Comparative Life Cycle Assessment of Geosynthetics versus Conventional filter layer

Analyse de cycle de vie comparative d'une couche de filtre géotextile et conventionnelle

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ABSTRACT: Geosynthetics made from plastics can replace filter layers made of gravel. In this article goal and scope, basic data and the results of a comparative life cycle assessment of gravel and geosynthetics based filter layers are described. The filter layers of a road made of 30 cm gravel and a filter geosynthetic, respectively, form the basis for the comparison. The filter layers have the same technical performance and the same life time of 30 years. The product system includes the supply of the raw materials, the manufacture of the geotextiles and the extraction of mineral resources, the construction of the road filter, its use and its end of life phase. The life cycle assessment reveals that the geosynthetics based filter layer causes lower environmental impacts per square metre. The cumulative greenhouse gas emissions amount to 7.8 kg CO_2-eq (mineral filter) and to 0.81 kg CO_2-eq (geosynthetic filter). The variation of the thickness of the gravel based filter layer confirms the lower environmental impacts of a geosynthetics based filter layer. Environmental impacts of the geosynthetic production are dominated by the raw material provision (plastic granulate) and electricity consumption during manufacturing.

RÉSUMÉ : Les géotextiles sont utilisés pour remplacer le gravier dans les couches de filtres. Cet article contient une description de la définition de l'objectif et du champ d'étude, de l'analyse de l'inventaire et des résultats d'un analyse de cycle de vie comparative d'une couche de filtre géotextile et conventionnelle. La couche de filtre d'une rue est construite avec 30 cm de gravier ou avec une couche géotextile. Les deux couches de filtres ont les mêmes propriétés techniques et la même durée de vie de 30 ans. Les systèmes contiennent la provision des matériaux, la fabrication des filtres géotextiles et l'extraction du gravier, la construction, l'utilisation et l'évacuation de la couche de filtre. L'analyse de cycle de vie démontre qu'un mètre carré d'une couche de filtre géotextile cause moins d'impacts environnementaux qu'un mètre carré d'une couche de filtre gravier. Une couche de filtre gravier entraîne 7.8 kg CO_2-eq, celle de filtre géotextile 0.81 kg CO_2-eq des émissions des gaz à effet de serre par mètre carré. La variance de l'épaisseur de la couche de gravier n'influe pas sur la séquence environnementale des deux couches. La provision des matériaux et l'électricité utilisé dans la fabrication de la couche de filtre géotextile sont des facteurs primordiaux en ce qui concerne les impacts environnementaux de la couche de filtre géotextile.

KEYWORDS: filter layer, geosynthetics, gravel, life cycle assessment, LCA

MOTS-CLÉS : couche de filtre, géotextile, gravier, analyse de cycle de vie, ACV

1 INTRODUCTION

Geosynthetic materials are used in many different applications in civil and underground engineering, such as in road construction, in foundation stabilisation, in landfill construction and in slope retention. In most cases they are used instead of minerals based materials such as concrete, gravel or lime.

Environmental aspects get more and more relevant in the construction sector. That is why the environmental performance of technical solutions in the civil and underground engineering sector gets more and more attention.

The European Association for Geosynthetic Manufacturers (E.A.G.M.) commissioned ETH Zürich and Rolf Frischknecht (formerly working at ESU-services Ltd.) to quantify the environmental performance of commonly applied construction materials (such as concrete, cement, lime or gravel) versus geosynthetics (Stucki et al. 2011).

In this article, the results of a comparative Life Cycle Assessment (LCA) of a filter function in road construction are described. The filtration function is either provided by a gravel or a geosynthetic filter layer.

The environmental performance is assessed with eight impact category indicators. These are Cumulative Energy Demand (CED, Frischknecht et al. 2007), Climate Change (Global Warming Potential, GWP 100, Solomon et al. 2007), Photochemical Ozone Formation (Guinée et al. 2001a; b), Particulate Formation (Goedkoop et al. 2009), Acidification (Guinée et al. 2001a; b), Eutrophication (effects of nitrate and phosphate accumulation on aquatic systems, Guinée et al. 2001a; b), Land competition (Guinée et al. 2001a; b), and Water use (indicator developed by the authors). The calculations are performed with the software SimaPro (PRé Consultants 2012).

