YEAR 26 NUMBER 4 DECEMBER 2022

GEO kunst

ONAFHANKELIJK VAKBLAD
VOOR GEBRUIKERS VAN
GEOKUNSTSTOFFEN

SPECIAL

GEOSYNTHETICS AND SUSTAINABILITY

GEOKUNST IS POWERED BY

MAIN SPONSORS

FREUDENBERG
INNOVATING TOGETHER

Westervoortsedijk 73
6827 AV Arnhem
Tel. +31 (0) 85 744 1300
www.enkasolutions.com

TENCATE GEOSYNTHETICS | A Solmax Company

TenCate Geosynthetics Netherlands BV
Europalaan 206
7559 SC Hengelo
www.tencategeo.eu

Naue

Naue GmbH & Co. KG
Gewerbestr. 2
32339 Espelkamp – Germany
Tel. +49 5743 410 *www.naue.com*

THE COLLECTIVE MEMBERS OF THE NGO ARE:

CDR International BV, Rijssen
Cofra B.V., Amsterdam
Deltares, Delft
Enviro Quality Control BV, Maarssen
Fugro NL Land B.V., Leidschendam

GEO2 engineering

Computerweg 11, 3542 DP Utrecht
Tel. 0031 (0)346 76 90 46
www.geo2.nl

Geonius, Geleen

GEOPEX

Middelblok 154, 2831 BR Gouderak
Tel. 0031(0)182 37 73 27
www.geopex.com

GeoTec Solutions BV, Culemborg

Genap waterproof solutions

Goorsestraat 1, 7041 GA 's-Heerenberg
Tel. 0031 (0)466 16 44
www.genap.nl

GID Milieutechniek, Velddriel
Havenbedrijf Rotterdam
Huesker Synthetic BV, Rosmalen

InfraDelft BV, Delft

JOOSTEN KUNSTSTOFFEN
KUNSTSTOF TOTAALOPLOSSINGEN VOOR INFRATECHNIEK, WATERMANAGEMENT EN GROENCONCEPTEN
WWW.JOOSTENKUNSTSTOFFEN.NL

Veilingweg 24, 6681 LA Bemmel
Tel. 0031(0) 481-42 47 21
www. joostenkunststoffen.nl

Juta Holland BV, Oldenmarkt
Kiwa NV, Rijswijk
Kwast Consult, Houten

FREUDENBERG
INNOVATING TOGETHER

Westervoortsedijk 73, 6827 AV Arnhem
Tel. 0031(0) 85 744 13 00
www.enkasolutions.com

Movares Nederland BV, Utrecht

Naue

Naue GmbH & Co. KG
Gewerbestr. 2 32339 Espelkamp – Germany
Tel. +49 5743 410 *www.naue.com*
netherlands@naue.com

Quality Services BV, Bennekom
Robusta BV, Genemuiden
Rijkswaterstaat, Utrecht
Strukton Civiel, Scharwoude

STYBENEX
vereniging van eps fabrikanten

Kerkstraat 14, 4191 AB Geldermalsen
Tel. 0031 (0) 6 10 97 58 26
www.stybenex.nl

TENCATE GEOSYNTHETICS | A Solmax Company

TenCate Geosynthetics Netherlands B.V.
Europalaan 206, 7559 SC Hengelo
Tel. 0031(0) 546 544811 *www.tencategeo.eu*

Tensar

Tensar International B.V.
Helftheuvelweg 11
5222 AV 's-Hertogenbosch
Tel. 0031(0) 73 624 1916 *www.tensar.nl*

TRISOPLAST Mineral Liners

Trisoplast Mineral Liners
Oude Weistraat 17, 5334 LK Velddriel
Tel. 0031(0) 418 63 6030 *www.trisoplast.com*

T&F Handelsonderneming BV, Gilze
Witteveen + Bos, Deventer

DEAR GEOKUNST READERS,

Stimulating the use of sustainable materials and solutions in the construction sector is a priority in the Netherlands. For the civil engineering sector it is a very challenging mission to become more sustainable and to reduce CO_2 and NOx emissions. For NGO-IGS Netherlands sustainability is an important topic. Applications using geosynthetics as a high-quality building material can make a big positive contribution on the sustainability programs in the civil engineering sector. The topic 'geosynthetics and sustainability' is not only important for the Netherlands, but also internationally. Therefore we decided to make a comprehensive GeoKunst special edition on sustainability in the English language.

The first article in this edition of GeoKunst is written by Wim Voskamp and Jan Retzlaff on the subject *'Geosynthetics; sustainability, durability and the environment'*. This is a major article covering 10 pages, but every word is worth reading. The article goes in depth to sustainability aspects of geosynthetics, listing CO_2 footprint savings by structure type. It analyses and evaluates the possibility of the degradation of geosynthetics into microplastics, the possibility of leaching hazardous substances from geosynthetics and how these effects can be counteracted. The plastic circular economy cycle is described, with details on quantities of used plastics per sector in Europe and the Netherlands. Based on this analysis it is concluded that geosynthetics as high performance building material cover approx. 0,4% of the total plastic market in Europe. The article analyses also the quantities for disposal of plastics per sector.
In the years to come there will be a strong push to recycle geosynthetics and close the gap in circular building. Sustainability aspects for geosynthetic structures at the end-of-life are becoming an important topic. Can we remove geosynthetics properly from the soil? What are the state-of-art recycling techniques? Can the materials be recycled to high grade and can the raw material be clean enough to produce new geosynthetic products? This state-of-the-art article can be considered as a milestone with wide international attention of the geosynthetic, geotechnical and construction society.

The second article in this special is written by Kent von Mauberge et al. on the subject of *'Geosynthetics: responsible and sustainable solutions to reduce environmental impact'*. The impact of climate change can be seen in the daily news. The article describes the contribution of geosynthetics to respond to climate change by mitigation and adaptation. One of the major goals of the EU Green Deal and programs on national levels is to reduce the CO_2 emissions significantly (mitigation). Geosynthetic applications in structures can make an important contribution, for example in retaining walls, where a reinforced soil retaining structure can reduce CO_2 emission by an average of 75% compared to traditional solutions with concrete walls or steel sheetpiles.
Climate adaptation aims to adapt life to the new reality of changing environmental conditions. Adaptation can be realised by improvements in flood defences, green solutions to stimulate vegetation and water containment systems for extreme and more intense dry periods. The article focuses on multiple applications of structures with geosynthetics to create sustainable and resilient solutions.

Due to climate change humanity faces multiple and increasing challenges, the milestone year 2030 is rapidly approaching. We still have seven years to make big steps forward together to make geosynthetics part of the sustainable future. Who takes up the challenge?

I hope you will enjoy this edition and wish you inspiration.
Be smart. Be sustainable.

Rijk Gerritsen
Editor-in-chief GeoKunst Magazine

COLOPHON

Geokunst is published by the Dutch Geotextile Organization (NGO). The NGO the official Dutch chapter of the IGS, representing the Netherlands in the International Geotextile Society (IGS). The NGO stimulate knowledge of the sustainable design, responsible use and construction with high-quality performance geo building materials. Materials as geotextiles and geosynthetics are used in many construction projects in civil engineering, hydraulic engineering, environment and building. The NGO is a non-profit association comprising knowledge institutes, inspection and engineering firms, contractors, authorities, producers and suppliers. Geokunst is published four times per year and is sent to magazine subcribers or on request.
For articles published in Geokunst the authors remain responsible for the content.

Editor-in-chief **Rijk Gerritsen**
Text editor **Jurjen van Deen**
Editorial Board **Adam Bezuijen**
Piet van Duijnen
Suzanne van Eekelen
Paul ter Horst
Tara van der Peet
Production **Uitgeverij Educom**

A subscription can be requested at:
Nederlandse Geotextiel Organisatie (NGO)

info@ngo.nl
www.ngo.nl


Wim Voskamp
retired director R&D and technical marketing of Colbond B.V.


Dr-Ing. Jan Retzlaff
managing director GEOscope GmbH & Co

GEOSYNTHETICS, SUSTAINABILITY, DURABILITY AND THE ENVIRONMENT

1. Introduction

The rise in global temperature and consequent climate change require a reduction in greenhouse gas emissions by reducing the use of raw materials and fossil fuels. Sustainability is important, both in the production of building materials, as well as in the construction process. The use of geosynthetics can play an important role in this transition.

The major advantage of using geosynthetics in a structure is the reduction in CO_2 emissions. Compared to traditional construction products such as concrete, sand, gravel and steel the reduction can amount to 32 – 89%, dependent on the application (table 3). In addition, there is also a large reduction of the required energy compared to the traditional construction method. This can be up to 85% depending on the chosen technology. The use of geosynthetics results in considerable reduction of transport, as less traditional (heavy) construction materials need to be transported, sometimes over large distances. Also energy savings as result of reduced quantities of used construction materials can be achieved.

In addition to these advantages, there are some practical drawbacks. The use of plastic material creates waste that must be processed and removed from the environment. Geosynthetics have a long lifespan and are removed when the structure (e.g. a road) in which they are used is demolished.

After use, they can in some cases be recycled, after which the polymer can be re-used as a base material for new plastic material to be produced. In other cases, it is incinerated. Although energy is generated by combined heat and power installations, incineration leads to the emission of CO_2.

When geosynthetics are used, nearly no fine particles are released in the environment, for example by leaching out in water. The composition of the polymer compound is designed in such a way that this does not happen since it would influence the material properties unfavourably. In addition, geosynthetics are tested for the release of environmentally harmful components and are only approved for use if they meet strict requirements.

Because geosynthetics are built into ground structures and they are designed to meet the service life of these structures, in normal cases little or no material is released after installation that may end up in the environment as litter. There is no abrasive- mechanical or hydraulic stress to create microplastics from geosynthetics inside the earth structure. Only in case the geosynthetics are not covered, small particles can be torn off by wear or abrasion. When handled properly, the post-use disposal and processing of the waste material have no negative environmental effects.

It is important that the correct geosynthetics are selected that suit the specific application. Selecting the wrong materials can cause problems in the long run. It is very important that the correct controls are made and management measures are taken in all project phases. This involves the design phase (specific expertise required), material delivery (manufacturer supplies materials according to specifications), execution phase (contractor/installer with knowledge of geosynthetics) and operational phase (inspections, maintenance where necessary). Recently, some examples were reported of geotextiles that were not properly installed and that lay on the surface in riverbank structures. The movement of rocks caused wear and tear and pieces of geotextile were torn off. This is a typical example of overdue maintenance and poor operational management. The geotextile that has come to the surface must be covered in accordance with the regulations during the following maintenance rounds. Although these problems are rare, there is a perception that geotextiles can lead to substantial amounts of microplastics in the environment. This article demonstrates that this needs not be the case.

2. Durability of Geosynthetics

Geosynthetics are building materials that are used as soil reinforcement in road construction or in hydraulic engineering applications. They are also used in filter constructions in dikes, as separating layers in road construction and in many more applications. The various types and applications of geosynthetics are described in many reports, for

Table 1 – Required minimum service life of geosynthetics (Voskamp, W. e.a., Durability of Geosynthetics, 2016, page 15, extended version).

Separation layer only during the construction phase	0,5 - 1 year
Permanent separation layer	80 - 100 years
Replaceable filter layer	10 - 25 years
Permanent filter layer (e.g. below stone revetment)	80 - 100 years
Soil reinforcement under an embankment	10 years
Reinforcement of retaining wall	80 - 100 years
Pile-supported geosynthetic reinforced embankments	100 - 120 years
Vertical drainage 1 - 3 years	
Geomembrane in a landfill	100+ years
Waterproof tunnel lining	100+ years

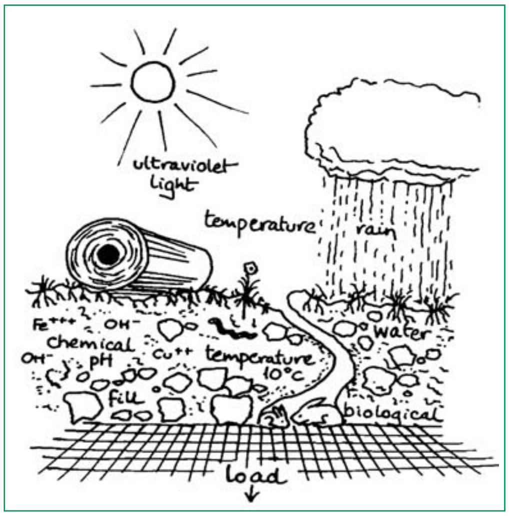


Figure 1 – Environmental factors, courtesy J.H. Greenwood (Voskamp et al., 2016).

SUMMARY

Major savings in CO_2 emissions and in the use of energy are reached when geosynthetics are applied in construction projects. But there are also potential environmental issues to be addressed, such as leaching and microplastics. This article examines the use of geosynthetics from different perspectives: the share of geosynthetics in the total use of plastics as well as the share in the waste stream in Europe and the Netherlands; the possible leaching of hazardous substances from the geosynthetics during the life time and EU regulations in this respect; the various methods of recycling geosynthetics after the life time; and whether microplastics could potentially be generated from geosynthetics.

example by Van Deen et al. (2019) and Voskamp et al. (2016). In many of these applications, the geosynthetics must maintain their function throughout the life of the structure, which can be more than 100 years. Geosynthetics can meet this requirement if they are made of polymers with an inherent durability, like polyester (PET) or a compound with the right additives like polyethylene (PE) or polypropylene (PP).

