Comparative life cycle assessment of geosynthetics versus conventional construction materials in infrastructure, filter function in a river construction, a study on behalf of the EAGM

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ABSTRACT: The European Association of Geosynthetic product Manufacturers (EAGM) commissioned ETH Zürich and ESU-services Ltd. to quantify the environmental performance of commonly applied construction materials (such as concrete, cement, lime, or gravel) versus geosynthetics for 4 cases. Geosynthetic materials are used in many different applications in civil and underground engineering. In most cases, the use of geosynthetic material beneficially replaces the use of other construction materials. To this end, a set of comparative life cycle assessment studies are carried out, concentrating on various functions or application cases. The environmental performance of geosynthetics is compared to the performance of competing construction materials used. Further new cases have been evaluated since 2020. This paper presents the results of a case with a filtration function (the construction of a filter, where geosynthetics are used, is compared to the case of a mineral filter) in a river construction with a typical geotextile filter in comparison to a gravel/sand filter. The study shows benefits in sustainable constructions using geosynthetics.

1 INTRODUCTION

Geosynthetic materials are used in civil engineering in many different areas. In most cases, the use of geosynthetics replaces or improves the use of other materials. For the first time in 2010, the European Association of Geosynthetic Materials Manufacturers (EAGM) commissioned ETH Zürich and ESU-services Ltd. to quantify the environmental impact of commonly used construction materials (such as concrete, cement, lime, or gravel) compared to geosynthetics in civil engineering.

To this end, a series of comparative life cycle assessment (LCA) studies were conducted focusing on different use cases, namely filtration, foundation-stabilised road, landfill construction, and slope stabilisation structures. The environmental performance of geosynthetics and competing construction materials was compared.

In 2018, it was verified if the obtained results were still up to date or whether the study needs to be renewed. EAGM commissioned treeze Ltd (the successor company of ESU-services Ltd) with the review.

The assessment confirms the timeliness of the study. The full study, including the results of the critical reviews, is available at: http://www.eagm.eu/. The latest results were presented in detail at EUROGEO 7 in Warsaw in 2022. In 2021 and 2022, another study was prepared based on the findings, which are presented in detail below.

2 FILTRATION FUNCTION INFRASTRUCTURE IN A RIVER CONSTRUCTION

This paper presents the results of a case with a filtration function (the construction of a filter where geosynthetics are used is compared to the case of a mineral filter) in a river construction with a typical geotextile filter in comparison to a gravel/sand filter. The study shows benefits in sustainable constructions using geosynthetics. treeze Ltd. evaluated the study.

The life cycle assessments carried out within this study follow a cradle-to-grave approach. The product systems of the waterway analysed encompass the extraction of the raw materials, their processing into building materials, the construction and disposal of the waterway (infrastructure element, see Fig. 1). Operation and maintenance of the waterways are excluded. Transport processes and infrastructure are included. All processes describe average European conditions.

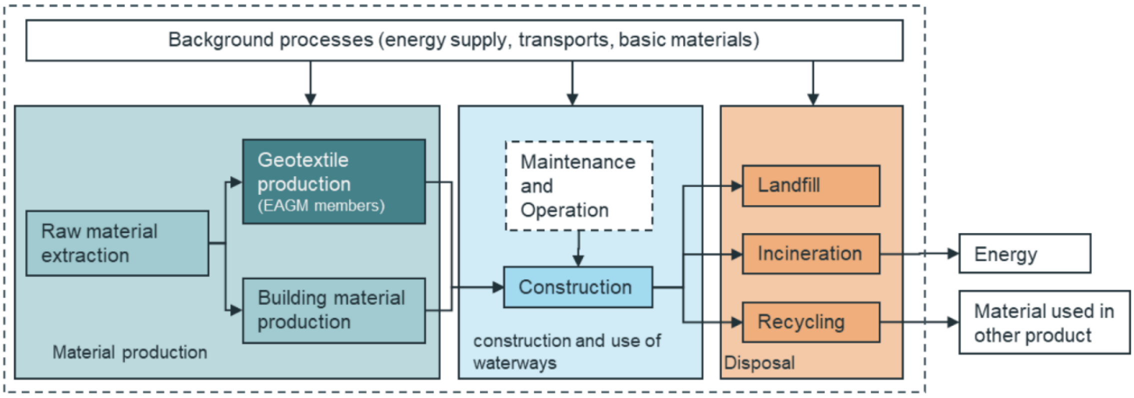

Figure 1. Simplified process flow chart showing the most important process steps.
Maintenance and operation of the infrastructure element are not included in the system boundaries.

