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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.

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.

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 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.

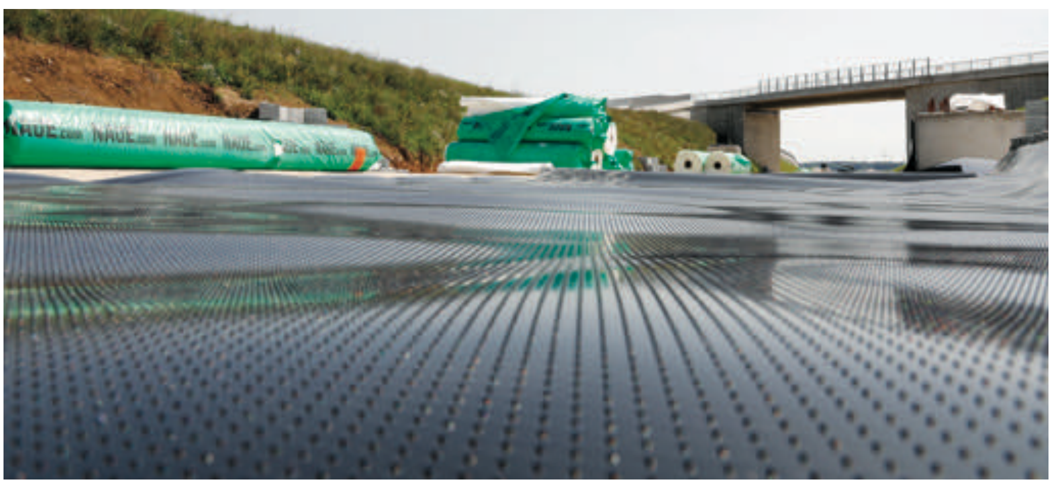

Figure 8 – Sealing the subsoil for groundwater protection with a HDPE geomembrane and nonwoven protection layers at the railway Wendlingen-Ulm parallel to the A8 federal highway, Germany.

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 m^3 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 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

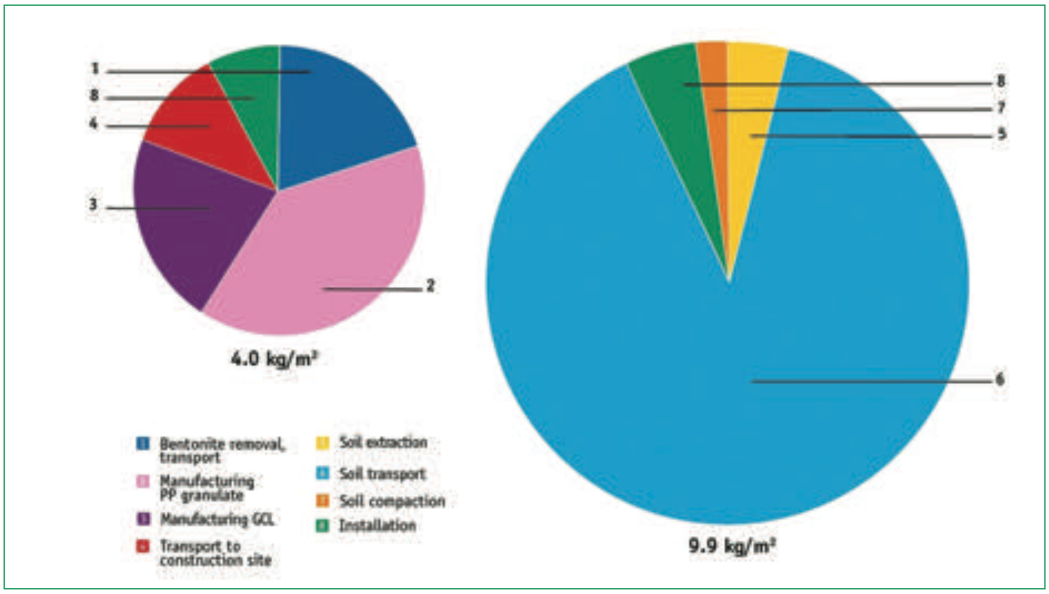

Figure 12 – Comparison of a bentonite mat (left) with a traditional compacted clay layer of 0.5 m (right) in terms of CO_2 emissions from a 36,000 m³ barrier project (von Maubeuge et al., 2021).

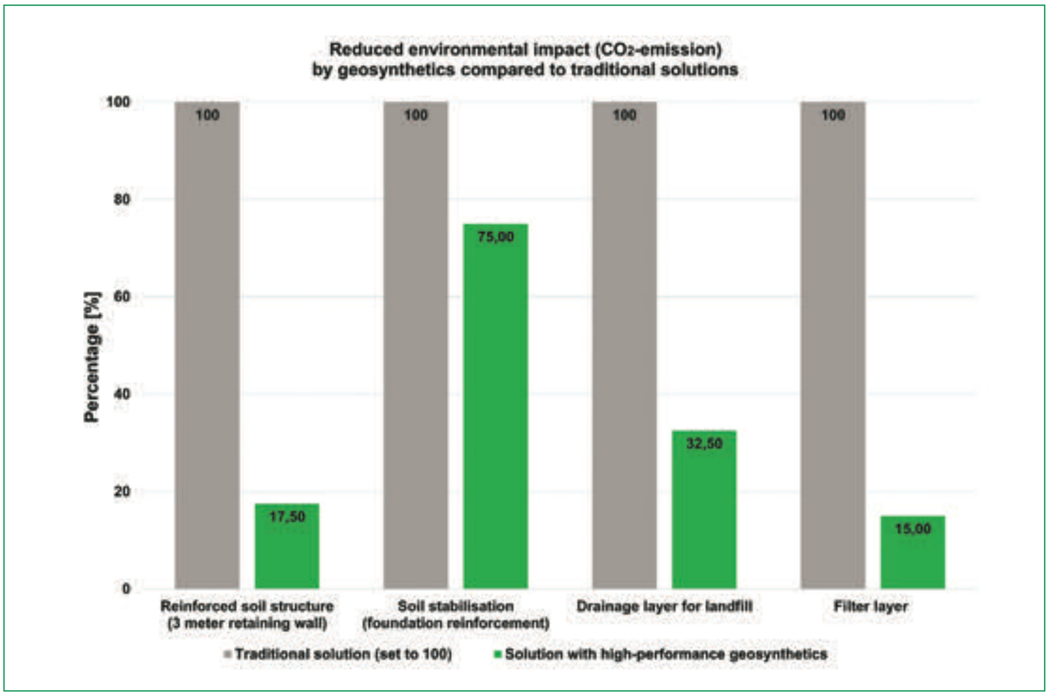

Figure 13 – Environmental impact (CO_2-emission) of traditional solutions (left grey column, benchmark to 100%) compared to geosynthetic solutions (right green column) plotted as average percentage values (adopted from www.ivgeobaustoffe.de).

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.

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