Ecosystem services for compensation of artificial turf systems*

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1. Introduction

Constructing football fields in Sweden with artificial turf has grown in popularity in recent years. Although the increase in playing time per year is a significant benefit of using artificial turf, there are many potential environmental costs. The environmental impact of foregone ecosystem services has received relatively little attention, as most emphasis has been put on understanding other environmental impacts, such as microplastics released from artificial turf. However, it is important to consider that natural grass provides ecosystem services, which are lost once the land is converted to artificial turf.

The purpose of this report is to study the potential loss of ecosystem services when converting land to artificial turf. The report begins with a background on the construction of artificial turf fields in Sweden and the types of artificial turf. The report then summarizes the main environmental impacts of artificial turf compared to natural grass turf. The report then focuses on the ecosystem services from grass turf that are potentially lost when converted to artificial turf. The types of ecosystem services are first described, then a monetary value is given when possible. The main finding is that the value of foregone ecosystem services is estimated to be 1 SEK per square meter per year. A description of potential compensation measures for the foregone ecosystem services are also provided. Conclusions follow in the final section of the report.

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2. Background

By September 2020, there are (at least) 1149 artificial turf pitches in Sweden, out of which 772 are 11-man football fields, 289 are 5-7-9-man football fields and 88 smaller football halls (Svenska Fotbollsförbundet, 2021)[4]. The total surface area of these fields is estimated at 6.9 km^2 (Krång et al. 2019), although it is likely larger by 2020. The artificial turf fields can be used 2000 hours on average per year (Länsstyrelsen Skåne, 2016).

In Scandinavia, there are around 3000 artificial turf fields to date (KG 2021), and it has been estimated that 21000 full-sized pitches and about 72000 mini-pitches would exist in Europe by 2020 (ECHA 2017). Different reasons motivate the rapid growth of the artificial turf field market worldwide in the last decade. Artificial turf fields are generally installed as a complement to natural turf. There are about 4000 natural turf fields in Sweden[5]. Compared to natural fields, artificial turf systems provide increased playing hours, (almost) all-weather availability and reduced maintenance. In the United States, natural turf pitches can provide between 300 to 816 hours of annual playable time, whereas artificial turf fields are estimated to have a usable time from 2000 to 3000 hours on average per year (Simon 2010). Artificial turf recovers quickly after precipitation, which decreases weather-related use-time loss in relation to natural fields. Moreover, reduced maintenance is often cited as one of the major benefits of synthetic turf[6]. While natural turf requires mowing, fertilizing, application of pesticides if necessary, aeration and irrigation, the latter demands some minimum level of grooming (upkeep of seams, fibers, infill and drainage system), debris control and additional cleaning, in order to maintain the surface quality. In spite of requiring low maintenance, artificial turf can decline in performance because of carpet wearing and weathering (McLaren et al. 2012). However, the increased playing time and availability of synthetic turf pitches make them a relatively more cost-efficient investment. For instance, Simon (2010) estimates that the total cost of ownership over a ten year period is from 10% to 20% less than a natural turf field.

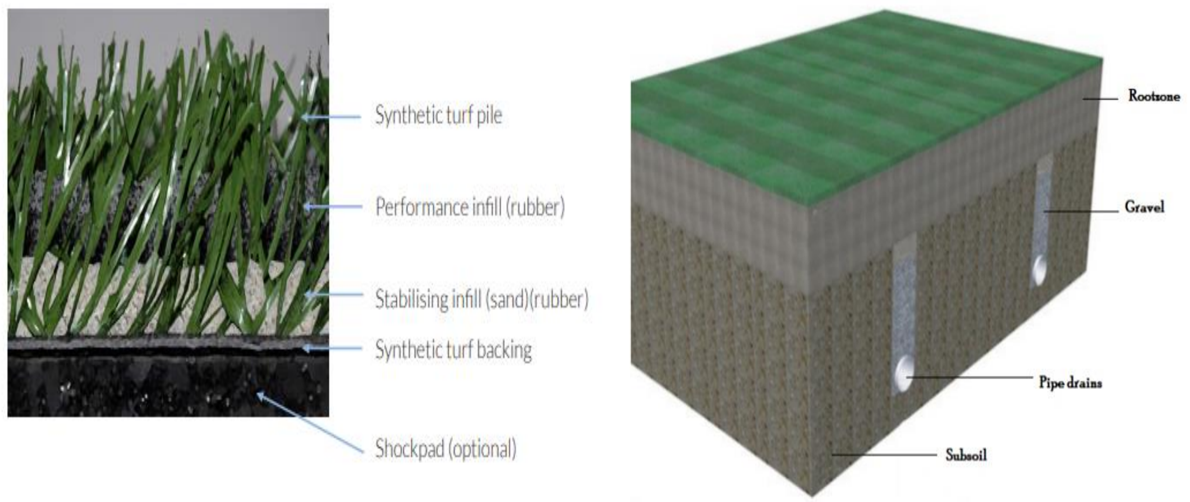
[4] It was also investigated the number of natural grass (football) pitches in Sweden. However, such inventory records are deficient according to officers from the Swedish Football Association. Nonetheless, some rough estimations were provided by e-mail correspondence: 2600 for 11-man fields, 175 for 9-man fields, 975 for 7-man fields, and 250 for 5-man fields. Actual numbers may be overestimated as some football fields can be double registered.

[5] Based on personal correspondence with SVFF.

[6] This report uses the terms “artificial turf” and “synthetic turf” interchangeably. Moreover, the report does not make any distinction between “artificial turf”, “artificial turf pitches”, “artificial turf fields”, “synthetic turf”, “synthetic turf fields”, and “synthetic turf pitches”. Also, “natural grass” refers to “natural turf fields”.