2 GEOSYNTHETIC FILTER VERSUS MINERAL FILTER

Filters systems in road construction assure that the base soil is retained with unimpeded water flow. In this article, the case of a geosynthetic filter layer is compared to the case of a mineral filter layer.

Polypropylene granules are used as basic material for the geosynthetic layer. They need to be UV stabilised to meet the requirements. The average weight of the polymer is 175 g/m^2.

The way of the construction of the filter depends on several factors. The basic conditions are shown in Tab. 1 and Fig. 1. The two alternative cases compare the environmental impacts of one square meter of the filter area below the road. The additional excavation needed at the boundary area of the mineral filter is not considered in the comparison.

Table 1. Design criteria of the two filter systems.

Parameter	Unit	*Gravel filter*	*Geosynthetic filter*
Filter size	m^2	1	1
Filtration geosynthetic	g/m^2	0	175
Gravel	cm	30	0

From these parameters it is calculated that the required thickness D of the mineral filter is 300 mm and the one with the geosynthetic filter layer is 1-2 mm. Fig. 1 shows a cross section of the filter profile as modelled in this LCA.
In a sensitivity analysis the thickness of the gravel filter is varied by +/- 10 cm.

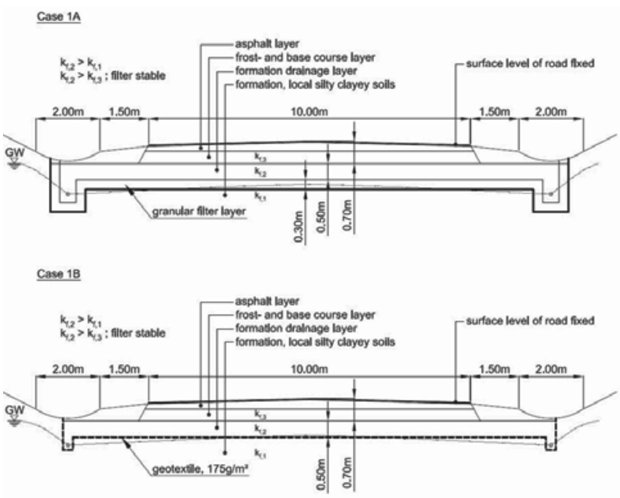

Figure 1. Cross section of the mineral filter (top) and geosynthetic filter system (bottom)

The functional unit in the comparative LCA is the provision of 1 m^2 of filter with a hydraulic conductivity (k-value) of 0.1 mm/s or more and an equal life time of 30 years.
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 filter systems are summarized in Tab. 2. The information refers to one square meter filter and a life time of 30 years. The figures shown regarding the particulate emissions refer to emissions from mechanical processes (e.g., pouring, compacting of gravel). Direct land use is not included in this LCI because the type of land use under which the filter is being built in is not known.

Table 2. Selected key figures describing the two constructions of one square meter of filter

Material/Process	*Unit*	*Gravel filter*	*Geosynthetic filter*
Gravel	t/m^2	0.69	0
Geosynthetic layer	m^2/m^2	0	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	0.07
Particulates, >10 µm	g/m^2	4.8	0
Particulates, >2.5 µm & <10 µm	g/m^2	1.3	0

3 MANUFACTURING OF THE GEOSYNTHETIC LAYER

Data about geosynthetic material production are gathered at the numerous companies participating in the project using pre-designed questionnaires. The company specific life cycle inventories are used to establish average life cycle inventories of geosynthetic material.
The data collected include qualitative information of system relevant products and processes from the producer, information from suppliers of the producer (where possible) as well as data from technical reference documents (e.g. related studies, product declarations, etc.). Average LCI are established on the basis of equally weighted averages of the environmental performance of the products manufactured by the participating companies.
The primary source of background inventory data used in this study is the ecoinvent data v2.2 (ecoinvent Centre 2010), which contains inventory data of many basic materials and services.
In total, data from 13 questionnaires 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.
Tab. 3 shows important key figures of the production of an average geosynthetic layer.

