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GEOTEXTILES AND MICROPLASTICS IN SWEDEN
AN ASSESSMENT

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1. SUMMARY

In the EU, there are ongoing efforts that aim to reduce the presence of microplastic release to the environment. In addition to the proposed restriction under REACH of intentionally added microplastics in products, the strategy also includes measures directed towards the unintentional release of microplastics. In a public consultation, the European Commission included questions related to geotextiles and their release of microplastics. In order to map the situation in Sweden and improve knowledge on geotextiles, the Swedish Environmental protection Agency (Swedish EPA) has commissioned Ramboll to provide this information, to assess geotextiles as a source of microplastics in Sweden and to suggest further studies. The information will also provide input to the ongoing governmental assignment the Swedish EPA has on mapping and monitoring plastic flows towards the transition to a circular economy.

Geotextiles are synthetic or natural polymeric textile materials used in contact with soil and/or other materials in geotechnical and civil engineering applications. Its use in Europe began in the 1950's but accelerated during the 1980's and -90's. In Sweden, the use of geotextiles was approximately 14900 tonnes in 2021 and its major use was for separation and filtration applications. A vast majority (>95%) of the geotextiles used are made of nonwoven polypropylene (PP). Geotextiles are classified as construction products and fall under Regulation (EU) No 305/2011. To be placed on the EU market, geotextiles must conform with technical criteria, including durability requirements, in harmonised standards and be CE labelled. Since the service life of geotextiles in many applications is expected to be 100 years, not much of the geotextiles used to date have been recovered or treated as waste and very little experience of this therefore exists. Used geotextiles are sorted as either plastic waste or in fractions for combustible waste. Recycled content in geotextile manufacturing is very limited, partly due to limitations of use laid down in the harmonised standards.

There is not much research on geotextiles and their release of microplastics. A previous estimation of global geotextile release of microplastics appears to have used flawed assumptions and exaggerates the release. It is known that geotextiles are exposed to several environmental factors that all can contribute to their degradation, of these, exposure to UV-light is arguably the most important. In this study, two cases are identified that could potentially lead to microplastic release. Hydraulic applications, where geotextiles are in contact with water and exposed to several degradation factors, is a higher risk application. The other identified risk is the use of geotextiles for soil applications that are not installed according to manufacturer's instructions and left exposed to UV and other degradation factors.

In this report, it is estimated that geotextiles currently release 2-32 tonnes of microplastics per year in Sweden. The estimation is based on several assumptions regarding release of microplastics due to lack of information. As a comparison, this is similar to other sources of unintentionally released microplastics such as fishing gear (4–46 tonnes/year) or industrial laundry (2–115 tonnes/year). The estimation also shows that the accumulation and ageing of geotextiles may cause this to become a major source of microplastics in the future. In the worst-case scenario, approximately up to 800 tonnes per year would be released by 2050 and in 100 years from now, the amount would be closer to 21 000 tonnes. The calculation includes several limitations and uncertainties and should be seen as an indication until further research is performed.

Ramboll proposes to advance the understanding of microplastics release from geotextiles by performing actual measurements, such as leaching tests and to investigate whether also new

unused geotextiles release fibres. It is equally important to develop an understanding of the relationship between degradation and microplastics, i.e., what kind of degradation (measured by e.g., strength retention tests) is required to cause microplastics emissions and at what rate.

2. SVENSK SAMMANFATTNING

Inom EU pågår det ett arbete för att minska utsläppen av mikroplaster till miljön. Förutom en föreslagen begränsning inom REACH av avsiktligt tillsatta mikroplaster i produkter så omfattar strategin även åtgärder som är inriktade på oavsiktlig spridning av mikroplaster. I ett offentligt samråd inkluderade Europeiska kommissionen frågor om geotextilier och dess bidrag till utsläpp av mikroplaster. För att kartlägga situationen i Sverige och förbättra kunskapsläget om geotextilier har Naturvårdsverket givit Ramboll i uppdrag att sammanställa denna information, bedöma geotextilier som källa till mikroplast i relation till andra kända källor i Sverige samt föreslå ytterligare studier för att täppa till identifierade kunskapsluckor.

Informationen som tas fram i uppdraget ska också användas av Naturvårdsverket i regeringsuppdraget ”Rätt plast på rätt plats”. I regeringsuppdraget ingår bland annat att kartlägga plastflöden och hur dessa kan följas i en cirkulär ekonomi samt att undersöka vilka plaster som lämpar sig för olika typer av användningar.

Om geotextil

Geotextil omfattar syntetiska eller naturliga polymera textilmaterial som används i kontakt med jord och/eller andra material i geotekniska och civiltekniska tillämpningar. Geotextilier är plana, genomsläppliga och kan vara vävda, nonwowen[1] eller stickade. Geotextil tillhör geosynteter, vilket är en term som beskriver produkter med minst en komponent som är tillverkad av en syntetisk eller naturlig polymer i form av ett ark, en remsa eller en tredimensionell struktur och som används i kontakt med jord och/eller andra material. Det finns också geotextil-relaterade produkter som är plana, genomsläppliga, polymera (syntetiska eller naturliga) material som används i samma tillämpningar men som inte motsvarar definitionen av geotextil då de inte är vävda, nålfiltade eller stickade. Det här gäller t.ex. geonät, geomattor och geoceller.

Geotextiler används för fyra huvudsakliga syften;

- Dränering: samlar upp och avlägsnar regnvatten eller överflödigt vatten i marken.
- Separering: förhindrar blandning av jordarter eller material med olika egenskaper.
- Filtrering: låter vatten passera igenom samtidigt som partiklar hålls kvar.
- Förstärkning: förstärkning och stabilisering av jordområden.

Det i särklass största användningsområdet för geotextil i Sverige är separering och filtrering som utgör mer än 99% av all användning. På samma sätt domineras användandet av nonwoven produkter tillverkade av polypropen (PP). Endast några få procent av den geotextil som används utgörs av andra polymerer och då främst polyetentereftalat (PET), polyeten (PE) samt polyamid (PA). I Tabell 1 sammanfattas data över polymerernas fördelning.

[1] Nonwoven geotextil är samma sak som nålfiltad som ibland förekommer som benämning på svenska

Tabell 1. Sammanställning och fördelning av polymerer som används i geotextil. För andelen av den totala marknaden kan siffrorna skilja sig åt på grund av skillnader i geografiska områden. Studien av Wu et al. avser sannolikt global användning, EAGM europeisk användning och intervjuade återförsäljare deras försäljning i Sverige.

Polymer	Marknadsandel	Källa
PP	92 %	Wu, o.a., 2020
	>95%	EAGM
	99%	Intervjuvade återförsäljare
PET	5 %	Wu, o.a., 2020
PE	2 %	Wu, o.a., 2020
PA	1 %	Wu, o.a., 2020
Naturliga eller bionedbrytbara	2%	Vé Wiewel & Lamoree, 2016 Burgstaller, Prambaur, Wendeler & Weitzenböck, 2019 Wu, o.a., 2020

Endast en mycket liten andel av den geotextil som säljs är tillverkad av antingen naturliga material eller bionedbrytbara polymerer. Marknaden för dessa alternativ är begränsad av flera anledningar där den viktigaste sannolikt är den korta livslängden jämfört med polymera material. För de flesta av de funktioner och tillämpningar där geotextiler används så är geotextiliernas roll att bidra till att konstruktioner såsom vägar, järnvägar och byggnader behåller sin funktion tills de inte längre behövs. Genom att införa material som bryts ned efter en begränsad tid och därmed förlorar sin funktion motverkas detta syfte. Naturliga material används ibland i t.ex. sluttningar för att motverka erosion där dess funktion på sikt ersätts av växter.

Naturliga fibrer som kan användas för att tillverka geotextiler inkluderar växtfibrer, djurfibrer och mineralfibrer. Av dessa är växtfibrer de som tycks vara mest användbara och fibertyper som har testats inkluderar kokos, palm, sisal, jute, lin, kenaf, hampa, bomull, bambu, trä, vete och ris. Jute och kokos är de viktigaste typerna av geotextilier tillverkade av naturfibrer som finns på marknaden.

Vad gäller bionedbrytbara polymerer så tycks de flesta alternativ fortfarande vara på försöksstadiet. Ett antal polymerer och blandningar därav har identifierats som möjliga kandidater inklusive polylaktid (PLA), termoplastisk stärkelse (TPS), polyhydroxialkanoat (PHA), cellulosaacetat samt andra cellulosaestrar (CA).

Mängder

Inga data har kunnat identifierats över den mängd som används historiskt men enligt uppgifter från intervjuer så tog användningen av geotextiler fart på 1980 och 90-talet. Enligt data från branschföreningen EAGM (European Association of Geosynthetic product Manufacturers), så användes totalt 14900 ton geotextil år 2021 i Sverige. För andra geosynteter, inklusive geonät och geokompositer så var användningen ca 1000 ton. I Tabell 2 redovisas mängder till yta, vikt och fördelning mellan funktioner.

Tabell 2. Total användning av geosynteter i Sverige 2021. Baserat på data från EAGM.

	Produktfamilj			
	Geotextilier		*Icke-geotextil*	
	Nonwoven	Vävda	Nät	Kompositer
M² * 1000	94 350	380	2000	730
Ton	14 820	80	610	420
	Funktion			
	Separering & filtrering	Skydd	Förstärkning	Dränering
M² * 1000	93 770	790	2240	590
Ton	14 470	350	710	350

Geotextilcertifieringar
Geotextilier räknas som byggprodukter och omfattas därmed av bestämmelserna i EU:s byggproduktförordning (EU) nr 305/2011. Geotextilier omfattas av harmoniserade standarder som innehåller tekniska krav som produkterna måste uppfylla. Tillverkare måste utfärda en prestandadeklaration och CE märka produkterna som ett sätt visa att produkter överensstämmer med kraven i standarderna. De harmoniserade standarderna omfattar en mängd olika användningsområden och innehåller krav på att geotextilerna ska klara av ett antal tester som ska visa att de tål belastning och inte bryts ned av omgivningsfaktorer. Testerna omfattar bland annat exponering för UV-ljus och höga temperaturer och utifrån resultaten anges det på produkten hur länge den får förvaras utomhus utan att täckas samt hur många år den förväntas behålla sin funktion, 25, 50 eller 100år.

I Norden används en frivillig certifiering som benämns NorGeoSPec. Certifieringen går utöver kraven i CE märkningen och har tagits fram tillsammans med ansvariga trafikmyndigheter i Norden. För geotextil som används i infrastrukturprojekt krävs certifiering av NorGeoSpec.

Avfall och återvunna material
På grund av den långa livslängden för geotextil och den förhållandevis korta tid som produkterna har använts så finns det begränsat med erfarenhet av avfallshantering. I de fall då geotextil grävs upp så sorteras större stycken antingen som plast eller som brännbart. I samband med uppgrävning så förekommer det att mindre bitar fastnar i skopor och följer med massorna. Ingen sortering av detta sker. Återvunnet material används mycket sällan, sannolikt främst på grund av att de harmoniserade standarderna utesluter användandet av återvunnet material i annat än produkter med kort livslängd. Därmed begränsas användningsområdet kraftigt. Högre priser än motsvarande produkt tillverkad av jungfruligt material är också en bidragande orsak.

Geotextil som en källa till mikroplast
Forskning över utsläpp av mikroplast från geotextilier är än så länge mycket begränsad. En särskilt uppmärksammad studie av Bai et al från 2022 studerade utsläpp av mikroplast från geotextilier både i laboratoriemiljö och i fältprover. Enligt analysen av laboratorieförsöken

släpptes ett stort antal nanofibrer ut i vattnet från PET-geotextilier. Slutsatsen i studien är att geotextilier som exponeras för UV-ljus i längre perioder kan brytas ner eller skadas och att mikroplaster då läcker ut i miljön. Resultatet från studien har kritiserats och IGS (International Geosynthetics Society) påpekar bland annat att studien kraftig överdriver den mängd geotextil som används i kustnära tillämpningar samt att den antar att all geotextil bryts ned inom 1 år, något som inte är realistiskt. Resultaten från studien bör därför inte användas i syfte att uppskatta utsläpp av mikroplast från geotextil till vatten. En annan studie nämner att mikroplast från geotextil har identifierats i miljön (Vé Wiewel & Lamoree, 2016) men i de ursprungliga källorna nämns inte geotextil utan andra mer troliga källor såsom rep och förpackningar. En studie har identifierat fragment av geotextil längs med stränder i Östersjön (Esiukova, Chubarenko, & Simon, 2018).

Ett antal faktorer finns beskrivna i litteraturen som behandlar nedbrytning av plast. Den viktigaste påverkansfaktorn för nedbrytning av geotextilier är exponering för UV-ljus, men även mekanisk påverkan och nötning, kemisk nedbrytning och nedbrytning av mikroorganismer kan förekomma i olika utsträckning och beroende på platsen. Dessa påverkansfaktorer har en synergistisk effekt och om en geotextil har påverkats av t.ex. UV-ljus, så kan den vara känsligare för de andra faktorerna. För att förhindra nedbrytning och stabilisera geotextilerna används olika additiv. Dessa är dock ofta inte bundna till materialet och kan läcka från materialet över tid vilket bidrar till åldrandet. Additiven kan också vara skadliga i sig själva även om kända problemkategorier av additiv såsom flamskyddsmedel och mjukgörare inte används i geotextil.

Riskanvändningar

I vilken utsträckning en geotextilprodukt exponeras för de ovan beskrivna faktorerna varierar både med användningsområde och tillämpning. Att de olika faktorerna kan ha en påverkan går inte att bortse från. Vad som inte är känt är hur mycket exponering för dessa förhållanden som krävs för att geotextilier ska brytas ned tillräckligt mycket för att bilda mikroplaster.

Användning i vattennära tillämpningar lyfts ofta som ett exempel där risken för utsläpp av mikroplast är förhöjd. Anledningen är att geotextilen riskerar att exponeras för flera av de beskrivna påverkansfaktorerna samtidigt såsom nötning från vatten och vågrörelse, UV-ljus och urlakning.

Med utgångspunkt i geotextilens känslighet för UV-strålning och hur länge den får förvaras utan att täckas så är det uppenbart att felaktig användning eller tillämpning som gör att geotextilen utsätts för solljus avsevärt kan påverka plastens egenskaper och därmed öka risken för att mikroplast bildas. Utifrån intervjuer med entreprenadföretag som anlägger geotextiler så framkommer det att tillverkarnas riktlinjer inte alltid följs. Användare har också noterat att geotextil som har utsatts för sol före installationen har ändrat textur och ibland blivit spröd. För markanvändning, utom i vattennära tillämpningar, bedöms därför felaktig användning som leder till att geotextilier exponeras för solljus vara en faktor som påverkar bildandet av mikroplast. Detta gäller både yrkesmässig och konsumentanvändning där de senare inte antas känna till eller följa några särskilda installationsanvisningar. När geotextilerna väl är i jorden och täckta kommer färre av de förhållanden som bidrar till nedbrytning att påverka materialet. Om geotextilen är försvagad redan vid installationstillfället blir den dock känsligare för återstående nedbrytningsfaktorer, t.ex. kemisk och biologisk nedbrytning. I fuktiga jordförhållanden kan även utlakning av additiv vara en faktor.