The lifetime of the waterways is expected to be the same (100 years) for both options assessed in this study.

7 European producers, all members of the EAGM, provided data on the production of geosynthetic materials. The required data were collected by means of prepared questionnaires. An industry expert provided data on construction and de-construction efforts. The primary source of background inventory data used in this study is UVEK LCI data DQRv2:2022. The LCA software SimaPro v 9.3.0.3 was used to model and calculate the life cycle based environmental impacts.

The first seven environmental impact category indicators form part of the Environmental Footprint method v3.0 published by the European Commission (2017). The cumulative non-renewable energy demand is based on the approach published by Frischknecht et al. (2015).

- climate change (greenhouse gas emissions),
- photochemical ozone formation (summer smog),
- particulate formation,
- acidification,
- freshwater eutrophication,
- land use impacts,
- abiotic resource depletion (minerals and metals)
- cumulative energy demand (primary energy consumption), non-renewable

Sensitivity and uncertainty analyses were carried out to learn more about the stability of the comparative results. Not included are:

- Operation and maintenance of the infrastructure element (e. g. shipping, cleaning) because these activities do not differ between the alternatives;
- Manufacturing equipment (machinery) at the geosynthetics manufacturer's site, because of its minor importance (see e. g. Frischknecht et al. 2007);
- Operation of the storage of raw and geosynthetic materials at the manufacturer's site because the energy consumption is considered negligible;
- Packaging of the geosynthetics because they are of minor importance (less than 3 % of mass contribution);

- Efforts and emissions of thorough end-of-life cleaning (decontamination) of the filter materials because of missing information and empirical data.

The study refers to the year 2019. Foreground data about geosynthetic materials gathered by questionnaires refer to 2019 or, in a few exceptional cases, 2018. Data available about further material inputs and the use of machinery are somewhat older. The characterisation of the waterway analysed represents current best practices. Age differences are discussed in the data quality section of the results chapters.

All data refer to European conditions. Some background data referring to Switzerland are used to estimate European conditions, particularly regarding landfilling and incineration of wastes.

3 EVALUATED CASES

The waterways assessed in this report are defined in a way that they represent commonly applied new constructions. Nevertheless, construction methods may vary from one EU member state to the other. Thus, the case should be perceived as an exemplary model of the common and frequent application of geosynthetic materials in waterways. The functional unit is 1 meter of an inland waterway with a width of about 34 meters (water level, see Fig. 2). The upper layer consists of water stones in both cases. The filter layer is either gravel/sand of two times 20 cm (left side see Fig. 2) or a geosynthetic filter (right side see Fig. 2).

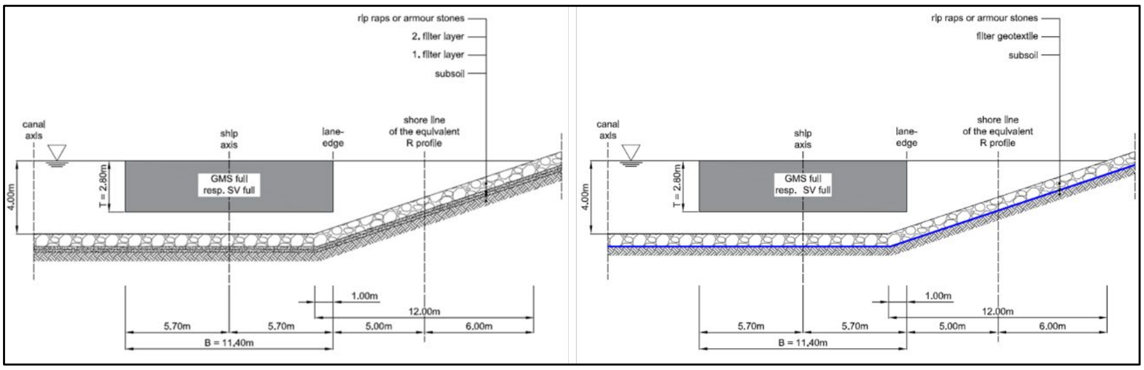

Figure 2. Cross-section of the waterway analysed in this study (left: gravel filter; right: geosynthetics filter).