Table 3. Selected key figures referring to the production of 1 kg geosynthetic layer used in filter applications

Material	*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
Factory building	m^2/kg	2.51E-5

4 LIFE CYCLE IMPACT ASSESSMENT

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

In Fig. 2 the environmental impacts of the full life cycle of the filter are shown. The environmental impacts of the case with highest environmental impacts (mineral filter 1AS1) 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).

Fig. 2 shows that the average geosynthetic filter system (1A) causes lower environmental impacts compared to the mineral filter system with regard to all indicators investigated. For all indicators the average filter with geosynthetics (1A) causes less than 25 % of the environmental impacts of a conventional gravel based filter (1B). The geosynthetic filter (1B) layer causes between 0.2 % and 14.3 % of the environmental impacts of the mineral filter layer (1A, water use, CED non-renewable). The greenhouse gas emissions caused by the geosynthetic filter (1B) are 10.4 % of the greenhouse gas emissions caused by the mineral filter (1A).

The non-renewable cumulative energy demand of the construction and disposal of 1 square meter filter with a life time of 30 years is 131 MJ-eq in case of the mineral filter and 19 MJ-eq in case of the geosynthetic filter. The cumulative greenhouse gas emissions amount to 7.8 kg CO_2-eq (mineral filter) and to 0.81 kg CO_2-eq (geosynthetic filter).

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.

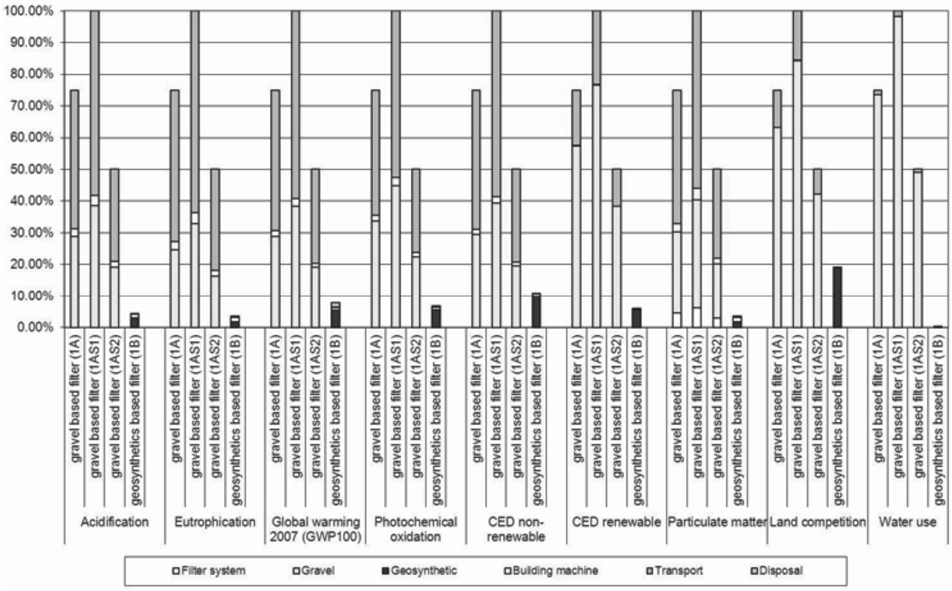

Figure 2. Sensitivity analysis: environmental impacts of the life cycle of 1 m2 of filter layer. 1AS1 and 1AS2 refer to the sensitivity analysis with a different thickness of the gravel based filter layer. For each indicator, the case with highest environmental impacts is scaled to 100°%.

