76, 0.53 (d)			0.1- <0.09	<0.09-2.24	1.32-2.53	
Benzo(b)fluoranthene*		0.09-0.11, (including B(j)FA		0.12-0.17	<0.09-4.00		
Benzo(k)fluoranthene*							
Benzo(a)pyrene*	0.02, <0.01 (g) 1.15, 0.56 (d)	0.04-0.06	0.3, 0.5	<0.09	<0.09-1.75	0.19-0.89	7.43 and 12.34, 7.21-13.69
Dibenz(a,h)anthracene*	<0.02, <0.01 (g) 0.13, 0.07 (d)	0.01-0.01 (including DBacA)	0.1, 0.1 (including DBacA)	<0.09	<0.09-0.19		
Indeno(123-c,d)pyrene	<0.02, <0.01 (g) 1.11, 0.73 (d)	0.05-0.06	0.5, 0.6		<0.09-1.03		
Benzo(g,h,i)perylene	<0.02, <0.01 (g) 1.11, 0.84 (d)		0-3-0.9	<0.09-0.12	<0.09-1.22	0.49-1.28	
Dibenzo(al)pyrene			<0.03, nc				
Dibenzo(ae)pyrene	<0.01, <0.01 (g)		<0.03, <0.1				

	Norwegian Institute for Air Research (2006) (ng/m^3) (indoor fields, gas phase (g) and airborn dust (PM10) (d); 2 samples from tyres: black and an unknown type (green)) and SBR) (note: some other PAHs measured but not added)	Menichini et al. (2011) (ng/m^3) (sampler within the field, 2-3 hours, 3 days)	Menichini et al. (2011) (ng/m^3) (personal sampler, 1 hour (four samplers), 2 days)**	Ruffino et al. (2013) (4 samples) (ng/m^3)	Schilirò et al. (2013) (ng/m^3) (4 fields, 2 samples, 2 m height from street level) (from PM10 and PM2.5 filters)	Marsili et al. (2014) (4 samples) (mg/kg) (laboratory, 60°C)	Waste and chemicals (2016) (ng/m^3) (2 samples: before the match, during the match (ambient air); 3 personal samples during the match)
	0.06, <0.01 (d)						
Dibenzo(ai)pyrene	<0.01, <0.01 (g) 0.04, <0.01 (d)		<0.03, <0.1				
Dibenzo(ah)pyrene	<0.01, <0.01 (g) <0.01, <0.01 (d)		<0.03, <0.1				

Table I.12, Type B - Concentration of other substances (other than PAHs and metals) measured above the fields or in laboratory tests from recycled rubber granules, samples from suppliers or from fields

	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (gas phase, 70 c, 30 min) (µg/kg)	Norwegian Institute for Air Research (2006) (indoor fields, gas phase (µg/m^3) (g) and airborn dust (ng/m^3) (PM10) (d); 2 halls with black and an unknown type (green)) and SBR)	Nilsson et al. (2008) (3 new samples from supplies, one coated (co)) (µg/g)	Ruffino et al. (2013) (4 samples) (µg/m^3)	Schilirò et al. (2013) (ng/m^3) (4 fields, 2 samples, 2 m height from street level	Simcox (indoor) µg/m3	Salonen et al. (2015) (4 indoor samples, recycled SBR***) (µg/m^3)
Benzene				1.3-2.2	1.3-6.0	ND	0.5-7.0
Toluene	28-80	15.0-85.0 (g)		4.2-10.2	4.2-31.2	135.4	1.5-84
Xylene (o-, m-, p-)	45-78			7.6-20.9	7.2-33.7	12.13	0.7-69
Phthalates							
di-2-ethylhexylphthalate (DEHP)		31.3, 17.7 (d)					
di-isobutyphthalate		0.01-0.13 (g)					
di-isononylphthalate (DINP)							
Dicyclohexylphthalate							
di-n-nonylphthalate							
Difenylphthalate							
Bis(2-ethylhexyl)phthalate							
Dimethylphthalate (DMP)		39.1, 50.3 ((d)					
Diethylphthalate (DEP)		0.01-0.06 (g) 24,4 10,4 (d)					
Dibutylphthalate (DBP)		0.07-0.38 (g) 31.4 51.7 (d)					
Benzylbutylphthalate		5.2, 4.3 (d)					
Di n-octylphthalate		<0.01, <0.01 (d)					
di-isodecylphthalate (DIDP)							
Benzothiazols							
Benzothiazol		4.5-31.7 (g)	0.1 (co)				1-13
2-hydroxybenzothiazol		346, 566 pg/m^3 (d)					
2-mercaptobenzothiazol		287, 352 pg/m^3 (d)					
2-methoxybenzothiazol							
2-aminobenzothiazole		54, 28 pg/m^3 (d)					

	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (gas phase, 70 c, 30 min) (µg/kg)	Norwegian Institute for Air Research (2006) (indoor fields, gas phase (µg/m^3) (g) and airborn dust (ng/m^3) (PM10) (d); 2 halls with black and an unknown type (green)) and SBR)	Nilsson et al. (2008) (3 new samples from supplies, one coated (co)) (µg/g)	Ruffino et al. (2013) (4 samples) (µg/m^3)	Schilirò et al. (2013) (ng/m^3) (4 fields, 2 samples, 2 m height from street level	Simcox (indoor) µg/m3	Salonen et al. (2015) (4 indoor samples, recycled SBR***) (µg/m^3)
N-cyclohexyl-2-benzothiazolsulfenamide		23, 3 pg/m^3 (d)					
Other							
Methyl-isobutyl-ketone (MIBK)		3.4-12.7 (g)	5, 12, 3.4 (co)				0.8-14.5
Formaldehyde							1.7-4.2
TVOC							10.0-70.00

Table I.13, Type C - Migration of substances from recycled rubber granules

	RIVM/van Bruggen M. et al. (2007) (6 fields, 5 with SBR and one with TPE type) (artificial fluid which simulates human saliva) (µg/kg)	RIVM (2016) (7 samples, SBR rubber from tyres) (artificial sweat) (ng/g) (median and max)	RIVM (2016) (metals: 2 samples, PAHs: 5 samples, SBR rubber from tyres) (stomach/intertinal fluid) (total amount released, max) (µg/g)	The FA Group (2016) (migration using EN standard for toys, mg/kg) (SBR, newly constructed artificial pitch, origin not known)
Metals				
Aluminium				6.15
Antimony			nd	0.05
Arsenic			nd	<0.05
Barium			6	3.7
Beryllium				
Boron				2.7
Cadmium		<0.03, 20	nd	<0.05
Chromium			1	
Chromium III				1.9
Chromium VI				<0.004
Cobalt		280, 480	2	0.65
Copper			78	41
Iron				
Lead		30, 70	9	0.8
Lithium				
Magnesium				
Manganese				2.65
Mercury			nd	0.008
Molybdenum				
Nickel			2	0.05
Rubidium				
Selenium			1	0.2
Strontium				6.6
Tin			nd	0.15
Titanium			1	
Vanadium			nd	
Wolfram				
Zinc			419	365
PAHs				
Naphthalene		<LoD, 0.39	0.37	
Acenaphthalene				
Acenaphthene		<0.5	0.02	

	RIVM/van Bruggen M. et al. (2007) (6 fields, 5 with SBR and one with TPE type) (artificial fluid which simulates human saliva) (µg/kg)	RIVM (2016) (7 samples, SBR rubber from tyres) (artificial sweat) (ng/g) (median and max)	RIVM (2016) (metals: 2 samples, PAHs: 5 samples, SBR rubber from tyres) (stomach/intertinal fluid) (total amount released, max) (µg/g)	The FA Group (2016) (migration using EN standard for toys, mg/kg) (SBR, newly constructed artificial pitch, origin not known)
Fluorene		<0.4	<LoD	
Phenanthrene		<0.3	0.13	
Anthracene		<0.3	<LoD	
Fluoranthene		<0.3, 0.61	1.02	
Pyrene		0.20, 1.76	1.13	
Benzo(a)anthracene*		<0.3	0.01	
Chrysene*		<0.2, 0.31	0.15	
Benzo(b)fluoranthene*		<0.3	0.05	
Benzo(k)fluoranthene*		<0.3	<LoD	
Benzo(a)pyrene*		<0.4	0.03	
Benzo(e)pyrene		<LoD, 0.7		
Dibenz(a,h)anthracene*		1.08	0.02	
Indeno(123-c,d)pyrene		<0.5	0.03	
Benzo(g,h,i)perylene		0.47, 1.02	0.29	
Dibenzo(al)pyrene				
Dibenzo(ae)pyrene				
Dibenzo(ai)pyrene				
Dibenzo(ah)pyrene				
Phthalates		All LoD (µg/l)		
di-2-ethylhexylphthalate (DEHP)			1.84	
di-isobutyphthalate (DIBP)			0.18	
di-isononylphthalate (DINP)			<LoD	
Dicyclohexylphthalate (DCHP)			0.27	
di-n-nonylphthalate (DNNP)			0.06	
Difenylphthalate (DPP)			0.09	
Dimethylphthalate (DMP)			0.05	
Diethylphthalate (DEP)			0.26	
Dibutylphthalate (DBP)			0.08	
Benzylbutylphthalate (BBP)			0.29	
Di n-octylphthalate (DNOP)			<LoD	
di-isodecylphthalate (DIDP)			0.28	
Bis (2-ethylhexyl) adipate (DEHA)			<LoD	
Nitrosamines				

	RIVM/van Bruggen M. et al. (2007) (6 fields, 5 with SBR and one with TPE type) (artificial fluid which simulates human saliva) (µg/kg)	RIVM (2016) (7 samples, SBR rubber from tyres) (artificial sweat) (ng/g) (median and max)	RIVM (2016) (metals: 2 samples, PAHs: 5 samples, SBR rubber from tyres) (stomach/intertinal fluid) (total amount released, max) (µg/g)	The FA Group (2016) (migration using EN standard for toys, mg/kg) (SBR, newly constructed artificial pitch, origin not known)
N-nitrosodimethylamine	<0.2-0.6 (SBR), <0.2 (TPE)			
N-nitrosomethylethylamine	nd			
N-nitrosodiethylamine	<0.2 (SBR), 0.7 (TPE)			
N-nitrosomorpholine	1.2-4.0 (SBR), 2.5 (TPE)			
N-nitrosopyrrolidine	nd			
N-nitrosopiperidine	nd			
N-nitrosodibutylamine	nd			
LoD – Level of Detection, nd – not detected				

Table I.14, Type D - Leaching of metals from recycled rubber granules, samples from manufacturers, stocks etc.

	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (µg/l)	Nilsson N. (2008) (mg/l (2 samples)	Gomes et al. (2010) (mg/l) (one sample, non-coated) (acidic water, pH ~4-5) (24 h and 48 h)	Gomes et al. (2010) (mg/l) (two samples, coated) (acidic water, pH ~4-5) (24 h and 48 h)
Aluminium				
Antimony				
Arsenic				
Barium				
Beryllium				
Cadmium			0.001 and <0.001	0.001, <0.001 and <0.001, <0.001
Chromium	-		0.003 and 0.002	<0.001, 0.002 and <0.001, <0.001
Cobalt				
Copper				
Iron				
Lead			0.003 and 0.006	0.003, 0.019 and <0.003, 0.006
Lithium				
Magnesium				
Manganese				
Mercury			<0.0008 and <0.0008	<0.0008, <0.0008 and <0.0008, <0.0008
Molybdenum				
Nickel				
Rubidium				
Selenium				
Strontium				
Tin			<0.005 and <0.005	0.02, 0.47 and 0.009, 0.31
Titanium				
Vanadium				
Wolfram				
Zinc	590-2290	0.36-1.4*	6.9 and 1.6	1.7, 3 and 0.3, 0.9

Table I.15, Type D - Leaching of metals from recycled rubber granules, samples taken from the fields

	Nilsson N. (2008) (μ/l) (1 sample)	Bocca et al. (2009) (μg/l) (32 samples: black, white and coloured) (acetic acid, pH 5)	Bocca et al. (2009) (μg/l) (5 samples: black, white and coloured) (water, median concentration)	Gomes et al. (2010) (mg/l) (one sample) (acidic water, pH ~4-5) (24 h and 48 h)	Ruffino et al. (2013) (4 samples) (μg/l)	RIVM (2016) (mg/kg) (max value)
Aluminium		2.00-3 940			7.97-39.8	
Antimony		<LoQ-18.0				
Arsenic		<LoQ-2.40			<5.3	
Barium		2.00-2 050			10.9-21.3	0.2
Beryllium		<LoQ-<LoQ				
Cadmium		<LoQ-0.70	<LoQ	0.001 and <0.001	<0.25	
Chromium		0.20-10.0	0.20	0.003 and 0.002	<0.71	
Cobalt		<LoQ-41.00			9.03-12.5	0.4
Copper		0.20-216			6.62-22.1	0.9
Iron		6.00-3 220			18.3-53.9	
Lead		<LoQ-27.00	<LoQ	0.003 and 0.006	<4.2	
Lithium		<LoQ-440				
Magnesium		122-28200				
Manganese		7.00-220			12.3-42.4	
Mercury		<LoQ-<LoQ	<LoQ	<0.0008 and <0.0008		
Molybdenum		<LoQ-6.00				
Nickel		<LoQ-10.00			<1.5	
Rubidium		<LoQ-186				
Selenium		<LoQ-<LoQ				
Strontium		3.00-713				
Tin		<LoQ-<LoQ	<LoQ	<0.005 and <0.005	25.3-47.7	
Titanium		<LoQ-<LoQ			0.848-2.88	
Vanadium		0.14-11.0				
Wolfram		<LoQ-<LoQ				
Zinc	800	2.00-62 120	966	6.9 and 1.6	1 143-2 729	129

Table I.16, Type D - Concentration of polycyclic aromatic hydrocarbons leached from new recycled rubber granules, sample from manufacturer, stocks, etc.

	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (µg/l)	Gomes et al. (2010) (one sample, non-coated) (mg/kg) (water)	Gomes et al. (2010) (two sample, coated) (mg/kg) (water)	Ruffino et al. (2013) (4 samples) (µg/l)
Naphthalene	>0.1, 0.15	<0.005	<0.001, <0.001	
Acenaphthalene	<0.01, 0.27	<0.003	<0.001, <0.001	
Acenaphthene	0.02, 0.03	<0.003	<0.001, <0.001	
Fluorene	0.04, 0.04	<0.003	<0.001, <0.001	
Phenanthrene	0.16, 0.17	<0.003	<0.001, <0.001	
Anthracene	0.03, 0.03	<0.003	<0.001, <0.001	
Fluoranthene	0.06, 0.06	<0.003	<0.001, <0.001	
Pyrene	0.12, 0.13	<0.003	0.001, <0.001	0.03-0.06
Benzo(a)anthracene*	<0.01	<0.003	<0.001, <0.001	<0.001-0.01
Chrysene*	<0.01	<0.003	<0.001, <0.001	<0.001-0.04
Benzo(b)fluoranthene*	<0.01	<0.003	<0.001, <0.001	<0.001-0.04
Benzo(k)fluoranthene*	<0.01	<0.003	<0.001, <0.001	<0.001-0.02
Benzo(a)pyrene*	<0.01	<0.003	<0.001, <0.001	<0.001-<0.001
Dibenz(a,h)anthracene*	<0.01	<0.003	<0.001, <0.001	<0.001-<0.001
Indeno(123-c,d)pyrene	<0.01	<0.003	<0.001, <0.001	
Benzo(g,h,i)perylene	<0.01	<0.003	<0.001, <0.001	<0.001-0.04

Table I.17, Type D - Concentration of polycyclic aromatic hydrocarbons leached from recycled rubber granules analysed and reported in scientific literature, samples from manufacturers, stocks and fields

	Ruffino et al. (2013) (4 samples from fields) (µg/l)
Naphthalene	
Acenaphthalene	
Acenaphthene	
Fluorene	
Phenanthrene	
Anthracene	
Fluoranthene	
Pyrene	0.03-0.06
Benzo(a)anthracene*	<0.001-0.01
Chrysene*	<0.001-0.04
Benzo(b)fluoranthene*	<0.001-0.04
Benzo(k)fluoranthene*	<0.001-0.02
Benzo(a)pyrene*	<0.001
Dibenz(a,h)anthracene*	<0.001
Indeno(123-c,d)pyrene	
Benzo(g,h,i)perylene	<0.001-0.04

Table I.18, Type D - Concentration of other substances (other than PAHs and metals) leached from recycled rubber granules, samples from manufacturers, stocks and fields

	Nilsson N. (2008) (µ/l) (3 samples)	Norwegian Building Research Institute (2004) 3 samples of recycled rubber from supplier (origin not known) (µg/l)	Ruffino et al. (2013) (4 samples from fileds) (µg/l)
Benzene			<0.001-<0.001
Toluene			0.29-0.43
Xylene (o-, m-, p-)			0.34-0.42
Phthalates			
di-2-ethylhexylphthalate (DEHP)		5.1, 5.6	
di-isobutyphthalate	21-98		
di-isononylphthalate (DINP)		2.7, 2.2	
Dicyclohexylphthalate			
di-n-nonylphthalate			
Difenylphthalate			
Bis(2-ethylhexyl)phthalate			
Dimethylphthalate (DMP)		0.6, 1.6	
Diethylphthalate (DEP)	61	6.6, 8.3	
Dibutylphthalate (DBP)	72	3.3, 2.1	
Benzylbutylphthalate		<0.1, 0.3	
Di n-octylphthalate		2.9, 4.4	
di-isodecylphthalate (DIDP)		<1.0, 1.0	
Benzothiazols			
Benzothiazol	293, 528		
2-hydroxybenzothiazol			
2-mercaptobenzothiazol			
2-methoxybenzothiazol			
2-aminobenzothiazole			
N-cyclohexyl-1,3-benzothiazol-2-amine			
2,2-dithiobis-(benzothiazol)			
N-cyclohexyl-2-benzothiazolsulfenamide			
Other			
4-tert-octylphenol		3 600, 2 950	
Bisphenol-A			
4-n-nonyphenol		43, <20	
Iso-nonylphenol		1 120, 568	
PCBs		<0.01	

ANNEX II - SCREENING OF SUBSTANCES – CMRs CATEGORIES 1A OR 1B

(EU classification and labelling database, accessed 27.01.2017)

ECHA used substances listed in the US EPA Research Protocol[6] as a basis for the screening. Out of 221 substances, 20 had a harmonised classification as carcinogenic, mutagenic and/or toxic to reproduction categories 1A or 1B.

Table II.1 Screened substances with harmonised classification as CMR, Cat 1A or 1B

Substances	CAS number	EU harmonised classification as CMR, Cat 1A or 1B
Formaldehyde	50-00-0	C1B
Benzene	71-43-2	C1A, M1B
Trichloroethylene	79-01-6	C1B
di-isobutylphthalate	84-69-5	R1B
dibutylphthalate	84-74-2	R1B
benzylbutylphthalate	85-68-7	R1B
Imidazolidine-2-thione	96-45-7	R1B
Buta-1,3-diene	106-99-0	C1A, M1B
Bis(2-ethylhexyl) phthalate	117-81-7	R1B
1-methyl-2-pyrrolidone	872-50-4	R1B
Mercury	7439-97-6	R1B
Beryllium	7440-41-7	C1B
Cadmium	7440-43-9	C1B
Benzo[def]chrysene	50-32-8	C1B, M1B, R1B
Dibenz[a,h]anthracene	53-70-3	C1B
Benz[a]anthracene	56-55-3	C1B
Benzo[e]pyrene	192-97-2	C1B
Benzo[e]acephenanthrylene	205-99-2	C1B
Benzo[k]fluoranthene	207-08-9	C1B
Chrysene	218-01-9	C1B

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[6] See: https://www.epa.gov/sites/production/files/2016-08/documents/tcrs_research_protocol_final_08-05-2016.pdf

ANNEX III - RECYCLED TYRES (OR OTHER RECYCLED RUBBER PRODUCTS) USED AS INFILL MATERIAL – WASTE STATUS IN SOME EU MEMBER STATES, INCLUDING INFORMATION FROM SOME STAKEHOLDERS

Finland

Finland does not have national end-of-waste criteria for rubber granulates that are produced from recycled tyres. So, in principle, recycled rubber granulates are regarded as waste, and therefore the professional and industrial treatment of rubber granulates need to have a permit.

Waste, which does not have EU or national end-of-waste criteria can cease to be waste in a case- by-case examination during the environment permit procedure, according to the Finnish Environmental Protection Act (257/2014). In an environment permit, conditions or criteria, based on the definition of waste (Section 5 of Waste Act (646/2011)), could be defined when a certain waste ceases to be waste and so becomes either an article or a mixture.

The Finnish waste permitting procedure is described in a Finnish study "National Implementation of Waste permitting Obligations in Various European Countries":

http://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/78887/YMre_29en_2016.pdf?sequence=1

The Finnish producers of rubber granulates sell their granulate as waste. The use of rubber granulates therefore requires permits. The permitting procedure for a certain use of this material will be lightened with the amendment of a government decree concerning the recovery of certain wastes in earth construction.

Finnish rubber granulate is not used for synthetic turf. It is not suitable for synthetic turf and it is not processed for that kind of use.

The Finnish company producing synthetic turf (Saltex Oy) imports SBR rubber granulates for synthetic turf. The import is as a product, not as waste. The company is not aware what kind of procedure is in place in that particular country to make the rubber granule as a product. REACH is applied for this imported SBR.

Ireland

Tyre-derived rubber material is generated by two main waste recyclers in Ireland. These waste operators are in turn regulated by two local authorities. The recycling of waste tyres and the production of granules for use in artificial turf is considered a "recovery operation" at all regulatory and policy levels in Ireland.