Geosynthetics can be applied in the ground, above the ground, under and above water or on the waterline. These conditions significantly affect the service life of a geosynthetic material. Soil temperature, rainfall, soil type and particle size, installation method, soil chemical composition and intensity of UV radiation, may influence the geosynthetic service life (Voskamp et al., 2016).

The main polymers from which geosynthetics are made, are polyester (PET), polypropylene (PP) and polyethylene (PE). Geosynthetics made of these polymers are discussed in this paper. In some cases, other polymers are used such as expanded polystyrene (EPS) and polyvinylchloride (PVC). For specific environmental information about these polymers, used as geosynthetics, we refer to Plastics Europe (2022).

Additives are added to the base polymer, such as antioxidants, carbon black and/or other additives with specific properties. This is done to improve the processability of the polymer or to achieve the needed properties of the final product. The composition of the raw material can thus vary considerably. The additives can absorb UV radiation, be thermal stabilizers, antioxidants, etc.
To ensure that the geosynthetic retains the required properties during its life, these additives shall not disappear from the geosynthetic. This is a design requirement and the materials are tested for this and the properties are recorded in CE certificates.

The main chemical degradation mechanisms are reactions resulting in polymer (chain) scissions or chemical modifications. Such reactions are affected by additives, oxygen, water, or dissolved substances in the soil.
Special chemicals are added to polypropylene (PP) and polyethylene (PE), so-called antioxidants, which counteract oxidation. Oxygen will be inactivated by chemical bonding with the additives. In the long run, these antioxidants are used up or become ineffective, starting the oxidation process. Hydrolysis occurs when polyesters (PET) are exposed to humidity. This is a very slow process that depends on the temperature. The effect of water will be reduced with a low carboxyl end group content of PET, thereby counteracting possible cuts of the molecular chains. A high degree of orientation and crystallinity reduces the free volume of the amorphous phase where the reaction takes place and thus increases the resistance to hydrolysis. The effects of oxidation and hydrolysis usually manifest as loss of strength. Both oxidation and hydrolysis can occur with polyamide (PA). Due to the lifetime design requirements for geosynthetics in a structure, it can be assumed that the chemical composition of the polymer compound is chosen in such a way that there will be no noticeable degradation of the polymer during the lifetime of the geosynthetics. (Voskamp et al., 2016)

At the end of the service life of the structure, the geosynthetic is in most cases removed from the ground. After removal it can be incinerated or recycled. Recycling is not yet possible in all cases due to recycling limitations or the impurity of the polymer after use. Research continues to yield better purification results. Some geosynthetics are already fully recycled.

Table 2 – Case study results from WRAP report (2010)

Case History	*Traditional approach CO_2 Footprint (tons)*	*Geosynthetic approach CO_2 Footprint (tons)*
#1 Slope Stability	157	21
#2 Bridge Approach	500	346
#3 Crib Wall	35	11
#4 Sheet Piling Wall	433	69
#5 Concrete Wall	107	20

Table 3 – Savings in energy consumption and CO_2 emissions compared with traditional structures, (Stücki et al., 2019)

	Savings compared to traditional structures	
Application	*Energy consumption*	*CO_2 emission*
Separation material in a road construction	85%	89%
Road foundation reinforcement	5-10%	32%
Drainage layer	56%	67%
Retaining wall	85%	75%

Table 4 – Case studies from GRI-24 Conference (March, 2011)

Application area	*No. cases described*	*Average Carbon Savings*
Walls	6	69%
Embankments and Slopes	4	65%
Armoring	4	76%
Landfill Covers	3	75%
Landfill Liners	2	30%
Retention	3	61%
Drainage Pipe	3	40%
Totals	**25**	**65%**

3. Sustainability aspects of geosynthetics

The traditional civil engineering materials concrete, steel, clay and gravel, contribute greatly to the carbon footprint of any construction project. Avoiding or minimizing the use of these primary materials by using geosynthetics helps to reduce the inherent embodied carbon of these projects. Of course, the environmental impact of the geosynthetic solution must be calculated in the same way as this is done for the traditional material solution. Several studies show numerically that the use of geosynthetics will reduce the CO_2 emissions and energy consumption considerably, we mention three of these studies:

Quantitatively, the numeric decrease in carbon footprint using geosynthetics solutions for walls and slopes is shown in the Waste and Resources Action Program (WRAP, 2010) (Table 2).

Table 3 shows the savings in energy consumption and CO_2 emissions compared with traditional structures found by Stücki et al. (2019) in an extensive study.

The GRI-24 Conference on Sustainability in 2011 listed the average embodied carbon savings in 25 analysed applications in the USA. An overall average of 65 % reduction in carbon footprint using geosynthetic related alternatives was realized (Geosynthetics Research Institute, 2019).

Depending on the application it may be concluded that the use of geosynthetics reduces the carbon footprint with 32 – 89 % compared to the use of traditional civil engineering materials as concrete, steel and gravel. The savings in energy vary from 5 – 85 %, heavily influenced by the transport distance and the volume (and weight!) of the building materials.

Table 5 – Overview of the quantities of used plastic materials in Europe and the Netherlands.

	Packaging	*Construction building materials*	*Household goods*	*Others / unknown*	*Total*	*Source*
Plastics marketsize Europe, 2020	16.7 Mt	10.3 Mt	9.9 Mt	12.5 Mt	49.4 Mt	(Systemiq, 2022)
Plastics marketsize Netherlands, 2020	627 kt	313 kt	836 kt	314 kt	2090 kt	Calculated, based on (CE Delft, 2019)

Table 6 – Estimate of the market size of geosynthetics.

Geosynthetics market	*Area*	*Weight*	*Source*
Europe, 2020	650 mio m2	200 kt	Estimate based on EAGM data
The Netherlands	37 mio m2	11.4 kt	Estimate based on EAGM data

Table 7 – Plastic waste processing in Europe and the Netherlands.

Plastic waste processes	*Landfill*	*Recycling*	*Energy conversion / incineration*	*Total*	*Source*
Plastic waste Europe, 2020	6.9 Mt	10.2 Mt	12.4 Mt	29. 5 Mt	Plastics Europe, 2022
Plastic waste Netherlands, 2020	13.9 kt (1%)	644 kt (39 %)	990 (60 %)	1650 kt	CE Delft, 2019
Plastic waste construction sector, Netherlands, 2020	7 kt (10%)	17 kt (25 %)	44 kt (65 %)	68 kt	CE Delft, 2019, Plastics Europe, 2022, NRK, 2018

4. Circularity of Plastic

The plastic circular economy cycle consists of various steps:

– Polymer raw material is converted into plastic products.
  - *Waste material during production is fed into the process again as pre-consumer recycled plastic.*
– These products are used by consumers and in industrial applications.
– They perform during their service life.
– After completion of their service life they are collected and sorted.
  - *Used for recycling.*
  - *Stored at landfills.*
  - *Burned with energy conversion.*
  - *Lost in the environment.*
– Post-consumer waste is after mechanically processing fed into the production process.

The circular plastic economy is shown in figure 2.

4.1 AMOUNTS OF PLASTIC IN SOCIETY

As shown in figure 2, plastic material is applied in many sectors of the society. The most important are: packaging material, household goods and construction material. Geosynthetics fall under the category construction material, but are only a small part of it.

Systemiq (2022) analysed the European plastic market and concluded that the total demand in

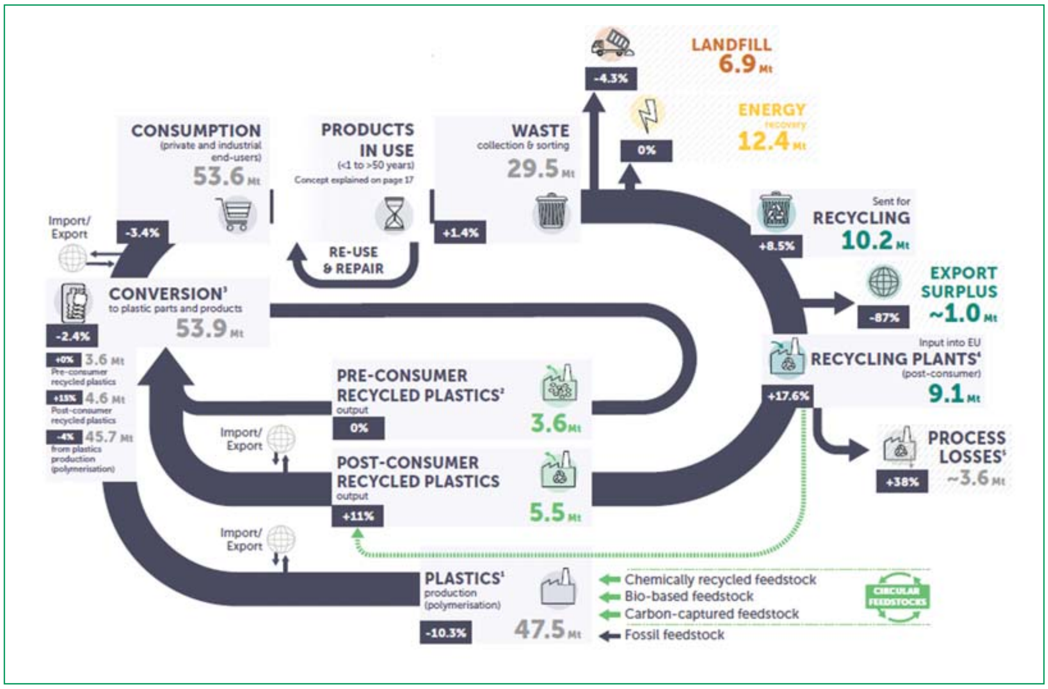
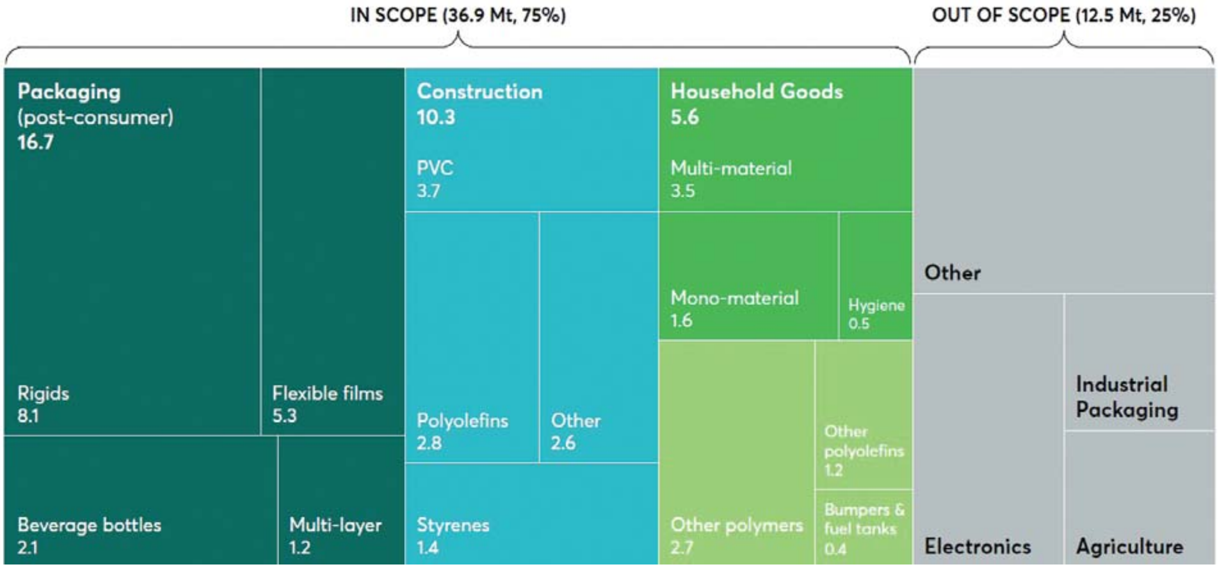


Figure 2 – Plastic circular cycle, with quantities of material in 2020, the percentages are the change between 2018 and 2020. The thickness of the arrows or bars is not to scale.
Reference courtesy Plastics Europe, 2022.

Figure 3 – Composition of the European plastic market broken down in categories *(Systemiq, 2022).*



2020 was 49.4 Mt The division in categories packaging (16.7 Mt), construction (10.3 Mt), household goods (5.6 Mt) and others (industrial packaging, electronics and agriculture) (12.5 Mt) is shown in figure 3 (Mt = million tonnes).

The construction sector sizes 10.3 Mt. Most geosynthetics are made of poly-olefins (PP and PE) or polyesters (PET). These categories are resp. 2.8 Mt and 2.6 Mt (in total 5.4 Mt). It is expected that the construction sector will grow with a long-term average of 1 – 1.5 %/yr.

CE Delft estimated that in 2017 approximately 1900 kt (1 kt = 1000 t) of plastic material was used in the Netherlands. 40% of this is used in consumables, 30% in packaging, 15% in construction materials, 11% in clothing and textiles and 3% in cars and electrical appliances (CE Delft, 2019).

With an average growth of 2% / year, that would be about 2090 kt of new plastic material used in 2022.