4.1 *Sensitivity analysis*

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

Fig. 2 reveals that, if a thicker filter layer is constructed, the environmental impacts of the gravel based filter increase by 33 % and if a thinner filter layer is constructed, the environmental impacts of the gravel based filter are decreased by 33 %. Nevertheless, in all cases the environmental impacts of a filter with geosynthetics (1B) are considerably lower than the environmental impacts of a gravel based filter (1A, 1AS1, 1AS2).

4.2 *Contribution Analysis Geosynthetic Production*

In this section the environmental impacts of 1 kg geosynthetic layer are evaluated. The life cycle includes the provision and use of raw materials, working materials, energy carriers, infrastructure and disposal processes. The category geosynthetic in Fig. 3 comprises the direct burdens of the geosynthetic production. This includes land occupied by the factory producing the geosynthetic as well as process emissions (e.g. NMVOC, particulate and COD emissions) from the production process but not emissions from electricity and fuel combustion.

The environmental impacts of the geosynthetic filter are shown in Fig. 3. The cumulative greenhouse gas emissions amount to 3.2 kg 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 the electricity mixes of several factories.

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 feedstock and no land intensive products such as 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 bears about 15°% of the total amount of water used.

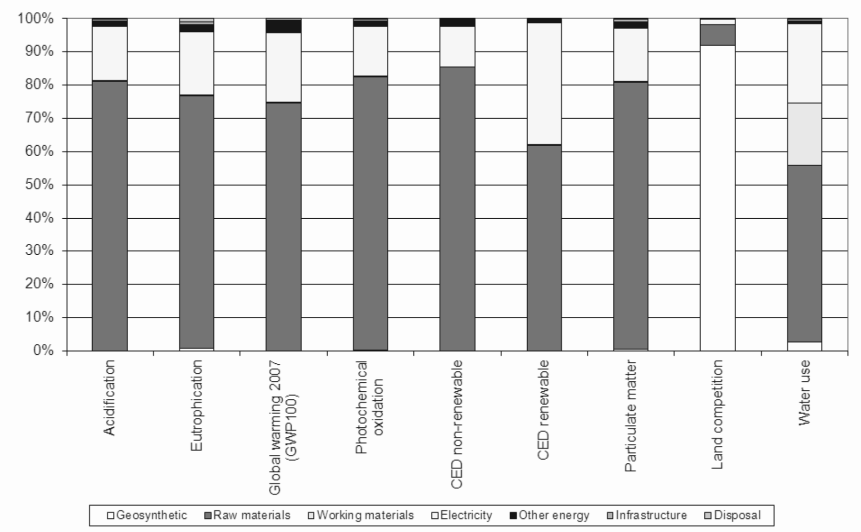

Figure 3. Environmental impacts of the life cycle of 1 kg geosynthetic layer. Geosynthetic includes direct burdens of the geosynthetic production. Raw materials include plastic, extrusion if necessary, and additives, working materials include water (tap and deionised) and lubricating oil, other energy 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.

5 DISCUSSION AND CONCLUSION

A filter using a geosynthetic layer causes lower environmental impacts compared to a conventional gravel based filter layer with regard to all impact category indicators investigated. If 30 cm of gravel are saved, the specific climate change impact of the construction of 1 square meter filter using geosynthetics is about 7 kg CO_2-eq lower compared to the impacts from the construction of an equivalent gravel based filter.

The difference is considerable for all indicators (more than 85 %) and reliable. The difference in the environ¬men¬tal impacts arises mainly because the applied geosynthetic substitutes gravel, which causes considerably higher impacts when extracted and transported to the place of use. At least a layer of 8 cm of gravel must be replaced by geosynthetics used as a filter in order to cause the same or lower environmental impacts regarding all indicators.

The environmental impacts of the gravel based filter are significantly reduced, when constructing smaller filters (20 cm instead of 30 cm). Nevertheless, the sequence of the two cases does not change and the difference is still significant between the sensitivity cases of the mineral filter and the geosynthetic filter.

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