Antaganden och beräkning av mikroplastutsläpp
Utifrån antaganden kring utsläpp av mikroplaster och beräkningar av mängden geotextil som har använts historiskt så har två scenarier skapats. Utsläppet av mikroplaster från geotextilier år 2022 varierar i dessa scenarier från cirka 2 ton per år till 32 ton per år i ett värsta scenario. Utsläppet från geotextilier skulle enligt denna uppskattning ligga i samma storleksordning som fiskeredskap (4-46 ton/år) eller industritvättar (2-115 ton/år) som uppskattats i tidigare undersökningar (Magnusson, et al., 2016). Mängden mikroplaster som släpps ut beräknas dock öka stadigt på grund av den ökande åldern på redan installerade geotextilier och den ackumulerade mängden av installerade material. I det värsta scenariot skulle cirka 55 ton per år släppas ut år 2030 och år 2050 upp till 800 ton per år. Som jämförelse kan nämnas att den största källan till mikroplaster i Sverige i dag är vägtrafiken som beräknas uppgå till cirka 8 190 ton/år.

Slutsatser
Användningen av geotextil i Sverige domineras av nonwoven produkter tillverkade av polypropen. Mängden geotextil som sattes på den svenska marknaden uppgick till cirka 14900 ton år 2021. Väldigt lite är känt om geotextilers utsläpp av mikroplast och om kopplingen mellan exponering för olika påverkansfaktorer och utsläpp av mikroplast. Utifrån antaganden kopplade till nedbrytning och ålder så har mikroplastutsläpp från geotextiler beräknats till mellan 2-32 ton per år i Sverige. Utsläppen bedöms dock öka i framtiden och mikroplast från geotextil kan komma att bli en betydande källa till mikroplast.

Förslag på fortsatta studier
Då kunskapen om geotextilier och mikroplast fortfarande är låg så föreslås tre olika studier som kan bidra till en ökad förståelse. I en första typ av studie kan geotextilier exponeras för påverkansfaktorer som mer speglar verkliga förhållanden än laboratoriestudierna som utförs inom CE märkningen. De olika faktorerna kan på detta sätt övervakas för att se hur de påverkar det geotextila materialet och om och hur dessa mekanismer samverkar. I samband med detta skulle också tester genomföras för att kartlägga förhållandet mellan material och hållfasthetsförluster. En andra typ av studie föreslås vara lakningstester där mätning av fiberurlakning från geotextila material mäts. För att underlätta identifiering av geotextilier som en källa i fältstudier föreslås till sist studier för att karaktärisera materialet och ta fram så kallade kemiska fingeravtryck.

3. BACKGROUND AND OBJECTIVES

In 2018, the European Commission requested ECHA to prepare an Annex XV restriction dossier concerning the use of intentionally added microplastic particles to consumer or professional use products of any kind. This request is a part of a strategy to reduce the presence of microplastics in the environment laid down in the new circular economy action plan[2] and EU plastics strategy[3]. In addition to the restriction of intentional use of microplastics, the strategy also includes measures directed towards the unintentional release of microplastics. This includes actions to increase the capture of microplastics at all relevant stages of products' lifecycles as well as further developing and harmonising methods for measuring unintentionally released microplastics. In 2022, a public consultation was launched within the framework of the Commission initiative[4] *Microplastics pollution – measures to reduce its impact on the environment*. This initiative specifically aims at developing measures towards the following sources of unintentional microplastics release:

- Tyre abrasion
- Plastic pellet loss
- Synthetic textiles
- Paints
- Detergent laundry and automatic dishwasher capsules
- Geotextiles

Geotextiles are synthetic or natural polymeric textile materials used in contact with soil and/or other materials in geotechnical and civil engineering applications. The global geotextile market size was estimated to be 6.72 billion US dollars in 2021, with an expected annual compound growth rate of 6.5%[5]. The Asia Pacific region is the largest geotextile market, driven by China and India (Wu, et al., 2020). In Sweden, the use of geotextiles amounted to approximately 14900 tonnes in 2021 (EAGM, 2022).

Seeing that geotextiles is a potential source of microplastics and that this has not previously been investigated in Sweden, the Swedish Environmental Protection Agency (Swedish EPA) commissioned Ramboll to perform an assessment of geotextiles use in Sweden and its significance as a source of unintentionally released microplastics. More specifically, this report aims to clarify and answer questions related to geotextiles including how geotextiles are defined, its composition, how they are used and since when and what quantities that are used. Furthermore, the report should make clear what happens to geotextile waste, what factors influence the risk of microplastics formation, for which uses the risk for microplastic release is the greatest and if there are alternatives to polymeric materials. The report also suggests further studies to reduce uncertainties. The scope of this study is limited to geotextiles which, as can be seen under 5.1, excludes other geosynthetics such as geosynthetic barriers, geocomposites and geotextile related products. In terms of possible microplastic emissions, geotextiles are however assessed to be the

[2] European Commission 2020 - A new Circular Economy Action Plan For a cleaner and more competitive Europe COM/2020/98 final. See 3.4. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

[3] European Commission, 2018 - A European Strategy for Plastics in a Circular Economy {SWD(2018) 16 final} https://eur-lex.europa.eu/resource.html?uri=cellar:2df5d1d2-fac7-11e7-b8f5-01aa75ed71a1.0001.02/DOC_1&format=PDF

[4] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12823-Microplastics-pollution-measures-to-reduce-its-impact-on-the-environment_en

[5] Grand View Research, 2022. Geotextiles Market Size, Share & Trends Analysis Report By Material (Polypropylene, Polyethylene), By Application (Road Construction), By Product, By Region, And Segment Forecasts, 2022 – 2030. Report ID: 978-1-68038-023-1. https://www.grandviewresearch.com/industry-analysis/geotextiles-industry

most relevant, both due to their characteristics but mainly due to their dominating volumes of use. This report therefore covers the majority of geosynthetics use in Sweden.

4. METHODOLOGY

Two primary methods have been used to collect the necessary information to answer the questions on geotextiles: literature research and interviews. For the literature search, Google Scholar was used to identify research articles using the keywords “geotextiles” and “microplastics” in various combinations. Abstracts were screened for relevance and articles of interest were downloaded and scrutinized. This research was performed to give a general knowledge and background of geotextiles and to enable posing relevant questions for interviews. The literature research was not performed as a systematic literature review, i.e., not all published articles in the field were assessed.

To collect data specific to Sweden, experiences from users of geotextiles and information on potential leakage of microplastics, stakeholders in the field were identified, contacted, and interviewed. In two cases, written answers to questions were sent instead of participation in an interview. Stakeholders were identified based on their relevance as actors on the Swedish market, such as suppliers, researchers, construction companies and industry associations. Industry associations were selected based on their previous involvement in investigations where geotextiles have been highlighted as a possible source of microplastics. The majority of all contacted stakeholders participated in the study and the sample is assessed to be representative. All interviewed stakeholders are presented in Table 1.

Table 1. Interviewed stakeholders

Stakeholder	Role
The Swedish School of Textiles- University of Borås	Researcher
Dahl	Supplier
European Association of Geosynthetic product Manufactures (EAGM)	Industry association
Chalmers University of Technology	Researcher
International Geosynthetics Society (IGS)	Industry association
NorGeoSpec	Certification body
PEAB	Construction company
Skanska	Construction company
Ponova	Supplier
Scandinavian Nonwoven	Supplier
The German Federal Institute for Materials Research and Testing (BAM)	Researcher
Svenska Geotech	Supplier
Tecca	Supplier
Västmark	Construction company

5. GEOTEXTILES

This chapter aims to give an overview of composition, functions and use of geotextile, which alternative materials that can be used instead of non-degradable polymers, expected lifetime and the condition of recovered geotextiles. The information in this chapter is based on both literature and interview findings.

5.1 Definition

Geotextile is a polymeric, synthetic or natural, textile material used in contact with soil and/or other materials in geotechnical and civil engineering applications. Geotextiles are planar, permeable and can be woven, nonwoven or knitted. Geotextiles belongs to geosynthetics which is a generic term describing products with at least one component made from a synthetic or natural polymer, in the form of a sheet, a strip, or a three-dimensional structure, used in contact with soil and/or other materials. There are also geotextile-related products which are planar, permeable, polymeric (synthetic or natural) materials used in the same applications which does not comply with the definition of a geotextile. That is, they are not woven, nonwoven or knitted.[6] These include geogrids, geonets, geomats, geocells, geostrips and geospacers. Furthermore, geosynthetic barriers and geocomposites also belong to the group of geosynthetics. Figure 1 below shows how the different expressions relate to each other.

5.2 Functions and use

There are different kinds of geotextiles on the market e.g., nonwoven, woven, knitted and glued and these are used for different applications. Nonwoven fiber sheets account for the major share of geotextiles and these are preferably used in filtration and drainage applications due to their 3-dimensional structure, which results in high porosity and permeability with varying pore sizes. Woven fabrics are more commonly used in the field of soil reinforcement and stabilization due to its greater mechanical properties (Burgstaller, Prambauer, Weitzenböck, & Wendeler, 2019).

Geotextile mainly serves the function of separation of different materials and has four principal functions which are defined as:

- Drainage: gathering and removing rainwater or redundant water in the soil
- Separation: preventing the mixing of soils with different properties
- Filtration: allowing water to pass through while retaining particles
- Reinforcement: strengthening and stabilizing of soil areas

In addition to these, protection is often mentioned as a fifth function, meaning barrier and erosion protection such as protecting construction systems against mechanical damage (Vé Wiewel & Lamoree, 2016) (Wu, et al., 2020). According to Daria et al. (2020) improving plant vegetation conditions is also one of geotextiles main functions. However, this is similar to soil remediation, a sub function of separation. Geotextiles are mainly in contact with soil, and/or covered by soil or other materials. Due to the functions of geotextile, it can be applied in many fields of engineering, such as hydraulic, construction, structural and agricultural engineering (Vé Wiewel & Lamoree, 2016). More specifically, application areas include:

- Road construction, as elements reinforcing the surface of airports, car parks, and asphalt paving,

[6] SS-EN ISO 10318-1:2015. Geosynthetics - Part 1: Terms and definitions

- Reinforcement systems on embankments, railroad track beds, reinforcement of the banks of natural and artificial water reservoirs, or the abutments of bridges and overpasses,
- The construction of artificial water channels, reinforcement of high and steep earth walls to prevent them from sliding,
- The construction of landfills, drainage of paved areas, sports facilities and roads

See Table 2 for a summary of different applications in terms of function in combination with the engineering field.

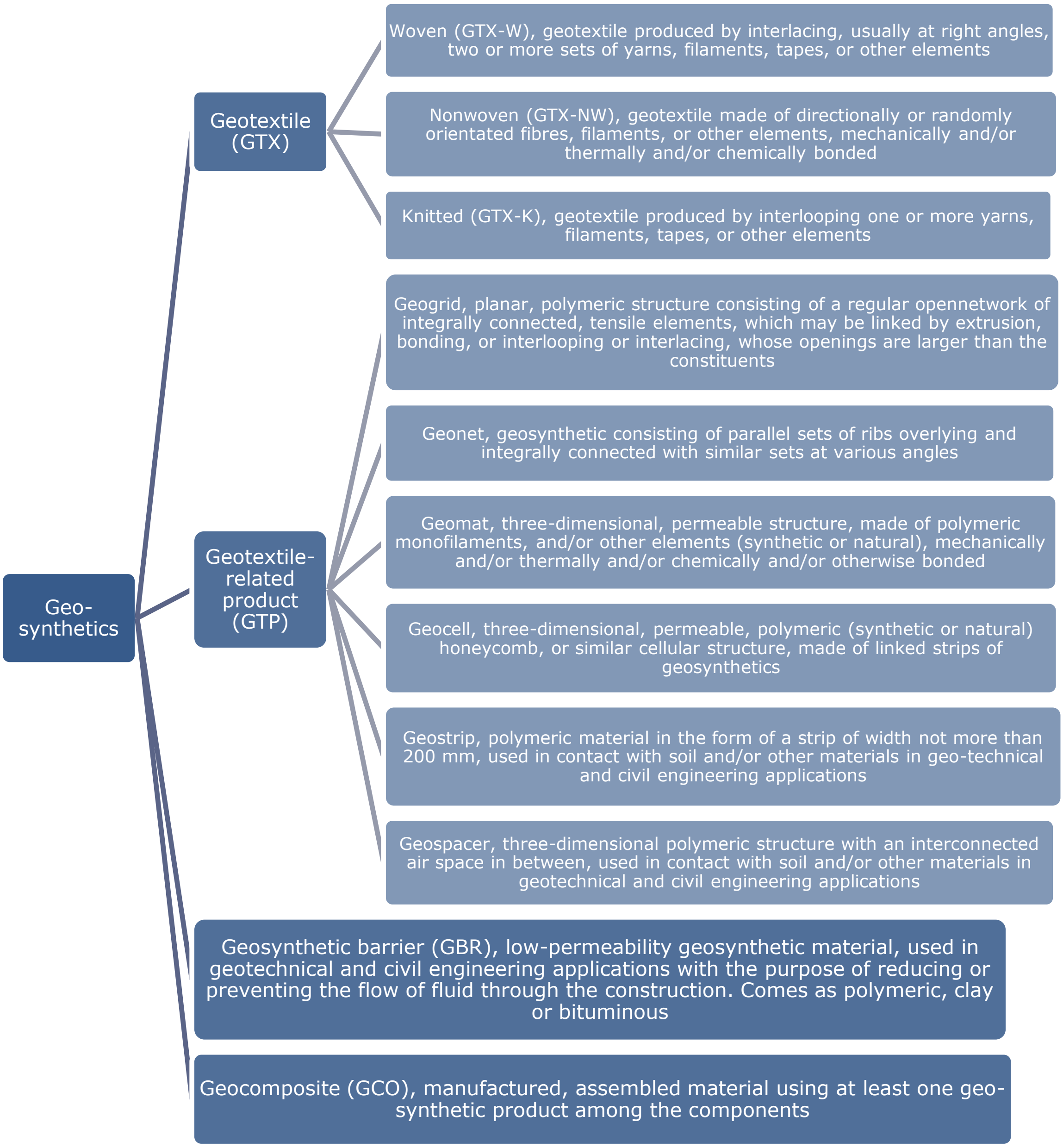


Figure 1. Explanation of geosynthetics and how the different expressions relate to each other. Description from SS-EN ISO 10318-1:2015.

Table 2. Summary of different applications of geotextiles (Vé Wiewel & Lamoree, 2016)

Function	Engineering field
Drainage	
- Horizontal and vertical drainage	Construction
- Fresh water storage	Hydraulic
Separation	
- Ground separation	Construction; Hydraulic; Agricultural; Civil
Filtration	
- Filtration systems	Hydraulic
- Absorption of oils	Agricultural
Reinforcement	
- Foundation of road/ terrain	Civil
- Bedding for vegetation/ grass (dikes)	Hydraulic
- Bedding for constructing elements	Hydraulic
- Sand elements	Hydraulic
Protection	
- Erosion protection	Civil; Agricultural
- Protection of trees and plants	Agricultural
- Riverbank protection	Agricultural
- Protection of construction elements (pipelines, roofing, etc.)	Construction
Other	
- Sand dust protection (screens)	Construction
- Sound walls	Construction
- Floatlands	Hydraulic

Hydraulic applications cover a wide variety of uses, both those related to surface waters (offshore and coastal works, rivers and their estuaries, lakes, reservoirs and canals) but also other types of uses could be seen as hydraulic, such as drilling rigs and pipelines, coastal protection structures, river training measures, hydropower stations, locks and weirs, harbors, dams and embankments, dikes and levees and irrigation facilities. Additionally, the term could also be used for subsurface water uses (e.g., groundwater) and in situations where land and water interact (e.g., during floods, in wetlands and for land reclamation (Heibaum, et al., 2006)

5.3 Composition

The composition and the choice of polymer depends on the condition in the environment where the geotextile is placed and on the properties of the polymer (Vé Wiewel & Lamoree, 2016). According to interviews with stakeholders, the choice of geotextile is also dependent on the cost and mechanical properties. Most geotextiles are made from non-degradable polymers from the polyolefin and polyester family. Polypropylene (PP) is the most frequently used material accounting for at least 92% of total geotextile production, followed by polyethylene terephthalate (PET), polyethylene (PE) and polyamide (PA) accounting for the remaining 5%, 2% and 1% of the production respectively (Wu, et al., 2020) (Burgstaller, Prambauer, Wendeler, & Weitzenböck, 2019). See Table 3 for a summary of polymers used in geotextiles.

