Comparative life cycle assessment of geosynthe-tics versus conventional construction materials, a study on behalf of the e.a.g.m., case 1, filter func-tion

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ABSTRACT: The European Association for Geosynthetic Products Manufacturers (E.A.G.M.) 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. Geosynthetic materials are used in many different applications in the 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 (LCA) 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.

1 INTRODUCTION

Geosynthetic materials are used in many different applications in civil and underground engineering. In most cases, the use of geosynthetic material replaces or enhances the use of other materials. The European Association for Geosynthetic Products 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. To this end a set of comparative life cycle assessment (LCA) studies are carried out concentrating on various application cases, namely filtration, foundation stabilised road, landfill construction and retaining structures. The environmental performance of geosynthetics is compared to the performance of competing construction materials used.

The specifications of four construction systems are established by the E.A.G.M. members representing a significant majority of the European market of geosynthetic materials:

- Case 1 Filtration
- Case 2 Foundation stabilisation
- Case 3 Landfill construction drainage layer
- Case 4 Soil retaining wall

This paper presents the results of case 1 - Filtration function, the basis of the whole assessment, and the detailed results of the further cases will be shown in further papers at this conference (see References).

The whole study including the results of a critical review is available on: http://www.eagm.eu/

2 CHARACTERISATION OF THE ALTERNATIVES

Geosynthetics are used in soil engineering, where they can serve as filter medium.

The case of the construction of a filter where geosynthetics are used (case 1B) is compared to the case of mineral filter (case 1A).

The average of 3 types of different geosynthetics is used to represent its performance, namely

- continuous filament nonwoven
- staple fibre nonwoven and
- woven fabrics

Polypropylene granules are used as basic material (in case 1B). They need to contain stabilisers to meet the durability requirements. The average mass per unit area of the geosynthetic is 175g/m².

The way the filter is constructed depends on several factors. The basic conditions are shown in table 1 and figure 1. A more detailed cross section of the adjacent area is shown in figure 2. The cases 1A and 1B compare the environmental impacts of 1 square meter of the filter area below the road. A deeper excavation needed at the adjacent area for case 1A is not considered in the comparison.

Parameter	**Unit**	**Case 1A Mixed grain filter**	**Case 1B Filter with geosynthetics**
Filter size	m^2	1	1
Filtration geosynthetic	g/m^2		175
Gravel layer thickness	cm	30	

Tab.1: Design criteria of the filter system of cases 1A and 1B

From these parameters it is calculated that the required thickness D of the mineral filter (case 1A) is 300mm and the alternative with the geosynthetic, case 1B – is 1-2mm. Figure 1 shows a cross section of the filter profile as modelled in this LCA.

The impact from the thickness of the gravel filter on the LCA is evaluated by varying +/- 10cm.

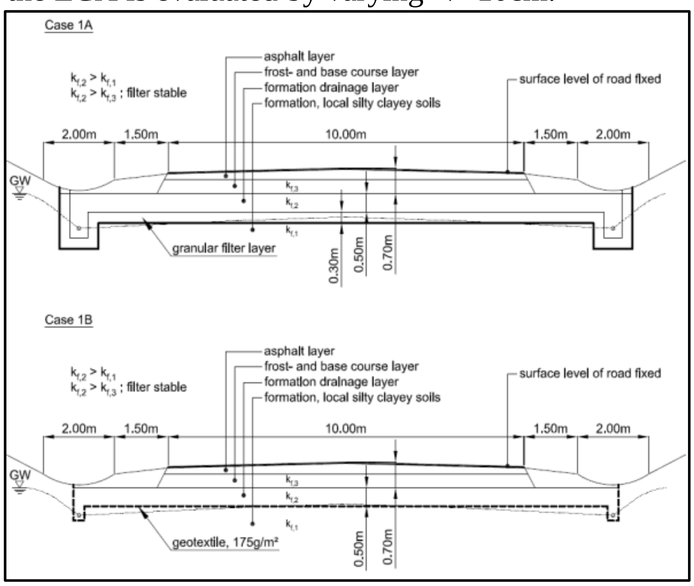

Fig.1: Cross section of mineral filter (case 1A, top) and geosynthetic filter system (case 1B, bottom)