There are no published end-of-waste criteria for tyre-derived materials at EU level or Ireland and the granules are not classified as waste by the producers. One tyre recycling company sought to clarify the matter with the Irish Environmental Protection Agency and was informed that pending the introduction of national end-of-waste criteria for tyre-derived rubber materials, and as an interim measure, any tyre-derived rubber materials that comply with the requirements of the UK Quality

Protocol on Tyre-Derived Rubber Materials (WRAP/EA, 2009) would not be classified by the EPA as waste. The second major producer has not sought to clarify the classification of its product and has not been required to do so. Pending the publication at EU or national level of end-of-waste criteria, the EPA has not instigated or applied any general policy of requiring Irish recyclers to classify their recycled or recovered products.

Sweden

Sweden has no end-of-waste criteria in place for rubber crumb. In general, the manufacturers of the granules currently assess the material as waste when sold for further use in pitches. The supervisory regional authority has a continuous dialogue with the company through inspection visits at the facility to make sure that the applicable waste legislation is fulfilled. The Swedish EPA is involved in the process by providing guidance.

The use of rubber crumb in pitches (when the rubber crumb is classified as waste) is not waste disposal but a recycling/recovery operation for construction purposes (in Swedish "återvinning av avfall i anläggningarbeten"). This kind of recovery operation can require notification to the local authority or a permit depending on, for example, the content of hazardous substances in the material. The Swedish EPA has specific guidance on when notification or permits are required. The guidance (in Swedish) can be found at this link: http://www.naturvardsverket.se/Om-Naturvardsverket/Publikationer/ISBN/0100/978-91-620-0164-3/

The United Kingdom

The United Kingdom has end-of-waste criteria for the production and use of tyre-derived rubber materials. The UK has notified its criteria to the Commission. See criteria: Quality protocol: Tyre-derived rubber materials. End of waste criteria for the production and use of tyre-derived rubber materials.(see: https://www.gov.uk/government/publications/quality-protocol-tyre-derived-rubber-materials)

Stakeholder information

Ragn-Sells AB, Sweden (2016) considers that it is important to get consensus in the EU on how granulates from used tyres should be classified, i.e. if the granules are sold as a waste or as a product. In Sweden and France, granules that are sold are classified as waste.

Celanese, Germany (2017) states that it could be relevant to specify for ELT at which stage they cease to be waste.

According to ETRMA (2016), the classification as a waste or a mixture depends on a Member State; ELT granules may be a mixture or a waste – and classification may also change if transported.

ANNEX IV - SELECTED SUBSTANCES AND SOME METALS – LIMIT VALUES

This annex provides limit values in different legislation for the purpose of comparison. It is to be noted that they are not applicable to the recycled rubber granules.

Table IV.1 Limit values from different legislations

Substance	Limit values from different legislations		
	REACH Annex XVII	**Directive 2009/48/EC (safety of toys; dry brittle powder like or pliable toy material as example)**	**Regulation EC 1881/2006 (contaminants in foodstuffs – one group as example)**
Benz[a]anthracene*	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		smoked meat and smoked meat products 12.0 µg/kg (sum of *-substances)
Chrysene*	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		smoked meat and smoked meat products 12.0 µg/kg (sum of *-substances)
Benz[b]fluoranthene*	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		smoked meat and smoked meat products 12.0 µg/kg (sum of *-substances)
Benz[j]fluoranthene	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		
Benzo[k]fluoranthene	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		

Substance	Limit values from different legislations		
Benzo[a]pyrene*	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		smoked meat and smoked meat products 2.0 µg/kg, 12.0 µg/kg (sum of *-substances)
Benzo[e]pyrene	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		
Dibenz[a,h]anthracene	Entry 50: a) 1 mg/kg (0.0001% by weight of the component) in articles supplied to the general public; b) 0.5 mg/kg (0.00005% by weight of this component) in toys and childcare articles		
di-2-ethylhexylphthalate	Entry 51: 0.1% by weight of the plasticised material in toys and childcare articles.		
di-isobutyphthalate			
dibutylphthalate	Entry 51: 0.1% by weight of the plasticised material in toys and childcare articles.		
benzyl butyl phthalate	Entry 51: 0.1% by weight of the plasticised material in toys and childcare articles.		
Benzene	Entry 5: a) in mixture 0.1 % by weight (applicable to recycled rubber granules); b) 5 mg/kg (0.0005%) of the weight of the toy or part of toy.		
Benzothiazol			

Substance	Limit values from different legislations		
benzothiazole-2-thiol			
Methyl-isobutyl-ketone			
Formaldehyde			
2,6-di-tert-butyl-p-cresol (Butylated hydroxyltoluene)			
Cadmium	Entry 23: in certain plastic material and in jewellery 0.01 % expressed as Cd metal	Migration limit value 1.3 mg/kg	Wheat grains, rice grains 0.2 mg/kg wet weight
Chromium VI	Entry 47: a) in cement and cement containing mixtures 2 mg/kg (0.0002 %); b) in leather articles 3 mg/kg (0.0003 %)	Migration limit value 0.02 mg/kg	
Lead	Entry 63: in jewellery articles and in articles supplied to the general public 0.05 % by weight (expressed as metal)	Migration limit value13.5 mg/kg	Fruit, excluding berries and small fruits 0.1 mg/kg wet weight
Mercury		Migration limit value 7.5 mg/kg	Fishery products 0.1 mg/kg

Substance	Limit values from different legislations		
Nickel	Entry 27: a) migration limit 0.2 µg/cm^2/week (post assemblies); b) migration limit 0.5 µg/cm^2/week		

ANNEX V - OVERVIEW OF THE TYRE MARKET IN EUROPE

This Annex gives an overview of the car, trucks, agricultural and motorcycles tyres' segments of the European tyre market with a special focus on the imports (of new tyres).

According to the European Tyre & Rubber Manufacturers' Association's (ETRMA) statistic report 2015, members account for 89 tyre plants in the EU. A detailed distribution of the plants in the EU, is shown in Figure 2.

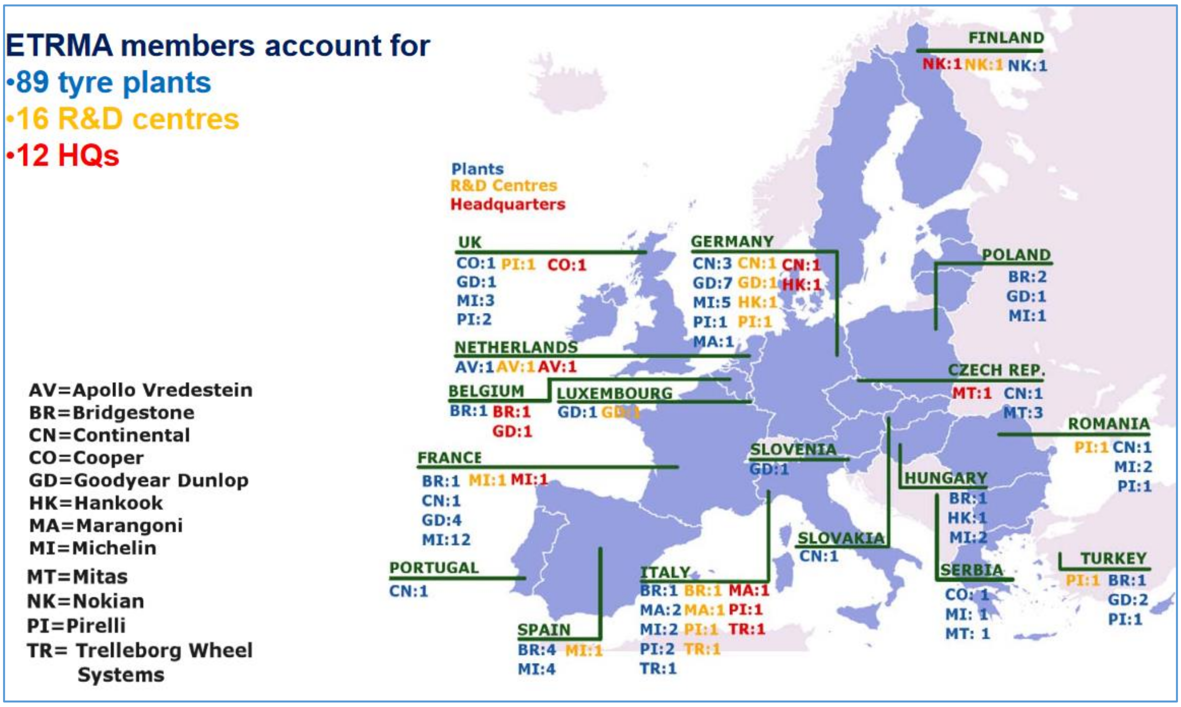

Figure 2: ETRMA's tyre companies' plants (ETRMA, Statistics Report 2015)

In 2014, tyre production in the EU for ETRMA members (ETRMA, 2015) was estimated to account for 20 % of the world's tyre production, i.e 4.8 million tonnes. The total production, including also non-ETRMA members, is currently not known.

In Figure 3, the tyre replacement sales of ETRMA members are reported for the first quarter of 2016 compared to the first quarter of 2015. Replacement sales of car tyres accounted for more than 50 million units for the first quarter of 2016, compared to the other types of tyres (more than 2 million units for truck tyres and more than 3 million units for motorcycles tyres).

Regarding the imports, in April 2016[7], ETRMA confirmed that the pressure to import tyres remained high in 2015, compared to the previous years. Especially:

- With regard to consumer tyres, imports into the EU increased by +6 %
- The overall EU imports of truck and bus tyres increased by +10 %.

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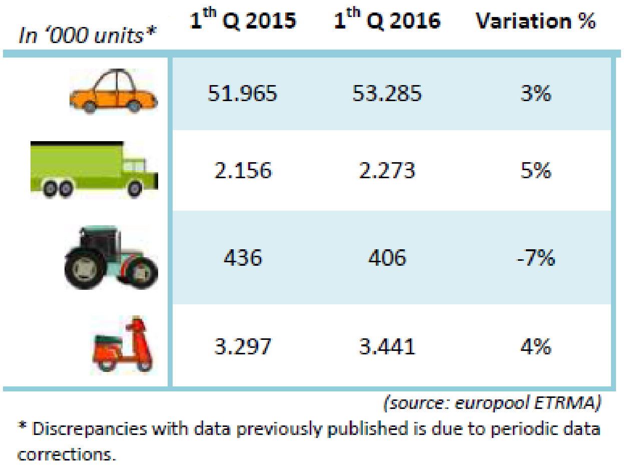
[7] http://www.etrma.org/uploads/Modules/Newsroom/20160414---eu-tyre-market-1q-2016.pdf



*In '000 units**	1th Q 2015	1th Q 2016	Variation %
🚗	51.965	53.285	3%
🚚	2.156	2.273	5%
🚜	436	406	-7%
🛵	3.297	3.441	4%

(source: europool ETRMA)

* Discrepancies with data previously published is due to periodic data corrections.

Figure 3: Tyre replacements sales of ETRMA Members for the first quarter of 2016 versus first quarter of 2015 (car, trucks, agricultural and motorcycles tyres' segments)

In the last decade, imports from China are dominating the tyre imports, especially in the passenger and truck tyres segments. Detailed data released by ETRMA for the 2013 (Statistics Report 2014) showed that imports from China for the truck segment accounted for 54 % of the overall imports, while for passenger and light vehicles tyres accounted for the 45 %.

In relation to the motorcycles tyres (Harmonised System code: 4011.4000 to 4011.4020 + 4011.4080 + 4011.4091 + 4011.4099) the main commercial partner in 2013 was represented by ASEAN (Association of Southeast Asian Nations). Imports from ASEAN accounted for 29 % of the overall market (ETRMA Statistics Report 2014).

Regarding the agricultural tyres, in 2013 the imports from India and China accounted for 31 % and 29 % respectively of the overall imports (source ETRMA Statistics Report 2014).

Figure Figure 4, Figure 5, Figure 6, Figure 7 show imports in different segments of the tyre industry: car, truck, agricultural and motorcycle tyres. In the same figures, the exports and main export destinations are also reported. Canada, the United States, and Mexico are indicated in the tables as NAFTA (North American Free Trade Agreement) and represent one of the major markets for EU exports, especially for passenger and light vehicle tyres.

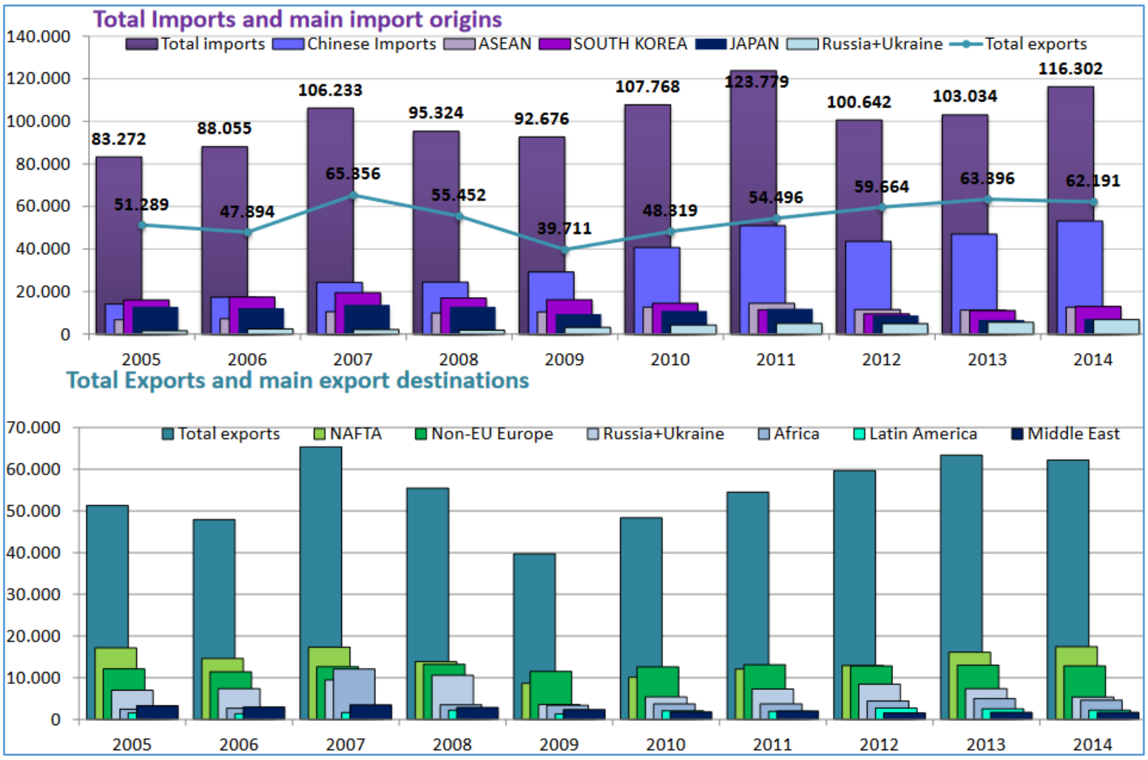


Figure 4: Passenger and light vehicle tyres, trade in '000 units: total imports/exports and main import/export origins/destinations of (Eurostat, as reported in the ETRMA Statistics Report 2015)

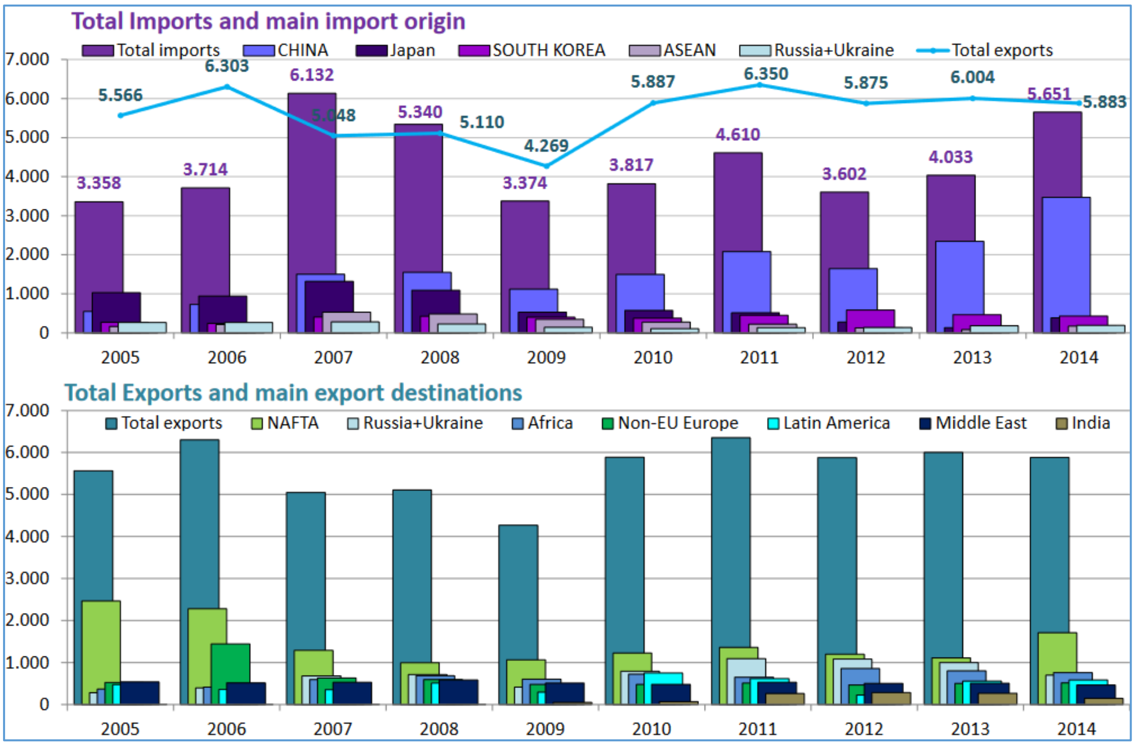


Figure 5: Truck tyres, trade in '000 units: total imports/exports and main import/export origins/destinations (Eurostat, as reported in the ETRMA Statistics Report 2015)

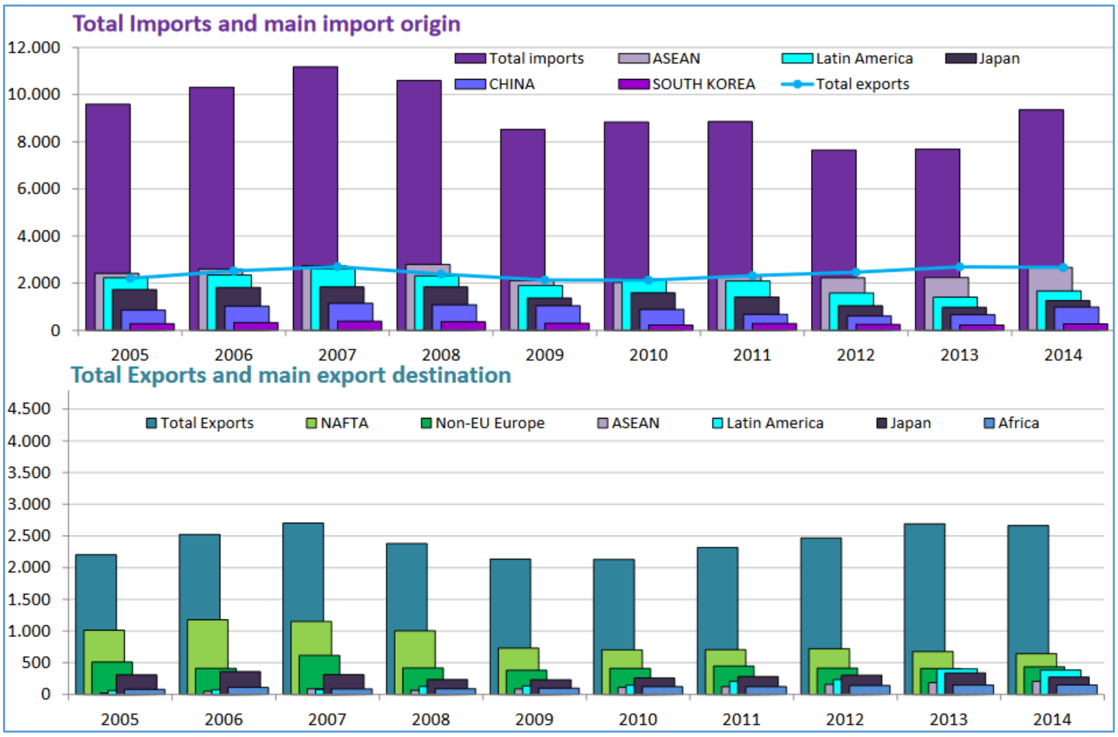


Figure 6: Moto/scooter tyres, trade in '000 units: total imports/exports and main import/export origins/destinations (Eurostat, as reported in the ETRMA Statistics Report 2015) *HS code: 4011.4000 to 4011.4020 +4011.4080 +4011.4091 + 4011.4099*

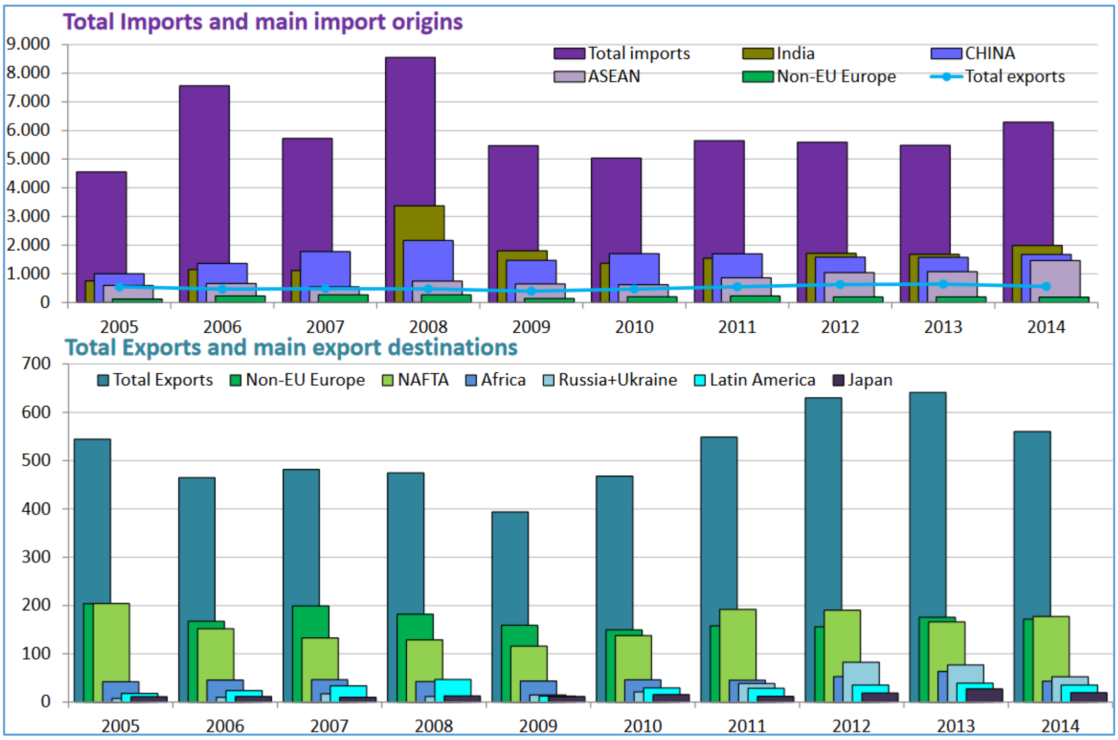


Figure 7: Agricultural tyres, trade in '000 units: total imports/exports and main import/export origins/destinations (Eurostat, as reported in the ETRMA Statistics Report 2015) *HS code: 4011.6100 +4011.9200*

Possible differences in tyre composition between tyres produced in the EU versus tyres produced outside the EU

The main possible differences in the composition of tyres produced in the EU versus tyres produced outside the EU are related to:

- Type of extender oils used; and
- Type of reinforcement used[8].