In 2009, 523 million m2 of geosynthetic material was used in Europe. With an average weight of 300 g/m2, this gives 157 kt. Assuming a volume increase of 25% over the period up to 2022, the use of geosynthetics in Europe can be estimated at approximately 200 kt.

Based on numbers above it can be concluded that the quantity of geosynthetics used in Europe is 1.9 % of the total use of plastics in the category construction materials (200 kt/10300 kt) and only 0.4% of the total quantity of used plastic in Europe (200 kt / 49400 kt).

The size of the Dutch market in geosynthetics is estimated at about 5.7 % of the European market. This means that the quantity of new geosynthetics used in the Netherlands in 2022 can be calculated as 5.7% of 200 kt = 11.4 kt.

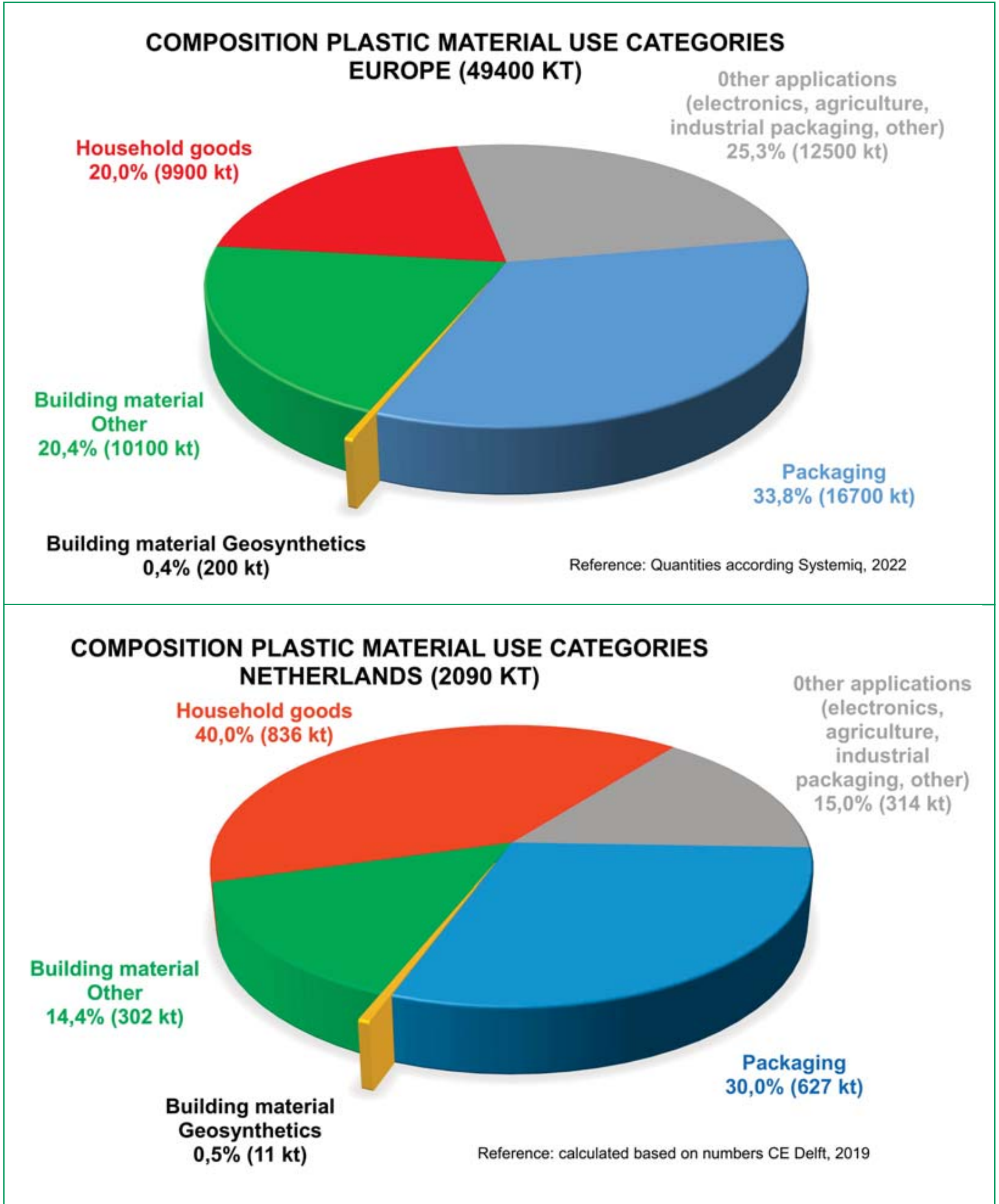


Figure 4 – Overview of the quantities of used plastic materials in Europe and the Netherlands.

Based on the numbers in table 6 it can be concluded that the quantity of geosynthetics used in the Netherlands is 11.4 kt / 313 kt = 3.6 % of the plastics used in the construction market and 11.4 kt /2090 kt = 0.5 % of the total amount of plastic used in the Netherlands.

4.2 DISPOSAL OF PLASTICS

Waste from plastic material is the material that is left over during or after use and that is disposed of. It may be packaging material of, for example, food, or utensils after use, or construction material after demolition. It can therefore have a very short lifespan (packaging) or have a long service life in the case of construction materials in civil engineering structures. Plastic waste material must be collected appropriately, recycled and re-used where possible. It is still partially incinerated because recycling is not yet sufficiently organized in many countries. Incineration in combined heat- and power plants recovers energy, but it results also in extra emissions of CO_2. The long-term goal is to recycle as much as possible.

The total quantity of waste of plastic material in Europe was 29.5 Mt in 2020 (Plastics Europe, 2022). This is approx. 60 % of the supply of new products. 6.9 Mt was sent to landfills, 10.2 Mt was sent for recycling, and 12.4 Mt was incinerated. The waste in poly-olefins or polyester in Europe can be calculated as 1.7 Mt and 1.6 Mt, resp. 5.7 % and 5.4 % of the total quantity of waste.

The quantity of plastic waste in the Netherlands in 2017 was about 1650 kt (CE Delft, 2019). 32% of this consists of plastic single-use packaging, 12% of consumer articles, 9% of clothing and textiles, and 4% of construction materials. The rest is from other, undefined, sources. The quantity of waste in the construction material sector is 68 kt. Of this 68 kt, 17 kt (25 %) was recycled, 44 kt (65 %) incinerated and 7 kt (10 %) landfilled. The construction material category consists of pipes, insulation material, window profiles and other plastics, including geosynthetics.
Geosynthetics form 11.4 / 313 = 3.6 % of the plastics used in the construction market in the Netherlands. The quantity of waste resulting from the use of geosynthetics in the Netherlands can be estimated at 3.6 % of 68 kt = 2.5 kt, which is a very small percentage of the total plastic waste in the Netherlands (2.5 / 1650 = 0.15 %). The quantity of waste resulting from the use of geosynthetics in Europe can be estimated at 120 / 29500 = 0.41 % of the total plastic waste material.

Geosynthetics are used in applications with a long service life, so it will take time before these products will reach their end of use, and the quantity of material that comes available as waste per year is still relatively small.
The largest part of waste from geosynthetics in the Netherlands is incinerated (65%). Mechanical recycling is done in 25 % and dumping on landfills is done in 10%. The policy is to reduce the dumping on landfills as much as possible. The incineration is done in ovens, which generate power by coupling to a power plant. The investments in these ovens are rather recent and it will take time before they are phased out. Simultaneously mechanical recycling processes are improved enabling more waste material to be recycled.

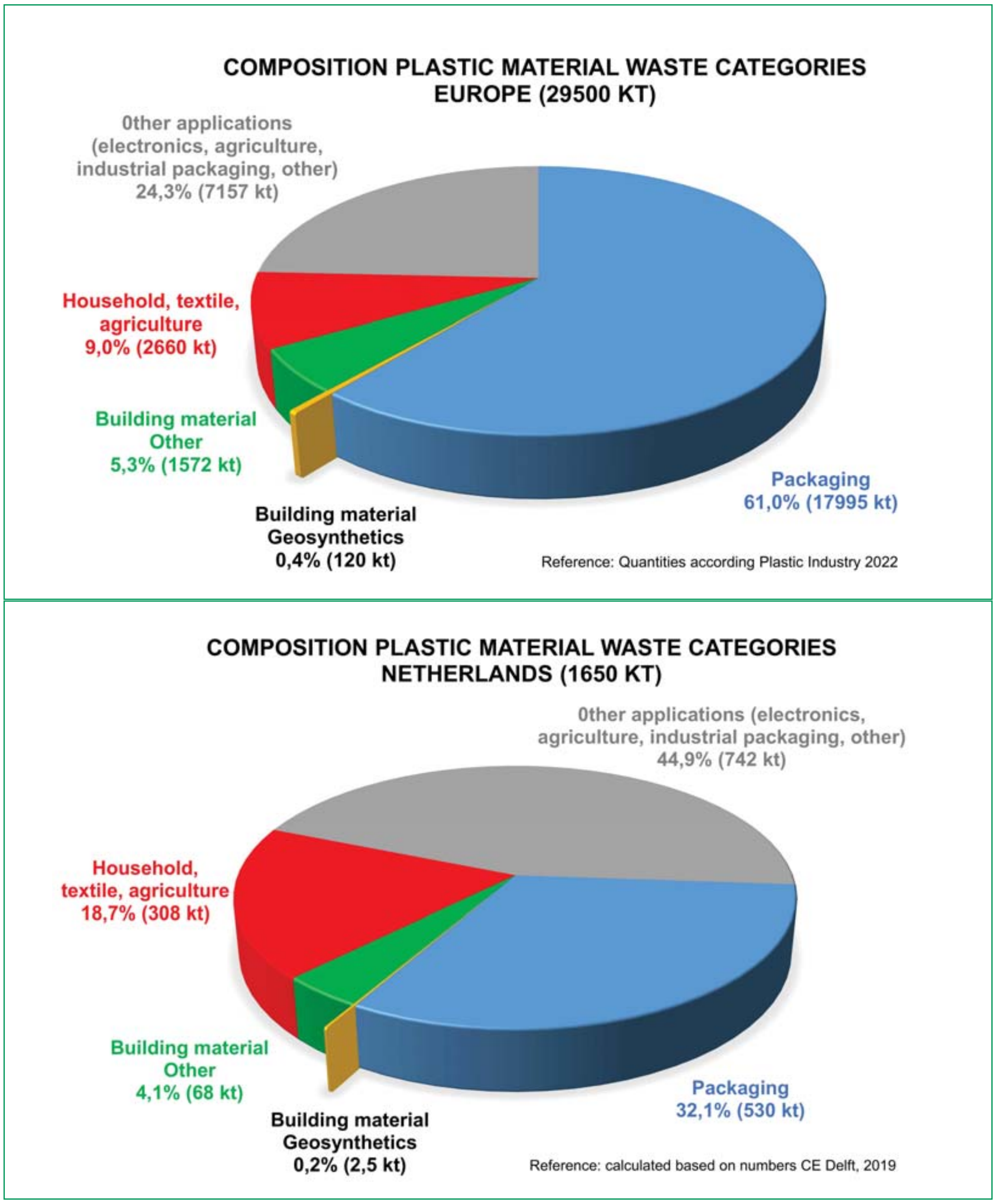


Figure 5 – Overview of the quantities of plastic waste materials in Europe and the Netherlands.