The two alternatives are defined such that they can be considered technically equivalent or at least comparable. The geosynthetics used represent a mix of different brands suited for waterways. Scenario 2 and 3 include a typical geosynthetic as used in Germany in this application. The conventional systems represent the most common type of construction.

3.1 *Base scenario*

The base scenario shows a geosynthetic filter with a specific weight of 350 g/m² and a shipping distance of mineral material (water stones and gravel/sand filters) of 20 km. Based on the evaluation with 7 manufacturers of the EAGM for the year 2019, the delivery distances and the type of transports are determined.

For the raw materials, an average distance of 820 km was evaluated, with a weighted distribution of 600 km per truck and 220 km per ship.

For the nonwovens, an average distance of 795 km was evaluated, typically by truck (62 %) and in special cases by train (38 %).

Alternatives to the base scenario are described in detail in the following Table 1.

Table 1. Overview of different scenarios.

	Unit	**Base**	Scenario 1	Scenario 2	Scenario 3
Geosynthetics basis weight	g/m²	**350**	350	750	750
Distance supply of mineral materials	km	**20**	50	20	50

3.2 *General Information*

The calculated nonwoven geosynthetics used in waterways construction are made from polypropylene staple fibres and have a specific weight of about 350 g/m². In some countries like Germany, geosynthetics with a specific weight of 750 g/m² are used. The life cycle inventory of manufacture of nonwoven geosynthetics is based on data and information provided by seven European manufacturers. They collected data on consumption of raw materials, working materials, packaging materials, fuel, steam and electricity consumption, water consumption and release, pollutants emissions to air and water, wastes (including the kind of treatment), supply and delivery logistics, as well as land use and infrastructure (such as factory halls and office buildings). Production volume weighted average datasets on the manufacture of nonwoven geosynthetics with a specific weight of 350 g/m² and 750 g/m² were established.

The material demand of gravel/sand was determined by Norbert Kunz, BAW (Bundesanstalt für Wasserbau, Germany; Federal Waterways Engineering and Research Institute, Germany) based on the regular cross-section of a typical inland waterway. The material additionally excavated is assumed to be shipped to a landfill site over a distance of 20 km.

4 RESULTS OF THE SCENARIOS

4.1 *Detailed results base scenario*

Figure 3 shows the comparison of all impact categories and gives in detail the proportion of each construction / production step.

For example, the first part shows

- in the first line the highest proportion of greenhouse gas emissions with e. g. roughly 30 % (light blue) for the construction efforts and
- in the second line the highest proportion of greenhouse gas emissions with e. g. roughly 20 % (brown) for the deconstruction efforts

In general, the first line (greenhouse gas emissions) shows that the geosynthetic construction method reduces the production of greenhouse gas emissions by more than 25 % compared to the classic construction method.

The results for the scenarios 1, 2 and 3 are similar and can be seen in detail at www.eagm.eu.