Oils used in tyre production may belong to the class of substances known as TDAE (Treated Distillate Aromatic Extracts) or to DAE (Distillate Aromatic Extracts). Aromatic oils belonging to the DAE class of substances, have been replaced on the EU market by oils belonging to the TDAE class, due the concerns related to the content of polycyclic aromatic hydrocarbons (PAHs) in DAE.

Entry 50 of Annex XVII to REACH[9] prohibits the production or import into the EU of tyres produced with non-complying oils since 1 January 2010. As far as imports are concerned, it may be complicated to check what types of oils have been used in the production of tyres, using the ISO 21461:2006 method[10]. The current level of compliance with entry 50 of Annex XVII to REACH for all different types of imported tyres[11], from different worldwide countries, is not available.

The use of silica reinforcement instead of carbon black for passenger car tyre treads (introduced in Europe in the early 90s) is another possible difference in the composition of tyres. This technology provides for a 30-50 % lower rolling resistance of the tyres, corresponding to 5-10 % fuel savings for the cars. Since the introduction of the tyre labelling regulation by the EU, which provides a means to the customer to compare tyres on their rolling resistance, most non-European producers have adopted this technology (at least for the EU market). The silica-reinforced tyres contain about 1.5 times more oil than the carbon black-reinforced ones.[12]

ELT market and management schemes in Europe

The information presented in this chapter has been mainly (but not only) collected from two sources: ETRMA (European Tyre Rubber & Manufacturers' Association) and ETRA (European Tyre Recycling Association), the body representing the independent tyre recycling industry in Europe.

Extended producer responsibility (EPR) often referred to as producer responsibility, is in place in many European countries as can be seen from Figure 8. In the EU, landfilling end-of-life tyres (ELTs) have been prohibited since 2006 following the European Directive 1999/31/EC. Under the EPR, ELTs have to be managed by their manufacturers and importers: they must collect and manage, every year, an amount of ELTs that is at least equivalent to the amount of tyres they have fed into the domestic spare parts'

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[8] Based on information exchanged with Jacques W.M. Noordermeer, em. Professor of Elastomer Technology and Engineering (University of Twente).

[9] See: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32005L0069;
REACH Regulation 1907/2006: entry 50 of Annex XVII contains the list of PAHs tha are subject to restriction in oils for tyre production. In 2010, entry 50 entered into force.

[10] 1H-NMR bay-proton analysis is a very complex technique (both expensive and requiring high skills) and furthermore a destructive test (as confirmed by Prof. Jacques W.M. Noordermeer).

[11] including imported used tyres

[12] Based on information exchanged with Jacques W.M. Noordermeer, em. Professor of Elastomer Technology and Engineering (University of Twente).

market in the previous year or in the same year. They may fulfil the required obligations by setting up 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.

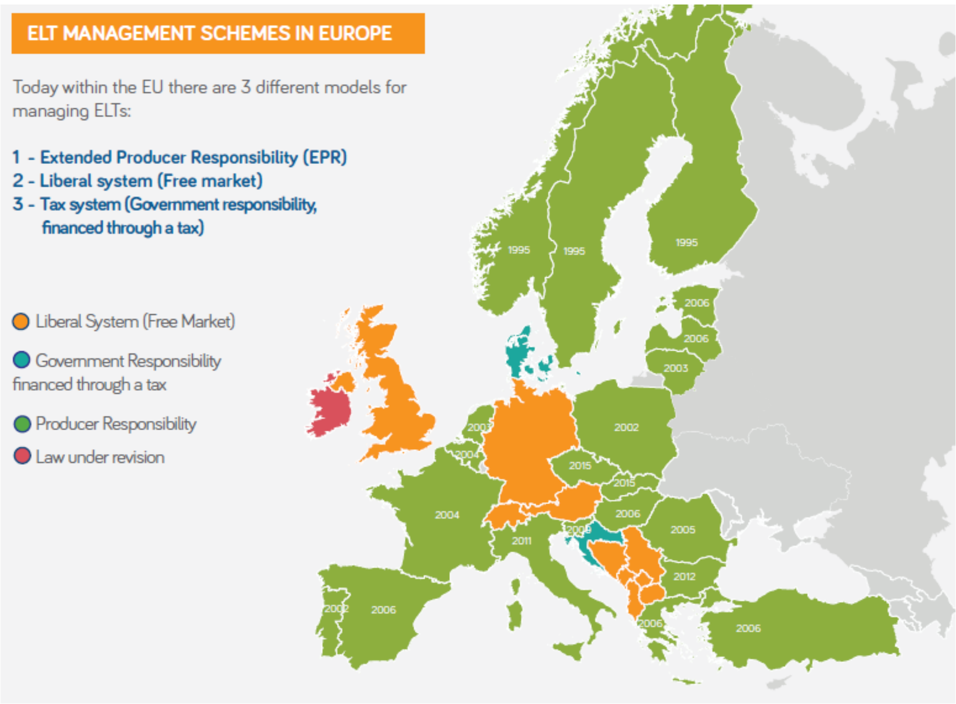


Figure 8: Country specific implementation of ELT management models (End of Life Tyre Report 2015, ETRMA). Where implemented, it is indicated the year of publication of the EPR law.

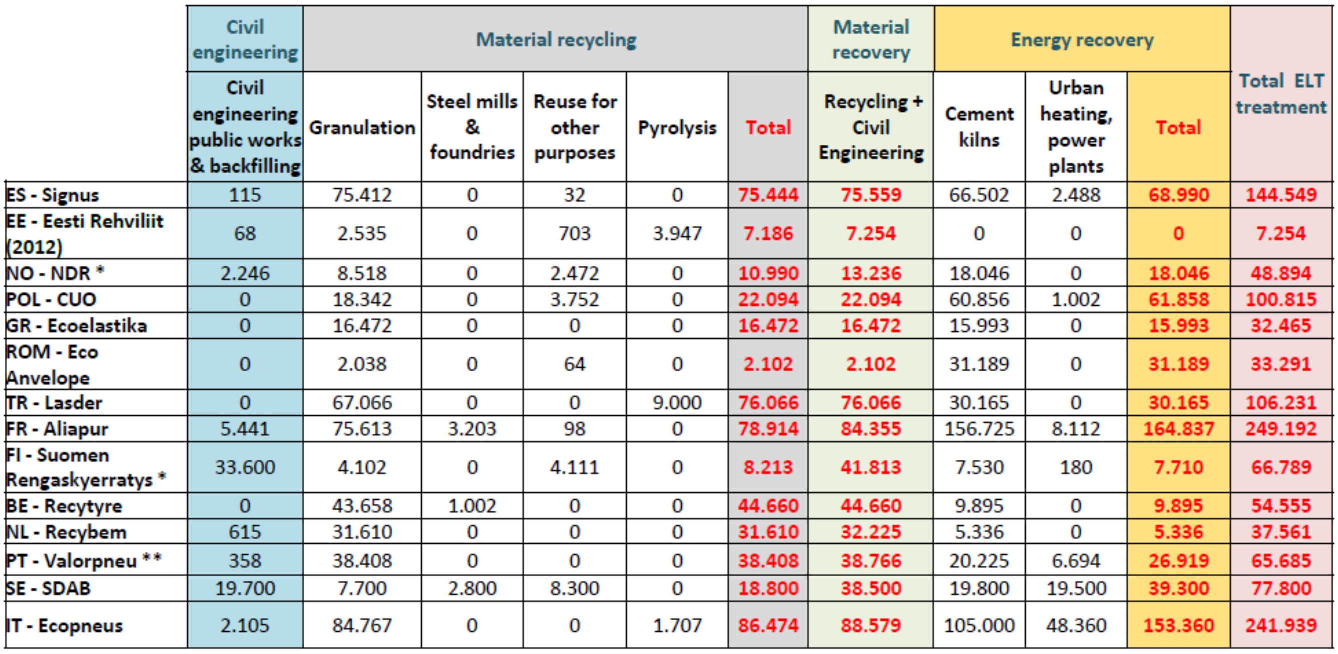
As described in the End of Life Tyre Report 2015 (ETRMA), where implemented, the EPR is followed through in various ways from a single ELT management company dealing with ELT collection and treatment in a country (such as in Portugal, the Netherlands or Sweden), through multiple ELT management companies or a consortium (such as in Italy, France or Spain) or through individual producer responsibility (in Hungary).

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.

EPR is today a widespread system in Europe with 21 countries (most of the EU-28 countries + Norway and Turkey) having adopted a legal framework assigning the responsibility to the producers (tyre manufacturers and importers) to organise the management of ELTs.

Free market systems operate in Austria, Switzerland, Germany and the UK. The UK operates a ’managed free market�much system, as ELT collectors and treatment operators have to report to national authorities. Another model, government responsibility through a tax system is applied in Denmark and Croatia. Under the tax system, each country is responsible for the management of ELTs. It is financed by a tax levied on tyre producers and subsequently passed on to the consumer.

In Figure 9, data related to the ELT Management companies in the ETRMA network for 2013 are reported. Thefigure provides information about ELT recycled quantities limited to the countries with extended producer responsibility in place and with an ELT management company operating within the ETRMA network. These values do not represent the total ELT volumes in the 14 countries where the ELT companies are located. The ELTs collected and treated in 2013 by the ELT management companies within the ETRMA network represented around 71 % of the total arisings of these 14 countries (as clarified by a public statement made by ETRMA in April 2015)[13].



	Civil engineering	Material recycling					Material recovery	Energy recovery			Total ELT treatment
	Civil engineering public works & backfilling	Granulation	Steel mills & foundries	Reuse for other purposes	Pyrolysis	Total	Recycling + Civil Engineering	Cement kilns	Urban heating, power plants	Total	
ES - Signus	115	75.412	0	32	0	75.444	75.559	66.502	2.488	68.990	144.549
EE - Eesti Rehviliit (2012)	68	2.535	0	703	3.947	7.186	7.254	0	0	0	7.254
NO - NDR *	2.246	8.518	0	2.472	0	10.990	13.236	18.046	0	18.046	48.894
POL - CUO	0	18.342	0	3.752	0	22.094	22.094	60.856	1.002	61.858	100.815
GR - Ecoelastika	0	16.472	0	0	0	16.472	16.472	15.993	0	15.993	32.465
ROM - Eco Anvelope	0	2.038	0	64	0	2.102	2.102	31.189	0	31.189	33.291
TR - Lasder	0	67.066	0	0	9.000	76.066	76.066	30.165	0	30.165	106.231
FR - Aliapur	5.441	75.613	3.203	98	0	78.914	84.355	156.725	8.112	164.837	249.192
FI - Suomen Rengaskyerratys *	33.600	4.102	0	4.111	0	8.213	41.813	7.530	180	7.710	66.789
BE - Recytyre	0	43.658	1.002	0	0	44.660	44.660	9.895	0	9.895	54.555
NL - Recybem	615	31.610	0	0	0	31.610	32.225	5.336	0	5.336	37.561
PT - Valorpneu **	358	38.408	0	0	0	38.408	38.766	20.225	6.694	26.919	65.685
SE - SDAB	19.700	7.700	2.800	8.300	0	18.800	38.500	19.800	19.500	39.300	77.800
IT - Ecopneus	2.105	84.767	0	0	1.707	86.474	88.579	105.000	48.360	153.360	241.939

*In Norway & Finland, the total ELT treated also includes ELTs in stocks waiting for treatment (17.612 tonnes for NO and 17.266 tonnes for FI).
**The total ELT treated in Poland includes ELTs treated during the same year and the accounting of ELTs treated from previous years in excess of the ELT management company obligation (16.863 tonnes).

Figure 9: ELT treatment (tonnes) from 14 ELT Management companies in the ETRMA network, in 2013 (ETRMA Statistics Report, 2014).

However, data provided in the previous figure are not comprehensive regarding historical stockpiles. Norway and Finland are reported to have both dealt with stockpiles (accounting for 17 612 and 17 266 tonnes respectively) in 2013.

In Figure 10[14] the tyres recovery for 31 countries (including EU 28) is reported, based on recently reviewed data collected by ETRMA.[15] The data comes from ELT management

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[13] http://recyclingportal.eu/wp-content/uploads/2015/04/ETRMA_statistics.pdf

[14] Source: End of Life Tyre Report 2015.

[15] Regarding the two main countries operating under the free market scheme (the UK and Germany), data for the UK are based on the audited arisings recorded by the UK UTWG (Used Tyres Working Group) while German arisings and treatments are compiled by GAVS (Gesellschaft für Altgummi Verwertungs Systeme mbH), a WdK study company.

companies (not only within the ETRMA network) as well as when available from national statistics reported by public authorities.

Recycling figures from Figure 10 include ELT sent to granulation (1 119 000 tonnes)[16], ELT used in steel mills and foundries and other uses. As clarified in the End of Life Tyre Report 2015, national used tyre (UT) arisings comprise: UTs arising from the sales of new tyres on the replacement market, UTs arising from retreading activity, and UTs arising from imported second-hand tyres.

Additional information on the imports of used pneumatic tyres under TARIC 4012200090 is provided in the confidential Annex IX. TARIC 4012200090[17] includes all types of imported used pneumatic tyres, other than those used on civil aircraft (i.e. TARIC 4012200010). Constraints in the dissemination of statistics on imports under TARIC codes is laid down by the EU legislation[18].

In 2013, the European UT arisings[19] were estimated at about 3.6 million tonnes, of which after sorting, an estimated 2.8 million tonnes of ELTs entered the recovery market.

Considering the values in Figure 10, France, Germany, Italy, Spain and the UK accounted for 63 % of the ELT totally recycled in the EU-28 in 2013.

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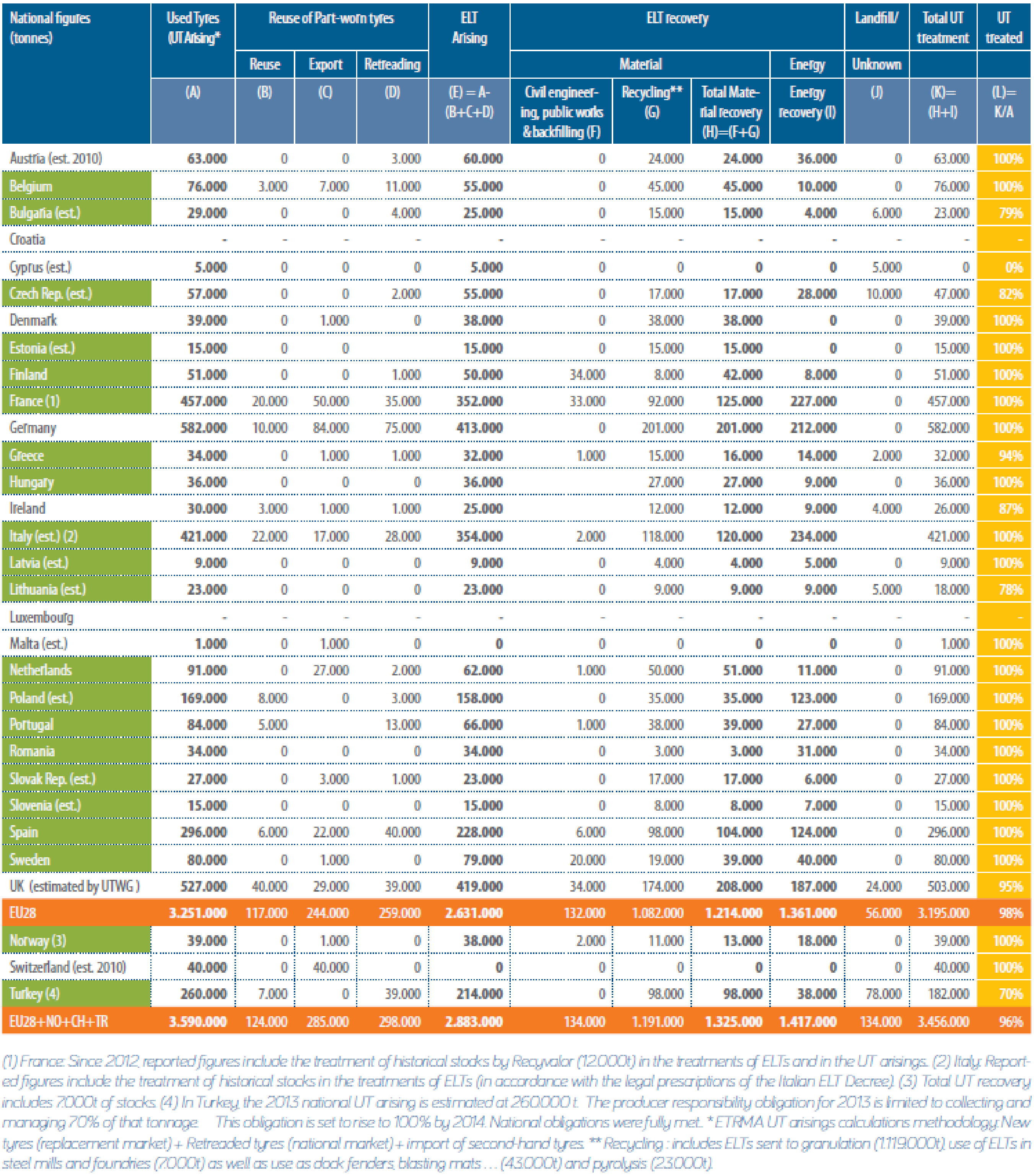
[16] Data refers to EU-28 plus Norway, Switzerland and Turkey. See footnote of Figure 10.Figure 8.

[17] Under Commission Implementing Regulation (EU) 2016/1245, setting out a preliminary correlation table between customs and waste codes, the import of used tyres (TARIC 4012200090) alerts customs officials that this material may be waste.

[18] Statistics on trade in goods with non-EU countries are collected and compiled on the basis of RegulationRegulation (EC) No 471/2009 of the European Parliament and of the Council. According to Article 10 "Dissemination of external trade statistics", paragraph 2: *"Without prejudice to data dissemination at national level, detailed statistics by the TARIC subheading and preferences shall not be disseminated by the Commission (Eurostat) if their disclosure would undermine the protection of the public interest as regards the commercial and agricultural policies of the Community.*

[19] EU (28) plus Norway, Switzerland and Turkey.