Artificial turf surfaces are manufactured to replicate the appearance and performance of natural grass in residential lawns, golf courses, athletic pitches, playgrounds and sports fields (Wattersson 2017). Artificial grass fibers, carpet backing and infill are the primary layers that compose an artificial turf system (Cheng et al. 2014). In Sweden, fibers are generally made of polypropylene or polyethylene (plastic), and these are sewn and fastened on the carpet backing (Svenska Fotbollsförbundet 2020). The carpet backing holds the fibers and allow vertical drainage. The infill is added to soften the field and let the individual fiber blades to stand up. In Sweden, SBR (Styrene Butadiene Rubber) crumb is the traditional infill material. This consists of rubber granulate, also known as rubber crumb, made from recycled scrap tires. Artificial turf systems can include a shockpad, which is an additional layer beneath the surface system to enhance shock absorption (Fleming 2016). The type of shockpad can decrease the needed amount of infill material (Bauer et al. 2017). A sand layer is added beneath the infill material to be used as ballast and reduce carpet displacement. Unlike natural grass that can be waterlogged in rainy periods, synthetic turf fields are constructed with a built-in drainage system (Cheng et al. 2014). A typical synthetic turf system in football pitches is illustrated in Figure 1. Synthetic turf playgrounds usually do not contain rubber crumb granules but sand as the only infill material. Hence, the presence of the shockpad is customary in playground installations whilst optional in football pitches.

Figure 1. Artificial turf system (left) and Natural grass system (right)



Source: EMEA Synthetic Turf Council and SVFF

Besides the traditional SBR granulates, there are different infill materials available: TPE, EPDM and organic materials. The TPE (Thermoplastic Elastomer) is a crosslink of plastic and rubber. The EPDM (Ethylene Propylene Diene Monomer) is a polymer with elastic or rubber-like characteristics. The organic infills available in the market are sand, coconut, cork, bark, pine and sugar cane (Svenska Fotbollförbundet 2020).

Currently, the Swedish Football Association roughly estimates that 70% of the artificial turf pitches uses SBR, 20% uses EPDM or TPE, and the remaining 10% uses organic infills[7]. In the Netherlands, there are about 2000 synthetic turf pitches for football, which 90% have rubber crumb infill and 10% have another infill material (Pronk et al. 2018). In Norway, about 1600 artificial turf fields have been established, and 85%-90% of the football pitches have crumb rubber infills (Bauer et al. 2017; ECHA 2016).

The demand of artificial turf systems is projected to increase worldwide, mainly because these can provide substantially more hours of playing time than natural grass fields (Simon 2010). However, the concerns on the potential environmental hazards of microplastic emissions from rubber granules are leading to the development of alternative infill materials. For instance, the BioPitch project aims to develop biobased infills that can be recycled and are biodegradable (Stockholms Fotbollförbund 2020). These new infills would be expected to use forest raw constituents to substitute the current fossil-based materials without compromising performance, safety and playability. Furthermore, current artificial turf systems are trying to remove elastic infills and introduce filament fibers of higher density with a sand-only infill to stabilize the turf. The use of non-infill systems and/or the reduction of synthetic infill materials aim to lessening the environmental impact of artificial turf systems (KG 2021).

3. Comparative review of environmental impacts of natural and artificial turf systems

This section summarizes a compendium of research studies and reports addressing the environmental impacts of natural and artificial turf fields. A comparative review is relevant to identify and understand potential foregone benefits of converting natural into artificial turfgrass.

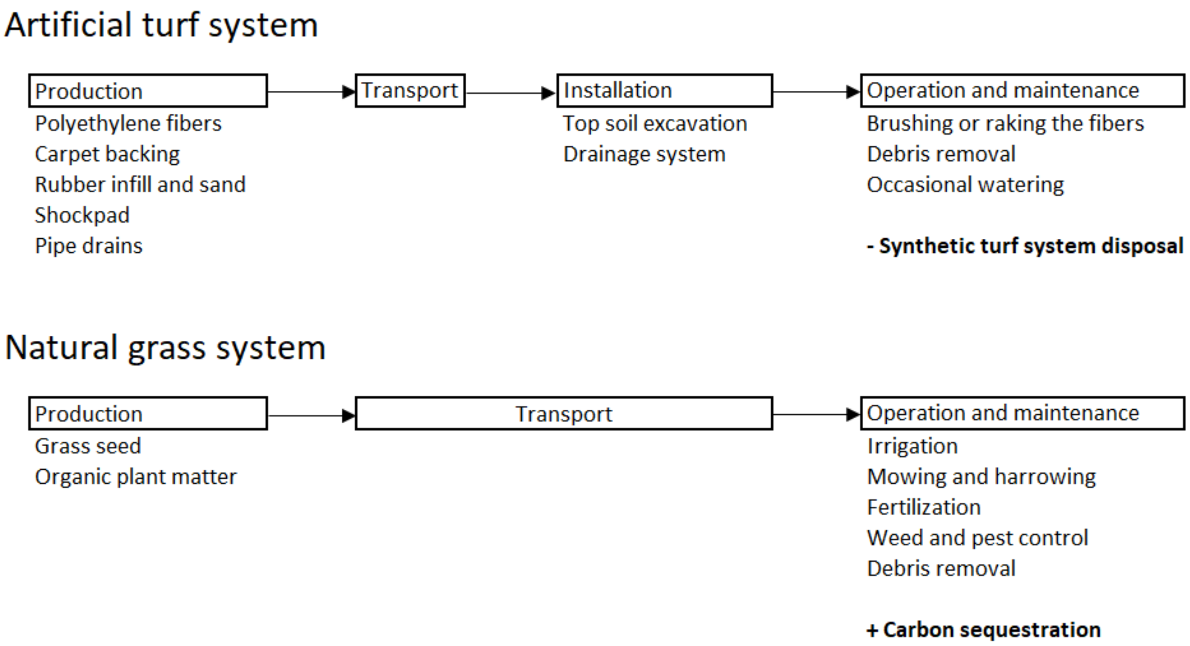
Greenhouse gas emissions

[7] These percentages are based on e-mail communications with construction consultants (anläggningkonsulent) from Svenska Fotbollsförbundet in march of 2021.