Table 3. Summary of polymers used in geotextile. For the share of total market, the numbers may differ due to differences in geographies. The Wu et al study likely refers to global use, EAGM to European use and interviewed suppliers to their sales in Sweden.

Type of polymer	Share of total market	Source
PP	92 %	Wu, et al., 2020
	>95%	EAGM
	99%	Interviewed suppliers
PET	5 %	Wu, et al., 2020
PE	2 %	Wu, et al., 2020
PA	1 %	Wu, et al., 2020
Natural or biodegradable	2%	Vé Wiewel & Lamoree, 2016 Burgstaller, Prambaur, Wendeler & Weitzenböck, 2019 Wu, et al., 2020

The majority of all geotextile products used in Sweden are certified according to NorGeoSpec (see 5.5.2), which in almost all instances are made by PP and used for separation. The certification system does not require a certain type of material, but due to the favorable properties of PP, this is the standard polymer used. PP is favorable due to its mechanical properties, such as tensile strength and high resistance against chemical attacks, see 6.2.3 for more information. In addition, PP is inexpensive due to its low density and has very low cost per volume. Since hydraulic applications have been identified as a concern in previous research (see 6.1), the polymer types used for those applications may be of interest. According to the European Association of Geosynthetic product Manufactures (EAGM), the majority of geotextiles used in hydraulic applications in Europe are well stabilised polypropylene (PP) products (EAGM, 2022).

The main disadvantage of PP is its poor resistance to UV and high temperatures (Wu, et al., 2020). However, PP can be effectively stabilized against UV rays, and this is applied in situations where the geotextile remains uncovered and thus the UV exposure is high (Vé Wiewel & Lamoree, 2016). According to EAGM, geosynthetics use very small quantities (0.1 – 2%) of chemical additives to meet the durability requirements. The additives are typically antioxidants and UV stabilizers. Different kinds of stabilizers can be used to ensure the long-term performance and that the function is retained for more than 100 years.

One supplier mentioned that geotextile made by PET can be used in some applications, mainly in reinforcement and when used in water. For certain use in water, PET is a better alternative as it sinks which PP does not. It is characterized by great tensile properties, as well as high creep resistance and insensitivity to high temperature. However, PET fibers can be affected by hydrolysis and degrades in soil with a pH value more than 10 (Wu, et al., 2020). One stakeholder highlights that PET is only used in special conditions. PE is especially used in landfills since it has high resistance to chemicals, and it is more commonly used in geomembranes than in geotextile. It appears however, that the chemical resistance differences are very small although the considerably higher price for PE has led to it mainly being used in geomembranes. A comparison of the different characteristics between different polymers can be found in Table 4. The resilience of different polymers to various types of degradation is further described in 6.2.

Table 4. Comparison of different polymer characteristics. Adopted from (Rawal, Shah, & Anand, 2010)

Polymer group				
Comparative properties	**Polyester**	**Polyamide**	**Polypropylene**	**Polyethylene**
Strength	High	Moderate	Low	Low
Elastic modulus	High	Moderate	Low	Low
Strain at failure	Moderate	Moderate	High	High
Creep	Low	Moderate	High	High
Resistance to UV light				
Stabilized	High	Moderate	High	High
Unstabilized	High	Moderate	Moderate	Low
Alkalis	Low	High	High	High
Fungus, vermin, insects	Moderate	Moderate	Moderate	High

5.3.1 Alternative materials

A large majority (approximately 98%) of geotextiles currently used consists of non-degradable polymers as has been shown in Table 3. There are however two alternative material classes available, natural fibres and biodegradable polymers (Burgstaller, Prambauer, Wendeler, & Weitzenböck, 2019). The market for these alternatives is limited for several reasons, the main reason most likely being the lack of longevity compared to polymeric materials. For most of the functions and uses described under 5.2, the role of geotextiles is to assist in ensuring that constructions such as roads, railroads and buildings will maintain their function until no longer needed. By introducing materials that degrade after a limited time and hence lose their function, this purpose is contradicted.

There are however applications for which use of natural or biodegradable materials would probably be more useful compared to non-degradable polymers, e.g., in private gardens or driveways where such longevity is not necessary. As long as their limitations are taken into account already at the design stage, the use of geotextiles made of natural materials can offer beneficial properties not possible with polymers. As an example, the installation of natural geotextiles could offer instant protection against e.g., slope erosion while during their degradation, they supply organic matter and nutrients to plants which improves the vegetation that takes over the stabilising role (Daria, Krzysztof, & Jakub, 2020). This kind of use may however be complicated due to natural fibres having a higher surface weight than its synthetic counterparts, a weight that also is prone to increase when exposed to water due to its absorptive properties. This could be problematic in some cases, especially for steep slopes (Prambauer, Weitzenböck, Wendeler, & Burgstaller, 2019) but beneficial in other applications where e.g. the ability of jute to absorb up to 500% of its dry weight in water could reduce surface runoff, increase soil filtration properties as well as retain and balance soil moisture.

There are three different types of naturals fibres that could be used: plant fibres, animal fibres and mineral fibres (Wu, et al., 2020). Out of these, plant fibres are the most preferable due to rich sources, low cost, superior performance and easy extraction. The main application for natural fibres is reinforcement of slopes and exposed landscapes (Burgstaller, Prambauer, Wendeler, & Weitzenböck, 2019). Several types of plant fibres have been tested and described in literature, this includes coir, palm, sisal, jute, flax, kenaf, hemp, cotton, bamboo, wood, wheat and rice (Daria, Krzysztof, & Jakub, 2020). Jute and coir are the main type of natural fibre geotextiles available on the market.

I addition to the natural fibres, there are biodegradable polymers. The term biodegradable polymers refer to polymer materials that may be decomposed to carbon dioxide, methane, water, inorganic compounds or biomass (Daria, Krzysztof, & Jakub, 2020). These polymers are however only referred to as suitable candidates for geotextile applications and no examples of actual use were found in a recent review (Prambauer, Weitzenböck, Wendeler, & Burgstaller, 2019). There are several different biodegradable polymers mentioned in literature, these include polylactic acid (PLA) and blends thereof, thermoplastic starch (TPS) and blends, poly(hydroxyalkanoates) (PHAs), cellulose acetate and other cellulose esthers (CA).

Biodegradable materials can provide a good alternative to the conventional materials in certain applications and in 2016, 2% of the total market of geotextile was made of biofibres (Vé Wiewel & Lamoree, 2016). Biopolymers (meaning either made from natural materials or biodegradable polymers) have been estimated to be suitable in about 50% of all geotextile applications, see Table 5. The expected lifetime of bio-based geotextile is about 6 months up to 10 years (Vé Wiewel & Lamoree, 2016), but it can vary due to environmental influences (Prambauer, Weitzenböck, Wendeler, & Burgstaller, 2019).

Table 5. Possible uses of geotextile made of biopolymers (Vé Wiewel & Lamoree, 2016)

Function	Engineering field
Reinforcement	
- Bedding for vegetation/grass (dikes)	Hydraulic
Protection	
- Erosion protection	Civil; Agricultural
-Protection of trees and plats	Agricultural
-Riverbank protection	Agricultural
Other	
-Sand dust protection (screens)	Construction
-Sound walls	Construction

Although there does not appear to exist any formal restrictions for the use of biopolymers in e.g., NorGeSpec, the technical requirements that must be fulfilled exclude their use. EAGM believes that the market for degradable products is limited due to:

- Sustainability of the alternative raw materials are not (documented or perceived by customers as) being significantly better. As example: some are based on agriculture products and require more energy to mine and produce, without sufficient sustainable energy available[7].
- Alternatives are not available in industrial quality or scale
- Differences in quality and/or variations in quality induce liability risks, such as durability, health & safety
- They are more expensive

[7] For more detailed information on this topic, see IVL, 2022. Biorårvara till plast - nuläge och trender. Report Nr C 653 https://www.ivl.se/download/18.3b83004f180a41807a38b7/1652095265416/C653.pdf

EAGM believes that degradable materials only should be used for temporary applications as they are not as durable as plastics. Other stakeholders also mention that since the expected lifetime is shorter, this limits the possible applications. Degradable products are occasionally used for temporary applications or in gardening and landscaping. The product-specific service life depends largely on the environmental conditions.

One supplier mentions that customers have been asking for more environmentally friendly materials, but since they are more expensive, many customers turn them down. In one of the interviews, it was mentioned that various materials have been tested on the market, including biodegradable geotextiles made from starch. This has mainly been used in applications such as nonwoven fabrics and planting due to the materials susceptibility for degradation within approximately 5 years. Similarly, cellulose is also a material that has been tested but it is difficult to get moisture stable. In cases where such properties as moisture stability are required, use of plastics is beneficial, and has a longer expected lifetime.

5.3.2 Use of recycled content

Theoretically, geotextiles can be recycled and reused since they are manufactured out of relatively pure single polymer materials. Used geotextiles will be dirty from soil, sand or other materials from the site they were used at. This could however most likely be taken care of at recycling facilities, similar to what is performed for agricultural plastics that is cleaned before recycling. The incentive for manufacturers to make use of recycled material appears however to be very low. The main reason for this is that the CE requirements determine that if recycled materials are used, there has to be a nonwoven declared lifetime of maximum five years. Hence, if a recycled material is used in a reinforcement product, it limits the use and market for these products to applications such as e.g., temporary roads. Furthermore, there is no producer responsibility for geotextiles and therefore, no obligation for manufacturers to collect and recycle materials they have placed on the market. Lastly, as in all discussions revolving around recycling of plastics, the use of fossil feedstock used to produce the geotextiles and its associated environmental effects are not reflected in the products´ price. To arrange take-back schemes and recycling of geotextiles would be costly and more expensive than using virgin materials.

The industry represented by EAGM, mentioned during the interview that they are working on how they can separate the geosynthetics from the soil and how they can recycle them but that this is still in early development.

One supplier emphasizes that in order for recycling to be possible, the manufacturer who produced the material should also recycle it. That is because the raw material comes from different recipes. The supplier also mentions that there are ongoing discussions about DNA labelling of raw materials so that when they are recycled, the same manufacturer who produced the material in the first place recycles it. Exactly why this would be necessary for recycling of geotextiles was not further clarified.

5.4 Use volumes

To determine the amount of geotextiles used or placed on the Swedish market, data from Statistics Sweden were retrieved on both domestic production and import/export. The results however proved to be unfeasible to use as the commodity codes (CN) that includes geotextiles were too broad to enable an assessment. According to correspondence with Statistics Sweden, the applicable CN codes are:

- 3919 Self-adhesive plates, sheets, film, foil, tape, strip and other flat shapes, of plastics, whether or not in rolls
- 3920 Plates, sheets, film, foil and strip, of plastics, non-cellular and not reinforced, laminated, supported or similarly combined with other materials, unprocessed or merely surface-treated, not cut to shape or merely cut into squares or rectangles
- 3921 Plates, sheets, film, foil and strip, of plastics, reinforced, laminated, supported or similarly combined with other materials, unprocessed or merely surface-treated, not cut to shape, or merely cut into squares or rectangles

The information on volumes was instead retrieved through a request to the European Association of Geosynthetic product Manufacturers (EAGM). According to EAGM, their members account for approximately 85% of the geosynthetics manufactured and sold in the EU. Based on a survey amongst their members, data on the amounts of geosynthetics manufactured and sold on the Swedish market in 2021 were shared with Ramboll (EAGM, 2022). The total use of geosynthetics in Sweden during 2021 was calculated based on these data are presented in Table 6.
From these calculations, the total amount of nonwoven and woven geotextiles in Sweden 2021 amounts to approximately 14900 tonnes. As a comparison, the same calculation for grids and composites results in approximately 1000 tonnes and thus, geotextiles correspond to approximately 94% of the total geosynthetics use in Sweden 2021. The term composites in this case refers to products in which a geotextile or geomembrane is combined with either a geonet or a geogrid e.g., for drainage functions. The grids or nets are often made from HDPE while the geotextiles are the normal nonwoven PP. See Figure 2 for an example. It is not clear whether product types not explicitly mentioned in the data are either included in one of the categories or if its use is insignificant and not reported. This includes e.g., knitted geotextiles, geosynthetic barriers and geomats.

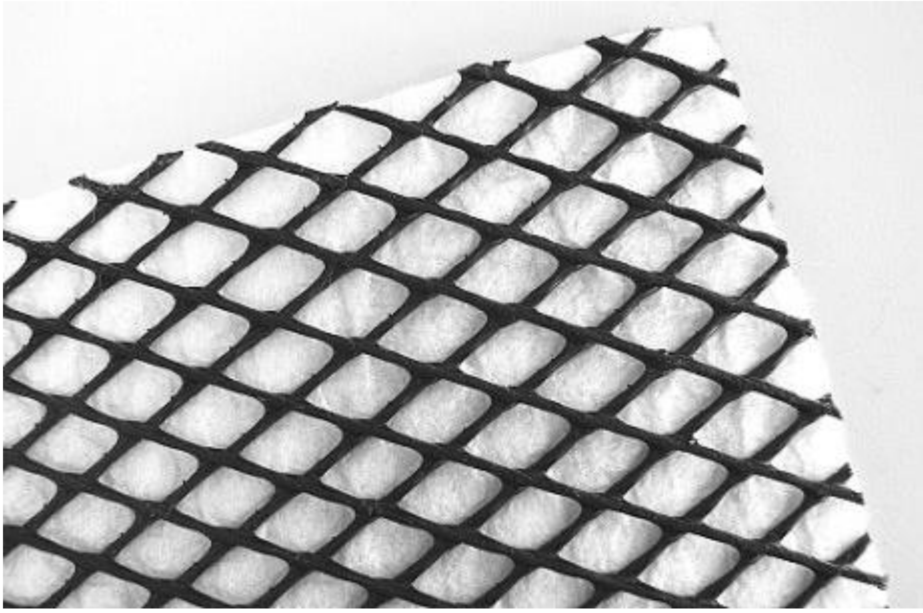


Figure 2. Picture of a geocomposite consisting of a HDPE net bonded with a PP geotextile. Picture from Geomat.eu[8]

[8] https://www.geomat.eu/en/drainage-geocomposites

Table 6. Total use of geosynthetics in Sweden 2021 based on EAGM data.