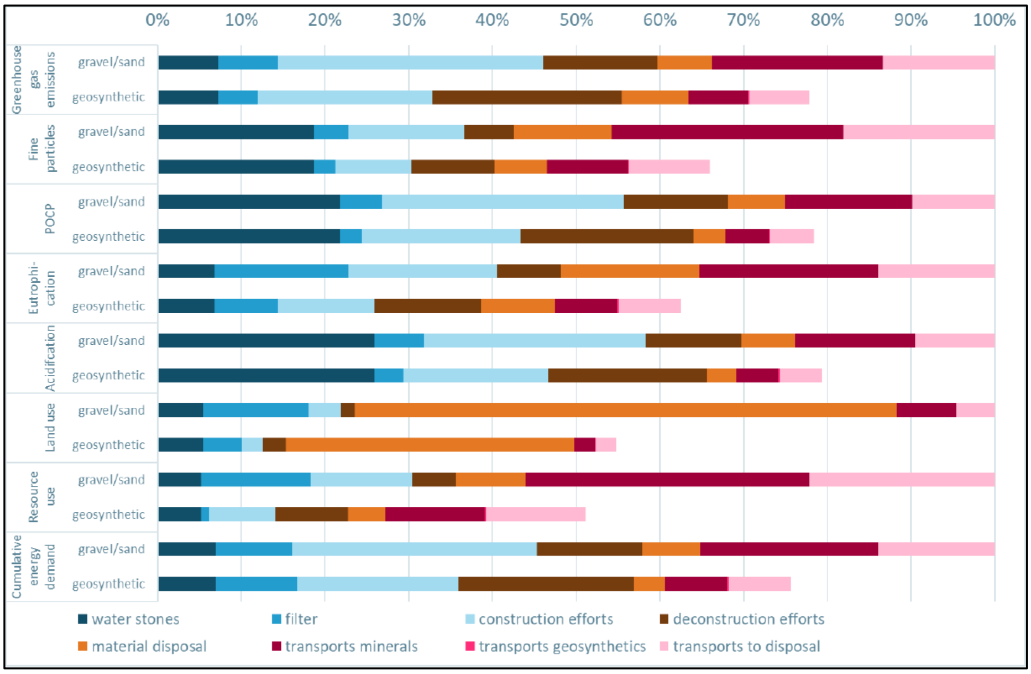

Figure 3. Environmental impacts and their main contributors caused by 1 m of the inland waterway (width of about 34 m, water surface) relative to the environmental impacts of the waterway with gravel/sand (which equal to 100 %); base scenario.

5 SUMMARY OF RESULTS

Two significant impacts discussed in the last years are climate change (greenhouse gas / CO_2 emissions) and cumulated energy demand. In the last years, the saving of natural resources, e. g. minerals (abiotic resource depletion), is coming more in mind.

Figure 4 shows that the use of a filter nonwoven leads to lower impacts compared to the classic construction with a mineral filter layer in the base scenario.

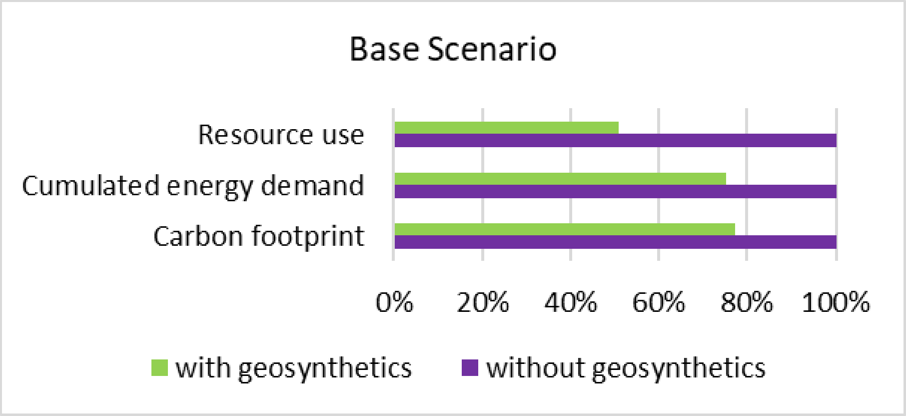

Figure 4. Relative differences in resource use, cumulated energy demand and carbon footprint; base scenario (details see Table 1, 350 g/m² geosynthetic, 20 km transportation distance for minerals).

The results for the scenarios 1, 2 and 3 are similar and show that the use of a filter nonwoven in all three above-mentioned impact categories leads to lower impacts compared to the classic construction with a mineral filter layer in all four evaluated scenarios. The results can be seen in detail at www.eagm.eu.

6 CONCLUSION

Given the goal in the European Climate Law of the European Union to become climate neutral by 2050, a further and substantial reduction in greenhouse gas emissions and other impacts is required. This involves low CO_2 construction equipment and freight transports, and the reduction in greenhouse gas emissions during the manufacture and disposal of geosynthetic materials. Filters constructed in Europe may differ in cross-section and materials used. Thus, generalised assumptions were necessary to model a filter layer of a typical channel.

In this study, the environmental impacts of construction and deconstruction of two different alternatives for inland waterways were quantified and assessed. The results show that the alternative with a geosynthetic filter causes up to 50 % less environmental impact than the alternative with a gravel/sand filter. Even with the least favourable alternative for geosynthetic filters with a relatively heavy geosynthetic (750 g/m^2) and in comparison, a rather short transport distances (20 km) for the mineral components, emissions are reduced when using the geosynthetic filters.

Furthermore, it was shown that the use of geosynthetics means a high saving of natural resources, as minerals such as sand and gravel from a mineral filter are saved.

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