Natural grass has the ability to store organic carbon in the soil, and thus have a relatively smaller carbon footprint compared with artificial turf systems (Cheng et al. 2014). However, intensive management practices as inorganic fertilization, irrigation and fuel consumption from mowing and leaf blowing can decrease the likelihood that natural grass fields can mitigate greenhouse gas emissions in cities (Townsend-Small and Czimczik 2010b). Urban turf grass emits N_2O (nitrous oxide) after fertilization and/or irrigation (Hall et al. 2008).

In 2007, the Athena Institute of Ontario Canada quantified the greenhouse gas (GHG) emissions during the life cycle of a synthetic turf system as opposed to a natural grass surface (Meil and Bushi 2007). The study was commissioned by the Upper Canada College (UCC) to offset the GHG emissions when replacing its natural grass playing field by artificial turf grass. Using a life cycle approach, the study identified the main stages in the installation of the artificial turf system: production of the main components, maintenance, disposal (recycling) and transportation. The main components used in the synthetic field installation were: (1) turf fibers of polyethylene, (2) a primary backing material made up of three layers: a woven fiberglass layer, a woven polypropylene/polyester blend layer, and a fiber fleece layer (3) a secondary backing of polyurethane, (4) rubber infill granules from recycled tires, and (5) PVC piping to provide field drainage. Figure 2 illustrates the main stages of the life cycle of an artificial turf system and a natural grass system. The life cycle approach is presented to illustrate the stages involved when converting to artificial turf from an already installed natural grass field. Moreover, the purpose of this illustration is to present the stages where greenhouse gas emissions (and carbon sequestration) can take place.

Figure 2. Life cycle of an artificial turf (left) versus an installed natural grass system (right).



Source: Based on Athena Institute's study

By taking a reference field size of 9000 m^2, natural grass yielded GHG emissions of -16.9 metric tonnes (i.e., a net reduction in GHG release of CO_2e) whereas artificial turf yielded GHG emissions of 55.6 metric tonnes (i.e., a net increase in GHG release of CO_2e). The study determined that 1891 coniferous trees were needed to be planted over a ten-year period in order to balance the carbon footprint of the new artificial turf system. The Athena Institute's study can provide an informative benchmark and methodological approach to calculate and compare GHG emissions from the two different systems. Nonetheless, there are limiting factors in extrapolating the findings. The transportation of materials are site-specific, thus GHG emissions will vary depending on the logistics, distance and means of transport used to carry, assemble and install the turf components. Also, fertilizer production and transport are ignored in the Athena Institute's study. This is an important caveat because fertilizers have a very high global warming potential. Simon (2010) states that that fertilizers are made using very energy-intensive manufacturing processes to produce nitrogen; moreover, natural gas is a petroleum-based product and the basic feedstock of nitrogen fertilizers.

Townsend-Small and Czimczik (2010a) find that the organic carbon stored in urban (natural) turf athletic fields does not compensate the total GHG emissions of these surfaces. Athletic fields (soccer and baseball) were constructed from imported turf grass sods, and underwent renovations every year including tilling and re-sodding. Regular maintenance involved grass trimming, mulching, fertilization (from 2 to 15 times a year) and watering with recycled wastewater. The time since establishment of the athletic fields was between 2 and 33 years.

The results yielded no net storage of CO_2 to offset the N_2O emissions in the athletic fields. This was motivated by: (1) the fuel consumption to maintain the natural turf grass such as the fuel transport and the fuel used for mowing, trimming and mulching; (2) the energy required for irrigation, and (3) the fertilizer production, which vary depending on the application frequency[8].

Microplastic emissions

Microplastics are plastic particles smaller than 5 mm (FIFA 2017), which break down very slowly and can end up in coastal waters and ingested in marine ecosystems (e.g. by plankton). However, there is scarce data on how much of the microplastic into the ocean is coming from synthetic turf fields. After road traffic, synthetic turf has been identified as the second largest quantifiable source of microplastic particle emissions in Sweden, and it is responsible for approximately 2300 – 3900 tonnes (Swedish Environmental Research Institute, in press 2016). In Norway, about 3000 metric tonnes per year of microplastics are lost from artificial turfs (Mepex 2016). In Denmark, 380 – 640 tons per year were expected to be lost from 254 synthetic turfs in 2015 (Lassen et al. 2015). The possible pathways are through storm water drains, snow removal, and granulate sticking on clothes, skin and shoes (KG 2021). By taking a survey of 141 fields in Norway, it has been estimated that granulate loss increases by 70% during winter operations (Rambøll 2017).

Risk assessments on Human health

Manufacturers promote synthetic turf as environmental friendly because of the water conservation potential (no need for irrigation) and the use of recycled tire rubber. However, synthetic turf infill contains chemical substances that can be harmful to human health. To characterize the potential risk from synthetic turf infills, a health risk assessment was conducted with rubber granule samples from turf sports sites in 14 European countries, including Sweden (Schneider et al. 2020a, 2020b and 2020c). Chemical substances from rubber granules were identified to assess the oral, dermal and inhalation exposure; however, the study acknowledges an identification gap of all relevant hazardous substances. The authors claim the results of the study to be in line with other epidemiological studies and risk assessments. For example,

[8] That study also conducted the same analysis for urban ornamental lawns and the results show that those ornamental turf fields may have a potential to sequester atmospheric CO_2 if managed conservatively. The main difference between the ornamental lawns and the athletic fields is that the latter is very likely more subject to intense physical perturbations.

carcinogenic contaminants (polycyclic aromatic hydrocarbons, PAH's) in rubber granules are found present below critical levels of concern (Bleyer and Keegan 2018), and the release of hazardous substances, e.g., biosphenol A, phthalates, heavy metals (e.g., cadmium), and benzothiazoles, does not exceed critical limits (Peterson et al. 2018, Pronk et al. 2018). Overall, the research finds negligible health risks in the use of synthetic turfs with rubber infill material from scrap tires. Nonetheless, the impact on human health remains controversial due to the microplastic emissions and the presence of zinc highlighted in other studies (Sweco 2016, Swedish Chemicals Inspectorate 2006).