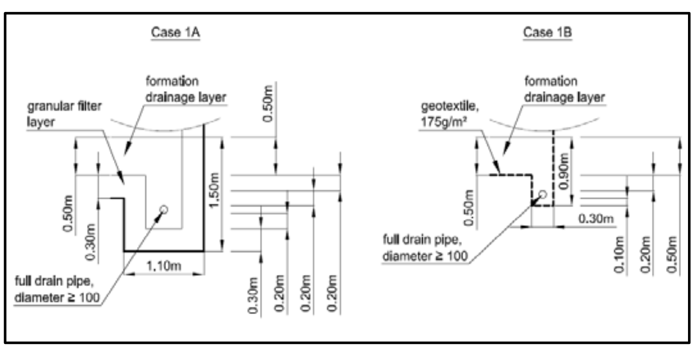

Fig.2: Cross section of drainage trench of mineral filter (case 1A, left) and geosynthetic filter system (case 1B, right)

The estimated typical life time of the filter system in case 1A or 1B is 30 years. The functional unit of case 1 is the provision of $1m^2$ of filter with a hydraulic conductivity (k-value) of 0.1mm/s or more and an equal life time of 30 years.

3 LIFE CYCLE INVENTORIES OF INFRASTRUCTURE ELEMENT

Case 1A and case 1B differ in the design of the filter. The difference between the two cases lies in the amount of primary gravel used, the energy consumption that is related to the filter material used (material transportation, excavation etc.), and the use of geosynthetics. Recycled gravel is not considered for the filter system since no onsite recycled gravel is available when building a filter for the first time.

Some important key figures of the construction of the case 1A and case 1B are summarized in table 2. The information refers to one square meter filter and a life time of 30 years. The shown figures regarding the particulate emissions refer to emissions from mechanical processes (e.g., pouring, compacting of gravel). Direct land use is not included in this Life Cycle Inventory (LCI) because the type of land use under which the filter is being built in is not known.

	Unit	**Case 1A** Total	**Case 1B** Total
Gravel	t/m^2	.69	-
Geosynthetic layer	m^2/m^2	-	1
Diesel used in building machines	MJ/m^2	2.04	1.04
Transport, lorry	tkm/m^2	34.5	0.035
Transport, freight, rail	tkm/m^2	-	0.07
Particulates, > 10 μm	g/m^2	4.8	0
Particulates, > 2.5 μm & < 10 μm	g/m^2	1.3	0

Tab.2: Selected key figures referring to the construction of one square meter of filter for the cases 1A and 1B

4 LIFE CYCLE IMPACT OF GEOSYNTHETIC LAYER

In total 13 questionnaires of E.A.G.M. members concerning the production of geosynthetic layers used in filter applications are included. The quality of the data received is considered to be accurate. The level of detail is balanced in a few cases before modelling an average geosynthetic layer. Table 3 shows important key figures of the production of an average geosynthetic layer.

	Unit	**Value**
Raw materials	kg/kg	1.05
Water	kg/kg	2.16
Lubricating oil	kg/kg	0.0026
Electricity	kWh/kg	1.14
Thermal energy	MJ/kg	1.49
Fuel for forklifts	MJ/kg	0.09
Building hall	m^2/kg	$2.51*10^{-5}$

Tab.3: Selected key figures referring to the production of 1kg

5 LIFE CYCLE IMPACT ASSESSMENT

In this Chapter the environmental impacts of 1 square meter filter over the full life cycle is evaluated. The life cycle includes the provision of raw materials as well as the construction and disposal phases.

In Figure 3 the environmental impacts (for detailed description see "Ehrenberg & Mermet", 2012) of the full life cycle of the filter are shown. The environmental impacts of the case with higher environmental impacts (case 1A) are scaled to 100%. The total impacts are subdivided into the sections filter system, raw materials (gravel, geosynthetic layer), building machine (includes construction requirements), transports (of raw materials to construction site) and disposal (includes transports from the construction site to the disposal site and impacts of the disposal of the different materials).