National figures (tonnes)	Used Tyres (UT Arising*	Reuse of Part-worn tyres			ELT Arising	ELT recovery				Landfill/	Total UT treatment	UT treated
		Reuse	Export	Retreading		Material			Energy	Unknown		
	(A)	(B)	(C)	(D)	(E) = A-(B+C+D)	Civil engineering, public works & backfilling (F)	Recycling** (G)	Total Material recovery (H)=(F+G)	Energy recovery (I)	(J)	(K)=(H+I)	(L)=K/A
Austria (est. 2010)	63.000	0	0	3.000	60.000	0	24.000	24.000	36.000	0	63.000	100%
Belgium	76.000	3.000	7.000	11.000	55.000	0	45.000	45.000	10.000	0	76.000	100%
Bulgaria (est.)	29.000	0	0	4.000	25.000	0	15.000	15.000	4.000	6.000	23.000	79%
Croatia	-	-	-	-	-	-	-	-	-	-	-	-
Cyprus (est.)	5.000	0	0	0	5.000	0	0	0	0	5.000	0	0%
Czech Rep. (est.)	57.000	0	0	2.000	55.000	0	17.000	17.000	28.000	10.000	47.000	82%
Denmark	39.000	0	1.000	0	38.000	0	38.000	38.000	0	0	39.000	100%
Estonia (est.)	15.000	0	0		15.000	0	15.000	15.000	0	0	15.000	100%
Finland	51.000	0	0	1.000	50.000	34.000	8.000	42.000	8.000	0	51.000	100%
France (1)	457.000	20.000	50.000	35.000	352.000	33.000	92.000	125.000	227.000	0	457.000	100%
Germany	582.000	10.000	84.000	75.000	413.000	0	201.000	201.000	212.000	0	582.000	100%
Greece	34.000	0	1.000	1.000	32.000	1.000	15.000	16.000	14.000	2.000	32.000	94%
Hungary	36.000	0	0	0	36.000		27.000	27.000	9.000	0	36.000	100%
Ireland	30.000	3.000	1.000	1.000	25.000		12.000	12.000	9.000	4.000	26.000	87%
Italy (est.) (2)	421.000	22.000	17.000	28.000	354.000	2.000	118.000	120.000	234.000		421.000	100%
Latvia (est.)	9.000	0	0	0	9.000	0	4.000	4.000	5.000	0	9.000	100%
Lithuania (est.)	23.000	0	0	0	23.000	0	9.000	9.000	9.000	5.000	18.000	78%
Luxembourg	-	-	-	-	-	-	-	-	-	-	-	-
Malta (est.)	1.000	0	1.000	0	0	0	0	0	0	0	1.000	100%
Netherlands	91.000	0	27.000	2.000	62.000	1.000	50.000	51.000	11.000	0	91.000	100%
Poland (est.)	169.000	8.000	0	3.000	158.000	0	35.000	35.000	123.000	0	169.000	100%
Portugal	84.000	5.000		13.000	66.000	1.000	38.000	39.000	27.000	0	84.000	100%
Romania	34.000	0	0	0	34.000	0	3.000	3.000	31.000	0	34.000	100%
Slovak Rep. (est.)	27.000	0	3.000	1.000	23.000	0	17.000	17.000	6.000	0	27.000	100%
Slovenia (est.)	15.000	0	0	0	15.000	0	8.000	8.000	7.000	0	15.000	100%
Spain	296.000	6.000	22.000	40.000	228.000	6.000	98.000	104.000	124.000	0	296.000	100%
Sweden	80.000	0	1.000	0	79.000	20.000	19.000	39.000	40.000	0	80.000	100%
UK (estimated by UTWG)	527.000	40.000	29.000	39.000	419.000	34.000	174.000	208.000	187.000	24.000	503.000	95%
EU28	3.251.000	117.000	244.000	259.000	2.631.000	132.000	1.082.000	1.214.000	1.361.000	56.000	3.195.000	98%
Norway (3)	39.000	0	1.000	0	38.000	2.000	11.000	13.000	18.000	0	39.000	100%
Switzerland (est. 2010)	40.000	0	40.000	0	0	0	0	0	0	0	40.000	100%
Turkey (4)	260.000	7.000	0	39.000	214.000	0	98.000	98.000	38.000	78.000	182.000	70%
EU28+NO+CH+TR	3.590.000	124.000	285.000	298.000	2.883.000	134.000	1.191.000	1.325.000	1.417.000	134.000	3.456.000	96%

*(1) France: Since 2012, reported figures include the treatment of historical stocks by Recyvalor (12.000t) in the treatments of ELTs and in the UT arisings. (2) Italy: Reported figures include the treatment of historical stocks in the treatments of ELTs (in accordance with the legal prescriptions of the Italian ELT Decree). (3) Total UT recovery includes 7.000t of stocks. (4) In Turkey, the 2013 national UT arising is estimated at 260.000 t. The producer responsibility obligation for 2013 is limited to collecting and managing 70% of that tonnage. This obligation is set to rise to 100% by 2014. National obligations were fully met. * ETRMA UT arisings calculations methodology: New tyres (replacement market) + Retreaded tyres (national market) + import of second-hand tyres. ** Recycling : includes ELTs sent to granulation (1.119.000t), use of ELTs in steel mills and foundries (7.000t) as well as use as dock fenders, blasting mats ... (43.000t) and pyrolysis (23.000t).*

Figure 10:Tyres recovery in Europe, 2013 (:End of Life Tyre Report 2015,ETRMA) for EU 28 plus Norway, Switzerland and Turkey.

According to the estimates made by ETRA[20], the total ELT arisings across Europe for 2014, may be as high as 2.99 million tonnes, a value very similar (magnitude) to the most recent one provided by ETRMA for 2013 (Figure 10). However, it is unclear whether the latter value refers to EU 28 or to a more extended EU and whether the methodologies and datasets used by ETRMA and ETRA to derive the ELT arisings are comparable.

According to ETRA the ELT figures have a high importance since these are the numbers upon which tyre recycling strategies and programs are established throughout Europe and investors base business plans. ETRA estimates that ELT arisings (EU/Norway) for 2015 were 3.2 million tonnes with an increasing quantity from manufacturers outside of the EU/Norway (which currently accounts for over 30 %).

According to a press release made in June 2015[21], ETRA said in relation to the exports of used tyres that reliance on it (to avoid stockpiling in Europe) is unsustainable since markets including China, India and Pakistan will import fewer tyres as they become self-sufficient. The main use of exported ELT is as tyre-derived fuel (TDF).

Stockpiles in the European market are a critical but well known problem. For example, in France since 2004 it was necessary to deal with abandoned ELT stockpiles of approximately 200 000 tonnes (World Business Council for Sustainable Development – WBCSD)[22].

To progress on its treatment, Aliapur (the French ELT management company within the ETRMA network) financed an abatement program to deal with 30 000 tonnes in 2005. A subsequent agreement was signed in February 2008 between the French manufacturers, distributors and the government to treat all remaining stockpiles over the next 10 years[23].

It is currently unclear what the status of the stockpiles in all the European countries is. If old stockpiles enter the recycling streams, it is possible that tyres produced before 2010 (when the restriction on PAHs in extender oils used in the production of tyres entered into force) may be present.

In a recent press release (June 2016), ETRA said that 39 % of recycled tyre rubber is being directed to sports surfaces (type of surfaces not specified) and that Europe has an oversupply of tyre derived stock and relies on exporting to India and other markets to prevent stockpiling[24].

Another issue to consider in the analysis is the extra quantity of ELT deriving from irregular sales. For example, as reported in February 2016 by Ecopneus[25] (responsible for the ELT management within the ETRMA network in Italy), a collection of ELTs more than 15 000 tonnes above the legal target[26] was recorded in 2015.). This means that

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[20] Presented at the 22nd ETRA Conference in Brussels (March 25-27, 2015)

[21] https://www.mrw.co.uk/home/tyre-recyclers-say-export-dependency-is-unsustainable/8684963.article

[22] End-of-Life Tyres: A framework for effective management systems- Appendix, WBCSD, Tyre Industry Project http://www.rubberassociation.ca/files/ELT%20Appendices,%202010.pdf (End-of-Life Tyres : A framework for effective management systems- Appendix, WBCSD, Tyre Industry Project)

[23] End-of-Life Tyres : A framework for effective management systems- Appendix, WBCSD, Tyre Industry Project

[24] http://www.recyclingtodayglobal.com/article/etra-takes-stance-on-crumb-rubber-infill/

[25] http://www.ecopneus.it/en/news/elts-beyond-the-target-it-is-not-possible-to-guarantee-collection-beyond-the-legal-objectives.html

[26] It is not clearly specified if this target refers to the quantity ETRMA is responsible for or to the overall Italian market.

there was no alignment between the quantity of tyres sold and the quantity of ELTs emerging in the country.

Obviously, the ELT management companies/consortiums are not able to collect quantities that exceed their financial resources, which are closely tied to the regular sale of tyres and to the relative contributions received. As a consequence of the irregular sales, Ecopneus was forced to confirm in February 2016 that it was not possible to satisfy all the collection requests received.

Sales which are not registered and not within the custom statistics have also been reported by SWEGO Environment AB/Walberg P. *et al.* (2016). Irregular, low price tyres are estimated to make up around 12-15 % of Swedish tyre markets[27]. This could happen through direct import by the car repair shops or through the import of vehicles. The composition of these tyres is not known.

Information on irregular sales and/or irregular imports are not easily available at European level.

As a consequence of the irregular sales, it is not possible to have certainties on the characteristics (origin, composition, etc.) of the extra quantities of tyres circulating in the overall European ELT market. However, it should also be noted that the restriction on PAHs in extender oils is applied to all tyres placed on the market in the EU.

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[27] SWEGO Environment AB/Walberg P. et al. (2016)

ANNEX VI - Exposure assesment studies - literature review

IndusTox and Kempeneers Milieu en Management BV (2009) (report in Dutch) investigated occupational exposure to inhalable and fine dust, volatile organic compounds (benzene, toluene, ethylbenzene, styrene and xylene) and PAHs by using biomonitoring of 1-hydroxypyrene. Sampling was done during different maintenance tasks (infilling, brushing/filling, emptying big bags) on the sport field with tyre crumb infill. Nine workers were monitored in three different locations in summer time (on 5th, 13th, and 14th July 2009). Outside temperature varied from 22 °C to 25 °C during the measurements.

The air measurements were done from the breathing zone of the workers. Inhalable dust was sampled with IOM samplers and sampling lasted from five to seven hours. Fine dust concentrations in the air were monitored with DustTrack which measured particles <10 µm. Volatile organic compounds were sampled with passive diffusion monitors (3M, type 3 500) from the breathing zone of the workers.

Inhalable dust concentrations (sampled with an IOM sampler) varied 0.1 – 3.1 mg/m^3 (8-hour TWA - time weight average), the mean concentration was 1.1 mg/m^3. Fine dust concentrations were between 0.01-2.5 mg/m^3 during infilling. The 1-OHP concentrations were increased after the work shift compared to the concentrations before the work shift, in seven cases out of nine. The mean concentration was 0.18 µmol/mol creat before the work shift and 0.24 µmol/mol creat after the work shift.

Additional measurements were done on 15th July and on 9th September 2009. The outside temperature was 20-24 °C. Tasks that were done during measurements were brushing, sucking/sieving and cleaning machines. Inhalable dust concentrations varied between 0.1 to 0.9 mg/m^3 (TWA 8 h), the mean value was 0.3 mg/m^3. The fine dust concentrations were 0.01-0.67 mg/m^3. 1-OHP was measured before and after the work shift from the urine of four workers. Three of them were smokers. In three cases the concentration of 1-OHP increased during the day. The mean concentration was 0.44 µmol/mol creat before the work shift and 0.53 µmol/mol creat after the work shift. The values for the non-smoker were 0.08 and 0.14 µmol/mol creat, accordingly.

The authors concluded that the inhalable dust concentrations after some risk management measures (second measurements) were acceptable; the applied limit value for inhalable dust was 3 mg/m^3. Four workers out of 13 had higher 1-OHP concentrations than the reference value for non-occupationally exposed workers (both non-smokers and smokers) that the American Conference of Industrial Governmental Hygienists (ACGIH) has recommended for 1-OHP, which is 1 µg/l (around 0.49 µmol/mol creat) urine (ACGIH 2005). All these four workers were smokers. It was concluded in the study that smoking was the main contributor to the 1-OHP concentration. The concentrations of volatile organic compounds were under the detection limits.

The study by **Hofstra, U., 2007** was based on a literature review supplemented with experimental research to fill gaps in the knowledge and to verify already available data. As part of the literature review, 17 research reports and 13 supplementary sources were investigated, and the Dutch and European legislation and guidelines were reviewed.

For the experimental investigation, samples were taken on three production plants of rubber infill and samples were taken on 14 synthetic turf pitches according to the FIFA protocol. The investigation was focused on the uptake of PAHs due to skin contact with rubber infill. A laboratory model migration test was applied to estimate the migration of PAHs from rubber infill into both massage oil and vaseline. Additionally, a field study was conducted among football players to determine the presence of PAH metabolite, 1-hydroxypyrene, in the urine before and after they had intensive skin contact with rubber crumb on a synthetic field pitch (van Rooij and Jongeneelen 2010). The results from both the laboratory test and the field study were compared with internationally accepted health limit values for PAHs.

Based on the literature review, the laboratory test and the field study, the author concluded that there is no significant health risk for football players due to the presence of rubber infill from used car tyres on synthetic turf pitches.

Van Rooij and Jongeneelen (2010) published the biomonitoring part of the same study that Hofstra 2007 reported above. 1-hydroxypyrene is a useful and widely used quantitative biological indicator of exposure to PAHs and it was used to estimate the exposure to PAHs among football players on synthetic sports field with tyre crumb infill.

Seven voluntary football players were trained and had a match with a total duration of 2.5 hours on the synthetic pitch. Urine samples were taken during a three-day period and analysed for 1-hydroxypyrene. The rubber crumb was analysed and the total PAH concentration was 24 mg/kg in the material (Hofstra 2007). At the time of the study, the EU restriction on PAHs in extender oil was not in place, as the companies had to comply with the restriction as of 2010.

Results show that the baseline of 1-hydroxypyrene measured in four of seven volunteers was sufficient stable and that one volunteer out of four showed a statistically significant increase in hydroxypyrene in urine. However, concomitant dietary uptake of PAH by this volunteer was observed. The authors concluded that uptake of PAH of football players on synthetic grass fields with rubber crumb infill is very limited and within the range of uptake of PAH from environmental sources and/or diet.

Rubber granulates were collected from 13 Italian fields and analysed for 25 metals and nine PAHs **(Menichini E. et al., 2011)**. One further granulate was analysed for non-dioxin-like (NDL)-PCBs, PCDDs, PCDFs and 13 PAHs. Air samples were collected on filters at two of the 13 studied fields, using a high volume static sampler close to the athletes and personal samplers worn by the athletes (at 1 m high, representing child exposure and worst case for adults), and at background locations outside the fields respectively. In the absence of specific quality standards, the study evaluated the measured contents with respect to the Italian standards for soils to be reclaimed as green areas. Zn concentrations (1 to 19 g/kg) and BaP concentrations (0.02 to 11 mg/kg) in granulates largely exceeded the pertinent standards, up to two orders of magnitude. No association between the origin of the recycled rubber and the contents of PAHs and metals was observed. The sums of NDL-PCBs and WHO-TE PCDDs+PCDFs were, respectively, 0.18 and 0.67×10^{-5} mg/kg. The increased BaP concentrations in air, due to the use of the field, varied approximately from <0.01 to 0.4 ng/m³, the latter referring to worst-case conditions as to the release of particle-bound PAHs. The outside temperature ranged between 22-24 °C during the first field measurements and 34-38 °C during the second field measurements. Based on the 0.4 ng/m³ concentration, an excess lifetime cancer risk of 1×10^{-6} was calculated for an intense 30-year activity. The PAH concentrations in the field during the use were 40 % to 82 % of the simultaneous PAH concentrations at the urban site. Both sites were in Rome.

Dye *et al*. (NILU (Norway), 2006) reported about the measurements of air quality for three indoor synthetic turf pitches. The measurements were taken in a hall with recently laid rubber granulate (SBR rubber or styrene butadiene rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall which used granulate made from thermoplastic elastomer (TPE).

The parameters covered, were the concentration and chemical composition of airborne dust and the concentration in indoor air of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs).

Quantity of airborne dust: elevated levels of the PM2.5 fraction were seen in two halls, which were close to the national recommended norm of 20 µg/m^3. In one hall the concentrations were similar to those in a typical indoor environment. Without full ventilation one hall will probably have high values of airborne dust.

Composition of airborne dust: The airborne dust in two halls contains large quantities of rubber from the granulate. The airborne dust contains PAHs, phthalates, semi-volatile organic compounds, benzothiazoles and aromatic amines. It also contains organic and inorganic pollutants, which were not specified in the study. The highest BaP concentration was 1.2 ng/m^3 and the highest total PAH concentration including methylated PAH-compounds was 370 ng/m^3. The main components were naphthalene and methylated naphthalenes (around 156 ng/m^3) and acenaphthylene.

Concentrations of benzothiazoles were higher in the halls that had SBR infilling compared to the hall with TPE infilling, 4.5 – 32 µg/m^3 and 3-4 µg/m^3 accordingly. Total phthalates were slightly higher in the hall with SBR than with TPE, being 131-134 ng/m^3 and 117 ng/m^3 accordingly. Benzene levels were the same in all halls. Possible problems related to latex exposure through the skin and air passages should be assessed by a specialist.

The concentration of volatile organic compounds (VOCs) reached very high levels (716 µg/m^3) in one hall that had no ventilation. Even with ventilation, the concentrations were high (150-255 µg/m^3). Also, in another hall, concentrations were high and level rises slightly over the evening (around 290 µg/m^3). The component spectrum has a clear signature from the rubber granulate. The national recommended norm for TVOC in indoor climates is not met in these two halls. TVOC concentrations were lower in the hall with TPE filling than with rubber filling.

Other factors, such as swallowing of granulate were discussed only briefly in the report. Many users have verbally stated that from time-to-time they can swallow rubber granulate accidentally. 10 granules weigh 0.007 – 0.015 g. In general, people who swallow granules will be exposed in the range of 0.1-1000 ng for each chemical depending on the chemical and granulate type. The report also states that it is not uncommon to observe football players sitting on the pitch with their hands in contact with granulate. Skin contact with the rubber granulate is possible.

Castellano *et al*. 2008 assessed exposure of synthetic turf pitch users (coaches, maintenance personnel) through the environmental and biomonitoring of toxic and carcinogenic substances found in infill materials. Benzene, toluene, xylene, PAHs and heavy metals (lead, cadmium, chromium, tin and zinc) were particularly studied. Biological monitoring was performed for PAHs and benzene by using the urinary metabolite 1-hydroxypyrene (1-OHP) in the first case, and the urinary trans, trans-muconic acid (t,t-MA) in the second case.

Personal sampling times ranged 2 – 2.5 hours and there were six coaches who took part in the study. Stationary sampling lasted 3 – 4.5 hours. NIOSH standard methods were applied for the sampling and analysis of BTX, PAHs and the metals. The maximum measured concentration was 2 µg/m^3 for benzene, 5 µg/m^3 for toluene, 1 µg/m^3 for ethyl benzene and 7 µg/m^3 for a sum of the xylenes. All the measured metal concentrations were below the detection limit. PAH concentrations varied from <0.1 to 131 ng/m^3.

Naphthalene was the main compound in many cases. Phenanthere, fluoranthene and pyrene were also measured from the breathing zone of the coaches. Air concentrations for BaP and for five ring PAHs, were below the detection limit of 0.1 ng/m^3. Urinary metabolites were analysed at the end of the day. The maximum concentration was 31 µg/g creat for t,t-MA and 0.42 µmol/mol creat for 1-OHP. There is an ACGIH reference value for urinary 1-OHP for non- occupationally exposed people, which is 0.49 µmol/mol creat (include non-smokers and smokers).

The exposure to toxic and carcinogenic compounds was low when the concentrations were compared to the current national OELs or the TLVs of ACGIH. The values of the t,t-MA that is a metabolite of benzene, were low when considering the limit value recommended by the ACGIH (500 µg/g creat). The average value of t,t-MA for non-smokers was 47 µg/g creat in the same city. The analysed 1-OHP values were lower than the no biological effect value of 1.4 µmol/mol creat indicated by the literature (Jongeneelen 2001). The measured values were also below the reference value for smokers and slightly higher than the reference value for non-smokers indicated in the same reference (Jongeneelen 2001).

Studies by Simcox *et al*. 2011 and Ginsberg *et al*. 2011 b

The primary purpose of the study by **Simcox *et al*. 2011** was to characterise the concentrations of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), rubber-related chemicals such as benzothiazole (BZT) and nitrosamine, and particulate matter (PM10) in air at synthetic turf crumb rubber fields.

Four outdoor fields, one indoor field and an outdoor natural grass field were studied during July. Bulk samples of turf grass and crumb rubber were analysed and both stationary and personal air sampling was applied. Personal air sampling was done during active soccer play among three to four players and the samplers located at the waist level for describing the situation with children. Activities and sampling lasted 120 min.

Results showed that personal concentrations were higher than stationary concentrations. Some VOC concentrations were higher on the turf than in background samples. Naphthalene (concentration in the indoor turf sample, 113 ng/m^3), methylated naphthalenes, fluorene (53 ng/m^3), phenanthrene (32 ng/m^3), BZT (max. 14 µg/m^3), methyl isobutyl ketone (MIBK, 36 µg/m^3) and butylated hydroxytoluene (BHT, max. 3.9 µg/m^3) were detected in greater concentration at the indoor field compared to the outdoor fields. Nitrosoamine levels were below reporting levels. It was concluded that more research is needed to better understand air quality at indoor facilities.

In the study by **Ginsberg *et al*. 2011**, the risk assessment through inhalation was performed to the same study. The following assumptions were made in the risk assessment: the air concentrations that were measured on a sunny and low windy summer day, can be applied to the four warmest months, and the highest concentration for each analyte found at the outdoor field represented a worst-case composite. Four exposure scenarios were included: child-indoor, child-outdoor, adult-indoor and adult-outdoor.

The scenario with the highest exposure was children playing on the indoor field. The main contributor was benzothiazole that was 14-fold higher indoors than outdoors. The cancer risks were at or below *de minimis* levels (1 x 10^{-6}) in all scenarios. Cumulative cancer risk for children indoors was found to be the greatest, 1.3 x 10^{-6}.