In 2005, the Norwegian Institute of Water Research conducted an environmental risk assessment of the leachate materials from artificial turf sports grounds (Källqvist 2005). The investigation claims that the most problematic pollution component originates from rubber granulates based on recycled rubber from car tires. Zinc concentrations represent the greatest risk to the water stream receiving the run-off from a football field[9]. The study claims that the total annual amounts of hazardous substances are fairly low, thus the scope of the environmental effects is expected to be slow (over the course of many years) and local only, i.e., will depend on local conditions. A noteworthy assumption (simplification) of the investigation is that the run-off occurs directly to a watercourse and not through infiltration into the ground (adsorption).

Natural grass fields can also have impact on human health under extreme weather conditions or poor maintenance practices. Upkeep of natural turf demands the use of fertilizers, herbicides and pesticides that can ultimately reach water streams if the soil becomes overly saturated under heavy rain seasons. Fertilization provides the nutrients (nitrogen, phosphorus and potassium) to stimulate plant growth and ensure the chemical balance in the soil (BASF 2010); while herbicide and pesticide agrochemicals can be applied for weed and pest control. In spite of water infiltration, leachate of (high) chemical pollutant concentrations can potentially be harmful for aquatic ecosystems and human health.

Water use

Artificial turf systems do not require irrigation; yet, the turf field can be watered occasionally for cooling down the surface under very high temperatures[10]. On the other hand, natural grass

[9] The environmental risk was also attributed to alkylphenols, and octylphenol in particular.
[10] This is a quick but temporary way to reduce the field temperature. The effect is very limited and may rather result in additional costs (Lavorgna et al. 2011).

demands regular irrigation to maintain the surface quality of the field, prevent drought stress and activate fertilizers, herbicides and pesticides. Water savings is a typical argument from synthetic turf companies to promote artificial turf installations. In 2010, the Synthetic Turf Council in the United States estimated that over three billion gallons of water were conserved through the use of synthetic turf fields[11]. A natural grass sports field in the US can roughly consume between 0.5 to 1 million gallons of water every year (Lavorgna et al. 2011).

4. Ecosystem services of natural grass and potential compensation measures

Ecosystem services refer to the benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005), and these can be classified into provisioning, regulatory, cultural and supporting services. Provisioning services encompass those benefits obtained from nature extraction (e.g., wood fibers from a forest ecosystem). Regulatory services refer to the benefits gained from the processes governing the natural phenomena in the ecosystem, such as, climate regulation through carbon storage, and flood protection through water absorption. Cultural services relate to experiential values such as outdoor recreation in forest or urban environments. Supporting services are those enabling the other ecosystem services to function, e.g., photosynthesis and soil formation (Naturvårdsverket 2018). Turf pitches are not intended to deliver provisioning services but to provide aesthetic and recreational value. However, the differences between natural and artificial fields concentrate mainly on the regulatory and supporting ecosystem services[12].

4.1 Ecosystem services of natural grass

Groundwater recharge and surface water quality: Perennial turfgrasses have an extensive and fibrous root system that tends to dominate the upper 200 -300 mm of the soil profile (Beard et al. 1994). Provided this root system, the turfgrass ecosystem forms a very dense aboveground biomass that reduces runoff and thus allows time for soil infiltration of water; as a result,

[11] STC (2010). Last accessed March 23 of 2021: https://www.syntheticturfcouncil.org/news/123873/Synthetic-Turf-Conserves-More-Than-Three-Billion-Gallons-of-Water-and-Helps-the-Environment.htm

[12] Natural and synthetic fields are constructed essentially to provide similar (or the same) recreational services, but there can also exist eventual marked differences concerning cultural values. For example, a natural grass field can embody distinct symbolic value for a specific community, which can affect the preferences toward converting such fields into an artificial alternative. Also, the aesthetic preferences can markedly differ from person to person.

fertilizers are unlikely to pass through the root zone into the groundwater or be transported by runoff water into surface streams (Gross et al. 1990). Under proper management practices, turfgrasses have displayed high capacities for nitrogen retention, which can prevent nitrogen from leaching into groundwater (Thomson and Kniffin 2017).

Artificial turf is constructed with porous backing layers in order to maximize drainage and minimize runoff or puddling. However, microplastic emissions from scrap tire materials may affect groundwater quality in artificial turf systems as opposed to natural grass fields (Cheng et al. 2014). Krång et al (2019) suggest a number of measures to minimize the transmission of microplastics. Some of these measures are associated with snow clearance which is critical to minimize the loss of rubber granulates. The proposed measures are the following: 1.) Placement of hard surfaces (e.g., asphalt) with surrounding frames for snow storage to collect granulates after snow melting, 2.) Closing the field during snow or reduce its use, 3.) Installation of granulate traps and/or finer filters in surface water drains. In addition, the risk of infill loss can be reduced with appropriate field boundary barriers, handling of infill bags and appropriate handling and storage of maintenance equipment (Magnusson and Mácsik 2020).

Soil erosion control and dust stabilization: According to Beard et al. (1994), the erosion control effectiveness of turfgrass is the combined result of a high shoot density and root mass for surface soil stabilization, plus a high biomass matrix that provides resistance to lateral surface water flow, thus slowing otherwise potentially erosive water velocities. Such control is very important in eliminating dust and mud problems around homes, factories, schools, and businesses.