	Product family			
	Geotextiles		*Non geotextiles*	
	Nonwovens	Wovens	Grids	Composites
M² * 1000	94 350	380	2000	730
Tonnes	14 820	80	610	420
	Function geosynthetics			
	Separation & Filtration	Protection	Reinforcement	Drainage
M² * 1000	93 770	790	2240	590
Tonnes	14 470	350	710	350

According to EAGM, erosion control in hydraulic applications represent approximately 7% of the total EU market for geosynthetics, which corresponds to approximately 11 500 tonnes (2021). By applying the percentage of hydraulic applications to the total use in Sweden, the estimated quantity of geotextiles for hydraulic applications in Sweden currently corresponds to approximately 1040 tonnes per year (14900*0,07).

The majority of all geotextiles are used in construction applications, but a minor share goes to consumers, such as for gardening or separation applications. The private sector is not covered by certifications such NorGeoSpec 2012, but all products must be CE labelled. According to interviews with the industry, the private sector is estimated to be less than 10% of the total market.

5.4.1 Historical use

No data has been found on historical use of geotextiles and on the market development in Sweden. Although early published trials of geotextile use were published as early as 1935 and use in Europe is known to have occurred in the 1950s, the first international conference on construction fabrics held in Paris, France, in 1977 seems to have sparked the interest and use of these products (Koerner, 2016). From the interviews, it was confirmed that production began in the late 1960s but that there was a marked increase in the 1980s and -90s. Geotextiles is a growing market, but the actual growth rate has not been identified. One of the interviewees, an excavator operator, had a distinct feeling that geotextile use had increased significantly since he began his professional career in 2008. There is a general opinion amongst those working in the field that geotextile use has become more and more common, also for applications where it is of questionable importance and rather a safety precaution.

5.5 Geotextile Certifications

Geotextiles are construction products and as such, fall under the scope of Regulation (EU) No 305/2011[9] laying down harmonised conditions for the marketing of construction products. The Regulation lays down conditions for the placing or making available on the market of construction products by establishing harmonised rules on how to express the performance of construction

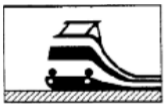
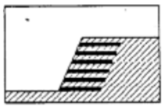
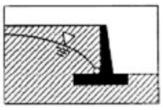
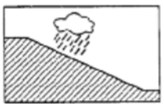
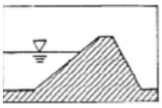
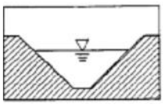
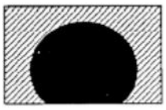
[9] Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011R0305-20140616

products in relation to their essential characteristics and on the use of CE marking on those products. Geotextiles are covered by harmonised standards and any manufacturer placing these products on the EU market have to issue a declaration of performance. The declaration is a way to assume responsibility and ensure that the essential characteristics of those products are in accordance with the relevant harmonised technical specifications, i.e., harmonised standards or a European Technical Assessment issued for the product in question (KEMI, 2021).

The harmonised standards applicable for geotextiles can be found in the EU Nando (New Approach Notified and Designated Organisations) database[10] and are listed in Table 7.

[10] https://ec.europa.eu/growth/tools-databases/nando/index.cfm?fuseaction=cp.hs&cpr=Y#hs

Table 7. List of EU harmonised standards for geotextiles.

Standard	Pictogram	Scope
EN 13249:2016		Geotextiles and geotextile-related products - Characteristics required for use in the construction of roads and other trafficked areas (excluding railways and asphalt inclusion).
EN 13250:2016		Geotextiles and geotextile-related products — Characteristics required for use in the construction of railways.
EN 13251:2016		Geotextiles and geotextile-related products — Characteristics required for use in earthworks, foundations and retaining structures.
EN 13252:2016		Geotextiles and geotextile-related products — Characteristics required for use in drainage systems.
EN 13253:2016		Geotextiles and geotextile-related products — Characteristics required for use in erosion control works (coastal protection, bank revetments).
EN 13254:2016		Geotextiles and geotextile-related products — Characteristics required for the use in the construction of reservoirs and dams.
EN 13255:2016		Geotextiles and geotextile-related products — Characteristics required for use in the construction of canals.
EN 13256:2016		Geotextiles and geotextile-related products — Characteristics required for use in the construction of tunnels and underground structures.
EN 13257:2016		Geotextiles and geotextile-related products — Characteristics required for use in solid waste disposal.
EN 13265:2016		Geotextiles and geotextile-related products — Characteristics required for use in liquid waste containment projects.
EN 15381:2008	No pictogram	Geotextiles and geotextile-related products - Characteristics required for use in pavements and asphalt overlays.

In each of these standards, there are technical requirements that the products must satisfy to allow the manufacturer to issue the declaration of performance and label the product with a CE mark. Of special interest for this assessment are the durability aspects described under Annex B in each of the standards. These requirements are described in 5.5.1 below.

5.5.1 CE-marking durability requirements

In terms of service life, the standards state that the provisions and assessment methods used are;

"*based upon the current state of the art, knowledge and experience. The service life refers to the period during which the geosynthetic retains the required properties of this annex, assuming it was properly installed, used and maintained.*"

Furthermore, the standards describe that for a geosynthetic that conforms with the requirements, the service life should be seen as a minimum indication. At the same time, the standard also states that the indicated service life should not be seen a guarantee but rather as a tool to choose a suitable product for the task.

5.5.1.1 Weathering

All CE labelled geotextiles must undergo a weathering test according to the requirements in CEN EN 12224[11] as laid down in Annex B.2 of EN 13249[12]. This test includes exposure to UV-light and succeeding strength retention tests. In Table 8 below, the strength retention result is translated to a maximum exposure time that the geotextile can be left under exposure to UV-light before they must be covered by soil when used in applications.

Table 8. Maximum exposure times of geotextiles before covering according to EN 13249.

Application	Retained strength	Maximum time of exposure after installation
Reinforcement or other applications where long-term strength is required	>80%	1 month
	60% to 80%	2 weeks
	<60%	1 day
Other applications (where long-term strength is not required)	>60%	1 month
	20% to 60%	2 weeks
	<20%	1 day

For products that will be exposed for longer duration than what is described below, extended testing is necessary bur this is not further described. Products that have not been tested for resistance to weathering, shall according to the standard, be covered on the day of installation. The standard also determines that products information shall include the text "*To be covered within (duration) after installation*".

5.5.1.2 Service life determination

Other than UV-light, other deteriorating factors include temperature, abrasion, pH, microbial degradation and possibly also pollutants. It seems however that especially temperature and pH within the normal intervals expected where geotextiles are applied, are minor factors.

[11] CEN EN 12224 - Geotextiles and Geotextile-Related Products - Determination of the Resistance to Weathering

[12] EN 13249 - Geotextiles and geotextile-related products – Characteristics required for use in the construction of roads and other trafficked areas (excluding railways and asphalt inclusion

Polypropylene and Polyethylene

As a part of the CE-labelling procedure, geotextiles made of PP and PE are subjected to, in addition to the weathering test described in 5.5.1.1, oxidation testing according to EN ISO 13438[13].

In this test, samples of the geotextile product are kept in 80 C° water for 28 days after which they are transferred to an oven and kept in 100 C° for between 28 and 112 days depending on the life expectancy that the product is to be classified for, see Table 9. After this artificial ageing process is finalised, a tensile strength test according to CEN EN 12226[14] is carried out and a minimum of 50% remaining tensile strength is required to pass.

Table 9. Temperatures and duration for oxidation test according to EN ISO 13438, method A.

Material	Application	Service life	Temperature and duration in water	Temperature and duration in oven
Polypropylene (PP), Polyethylene (PE), Polyamide (PA) and aramid (AR)	Non-reinforcing and reinforcing	25 years	80 °C for 28 days	100 °C for 28 days
		50 years		100 °C for 56 days
		100 years		100 °C for 112 days

The standard also states that the results shall be applicable for use in natural soils with 4 ≤ pH ≤ 9 and soil temperatures ≤ 25 °C.

Depending on the duration of the oven procedure and the succeeding test results, the product is given an estimated service life between 25 and 100 years.

Polyethylene terephthalate

For geotextiles manufactured from PET, the test required for service life determination is slightly different than for PP and PE. In Annex B.4.2.1 of the harmonised standards for geotextiles, it is determined that PET shall be tested according to EN 12447[15]. In the introduction to this standard, the following information can be found;

"*In certain polymers moisture leads to hydrolysis throughout the thickness of the fibre (internal hydrolysis) but the rate of degradation is such that over short periods it is only measurable at elevated temperatures, e.g., by immersion in hot water*."

The test procedure described in EN 12447 is very similar to that for PP and PE with the exception that it excludes the heat exposure in an oven, i.e., it only requires the sample to be immersed in 80 C° water but for varying duration depending on service life. The standard also differentiates between application for which PET geotextiles are used for reinforcement applications or other applications where long-term strength is required in natural soil or for other applications in natural

[13] EN ISO 13438:2018. Geosynthetics – Screening test method for determining the resistance of geotextiles and geotextile-related products to oxidation

[14] EN 12226 - Geosynthetics – General tests for evaluation following durability testing

[15] EN 12447:2021 - Geotextiles and geotextile-related products – Screening test method for determining the resistance to hydrolysis in water

soil, i.e., not requiring long-term strength. In Table 10 below, the test duration required for the different service lives are listed.

Table 10. Test duration for hydrolysis resistance test according to EN ISO 12447

Application	Test duration (days)	Service life
Reinforcement/long term strength	28	25 years
	56	50 years
	112	100 years
Other	14	25 years
	28	50 years
	56	100 years

5.5.1.3 Abrasion resistance

When it comes to abrasion, geotextiles used for hydraulic applications may be tested according to ISO 22182:2020[16]. This is not yet part of the harmonised standards but a requirement in certain geographies. In this test, samples of the geotextile are placed in a motor-driven steel drum filled with water and gravel of the following composition (BAW, 2021);

- 2 kg sharp-grained basalt gravel 8/11 mm
- 1 kg sharp-grained basalt gravel 5/8 mm
- 1 kg sharp-grained basalt gravel 2/5 mm
- 8 l water

The drum is set up to perform two abrasion sequences of 40 000 revolutions each at 16 drum revolutions per minute with the direction of rotation changing every 5 000 revolutions. After the first sequence of 40 000 revolutions, the test samples are assessed with regard to damage and fibre release. If the test samples are not destroyed, the abrasion material is replenished, and the second abrasion sequence is carried out. Before and after the abrasion, tests of tensile strength and characteristic opening size are performed. The changes in the test values compared to the initial values serve as a measure for evaluating the abrasion resistance. A visual inspection of the test material is also performed to assess whether fibres are loosened from the test samples by the abrasion stress. A sample of the actual standard has not been available to Ramboll and it is therefore uncertain whether the standard proposes any conditions/values for how much abrasion is acceptable for a product to pass the test.

5.5.1.4 Microbial degradation

Although microbial degradation of plastics has been reported in literature, see 6.2.4 for more information, testing for this is not something that is generally required by the standards listed in Table 7. A supporting standard, EN-12225[17] is however available and developed to determine microbiological resistance for geotextiles and geotextile-related products. In the standard, under the scope, the following note can be found;

[16] ISO 22182:2020. Geotextiles and geotextile-related products — Determination of index abrasion resistance characteristics under wet conditions for hydraulic applications.

[17] EN 12225, Geotextiles and geotextile-related products - Method for determining the microbiological resistance by a soil burial test.

"*NOTE — Experience and exhumation of geosynthetics which had performed successfully, in some cases for more than two decades, indicate that geosynthetics made out of synthetic materials are generally resistant against microbial initiated decay. It can therefore be expected that most of these products commercially available at the present time will pass the soil burial test successfully and it is probably not necessary to submit them all to this test independent of their function. However, if the requirements for appropriate functioning of the geosynthetics demand proof of microbiological resistance or if they are manufactured from newly developed polymers whose resistance is in any doubt, the soil burial test can provide additional information*."

From the above, it can be concluded that the dominating geotextiles manufactured out of PP, PET and PE will most likely not be tested for this and are expected to not be affected by microbial degradation to any large degree.

5.5.2 NorGeoSpec

NorGeoSpec (NGS) is a Nordic system for the certification and specification of geosynthetics and geosynthetic-related products for separation, filtration and/or reinforcement. The system[18] was cooperatively developed by the NGS certification body together with SINTEF Certification, different test laboratories and transportation authorities of the member states Finland, Sweden, Norway and Estonia. The certification is a voluntary system, but most products on the Swedish market are certified using this system since it is a requirement for use in public sector infrastructure projects.

It is important to illuminate however, that all products must have a CE mark and that the NGS requirements are not an alternative to those in the harmonised standards that must be fulfilled for CE marking. Instead, the NGS cover additional requirements related to product verification, identification, and quality. All NGS certified geotextiles are made by non-woven materials.

Within the NorGeoSpec certification, there are five different profiles for geotextiles. The material and quality of the profiles are the same, but their use depends on several factors. These factors include the solidity or looseness of the subsoil, the fill-material grain size to be used and the mechanical stress during the installation phase and the size and type of equipment/machinery to be used. N1-N5 are all made for separation of materials and according to the interviews with the industry, the most commonly used profiles in Sweden are N2 and N3. See Table 11 for the weights of the different profiles.

Table 11. The weight of the different classes of geotextile profiles in the NGS verification (made of 100% polypropylene).

Profile	Weight (g/m2)
N1	90-100
N2	130 -136
N3	190
N4	255-260
N5	340-350

[18] NorGeoSpec 2012 - A Nordic system for the certification and specification of geosynthetics and geosynthetic-related products. https://www.norgeospec.org/acms/data/uploads/dateien/sintef_guideline_2017.pdf

Information on the subsoil type and shear strength, construction conditions, road-quality requirements, the infill material's maximum grain size and traffic conditions (high or low) is all considered for the selection of the suitable profile.

How deep the geotextile is buried also depends on the profile. According to Svenska Geotech, geotextiles are used at different depths depending on the project and the area of use. It should be at least 150mm below the drivable surface to avoid damage. For example, N2 is often laid higher up under the base layer as it supports finer fractions while N3 is laid below the reinforcement layer and further down as this involves coarser fractions.

For conditions not covered by NorGeoSpec 2012 guidelines, a special evaluation of required specification profile should be made e.g., if conditions such as traffic load is unknown.
This evaluation only applies to smaller roads and areas such as forest roads, private parking lots, cottage roads, or in construction and civil engineering projects which do not include any guidelines in the technical description.

5.6 Geotextile waste

EAGM mentions that since much of the geotextile installed in soil has been in place shorter than its expected service life, the majority of all geotextiles are still in service. According to NorGeoSpec, it is still very rare that geotextiles are removed and therefore there is almost no knowledge or experience about the waste management. There are some applications where there is a need to remove geotextiles, e.g., when used for temporary roads.

Some of the interviewed stakeholders argue that the geotextile in theory can be recycled or reused since much of it is most likely still functioning and is intact. The geotextile materials are also made of single polymers which should simplify recycling. Nevertheless, the interviewees also state that in practice most geotextile will either go to landfills or will be incinerated. It is unlikely that small fractions of geotextiles will be separated from other excavated materials or separated through e.g., sieving of masses and hence, it will remain in the soil. Larger pieces or whole sheets are usually separated and sorted into either a plastics fraction or mixed with other combustible material and incinerated.

None of the interviewed stakeholders are aware of any large-scale attempts to collect and recycle geotextile waste but industry representatives mention that studies and trials on recycling are being performed.

