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Analysis of energy use and emissions of greenhouse gases, metals and organic substances from construction materials used for artificial turf

Simon Magnusson[a,*], Josef Mácsik[b]

[a] Luleå University of Technology, Department of Civil, Environmental and Natural Resources Engineering, Division of Mining and Geotechnical Engineering, SE-97187 Luleå, Sweden
[b] Ecoloop AB, Mosebacke torg 4A, 11646 Stockholm, Sweden

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ABSTRACT

This study applied a life cycle analysis approach to identify significant posts for energy and greenhouse gas (GHG) emissions associated with construction, use and removal of an artificial turf field. A chemical analysis of infills was conducted to describe leachability of metals and organic substances. The infill types studied were recycled tires (RT), virgin thermoplastic elastomers (TPE), virgin ethylene propylene diene monomer (EPDM) and recycled EPDM (R-EPDM) from cables and automotive mats. The result shows that energy use and GHG emissions of an artificial turf field significantly correlates with material choice, maintenance and management of removed turf. Energy use and GHG emissions for infills was highest for TPE followed by EPDM. In summary, use of recycled material as infill, reuse of soil and rock on site and reuse of removed turf and infill could reduce energy use and GHG emissions. Leachates from RT and R-EPDM contained detectable concentrations of zinc, which was relatively high from R-EPDM. Organic substances, harmful for aquatic environments and/or humans were detected in all leachates but in highest concentration from R-EPDM followed by EPDM. In the literature, risk assessments focused predominantly on RT while assessments of other infills was less extensive or was missing. The result in this article stressed the need to include all infill types in risk assessments. Previous environmental risk assessments based on field measurements concluded risks with infills to be small or minimal. However, since these assessments are few, this study suggested verification of those results by field measurements.

1. Introduction

Artificial turf fields are used by professional athletes, amateurs and for spontaneous play. Construction of artificial turf fields has greatly increased in northern Europe, such as in Sweden and Norway (Football Association of Norway, 2015; Swedish Football Association, 2015). Artificial turf produces significantly more user hours than natural grass fields due to its durability. The design of artificial turf fields is illustrated in Fig. 1. The upper layer consists of a synthetic carpet where synthetic fibers are attached to a perforated backing of textile and latex. A layer of fine sand and shock-absorbing infill supports the synthetic fibers. Infill from recycled tires (RT) can be used. Other polymer based infill types are new materials of thermoplastic elastomers (TPE) and ethylene propylene diene monomer (EPDM) and recycled EPDM rubber (R-EPDM) originating from products such as cables and automotive carpets. A shock pad, of permeable elastic compound can be installed beneath the synthetic carpet. These layers are followed by fine sand and crushed rock forming a subbase and a drainage system.

A local environmental impact from infill materials has been a concern. The infill materials consist of polymers and additives that provides material properties such as softness and ultraviolet protection. The materials can contain metals and organics substances that could leach to water. Mainly zinc has been detected in leachates from RT (Bocca et al., 2009; Plesser and Lund, 2004) and in less concentrations from TPE (Ruffino et al., 2013) and EPDM (Nilsson et al., 2008; Plesser and Lund, 2004). Other metals have been detected in leachates of RT and TPE infill, such as aluminum, copper, magnesium in lower levels (Ruffino et al., 2013). Polyaromatic hydrocarbons (PAH: s) have been detected in leachates from RT (Gomes et al., 2012; Plesser and Lund, 2004; Ruffino et al., 2013;)

Abbreviations: LCA, life cycle assessment; RT, recycled tires; TPE, thermoplastic elastomer; EPDM, ethylene propylene diene monomer; R-EPDM, recycled EPDM; GC–MS, gas chromatography mass spectrometry; PVC, polyvinylchloride; GHG, greenhouse gas; MDI, methylene diphenyl diisocyanate; SEBS, styrene ethylene butylene styrene; DOC, dissolved organic carbon; S-VOC, semi-volatile organic compounds.

* Corresponding author.
E-mail address: simon.magnusson@ltu.se (S. Magnusson).

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Table 1
Environmental and health risk assessments of artificial turf fields and its materials, sorted on risk assessment steps (RA 1–5) included. RA (1) information statement/problem definition, (2) impact analysis, (3) exposure analysis, (4) risk characterization, and (5) overall risk assessment (European Chemicals Bureau, 2003a,b).