Based on the findings in the study, outdoor and indoor synthetic turf fields are not associated with elevated adverse health risks. However, adequate ventilation should be applied at indoor fields.

Schiliro et al 2013 compared airborne concentrations of particles (PM10 and PM2.5), particulate PAHs, BTXs measured from synthetic turf football fields and from urban areas. The research group also studied the mutagenicity of organic extracts from PM10 and PM2.5. Sampling was performed twice, during summer and winter, and at six different football fields and two urban sites.

There were no differences in PM10 concentrations at an urban site and on a turf football field. PM2.5 concentrations were slightly greater at the urban site in the cold season as was the ratio of PM2.5 to PM10. BTXs were slightly greater at the urban sites than on turf football fields and the ratio of toluene to benzene (T/B ratio) was always comparable with normal urban conditions.

The highest benzene concentration was 6.0 µg/m^3 at the football field and 8.8 µg/m^3 at the urban site. The concentrations of PAHs on the monitored football fields was comparable with urban levels. The sum concentration of 12 PAHs varied between <0.09 – 34 ng/m^3. The PAH levels were greater in the winter than in the summer. The maximum BaP concentration was 2.1 ng/m^3. The mutagenicity of the PM10 extract was greater, and the PM2.5 extract was lower, when compared with the urban site samples.

The measured air impurities on the monitored football fields were comparable with urban air levels.

Salonen *et al*. (National Institute for Health and Welfare (Finland), 2015) investigated the effect of chemical composition of rubber granulates, the type of indoor air in the football arena and the effect of mechanical ventilation on the levels of air pollutants. The prevalence of various symptoms and nuisance were examined among adolescent users in four permanent arenas and two pressurized canvas domes.

The studied indoor football fields were built between 1996 and 2011. In the oldest field, the crumb rubber was installed in 2010. The type of the used crumb rubber was styrene-butadiene-rubber (SBR) in four cases (1996/crumb rubber was installed in 2010, 2007, 2009/5 years old crumb rubber and 2011/3 months old crumb rubber), thermoplastic elastomer (TPE, 2009) and ethylene-propylene-diene monomer (EPDM, 2002) in two cases.

PAH concentration in tyres was regulated in 2010. This is the reason why only the use of crumb rubber after 2010 is considered. Therefore, the results of the football field arena that was built in 2011 and the crumb SBR that was 3 months old are considered separately in this summary.

The total PAH contents of vacuum-cleaned SBR granulate samples varied from 38 to 81 mg/kg, where the lowest value was from the material that was applied in 2011 and was three-months old. The other types of rubber granulates (TPE 0.1 mg/kg, EPDM 1.5 mg/kg) had lower PAH concentration than SBR. However, all indoor air PAH concentrations were very low. The content of PAH in the vapour phase was in a range of 0-0.3 µg/m^3 and in the particulates phase less than the detection limit of the method.

The VOC emission from rubber granulates, especially SBR, consisted mostly of aldehydes and ketones, which together with benzothiazole were frequently also found in the indoor air of arenas. The highest concentration of aldehydes and ketones was 111 µg/m^3 and the highest concentration of benzothiazole was 13 µg/m^3 from the three months old SBR from hall 2 (built in 2012). The indoor air of the arenas that had SBR infilling, contained 4-methyl-2-pentanone (MIBK). The maximum concentration of MIBK was 14.5 µg/m^3 in hall 5 that was built in 2009. The concentration of TVOC compounds in the indoor air ranged from 30 to 450 µg/m^3. At the same time, the concentration of TVOC in outside air ranged from 7 to 17 µg/m^3. Volatile organic compounds found in the indoor air could cause the reported symptoms of sore throat, running nose, eye and skin irritation etc. Indoor air PAH concentrations were very low.

The indoor PM10 concentrations (10–20 µg/m^3) were comparable to urban outdoor levels and mainly due to the infiltration of outdoor air. Coarse dust measured inside arenas likely had an indoor source (e.g. bottom field layer of sand, dirt transported from outdoors).

The measured ventilation air supply, especially in permanent arenas, failed to meet the guideline level for sports arenas. Increased ventilation in two arenas reduced the VOC and CO2 concentrations but did not affect the PM10 levels.

It is not clear from the report if there were activities ongoing during the measurements.

More than half (49/90) of adolescent football players reported at least one symptom or nuisance (sore throat, running nose, eye or skin irritation, odd smell, dusty air). The indoor air of all studied arenas was reported to cause some harm.

The report contributors make a recommendation that SBR granulates cannot be recommended as fillings in synthetic turf fields in indoor football arenas, although they are highly unlikely to cause significant exposure to dust or persistent organic compounds. It is recommended that new installations of all types of fresh rubber granulates in permanent indoor arenas are done in May, and the arena is, thereafter, efficiently ventilated during the summer. The mechanical air exchange and control systems, including CO2-sensors, should be checked in all arenas. The fresh ventilation air supply should be adjusted to meet the Finnish guideline level of 2 dm^3/s/m^2 where necessary.

Marsili *et al*. (2015) investigated the release of PAH compounds and heavy metals from rubber crumb in synthetic turf fields in Italy. The most common source of rubber crumb is recycled tyres (recycled styrene-butadiene rubber – SBRs). Hazardous substances in crumb rubber infill are primarily, volatile components (nitrosoamines, xylenes), benzothiazoles, secondary amines, heavy metals (especially zinc) and polycyclic aromatic hydrocarbons (PAHs).

In this study nine samples of rubber crumb were evaluated, eight of them originated from recycled tyres. One sample was a virgin tyre rubber, which was not recycled. Five of the rubber crumb samples had not been installed yet, and four samples were installed on the fields one to eight years ago.

Some heavy metals (Zn, Cd, Pb, Cu, Cr, Ni, Fe) normally found in tyres and 14 US EPA priority PAHs were analysed from the material. PAH levels were also analysed from the evaporates of rubber crumb. The temperature at the synthetic fields can reach 60 °C when the air temperature is about 25 °C. The release of PAHs at this temperature was studied.

Heavy metals were extracted from rubber crumb with nitric acid and hydrogen peroxide in a microwave oven. After extraction, metals were analysed by using high-performance atomic absorption spectrometers with a graphite furnace or flame atomic absorption spectrophotometer. PAH compounds were extracted from rubber crumb with a mixture of KOH and methanol in a Soxhlet apparatus. After extraction, liquid-liquid separation, evaporation, resuspension and purification in a Florisil column was applied before analysing the compounds by using HPLC/fluorescence detector. The evaporates were collected as follows: small flasks contained rubber crumb and it was kept at 60 °C for five hours. A Florisil absorbent was placed to a closed trap of the flask. Then the PAH compounds were extracted from the absorbent and analysed with HPLC. The procedure was done four times. Efficiency of the traps was 90 %.

The concentrations of different separate PAH compounds varied from 38 ng/g to 15 715 ng/g with the uninstalled rubber crumb and from 5 ng/g to 10 280 ng/g with the installed rubber crumb. It was recognised that the level of PAH compounds reduced during the years in use. The uninstalled and one-year old rubber crumb had total PAH concentrations from 9 mg/kg to 58 mg/kg. The level of carcinogenic PAHs was between 2.5 – 16.6 mg/kg. As an example, concentrations of B(a)P varied from 119 ng/g to 663 ng/g (0.12-0.66 mg/kg).

Rubber crumb contained all metals that were analysed, zinc concentrations were especially high (3474 – 13 202 mg/kg). High levels of cadmium (>2 mg/kg) were found in two uninstalled rubber crumb and one eight-year old rubber crumb samples.

In addition the study investigated whether PAHs are released and at what concentrations they bocome bioavailable to synthetic turf at high temperatures (it is mentioned that synthetic turf may reach high temperatures, e.g. if air temperature is 26 °C, the synthetic surface may reach 60 °C).

Evaporation of four PAHs (BaA, chrysene, BaP and B(g,h,i)Per) from samples were observed/evaluated in the temperature of 60 °C. The levels of these PAHs varied from 0.11 to 5.82 ng/g (up to 0.006 mg/kg) for new rubber crumb and from 0.16 to 2.53 ng/g (up to 0.003 mg/kg) for used rubber crumb.

The study estimated respiratory uptake by athletes and assessed risks to human health through inhalation. As an example a chronic exposure of 0.06 to 0.45 µg/kg bw per day of BaP for a 70 kg athlete was seen. This exposure is higher than the 0.57 – 5.00 ng/kg bw per day that is stated as a virtually safe dose of BaP in food.

The results of the study show that PAHs are continuously released from rubber crumb through evaporation. Athletes frequenting grounds with synthetic turf are therefore exposed to chronic toxicity of PAHs. The main conclusion from this preliminary study that the authors draw is that although synthetic turf offers various advantages over natural grass, the quantity of toxic substances it releases when heated by the direct sunlight does not make it safe for public health. The authors however, state that this preliminary study must be considered as an extreme worst-case screening also because they did not take account of other sources for PAH compounds or dust in their assessment which was based only on the laboratory studies.

Ecopneus (Version 03-2016, Daniele Fornai) has studied rubber recycled from end-of-life tyres (ELT) and assessed the risks associated with dermal and inhalation exposure. This is a joint study with Waste and Chemicals and Mario Negri. Risk assessment was done by Dr Enrico Davoli from Mario Negri (Milan May 2016).

Chemical and physical analyses of ELT were done in four different laboratories; leaching/migration tests of PAHs into biological liquids (sweat and pulmonary surfactant) and a monitoring study to determine the inhalation and dermal exposure of workers during infill installation and the use of synthetic fields by amateur players. Monitoring included analysis of urinary 1-OHP from 15 volunteers before and after the exposure to ELT.

The concentration of eight PAHs listed in REACH Annex XVII entry 50, was on average between 5-10 mg/kg in the rubber recycled from ELT. The concentration of BeP was on average 2-4 mg/kg, while the concentration of BaP was on average 1-2.5 mg/kg.

The variability of the tyres according to the manufacturing year and location for the chemical content and migration was studied. The rubber samples from tyres were divided into four groups; tyres before and after 2010 and tyres manufactured in Europe and outside of Europe.

The migration tests of PAHs in artificial sweat (24 hours at 37 °C) confirm the low bioavailability of PAHs, with a maximum release of B(b+j)F (<0.2 ng/g of rubber) and BaA (<0.1 ng/g of rubber).

The migration rate of PAHs from rubber to artificial sweat is extremely limited and always less than 0.007 % of the quantity contained in the rubber analysed. Migration rates of PAHs in pulmonary surfactant were between 0.15 %and 0.2 % of the rubber PAH content. The results in the migration test in artificial sweat allows the release of PAHs by dermal contact to be defined as improbable.

The installation of recycled rubber infill on synthetic turf football fields and sports activity on these scenarios were studied closely. The workers were monitored for six days at four different facilities for a total of 14 days of monitoring. Outside temperatures varied from 6 °C to 25 °C during the measurements. Sampling times varied from 60- 225 minutes. At the same time, 10 players were monitored during a match played on an synthetic turf field.

The concentration of respirable dust in the breathing zone of the workers was in a range from 0.02 to 1.43 mg/m^2. The concentrations of BaP in the breathing zone of the workers was in a range from 0.00 to 26.72 ng/m^3. The concentrations of BaP on dermal pads applied on workers during the sampling campaign ranged from 0.00 to 0.19 ng/cm^2. Urine was sampled starting from four days before exposure up to three days after exposure. Other PAH sources were studied through a questionnaire of diet, smoking habits and any professional exposure to other sources of PAHs.

Five workers were monitored for 1-OHP in Rome and Milan. The 1-OHP concentrations were below 0.4 ng/ml (0.29 µmol/mol creat) and 0.1 ng/ml (0.07 µmol/mol creat), respectively, and there was no significant increase after exposure. 10 players were monitored in Trecella. The concentration of 1-OHP after the exposure was lower than 0.2 ng/ml (0.15 µmol/mol creat) for all other players except one player who had higher concentration after the exposure than before it. The concentration of 1-OHP for this player was around 0.48 ng/ml (correspond to 0.35 µmol/mol creat) after the match/exposure. The measured urinary 1-OHP values confirm the absence of a relevant absorption that can be associated with exposure to the rubber.

Generally (stationary sampling), the concentration of each of the 8 PAHs was less than 1.80 ng/m^2 during installation in the fields and in urban air nearby. The content of BaP was below the European target value of 1 ng/m^2, in all locations during the installation of the infill. However, the monitoring performed before and during the match played at Trecella in November 2015 (concentration for BaP around 7 - 12 ng/m^3) confirmed that the pollution due to traffic and heating plants is predominant in determining the quality of the air on the synthetic turf playing fields. PAH levels were higher during the cold season than the warm season.

The monitoring during the installation of rubber infill and during the use of the playing field shows that the total incremental carcinogenic risk is significantly lower, by an order of magnitude, that that recommended for the general population (1 x 10^{-6}). The risk through dermal exposure is less than through inhalation for both during installation of the infill and during sporting activity. The incremental risk for athletes was lower than for workers. The measured PAH concentrations in the air during monitoring were consistent with the level of local atmospheric pollution.

The conclusion was that the PAH content in tyres has decreased after 2010 because of the chances in regulation and the aromatic oil. There are not significant differences with the PAH content between tyres from Europe and outside of Europe. Bioavailability of PAHs in rubber is extremely limited. There are no risks associated with the use of rubber recycled from tyres.

Ventura *et al*. (2014) has evaluated the incidence of allergic contact dermatitis in a group of young people practising sports activities (cycling, sub, sailing, swimming, fishing, football, running and fencing). The highest number of positive cases was registered for thiourams and mercaptobenzothiazole. Nickel was third place followed by benzocaine and latex. The data show that most common causes of sensitisation in athletes are chemical substances used in rubber processing. These substances include thiourams and mercaptobenzothiazole. Thiourea compounds are used as accelerators in the rubber industry and are known to cause allergic contact dermatitis and photo contact dermatitis (exposure to sun favours its development).

Moretto *et al*. (2007) investigated airborne concentrations of VOCs and aldehydes from synthetic turf and reported results in “Environmental and health evaluation of the use of elastomer granulates (virgin and from used tyres) as filling in third-generation synthetic turf”. The emissions of VOC and formaldehyde were characterised with the aid of standards applicable for characterisation of emissions in indoor air of construction products. Emissions from the synthetic turf containing used tyre granulates were relatively low (TVOC 134 µg/m^3 at 28 days). The emissions from the synthetic turf containing EPDM granulates were greater (490 µg/m^3 at 28 days), from the synthetic turf containing ETP granulates were relatively low (118 µg/m^3 at 28 days) and from the synthetic turf very low (8.3 µg/m^3 at 28 days). The evaluation of health risks was limited in indoor usage, in closed gymnasium. The worst-case scenario (small and poorly ventilated gymnasium) was considered for the workers responsible for installing the surfaces, the professional athletes and coaches, the amateur athletes and the spectators at the sporting event. Each exposure group was considered to be exposed in an acute and chronic fashion.

According to the results and risk evaluation, three types of synthetic turfs studied in the indoor situation are of no cause for concern for human health, for the workers installing the surfaces as well as for the general public, professional or amateur athletes, adults and children, with the exception of workers installing synthetic surfaces in small and poorly ventilated gymnasium who are exposed for over five years. In such a case, it is recommended that during installation, an air renewal rate should be at least 2 vol/h.

It was concluded in the study that the health risks associated with the inhalation of VOCs and aldehydes emitted by synthetic surfaces on pitches in outdoor situations give no actual cause for concern for human health.

According to the compendium made by ETRA, a partial literature review of 10 studies, where five are unpublished studies concerning the measurement of emissions and immissions on the playing fields of synthetic turf were considered/summarised to determine the effects of the rubber from recycled tyre used as infill material on human health and on the environment. The compendium considered eight different countries, different latitudes, seasons and temperatures, indoor and outdoor pitches, laboratory and field studies, rubber granulates from car and truck tyres, and both human health and environmental risks.

The highest concentration of PAHs was 192 mg/kg and the highest value for zinc was 16 642 mg/kg in the analysis of rubber from recycled tyres. Airborne concentrations of inhalable dust, PM10 and 2.5, PAHs, TVOCs were compared during playing and without playing. Often the levels were slightly lower during playing than without playing. The highest measured BaP values were 2.6 µg/m^3 during playing and 7.5 µg/m^3 without playing. The total EPA PAH concentrations were 66 and 47 ng/m^3, respectively. Only the particulate phase was measured for PAHs.

TVOC concentrations were 50 and 300 µg/m^3 during playing and without playing and measured inhalable dust was 0.06 and 0.176 mg/m^3, respectively. All the high values were measured on December 2006 in Porto, Portugal. The sampling time was in the morning (9:30-12:30), with temperatureof 7-8 ºC, and a wind speed of 2.3 m/s nw in the measurement during playing activities. The sampling time was in the afternoon (17:00-19:00), with temperature of 8-10 ºC, and a wind speed of 0.4 m/s sw during measurement of without playing activities. The sampling time and the wind speed may explain the results.

The conclusion in the compendium was that there are no significant differences in the overall concentrations and there is no data that shows a potential high risk to human health.

OEHHA, 2007: Evaluation of health effects of recycled waste tires in playground and track products, January 2007.

In response to the California Integrated Waste Management Board's (CIWMB) need to better understand the potential health risks to children using outdoor playground and track surfaces constructed from recycled waste tires, the Office of Environmental Health Hazard Assessment (OEHHA) conducted the following studies.

- The playground surfaces were evaluated for the release of chemicals that could cause toxicity in children following ingestion or dermal contact. Three routes of child exposure to chemicals in the rubber were considered:
    1) ingestion of loose rubber tyre shreds (acute exposure);
    2) ingestion through hand-to-surface contact followed by hand-to-mouth contact (chronic exposure); and
    3) skin sensitisation through dermal contact (acute exposure).
- Playground surfaces constructed from recycled tyres were tested for their ability to attenuate fall-related impacts.
- The potential of these rubberised surfaces to impact the local environment, including the local ecology, was also addressed through a discussion of the published literature.

Overall, we consider it unlikely that a one-time ingestion of tyre shreds would produce adverse health effects. Seven of the chemicals leaching from tire shreds in published studies were carcinogens, yielding a 1.2 x 10-7 (1.2 in 10 million) increased cancer risk for the one-time ingestion described above. This risk is well below the *di minimis* level of 1 x 10-6 (1 in 1 million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).

All exposures (gastric digestion experiment) were at or below the screening values suggesting a low risk of non-cancer acute health effects. Five of the chemicals released by tire shreds in the gastric digestion experiment were carcinogens. If the released chemicals were ingested as a onetime event and averaged over a lifetime, the cancer risk would be 3.7×10^{-8} (3.7 in 100 million). This risk is considerably below the *di minimis* risk level of 1×10^{-6} (1 in 100 million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). The assumption that the risk from a one-time exposure is equivalent to the risk from the same dose spread over a lifetime is uncertain, and may overestimate or underestimate the true risk.

From the five chemicals identified by wipe sampling, the PAH chrysene is a carcinogen. Assuming playground use from 1-year through to 12-years of age, an increased cancer risk of 2.9×10^{-6} (2.9 in 1 million) was calculated due to the chronic ingestion of chrysene. This risk is slightly higher than the *di minimis* risk level of 1×10^{-6} (1 in 1 million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). Calculation of the 2.9×10^{-6} (2.9 in 1 million) value does not account for many uncertainties, some of which would decrease the risk while others would increase the risk.

Skin sensitisation testing in the guinea pig was performed by product safety laboratories (Dayton, NJ) with tyre derived playground surfacing as well as with the synthetic rubber EPDM; no sensitization was observed, suggesting that these surfaces would not cause skin sensitisation in children, nor would they be expected to elicit skin reactions in children already sensitised to latex.

New York City Department of Health and Mental Hygiene (Vetrano and Ritter 2009) has conducted a study concerning “Air quality survey of synthetic turf fields containing crumb rubber infill”. The study consisted of air sampling for SVOCs (17 PAHs and benzothiazole), VOCs, metals and particulate matter (PM10) at two outdoor crumb rubber athletic fields in New York City. A bulk sample of crumb rubber infill was also collected from each turf field.

Sampling was done over four separate days by using stationary samplers under simulated playing conditions in summer time. A total of eight VOCs and two metals (chromium and zinc) were detected in the air measurements. Of these, only three VOCs (2-butanone, chloroform and n-hexane) were found to be unique to the synthetic turf fields. Ranges of PM2.5 were within background levels.

None of the detected air measurements were found to be at a level that is likely to cause adverse health effects from typical exposures that occur at synthetic turf fields.

EPA (EPA/600/R-09/135, November 2009) conducted a monitoring study, where four synthetic turf fields and one playground were studied for particulate matter, VOCs and metals in air, wipes and materials.

Air PM10 concentrations on turf fields were at the same level (<32 µg/m^3) in the background. However, in the playground the PM10 concentrations were higher (27 µg/m^3) than in the background. Methyl isobutyl ketone (0.13 ppbV), toluene (0.42 ppbV), m&p -xylenes (0.17 ppbV) and hexane (0.21 ppbV) concentrations were higher in the samples from the studied fields than in background samples. Zinc, lead and chromium were measured from the air samples. However, the concentrations did not differ remarkably from background samples, except the zinc concentration measured from playground.

In surface wipes were collected near the air sampling locations from several turf fields. The total extractable Pb was less than 2.0 µg/ft2. The turf blade colour was identified to cause variation in the measured Pb concentrations. Extractable Cr was less than 0.6 µg/ft2 and extractable Zn ranged from 4.0 to 43 µg/ft2. Measurements of As and Cd were very low, <0.1 µg/ft2 and <0.025 µg/ft2, respectively.