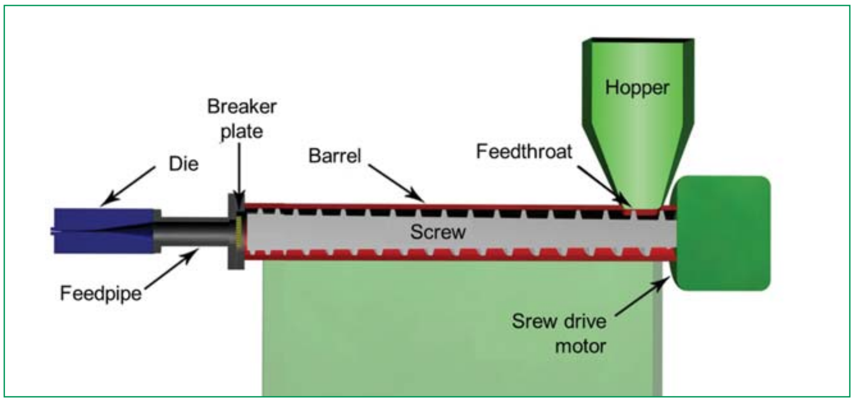


Figure 6 – Typical screw extruder *(Reference: https://en.m.wikipedia.org/wiki/Plastic_extrusion).*

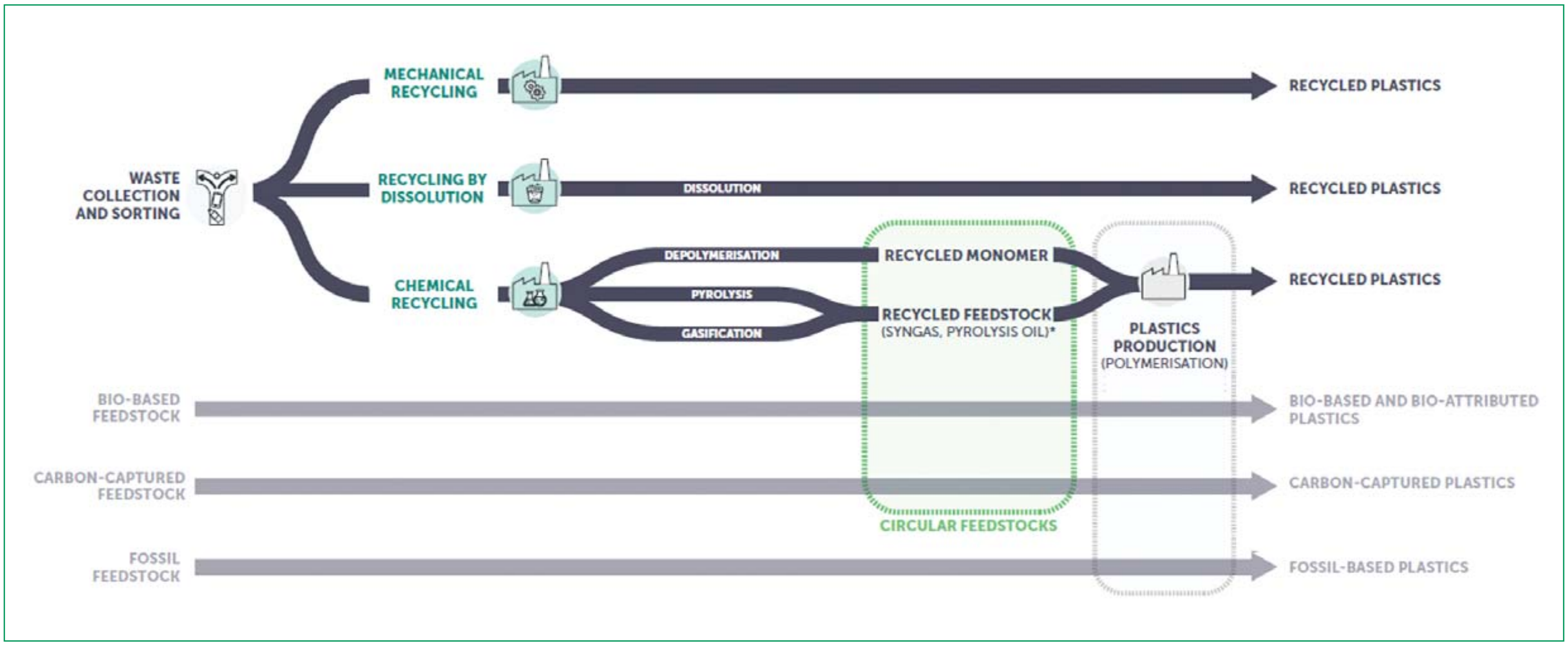


Figure 7 – Overview of recycling methods *(Plastics Europe, 2022).*

5. Sustainability in the production of geosynthetics

Geosynthetics are made of synthetic polymers, which are supplied by the chemical industry. Macro molecules are made by means of a polymerisation process in a reaction vessel. During the processing to the final granules or powder, additives like chain terminators, viscosity stabilizers, antioxidants, fire-retardants and others can be added to the polymer compound to create specific properties. The granules are melted by the producer of geosynthetics using an extrusion process and shaped through a fine opening, the die, to form filaments or sheets. In case of geotextiles, the filaments are stretched to improve the modulus of the final yarn. After that, mats or fabrics are formed by weaving, or by a mechanical or heat bonding non-woven process. Other production processes besides extrusion can be applied to manufacture geosynthetics, a.o. extrusion of a flat sheet or blown sheet extrusion, split fibre extrusion or calendaring.

The polymer properties such as molecular weight, degree of crystallinity, melt flow index, viscosity, melting temperature etc. are important properties for the final product performance. Any contamination of the polymer compound should be eliminated to prevent cutting of the yarn through the very small extrusion opening (100 – 25 µm).
In case recycled polymers are used in the production process, they must fulfil stringent requirements on the properties, no large variations are allowed. This results in high requirements in the recycling process.

The production of geosynthetics implicates energy use and CO_2 emissions. Improvements in the production processes may lead to significant reductions in emissions and energy use. Also environmental protection measures can be taken (Ramsey, 2022):

- The use of packaging material can be greatly reduced;
- The transport of semi-finished products in the factory and of finished products to storage and to the end-user can be organized more efficiently;
- Generation of energy by means of solar panels on the roofs of factory halls will increase the process sustainability;
- Extrusion of polymeric material is done at high temperature and the formed geosynthetic material must be cooled afterwards. In this process, heat can be recovered; In general, heat can be extracted from cooling water before it is discharged;
- Waste material that results from the production process, such as cut off sides of polymer sheets, short rolls etc. are shredded and are fed into the production process again;
- End-of-service-life material can be re-used after purification of contaminants as a separate raw material stream;
- Production methods that allow the use of other post-industrial polymer waste and post-consumer polymer waste material can be developed.

6. Sustainability at the end-of-life of plastic material

At the end-of-life of a structure, the geosynthetic material will have to be disposed of. The following paragraphs deal with four processes: removal, re-use, recycling and incineration.

6.1 REMOVAL

In order to separate the material properly, a few conditions must be met:
The geosynthetic material must have sufficient cohesion so as not to break down into small parts. This means that disassembly of the structure must be within the lifetime of the geotextile or that over-designed geosynthetics are used with sufficient strength end-of-life. This must be taken into account in the design stage and in the geosynthetic specification.

During the execution and installation of the geosynthetic, it must be recorded and checked where exactly the material is in the structure, preferably by means of a laying plan (including changes ʹas builtʹ).
In addition to the selection of a contractor who will carry out the dismantling, it must also be known which waste disposal system will be used.
Recycling should be preferred and stimulated. Incineration should not be preferred only for economic reasons (cheapest solution).
Producers of geosynthetics should enter into agreements with a number of (high-level) waste processors and recycling companies about the recycling of their products.

6.2 RE-USE

In addition to recycling end-of-life geosynthetics, it is also necessary to analyse whether a built-in product can be re-used as geosynthetics without any thermal treatment.

This means that it must be analysed whether, in the case of polyethylene (PE) and polypropylene (PP), there are still enough antioxidants present in the polymer material to be able to function for a number of years. This can be done using an oxidation induction time (OIT) test (Voskamp et al., 2016). In the case of polyester (PET), it will have to be determined how much creep has already taken place under the long-term load. (Voskamp W., 1997) and if any change in molecular weight and Carboxyl Endgroup Content (CEG) has taken place. It is also important to check that no unacceptable mechanical damage has occurred.

6.3 RECYCLING

In case end-of-life geosynthetics cannot be re-used as they are, they must be processed to prevent that the material ends in the environment.
There are basically three ways to process the waste:

1. Dumping at a landfill
2. Incineration of the plastic in combination with energy recovery.
3. Recycling the basic raw material

All kind of measures are taken to reduce the quantity of material that is dumped in landfills. Recycling is promoted as much as possible and incineration is taking place to eliminate the rest.
Recycling is the best method from the point of environmental protection. No new fossil raw materials are used, and the embodied carbon of the plastic material is preserved. Although incineration yields new energy, it results also in further CO_2 emissions. Therefore, the long-term plans focus on reduction of the incineration in favour of increased recycling. Recycling can be done in various ways.

An overview of the various recycling methods is given in the recycling diagram by Plastics Europe (2022).

6.3.1 MECHANICAL RECYCLING

The mechanical recycling process consists of:

1. Collection and distribution of post-consumer, post-industrial materials or end-of-use construction materials.
2. Sorting and categorizing, the different types of plastic are sorted, sometimes also on colour and use. This is done at the recycling plant.
3. Washing removes some of the impurities that can impede the operation, or completely ruin a batch of recycled plastic. The impurities targeted in this step are product labels and adhesives as well as dirt.
4. Shredding. The plastic is then fed into shredders, which break it down into much smaller pieces. These smaller pieces can be processed in the next stages for re-use. It allows also for any remaining impurities to be found, such as metal, which may not have been removed by washing but can be easily collected with a magnet at this stage.
5. Identification and separation of plastics. First, the plastic pieces are segregated based on density, which is tested by floating the particles of plastic in a container of water. This is followed by a test, which determines the thickness of the plastic pieces. The shredded plastic is placed into a wind tunnel, with thinner pieces floating while larger/thicker pieces stay at the bottom.
6. Extruding and compounding. This final plastic recycling process step is where the particles of shredded plastic are transformed into a usable product for manufacture. The shredded plastic is melted and crushed together to form pellets. The shredded plastic is divided per type, classification, and qualities of plastic.

The mostly used polymers for geosynthetics and their recycling practice are:

– **Polyester (PET) – Polyethylene Terephthalate**
One of the most common types of plastic which is used for the manufacture of products such as food containers and plastic bottles for water or soft drinks. PET is widely recycled. Special soil-reinforcing materials are made of PET.

– **HDPE – High-Density Polyethylene**
This type of plastic is used in detergent bottles, food and drink storage, bottle caps, some thicker shopping bags, and non-single-use plastic products like toys, helmets, and piping. Again, this type of plastic is widely recycled. Most geomembranes are made of HDPE.

– **PP – Polypropylene**
Commonly used in injection moulding, this plastic can be found in products from bottle caps to surgical tools and clothing. PP is recyclable but not so easy to process. Most geosynthetics are made of PP yarns or sheets. These categories are easier to recycle than materials that are made from two different polymers e.g. food packaging.

It must be noted that with each subsequent processing, the recycled material degrades and has a lesser quality than virgin materials. The quality of the polymer compound must be increased during the processing by adding additives or using a chemical recycling method. Also, the purity of the recycled compound is very important and often a decisive factor in the acceptance of recycled material to replace virgin polymer.

Various types of geosynthetics are currently being marketed that are made from recycled polymer, for example, polyester non-wovens made from 100% recycled bottle scrap (Ramsey, 2022). Sheets of 100% recycled PP are also made as a semi-finished product in the production of drainage material. Post-industrial waste, i.e. waste that arises during the production of geosynthetics, is often immediately re-used in the production process after shredding.

Until now, according to CEN regulations, no recycled raw materials may be used in the production of high-quality reinforcement mats due to uncertainty about the effects on the properties of these mats or for geosynthetics with an intended service life of more than 5 years in general. Also, there are limits given for the use of recycled material which have been thermally treated during the production. It is expected that these regulations are reconsidered based on the improved knowledge of the quality of (partly) recycled polymer compounds.

6.3.2 CHEMICAL RECYCLING

Chemical recycling is the process of returning used plastic material to its original building blocks, such as polymers, monomers, etc., by means of chemical processes, so that it can be used again as a raw material for new plastic products. Various methods are being developed for this:

– Solvent-based purification is a process in which the plastic is dissolved in a suitable solvent, in which a series of purification steps are undertaken to separate the polymer from additives and contaminants. The resulting output is the precipitated polymer, which remains unaffected by the process and can be reformulated into plastics. The technology is used in the recycling of EPS.

– Depolymerisation is the reverse of polymerisation and yields either single monomer molecules or shorter fragments. PET can be recycled with this technique.

– Pyrolysis and gasification transform plastics and most of its additives and contaminants into basic chemicals. These technologies are based on heating up the plastics in an atmosphere of no (pyrolysis) or limited (gasification) oxygen content. In pyrolysis, plastics are broken down into a range of simpler hydrocarbon compounds. There are many conventional pyrolysis factories which produce oil or naphtha. The output of pyrolysis can be processed much in the same way as oil, using conventional refining technologies to produce value-added chemicals, including building blocks for polymers. Gasification is less sensitive to the input quality than pyrolysis, but it requires more energy and large-scale operations. Gasification is a process where mixed after-use materials are heated (~1000 - 1500 °C) in the presence of limited oxygen to produce syngas (a mix of predominantly hydrogen and carbon monoxide). The syngas can then be used to produce a variety of chemicals and plastics (Velis, 2019). Most polymers can be recycled in this way (Vollmer, 2020, CE Delft, 2019, Plastics Europe, 2022).

The quantities are not large at the moment. This

is because the processes are often in the development phase of pilot plants. In addition, the (investment) costs are still high. It is expected that more and more of these techniques will be applied in the next 10 years, in particular to make high-quality polymer as a raw material for critical products. McKinsey expects a considerable increase of chemical recycling in the coming years. (McKinsey, 2019). They expect that the percentage chemical recycling will grow from 1 % in 2017 to 17 % of the global polymer waste in 2030. With pyrolysis/ liquid feedstock from 1 % in 2017 to 13 % in 2030, monomer recycling (depolymerisation and solvent based purification) to 4 %.
Mechanical recycling is expected to grow from 12 % to 22 % of the global polymer waste.
Detailed data about the plastic industry investments in a.o. chemical recycling can be found in (Plastics Europe, 2022). In 2020 the quantity was < 0.1 Mt. Due to 44 planned projects in 13 EU countries 3.4 Mt of recycled plastic are estimated to be produced via chemical recycling in 2030.

6.4 INCINERATION OF PLASTIC WASTE

Until 2050, the incineration of plastic waste material will be the most important part of waste disposal. Incineration with energy recovery is being increasingly used as an alternative for landfilling. Over the last years in the Netherlands multiple state-of-art incineration plants were built, giving overcapacity in the market. This has effected in import of waste from abroad to keep the plants running. This situation is not really sustainable. It can recover energy within the waste and in doing so substitute emissions related to fossil fuel energy. It is however not a climate-neutral solution for end-of-life plastic.