5.6.1 Condition of recovered geotextiles

There are different views in the industry about the condition of recovered geotextiles. NorGeoSpec mentions that there are no examinations on the quality of excavated geotextiles. Svenska Geotech believes that since the majority of used geotextile in constructions is excavated using heavy machines, the geotextiles risk being damaged in the process. According to one construction company, this is indeed the case and when geotextiles are dug up, it will break, and pieces will end up in the excavated material. The rupture of the geotextiles is a consequence of the force applied by the excavator bucket and teeth and not due to the material being brittle. In general, geotextiles are perceived by the operators to be of good quality when dug up. In another interview however, a construction company mentions that in cases where older geotextiles are dug up, they do not have the same strength and is easier to cut compared to a new fabric. In most cases though, it is impossible for the operator carrying out the excavation to know how old the unearthed geotextile is. Old geotextiles that are unearthed are often faded or visibly used, sometimes they are also stained green by algae as they retain moisture.

6. GEOTEXTILES AS A SOURCE OF MICROPLASTICS

This chapter aims to give a general overview on what is known about geotextiles and microplastics, which factors that influence degradation and for which applications there is a risk for such degradation leading to the formation of microplastics.

6.1 Previous research on geotextiles and microplastics

One previous study (Bai, Li, Ma, & Li, 2022) regarding leakage of microplastics from geotextiles has received a lot of attention and triggered investigations of geotextiles as a source of microplastics. The study investigates the photoaging behaviour of geotextiles and evaluate the possibility of leakage of microplastic from geotextile in hydraulic applications. This is done through a combination of laboratory experiments and field research. Field research in Yancheng, China, showed that many geotextiles made of PET existed in hydraulic applications and the laboratory experiments showed that UV exposure accelerated the photooxidative process and promoted the degradation of geotextiles made of PET. According to the analysis performed in the laboratory experiments, a large number of nanosized fibres were discharged into water from PET geotextiles. The conclusion from the study highlights that the geotextiles used in hydraulic applications are subject to breakdown or damage and leakage of microplastics into the environment under the exposure to UV.

This study has been criticized by several instances, among them the International Geosynthetics Society (IGS) that published a letter to the editors (IGS, 2022) of the publication. IGS claims that the publication wrongfully portraits geotextiles as a high-volume source of ocean microplastics. IGS criticize the estimate of the mass per unit area of geotextile. The estimate is based on a calculation of microplastics per m^2 of geotextile. According to IGS, most geotextile manufactured weigh less than 2 kg/m^2 and therefore there is not enough geotextile mass available to produce the calculated amount of microplastic stated in the study by Bai et al. Furthermore, the presented calculation would mean that the entire mass of the geotextile would degrade to 100% microplastic within 1-year, which IGS deems not realistic. Lastly, IGS also criticize the assumption made in the study that all geotextiles used in drainage applications (17% of worldwide production), made of PET (5% of total production) are used without being covered and in coastal protection applications. IGS claim that only very small amounts of geotextiles are used for drainage in coastal reclamation areas, in addition to small quantities of geotextile used in the applications of erosion control. Almost always, these geotextiles are covered, preventing UV exposure.

According to EAGM, the lifetime for geotextile, according to CE-marking, is more than 100 years and not 1 year as stated in the study. EAGM also state that the CE-marking requires that geosynthetics are covered within a maximum of 4 weeks after installation, so EAGM argues that the effect of UV is negligible. Although not specifically mentioning the Bai study, representatives from CEN TC189, the technical committee that develops the geotextile standards, questions the leakage of microplastics from geotextile in their response to the Commission consultation (Cazzuffi & Eufinger, 2022). According to them, 99.5% of geotextiles are designed to be placed under the ground and the expected lifetime is 100 years. Those geotextiles that are not placed protected under ground are also designed to have a long lifetime. They are arguing that this means that the main source of degradation of other plastics are not relevant for geotextiles and the only source of potential release of microplastic from geotextile is where the installation process is not done according to standards, e.g., covered within 4 weeks.

As a final note, the criticism highlights that the tests in the study were performed on samples of polyester (PET) nonwoven and without giving any specifications of UV stabilization and its chemical composition. However, as most geotextiles used in coastal/ hydraulic applications in

Europe are well-stabilized polypropene products, the analysed materials in the study do not represent the material commonly used in the products sold on the European market.

To conclude the discussion of the Bai et al study, it seems indeed that some of the assumptions were wrong or significantly exaggerated and that the calculated amounts of microplastic leakage therefore should not be used to represent microplastics release from geotextiles. The study does however support and provide insight in the strong effects that UV can exert on the degradation of geotextiles.

A review article by Vé Wievel & Lamoree (Vé Wiewel & Lamoree, 2016) also indicates that geotextile can be a potential source of microplastics. The aim of the study is to critically evaluate synthetic geotextiles in terms of their ecotoxicology and to give an overview of applications and compositions. According to the study, geotextiles are subject to several mechanisms of degradation and the type of degradation that may occur depends on which environmental stressor the geotextile is exposed to. Related to degradation of geotextile, the study state that, "*under environmental conditions, geotextiles may degrade into smaller particles, below 5 mm defined as microplastics, and these have been reported to enter the environment*". The references used for this statement do however not provide sufficient support that geotextile is a source of microplastic emissions. These references rather highlight packaging, rope, clothing and that the larger items can break down to smaller fragments as potential sources for microplastics. Although the same polymers as those used in geotextiles were identified at coastal locations, there is no mentioning of geotextiles and the other sources mentioned above appears more likely.

A third study aims to report on a new type of beach contamination, debris of geosynthetic materials (Esiukova, Chubarenko, & Simon, 2018). The study was carried out in the Baltic Sea shore within Kaliningrad Oblast where the shores are influenced by littering due to storms during the autumn- winter period. In this publication, out of 150 samples of geosynthetic materials collected on the beach, 47% were assessed as originating from geotextile. The distribution of the size of the samples were not described, only that they included both large (25mm up to 1m) and small (0.5 to 5 mm) items.

6.2 Factors influencing geotextile degradation

In this section, the factors influencing geotextile degradation are summarised.

6.2.1 Abrasion and mechanical effects

The mechanical degradation can be divided into three types of damages: mechanical damage, creep rupture and creep strain. In general, these damages occur in different phases of the geotextile lifetime (Greenwood J. H., 2015). Usually, the mechanical damage occurs in the installation phase and in some applications, this is one of the most relevant degradation effects (Carlos, Carneiro, & de Lurdes Lopes, 2019). Typical mechanical damages are cuts in fibers, holes, abrasion, punctures and stretching. A study on the mechanical damages of different aggregates on three nonwoven needle-punched geotextiles (PP) with different mass per unit found that the damages were related to both the mass per unit of the textile as well as the type of aggregate. From the different aggregates: sand, gravel, river gravel and corundum (synthetic aggregate of aluminium oxide), the least damaging aggregate was sand and the most damaging was corundum. As expected, the amount of damage was negatively correlated with mass per unit. Punctures and abrasion damage was found in all geotextiles for all aggregates but sand. Mechanical tests (tensile and puncture tests) following the mechanical damage-tests showed that all geotextiles had reduced mechanical properties and that it was correlated to the observed damage load (Carlos, Carneiro, & de Lurdes Lopes, 2019).
Another mechanical effect is creep rupture which can occur if a material is under permanent high pressure. This is a result of a slow reduction in strength that tends to accelerate over time. These damages are naturally harder to study than damage in the installation phase since the damage is

not induced instantly. However, tests have been made to be able to establish relationships between load and lifetime. To avoid creep rupture in geotextiles, local high loads should be avoided as well as presence of certain liquids e.g. lubricants and cleaning fluids known for together causing premature cracking of a polymer known as environmental stress cracking (ESC) (Greenwood J. H., 2015) (Chatten, 1999).
A third type of mechanical degradation is creep strain that, as with creep rupture, is mainly caused by high pressure. Creep strain is a permanent, non-elastic deformation which increases with time where the main mechanism is the breakage of bonds between the fibers, and reorientation of the fibers (Bourdeau, 1996). Since creep rupture increases with time it is an important factor to include in the calculations of maximum load. It is possible to calculate the maximum load that can be applied on a textile by using the maximum allowed strain for the specific textile combined with the required lifetime. Creep is intensified by temperature which is another factor that needs to be in the equation (Greenwood J. H., 2015).

6.2.2 Weathering

Exposure to sunlight is the most important factor in the weathering of geotextiles (Elayaperumal, 2010). The high energy photons, especially UV-light (<400nm), can break the polymer bonds in plastic material leading to the plastic becoming more brittle and prone to break known as photo-oxidation. How UV-radiation affects polymers differs depending on the type. In PE and PP it is known to induce oxidation while in polyester it can attack the polymer chain. In PVC it can reduce hydrochloric acid (Greenwood J. H., 2015). Polyester is known to have higher resistance to UV than HDPE and PP due to the resistance of ester bonds to breakage (Elayaperumal, 2010).
The solar radiation and hence the degradation rate of the textile depends on global location, season, and the current weather (Geofabrics, 2019). Due to the rather high sensitivity to UV-light, most geosynthetics have additives to increase the tolerance to UV-radiation (Greenwood J. H., 2015). One of the additives that is used is carbon black.
The level of UV-radiation that the textile will be exposed pre, during and post installation is of high importance when choosing an appropriate geotextile (Geofabrics, 2019). However, currently there is no short-term test that can predict the UV-effect on long term use. Therefore, the design must be based on experience and predictions of the manufacturers (Greenwood J. H., 2015).
Other factors such as rain, high temperature and atmospheric elements e.g., oxygen, ozone and hydrocarbons accelerate the weathering process (Elayaperumal, 2010).

6.2.3 Chemical degradation

Chemical degradation is regarded as the most complex type of degradation when it comes to geotextile and involves liquids or gases and are more intense in saturated and moist soils (Greenwood J. H., 2015). Various liquids such as water or active waste in landfills can alter the polymer chains by chain scission, oxidation, cross-linking, swelling or dissolution of the polymer. Chemical attacks can also cause volatilisation or extraction of ingredients in the polymer as well as increase the crystallinity (Elayaperumal, 2010).
There are two main types of chemical degradation: hydrolysis and oxidation, these are described below.
Oxidation is initiated by solar radiation, heat, mechanical stress or catalytic residues from the production(Elayaperumal, 2010). PE, PP and PS are all susceptible to photo-initiated (UV) oxidative degradation and this is believed to be the most significant degrading factor for these plastics in the environment.
Also polyester is prone to oxidative degradation. When PET is degraded, carboxylic acid is formed, which in turn promotes oxidative degradation (Gewert, 2015).

For PP and PE there are a number of available additives that can be used to prevent degradation such as antioxidants, UV-stabilizers and deactivators protecting the plastic from oxidation caused by metal ions. For polyesters there are no additives that can be added to increase the lifetime (Greenwood J. H., 2015).
Regarding geotextiles, oxidation can primarily be expected in environments where the material is exposed to sun and heat e.g., where the material is uncovered. This could be either in the installation phase where the material not yet has been covered, in faulty installations or in applications where the material per default is exposed, such as weed control applications. Oxidation will likely also be higher where the soil has an elevated temperature such as regions with higher temperatures.

6.2.3.1 Hydrolysis

Plastic materials with heteroatoms in the main chain like polyester and polyurethane are susceptible of hydrolysis. In hydrolysis of polyester the PET-molecule reacts with water in a reversed reaction in which it is formed, and terephthalic acid and ethylene glycol is formed (Gewert, 2015). There are two types of hydrolysis, one is the etching of the surface of the polymers and the second one is internal, affecting the entire cross section (Geofabrics, 2019). Studies have shown that the rate of the hydrolysis is primarily promoted by alkaline conditions because of the presence of reactive OH-ions but the reaction is also present in acidic environments (Mathur, 1994). Other factors that increase the rate of hydrolysis is low molecular weight, high temperature, high pH and humidity (Elayaperumal, 2010).
Visual effects of hydrolysis and oxidation in plastics is the plastics turning yellow (Gewert, 2015). Geotextiles installed in environments where humidity, temperature and pH is elevated will hence be more exposed to hydrolytic degradation. Examples of such application is hydraulic applications where the textile is permanently soaked in water but also alkaline soils and soils that has an elevated temperature due to sun exposure or other reason.

6.2.4 Biologic degradation

In general, high molecular weight increases the resistance to biodegradation since large molecules cannot pass though the cellular membranes of the microbes. Similarly, the lack of functional groups makes the molecule less hydrophilic which thereby reduces its bioavailability. PP is resistant to biodegradation for this reason. PE is less resistant to biodegradation than PP since it can be attacked by microorganisms at any terminal methyl group. Therefore, the degradation rate of PE depends strongly on additives. PET is very resistant to biodegradation in the environment due to its compact structure (Gewert, 2015). However weak degradation was shown by Zhang et al. (2004) when PET was exposed to microbes and lipase (Zhang, Wang, Gong, & Gu, 2004). Although most polymers are resistant to biodegradation, abiotic degradation such as oxidation due to UV or heat can cause the polymer chains to break, leading to the formation of smaller more bioavailable molecules with carboxyl functional groups.
However, as mentioned in 5.4.1.4. from the experience and by exhumation of geosynthetics by the geotextile industry, the textiles are generally resistant to microbial initiated decay[19]. There are situations where degradation is wanted as described in 5.3.1, e.g., in slopes where degradable geotextiles may assist with erosion prevention until plants can take over the function.
Microbial degradation of plastics takes place both in terrestrial and aquatic environments. In a recent literature study, the microorganisms and enzymes able to degrade commonly used plastics were summarized. The study shows that different types of microorganisms populate different environments e.g., soils of disposal sites, marine water, the gut of waxworms, plastic waste dump

[19] EN 12225, Geotextiles and geotextile-related products - Method for determining the microbiological resistance by a soil burial test.

sites etc. hence proving that the surrounding environment has an impact on the rate on the biodegradation of plastics. The study also showed that various organisms specialize in the degradation of different types of plastics. The exact understanding of depolymerases from microorganisms is however this far limited (Ru, Hou, & Yang, 2020).

6.3 Geotextile expected lifetime and experience from users

Most CE marked geotextiles and all products that are certified by NorGeoSpec are required to fulfil certain conditions to claim a lifetime up to 25, 50 and 100 years. The expected lifetime is based on normal soil conditions: pH-value between $4 \leq pH \leq 9$ and a temperature < 25°C. There are also recommended maximum UV-exposure periods for geotextiles as described in 5.5.1.1. According to EAGM, most products on the market are expected to have a lifetime of at least 100 years when installed correctly. They further state that if the material is used in road constructions, where degrading factors are small, the expected lifetime is decades or even centuries (EAGM, 2022).

The service life-tests performed during the CE marking process determines the maximum time that the material is allowed to be left uncovered. Where longer exposure may be required, samples of the exposed fabric should be taken periodically and tested to verify that a detrimental amount of strength loss has not occurred. The protective wrapper on rolls of geotextile when shipped should remain in place until the material is installed (Propex Geosolutions).

However, information from the construction industry given in interviews for this study reveals that geotextiles are not always handled according to instructions provided by the geotextile manufacturers. One of the construction companies mentioned that they are not aware of any information concerning how the geotextile should be handled, covered and stored related to UV-protection. They also explained that there are projects where work is paused for a period of time and the geotextile is left in the sunlight without protection. In these cases, they have noticed a difference in the texture and sometimes that the geotextile has become brittle. One construction firm stated that in large projects where 5-10 rolls are used, they are all are opened at the same time and if there are any geotextile left, these remnants are used in other projects. Opened geotextile rolls can remain open for more than 20 days before being used again. To facilitate the use and installation of geotextile in projects, special tools are available to hold the rolls. On these, which can be lifted by the excavators, there is also tarpaulin that is used in order to protect geotextile. Homemade solutions also exist used to hold the geotextile, and that has tarpaulin that can be pulled over. This is however not primality to protect against UV but against water and frost. Unless tools are available for installing, sometimes the textile is installed by kicking or pushing it manually.