Biodiversity[13]: Natural turf ecosystems can support abundant populations of earthworms (*Lumbricidae*; Potter et al. 1990) which activity increases the amount of macropore space within the soil resulting in higher soil water infiltration rates and water retention capacity (Lee 1985). Large populations of microflora and microfauna are supported by the soil-turfgrass ecosystem, being the microflora the largest proportion of the decomposer biomass of most soils. Soil invertebrates play an important part in the decomposition process, yet only 10% or less of the CO_2 produced during decomposition is attributed to them (Peterson and Luxton 1982). Microbial biomass of mowed turfgrasses is probably higher than un-mowed grass because of the high carbon biomass contained in grass clippings and to the more favorable soil

[13] Biodiversity is not considered an ecosystem service *per se* in most classifications, because it is not regarded as a prerequisite for all ecosystem services (Natursvårdsverket 2018).

moisture regime due to irrigation (Smith and Paul 1990). Microorganisms break down and recycle organic and inorganic products falling on the surface. Soil microbes decompose pesticides and bacteria produced by human fluids. Depending on the climate zone, the turfgrass ecosystem can support diverse communities of non-pest invertebrates including insects, mites, nematodes, annelids, gastropods, rove beetles, ground beetles, ants, spiders, earthworms, oribatid mites, springtails and others (Beard et al. 1994).

Heat dissipation: Natural turf grasses dissipate high levels of radiant heat in urban areas. Under similar weather conditions, natural grass fields generate lower surface and ambient temperatures than synthetic turf fields with crumb rubber infill in particular. Lavorgna et al. (2011) state that there could be some impact on urban heat islands associated with artificial turf fields, but the magnitude of such heat effect is unclear and will depend on, for example, the color and other specifications of the infill material and of the artificial turf carpet. According to a health risk assessment conducted for the municipality of North Cowichan in Canada, synthetic turf surfaces may pose a risk of heat-related illness, including burns, heat stress and dehydration (McKee 2015). Restricted use of artificial turf grasses during peak heat conditions shall be explored as a potential measure to reduce the risk of heat-related injuries.

The smell of grass fields is normally pleasing with proper maintenance, whereas tire rubber crumb in artificial turf can produce unpleasant odors above certain warm temperatures (Cheng et al. 2014). Irrigation and installation of head sprinklers can contribute to cooling down synthetic surfaces and reduce the surface temperature and strong smell. However, the cooling effect is normally very temporary (lasting less than 30 minutes; Serensits et al. 2011), and costly because of additional equipment and staff presence (Lavorgna et al. 2011). The use of organic infills (or fields without granules) can seemingly diminish the effect of heat in relation to crumb rubber materials, yet the latter plastic-based granules dominate the performance infill market (FIFA 2017).

Carbon storage: Carbon cycling in managed natural grasses is substantially different than that in natural environments because of human management practices such as irrigation, fertilization and mowing (Zhang et al. 2013). Carbon emissions from maintenance practices in natural turfgrasses (e.g., fossil fuel consumed by mowing, embodied energy in fertilizers, and energy for irrigation) may decrease or completely offset belowground carbon storage (Townsend-Small and Czimczik, 2010)[14].

Noise abatement and glare reduction: Beard et al. (1994) claim that turfgrass surfaces can reduce noise and light reflection significantly. Moreover, turfgrass can absorb harsh sounds better than hard surfaces such as pavement, gravel or bare ground. However, there is scant research comparing noise and glare reduction between natural grass and synthetic turf fields.

Air pollution control: Certain turfgrasses, such as the *Festuca arundinacea* (tall fescue), may be useful as an absorber of carbon monoxide (CO) from the urban environment provided that CO concentrations can be high near roadsides or areas with high traffic (Gladon et al. 1993).

4.2 Economic value of foregone ecosystem services

Air quality, soil quality and biodiversity-related ecosystem processes are potentially the main natural capital affected by the conversion of natural grass into artificial turf. Hence, the main foregone ecosystem services are those associated with air pollution control, noise reduction, solar heat dissipation, habitat provision, species richness, soil loss prevention and erosion control. Such ecosystem services are not traded on markets. This poses challenges on estimating economic values attached to those ecosystem functions[15].

A Canadian study provides an economic valuation of ecosystem services for the Greenbelt's grasslands in Ontario, Canada (Wilson 2008). The economic values provided in this section are based on the Canadian study because ecosystem services of (managed) grasslands can be similar to those of (managed) natural grass. The economic values provided in the Canadian study are adjusted to monetary values of 2021 and converted to Swedish kronor. According to the estimated calculations presented in Table 1, the foregone ecosystem services can be roughly estimated in nearly **1 SEK per m^2**. A full-size football pitch is about 105 meters long x 68 meters wide. This is an area of 7 140 square meters in total, which means that foregone services are about **7 140 SEK** per full-sized football field. A clear limitation of this estimated value is associated with the site characteristics. Namely, the calculation is based on Greenbelt's grassland soils in Ontario (Canada), which differ substantially from natural grass

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[14] Refer to *Greenhouse gas emissions* in section 2 for further details on carbon storage regarding both turf types, artificial and natural.

[15] Several techniques have been developed to estimate economic values for non-market ecosystem services: Travel Cost Method, Hedonic Pricing, Contingent Valuation, Replacement Cost Method, etc.

soils of playgrounds and football pitches in Sweden. The economic values provided in this study are rough estimations to be used very cautiously in further studies. As a general rule, valuations ought to be site-specific, but the values of this study are based on Canadian grasslands and not on Swedish ones. Moreover, there exists multiple indicators and measurements of biodiversity and ecosystem services, which would yield different economic valuations. The quantification does not include benefits associated with the foregone risks of artificial turf such as microplastic emissions.

Table 1. Estimated valuation of foregone ecosystem services of natural grass.