Figure 3 shows that case 1B causes lower impacts compared to case 1A with regard to all indicators investigated. The non-renewable cumulative energy demand (CED) of the construction and disposal of 1 square meter filter with a life time of 30 years is 131MJ-eq in case 1A and 19MJ-eq in case 1B. The cumulative greenhouse gas emissions amount to 7.8kg CO2-eq in case 1A and to 0.81kg CO2-eq in case 1B.

The filter layer in case 1B causes between 0.2% and 14.3% of the environmental impacts of the filter layer in case 1A (water use, CED non-renewable). The greenhouse gas emissions caused by the filter according to case 1B are 10.4% of the greenhouse gas emissions caused by the filter according to case 1A.

The main source of difference is the use and transportation of gravel. Hence, the use of geosynthetics may contribute to reduced environmental impacts of filter layers, because it substitutes the use of gravel.

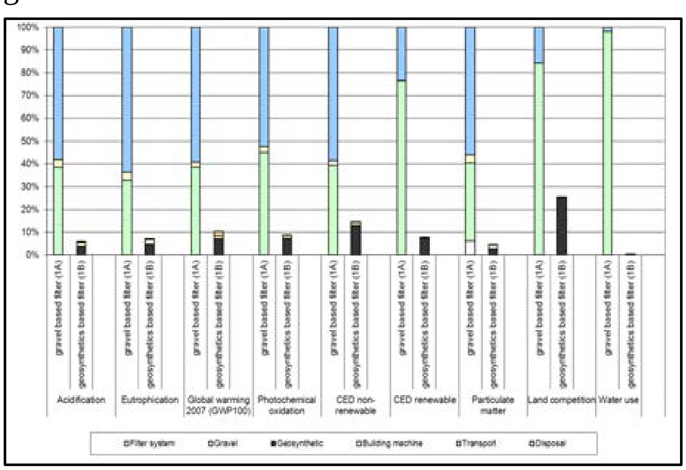

Fig.3: Environmental impacts of the life cycle of $1m^2$ filter cases 1A and 1B. For each indicator, the case with higher environmental impacts is scaled to 100%.

6 SENSITIVITY ANALYSIS

In a sensitivity analysis (cases 1AS1 and 1AS2), it is analysed how the results of the gravel filter layer change, if the thickness of the mineral filter is increased by 10cm to a total thickness of 40cm (1AS1) or if the thickness of the mineral filter is decreased by 10cm to a total thickness of 20cm (1AS2).

Figure 4 reveals that, if a thicker filter layer is constructed (case 1AS1), the environmental impacts of the gravel based filter increase by 33% and if a thinner filter layer is constructed (case 1AS2), the environmental impacts of the gravel based filter are decreased by 33%. Nevertheless, the environmental performance of a filter with geosynthetics (case 1B) is in each case considerably better than the environmental performance of the gravel based filters (cases 1A, 1AS1, 1AS2).

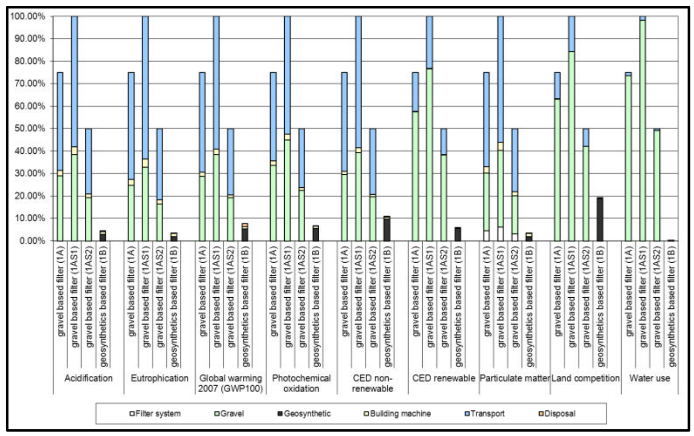

Fig.4: Sensitivity analysis: environmental impacts of the life cycle of 1m of filter layer, cases 1A and 1B. 1AS1 and 1AS2 refer to the sensitivity analysis with a different thickness of the gravel based filter layer. For each indicator, the case with highest environmental impacts is scaled to 100%.