The conclusions were that concentrations of PM10 and metals (including Pb, 7.7 ng/m^3) measured in air above the turf fields were similar to background concentrations. All PM10 concentrations were well below the national ambient air quality standards for PM10 (150 µg/m^3).

All air concentrations were well below the same standard for lead (150 µg/m^3). All VOCs were measured at extremely low concentrations that are typical of ambient air concentrations. One VOC, methyl isobutyl ketone (MIBK), was detected in the samples collected on one synthetic turf field but was not detected in the corresponding background sample.

The concentration of Pb in wipes was compared to the EPA standard for Pb in residential floor dust (40 µg/ft2). On average, concentrations of components monitored in the study were below levels of concern; however, this should be given to the very limited nature of this study because of the limited number of components monitored, samples sites, and samples taken at each site).

New York State Department of Health (Lim and Walker, 2009) conducted a series of studies to assess some potential impacts from the use of crumb rubber as infill material in synthetic turf fields. Field sampling was conducted to evaluate the release of airborne chemicals, release of particulate matter and measurements of heat.

The results of the evaluation indicate a potential for release of zinc (solely from truck tyres), aniline, phenol and benzothiazole. After attenuation by adsorption and degradation and further dilution, it was indicated that crumb rubber may be used as an infill without significant impact on groundwater quality. However, crumb rubber derived entirely from truck tyres may have an impact on aquatic life due to the release of zinc.

Many of the analytes detected (e.g. benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbontetrachloride) in air samples are commonly found in an urban environment. Chemicals e.g. 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11) were found at low levels in air samples collected from synthetic turf fields. However, the measured levels of chemicals in air at studied synthetic turf fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields. Lifetime human cancer risks were less than 1×10^{-6}; however, for 1,3-pentadiene it was 2×10^{-5}. Ambient air particulate matter sampling did not reveal differences in air levels on the field and background.

The surface temperature was significantly higher for synthetic turf fields compared to measurements obtained on nearby grass and sand surfaces.

Vidair *et al*. (OEHHA 2010) reported about the safety study of synthetic turf containing crumb rubber infill made from recycled tyres. Study goals were to determine whether these fields release significant amounts of VOCs or fine particulates (PM2.5) and associated metals into air and whether they increase the risk of serious skin infections in athletes either by harbouring more bacteria or by causing more skin abrasions than natural turf.

PM2.5 and associated metals were either below the level of detection or at similar level as the samples upwind of the fields (background samples). VOCs were mostly below the level of detection, however, seven VOCs were measured at the screening level. All exposures were below health-based screening levels suggesting that adverse health effects were unlikely to occur in people using synthetic turf. There was no correlation between the concentrations or types of VOCs detected above synthetic turf and the surface temperature.

The rate of skin abrasions due to contact with turf was two- to three-fold higher for college soccer players competing on synthetic turf compared to natural turf.

Shalat *et al*. 2011 investigated potential exposure to inhalable dust, lead and other metals form synthetic turf playing fields. Sampling was conducted by using a fully programmable robotic sampler to collect air samples but also wipes samples, which were fixed to the bottom of the robotic sampler. Stationary samplers were also collected and a 12-year old boy was recruited to jog, run and kick a football while breathing zone samplers were simultaneuously collected. Five synthetic turf fields were tested during summer time. The age of the fields were from 1 to 8 years.

The robotic sampler collected higher concentrations than did the stationary samplers. All inhalable dust concentrations were below 80 µg/m^3. The concentration of lead in inhalable particulate matter was about 8 ng/m^3 on the soccer player breathing zone (12-year old boy).

The results suggest that there is a potential for inhalable lead to be present on the turf fields.

Broderick (2007 a&b), performed air sampling and analysis for gaseous phase PAHs (air sampling only to the adsorbent) on and around the athletic field. They did not reveal the presence of any detectable concentrations of PAHs. All sixteen PAHs analysed were below the laboratory detection limit of 6 µg/m^3.

The report by **KeMI (Sweden), 2006** discusses the properties and use of synthetic turf from a chemical perspective. The scope of the report is limited to synthetic turf that contains granulate from recycled tyres used for football pitches. Synthetic turf that contains other material, such as new rubber, thermoplastics and rubber-coated sand, have not been assessed. Other uses of recycled tyres, such as their use in playgrounds, for horse-riding surfaces and other sporting activities, have also not been assessed.

The report briefly describes the health and environmental properties of certain substances, it summarises results from some relevant investigations into synthetic turf, and describes the work for standardisation that is currently being carried out in Europe. Furthermore, Swedish environmental quality objectives and guidelines for the assessment of water quality and air quality are presented. KemI's overall assessment is based on the material presented in the report.

The report lists the following uses of synthetic turf: football pitches, sporting surfaces, golfing greens, gardens, indoor gardens, school playgrounds and trade fairs.

In Sweden, 90 % of existing synthetic turf surfaces contain rubber from recycled tyres. Several different types of synthetic turf are available, but the principle is usually the same. The turfs are comprised of plastic fibres of polyethene, polypropylene or nylon, which are attached to a plastic web of polypropylene or polyester. Sand and rubber granulate is filled between the fibres. The sand provides weight and holds the plastic web in place, while the rubber provides elasticity. Synthetic turf is not totally maintenance-free. It must be washed and brushed, and new rubber must be added if the turf is to perform well.

The report refers to BLIC (Bureau de Liaison des Industries du Caoutchouc), who listed the average contents of a used European tyre in 2001 and found that it contained 63 substances.

The following list provides some of the substances found in rubber granulate: lead, cadmium, copper, chromium (not in recycled rubber), mercury, zinc, phenol (4-t-octylphenol and iso-nonylphenol), benzo(a)pyrene, and (total) PAHs. In addition, phthalates, principally dimethyl phthalate (DMP) and also dibutyl phthalate (DBP) and diethylhexyl phthalate (DEHP) and VOCs (volatile organic compounds) have been found from airborne dust in halls (Norwegian study) with synthetic turf.

The information available makes it difficult to make a reliable assessment of risk when it comes to health aspects. Results are available from few measurements in few halls on few occasions, and it is thus most appropriate to regard these as random samples rather than the basis of generally applicable assessments of risk.

All measurements of indoor air give results that lie under the established guidelines for occupational exposure and for the natural environment, and they thus indicate that there are no risks involved following exposure by air. However, the concentrations in halls were just under the applicable guideline in two cases.

The report states that the health risks are not connected only with air pollution caused by synthetic turf, and exposure may take place by other mechanisms. Examples are the attachment of rubber particles to clothing, which his subsequently placed in contact with the skin and the accidental swallowing of rubber granulate by players or small children. As a conclusion, the report states that comprehensive assessment of health risks cannot be obtained.

KemI's main recommendations based on the report are the following:

Material that contains substances of very high concern should not be used, as specified by the environmental objectives of the Swedish parliament. This means that granulate formed from recycled rubber should not be used when laying new surfaces of synthetic turf.

The rubber from recycled tyres that is present in newly laid synthetic turf surfaces need not be immediately replaced, since the current health and environmental risks are assessed as being small. In the long term, however, the rubber should be replaced by alternatives. Material that contains less hazardous substances should be used when it is necessary to add new rubber. Furthermore, the recycled rubber should be replaced when it displays signs of break-down and the formation of smaller particles.

KemI also states that more knowledge is needed.

The report also refers to the Norwegian Pollution Control Authority (SFT) opinion from January 2006 and its recommendations: granulate from recycled tyres is not used when laying new synthetic turf surfaces. It is not, however, necessary to remove granulate from surfaces that have been laid. More information is available at: www.sft.no .

In the Danish study (**Nilsson N. et al. (2008)**), it was concluded, based on four studies performed in Norway, Switzerland, the Netherlands and Sweden earlier, to focus only dermal and oral exposure on health scenarios. The project did not monitor PAHs, because all existing studies show that there are no problems in relation to PAH emissions. Particular focus was given to zinc, phthalates and nonylphenols as a consequence of the results from the foreign studies.

Four representative substances were selected for the health assessment: benzothiazole, dicyclohexylamine, cyclohexanamine and dibutyl phthalate. These substances are present in high concentrations in contact water from the leaching tests and are representative of the harmful substances emitted from the products.

On the basis of the results from foreign exposure studies, which have shown that effects caused by inhalation of vapour are insignificant and own analyses, it was decided to focus exclusively on exposure through skin contact and oral uptake from particles swallowed.

Microscopy of the dust particles from leaching tests has shown a particle size for the finest particles in the order of 10-50 µm, whereas the majority of the particles are approx. 2 mm. With a high content of fine particles, the leaching of health and environmentally harmful substances may increase due to the larger contact area, and the risk of inhalable flying dust is also increased.

However, as mentioned, the amount of fine dust in the products is limited. In the headspace analysis, recycled tire rubber infill emitted MIBK/2-hexanone (all three samples) in a range of 0.5-12 µg/g, cyclohexanone (two samples) in a range of 0.7-0.9 µg/g, benzothiazole (0.1 µg/g, one sample) and 1-methyl-2-pyrrolidinone (3.5 µg/g, one sample). In the extraction with dichloromethane e.g. aromatic amines, phthalates, benzothiazole, 1-methyl-2-pyrrolidinone and butylated hydroxytoluene were found.

In the health assessments of different exposure scenarios with the selected four substances, no health risks were found in connection with exposure through skin contact or oral intake to the substances among children, juniors or adult players, with the exception of a possible allergenic risk for sensitive individuals to benzothiazole and the amines.

Concerning different substances used in synthetic turf, the report states that other infill materials are available than rubber crumb. There may also be antioxidants added to plastic fibres to improve weather resistance, UV stabilisers to protect against light degradation and also colourants to make the fibres green.

New York City Department of Health and Mental Hygiene (Denly, Rutkowski and Vetrano, 2008) prepared a review of the potential health and safety risks from synthetic turf fields containing crumb rubber infill. The studies have found that polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), benzothiazole, and certain metals are the compounds of potential concern in crumb rubber.

Studies have also identified phthalates, alkylphenols and benzene, which likely become bonded to tyres during their use. The conclusion in the report was as following: “This comprehensive review of the available literature on the potential health effects of crumb rubber infill from synthetic turf fields has demonstrated that the major health concern from these fields is related to heat. Chemical of potential concern (COPC) concentrations from the crumb rubber vary depending on the type of crumb rubber, the method of extraction used for analysis, and the media measured (crumb rubber, air, leachate). Eleven different risk assessments applied various available concentrations of COPCs and none identified an increased risk for human health effects as a result of ingestion, dermal or inhalation exposure to crumb rubber. However, additional air studies at synthetic turf fields as well as background air measurements would provide more representative data for potential exposures related to synthetic field use in NYC, particularly among younger field users.”

Cheng *et al*. (2014) made a review article concerning environmental and health impacts of synthetic turf. They concluded in their review that tyre rubber crumb contains a range of organic contaminants and heavy metals that can volatilise into the air and/or leach into the percolating rainwater, thereby posing a potential risk to the environment and human health. A limited number of studies have shown that the concentrations of volatile and semivolatile organic compounds in the air above synthetic turf fields were typically not higher than the local background, while the concentrations of heavy metals and organic contaminants in the field drainages were generally below the respective regulatory limits. Health risk assessment studies suggested that users of synthetic turf fields, even professional athletes, were not exposed to elevated risks.

Toronto Public Health (Macfarlane *et al*., 2015) has performed a health impact assessment of the use of synthetic turf in Toronto. According to the report, available evidence indicates that under ordinary circumstances, adverse health effects among adults and children are unlikely to occur as a result of exposure to synthetic turf infilled with crumb rubber in both outdoor and indoor settings.

Studies show that people who would have relatively high exposures to rubber-infilled turf (workers and professional athletes) also do not have increased health risks. However, there are still some information gaps: the allergenic potential of latex in crumb rubber has not been thoroughly investigated; exposure to lead, other metals, carbon nanotubes, as well as other contaminants have not been fully evaluated in all types of turf systems; and the impact of low-level exposures during early childhood development is still uncertain.

- Hazardous substances from the crumb rubber can leach into surface or ground water; these releases are below levels of concern to human health. More research is needed to assess the potential impact on the health of aquatic ecosystems from the release of zinc and a few other substances that may be found in synthetic turf. Pesticides and fertilisers used in the maintenance of natural turf may also contaminate surface and ground water.

- Based upon a review of the available evidence, third generation synthetic turf is not expected to result in exposure to toxic substances at levels that pose a significant risk to human health provided it is properly installed and maintained and users follow good hygienic practices (for example, washing hands, avoiding eating on synthetic turf and supervision of young children to ensure they do not eat the infill material).

- There is insufficient evidence related to the allergenic potential of latex in crumb rubber; more study is required to address uncertainty in exposure estimates for lead, other metals, polycyclic aromatic hydrocarbons and other substances; and further research is needed to more fully understand the potential impact of low-level exposure to carbon nanotubes. These risks can be minimised through the use of standard hygienic practices.

Health risks associated with synthetic turf can be reduced or eliminated by following the following good practices:

1) Properly ventilating indoor synthetic turf facilities;

2) Washing hands after playing on synthetic turf;

3) Supervising small children to ensure they do not eat the infill material;

4) Not eating on the synthetic turf;

5) Preventing the tracking of infill material indoors (for example, shaking visible rubber pellets off or providing shoe/equipment cleaning areas before exiting the field);

6) Requiring the installation of synthetic turf made with the least toxic materials when available;

7) Adopting protocols for selecting and purchasing synthetic turf infilled with rubber crumb. Such protocols could include requirements for suppliers and manufacturers to provide information on the chemical content of products, contaminant emissions overtime, and other material safety information;

8) Ensuring that synthetic turf in childcare settings or other play areas meets the limits for children’s products as outlined in Health Canada's Consumer Products Containing Lead

Regulation before purchase and installation; to minimize exposure to lead, and prevent toddlers' direct exposure to synthetic turf that does not meet these limits;8

9) Performing regular monitoring of contaminants to account for risk at different stages throughout the lifecycle of an synthetic turf field, sampling for lead content in synthetic turf fibres is recommended at regular intervals (for guidance see Van Ulirsch *et al.*, 2010).

The design of synthetic turf surfaces and the materials used in them have changed over time to address earlier concerns related to environmental impacts, heat, injuries, and exposure to toxic substances. As the technology continues to evolve, it is possible that this will reduce their negative environmental and health impacts even further.

Synthetic turf surfaces become much hotter than natural grass which can be a risk for blisters, burns or heat stress during hot weather. Unlike natural grass which has evaporative cooling properties, synthetic turf is made of several heat-retaining materials which can significantly increase field surface temperatures, substantially increase air temperatures near fields, and thus contribute to the urban heat island effect in surrounding neighbourhoods. This increases the risk of heat-related health impacts during hot weather events. Widespread use of synthetic turf would also make Toronto less resilient to extreme weather events and increase adverse health impacts associated with these events.

While injury patterns differ among natural grass fields and different designs of synthetic fields, the available evidence suggests that overall, playing on third generation synthetic turf fields does not result in a higher overall risk of injury than playing on natural grass fields.

Conclusions of human exposure

Exposure of synthetic turf installation and maintenance workers (IndusTox 2009, Ecopneus 2016), coaches (Castellano, 2008) and athletes (VanRooij 2010, Menichini 2011, Simcox 2011, Ecopneus 2016) has been investigated in several studies.

Exposure assessment has been performed by measuring airborne impurities in the breathing zone of the workers or at the waist height of the players. The waist height sampling shows the worst-case scenario and also the exposure of children.

The air or the airborne dust on the synthetic turf fields in outdoor (ETRA, Ecopneus 2016, Schiliro 2013, Vidair 2010, Shalat 2011, Broderick 2007, Lim 2009, Vetrano 2009) or indoor (NILU 2006, Moretto 2009, Salonen 2015, Simcox 2011) air arenas has been studied. The sampling has been performed using stationary sampling or a robotic sampler. The main air impurities that have been monitored in all these studies are inhalable and respirable dust, PM10 and PM2.5 particulates[28], PAHs, volatile organic compounds (VOCs) as separate substances or as a total VOC and some metals.

According to the studies, exposure to the inhalable and respirable dust can be moderate during the installation and maintenance work. The highest measured value for inhalable dust has been 3.1 mg/m^3. The exposure to the inhalable dust during work can be controlled if the high exposure has been identified as it was performed in the study of Industox and Kempeneers Milieu (2009).

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[28] It can be said roughly that PM10 reflects throratic fraction and PM2.5 alveolic fraction.

Implementation of relevant risk management measures reduces the maximum exposure level to dust to below 1 mg/m^3. Respirable dust in the breathing zone of the workers during the installation of football fields has been seen in the range of 0.02 to 1.43 mg/m^3 in an Italian study (Ecopneus & Waste and chemicals 2016).

Generally, the PM10 concentrations have been comparable to urban outdoor levels and have been in a range of 10-40 µg/m^3 in indoor air arenas. The portion of rubber in PM10 dust was 23-28 % in the Norwegian study (NILU 2006).

The exposure to VOCs has some variation in indoor and outdoor arenas. The concentration of VOCs that were sampled with passive monitors from the breathing zone of workers, were below the detection limit. The concentrations of VOCs (sampled into the sorbent tube) have been higher in indoor air arenas than in outdoor arenas.

The maximum concentration of VOC has been 716 µg/m^3 measured from the indoor arena with SBR infilling and without ventilation. The portion of ketones and aldehydes can be relatively high (111 µg/m^3) in the air of indoor arenas.

Measured VOC compounds have included compounds that are skin sentisiters e.g. formaldehyde and benzothiazole-2-thiol. There is some evidence that chemical substances used in rubber processing e.g. thiourams and benzothiazole-2-thiol, are causing sensitisation in athletes (Ventura 2001). This information is not specifically linked to the rubber granules used in sports field, but generally to many different sports activities. However, both of these substances (group of substances) may be present in rubber granules.

Indoor VOCs may also cause irritation in eyes, skin and upper respiratory tract. In a Finnish study (Salonen 2015), the football players reported symptoms of sore throat, running nose and eye and skin irritation, and the VOCs were assumed to be the reason for these symptoms. The substances that have been identified and detected from air samples are e.g. 4-methyl-2-pentanone (MIBK) in a maximum range of 14.5-36 µg/m^3, formaldehyde (5-6 µg/m^3) and acetone (6-11 µg/m^3).

A typical rubber component is benzothiazole in a maximum range from 14-32 µg/m^3. Alkyl benzenes (e.g. styrene, xylene) have been analysed from the air of the indoor arenas. Also, 2-butanone, chloroform and hexane have been found to be unique to the synthetic turf fields, but not to the level that they would cause health effects.

Dimethylphthalate (DMP, max 50 ng/m^3), diethylphthalate (DEP, max 28 ng/m^3), dibutylphthalate (DBP, max 45 ng/m^3) and diethylhexylphthalate (DEHP, 31 ng/m^3) have been identified and analysed from airborne dust.

Diethylphthalate (DEP, 0.06 µg/m^3), diisobutylphthalate (DiBP, 0.10 µg/m^3) and dibutylphthalate (DBP, 0.38 µg/m^3) have been identified and analysed from air samples.

Many other organic compounds from the airborne dust with pg/m^3 level have been analysed e.g. different kind of bentzothiazoles, aromatic amines. The level of nitrosoamines has been below the detection limit. Benzene concentrations on the synthetic turf field have been at the same level as urban air, except in one measurement in an indoor arena where the concentration was 7 µg/m^3 and outside the concentration was 0.5 µg/m^3. In the same indoor arena, the concentrations of other

VOCs like toluene and xylene were also elevated. In this indoor arena, the ventilation was not working properly.

The measured airborne PAH concentrations are comparable with urban levels. In many studies, the airborne PAH levels have been greater in winter than in summer. This can be explained with external PAH sources such as heating and traffic exhaust which causes higher emissions during winter than in summer.

Naphthalene (113 ng/m^3), methylated naphthalenes, fluorene (53 ng/m^3), fluoranthene, phenanthrene (32 ng/m^3) and pyrene are the main PAH compounds when the vapour phase PAH compounds have been analysed.

Particle-bound PAHs (containing more than four aromatic rings) exist in much lower concentrations in the air above the synthetic fields and the concentrations are often below the detection limit.

In an unpublished study (provided by ETRA), particle-bound PAHs were measured during playing and without playing. The goal was to clarify if the playing resulted higher emissions of dust and PAHs. The highest PAH concentrations were measured in December 2006 in Porto, Portugal. The total EPA PAH concentrations were 66 ng/m^3 during playing and 47 ng/m^3 without playing. The highest measured BaP values were 2.6 µg/m^3 during playing and 7.5 µg/m^2 without playing. In other studies, the measured BaP concentrations have been in a range of 1.2 (indoor) – 0.4-2 ng/m^3 (outdoor) on an synthetic turf field.

Ecopneus (2016) and partners have analysed higher BaP levels from the breathing zone of the workers and football players in Italy. The measured BaP concentrations have varied from 0.0 to 26.7 ng/m^3 during installation of the football field. In this study, dermal exposure was studied by placing pads on the skin of the workers and players. BaP was analysed from the pads, and the concentrations ranged from 0.0 to 0.19 ng/cm^2.

The high concentration in the air did not correlate to the dermal contamination on pads. In the same study, the airborne BaP was measured during the match from the breathing zone of the players, levels being 7.2-13.7 ng/m^3. At the same time, BaP was measured in ambient air, and the concentration was 7.4 ng/m^3 before the match and 12.3 ng/m^3 during the match. Since the BaP levels in the breathing zone of the players were consistent with the levels in ambient air, the PAH exposure of players is presumably not related to the crumb rubber granules, but more to the external sources from background ambient air.