Ecosystem service	**Description**	**CAD per hectare per year (2008)**	**USD per hectare per year (2020)**	**SEK per hectare per year (2020)**	**SEK per m² per year (2020)**
Air quality	Removal of gaseous air pollution and/or airborne particles. Mitigation of "urban heat island". Noise reduction	12	10.54	97.08	0.01
Soil quality	Accumulation of organic matter. Role of vegetation root matrix and soil biota in soil retention. Prevention of soil loss and damage prevention from erosion.	60	52.70	485.37	0.05
Biodiversity-related services	Pollination is critical to the overall maintenance of biodiversity for grasslands. Pollination is used as rough approximation of biodiversity-related ecosystem services. This is because pollination allows a more straightforward economic quantification, and because there is a strong link between pollination services and biodiversity. Biodiversity can determine to a great extent the economic value of pollination in agricultural systems (de Groot et al. 2010). Natural controls of plant pests are included (Wilson 2008). Pest and disease control are directly linked to variation in biodiversity. A more diverse soil community will help promote key biological functions of the soil such as soil-borne pests and diseases.	1 149	1 009.11	9 293.91	0.93
	Estimated total	1 221	1 072	9 876	**0.99**

Notes: Exchange rates are the yearly average of 2020: 0.7465 USD/CAD, and, 9.2053 SEK/USD[16]. The cumulative price increment in Sweden[17] from 2008 to 2021 is 17.1%.

Biodiversity-related services: The role of biodiversity in the economic valuation of ecosystem services is of great complexity. It is difficult to quantify regulating ecosystem services, and mostly those associated with biodiversity. To circumvent this issue, this study relies on the value of ecosystem services that have been quantified for food production in grasslands. Such

[16] https://www.ofx.com/en-au/forex-news/historical-exchange-rates/yearly-average-rates/. Monetary values of 2008 are brought to 2020 with a cumulative price change of 21.47%.
[17] https://www.worlddata.info/europe/sweden/inflation-rates.php.

ecosystem services are those associated with crop yields, which are affected by pollination. Ecosystem services in grasslands are heavily influenced by pollination, and there is a strong relationship between biodiversity-related ecosystem services and food production (de Groot et al. 2010). To convey an economic value for the foregone ecosystem services from natural grass to artificial turf, the study takes the value of pollination in grasslands as a very rough approximation (species richness and nesting habitats above and belowground). Such economic value also includes the benefits from natural control of pests. Namely, a more diverse soil community will help promote key biological functions of the soil such as soil-borne pests and diseases (Wilson 2008).

<u>Air quality, soil quality and carbon storage:</u> Air quality regulation encompasses the reduction of air pollution and noise, and the mitigation of the "urban heat island" effect. Soil quality refers to the accumulation of organic matter, soil formation and sediment retention. The ecosystem services provided by carbon storage are not included because of the lack of scientific consensus in determining if managed natural grass is a net carbon source or not (see *Greenhouse Gas Emissions* in section 2).

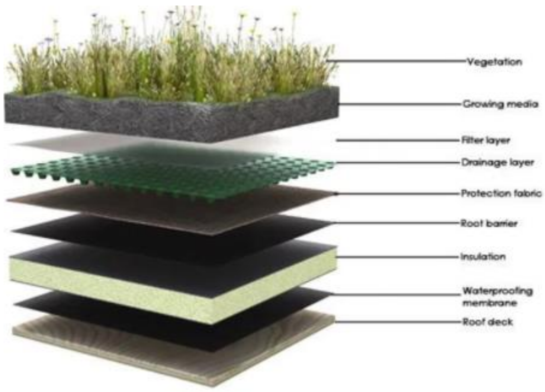
4.3 Compensation measures

The conversion of natural grass into artificial turf shall compensate the soil loss and its ecological functions by actions in other areas. The European Commission have described and discussed technical measures (and/or construction methods) to help conserve soil functions and mitigate the effects of soil sealing to a certain extent. Compensation measures build on the principle that soil consumption and hence the loss of soil functions (e.g., biodiversity, fertility, drainage capacity, erosion control, heat dissipation) is offset with restoration of soil functions somewhere else (Prokop et al. 2011).

Green roof systems in surrounding roof surfaces

Green roofs are vegetation systems on top of concrete decks (Figure 3). These can refer to roofs in terraces, courtyards, domestic homes and park spaces. Green roofs can be divided into *intensive* and *extensive* facilities depending mostly on the level of care required. Intensive roof plantation is a vegetation layer requiring continuous maintenance during the year, whereas extensive roof plantation refers to a vegetation layer that requires attention usually only up to twice per year (FLL 2008).

Figure 3. General composition of a green roof system



Source: Sustainable Facilities Tool (sftool.gov)

Green roof systems are composed of different layers. The top layer corresponds to the vegetation, which depends on the substrate depth and quality, and on the local climate (which should favor native plant species). The growing medium is the plant bed containing the substrate that provides the nutrients and the moisture. The drainage layer removes the excess water from the roof. The filter layer and protection fabric are permeable textiles used to protect the waterproofing membrane and root barrier from mechanical damage and physical strain. These geotextiles consist of a woven cloth or blanket made from polyester or polypropylene. The waterproofing membrane protects the whole system from flooding and moisture damage, and it is generally installed above the concrete deck. The waterproofing material comes as rolled-up mats or cloths or as liquid materials (Vinnova 2014). The waterproofing membrane can be protected further by installing a (thermal) insulation layer.

Roof vegetation contributes to water retention and stormwater management by absorbing rain water and reducing the strain placed on the city's stormwater management system. Depending on the design, green roofs can reduce annual runoff by 40% - 90% and delay the flow of stormwater by up to 30 minutes (Vinnova 2014). Green roof installations provide a cooling effect that mitigates the heat island effect from other surfaces. Evapotranspiration[18] (and sunlight reflection) from the green roofs returns the moisture to the surrounding environment and reduces the solar heat load. Prokop et al. (2011) state that green roof

[18] Evapotranspiration is the vertical transfer of water from Earth to the atmosphere (Chapin III et al. 2011). Evapotranspiration is the sum of surface evaporation and the loss of water from plant leaves (transpiration).

installations reduce the summer cooling needs (e.g., air conditioning) by 25% and the winter heat losses by 26%, which imply a massive reduction in energy demand and thus in carbon dioxide production (i.e., lower GHG emissions). Other important ecological benefits of green roofing are noise protection (increased soundproofing and reduced sound reflection), and binding dust and toxic particles (improved air pollution control). Depending on the design, green roofs can also serve as habitats for new species and/or species that are commonly present in natural grass. For example, pollinating bumblebees, bees and butterflies can be beneficial insects visiting plant beds of roof vegetation.