6.4 Geotextile and potential release of microplastics

To be able to withstand different environmental conditions under long periods of time, geotextiles must be resistant to mechanical effects, UV-light and thermal, chemical, and biological attacks. Geotextiles are rarely exposed to only one of these environmental conditions but often a combination and the mechanisms described in 6.2 have synergistic effects (Elayaperumal, 2010). The exposure to these conditions will vary with application but that they have effects on geotextile degradation cannot be contested. What is not known is how much exposure to these conditions that is required for geotextiles to degrade enough to form microplastics.

Throughout this project, hydraulic applications have been highlighted both by stakeholders and literature as a specific application where the risk for release of microplastics is elevated. In these applications, the geotextile will be exposed to abrasion both from water movement but also from surrounding materials such as sand, gravel and rocks whose movement will be triggered by the elements and act as abrasives. In addition to this, UV exposure and oxygen rich environments are more likely in this application than others, especially if geotextiles are uncovered above the water level. Even if the materials are covered according to instructions during installation, the exposed environment may lead to this coverage being compromised during the lifetime of the geotextile and thus increase UV exposure. Lastly, the constant exposure to water is likely to contribute to leaching of additives from the geotextiles which in turn will reduce its resistance and make it more prone to further degradation in the form of e.g., weathering or biological degradation. In Figure 3, an example of a hydraulic application is shown.

Figure 3. Installation of geotextile in a hydraulic application.

There seems to be a consensus amongst the stakeholders interviewed for this report that the single most influential degrading factor, affecting all types of polymers, is exposure to UV-light. Based on high sensitivity of geotextile to UV and the guidelines on maximum exposure times before covering the geotextile, it is clear that if these directions are not followed, i.e. mistakes or inaccurate use/application leaving the geotextile exposed to sunlight, it may significantly alter the characteristics of the plastics and hence, increase the risk for microplastics formation. From the dialogue with constructors, it is also apparent that the handling and installation of geotextiles does not always follow the guidelines provided by the manufacturers. It has also been noted that the geotextile that has been exposed to sun before installation has changed texture and sometimes become more brittle. Therefore, for other uses in soil that are not hydraulic applications, wrongful use in the form of leaving geotextiles exposed to sunlight is assessed to be a factor influencing the microplastics formation. This includes both installation by construction companies and the use by private consumers, the latter assumed not to be aware of or follow any particular installation instructions. Once in the soil and covered, fewer of the conditions contributing to degradation will be applicable i.e., no more UV-exposure, stable temperatures, no abrasion. Nonetheless, if the geotextile is weakened already at the time of installation, this will make it more sensitive to remaining degradation factors such as chemical and biological degradation. In wet soil conditions, leaching of additives may also be a factor.

6.5 Assumptions for potential microplastics emission

6.5.1 Historical usage

We have not found any statistics on the usage of geotextiles in the past, other than that production began in the late 1960s and that there was a marked increase in the 1980s and -90s. There are also signs that indicate that the market has grown faster and faster. Today, the global geotextile market is expected to show an annual compound growth rate of 6.5 percent. In an attempt to calculate the historical usage and amounts of already installed geotextiles in Sweden, we reverse calculated from today’s numbers to the beginning of the 1980s when we assume consumption began. Figure 4 below shows four different paths, from an exponential increase to a linear increase, with two customized potential developments. One called average which is the midpoint between exponential and linear each year, and one with an increasing growth rate each ten-year period.

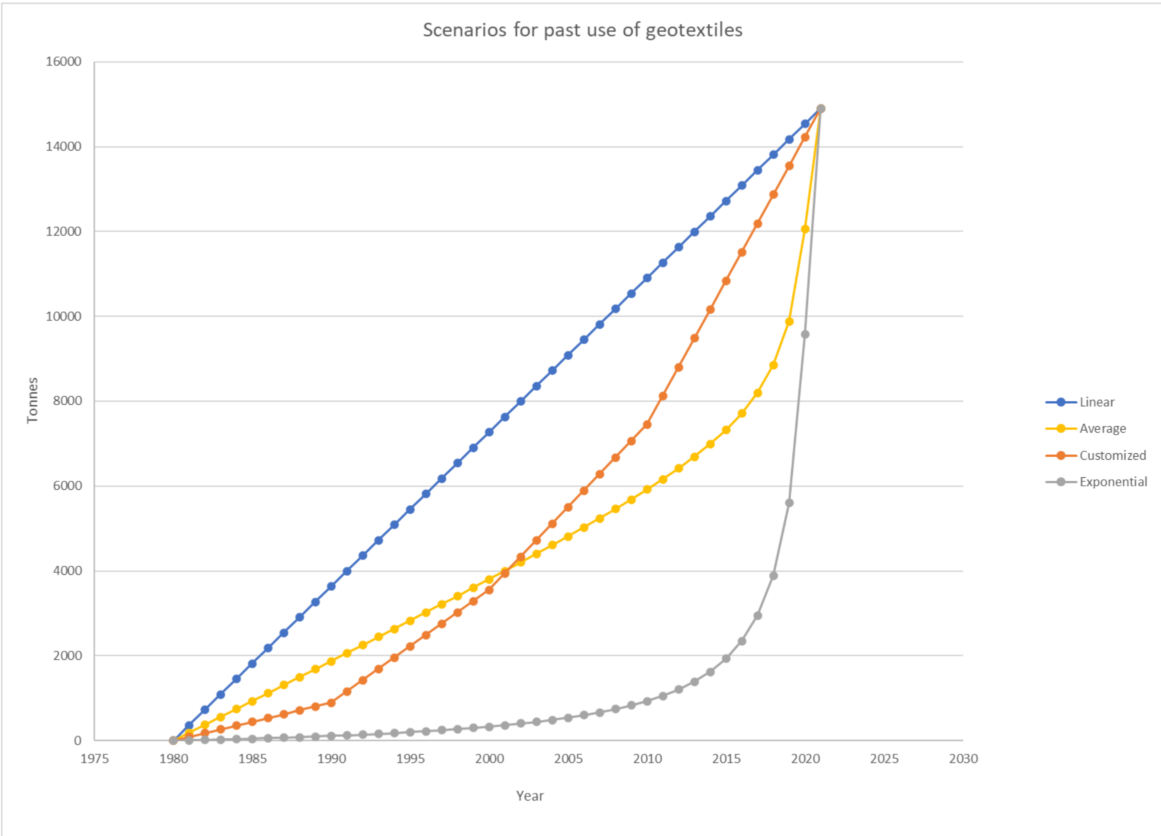


Figure 4. Estimated past use of geotextiles.

For each different path we have calculated the total installed amount of geotextiles from 1980 until today, see Table 12 below. The equivalent growth rate between 2020 and 2021 can also be seen in the table. The true number is probably somewhere between the exponential and the linear growth, and there are large uncertainties because a lack of information. From here on we assume the customized path of development to be the most accurate. One reason is because it best matches the global expected annual compound growth rate of 6.5 percent.

Table 12. Calculated total amount of installed geotextiles between 1980 and 2021 in Sweden for different possible developments

Total usage	Linear	Average	Customized	Exponential
Tonnes	312 900	184 000	212 100	55 200
Growth rate -20-21	3%	24%	5%	56%

6.5.2 Increase in usage and accumulation over time

Continuing on the estimated historical usage (from the customized path) we have prolonged the development with a linear growth of 1000 tonnes per year, corresponding to the current growth rate of 6.5% (14 900*0.065=969). This growth stays the same until the annual installed amount of geotextiles reaches 30 000 tonnes (a doubling of today's number of 14 900 tonnes), which happens in the year 2037. From then on, the market is stabilized at the same annual level, see Figure 5 below.

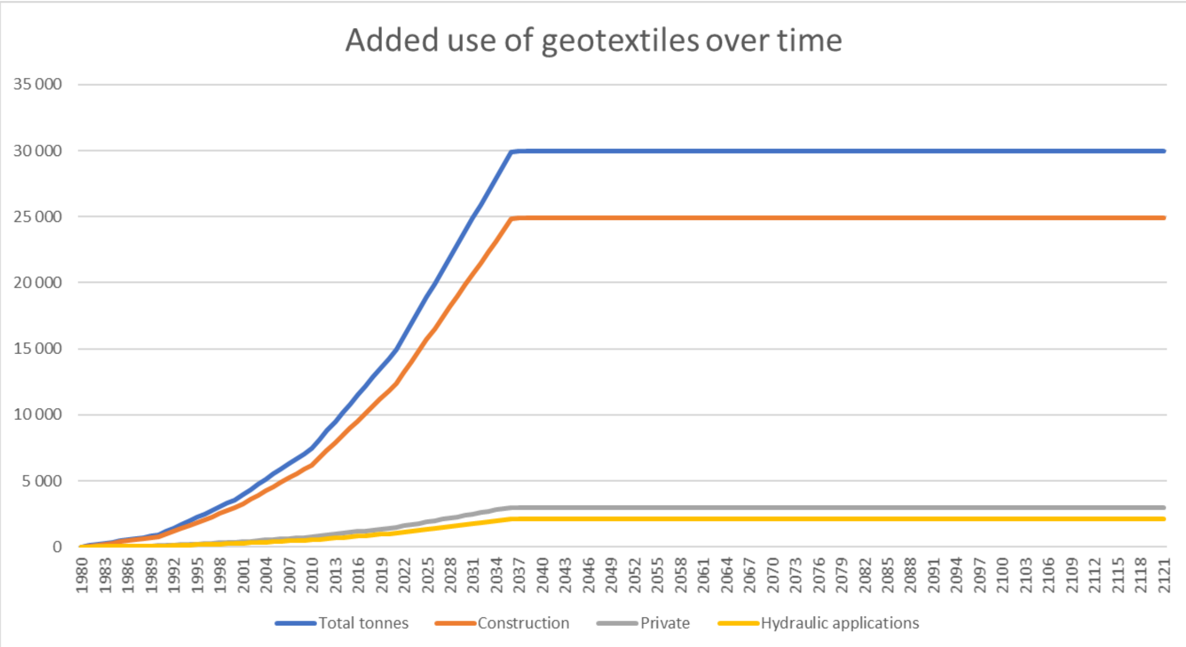


Figure 5. Projected yearly use of geotextiles in Sweden over time.

For the sake of simplicity, we assume that all geotextiles have an expected lifetime of 100 years and are all made of polypropylene (PP), or that all polymers have the same properties and quality. We also assume that seven percent of the total usage is in hydraulic applications, according to the information in section 5.4. The rest is divided between usage in construction (83%) and different applications (except hydraulic) by private consumers (10%). All follow the same development over time. With these assumptions the accumulated use over the time period

1980-2121 is 3 106 000 tonnes. This is equivalent to approximately 19 800 km^2 (based on 6370 m^2 per tonne for nonwowens), which is about 4% of Sweden's total surface.

6.5.3 Degradation of geotextiles

As stated in section 6.4, the two main possible reasons for release of microplastics from geotextiles are abrasion and other degradation factors in hydraulic applications and exposure to UV-light when the textiles are not handled properly according to manufacturer's instructions before installation. According to the best of our knowledge we assume that abrasion leads to a continuous release of microplastics from the surface of the geotextiles, while exposure to UV-light means a shortening of the expected lifetime. We further assume that after the lifetime has passed, a full degradation occurs of the geotextiles into smaller pieces, and eventually microplastics.

Based on assessments of the extent to which these reasons for microplastic release actually happen, we have created two scenarios to calculate emissions of microplastics. A worst-case scenario assumes that wrongful handling in construction applications affect 20% of installed geotextiles, and that the unwanted UV exposure in turn leads to a shortening of the expected lifetime to half of the normal time. The mismanagement in private use is expected to be higher and 50% of installed geotextiles are assumed to get their lifetime shorted into half of normal due to UV exposure. In hydraulic applications, we assume 20% of total geotextile mass to be released as microplastic over a lifetime due to abrasion. Assuming a lifetime of 100 years, this means a release of 0,2% of total mass per year. The number 20% comes from Magnusson et al. (2016) and is the quantity of a tire mass that is lost during its lifetime due to friction against the road. Rubber tires have a textile-like structure of woven threads holding several layers of rubber together. These structural threads can be made from e.g., PET, Nylon or Kevlar. The friction that a tire experience against the road when in motion we believe to be more severe than that of a geotextile affected by water movement, and therefore 20% of the weight is assumed to be the maximum release of microplastics. We have also formulated a more cautious scenario that serves as a lower bound for our estimation of microplastics emissions from geotextile. Our speculation is that the lower bound is a more likely scenario than the maximum.

Maximum scenario
Incorrect handling in construction uses (20%) and by private consumers (50%) ->
Expected lifetime shortened into half (50 years) due to UV-light exposure
Hydraulic applications (100%) -> 20% of mass lost due to abrasion, equal to 0,2% per year.

"More likely" scenario
Incorrect handling in construction uses (1%) and by private consumers (10%) ->
Expected lifetime shortened to 80 years due to UV-light exposure
Hydraulic applications (100%) -> 1% of mass lost due to abrasion, equal to 0,01% per year.

6.6 Estimation of microplastics emission

From the scenarios presented above we have calculated that the emission of microplastics from geotextile in 2022 is approximately 2 tonnes/year in the lower bound scenario and 32 tonnes/year in the maximum scenario, see Table 13. Estimated release of microplastics in tonnes per year from geotextiles over time. In 2022, the only source of microplastics is from hydraulic applications and caused by a continuous abrasion from day one of installation. However, from the year 2030, the portion of geotextiles wrongfully installed in 1980 will start degrading because of a shortened lifetime and contribute to increasing numbers. From the year 2080, the release of microplastics really starts to increase more rapidly when more and more geotextiles have exceeded their expected lifetime.

Table 13. Estimated release of microplastics in tonnes per year from geotextiles over time

Release of microplastics (tonnes/year)	Lower scenario	Maximum scenario
2022	2	32
2030	3	55
2050	42	800
2080	280	4710
2121	15 500	20 900

6.7 Microplastics in soil

Microplastics can be emitted into water, air, or deposited on the soil surface. In the latter case, particles may be removed by wind or water erosion, but a substantial part is expected to enter the soil. While in the soil, microplastics can affect the physicochemical and biological characteristics of the soil, such as microbial activities, porosity, and plant growth. Microplastics also play an important role in the transportation of toxic chemicals, which can be passed deep into the soil and pollute underground water (Sajjad, et al., 2022). Due to its long lifespan and potentially toxic effects, microplastics can be considered a threat to the soil ecology and ecosystems (Hidalgo-Ruz, Gutow, Thompson, & Thiel, 2012).

6.7.1 Microplastic movement into and within the soil

From experimental evidence, it is known that microplastic particles can move into the soil when deposited at the soil surface. Several studies have monitored particle movement through porous media from a soil physical perspective. There are also studies using mathematical models to describe the physical features of particle movement (Rilling, Ingraffia, & de Souza, 2017). In addition, there are examples of microplastic fibers being present below the soil mixing layer in field studies, which suggests surface-applied fibers (such as sludge) moves into the soil (Zubris & Richards, 2005).