There are four studies where biomonitoring has also been used to estimate the exposure to PAHs among workers and football players on synthetic sports fields with tyre crumb infill (VanRooij and Jongeneelen 2010, Castellano 2008, IndusTox 2009 and Ecopneus 2016). The benefit of using biomonitoring in exposure assessment is that it takes into account both inhalation and dermal exposure.

Urinary 1-hydroxypyrene is a useful and widely used quantitative biological indicator of exposure to PAHs. However, there are also many external PAH sources e.g. diet, smoking and traffic, which may alter the results by increasing the background value.

The concentration of 1-hydroxypyrene after the exposure to crumb rubber infill was mainly below the reference value that the American Conference of Industrial Governmental Hygienists (ACGIH[29]) has set for non-occupationally exposed workers (both non-smokers and smokers), 1 µg/l urine (0.49 µmol/mol creatine).

In some cases, there were increases in concentrations after the exposure compared to the concentration before the exposure, but the difference was not high and it could be explained by the external PAH source such as diet or smoking. *These studies provide evidence that the uptake of PAH by workers and football players is minimal and it is in the range of uptake of PAH from other sources in the environment and food.*

In a study by Castellano (2008), the metabolite of benzene was also analysed from the urine samples of coaches and maintenance personnel. The levels of t,t-MA benzene metabolite were low (average 21 µg/g of creatinine) when considering that the limit value recommended by ACGIH is 500 µg/g creatinine. The average value detected on 53 non-smokers residing in the same city was 46.9 µg/g of creatinine. *The study shows that the exposure level of benzene among coaches and maintenance workers is minimal.*

Chromium, lead and zinc have been detected in the air measurements performed on the synthetic turf field (Vetrano 2009 and EPA 2009). However, the concentrations have been very low and it has been concluded that these metals don't cause health effects or they have been at the same level with the background samples. In one study (Shalat 2011), it was concluded that it is possible that inhalable lead is present on the synthetic turf fields. The inhalable lead was measured from the breathing zone of a 12-year old boy who was playing on the field. The concentration was 8 ng/m^3.

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[29] See: http://www.acgih.org/

Table VI.1 The maximum air concentration from the exposure assessment studies from the literature and the reference limit values

Substance	Max. conc. in the literature	DNEL	Limit value for indoor air	Occupational exposure limit value	Other
Inhalable dust, mg/m3	3.1	-		10 for inorganic dust; 5 for organic dust (Sweden, Finland), 4 (Germany)	
Respirable dust, mg/m3	1.4	-		0.3 (Germany)	3 (ACGIH)
PM10, µg/m3	40	-			50 for 1 day; 40 calendar year (EU air quality limit value)
TVOC, µg/m3	715	-	100 (Finland)		
Benzene, µg/m3	7	-		3 250 (= 1 ppm, EU, the UK, France, Finland), 1 900 (tolerable cancer risk) or 200 (acceptable cancer risk) (Germany)	5 annual (EU air quality limit value)
Benzothiazole, µg/m3	32	No DNELs		20 000 (Poland)	
2-mercaptobenzothiazole, µg/m3	0.000352	1 090 (general population)		4 000 (inhalable aerosol, Germany)	
MIBK, µg/m3	36	83 000 (worker), 14 700 (general population)			
Formaldehyde, µg/m3	6		10 (France); 15 (Finland) 100; 30 min (WHO Guidelines for Indoor Air)	150 (The Netherlands), 370 (Germany)	[1)]

Substance	Max. conc. in the literature	DNEL	Limit value for indoor air	Occupational exposure limit value	Other
Naphthalene, ng/m3	122		10 000; (WHO Guidelines for Indoor Air)	500 000 (inhalable aerosol, Germany), 5 000 000 (Finland), 50 000 000 (EU)	2)
BaP, ng/m3	2 or 13.7[3]			70 (Germany); 551 (The Netherlands); 2000 (Sweden); 10 000 (Finland)	1 (EU Air quality target value), 4)., 5)
DEHP, µg/m3	0.031	880 (worker), 160 (adult, general population) and 120 (children, general population)			
DBP, µg/m3	0.43	130 (worker), 20 (general population)			
BBP, µg/m3		9 900 (worker), 1 700 (general population)	3 000 (Austria, Denmark, Sweden)		
DiBP, µg/m3	0.10	2 940 (worker), 720 (general population)	1 000 (Latvia), 3 000 (Denmark)		
Lead, µg/m3	0.008				0.5 annual (EU air quality limit value)

1. In the EXPOLIS study in Helsinki, the average air concentration of formaldehyde in homes was 41.4 µg/m^3 (range 8.1–77.8 µg/m^3) and at the workplace 15 µg/m^3, whereas average personal exposure was 26.8 µg/m^3 [20].
2. WHO Guidelines for Indoor Air Quality: naphthalene 0.01 mg/m^3 = 10 000 ng/m^3 (annual average concentration). In Europe, indoor concentrations and personal exposures to naphthalene are usually low, typically below 1–2 µg/m^3
3. The value 2 µg/m^3 or less is a typically measured concentration for BaP. The value 13.7 µg/m^3 has been measured on the outdoor field in winter, and the BaP concentration in ambient air was at the same level at the same time.
4. BaP: WHO Guidelines for Indoor Air Quality: 0.1 mg/m^3 (30-minute average concentration); Germany: TRK Limit value (Technische Richtkonzentration) 8 h and weekly 2 µg/m^3 = 2000 ng/m^3; Germany AGS: 0.00007 mg/m^3 = 70 ng/m^3 (inhalable fraction) workplace exposure concentration corresponding to the proposed preliminary acceptable cancer risk; Sweden 0.002 mg/m^3; Finland 0.01 mg/m^3; The Netherlands 0.0005507 mg/m^3.
5. BaP levels 0.01-0.65 ng/m^3 in European homes and 1.42 n/m^3 in Italian homes and the BaP concentration was 0.2 ng/m^3 (0.05 – 0.5 ng/m^3) in Helsinki, 2005.

ANNEX VII - RISK CHARACTERISATION AND EXCESS LIFETIME CANCER RISK ESTIMATIONS

Risk characterisation of selected substances through oral, dermal and inhalation in certain exposure scenarios

Table VII.1 Scenario 2; children 6-11 years - Scenario 6; professional goalkeepers - Scenario 5; professional players

Scenario 2; children 6-11 years														
	max. conc. in rubber granules from field	**Oral exposure**			**Dermal exposure**			**Inhalation**					**oral+dermal+inhalation**	
Substance	**mg/kg (µg/g)**	**conc, µg/kg bw/day**	**DNEL, µg/kg bw/day**	**RCR**	**conc µg/kg**	**DNEL, µg/kg bw/day**	**RCR**	**measured conc. µg/m3**	**calculated conc. µg/m3**	**DNEL, µg/m3**	**RCR meas.**	**RCR calc.**	**Combined RCRs (inh. meas.)**	**Combined RCRs (inh. calc.)**
MIBK	na	-	4200	-	-	4 200	-	36	-	14 700	2.45E-03	-	2.45E-03	-
benzothiazole	6.3	0.01296	310	4.18E-05	2.593	940	2.76E-03	32	-	1 090	2.94E-02	-	3.22E-02	-
2-MBT	7.6	0.01564	310	5.04E-05	3.128	940	3.33E-03	0.000352	0.000304	1 090	3.23E-07	2.79E-07	3.38E-03	3.38E-03
DEHP	52	0.02140	34	6.29E-04	0.00214	672	3.18E-06	0.031	0.002080	120	2.58E-04	1.73E-05	8.91E-04	6.50E-04
DBP	3.9	0.00160	6.7	2.40E-04	0.00016	70	2.29E-06	0.43	0.000156	20	2.15E-02	7.80E-06	2.17E-02	2.50E-04
BBP	2.8	0.00115	500	2.30E-06	0.00012	10 000	1.15E-08	na	0.000112	1 700	-	6.59E-08	-	2.38E-06
DIBP	77	0.03169	8.3	3.82E-03	0.00317	no hazard	-	0.1	0.003080	720	1.39E-04	4.28E-06	3.96E-03	3.82E-03
formaldehyde	na	-	-	-	-		-	6		100	6.00E-02	-	6.00E-02	-
Scenario 6; professional goalkeepers														
	max. conc. in rubber granules from field	**Oral exposure**			**Dermal exposure**			**Inhalation**					**oral+dermal+inhalation**	
Substance	**mg/kg (µg/g)**	**conc, µg/kg bw/day**	**DNEL, µg/kg bw/day**	**RCR**	**conc µg/kg**	**DNEL, µg/kg bw/day**	**RCR**	**measured conc. µg/m3**	**calculated conc. µg/m3**	**DNEL, µg/m3**	**RCR meas.**	**RCR calc.**	**Combined RCRs (inh. meas.)**	**Combined RCRs (inh. calc.)**
MIBK	na	-	4 200	-	-	4 200	-	36	-	14 700	2.45E-03	-	2.45E-03	-
benzothiazole	6.3	0.00183	310	5.91E-06	1.831	940	1.95E-03	32	-	1 090	2.94E-02	-	3.13E-02	-
2-MBT	7.6	0.00221	310	7.13E-06	2.209	940	2.35E-03	0.000352	0.000304	1 090	3.23E-07	2.79E-07	2.36E-03	2.36E-03
DEHP	52	0.00302	34	8.89E-05	0.00151	672	2.25E-06	0.031	0.002080	160	1.94E-04	1.30E-05	2.85E-04	1.04E-04
DBP	3.9	0.00023	6.7	3.38E-05	0.00011	70	1.62E-06	0.43	0.000156	20	2.15E-02	7.80E-06	2.15E-02	4.33E-05
BBP	2.8	0.00016	500	3.26E-07	0.00008	10 000	8.14E-09	na	0.000112	1 700	-	6.59E-08	-	4.00E-07
DIBP	77	0.00448	8.3	5.39E-04	0.00224	no hazard	0.00E+00	0.1	0.003080	720	1.39E-04	4.28E-06	6.78E-04	5.44E-04
formaldehyde	na	-	-	-	-	-	-	6	-	100	6.00E-02	-	6.00E-02	-

Scenario 5; professional players														
	max. conc. in rubber granules from field	Oral exposure			Dermal exposure			Inhalation					oral+dermal+inhalation	
Substance	mg/kg (µg/g)	conc, µg/kg bw/day	DNEL, µg/kg bw/day	RCR	conc µg/kg	DNEL, µg/kg bw/day	RCR	measured conc. µg/m3	calculated conc. µg/m3	DNEL, µg/m3	RCR meas.	RCR calc.	Combined RCRs (inh. meas.)	Combined RCRs (inh. calc.)
MIBK	na	-	4200	-	-	4 200	-	36	-	14 700	2.45E-03	-	2.45E-3	-
benzothiazole	6.3	0.00183	310	5.91E-06	1.099	940	1.17E-03	32	-	1 090	2.94E-02	-	3.05E-02	-
2-MBT	7.6	0.00221	310	7.13E-06	1.326	940	1.41E-03	0.000352	0.000304	1 090	3.23E-07	2.79E-07	1.42E-03	1.42E-03
DEHP	52	0.00302	34	8.89E-05	0.00091	672	1.35E-06	0.031	0.002080	160	1.94E-04	1.30E-05	2.84E-04	1.03E-04
DBP	3.9	0.00023	6.7	3.38E-05	0.00007	70	9.72E-07	0.43	0.000156	20	2.15E-02	7.80E-06	2.15E-02	4.26E-05
BBP	2.8	0.00016	500	3.26E-07	0.00005	10 000	4.88E-09	na	0.000112	1 700	-	6.59E-08	-	3.96E-07
DIBP	77	0.00448	8.3	5.39E-04	0.00134	no hazard	0.00E+00	0.1	0.003080	720	1.39E-04	4.28E-06	6.78E-04	5.44E-04
formaldehyde	na	-	-	-	-	-	-	6	-	100	6.00E-02	-	6.00E-02	-

na = not analysed, no information from literature, - = not possible to calculate

Table VII.2 Scenario 7 for worker (PM10) - Scenario 7 for worker (inhalable dust)

Scenario 7 for worker (PM10)														
	max. conc. in rubber granules from field	Oral exposure			Dermal exposure			Inhalation					oral+dermal+inhalation	
Substance	mg/kg (µg/g)	conc, µg/kg bw/day	DNEL, µg/kg bw/day	RCR	conc µg/kg	DNEL, µg/kg bw/day	RCR	measured conc. µg/m3	calculated conc. µg/m3	DNEL, µg/m3	RCR meas.	RCR calc.	Combined RCRs (inh. meas.)	Combined RCRs (inh. calc.)
MIBK	na	not relevant			-	11 800	-	36	-	83 000	4.34E-04	-	4.34E-4	--
benzothiazole	6.3	not relevant			0.734	940		32	-	1 090	2.94E-02	-	2.94E-02	-
2-MBT	7.6	not relevant			0.886	940		0.000352	0.000228	1 090	3.23E-07	2.09E-07	3.23E-07	2.09E-07
DEHP	52	not relevant			0.00061	1 882	3.22E-07	0.031	0.001560	880	3.52E-05	1.77E-06	3.55E-05	2.09E-06
DBP	3.9	not relevant			0.00005	190	2.39E-07	0.43	0.000117	130	3.31E-03	9.00E-07	3.31E-03	1.14E-06
BBP	2.8	not relevant			0.00003	28 000	1.17E-09	na	0.000084	9 900	-	8.48E-09	-	9.65E-09
DIBP	77	not relevant			0.00090	830	1.08E-06	0.1	0.002310	2 940	3.40E-05	7.86E-07	3.51E-05	1.87E-06
formaldehyde	na	not relevant			-			6		370	1.62E-02	-	1.62E-02	-
Scenario 7 for worker (inhalable dust)														
	max. conc. in rubber granules from field	Oral exposure			Dermal exposure			Inhalation					oral+dermal+inhalation	
Substance	mg/kg (µg/g)	conc, µg/kg bw/day	DNEL, µg/kg bw/day	RCR	conc µg/kg	DNEL, µg/kg bw/day	RCR	measured conc. µg/m3	calculated conc. µg/m3	DNEL, µg/m3	RCR meas.	RCR calc.	Combined RCRs (inh. meas.)	Combined RCRs (inh. calc.)
MIBK	na	not relevant	-	-	-	11 800	-	36	-	83 000	4.34E-04	-	4.34E-4	-
benzothiazole	6.3	not relevant	-	-	0.734	940		32	-	1 090	2.94E-02	-	2.94E-02	-
2-MBT	7.6	not relevant			0.886	940		0.000352	0.017670	1 090	3.23E-07	1.62E-05	3.23E-07	1.62E-05
DEHP	52	not relevant			0.00061	1 882	3.22E-07	0.031	0.120900	880	3.52E-05	1.37E-04	3.55E-05	1.38E-04
DBP	3.9	not relevant			0.00005	190	2.39E-07	0.43	0.009068	130	3.31E-03	6.98E-05	3.31E-03	7.00E-05
BBP	2.8	not relevant			0.00003	28 000	1.17E-09	na	0.006510	9 900	-	6.58E-07	-	6.59E-07
DIBP	77	not relevant			0.00090	830	1.08E-06	0.1	0.179025	2 940	3.40E-05	6.09E-05	3.51E-05	6.20E-05
formaldehyde	na	not relevant	-	-	-	-	-	6	-	370	1.62E-02	-	1.62E-02	-

na = not analysed or no information from literature, - = not possible to calculate

Lifetime risk for players

Table VII.3 Scenario 1&2 (childhood player 3-11 years)

Substance	Route of exposure													
ECHA 8 PAHs		Migration fraction	Max. conc. in rubber (µg/g)	Exposure conc. (µg/kg bw)	Frequency of events	Lifetime exposure (µg/kg bw/day)				BMDL10 (in mice) µg/kg bw/day	BMDL10 (in humans) µg/kg bw/day	Excess risk per µg/kg bw/day	Lifetime excess risk	Excess risk for the ES
	Oral	0.09	20	0.003704	0.476190	0.001764				490	70	0.001429	2.52E-06	2.88E-07
	Dermal	0.0002	20	0.001646	0.476190	0.000784				1225	175.000	0.000571	4.48E-07	5.12E-08
		PM10 in the air (g/m3)	Max. conc. in rubber (µg/g)	Exposure conc. (µg/m3)	Duration & frequency	Lifetime exposure (µg/m3)	Oral to inhalation absorption difference	Srv mouse* (m3/kg bw/d)	Light activity correction adults**		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and light activity	Lifetime excess risk	Excess risk for the ES
	Inhalation	0.00004	20	0.0008	0.029762	0.000024	0.5	2	0.67		82.075	0.001218	2.90E-08	3.32E-09
									High intensity activity correction adults***		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and intensive activity	Lifetime excess risk	Excess risk for the ES
									0.17		20.825	0.004802	1.14E-07	1.31E-08

Table VII.4 Scenario 4 (children 11-18)

Substance	Route of exposure													
ECHA 8 PAHs		Migration fraction	Max. Conc. In rubber (µg/g)	Exposure conc. (µg/kg bw)	Frequency of events	Lifetime exposure (µg/kg bw/day)				BMDL10 (in mice) µg/kg bw/day	BMDL10 (in humans) µg/kg bw/day	Excess risk per µg/kg bw/day	Lifetime excess risk	Excess risk for the ES
	Oral	0.09	20	0.000402	0.714286	0.000287				490	70	0.001429	4.10E-07	4.10E-08
	Dermal	0.0002	20	0.000295	0.714286	0.000210				1225	175.000	0.000571	1.20E-07	1.20E-08
		PM10 in the air (g/m3)	Max. Conc. In rubber (µg/g)	Exposure conc. (µg/m3)	Duration & frequency	Lifetime exposure (µg/m3)	Oral to inhalation absorption difference	Srv mouse* (m3/kg bw/d)	Light activity correction adults**		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and light activity	Lifetime excess risk	Excess risk for the ES
	Inhalation	0.00004	20	0.000800	0.052083	0.000042	0.5	2	0.67		82.075	0.001218	5.08E-08	5.08E-09
									High intensity activity correction adults***		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and intensive activity	Lifetime excess risk	Excess risk for the ES
									0.17		20.825	0.004802	2.00E-07	2.00E-08

Table VII.5 Scenario 5 (players-adults)

SCENARIO 5 (players-adults)														
Substance	**Route of exposure**													
ECHA 8 PAHs		**Migration fraction**	**Max. Conc. In rubber (µg/g)**	**Exposure conc. (µg/kg bw)**	**Frequency of events**	**Lifetime exposure (µg/kg bw/day)**				**BMDL10 (in mice) µg/kg bw/day**	**BMDL10 (in humans) µg/kg bw/day**	**Excess risk per µg/kg bw/day**	**Lifetime excess risk**	**Excess risk for the ES**
	Oral	0.09	20	0.000262	1.190476	0.000311				490	70	0.001429	4.45E-07	1.14E-07
	Dermal	0.0002	20	0.000349	1.190476	0.000415				1225	175.000	0.000571	4.48E-07	5.12E-07
		PM10 in the air (g/m3)	**Max. Conc. In rubber (µg/g)**	**Exposure conc. (µg/m3)**	**Duration & frequency**	**Lifetime exposure (µg/m3)**	**Oral to inhalation absorption difference**	**Srv mouse* (m3/kg bw/d)**	**Light activity correction adults****		**Inhalation BMDL10 µg/m3**	**Excess risk per µg/m3 for 24 h exposure and light activity**	**Lifetime excess risk**	**Excess risk for the ES**
	Inhalation	0.00004	20	0.000800	0.099206	0.000079	0.5	2	0.67		82.075	0.001218	9.67E-08	2.49E-08
									High intensity activity correction adults***		**Inhalation BMDL10 µg/m3**	**Excess risk per µg/m3 for 24 h exposure and intensive activity**	**Lifetime excess risk**	**Excess risk for the ES**
									0.17		20.825	0.004802	3.81E-07	9.80E-08

Table VII.6 Scenario 5 (veterans)

Substance	Route of exposure													
ECHA 8 PAHs		Migration fraction	Max. Conc. In rubber (µg/g)	Exposure conc. (µg/kg bw)	Frequency of events	Lifetime exposure (µg/kg bw/day)				BMDL10 (in mice) µg/kg bw/day	BMDL10 (in humans) µg/kg bw/day	Excess risk per µg/kg bw/day	Lifetime excess risk	Excess risk for the ES
	Oral	0.09	20	0.000233	0.238095	5.55E-05				490	70	0.001429	7.93E-08	1.81E-08
	Dermal	0.0002	20	0.000311	0.238095	7.40E-05				1225	175.000	0.000571	4.23E-08	9.67E-09
		PM10 in the air (g/m3)	Max. Conc. In rubber (µg/g)	Exposure conc. (µg/m3)	Duration & frequency	Lifetime exposure (µg/m3)	Oral to inhalation absorption difference	Srv mouse* (m3/kg bw/d)	Light activity correction adults**		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and light activity	Lifetime excess risk	Excess risk for the ES
	Inhalation	0.00004	20	0.000800	0.019841	1.59E-05	0.5	2	0.67		82.075	0.001218	1.93E-08	4.42E-09
									High intensity activity correction adults***		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and intensive activity	Lifetime excess risk	Excess risk for the ES
									0.17		20.825	0.004802	7.62E-08	1.74E-08
	Combined lifetime risk												**Light activity**	**6.62E-07**
													High intensity	**7.73E-07**