Vegetation barriers and tree plantings

Besides being an aesthetic amenity, trees improve air quality, enhance heat dissipation and reduce energy consumption by providing cooling shade in summertime (European Commission 2015). Trees constitute vegetation barriers for air pollution abatement, which can form natural walls between traffic emissions and adjacent areas (Bairwise and Kumar 2020). In addition, they can filter dust, reduce the urban heat island effect, emit oxygen and provide habitat for wildlife species. Landscape design, spatial planning, optimal configuration and plant composition of such green infrastructure ought to be investigated on the municipality level. Namely, planting of trees with high tolerance to urban conditions should be placed at the discretion of the municipality.

4 Conclusions

The artificial turf market has grown substantially the last decade. Artificial turf systems often represent a more cost-efficient investment than natural turf fields because of increased playing hours and reduced maintenance. Natural grass fields need regular irrigation and fertilization, whereas artificial turf needs not. Currently, the synthetic turf market is vastly dominated by plastic-based infills that can seemingly have repercussions on humans and on the environment (for instance, microplastic emissions). This dominance is constantly pushing innovation to reduce synthetic materials and remove or replace crumb rubber infills.

Extant research is still scarce when comparing greenhouse gas emissions (or carbon storage) from natural grass and artificial turf. Based on the studies addressed in this report, there is no conclusive evidence that (managed) natural grass pitches can store more carbon than is released. Greenhouse gas emissions in natural grass are caused by the processes and elements involved in the maintenance: mowing, irrigation and application of chemicals (fertilizers, pesticides and herbicides). On the other hand, the installation of artificial turf systems requires top soil excavation, which releases carbon dioxide to the atmosphere; moreover, artificial turf requires the production and transport of the synthetic turf components, which may have global warming potential.

Water flow regulation, flood control, groundwater management and reduced runoff are ecosystem services provided by the drainage systems of both natural grass and artificial turf installations. Some synthetic turf companies argue that drainage systems of artificial turf can actually outperform drainage efficiency of natural turf fields.

The ecological functions of the soil are the main ecosystem services that are lost when converting natural grass into artificial turf. Such foregone soil functions are those associated with the provision of biodiversity and the reduction of solar heat load, noise, glare and air pollution. Two measures are identified in this report that can offset, to some or large degree, the foregone ecosystem services produced by soil loss. These are green roofing and tree plantings. Both compensation measures involve vegetation structures delivering very similar soil processes that occur in natural grass fields.

By using as reference a Canadian study for grasslands in Ontario (Canada), the foregone ecosystem services from natural grass to artificial turf can add up to at least 1 SEK per m^2. This equates to about 7 140 SEK for a regular full-size football field. However, this economic estimation is only a very preliminary value if used for the Swedish context, and can vary greatly depending on multiple factors such as the site characteristics, the economic valuation method and the choice of biodiversity indicator.

References

Bairwise, Y. and Kumar, P. (2020) Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection. *npj Climate and Atmospheric Science* 3, No. 12.

Bauer, B., Egebaek, K. and Aare, A. K. (2017) Environmentally friendly substitute products for rubber granulates as infill for artificial turf fields. PlanMiljö ApS. Report to the Norwegian Environmental Agency.

Beard, J. B. and Green, R. L. (1994) The role of turfgrasses in environmental protection and their benefits to humans. *Journal of Environmental Quality,* Vol 23, No. 3.

Chapin III, F. S., Matson, P. A. and Vitousek, P. M. (2011) Principles of terrestrial ecosystems ecology. 2nd Ed. Springer.

Cheng, H., Hu, Y. and Reinhard, M. (2014) Environmental and Health Impacts of Artificial Turf: A Review. *Environmental Science & Technology* 48, 2114-2129.

De Groot, R., Fisher, B. and Christie, M. (2010) Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation.. *In:* The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations. Edited by Pushpam Kumar. Earthscan: London and Washington.

ECHA 2017. European Chemicals Agency. Annex XV report. An evaluation of the possible health risks of recycled rubber granules used as infill in synthetic turf sports fields.

European Commission (2015) Towards an EU research and innovation policy agenda for Nature-based solutions & Re-naturing cities. Final report of the horizon 2020 expert group on ‘nature-based solutions & re-naturing cities’ (full version). Annex 4. Directorate-General for Research and Innovation. Directorate I – Climate Action and Resource Efficiency.

FIFA (2017). Environmental impact study on artificial football turf. Eunomia Research & Consulting Ltd.

Fleming, P. (2016) Artificial turf systems for sport surfaces: current knowledge and research needs. *Proceedings of the Institution of Mechanical Engineers Part P Journal of Sports Engineering and Technology* 225(2):43-63.

FLL (2008). Guidelines for the Planning, Construction and Maintenance of Green Roofing: Green Roofing Guideline (Bonn: Forschungsgesellschaft Landschaftsentwickung Landschaftsbau).

Gladon, R. J., Brahm, D. J. and Christians, N. E. (1993) Carbon monoxide absorption and release by C3 and C4 turfgrasses in light and dark *Int. Turfgrass Soc. Res. J.* 7: 649-656.

Gross, C. M., Angle, J. S. and Welterlen, M. S. (1990) Nutrient and sediment losses from turfgrass. *J. Environ. Qual.* 19: 663-668.

Hall, S. J., Huber, D. and Grimm, N. B. (2008) Soil N_2O and NO emissions from arid, urban ecosystem. *J. Geophys. Res*., 113, G01016.