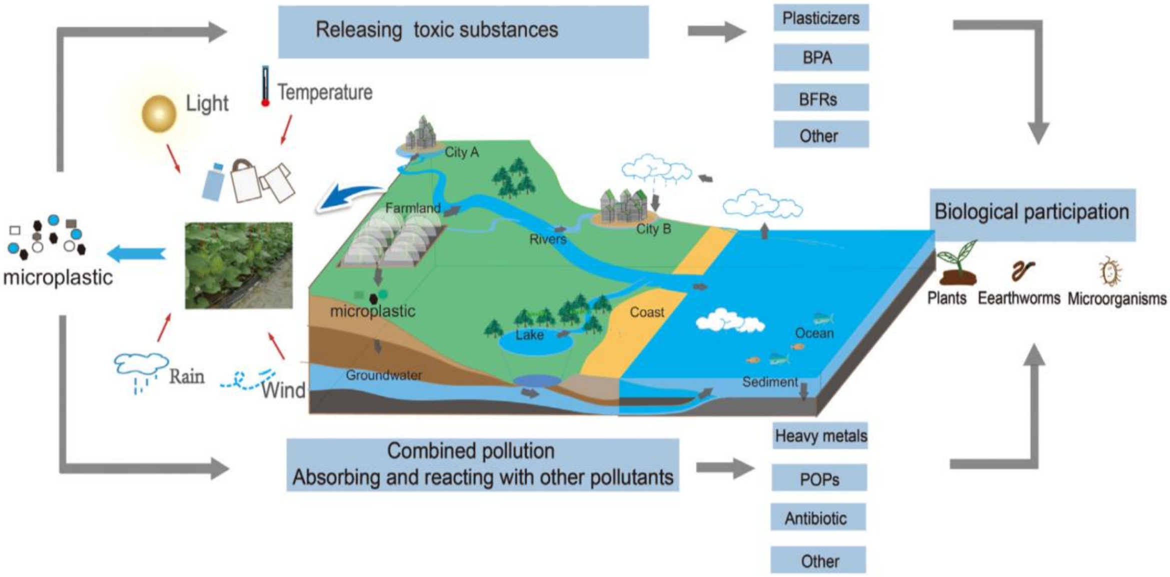
It has been suggested that the soil biota, especially animals such as earthworms, are one of the drivers in microplastic transportation in the soil. Microplastic particles can be transported both vertically and horizontally when latched on to animals such as larvae and earthworms, or plant parts during root growth, uprooting, and other plant processes (Rilling, Ingraffia, & de Souza, 2017). Another factor affecting microplastic movement is particle properties, such as size, charge, and hydrophobicity. The property of the soil is also an important feature, where macropores enhance movement of particles. Dry soils with cracks create open entryways for particles to move into deep layers of the soil quickly.

6.7.2 Interactions and effects on soil properties, soil biota and humans

The presence of microplastics in the soil affects the physio-chemical properties of the soil. It has been suggested that plastic particles have negative effects on the water holding capacity of the soil, act as obstacles to evaporation as well as reduces the permeability (porousness) and aeration (entry of air containing oxygen). Microplastics affects the biological aspects of the soil as well, including negative effects on enzymatic activity, microbial activity and diversity, and plant growth. When consumed by soil organisms, microplastics can affect the growth, development, reproduction, the immune system of soil organisms, as well as be transferred to predators and further up in the food chain (Sajjad, et al., 2022). It has also been suggested that crops absorb microplastics from the soil, which potentially could affect animals and humans eating these crops.

Antibiotics are used in animal husbandry and becomes part of the soil through animal manure. In the soil, microplastics can act as vectors, carrying antibiotics deep into the soil and ultimately end up in the groundwater. This is also the case for other pollutants, such as heavy metals and persistent organic pollutants (POPs), as can be seen in Figure 6. The effect of microplastics on underground water is not clear, and further research is required.

Figure 6. Microplastics found as contaminants in the soil system (Sajjad, et al., 2022)



7. COMPARISON TO OTHER SOURCES OF MICROPLASTICS

This chapter aims to give an overview of the various sources of microplastics in Sweden and assess their size in relation to that of geotextiles.

Microplastics can be divided into *primary microplastics* that are intentionally produced, and *secondary microplastics* that have unintentionally been formed from the breakdown or abrasion of larger plastic items. Primary microplastics are often used as raw materials in the industrial sector in the form of plastic pellets, or in consumer products such as cosmetics and pharmaceuticals. Intentionally produced microplastic particles can also be found in other applications, such as air blasting.

Secondary microplastics are derived from fragmentation or abrasion of larger plastic items and can be found in many sectors of society. Examples of activities unintentionally releasing microplastics are wear and tear of plastics, work with plastics, maintenance of plastic products and fragmentation of plastic litter.

Estimated annual emissions of primary and secondary microplastics in Sweden are presented in Table 14 and Table 15, as well as described in detail in chapter 7.1 and 7.2.

Table 14 Primary microplastics

Sources of microplastics	Emitted microplastics	Information source
Industrial production and handling of plastic pellets	310–530 tonnes/year	(Magnusson et al., 2016)
Personal care products	66 tonnes/year	(Magnusson et al., 2016)

Table 15 Secondary microplastics

Sources of microplastics	Emitted microplastics	Information source
Tyre and road wear	8 190 tonnes/year	(Magnusson et al., 2016)
- abrasion of tires	7 670 tonnes/year	(Magnusson et al., 2016)
Artificial turfs		
- with rubber granulates	1 640–2 460 tonnes/year	(Magnusson et al., 2016)
- with rubber granulates	475 tonnes/year	(Swedish Environmental Protection Agency, 2019)
- with rubber granulates	676 tonnes/year	(Olshammar et al., 2021)
- without rubber granulates	2 tonnes/year	(Olshammar et al., 2021)
Laundry		
- households	8–950 tonnes/year	(Magnusson et al., 2016)

- industrial laundry	2 – 115 tonnes/year	(Brodin, Norin, Hanning, Persson, & Okcabol, 2018)
Wear from boat hulls	160–740 tonnes/year (revised from 484–1364 tonnes/year)	(Magnusson et al., 2016)
Protective and decorative coatings on buildings etc.	130–250 tonnes/year	(Magnusson et al., 2016)
Wear of fishing gear	4–46 tonnes/year	(Magnusson et al., 2016)
Buoys and floating jetties	2–176 tonnes/year	(Magnusson et al., 2016)
Household dust from the use and wear of plastic	1–19 tonnes/year (40% of total – the rest is vacuumed)	(Magnusson et al., 2016)

7.1 Primary microplastics

7.1.1 Industrial production and handling of plastic pellets

When manufacturing plastic products, plastic raw material is used in the form of plastic pellets or powder. Microplastic emissions in the form of plastic pellets/powder to water and air can occur both from facilities that manufacture pellets and facilities that use pellets as inputs. The plastic pellets used in manufacturing of plastic products are usually 2-5 mm in diameter, which is considered microplastics[20]. The pellets/powder may also contain pieces of scrap plastics from the manufacturing, or finer plastic dust from handling of the material (Moore, 2008). Material losses can also occur during transport of plastic pellets between these facilities. IVL estimates the total annual material losses of plastic pellets in Sweden to 310–533 tonnes (Magnusson, et al., 2016). The estimate is based on the total production and use of plastic pellets in Sweden multiplied by an emission factor from studies in Denmark and the US.

7.1.2 Personal care products

Microplastic beads have been used in personal care products, such as skin cleaning products, hair products, toothpaste, and makeup products, for the past 60 years. The microplastic content in personal care products can account for up to 12% of the total weight. Based on previous studies on emission factors, consumer behaviors, and data on the Swedish population from 2012[21], IVL estimates the total annual discharge of microplastics from personal care products in Sweden to 66 tonnes (Magnusson, et al., 2016).

Microplastic emissions from hygiene products have attracted attention both internationally and in Sweden, with bans, proposals for bans and voluntary commitments in the industry following attention from consumers. In Sweden, it is prohibited to put a cosmetic product on the market that is intended to be rinsed off or spit out after having been used on skin, hair, mucous membranes or teeth, and which contain plastic particles (smaller than 5mm) that have been added for a cleaning, scrubbing or polishing effect (SFS 1998:944, 4§)[22].

[20] Definition of microplastics used in this report is 1 nm - 5 mm, which is based on the definition used by The Swedish EPA in 2017.

[21] It should be noted that since 2012, the Swedish population has grown by approx. 1 million.

[22] SFS 1998:944 https://rkrattsbaser.gov.se/sfst?bet=1998:944

7.1.3 Other sources of primary microplastics

There are several additional sources of primary microplastics where there are no emission estimations to date because of knowledge gaps. These sources include:

- Abrasive blasting with plastic media
- Pharmaceutical products

7.2 Secondary microplastics

7.2.1 Road traffic

The friction between tires and the road surface results in emissions of microplastics from road traffic. Characteristics of the tires, vehicles and roads affect the size of the emissions**,** as well as driving style and traffic volume. There are plastic materials in both the tyres and the road surface which contribute to the total emissions of microplastics from road traffic in Sweden. IVL has estimated the total annual emissions of microplastics from road traffic to 8 190 tonnes, based on existing data on traffic work (km per year), emission data on tires, asphalt wear and more, see Table 16 (Magnusson, et al., 2016).

Table 16. Estimated emission of microplastics from road wear and abrasion of tires

Sources of microplastics	Emitted microplastics
Polymer modified bitumen	15 tonnes per year
Car tires	7 674 tonnes per year
Road marking	504 tonnes per year
Total	8 193 tonnes per year

Road wear

Swedish roads consist of several layers of gravel and stone materials. The top layer exposed to wear from traffic is called the wear layer and usually consists of asphalt. Asphalt is made of mineral aggregates and a binder, usually bitumen. Sometimes polymers (PMB) are used as additives in bitumen, which are believed to give rise to the release of microplastics from road wear. Road wear is, among other things, affected by traffic load, winter road maintenance and climatic factors such as rain, snow, and temperature changes. Passenger cars with studded tires in the winter causes the most extensive road wear.

Road markings wear out just like road surfaces due to traffic load, winter road maintenance, climate factors etc. Wear and tear of road markings is another source of microplastics. The annual emission of microplastics from the abrasion of road marking paint is estimated by IVL at 504 tonnes per year. In a report by the Swedish Environmental Protection Agency, the authors argue there are findings that suggest both the polymer content and the emission factor are lower than in IVL's calculations (The Swedish Environmental Protection Agency, 2017). This would imply the wear of road marking paint probably gives rise to less than 504 tonnes of microplastics per year in Sweden.

Abrasion of tires
Vehicle tires wears while driving due to friction against the road surface. Approximately 20 percent of the mass of a tire is worn out during the tire's lifetime[23]. The emissions of rubber particles from tire wear is, according to IVL, 7 674 tonnes per year (Magnusson, et al., 2016).

Studded tires rough up the road surface, which in turn wears more on the tires even after the studded tires are changed into unstudded summer tires in April every year (at the latest). During summer and early autumn, the road surface is polished by unstudded tires so that it gradually wears less on the tires that roll on it (Johannesson, Andersson-Sköld, Gustafsson, & Järlskog, 2021).

7.2.2 Artificial turfs
Artificial turfs are used in sport fields, playgrounds, traffic islands and roundabouts, public spaces in parks, and outdoor fitness areas. In order for the surface of an artificial turf to have the desired properties, it is usually filled with large amounts of filler material, typically in the form of rubber granulates. The granulates used in artificial turfs are so small that they count as microplastics. Regular use and care of the turf leads to granulates disappearing and needing to be replaced. In a report from 2016, it is assumed that artificial turfs in Sweden are filled with 2-3 tonnes of rubber granulates every year – indicating that the same amount of microplastics disappear from each turf annually. Given the number of artificial turfs at the time, the estimated annual emissions of microplastics from artificial turfs were 1 640–2 460 tonnes (Magnusson, et al., 2016).

However, in 2019 IVL argued that since 2016, awareness and knowledge of the microplastic problem has increased. The supply of granulates has decreased while reuse has increased, and protective measures have been put in place. The authors estimate that artificial turfs in Sweden are filled with 1-2 tonnes of rubber granulates every year instead of 2-3 tonnes per year as previously estimated by Magnusson et al. in 2016 (Krång, et al., 2019). Using new knowledge and an adjusted calculation method, the annual emissions of microplastics from artificial turfs was estimated to 475 tonnes per year in 2019 (Swedish Environmental Protection Agency, 2019). In these calculations, it is assumed that the entire amount of re-filled rubber granulates is not spread to the surrounding environment, some remains in the turf, is brought back (when plowing etc.) or discarded.

Two years later, another number was reported based on the same assumption that artificial turfs being re-filled with 1-2 tonnes of rubber granulates per year. This time, the authors estimate the annual emissions of microplastics from artificial turfs (with infill) to 676 tonnes (Olshammar, Graae, Robijn, & Nilsson, 2021). In the same study, the annual emissions of microplastics from artificial turfs (without infill) is estimated at 2 tonnes.

7.2.3 Laundry

Households
All textiles wear and tear during use and washing, which leads to microparticles in the form of small fibers being released. In the case of textiles made from synthetic fibers, microplastics are released when washed, and end up in the wastewater. Based on discharge rates of synthetic fibers from washing of clothes, Swedish households washing habits, population, and an assumption that 30-50 percent of all textiles are synthetic, the annual microplastic discharge from

[23] Luleå University of Technology (2014) https://www.ltu.se/research/subjects/Geotechnical-engineering/2.58565/Materialatervinning

household laundry has been estimated at 8-945 tonnes. The authors point out these are rough estimations based on the limited data available (Magnusson, et al., 2016).

Industrial laundry
Industrial laundries in restaurants, hotels, hospitals, industries etc. cause emissions of microplastics. In a study by Brodin et al. (2018), water samples from industrial laundries were collected and analyzed for their microplastic content. The results from microscopic particle counting as well as from a chemical analysis of the microparticles were used to estimate the release of microplastics from industrial laundries. Using data on the weight of textiles washed at industrial laundries, 2-115 tonnes of microplastics are estimated to be released annually from industrial laundries in Sweden.

7.2.4 Wear from boat hulls
Commercial vessels and leisure boats both use antifouling paint and paint used for solid coating – which can contain several types of plastics. When the surface of the boat is worn over time or when the boat is washed, scraped, or sanded during maintenance, microplastics can be released. Release of microplastics from boat hulls was originally identified as one of the major sources of microplastics in Sweden. IVL estimated the emissions of microplastics from boat hulls at 484–1364 tonnes per year. The emissions calculations were later revised to 160–740 tons of microplastics per year (Magnusson, et al., 2016). However, continued studies of emissions of microplastics from boat hulls, for example in Norway, have shown that the emission volumes are probably significantly lower. The lower emission-figures can be explained by assuming lower polymer content in the paint (The Swedish Environmental Protection Agency, 2017).

7.2.5 Protective and decorative coatings on buildings etc.
Polymers are often used as binders in both protective and decorative coatings. Based on data regarding sales volumes, fraction of polymeric binders and an emission factor, IVL estimates the microplastic emissions from protective coatings in Sweden to 93 tonnes per year. The corresponding number for decorative coatings is 35-158 tonnes per year. The total emission of microplastics from protective coatings and decorative paint sums up to 128-251 tonnes per year (Magnusson, et al., 2016).