European policy is aimed at promoting recycling as much as possible, as this leads directly to a reduction in the use of fossil materials. It replaces the use of virgin plastic material that emits approximately 4 kg CO_2/kg plastic material. As a result, the incineration of residual plastic waste will also decrease. (in absolute terms, it may still increase slightly due to an increase in the total use of plastics). Incineration in itself leads to the emission of 2.6 kg CO_2/kg plastic, but at the same time it generates energy through recovery, which leads directly to a reduction of energy production based on fossil material and thus a saving of CO_2. (CE Delft, 2019)

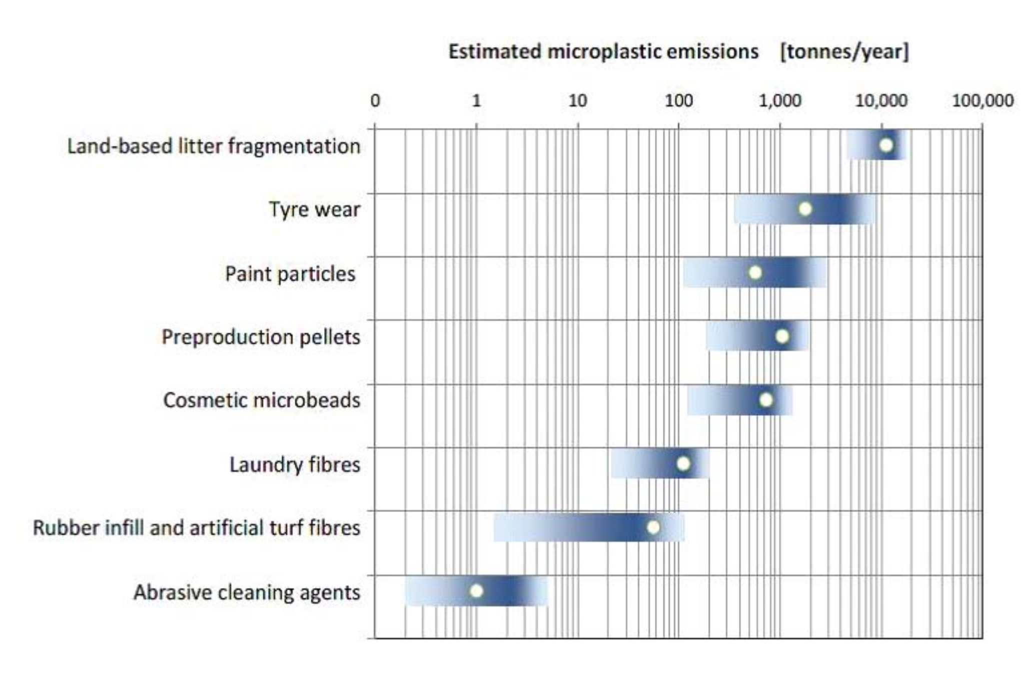


Figure 8 – Estimated emissions of microplastics in the Netherlands in tons/year *(Verschoor, 2018)*.

7. Contamination of the environment as a result of the use of geosynthetics

Residues of geosynthetic material can end up in the environment in a number of ways:

- As litter, if residues are left behind after the end of its service life (microplastics).
- Formation of small particles due to wear or surface damage during the service life (microplastics)
- Contamination due to leaching of additives during the service life.

Through implementation of guidelines, the creation of residual material after the end of its service life, which can lead to microplastics, needs to be avoided.

Also, leaching contamination must be avoided, which means that the geosynthetic material used must comply with requirements regarding maximum quantities of leached material. These requirements are based on the EU Directive EU 2020/2184: On the quality of water intended for human consumption.

7.1 CONTAMINATION BY MICROPLASTICS AND NANOPLASTICS

Microplastics are small plastic particles (< 5 mm), nanoplastics are very small particles (< 100 nanometre). They consist largely of synthetic polymers to which additives, oils, fillers, flame retardants, etc. have been added during the production process. A distinction is made between primary microplastics, which are produced and used as a separate particle, and secondary microplastics which are particles formed from plastic material by weathering or damage. (Stowa, 2022).
Microplastics from geosynthetics can come into the environment via land-based litter fragmentation, as is shown in figure 8.

When geosynthetics are installed in accordance with the methods described in the product installation guides nearly no litter is created during the installation of geosynthetics. The material is supplied in large rolls that are cut to size and built into the ground. Only packaging material of the rolls can lead to litter if not properly cleaned up. At the end of its life, when the geosynthetic is removed, litter can form. This can then consist of pieces of material left behind. The quantity will be small compared to the area of installed material and compared to the quantity of litter from packaging and other consumer goods. Execution guidelines for the disposal of used geosynthetics must ensure that the disposal takes place efficiently and that no residual material is left behind on the construction site.
Of course, not all waste plastic material ends in litter. Most of it is collected and reprocessed. To get an idea of the quantity of plastic waste material that can end up in the environment, the quantity of litter must be looked at.

KIVD indicates that about 9 kt of plastic is present in the total quantity of litter in the Netherlands, of which about 8.3 kt consists of packaging (KIDV, 2017). Verschoor (2018) gives a margin between 1.4 kt and 11.kt with an average of 10 kt for the quantity of plastic in litter (quantities are per year). All this litter will ultimately not end up in the environment, a large part will still be removed by municipalities (street sweepers) and water boards. According to KIVD, 0.7 kt of plastic waste belongs to the other categories (non-packaging). The quantity of new plastic without the category packaging in the Netherlands is 2090 – 627 = 1463 kt. (see table 5). Geosynthetics form 11.4 kt / 1463 kt

= 0,78 % of this quantity (see table 6). This results in an estimate of 0.78 % of 0.7 kt = 5.46 t /year litter from geosynthetics. The total quantity of waste from geosynthetics in the Netherlands is calculated in section 4 as 2,5 kt. Therefore the percentage of litter that can arise from the quantity of waste material of geosynthetics is 5.46 t/ 2500 t = 0.21 % and 5.46 t / 11400 t = 0.05 % of the yearly installed new geosynthetics. This litter will partly be removed by (street/building site) cleaning operations and only partly end as microplastic parts in the environment.

So, in order to address the general problem of (micro)plastic litter, the focus should be on reducing litter from the packaging category in particular. To this end, the EU 2019/904 directive has entered into force in 2021. This directive contains a ban on the marketing of a number of single-use plastic products. Deposit schemes for plastic bottles will further reduce the number of plastic bottles in litter and regulations are being developed in the EU requiring that by 2030 all packaging in Europe will be economically reusable, recyclable or biodegradable.

Most geosynthetics are built in the ground and are not exposed to ultraviolet (UV) radiation or direct wear. Therefore, the chance of fine particles being released as a result of wear or abrasion is very small. Wear can occur in some applications, for example when a geosynthetic is built in as a filter layer in the bank of a waterway. Then wear could occur due to abrasion.

This means that during the design of geosynthetics and the selection of the applied geosynthetics, requirements should be set for resistance to wear. Geosynthetics can be tested for this property. In ISO TC 221 a test method has been developed (ISO 22182: 2019-04), with which the resistance to wear can be measured. Requirements are then set at the national level. The Bundesanstalt für Wasserbau (BAW) requirements in Germany can be mentioned as an example (Maisner, 2019). By setting limitations and specifications in this way the wear or abrasion of geosynthetics can be largely avoided.

7.2 CONTAMINATION DUE TO LEACHING OF ADDITIVES DURING THE SERVICE LIFE

The application of construction material in the EU is regulated in Regulation EU 305/2011, the Construction Products Regulation (CPR). In 2011 the mandate of the Product Committee has been extended to include basic requirement 3 (Hygiene, health and environment) in the product standards. Technical Committee 189 is responsible for setting standards in the field of geosynthetics. With the test method CEN/TS 16637-2 Construction products – assessment of release of dangerous substances, a standardized method has become available to determine how much material is released through leaching. The maximum quantity of material that may be leached is based on the quantities laid down in EU-Directive 2020/2184: On the quality of water intended for human consumption. The exact values for all types of harmful substances will be fixed on national level. They must be less than the values of Directive 2020/2184. Only products that have a CE mark may be used. A CE mark may only be used after initial type testing and the declaration of performance procedure, which establishes that the product meets all requirements that apply under the CPR directive. In this way it is ensured that the quantity of harmful substances that could end up in the environment will never exceed the maximum allowed quantity. An example of the maximum permitted quantities can be found in MGeokE (2016).

Geosynthetics which are used in road- and waterway applications in Germany must fulfil the requirements of MGeokE since 2005. Based on the results of these tests, it can be concluded that if a good formulation for the base polymer and the quantity and type of additives is chosen, the environment is not burdened by the release of hazardous substances from the geosynthetics.

The base polymers are not soluble. Only the additives, such as oxidation stabilizers or residues or over dosage of, for example, catalysts used in the production of the polymer and which are not sufficiently integrated into the polymer compound, can be released. Examples of these are antimony-(III)-oxide as a catalyst used to improve the condensation of PET, or metals such as copper, molybdenum or zinc which are added for various reasons during the melting phase of PE or PP.

In addition to the possible release of these inorganic substances, the release of a number of organic substances is also being investigated. The total quantity of organic carbon plays a key role in the assessment. The quantity released is measured after different periods of time, so that a good extrapolation can be made. Rules for this are laid down in the test procedure.

Since the number of organics in polymers is quite large and because it is almost impossible to analyse them all, indicator parameters of the total organic hydrocarbon content are used to get the first indication of the quantity of organics that are released. Total levels of polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (PAHs) are suitable indicators to determine whether further testing is required on the polymer tested. Naphthalene, that falls in the category PAH, is a frequently formed chemical during the polymerization process.

A well-controlled production process will limit all these substances that can leach out, to below the critical limits. Incorrect dosing of the additives during production or contamination of the machine with oil or solvents after maintenance cause the critical allowable limits to be exceeded. The substances that can be released from geosynthetics are not parts of the polymer itself but are always additives that can be chosen freely.
In recent decades under pressure from the rules of the EU Directive 1907/2006, replacements have been found for a number of hazardous additives, e.g. plasticizers for PVC. A number of other substances are also included in these tests, but the concentration of these in the eluate is often so low that the quantity cannot be measured even with modern analysis equipment.

The list of assessment criteria and critical limits for the leaching of hazardous substances from geosynthetics into water is one of the most extensive that is used with testing of building materials. The German rule (MGeokE, 2016, section 7.6) requires evaluation of the concentration of 26 chemicals. Based on the measurement results collected in Germany in recent years, it can be concluded that the critical limits were only reached in an incidental case, mostly caused by failures during production. By performing these tests on geosynthetics during the CE initial type testing procedure, the Certified Body assessing the test results will, after these directives come into effect, be able to ensure that a good polymer formulation has been selected. If a product does not meet the requirements, the product will not be approved, it cannot receive a CE mark and therefore cannot be placed on the European market or used in European building projects.

Application of the test CEN/TS 16637-2 and assessing its results based on the criteria laid down in Directive EU 2020/2184 on the quality of water for human consumption, as part of the CE initial type testing of geosynthetics will, after these directives come into effect, ensure that only geosynthetics are used in Europe that are safe for the environment.

8. Conclusions

8.1 GEOSYNTHETICS SHARE IN TOTAL PLASTIC USE

Geosynthetics belong to building materials used in environmental, civil and hydraulic engineering. They form 0.4 % of the total yearly use of plastic material in Europe. Geosynthetics are building materials, which can be removed adequately after end-of-life. They are robust and heavy compared to other plastic materials and are supplied and installed in large sheets, in contrast to consumer goods' plastics. Therefore, rest material from geosynthetics is nearly absent in small litter pieces or microplastics.

8.2 DEMOLITION AND REMOVAL OF GEOSYNTHETICS IS EXECUTABLE

Removal of geosynthetics after end-of-life is a matter of good practice for civil engineering contractors. However, it is advised that rules about it become a standard part of building contracts.

8.3 RECYCLING

Mechanical recycling is possible for geosynthetics. Promising are the chemical recycling techniques which would make it possible to upgrade used polymeric material to an acceptable level to be used as feed in the polymerisation process.

8.4 SUSTAINABLE EFFECTS OF THE USE OF GEOSYNTHETICS

Geosynthetics have considerable sustainability effects in the form of energy savings and reduction of CO_2 emissions. Compared to the use of other building materials, the use of geosynthetics will result in a reduction of embodied carbon and energy consumption due to the decrease in use of primary construction materials and due to the reduction of transport of building materials.

8.5 GEOSYNTHETICS ARE NOT A MAJOR SOURCE OF MICROPLASTICS.

The percentage of litter that can result from waste material of geosynthetics in the Netherlands is estimated to approx. 0.21 % of the quantity of waste material from geosynthetics and approx. 0,05 % of the yearly installed new geosynthetics. This litter will partly be removed by street or building site cleaning operations and can potentially partly end as microplastic parts in the environment.