7 CONTRIBUTION ANALYSIS GEOSYNTHETIC PRODUCTION

In this section the environmental impacts of 1kg geosynthetic layer are evaluated. Included are the provision and use of raw materials, working materials, energy carriers, infrastructure and disposal processes. The category geosynthetic in Figure 5 includes the direct impact of the geosynthetic production. This includes land occupied to produce the geosynthetic as well as process emissions from the production process but not emissions from electricity and fuel combustion.

The environmental impacts of the foundation separator are shown in Figure 5. The cumulative greenhouse gas emissions amount to 3.2kg CO_2-eq per kg.

Environmental impacts are mostly dominated by the raw material provision and electricity consumption. Raw material includes plastics, chemicals, printing colours, and other additives. Plastic raw materials are responsible for between 4% (land competition) and 80% (CED non-renewable) of the overall impacts, printing colours, chemical and additives for between 2% and 10%.

Country-specific electricity mixes are modelled for each company and thus impacts of electricity consumption depend not only on the amount of electricity needed but also on its mix. The high share of electricity in CED renewable can be explained by the use of hydroelectric power plants in several electricity mixes.

Heating energy and fuel consumption for forklifts are of minor importance. With regard to land competition the geosynthetic production plays an important role (92% of overall impacts). The impacts are dominated by the direct land use, i.e. land which is occupied by the manufacturer plant in which the geosynthetic is produced. Indirect land use, i.e. land occupation stemming from upstream processes, is significantly lower because no land occupation is reported in the inventories of plastic feedstocks and no land intensive products as e.g. wood are used in considerable amounts.

Water consumption (tap water, deionised water, decarbonised water) is included in the working materials. As a consequence, this category represents about 15% of the total amount of water used.

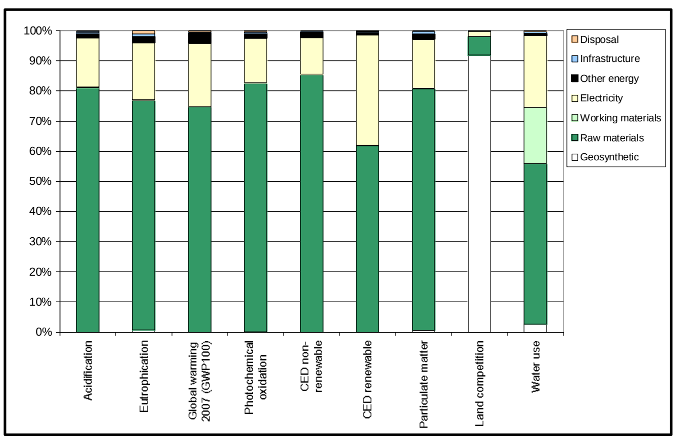

Fig.5: Environmental impacts of the life cycle of 1kg geosynthetic layer. Geosynthetic includes direct contribution of the geosynthetic production. Raw materials include plastic, extrusion if necessary, and additives, working materials include water (tap and deionised) and lubricating oil, other energy includes thermal energy and fuels, infrastructure covers the construction of the production plant and disposal comprises wastewater treatment and disposal of different types of waste.

8 CONCLUSION

A filter using a geosynthetic layer (case 1B) causes based filter layer (case 1A) with regard to all impact category indicators investigated. For all indicators the filter with geosynthetics causes less than 25% of the impacts of a conventional gravel based filter. The non-renewable cumulative energy demand of the construction of 1 square meter filter with a life time of 30 years is 131MJ-eq in case 1A and 19MJ-eq in case 1B (almost 7 times lower). The cumulative greenhouse gas emissions amount to 7.8kg CO_2-eq/m² in case 1A and 0.81kg CO_2-eq/m² in case 1B (almost 10 times lower). If a thinner gravel based filter is constructed, the environmental impacts of the gravel based filter are significantly reduced. Nevertheless, the sequence of the two cases does not change and the difference is still significant between the cases 1AS2 and 1B.

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 road. Data about gravel extraction and the use of building machines are based on generic data and knowledge of individual civil engineering experts.

The additional excavation needed for the adjacent area (Figure 1 and Figure 2) of case 1A is not considered in the comparison. An additional increase of the excavated volume would cause a further increase of the environmental impacts of case 1A compared to case 1B.

Despite the necessary simplifications and assumptions, the results of the comparison are considered to be significant and reliable.

9 REFERENCES

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