Källqvist, T. (2005) Environmental risk assessments of artificial turf systems. Report to the Norwegian Institute of Water Research.

KG (2021) Report for the purchasing group of The Swedish Association of Local Authorities (SKL). Market analysis artificial turf 2018-08-31.

Lassen, C., Hansen, S. F., Magnusson, K., Hartmann, N. B., Jensen, R., Nielsen, P., Gissel, T. and Brinch, A. (2015). Microplastics Occurrence, effects and sources of releases to the environment in Denmark. Danish Environmental Protection Agency.

Lavorgna, J., Song, J., Beattie, W. D., Beil, C., Levchenko, K. and Shofar, S. (2011) A Review of Benefits and Issues Associated with Natural and Artificial Turf Rectangular Stadium Fields - Final Report. Montgomery County. United States of America.

Lee, K. E. (1985) Earthworms. Their ecology and relationships with soil and land use. Academic Press, New South Wales, Australia.

Magnusson, S. and Mácsik, J. (2020) Determining the effectiveness of risk management measures to minimize infill migration from synthetic turf sports fields. Ecoloop, Sweden.

McLaren, N., Fleming, P. and Forrester, S. (2012) Artificial grass: A conceptual model for degradation in performance. 9th Conference of the International Sports Engineering Association (ISEA). *Procedia Engineering* 34: 831-836.

McKee, G. (2015) The Health Implications of Synthetic Turf Fields with Crumb Rubber Infill. A Human Health Risk Assessment for the Municipality of North Cowichan. Island Health.

Meil, J.; Bushi, L. (2007) Estimating the Required Global Warming Offsets to Achieve a Carbon Neutral Synthetic Field Turf System Installation; Athena Institute: Ontario, Canada.

Mepex (2016). Primary microplastic-pollution: Measure and reduction potentials in Norway. Norwegian Environment Agency.

Naturvårdsverket (2018) Guide to valuing ecosystem services. Report 6584.

Peterson, H. and Luxton, M. (1982) A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos 93: 297-388.

Potter, D. A., Powell, A. J. and Smith, M. S. (1990) Degradation of turfgrass thatch by earthworms (Oligochaeta: Lumbricidae) and other soil invertebrates. *J. Econ. Entomol.* 83: 205-211.

Prokop, G., Jobtsmann, H. and Schönbauer, A. (2011) Overview of best practices for limiting soil sealing or mitigating its effects in EU-27. Technical Report – 2011 – 050. European Commission. Environment.

Rambøll (2017). Kartlegging av håndtering av granulat på kunstgressbaner. Ministry of Climate and Environment.

Simon, R. (2010) Review of the impacts of crumb rubber in artificial turf applications. UC Berkeley. Green Manufacturing and Sustainable Manufacturing Partnership.

Smith, J. L. and Paul, E. A. (1988) The role of soil type and vegetation on microbial biomass and activity. P. 460-466. *In:* Fegusar, M. and Gantar, M. (ed.) *Perspectives in microbial ecology*. Slovene Soc. For Microbiology, Ljubljana, Yugoslavia.

Stockholms Fotbollsförbund 2020. Last accessed February 26 of 2020. Source: https://fotbollsyta.nu/biopitch/

Svenska Fotbollsförbundet 2021. Inventering av konstgräsplaner och fotbollshallar med konstgräs i Sverige. Revised 2020-09-28.

Svenska Fotbollsförbundet 2020. Rekommendationer för anläggning av konstgräsplaner. Utförandebeskrivning.

Schneider, K., De Hoogd, M., Haxaire, P. and Philipps, A., Bierwisch, A. and Kaiser, E. (2020a) ERASSTRI - European risk assessment study on synthetic turf rubber infill – part 1: analysis of infill samples. Sci. Total Environ., 718.

Schneider, K., De Hoogd, M., Haxaire, P. and Philipps, A., Bierwisch, A. and Kaiser, E. (2020b) ERASSTRI - European risk assessment study on synthetic turf rubber infill – part 2: migration and monitoring studies. Sci. Total Environ., 718.

Schneider, K., De Hoogd, M., Haxaire, P. and Philipps, A., Bierwisch, A. and Kaiser, E. (2020c) ERASSTRI - European risk assessment study on synthetic turf rubber infill – part 3: Exposure and risk characterization. Sci. Total Environ., 718.

Serensits et al. (2011). Human health issues on synthetic turf in the USA. J. Sports Engineering and Technology 225: 139-146.

Sweco (2016) Däckmaterial I konstgräsplaner. Rapport. Sweco Environment AB.

Swedish Chemicals Inspectorate (2016) Synthetic turf from a chemical perspective – a status report.

Thompson, G. L. and Kao-Kniffin, J. (2017) Applying Biodiversity and Ecosystem Function Theory to Turfgrass Management. *Crop Sci.* 57: 238-248.

Townsend-Small, A. and Czimczik, C. I. (2010a) Carbon sequestration and greenhouse gas emissions in urban turf. Geophysical Research Letters, Vol. 37, L02707.

Townsend-Small, A. and Czimczik, C. I. (2010b) Correction to "Carbon sequestration and greenhouse gas emissions in urban turf". Geophysical Research Letters, Vol. 37, L06707.

Vinnova (2014) Swedish guidelines for green roofs. Last accessed: March 22nd of 2021: https://greenroof.se/wp-content/uploads/2017/04/Swedish-handbook.-Translated-short-version.pdf

Watterson, A. (2017) Artificial turf: Contested terrains for precautionary public health with particular reference to Europe? International Journal of Environmental Research and Public Health 14, 1050.

Whitcomb, C. E. and Roberts, E. C. (1973) Competition between established tree roots and newly seeded Kentucky bluegrass. Agron. J. 65: 126-129.

Wilson, S. J. (2008) Ontario's wealth Canada's future: Appreciating the value of the greenbelt's eco-services. David Suzuki Foundation.