8.6 RESPONSIBILITIES TO LIMIT THE ENVIRONMENTAL IMPACT

At the end-of-life of a structure, the geosynthetic material will have to be removed. In order to separate it properly, guidelines must be set and implemented for all phases of the application: during design (durable designs, appropriate and robust material selection), construction (responsible installation, handling of waste materials), maintenance (inspections to the well-behaviour of the structure, maintenance where needed) and removal (how to remove and recycle). A project owner can require that at the end of the service life of the structure, all geosynthetic materials need to be removed and recycled. The project owner has to include these requirements in the contract specifications and has to provide a budget for it. In this way, the forming of microplastics as result of the application of geosynthetics in earth structures is prevented.

8.7 LEACHING OF HARMFUL ELEMENTS FROM GEOSYNTHETICS

Leaching of harmful elements from the geosynthetics during the service life can theoretically take place. However, only materials that fulfill the strict requirements on the quantities of leachate, based on the requirements listed in the EU directive for drinking water, are allowed to be used. In this way the environment is protected in accordance with the EU Construction Products Regulation EU 305/2011.

Application of the test CEN/TS 16637-2 and assessing its results based on the criteria laid down in Directive EU 2020/2184 on the quality of water for human consumption, as part of the CE initial type testing of geosynthetics will, after these directives come into effect, ensure that only geosynthetics are used in Europe that are safe for the environment.

8.8 EUROPEAN REGULATIONS

Geosynthetics may only be used after fulfilling the requirements of the EU Construction Products Regulation. This means tested according to the CEN requirements and the quality control procedures and supplied with a CE mark. In this way a good quality control system is in place which makes sure that the materials are applied in a safe way and do not form a risk for the environment.

8.9 NECESSARY UPDATE OF CEN NORMS

The use of post-industrial and post-consumers recycled polymer in the polymer compound of geosynthetics with a required service life of 5 years and more is not allowed according to the application norms EN 13249 – 13257 Annex B. The state of knowledge of the effects of the use of recycled polymer feedstock, whether or not mixed with virgin material, develops quickly. CE rules shall not forbid in general the use of recycled material when similar behaviour can be proven.

References

- CE Delft (2019). Chemische recycling in het afvalbeleid.
- CE Delft (2019). Plasticgebruik en verwerking van plastic afval in Nederland. Delft: Greenpeace Nederland.
- Directive EU 1907/2006. (n.d.). REACH.
- Directive EU 2020/2184: On the quality of water intended for human consumption.
- Directive EU 305/2011. (n.d.). Construction Products Regulation.
- EAGM, European Association of Geosynthetics Manufacturers, personal communication.
- Egloffstein, T. (2009). Bauverfahren mit mineralischen Baustoffen und Bindemitteln im ökologischen Vergleich mit dem Einsatz von Geokunststoffen.
- Geosynthetics Research Institute (2019). White paper #41 Sustainability.
- KIDV. (2017). Overzicht van de keten kunststofverpakkingsmateriaal. Den Haag: Kennisinstituut duurzaam verpakken (KIDV).
- Maisner. (2019). Geokunststoffe im Verkerhswegebau in Kontakt mit Grund- und Oberflaechenwasser - Umweltaspekte. Geosources.
- McKinsey. (2019). How plastics waste recycling could transform the chemical industry. Retrieved from https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could -transform-the-chemical-industry.
- MGeokE (2016). Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Strassenbaues. Koln: FGSV.
- NRK (2018) Fedratie Nederlandse Rubber en Kunststofindustrie, marktverkenning.
- Plastics Europe (2022). The circular economy for plastics, A European overview. Brussels.
- Ramsey, B. (2022, April 1). Geosynthetics and sustainability: How is our industry doing? Geosynthetics Magazine, p. 4. Retrieved from https://geosyntheticsmagazine.com/category/features.
- Rebelgroep (2020). Roadmap chemische recycling kunststof 2030 Nederland. Den Haag: VNO NCW.
- Stowa (2022). Microplastics. Retrieved from Deltafacts: https://www.stowa.nl/deltafacts/waterkwaliteit/kennisimpuls-waterkwaliteit/microplastics.
- Stücki, M. e. a. (2019). Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials. Uster: ESU-services Ltd.
- Systemiq. (2022). Reshaping Plastics: Pathways to a Circular, Climate Neutral Plastics System in Europe.
- TNO. (2020). Verspil het niet, pak de schaduwzijde van plastics met urgentie aan.
- van Deen J., Voskamp W. en Bezuijen A. (2019, september). Geokunststoffen en het milieu. Geokunst.
- Velis, C. (2019). A circular economy for plastics : insights from research and innovation to inform policy and funding decisions, https://data.europa.eu/doi/10.2777/269031: Publications Office EU.
- Verschoor. (2018). Potential measures against microplastic emissions to water. RIVM: 64.
- Vollmer, e. a. (2020). Die naechste Generation des Recyclings - neues Leben fuer Kunststoffmuell. Weinheim, Germany: Angewandte Chemie.
- Voskamp, W. e. a. (2016). Durability of Geosynthetics. Leiden: CRCpress.
- Voskamp, W. (1997). Proposed method to determine the safety capacity of reinforced soil structures during the lifetime. Earth reinforcement, Ochiai (pp. 1075 - 1080). Fukuoka: Balkema.
- Voskamp, W. (2016). Duurzaamheid van geokunststoffen. Delft: CROW / SBRCURnet.
- wikipedia. (2022, 6 16). Retrieved from https://en.m. wikipedia.org/wiki/Plastic_extrusion.
- WRAP, Waste & Resources Action Programme. (2010). Geosystems Report, Sustainable Geosystems in Civil Engineering Applications. London: WRAP.


enka®solutions
ENKAMAT® A20
EROSION PROTECTION MAT
Strengthens natural root systems resulting in green embankments
and long-term protection. Proven performance for more than 40 years.
www.enkasolutions.com
FREUDENBERG
PERFORMANCE MATERIALS
FREUDENBERG
INNOVATING TOGETHER


TENCATE
Geolon® HMi
ALLES-IN-ÉÉN OPLOSSING:
STERKE KWALITEIT DIE JE ZIET!
Een onmiskenbaar design gecombineerd
met de hoogste technische prestaties
Tel: + 31 (0)546 544 811
nederland@tencategeo.com
www.tencategeo.eu
TENCATE
GEOSYNTHETICS
A Solmax
Company


Kent von Maubeuge
Naue GmbH & Co. KG


Rijk Gerritsen
Naue Prosé Geotechniek B.V.


Henning Ehrenberg
Naue GmbH & Co. KG

GEOSYNTHETICS: RESPONSIBLE AND SUSTAINABLE SOLUTIONS TO REDUCE ENVIRONMENTAL IMPACT

Introduction

Geosynthetics are high-performance construction products that replace or reduce the use of traditional mineral building materials, such as gravel, sand, clay or other soil materials. In contact with soils and other construction materials, geosynthetics are used for the functions of filtration, drainage, separation, reinforcement, protection, soil encapsulation, erosion control, and sealing (barrier). The wide applications of geosynthetics can be found in the following segments.

– Civil engineering: road building, working platforms, steep slopes, tunnelling.
– Hydraulic engineering: flood defences, canal construction, coastal protection control, water collection structures.
– Environmental protection: landfills, groundwater protection, contaminated soil encapsulation
– Mining, waterproofing.

Figure 1 shows a cross section of a flood defence construction, with multiple geosynthetics for various functions. These multiple geosynthetic applications at flood defences reduce the use of primary soil building materials, stimulate the use of locally available soil and reduce the environmental impact by a significant lower CO_2 emission.

Climate change and the contribution of geosynthetics

Due to climate change, humanity will face multiple and increasing challenges to keep safe and resilient living areas. The impact of climate change can be seen in the daily news. In July 2021, there were significant floods, e.g. in the cross-border region of Germany, Limburg (NL) and Belgium. Between April and August 2022, large parts of Europe were exposed to severe droughts. The levels of rivers like the Rhine were so low that this had tremendous impact to logistics by inland waterway vessels. The stagnation of the supply of sand/gravel is a significant threat to construction. The good news is that applications with geosynthetics can significantly add value to limit the impacts of climate change. This can e.g. be realised with flood defences improvements, river bank restoration works, mitigation of eroding river beds and water containment systems for dry periods. With geosynthetic applications CO_2 emissions for structures can be reduced significantly, which is one of the major goals of the EU (Green Deal) and programs

What is a geosynthetic product?

According to the ISO 10318-1 (2018) definition, a geosynthetic is a product where at least one of its components is made from a synthetic or natural polymer (authors note: also known as bio-polymer), in the form of a sheet, a strip, or a three-dimensional structure and is used in contact with soil and/or other materials in geotechnical and civil engineering applications. Geosynthetics are engineered materials with a focus on the long-term performance, robustness and durability, and can be permeable or impermeable. Permeable geosynthetic products include nonwovens, wovens, geogrids, erosion control and geosynthetic drainage systems. Impermeable geosynthetic products (barriers) are geomembranes and geo-synthetic clay liners (bentonite mats).

Figure 1 – Systematic section of a high-performance flood defence construction with soil reinforcement, geosynthetic clay liner as a barrier, nonwoven geotextile for filtration and separation and erosion control products on the embankments.

SUMMARY

Using geosynthetics, more sustainable and economical structures can be built than with traditional methods using mineral aggregate, clay, steel or concrete. Geosynthetics can replace or significantly reduce the use of these primary building materials. They also increase the service life of structures, like roads, railways or dykes. Compared to traditional construction methods, building with geosynthetics means in most cases a lower total energy demand, substantial reduction of CO_2 emissions and cost savings. Various applications and geosynthetic functions as well as the sustainability benefits are summarised in this article. It will be illustrated how responsible and sustainable solutions can be obtained by using geosynthetics. More important, the positive environmental impact of these solutions in comparison with traditional building methods are described. The contribution of geosynthetics to the construction of resilient structures as the big future challenge for climate change adaptation are outlined.

Figure 2 – Dyke foreland improvement with a bentonite mat creating sufficient length against the piping phenomena and meeting the Limburg Water Board design requirements for flood defence, Neer, The Netherlands.

on national levels. Geosynthetics can reduce the negative impact, as will be shown with CO_2 footprints and Life Cycle Analyses (LCA). Examples will address flood defence structures, stable infrastructure solutions, groundwater and erosion protection applications.

Standardisation and societies

At the European and international level, standards on geosynthetics are being developed in various committees of CEN and ISO. Besides product and test standards it also implies application standards. Important work is done by the European technical committee CEN/TC 189 Geosynthetics, the international technical committee ISO/TC 221 Geosynthetics and the corresponding working groups. National mirror committees reflect, align and approve on content, before a standard becomes normative.

The German Geotechnical Society (DGGT) has its own specialist section on synthetics in geotechnics. Multiple agencies and societies in Germany have been working for decades on the proper use and applications of geosynthetics. In the Netherlands, there are several specific working groups from CROW (engineering technology platform for transport, infrastructure and public space). These working groups are dealing with geosynthetic subjects as sustainability and filtration below stone revetments. The NGO (Nederlandse Geotextiel Organisatie) is the non-profit association in The Netherlands that connects various parties on the subject of geosynthetics. The NGO stimulates knowledge for sustainable design and construction with geosynthetics. The world-wide active, non-profit International Geosynthetics Society (IGS) is an industry society dedicated to the scientific and engineering development of geosynthetics and associated technologies. The IGS provides greater understanding of geosynthetic technology and stimulate the appropriate and responsible use throughout the world. Since 2019, there is also a separate IGS technical committee dealing especially with all aspects of sustainability.

CROW working group sustainability

In the Netherlands a CROW working group on the subject of sustainability of geosynthetics started in 2021. This Dutch working group consists of designers, researchers, contractors, members from authorities, and the building industry. The aim of the CROW working group is to make a guideline from the wide and comprehensive perspective of sustainability for the application of geosynthetics in civil engineering projects. The planned guideline will comprise applications, sustainable design considerations, environmental impacts (like micro-plastics, COO_2 emissions, use of primary granular soils), life-cycle-analyses (LCA), construction/installation, maintenance, and end-of-life approach (circular building, recycling). From the CROW working group the full publication is to be expected in 2023. This publication will be written in English and translated to Dutch.

Stable flood defences and ensuring water safety

There are many possible solutions with geosynthetic materials for flood defences (see Figure 1). Levees or dykes are traditionally constructed with a 0.5 m to 1 m thick clay layer that functions as barrier. A bentonite mat (also known as geosynthetic clay liner, GCL) can replace such a clay layer. The benefits for this application can be summarised as follows:

- Saving natural resources (no clay required), and stimulating the use of locally available soils.
- Less sensitive to dry/wet cycles, so better resistant to periods of extreme drought which are expected due to climate change.
- Lower transportation costs and therefore less CO_2 emissions.
- Faster installation and reduction of the overall construction time.

At the location of Neer (Limburg, The Netherlands), the Water Authority Limburg improved the foreshore of the dyke using a bentonite mat (geosynthetic clay liner, GCL) as a measure against piping (see Figure 2). The GCL panels were laid in connection with a natural clay top layer to lengthen the necessary seepage path. A second dyke improvement project is done in Beesel, where GCLs are applied on the crest and the slopes, replacing the full clay cover layer on the dyke (Figure 3). This project is unique for dyke building techniques in The Netherlands, as it is the first time ever that GCLs are applied directly at the core of the flood defence. The pilot project is closely followed by several other regional water authorities and the HWBP (Hoogwater Beschermingsprogramma –

Flood Protection Program). The experiences will give input and learning points to other flood defence projects in future.