7.2.6 Wear of fishing gear
Fishing gear made from plastic, mainly polyethylene (PE), polypropylene (PP) and nylon, could give rise to microplastic emissions. It is assumed that proper use of plastic fishing gear is not a significant source of microplastics, the equipment is replaced before too much microplastic has been formed. However, some equipment is either lost or discarded at sea, and this is a significant source of macroplastics in oceans and seas (Andrady, 2014). In these cases, the macroplastic waste may degrade chemically and deteriorate physically into microplastics. In an attempt to quantify the emission of microplastics from fishing equipment in Sweden, IVL uses data on discarded equipment and weathering. The estimated annual macroplastic emissions from fishing gear in Sweden is 4-46 tonnes (Magnusson, et al., 2016).

7.2.7 Buoys and floating jetties
Both leisure boats and fishing boats uses buoys and floating jetties for mooring. Assuming the lifetime of buoys and floating elements is 10-20 years, and weathered material when discarded is assumed to be 5-20 percent, IVL estimates the total amount of microplastics formed is in the range of 2-176 tons annually (Magnusson, et al., 2016).

7.2.8 Household dust from the use and wear of plastic

Daily activities within our homes and the use of plastic products will lead to shedding, abrasion, wear and tear of plastic items that contribute to release of microplastics which settles in the indoor dust. Products containing plastics that we use frequently in our homes include toys, carpets, furniture, kitchen ware, electric wiring, electronics, indoor paint, textiles, cleaning agents etc. IVL estimates 1-19 tonnes of microplastic particles are formed in household dust per year (Magnusson, et al., 2016).

7.2.9 Other sources of secondary microplastics

There are several additional sources of secondary microplastics where there are no emission estimations to date because of knowledge gaps. These sources include:

- Microplastics released from waste management and recycling
- Littering
- Construction dust
- Rubber emissions from building, maintenance, and construction work
- Agricultural plastics
- Microplastics from activities onboard ships

Amongst all sources listed in this chapter, littering is likely the most important factor contributing to microplastics emissions. It is however very difficult to quantify and hence, no emission estimation is available.

7.3 Microplastic emissions from geotextiles in relation to other sources

The release of microplastics from geotextiles in 2022 is approximately 2 tonnes per year, with a worst-case scenario at 32 tonnes per year. The release from geotextiles would with this estimation be within the same order of magnitude as fishing gear (4–46 tonnes/year) or industrial laundry (2–115 tonnes/year). However, the amount of microplastics release will steadily increase due to the increasing age of already installed geotextiles and the accumulation in mass of materials installed. In the worst-case scenario, approximately 55 tonnes per year would be released by 2030 an in 2050 up to 800 tonnes per year. In comparison, the largest quantified source of microplastics in Sweden today, which is road traffic, is estimated to 8 190 tonnes/year.

8. CONCLUSIONS

- **Composition, amounts and usage of geotextiles**. Approximately 14900 tonnes of geotextiles are used yearly in Sweden. This is based on manufacturers' data and is valid for 2021. The most common type of geotextile is needle punched nonwoven textiles typically made out of 100% polypropene that accounts for >95% of all use. This geotextiles type is most used for separation and filtration purposes. Other polymers used for geotextiles are polyethylene terephthalate (PET) and polyethylene (PE). Geotextile use is increasing but it has not been possible to determine the historical development in terms of volumes. Use of geotextiles started already in the 1950-ties in Europe but significantly increased during the 80-ties and 90-ties.

- **Alternative materials and recycled content**. There are alternative geotextiles made from natural fibres on the market, predominantly made of jute or coir. These have considerably shorter lifetimes than synthetic geotextiles which limits their use to applications that do not require long term stability. Their market share has been estimated to 2% of the total geotextile market. In literature, other materials are mentioned as possible or promising but they do not appear to be available for geotextile applications. These include biodegradable polymers such as polylactic acid (PLA) and blends thereof, thermoplastic starch (TPS) and blends, poly(hydroxyalkanoates) (PHAs), cellulose acetate and other cellulose esthers (CA). Post-consumer recycled content is not used at all or to a very limited degree in geotextiles. The reason for this mainly due to the harmonised standards applicable for geotextiles that only allow recycled content to be used in products with short lifetimes, a market segment that is small. Higher cost is another reason.

- **Certifications**. Geotextiles are construction products and as such fall under the EU Construction Products Regulation, (EU) No 305/2011. Geotextiles are covered by a number of harmonised standards containing technical requirements that the products must satisfy to allow the manufacturer to issue a declaration of performance and label the product with a CE mark. These standards include durability testing such as UV-exposure and resistance to oxidation. The tests do not cover release of microplastics. NorGeoSpec is s certification system for geotextiles used in the Nordic countries. It is voluntary but a requirement for suppliers that aim to deliver to public projects, e.g., road construction. Its requirements complement and do not replace CE labelling. NorGeoSpec specifies five different classes of geotextiles depending on situation, N1 to N5, that differ in density.

- **Waste handling**. Due to the expected longevity of geotextiles together with the relatively short time that they have been used, there seems to be little experience of waste handling. In those cases where geotextiles have been dug up, large sections or parts are usually sorted as plastic waste or combustibles and are incinerated. During excavation, it occurs that small strips or fragment of geotextiles are removed unintentionally and end up in the excavated soil. Old geotextiles that are unearthed are often faded or visibly used and sometimes also stained green by algae. These geotextiles are often perceived by operators to be in a good shape but to have lost some of their strength and is easier to cut through compared to new products. There are no specific restrictions, permits or waste handling requirements associated with using geotextiles.

- **Factors influencing degradation of geotextiles**. Based on both literature sources and interviews conducted in this study, there are some factors that seem to play a key role in the degradation of geotextiles and hence, the potential release of microplastics. Degradation is mainly caused by UV-radiation but abrasion due to movement, chemical degradation, pH (especially alkaline environments) and heat (thermal oxidation) also affects the lifetime of the material. Another factor that could possibly affect degradation of geotextiles is microbial activity. Although the test described in EN-12225 covering microbial degradation states that synthetic materials are generally resistant against microbial initiated decay, recent studies suggest that microbial activity could play a role in the degradation of plastics. Although the above-mentioned factors are known to influence the degradation of geotextiles and reduce its strength, it is unknown how this translates into microplastics formation.

- **Risk applications**. In general, if the geotextile is used in accordance with construction standards and is not continuously exposed to any of above degradation factors it seems the material is tolerant to environmental stress. However, maybe the most crucial of all factors affecting the lifetime of geotextile is the application, the implementation method and using the right type of geotextile for the intended application. According to interviewees, incorrect installations and/or geotextile material is rather common in professional applications. It can be assumed that this is true also for consumer use. For a large part of the geotextile usage, such as road applications, several of the degradation factors above are presumably small and hence the degradation in these applications could be low or insignificant. This is also claimed by several of our sources. There seem to be a general agreement that the risk for degradation of geotextile and thereby an increased potential for the release of microplastics is largest in hydraulic applications such as shorelines, rivers, canals, steep slopes and erosion protection due to water and material movement and possible UV-exposure. This application covers only a small part, approximately 7% of the European market. Private use is also identified as a potential risk for microplastics formation due to the uncontrolled handling, shallow application and assumed lack of knowledge. This market is estimated to represent approximately 10% of the market.

- **Estimation and comparison of geotextiles as a source of microplastics.** Based on several assumptions, the release of microplastics from geotextiles in Sweden is approximately 2 tonnes per year, with a worst-case scenario at 32 tonnes per year, starting from 2022. The release from geotextiles would with this estimation be within the same order of magnitude as fishing gear (4–46 tonnes/year) or industrial laundry (2–115 tonnes/year). However, the amount of microplastics release will steadily increase due to the increasing age of already installed geotextiles and the accumulation in mass of materials installed. In the worst-case scenario, up to 800 tonnes per year would be released by 2050 and in 100 years from now, the amount would be closer to 21 000 tonnes (also in a more likely scenario the estimated amount is as high as 15 500 tonnes/year by 2120, since much of the installed geotextiles will have reached its expected lifetime by then). In comparison, the largest quantified source of microplastics in Sweden today, which is tyre and road wear particles, is estimated to 8 190 tonnes/year. It must be clearly stated though that there are many uncertainties, and that this scenario is worst case. A more probable number is somewhere between closer to zero and the highest estimate. From these estimations, it can be concluded that geotextiles are currently not a significant source of microplastics but that there is a risk that it becomes a major source in the future.

- **Uncertainties and data gaps**. There are many challenges associated with studying the release of microplastics from geotextiles once it is used in its intended environment, mainly access to the source and its surroundings. Furthermore, the receiving media is often soil for which there are no efficient standardized analytical methods. There are few studies focusing on the release of microplastics from geotextile and the scarce data in combination with unstandardized methods makes it difficult to draw any firm conclusions. Furthermore, not enough is known about the relationship between degradation, strength loss and microplastics formation and there is also a lack of studies investigating geotextile release of fibres besides that occurring through degradation.

9. PROPOSAL FOR FURTHER INVESTIGATIONS

There are few available studies where the release of microplastics from geotextiles have been assessed. In addition, there are few standardized methods for sampling, sampling preparation and analyzing microplastics and therefore it is difficult to draw conclusions from the scarce amount of available data. There is ongoing work to establish standards for e.g., material loss from fabrics during washing[24] and analysis of microplastics in water[25] but there may be a need to also look at geotextiles and microplastic particles in soil samples. Extensive testing of geotextiles is conducted in conjunction with the certification process and results have shown that geotextiles are highly tolerable to several environmental factors. However, the release of microplastics is not included in these standardized tests.
Therefore, to complement knowledge gained from this study, more research is needed where release of microplastics from geotextiles are assessed, both in laboratory environment and in field studies. We propose to start with building an understanding of what is required for geotextiles to form microplastics. Once this has been established, this knowledge can be applied to perform more informed calculation of microplastics release.

9.1 Simulations – Exposure to degradation

In this study we found that it is essential for the lifetime of geotextiles that they are accurately installed and handled during the installation phase. Exposure to sunlight is one of the main factors that alter the characteristics of the plastics and increase the risk for microplastics formation. It is foreseeable and also confirmed by some of the interviewees in this study that the instructions for correct installation and handling do not always reach and/or is not always implemented by the contractor or consumer that install the geotextile. There are also some applications where exposure to degrading factors is recognized by the producers such as hydraulic uses.

Therefore, we propose that future studies include simulations where geotextiles are placed in environments that mimic the conditions that geotextiles are naturally exposed to in Sweden in various applications. In this study we have identified two areas of use where the risk of release of microplastics is higher due to the likeliness of exposure to a higher load of degrading factors; consumer use/private applications and hydraulic use. We therefore propose these areas of use as prioritized study objects.

For consumer applications a study could be performed by installing geotextiles in small patches with various types of applications typical for consumer uses. The chosen installation procedure should take into account the knowledge of a layperson e.g., by including incorrect installations of various kinds, exposure to UV and other weathering factors exceeding recommendations prior to installation, using the incorrect type of geotextile for the intended function etc.

For hydraulic application assessments could be made by installing geotextiles in suitable locations or possibly using objects where textiles are already installed (given they are accessible and possible to monitor). These installations should preferably include common hydraulic uses such as drainage/cable channels, steep slopes and erosion protection.
Furthermore, isolated tests, similar to the weathering and oxidation tests conducted in the certification process such as soils with different pH-levels, heated soil and soils with various types and amounts of microbes could also be replicated.

[24] ISO 4484-1 Textiles and textile products — Microplastics from textile sources — Part 1: Determination of material loss from fabrics during washing
[25] ISO/AWI 16094-1 Water quality — Analysis of plastics in water — Part 1: General and sampling

The different degrading factors could in this way be monitored to see how they affect the geotextile material as well as if and how these mechanisms interact. We suggest to also consider including testing the effect of typical chemicals/pollution that are known in natural soils in Sweden. In all of these tests, continuous evaluation of strength retention should be used according to those already used for the CE process together with some kind of measure of fiber or material loss, e.g., weighing. The loss of material could then be related to a certain strength loss which would be helpful to know for future field studies where samples of geotextiles in use could be tested for retained strength and the result used to estimate material losses.

9.2 Leakage tests

Resent research on microplastic release from fabric in washing machines suggests that both fabric structure e.g. how tightly the fabric is knitted (Pirc, Vidmar, Mozer, & Krzan, 2016), how many times the fabric has been washed as well as if it was used between washings affect the release of microplastics (Roos, Levenstam Arturin, & Hanning, 2017).
To be able to understand geotextile as a potential source of microplastics in a similar manner, there is a need to assess how the life cycle of the textile is related to the potential release of microplastics.
It might for example be that some types of degradation increase formation of microplastics more than others.
We therefore suggest that the simulations mentioned in 9.1 are supplemented with parallel testing of the leakage of microplastics from geotextiles.
There are many types of leaching tests however few studies have been conducted on leakage of microparticles using these tests and therefore there is no standard method available. In a recent study where the leakage of microplastics from different types of plastic waste was assessed, a modified version of Toxicity Characteristics Leaching Procedure (TCLP) often used to assess leachate from landfills were used. In this study, pieces of plastics were left for 3h in a shaker table (instead of a centrifuge, as in the standard TCLP-test). The samples were then analyzed using microscopic and spectroscopic methods to count and characterize microplastic particles (Mortula, Atabay, & Parvez Fattah, 2021). This method could potentially be suitable also for geotextile studies. There are also standard tests developed to assess leaching from construction products such as CEN/TS 16637-2:2014[26], a Dynamic Surface Leaching Test (DSLT) which is aimed at determining the release per unit surface area as a function of time of inorganic and/or non-volatile organic substances from a monolithic, plate- or sheet-like product, when it is put into contact with an aqueous solution. Instead of measuring substances, this test could possibly be adapted to instead measure microplastics in the leachate.

9.3 Analytical methods and Fingerprints

In this study we have not approached the physiochemical properties of microplastics originating from geotextiles. To be able to identify, track movements and find sources of geotextile microplastics there is a need to characterize them. There are different methods involved when identifying and characterizing microplastics. To get a full understanding of sizes, shapes, and polymer types both physical characterization (e.g., microscopy) and chemical characterization (e.g. spectroscopy) is needed (Hong, EoEo, & Shim, 2016). Since visual identification in microscope and other types of manual identification methods involves inaccuracy, methodologies to identify microplastics using chemical identification techniques are currently under development (Grant, 2022). The so-called chemical fingerprint is a spectral fingerprint that describes the elemental composition of the plastic material including the plastic polymer type and potential additives and leachable substances that are bound in the plastic. It can be derived using e.g.

[26] CEN/TS 16637-2:2014. Construction products - Assessment of release of dangerous substances - Part 2: Horizontal dynamic surface leaching test

Fourier Transform infrared (FTIR) spectroscopy and Raman spectroscopy. Currently there are initiatives collecting this chemical data in accessible libraries (Munno, De Frond, Bridget, & Rochman, 2020).
To facilitate future research on microplastics from geotextiles we propose that future studies include characterization of geotextile microplastics.
Suggested analytical methods based on previous studies of microplastics are SEM for high resolution images of particles and microstructure characterization, EDX for elemental identification and FTIR for specifying chemical structures. Usually, a combination of these methods is needed to get a holistic understanding of the analyzed material (Zhang, Mell, & Li, 2019).
This could be done by sampling microplastics from different types of known geotextiles and analyzing these samples using e.g., above-mentioned techniques. The results could then be used in field studies assessing the release of microplastics from geotextiles but also to expand the current libraries of microplastic fingerprints.

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