Reference	RA step	Materials/system studied. (Material supplied = MS)	Assessment results (Local environmental risk = ER, Health risk = HR)
Pavilonis et al. (2014)	1,2,3,4	Infill (RT) and turf fibers. Outdoor or indoor not specified. *MS*: US	*HR*: Risk due to dermal, ingestion and inhalation exposure to infill and artificial turf was generally considered de minimus. Relatively high content of lead in one turf fiber.
Ruffino et al. (2013)	1,2,3,4	Outdoor fields with (RT and TPE) infill. *MS*: Italy	*HR*: For dermal and inhalation exposure, the cumulative carcinogenic risk was lower than 10 − 6 and the cumulative noncarcinogenic risk lower than 1.
Kim et al. (2012)	1,2,3,4	Turf, infill (RT, EPDM), back coating, elastic pavement. *MS*: Korea	*HR*: Minimal direct health risk regarding dermal, inhalation and ingestion exposure, except for ingestion exposure for children with pica.
Ginsberg et al. (2011)	1,2,3,4	Outdoor and indoor fields with infill (RT). *MS*: N/A	*HR*: No elevated adverse health risks due to inhalation exposure. Adequate ventilation is recommended.
Menichini et al. (2011)	1,2,3,4	Outdoor field and Infill (RT, coated RT, TPE and R-EPDM). *MS*: Italy	*HR*: For the benzopyrene. an excess lifetime cancer risk of $1 \times 10 - 6$ due to inhalation was calculated for an intense 30-year activity at RT fields.
Lim and Walker (2009)	1,2,3,4	Infill material (RT) and outdoor field *MS*: USA	*ER*: No organics and low levels of metals detected in surface water. No impact on groundwater. RT entirely from truck tires was estimated to possibly have an impact on aquatic life due to zinc exposure. *HR*: Inhalation exposure does not indicate a concern for non-cancer or cancer effects. Football fields are not important contributors of exposure to particulate matter. RT is no source for lead exposure when compared to federal hazard standard for lead in soil.
Nilsson et al. (2008)	1,2,3,4	Infill (RT, coated RT, TPE, EPDM and coir), turf mats, pad and road salt. *MS*: Norway	*ER*: No major risk. *HR*: Dermal and oral exposure is concluded to cause minimal risk. Potential allergic risk due to dermal exposure for benzothiazole and amines in RT and EPDM for sensitive individuals.
Verschoor (2007)	1,2,3,4	Infill (RT) *MS*: Netherlands	*ER*: Potential ecotoxicological risk in surface water, groundwater and soil may occur.
Vidair et al. (2007)	1,2,3,4	Infill (RT), rubber surfaces (RT), soil *MS*: USA	*ER*: Small regarding exposure to soil and ground water. *HR*: Minimal regarding ingestion and dermal exposure. Slightly above minimal regarding chronic hand to mouth activity
Moretto (2007)	1,2,3,4	Infill (RT, EPDM, TPE) at outdoor and indoor fields *MS*: France	*ER*: Minimal impact on water resources and the aquatic environment in the short and medium term. *HR*: Health risks associated with the indoor inhalation of VOC and aldehydes present no actual cause for human health. No cause for concern as regards human health for the workers, general public and professional or amateur athletes, whether adults or children indoors. Good ventilation is recommended in case of workers installing artificial surfaces in small and poorly ventilated gymnasia.
Birkholz et al. (2003)	1,2,3,4	Infill (RT) *MS*: Canada	*ER*: Significant risk of contamination in surface water or groundwater is doubtful. *HR*: The cancer risk due to ingestion exposure is minimal.
NIPH and the Radium Hospital (2006)	1,2,3,4	Indoor fields and Infill (RT) *MS*: Norway	*HR*: No increased risk of leukemia due to inhalation exposure. No elevated risk for contact allergies due to dermal exposure. The possibility for latex allergy due to inhalation exposure cannot be entirely eliminated. RT should not be used indoors when infill is replaced, due to lack of knowledge about potential latex allergy risk.
Schiliro et al. (2013)	1,2,3	Outdoor fields with (RT and TPE) infill *MS*: Italy	*HR*: Inhalation exposure present no more exposure risks than the rest of the city.
USEPA (2009)	1,2,3	Outdoor field with RT infill *MS*: USA	*ER*: No conclusions on risks are made. *HR*: No conclusions on risks are made.
Joost and Jongeneelen (2010)	1,2,3	Outdoor field with RT infill *MS*: Netherlands	*HR*: Minimal uptake of PAHs regarding all exposure ways.
Johannesson and Sandén (2007)	1,2,3	Outdoor field with RT infill *MS*: Sweden	*HR*: No increased risk for cancer regarding dermal, ingestive and inhalation exposure.
Dye et al. (2006)	1,2,3	Indoor halls with infill (RT and TPE) *MS*: Norway	*HR*: The use of RT causes a considerable burden on the indoor environment. For all three halls, organic chemicals are found in air.
Tekavec and Jakobsson (2012)	1,2,3	Outdoor field and RT infill *MS*: Sweden	*HR*: Levels of PAH and phthalates was similar to levels in general population. Due to the precautionary principle, other types of infill than RT is recommended to be used.
Christensson and Antonsson (2004)	1,2,3	Indoor field with 50% RT and 50% EPDM infill *MS*: Sweden	*HR*: Levels of heavy metals and benzoaporen was significantly below air limit standards.
Ottesen et al. (2011)	1,3	Shock-absorbing surfaces with RT and EPDM *MS*: Norway	*ER*: N/a. Leaching of THC (C12–C35), PAH, PCB, A health risk assessment needs to be conducted. THC (>C5–C35), zinc, nonylphenol, PAHs and PCBs was found in all products.
Widenbrant (2011)	1,3	Outdoor fields with RT infill *MS*: Sweden	*ER*: Water quality is within drinking water standard.
Ulirsch et al. (2010)	1,3	Turf fibers. *MS*: USA and South Korea	*HR*: Synthetic turf can deteriorate to form dust containing lead at levels that may pose a risk to children. Exposure pathways have not been specified.