Another important application in flood defence systems (levees or dykes) is the use of nonwoven filter geotextiles under stone revetments. The onwoven replaces the use of finer gravel and sand interlayers which otherwise are needed to build up a natural filter layer to the very coarse rock layer. In case of limited space, the slope of dykes can additionally be steepened by using geogrid-reinforced soil constructions.

Long-term and stable substructure in road and railway construction

The long-term functional efficiency of a separation and filtration geosynthetic in road construction is of fundamental importance so that the construction task assigned can be fulfilled. As an example, if the filtration and separation function underneath the road or railroad track is not achieved, there will be a risk of local failure in the structure.

A simple and proven methodology for establishing filter stability between the base course material and the underlying subsoil involves laying a geotextile between these two layers. This can permanently prevent the migration of fine soil particles from the subsoil layer into the coarse aggregate of the base course, which otherwise would reduce the bearing capacity and frost resistance of the structure. In Figure 4 an example is given in a rail application, where a separating geotextile is installed between the fine-grained subgrade and the coarse-grained base course layer of the railway ballast bed.

Figure 3 – Dyke improvement with installation of a bentonite mat on the crests and slopes of the flood defence to replace a full clay cover of 1 meter and stimulating re-use of local soil, Beesel, The Netherlands.

Figure 4 – Separating geotextile between the fine-grained subgrade and the coarse-grained base course layer in railway construction.

Figure 5 – EN ISO 12236 Geosynthetics – static puncture test (CBR test) - Simulation of the penetration of a stone through a geotextile for classification of the robustness class.

Figure 6 – Large scale geogrid-reinforced earth structures as sound barriers and soil retaining walls at highway junction A2 Hooggelegen Utrecht, The Netherlands.

Figure 7 – Use of a bentonite mat to protect groundwater on the A33 motorway, Halle, Germany.

Figure 8 – Sealing the subsoil for groundwater protection with a HDPE geomembrane and nonwoven protection layers at the railway Wendlingen-Ulm parallel to the A8 federal highway, Germany.

In addition to the separation function, the geotextile often also has a filtration function if groundwater can rise up to the subgrade or surface water seeps through the base course. If the subsoil layer does not achieve a minimum required bearing capacity, additionally a geogrid might be necessary to improve the overall bearing capacity. In this case, composite geosynthetic products are recommended, which have the required geogrid and the filter geotextile combined in one product to reduce installation work.

Several national guidelines place great emphasis on the robustness of such a geotextile (like the German FGSV 535, 2016). Robustness can be tested by the static puncture test EN ISO 12236 (see Figure 5). The correct selection of the geotextile robustness class can ensure the service life of the structure to be built. In addition, the possible maintenance costs for the road/railway construction can be reduced.

Geogrids for stable infrastructure

In infrastructure projects, subgrades with insufficient bearing capacity can drastically reduce the service life of traffic surfaces and cause damage to the road pavement. The main causes are deformations in the subgrade caused by traffic loads over the course of the service life. Higher loads due to increasing traffic accelerate the deformations and therefore an earlier failure of the road pavement. By using geogrids, the granular structure of the base course can be effectively stabilised and reinforced by interlocking with the mesh openings of the geogrid. This interaction mobilises tensile forces in the geogrid (reinforcement) and activates effective resistance to aggregate displacement in the base course. The load-bearing capacity of the overall system is increased, the maintenance intervals are extended and the service life of infrastructure measures is significantly increased. As a result, the overall costs for the structure can be reduced and at the same time the design life of the structure is increased. With geogrids, the thickness of foundation layers can be reduced, so that less granular material is required. This results in less excavation and substantially limits the number of transport movements by trucks, thereby reducing CO_2, nitrogen (NOx) emissions and micro-plastic abrasion of truck rubber tyres.

Geogrid-reinforced earth structures such as bridge abutments and retaining walls (Figure 6) contribute to extending the service life of structures due to their high stability and resistance. Geogrid-reinforced earth structures are often a good alternative to concrete L-walls or steel sheet piles as soil retaining walls. Analysis shows that the environmental impact of a reinforced soil construction on CO_2 emissions can be reduced by appr. 65% – 69 % compared to a conventional design (GSI, 2019). This offers enormous potential for civil engineering projects to reduce the environmental impact by using geosynthetic reinforcement. An additional advantage is that geosynthetics can significantly reduce the use of primary granular building materials (sand, aggregates). When geosynthetics are incorporated, it is often possible to work with local available soil, which would normally not be suitable for use in these structures. For projects, this means optimisation of soil transport logistics. Less transport movements reduce also the nuisance for the surrounding area around the building site. Another advantage for this geosynthetic solution is the faster construction time compared to conventional methods. The time savings and also the construction material savings (because steeper slope inclinations are possible) lead to lower overall construction costs.

Permanent and safe sealing for groundwater protection

The solid, liquid and gaseous emissions caused by motor vehicle traffic contribute to the pollution of the subsoil, water bodies and groundwater. In areas of roads and railroads, waterproofing for environmental protection is intended to protect the subsoil and groundwater from water-polluting substance inputs, especially in water protection areas.

If a road is routed through a ground water protection area, a number of measures are necessary to exclude any risk to water resources as far as possible. In Germany, these construction measures are described in details in the (FGSV 514, 2016). If the protective effect of the existing soil layers is not sufficient, the use of geosynthetic sealing systems is required additionally. A groundwater application with a bentonite mat and geomembrane is shown in Figures 7 and 8.

A Geosynthetic Clay Liner (GCL, bentonite mat) is a geosynthetic barrier with a sealing sodium bentonite layer encapsulated between geosynthetics (cover and carrier geotextile). A new product development is the polyethylene-coated geosynthetic clay liner, a barrier composed of sodium bentonite sealing core and an additional polymeric sealing layer. These products are used where, for example, desiccation is to be permanently prevented, a root barrier is required, or the presence of gravelly subsoils. Another advantage of the coating on the GCL is that the bentonite can be protected against critical chemical liquids.

Geomembranes made of high-density polyethylene (HDPE), similar to the ones used in landfills for decades, are durable barriers even against chemically aggressive media and have been already successfully installed for years in many applications, also in groundwater protection applications (Figure 8).

Figure 9 – Installation of a permanently reinforced erosion control system, securing an embankment slope next to a railway, Groenekan, The Netherlands.

Erosion protection for stable slopes

Newly constructed embankments in earthworks, traffic route construction or landfill construction are particularly at risk of erosion due to a lack of vegetation. Due to climate change, extreme rainfall events will occur more often and will be more intense. Due to these extreme rainfalls, soil erosion is becoming a more critical phenomenon which can dramatically increase the risk of instability to slopes. As result of extreme rainfall, soil particles can be loosened and then transported downslope by run-off water. Depending on the soil type, the consequences are vertically running linear rills or gullies. Without immediate remedial action, initial small erosions can quickly regress to deep gully erosion. In the worst case, this can result in levee/dyke breaches or large-scale landslides, with possible hazards to adjacent traffic routes or even human casualties.

The use of geosynthetic erosion control systems can counteract the effects of rainfall, like the impact of raindrops, softening of the surface and removal of soil particles by precipitation. Geo-synthetic erosion control systems are available in two-dimensional (nonwoven, woven, knitted materials) and three-dimensional structures (geocomposites, geomats, geocells).

However, the important point with all systems is that immediate or subsequent revegetation is possible, which ultimately completes safe erosion control. If rapid revegetation and soil rooting can be assumed, biodegradable raw materials are suitable for temporary erosion control. For permanent erosion control on steeper slopes, a product suitable for permanent use is required. Especially for steeper slopes, the three-dimensional geosynthetic products are used because they can stably embed the topsoil, seeding and vegetation development. In addition, if slope sliding forces have to be absorbed, special reinforced erosion control mats can be used.

On embankments with railways or roads, structure stability and soil erosion during extreme rainfall need to be investigated as well. At Groenekan (The Netherlands), the railway embankments are restored by installing a permanent erosion protection system. The embankments are then covered with soil and a grass/herbs mixture, creating a green surface. The application of these reinforced erosion control mats on railway embankments is unique in the Netherlands and makes this railway embankment resilient to severe climate conditions (see Figure 9).

Biodegradable geotextiles geo-natural or biopolymer material

A significant benefit of traditional geosynthetics is their extremely long durability. This ensures the functionality of the structure over long time periods. On the other hand, where temporary solutions are required (e.g. for a few months or up to 5 years), geonatural or biopolymer products made of degradable materials can be used. At the end of the service life, these materials can remain on site or be composted. For these applications (Figure 10), biodegradable alternatives are therefore being specifically sought and their material behaviour in the specific applications analysed. The raw materials for manufacturing such products can come from different renewable sources.

There are already mechanically bonded nonwovens made from industrially processed fibres from natural source that are fully biodegradable. Due to the uniform nature of the fibres used and their constant mechanical properties, it is possible to produce such a nonwoven into e.g. the German robustness classes (GRK 3 to 5), which is a significant advantage in comparison with highly varying properties of biological products from natural fibres such as straw, coconut or jute.
Over time, the non-woven will biodegrade in-situ without causing any effects to the environment, organisms or ecosystem. Another option is to remove the material from the construction site when it is no longer needed and allow it to decompose. With the right choice of raw materials, these products naturally degrade in the environment to biomass, water and CO_2. This degradable nonwoven offers good opportunities in applications with a temporary function for layer separation, protection or filtration. It can be used in various applications, such as under pavements, in temporary roads, shore sand dunes, bank protection, horticultural applications, green roofs or as bank protection with sandbags, etc. Figure 10 shows an example of an access road, where the separation nonwoven is used under the temporary road paving.

The amount of CO_2 released in the case of renewable raw materials corresponds to the amount of CO_2 bound during the growth phase. This makes it the ultimate sustainable solution, totally meeting the EU/national goals on sustainable building, reducing waste and CO_2 emissions.

Responding to climate change - climate adaptation and mitigation

Climate adaptation means anticipating the negative impacts of climate change and taking appropriate action to prevent further damage. There are two basic principles to respond on climate change: mitigation and adaptation. While mitigation aims to limit negative impacts by reducing greenhouse gases, climate adaptation aims to adapt life to changing environmental conditions.

Before humans began to influence and significantly alter climate, they adapted to living in extremely dry regions, surviving in ice deserts, river flood plains or low-lying delta areas. Humans have developed strategies to adapt to these inhospitable conditions. Today's population densities and resource demands make adaptation by evasion less and less feasible. Concepts that enable and secure life in all parts of the world by increasing resilience and adaptation to new conditions are needed. Well-planned and early adaptation measures using geosynthetics save money, resources and lives later. Examples of these measures are given in the paragraphs before.

In terms of mitigation, geosynthetics in retaining structures reduce CO_2 release by approx. 70 % in comparison with traditional methods like concrete walls or steel sheet piles (GSI, 2019). This means that alternative and smarter designs with geosynthetics can reduce global warming effects. At the same time, such structures are robust, economical and ecological. For climate adaptation geosynthetics can be used in multiple ways (see Figure 11). Examples are embankment reinforcement, stabilising roads, structure waterproofing, slopes and flood defences. The hinterland can be protected from flooding by a double dyke / levee system.

CO_2 emissions and life cycle assessment (LCA)

By using geosynthetics, CO_2 emissions can strongly be decreased. In Figure 12, a CO_2 emission comparison of a 36,000 m³ large barrier application (Figure 7) with a 50 cm thick traditional compacted clay layer and a technically equivalent 10 mm thick bentonite mat is shown. It turns out that the use of the bentonite mat is ecologically much more favourable than the use of traditional compacted clay layers, with at least identical or even improved effectiveness. The enormous soil masses of a traditional compacted clay liner have to be trans-

Figure 10 – Biodegradable nonwoven made from renewable raw materials as a separation and filter layer in a temporary construction road, Dettingen, Germany.

Figure 11 – Cross-section illustration of climate adaptation with multiple options for geosynthetic applications.

ported. This requires a lot of energy, mostly in the form of diesel fuel, which of course emits huge amounts of CO_2 (in this project 9.9 kg/m³). The total CO_2 emissions of the bentonite mat (geosynthetic clay liner – GCL) are with 4.0 kg/m² significantly lower than the values of the compacted clay liner (9.9 kg/m³ - a factor of 2.5 higher).

In principle, it is advisable to carry out an overall assessment, and this is possible with a life cycle assessment (LCA). For the (near) future LCA will be an important part of construction measures and will therefore become increasingly important. The method of "ecological balancing" emerged from the balancing methodology following Stolz et al. (2019) and has been currently further developed. An important driver for the implementation of comparative LCA is the international and EU-internal emission rights trading with greenhouse gases. Only the value of such CO_2 certificates makes it clear how important the intelligent selection of materials and construction methods can be for the environment. It would therefore be important in the EU to implement the issue of comparative LCA more strongly. The goal must be to introduce an assessment in construction measures that allows a comparison of building systems.