*srv rat = 1.15 m3/kg bw/d and AS = 4, for mouse AS = 7, thus srv mouse = 1.15 m3/kg bw/d *7/4 = 2.01 m3/kg bw/d

**6.7 m3/10 m3 (or 20.1 / 30 m3)= 0.67

*** 95th p high intensity for 21-31y old males is 8.21E−02 m3/min or 118 m3 per day: 20.1/118 = 0.17

Lifetime risk for goalkeepers

Table VII.7 Scenario 1&3 (childhood, goalkeeper 3-11 years)

Substance	Route of exposure													
ECHA 8 PAHs		Migration fraction	Max. conc. in rubber (µg/g)	Exposure conc. (µg/kg bw)	Frequency of events	Lifetime exposure (µg/kg bw/day)				BMDL10 (in mice) µg/kg bw/day	BMDL10 (in humans) µg/kg bw/day	Excess risk per µg/kg bw/day	Lifetime excess risk	Excess risk for the ES
	Oral	0.09	20	0.003704	0.476190	0.001764				490	70	0.001429	2.52E-06	2.88E-07
	Dermal	0.0002	20	0.000543	0.476190	0.000259				1225	175.000	0.000571	1.48E-07	1.69E-08
		PM10 in the air (g/m3)	Max. Conc. In rubber (µg/g)	Exposure conc. (µg/m3)	Duration & frequency	Lifetime exposure (µg/m3)	Oral to inhalation absorption difference	Srv mouse* (m3/kg bw/d)	Light activity correction adults**		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and light activity	Lifetime excess risk	Excess risk for the ES
	Inhalation	0.00004	20	0.000800	0.029762	0.000024	0.5	2	0.67		82.075	0.001218	2.90E-08	3.32E-09
									High intensity activity correction adults***		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and intensive activity	Lifetime excess risk	Excess risk for the ES
									0.17		20.825	0.004802	1.14E-07	1.31E-08

Table VII.8 Scenario 4 (children 11-18)

Substance	Route of exposure													
ECHA 8 PAHs		**Migration fraction**	**Max. conc. in rubber (μg/g)**	**Exposure conc. (μg/kg bw)**	**Frequency of events**	**Lifetime exposure (μg/kg bw/day)**				**BMDL10 (in mice) μg/kg bw/day**	**BMDL10 (in humans) μg/kg bw/day**	**Excess risk per μg/kg bw/day**	**Lifetime excess risk**	**Excess risk for the ES**
	Oral	0.09	20	0.000402	0.714286	0.000287				490	70	0.001429	4.10E-07	4.10E-08
	Dermal	0.0002	20	0.000295	0.714286	0.000210				1225	175.000	0.000571	1.20E-07	1.20E-08
		PM10 in the air (g/m3)	**Max. conc. In rubber (μg/g)**	**Exposure conc. (μg/m3)**	**Duration & frequency**	**Lifetime exposure (μg/m3)**	**Oral to inhalation absorption difference**	**Srv mouse* (m3/kg bw/d)**	**Light activity correction adults****		**Inhalation BMDL10 μg/m3**	**Excess risk per μg/m3 for 24 h exposure and light activity**	**Lifetime excess risk**	**Excess risk for the ES**
	Inhalation	0.00004	20	0.000800	0.052083	0.000042	0.5	2	0.67		82.075	0.001218	5.08E-08	5.08E-09
									High intensity activity correction adults***		**Inhalation BMDL10 μg/m3**	**Excess risk per μg/m3 for 24 h exposure and intensive activity**	**Lifetime excess risk**	**Excess risk for the ES**
									0.17		20.825	0.004802	2.00E-07	2.00E-08

Table VII.9 Scenario 6 (adult goalkeepers)

Substance	Route of exposure													
ECHA 8 PAHs		**Migration fraction**	**Max. conc. in rubber (µg/g)**	**Exposure conc. (µg/kg bw)**	**Frequency of events**	**Lifetime exposure (µg/kg bw/day)**				**BMDL10 (in mice) µg/kg bw/day**	**BMDL10 (in humans) µg/kg bw/day**	**Excess risk per µg/kg bw/day**	**Lifetime excess risk**	**Excess risk for the ES**
	Oral	0.09	20	0.000262	1.190476	0.000311				490	70	0.001429	4.45E-07	1.14E-07
	Dermal	0.0002	20	0.000581	1.190476	0.000692				1225	175.000	0.000571	3.96E-07	1.02E-07
		PM10 in the air (g/m3)	**Max. conc. in rubber (µg/g)**	**Exposure conc. (µg/m3)**	**Duration & frequency**	**Lifetime exposure (µg/m3)**	**Oral to inhalation absorption difference**	**Srv mouse* (m3/kg bw/d)**	**Light activity correction adults****		**Inhalation BMDL10 µg/m3**	**Excess risk per µg/m3 for 24 h exposure and light activity**	**Lifetime excess risk**	**Excess risk for the ES**
	Inhalation	0.00004	20	0.000800	0.099206	0.000079	0.5	2	0.67		82.075	0.001218	9.67E-08	2.49E-08
									High intensity activity correction adults***		**Inhalation BMDL10 µg/m3**	**Excess risk per µg/m3 for 24 h exposure and intensive activity**	**Lifetime excess risk**	**Excess risk for the ES**
									0.17		20.825	0.004802	3.81E-07	9.80E-08

Table VII.10 Scenario 7 (veterans)

Substance	Route of exposure													
ECHA 8 PAHs		Migration fraction	Max. conc. in rubber (µg/g)	Exposure conc. (µg/kg bw)	Frequency of events	Lifetime exposure (µg/kg bw/day)				BMDL10 (in mice) µg/kg bw/day	BMDL10 (in humans) µg/kg bw/day	Excess risk per µg/kg bw/day	Lifetime excess risk	Excess risk for the ES
	Oral	0.09	20	0.000233	0.238095	0.000056				490	70	0.001429	7.93E-08	1.81E-08
	Dermal	0.0002	20	0.000311	0.238095	0.000074				1225	175.000	0.000571	4.23E-08	9.67E-09
		PM10 in the air (g/m3)	Max. conc. in rubber (µg/g)	Exposure conc. (µg/m3)	Duration & frequency	Lifetime exposure (µg/m3)	Oral to inhalation absorption difference	Srv mouse* (m3/kg bw/d)	Light activity correction adults**		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and light activity	Lifetime excess risk	Excess risk for the ES
	Inhalation	0.00004	20	0.000800	0.019841	0.000016	0.5	2	0.67		82.075	0.001218	1.93E-08	4.42E-09
									High intensity activity correction adults***		Inhalation BMDL10 µg/m3	Excess risk per µg/m3 for 24 h exposure and intensive activity	Lifetime excess risk	Excess risk for the ES
									0.17		20.825	0.004802	7.62E-08	1.74E-08
	Combined lifetime risk												**Light activity**	**6.39E-07**
													High intensity	**7.50E-07**

*srv rat = 1.15 m3/kg bw/d and AS = 4, for mouse AS = 7, thus srv mouse = 1.15 m3/kg bw/d *7/4 = 2.01 m3/kg bw/d

**6.7 m3/10 m3 (or 20.1 / 30 m3)= 0.67

*** 95th p high intensity for 21-31y old males is 8.21E−02 m3/min or 118 m3 per day: 20.1/118 = 0.17

Lifetime risk for workers

Table VII.11 Scenario 8 (workers)

substance	route of exposure													
ECHA 8 PAHs		**migration fraction**	**max. conc. in rubber (µg/g)**	**exposure conc. (µg/kg bw)**	**frequency of events**	**lifetime exposure (µg/kg bw/day)**				**BMDL10 (in mice) µg/kg bw/day**	**BMDL10 (in humans) µg/kg bw/day**	**excess risk per µg/kg bw/day**	**lifetime excess risk**	**excess risk for the ES**
	oral	0.09	20	0.000000	1.190476	0.000000				490	70	0.001429	0.00E+00	0.00E+00
	dermal	0.0002	20	0.000466	0.214286	0.000100				1225	175.000	0.000571	5.71E-08	3.26E-08
		PM10 in the air (g/m3)	**max. conc. in rubber (µg/g)**	**exposure conc. (µg/m3)**	**duration & frequency**	**lifetime exposure (µg/m3)**	**oral to inhalation absorption difference**	**sRV mouse* (m3/kg bw/d)**	**light activity correction adults****		**inhalation BMDL10 µg/m3**	**excess risk per µg/m3 for 24 h exposure and light activity**	**lifetime excess risk**	**excess risk for the ES**
	inhalation	0.00004	20	0.000800	0.071429	0.000057	0.5	2	0.67		82.075	0.001218	6.96E-08	3.98E-08
	Combined lifetime risk											**light activity**		**7.24E-08**

*sRV rat = 1.15 m3/kg bw/d and AS = 4, for mouse AS = 7, thus sRV mouse = 1.15 m3/kg bw/d *7/4 = 2.01 m3/kg bw/d

**6.7 m3/10 m3 (or 20.1 / 30 m3)= 0.67

*** 95th p high intensity for 21-31y old males is 8.21E−02 m3/min or 118 m3 per day: 20.1/118 = 0.17

Exposure scenarios

Table VII.12 Parameters used in exposure scenario 1-7

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
	1 – Children from 3 to 6 years (heavy exercise)	**2 – Children from 6 to 11 years (heavy exercise)**	**3 – Children from 6-11 goalkeeper (heavy exercise)**	**4 – Children from 11 to 18 years (heavy exercise)**	**5 – Adults, professionals (heavy exercise)**	**6 – Adults, professional goalkeepers (heavy exercise)**	**Veterans**
Bodyweight (kg)	15.7	24.3	24.3	44.8	68.8	68.8	77.2
Duration of the exposure (Training/playing) (hours per event)	1	1.5	1.5	1.5	2+2	2+2	2
Frequency of exposure (h/week)	1	4.00	4	7	5	5	2
Months per year	6	10	10	10	10	10	10
Skin contact area (cm^2)	1 260	1 750	1 290	2 680	3 680	2 780	
	(1/4 legs, ½ arms and hand)	(1/4 legs, ½ arms and hand)	(1/4 legs, ½ arms)	(1/4 legs, ½ arms and hand)	(1/4 legs, ½ arms and hand)	(1/4 legs, ½ arms)	
Amount of granulates (g) in contact with skin	1	10	3.3	3.3	6	10	6
Inhalation rates (m3/hour)	1.58	1.92	1.92	2.53	3.07	3.07	
PM10 (µg/m3) max. conc. in the air	40	40	40	40	40	40	40
Direct ingestion (g/event)	0.05	0.05	0.05	0.01	0.01	0.01	0.01
Dermal exposure (mg/cm2)	1	1	1	1	1	1	

Table VII.13 Parameters used in exposure scenario 8-10

	Scenario 8	Scenario 9	Scenario 10
	Workers doing the installation, infilling (light exercise)	**Workers doing the maintenance work/refilling (light exercise)**	**Workers doing the other type of maintenance work/brushing (light exercise)**
Bodyweight (kg)	77.2	77.2	77.2
Duration of the exposure (hours per day)	6	6	2
Frequency of exposure (days/week)	3	1	1
Months per year	6	1	10
Skin contact area (cm2)	1 500	1 500	1 500
	½ arms	½ arms	½ arms
Inhalation (m3/hour)	1.61	1.61	1.61
Direct ingestion (g/event)	0	0	0
Dermal exposure (mg/cm2)	1	1	1
Amount of granules contact with skin (g)	9	9	3
PM10 (µg/m3)	40	40	40
Respirable dust (µg/m3)	1 400	1 400	1 400
Inhalable dust (µg/m3)	3 100	3 100	3 100

ANNEX VIII - INFORMATION ON ALTERNATIVE INFILL MATERIALS

Information gathered through several studies and also received from stakeholders is included in this section. However, some studies do not provide a clear definition of which material was analysed.

The concentrations of substances analysed from the alternative infill materials are summarised in the tables below. Most of the studies have measured recycled rubber infill materials as well and the studies are also described in Annex I.

Ethylene propylene diene monomer (EPDM)

According to Nilsson N. *et al.* (2008), EPDM rubber consists of carbon chains constructed from the monomers ethylene and propylene and a diene component, built in as a side chain. The advantage of this polymer structure is increased weather resistance, so that antiozonants are not needed and volumes of antioxidants are less. EPDM can be subjected to either peroxide or sulphur vulcanisation. The softeners used for EPDM are mainly naphthenic oils with a relatively low aromatic content. Triallyl cyanurate is used in peroxide vulcanised EPDM rubber as a cross-linking regulator.

Thermoplastic elastomers (TPE)

TPE is typically based on styrene ethylene butadiene styrene structure. TPE is not vulcanised, the mesh structure is formed by the styrene segments forming chrystalline domains. TPE has good weather resistance, similar to EPDM rubber.

Substances measured from alternative infill materials

The Norwegian Building Research Institute (2004) studied the content of recycled rubber (three samples), but also EPDM obtained from suppliers. In addition to substances in the material, leaching of zinc and chromium and organic compounds and substances from a gas mixture were analysed.

Leaching of chromium from EPDM was below 2 μg/l and leaching of zinc was 80 μg/l, which was slightly lower than for the recycled rubber. The concentrations of volatile organic compounds from EPDM infill material were lower compared to the recycled rubber granules. With the exceptions of chromium and zinc, the EPDM rubber contains lower concentrations of hazardous substances that the recycled rubber types overall. The airborne dust concentrations in the hall using EPDM were similar to other indoor environments, both PM10 and PM2.5 fractions.

The Norwegian Institute for Air Research (NILU, 2006) investigated air quality in three indoor artificial turf pitches. Two of the fields used SBR rubber granulates that originatedfrom recycled tyres. One field was using thermoplastic elastomer granulates. The total volatile organic compounds (TVOC) were lower in the hall which used TPE infill material. However, the authors state that there is little information available on this elastomer in the literature and further studies would be desirable to map the occurrence of other components.

Menichini E. *et al.* (2011) measured metals and several other substances from thermoplastic granules (virgin) collected from the field. The sum of 9 PAHs from one TPE sample was lower compared to the respective concentration from other infill materials. However, the other TPE sample had higher PAH concentrations compared to some samples from recycled material. The concentrations of some metals (Cd, Co, Cr, Li, Mg, Ni and Pb) in the other TPE were in the same order of magnitude than recycled rubber and some (Al, Ba, Be, Cu and Mo) higher.

Schiliro T. *et al.* (2013) investigated different types of fields among which were one field with clay and another field with thermoplastic as infill material. The conclusion was that there were no differences found between artificial football fields and 'natural' football fields.

In addition to fields using SBRs from shredded tyres, Ruffino, B. *et al.* (2013) studied substances from fields with thermoplastic elastomers and natural turf field with natural soil as infill material. The result showed that the thermoplastic sample had a lower total content of both benzene-toluene-xylene (BTX) and PAHs than the samples made of SBRs.

Marsili L. *et al.* (2014) tested samples from football fields in Italy. One of the 9 samples was from virgin rubber (natural rubber granules from stock, not more specified) and others from recycled tyres. The absolute levels of PAHs from this alternatives sample were high with higher concentrations of fluorene, pyrene and fluoranthene and benze(b)fluoranthene. These substances are not typically that high in recycled rubber. The PAHs measured in the evaporation test were at the low or average levels compared to recycled rubber.

Salonen R. *et al.* (2015) measured concentrations of 16 PAHs from different infill materials (TPO[30], SBR and EPDM). The concentrations of PAHs from TPO and EPDM samples were lower (0.1 and 1.5 mg/kg, respectively) compared to the concentrations from recycled rubber (38-81 mg/kg). Indoor PAH concentrations were very low in all halls. High aliphatic and alicyclic compounds from TPO infill were measured. From other infill materials, a group of aldehydes and ketones were dominating and for halls using SBR infill this was mainly from 4-methyl-2 pentanon (MIBK).

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[30] Thermoplastic polymer (thermoplastic olefin, i.e. olefinic thermoplastic elastomer)

Table VIII.1 Concentrations of metals in alternative infill material

	Norwegian Building Research Institute (2004) (EPDM from supplier, 1 sample) (mg/kg)	Menichini et al. (2011) (virgin thermoplastic, 1 sample) (mg/kg)	Marsili et al. (2014) (virgin rubber, 1 sample) (mg/kg)
Aluminium		1.2, 6 680	
Antimony		0.34, 7.7	
Arsenic	<2	0.14, 0.94	
Barium		4.4, 3 485	
Beryllium		0.001, 0.11	
Cadmium	<0.5	0.11, 0.37	2.68
Chromium	5 200	49, 56	2.84
Cobalt		<0.5, 27	
Copper	<3	0.82, 55	9.5
Iron		15, 4318	355.4
Lead	8		11.23
Lithium		4.3, 4.1	
Magnesium		470, 456	
Manganese		5.2, 30	
Mercury	<0.03	<0.02, 0.05	
Molybdenum		0.04, 2.1	
Nickel	<5	0.67, 1.5	8.95
Rubidium		0.65, 12	
Selenium		<0.3	
Strontium		17, 90	
Tin		0.12, 2.5	
Titanium		0.02, 0.09	
Vanadium		0.38, 2.4	
Wolfram		0.02, 0.84	
Zinc	9 500	118, 6 813	6 462

Table VIII.2 Concentration of polycyclic aromatic hydrocarbons in alternative infill material or infill material which origin is not known

	Norwegian Building Research Institute (2004) (EPDM from supplier, 1 sample) (mg/kg)	Menichini et al. (2011) (virgin thermoplastic, 2 samples) (mg/kg)	Fraunhofer IVV (2016) (rubber granulate, 1 sample) (mg/kg)
Naphthalene	0.19		
Acenaphthalene			
Acenaphthene	<0.08		
Acenaphthylene	<0.08		
Fluorene	<0.08		
Phenanthrene	0.43		
Anthracene	<0.08		
Fluoranthene	0.12		
Pyrene	0.16	0.02, 1.51	
Benzo(a)anthracene*	<0.08	0.001, 0.29	0.05
Chrysene*	<0.08	0.01, 1.43	0.06
Benzo(b)fluoranthene*	<0.08	0.001, 0.03	0.29
Benzo(k)fluoranthene*	<0.08		0.12
Benzo(a)pyrene*	0.12	<0.001, 0.05	0.75
Benzo(e)pyrene*			1.61
Dibenz(a,h)anthracene*	<0.08	<0.001	<LoD
Indeno(123-c,d)pyrene	<0.08		
Benzo(g,h,i)perylene	<0.08	0.01, 0.28	
Total PAHs	1	0.04, 3.67	2.96
Carcinogenic PAHs listed in entry 50 of Annex XVII to REACH*	0.12	0.012, 1.8	2.96

Table VIII.3 Concentration of other substances (other than PAHs and metals) from alternative rubber granules

	Norwegian Building Research Institute (2004) (EPDM from supplier,1 sample from supplier (mg/kg)	Norwegian Institute for Air Research (2006) (indoor fields, gas phase (µg/m^3) (g) and airborn dust (ng/m^3) (PM10) (d); 2 halls with black and an unknown type (green)) and SBR)	Ruffino et al. (2013) (4 samples) (µg/m^3)	Schilirò et al. (2013) (ng/m^3) (4 fields, 2 samples, 2 m height from street level	Simcox (indoor) µg/m3	Salonen et al. (2015) (4 indoor samples, recycled SBR***) (µg/m^3)
Benzene			1.3-2.2	1.3-6.0	ND	0.5-7.0
Toluene	28-80	15.0-85.0 (g)	4.2-10.2	4.2-31.2	135.4	1.5-84
Xylene (o-, m-, p-)	45-78		7.6-20.9	7.2-33.7	12.13	0.7-69
Phthalates						
di-2-ethylhexylphthalate (DEHP)	3.9	31.3, 17.7 (d)				
di-isobutyphthalate		0.01-0.13 (g)				
Dimethylphthalate (DMP)	3.4	39.1, 50.3 (d)				
Diethylphthalate (DEP)	1.5	0.01-0.06 (g) 24.4 10.4 (d)				
Dibutylphthalate (DBP)	1.6	0.07-0.38 (g) 31.4 51.7 (d)				
Benzylbutylphthalate	<1.0	5.2, 4.3 (d)				
Di n-octylphthalate	3.2	<0.01, <0.01 (d)				
Benzothiazols						
Benzothiazol		4.5-31.7 (g)				1-13
2-hydroxybenzothiazol		346, 566 pg/m^3 (d)				
2-mercaptobenzothiazol		287, 352 pg/m^3 (d)				
2-aminobenzothiazole		54, 28 pg/m^3 (d)				
N-cyclohexyl-2-benzothiazolsulfenamide		23, 3 pg/m^3 (d)				
Other						
4-tert-octylphenol	49.8 (µg/kg)					
4-n-nonylphenol	<5 (µg/kg)					
Iso-nonylphenol	1 120 (µg/kg)					
PCBs	>0.004					
Methyl-isobutyl-ketone (MIBK)		3.4-12.7 (g)				0.8-14.5
Formaldehyde						1.7-4.2

	Norwegian Building Research Institute (2004) (EPDM from supplier,1 sample from supplier (mg/kg)	Norwegian Institute for Air Research (2006) (indoor fields, gas phase (µg/m³) (g) and airborn dust (ng/m³) (PM10) (d); 2 halls with black and an unknown type (green)) and SBR)	Ruffino et al. (2013) (4 samples) (µg/m³)	Schilirò et al. (2013) (ng/m³) (4 fields, 2 samples, 2 m height from street level	Simcox (indoor) µg/m3	Salonen et al. (2015) (4 indoor samples, recycled SBR***) (µg/m³)
TVOC						10.0-70.00

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