As the consequences of climate change can be seen all around, reducing CO_2 emissions is priority to regional, national and international agendas. With the European Green Deal set on 14 July 2021, governments in the EU are bonded to substantially reduce CO_2 emissions. This complies the targets at 2030 with ≥ 55% CO_2 reduction compared to the 1990 levels, and by 2050 no net emission of greenhouse gases. This emission reduction program to transform to green energy and related sustainable building techniques has already been called the third industrial revolution. Reducing CO_2 emissions is of significant importance to keep the global warming below 2° C, which could limit the impact for human society worldwide. It's obvious that geosynthetics have a significant potential in civil engineering to contribute to these sustainability programs and achieve these goals for humanity. To illustrate the contribution, the International Geosynthetics Society (IGS) published a document on applications, related to sustainability goals of the United Nations (IGS, 2021).
Related to EU legislation, the Ministry of Infrastructure and Water Management in the Netherlands (Rijkswaterstaat) published an ambitious strategy on climate-neutral and circular government infrastructure projects. In order to reduce the emission of CO_2, the Ministry of Infrastructure and the Environment has set the ambition of becoming fully climate-neutral by 2030 and to work in a circular way. This governmental strategy is translated to tender contracts, where contractors are awarded for having designs and construction methods with minimised CO_2 emissions and

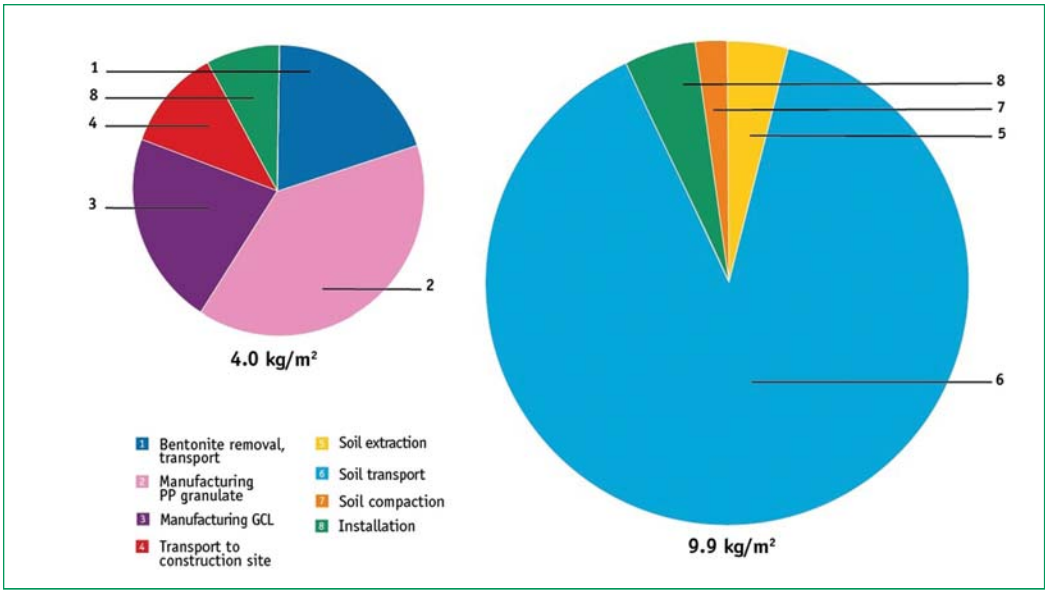


Figure 12 – Comparison of a bentonite mat (left) with a traditional compacted clay layer of 0.5 m (right) in terms of CO_2 emissions from a 36,000 m³ barrier project (von Maubeuge et al., 2021).

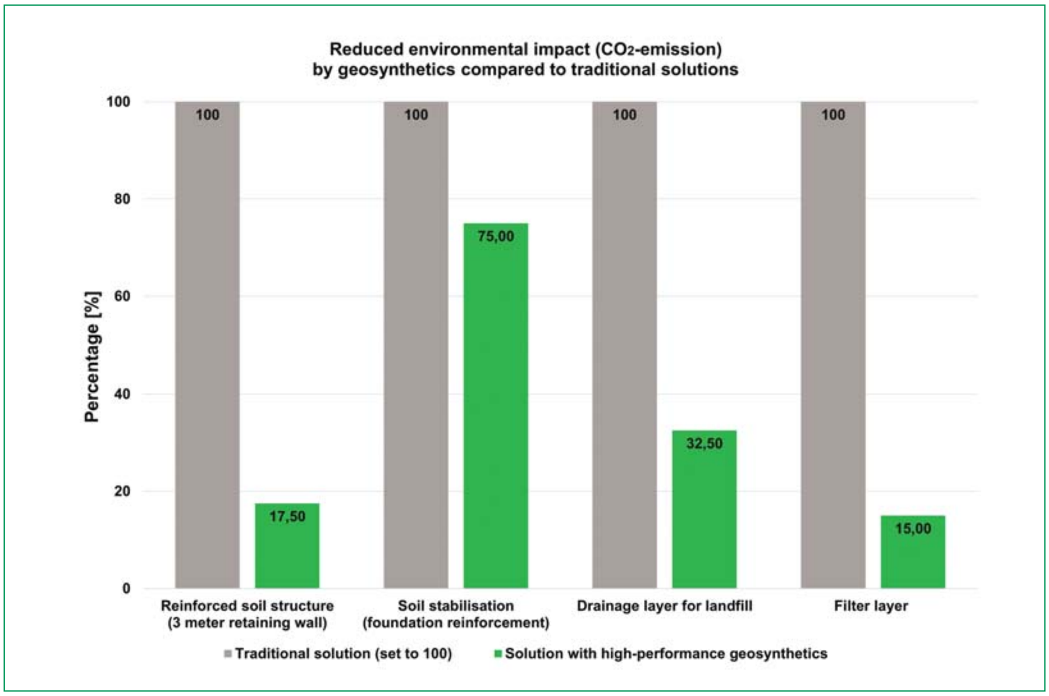


Figure 13 – Environmental impact (CO_2-emission) of traditional solutions (left grey column, benchmark to 100%) compared to geosynthetic solutions (right green column) plotted as average percentage values (adopted from www.ivgeobaustoffe.de).

circular building techniques. The strategy with milestone 2030 can be summarised as follows:

- Reducing the use of primary raw materials to infrastructure projects by 50%.
- Producing as little waste as possible in application with products and materials.
- Full circular operations with re-use of all materials.
- Full climate-neutral, 0% emission to civil engineering structures.

In an extensive study (GSI, 2019), several geosynthetic construction methods have been investigated and compared with traditional construction methods. It shows the geosynthetic construction methods to be environmentally friendly. This can be summarised as follows and is visualized in Figure 13.

- The reduction in CO_2 emissions when using a retaining structure reinforced with geosynthetics compared to a concrete structure is 80% to 85%, and energy consumption is reduced by 70% to 75%.
- For soil stabilisation with geosynthetics, the reduction in CO_2 emissions accounts for approximately 15% compared to a conventional gravel

or crushed stone base course. Compared to a cement- or lime-stabilised construction method, the value is even between 30% and 35%. The cumulative energy input with geosynthetics is as high as 64%.

– A geosynthetic drainage layer for a landfill surface liner reduces CO_2 emissions by 65% to 70% and has a 50% to 60% lower cumulative energy cost.
– If a mineral gravel filter in road construction is replaced by a geosynthetic filter layer, CO_2 emissions and cumulative energy consumption can be reduced by approximately 80% to 90%.

Concluding remarks

The use of the economic and ecological "geosynthetic" construction material has become widespread in many areas of geotechnical engineering in the past decades. Geotextiles, geogrids, geosynthetic sealing and drainage systems allow technically accurate, low-cost, alternative solutions and offer advantages like reduced environmental impact.

Geosynthetics are used in a wide variety of areas. They are used in road construction, hydraulic engineering, landfill construction, dyke construction, civil engineering, and many other applications. For each area of application, a geosynthetic developed for the individual requirements is to be selected properly. A geosynthetic used in landfill construction has to meet different requirements than a geosynthetic used in dyke construction, and one used in hydraulic engineering has to meet different requirements than one used in civil engineering. Geosynthetics are multifunctional with functions such as separation, reinforcement, protection, filtration, drainage, sealing (barrier), soil encapsulation. It is also possible to combine different geosynthetics with each other in high-level engineered structures to ensure safer and long-lasting structures. The advantages of geosynthetics can be summarised as follows:

- **Reliability**: high-quality control standards, lifetime verification and multiple proven project applications.
- **Ecology**: significantly lower CO_2 emissions, supporting EU climate goals, lower energy consumption, reduction of transport amount or kilometres.
- **Sustainability**: limit the use of all resources (like primary granular building materials, energy demand), less noise impact.
- **Cost-effectiveness**: reduced building cost compared to traditional methods, longer service life, less maintenance.
- **Easiness**: easy to handle and install on project sites, saving time in the construction process.
- **Resilience**: improved structural behaviour with the ability to respond, absorb, adapt or recover from extreme load cases caused by climate changes.
- **Safety**: increased serviceability and protection at dykes, groundwater, infrastructure, and environmental protection (waste management, chemicals).

It can be concluded that the development of geosynthetics is one of the most significant developments in geotechnical engineering, especially when looking at the positive environmental impact. Research and developments on these engineered materials are ongoing. The outcome and improvements are promising: new sustainable materials, bio-based products, smarter products with better and durable properties, innovative designs and structures realised with new building methods.

Due to climate change, humanity will face multiple and increasing challenges to keep safe and resilient living areas. Applications with geosynthetics can add significant value to limit the impacts of climate change. This can e.g. be implemented to flood defences improvements, river bank restoration works, mitigation of eroding river beds, water containment systems for dry periods, etc. With geosynthetic applications, CO_2 emissions for structures can be reduced significantly. Geosynthetics contribute to the goals for sustainability set in the EU Green Deal and derived programs on national levels. Geosynthetics contribute to secure safe and convenient living areas today, also because of their resilient performance.

References

- Barrett, R.J. (1966), "Use of Plastic Filters in Coastal Structures", Proceedings from the 16th International Conference Coastal Engineers, Tokyo, pp. 1048-1067.
- Bundesgesetzblatt (2021), „Verordnung zur Einführung einer Ersatzbaustoffverordnung, zur Neufassung der Bundes-Bodenschutz- und Altlastenverordnung und zur Änderung der Deponieverordnung und der Gewerbeabfallverordnung (vom 9. Juli 2021)"; https://www.bvse.de/dateien2020/ 2-PDF/03-Themen_Ereignisse/01-bvse/ bgbl121 s2598 _79885.pdf.
- EN ISO 10318-1: 2018-10, "Geosynthetics – Part 1: Terms and definitions (ISO 10318-1:2015 + Amd 1:2018)"; Trilingual version EN ISO 10318-1:2015 + A1:2018; Beuth Verlag GmbH.
- EN ISO 12236:2006-11, "Geosynthetics – Static puncture test (CBR test)"; Beuth Verlag GmbH.
- EN 15382:2018-07, "Geosynthetic barriers – Characteristics required for use in transportation infrastructure"; Beuth Verlag GmbH.
- European Green Deal, full program and background information https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.
- FGSV 514 (2016), „Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten (RiStWag)", Forschungsgesellschaft für Straßen- und Verkehrswesen (Hrsg.).
- FGSV 535 (2016), „Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Straßenbaus (M Geok E)", Forschungsgesellschaft für Straßen- und Verkehrswesen (Hrsg.).
- FGSV 559 (2017), „Merkblatt über Bauweisen für Technische Sicherungsmaßnahmen beim Einsatz von Böden und Baustoffen mit umweltrelevanten Inhaltsstoffen im Erdbau (M TS E)", Forschungsgesellschaft für Straßen- und Verkehrswesen (Hrsg.).
- Geosynthetics Research Institute, (2019), GSI White paper #41, "Relative Sustainability (i.e., Embodied Carbon) Calculations With Respect to Applications Using Traditional Materials Versus Geosynthetics", https://geosynthetic-institute.org/papers/paper41.pdf
- International Geosynthetics Society, "Preparing the ground for a brighter future – How geosynthetics have been serving society for half a century", ebook: https://www.geosynthetics-society. org/wp-content/uploads/2021/05/IGS_Ebook. pdf , may 2021.
- Koerner, R. M. (2012), "Designing with Geosynthetics", 6th edition vol 1, ISBN 978-1-4628-8288-5, pp 33 - 35.
- Lauritzen, C. W. (1963), "Plastic Films for Water Storage", Journal of American Water Works Assoc., vol. 53, no. 2, pp 135-140.
- Ministerie van Infrastructuur en Waterstaat, Naar klimaatneutrale en circulaire rijksinfrastructuurprojecten, https://open.overheid.nl/repository/ronl-9a139fb8-3bbb-4710-91a0-ecd523266bae/1/pdf/bijlage-1-strategie-naar-klimaatneutrale-en-circulaire-rijksinfraprojecten.pdf, januari 2020 (in Dutch).
- Stolz, P, Frischknecht, R. (2019), "Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction materials", www.eagm.eu/_files/ugd/345956_2d895800c5b6409892cdf7d847bd6ab4.pdf
- Von Maubeuge, K. P., Stoyle, J. (2021), "The ISO design guide for geosynthetic barriers and the use for safe and economic barrier solutions",11th Int. Conference on Geotechnique, Construction Materials & Environment, Kyoto, Japan, 3-5 November 2021, ISBN: 978-4-909106063 C3051, page 428 – 435.