comparative life cycle assessment of geosynthe-tics versus conventional construction materials, a study on behalf of the e.a.g.m., case 3, landfill construction drainage layer

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ABSTRACT: The European Association for Geosynthetic 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 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 the 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 studies are carried out concentrating on various application cases, namely filtration, foundation stabilised road, landfill construction and retaining walls. The environmental performance of geosynthetics is compared to the performance of competing construction materials.

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 3 - Landfill construction drainage layer, 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

European Regulations specify the thickness of gravel for a drainage system in a cap of a hazardous/non-hazardous waste landfill site. The grain size is not defined in particular. A geosynthetic on top of the drainage gravel is often used to prevent migration of fines from the top soil into the drainage layer. A second geosynthetic is used below the drainage as a protection layer to ensure that the sealing element is not damaged by the drainage. Instead of the conventional gravel drainage layer a geosynthetic composite drainage layer may be used. All the other layers in a landfill site change neither in thickness nor in material requirements. The profiles of the conventional and geosynthetic alternatives are shown in figure 1.

The average of two types of different drain cores are used to represent the performance of these products, namely with drainage nets and drainage 3D filament as drain core. Polypropylene or polyethylene granulates are used as basic material in case 3B. The average weight of the drain core is 500g/m^2 (excluding 2 geosynthetic filters). Gravel with a rather uniform grain size of 16-32mm and a layer thickness of 50cm is used in case 3A.

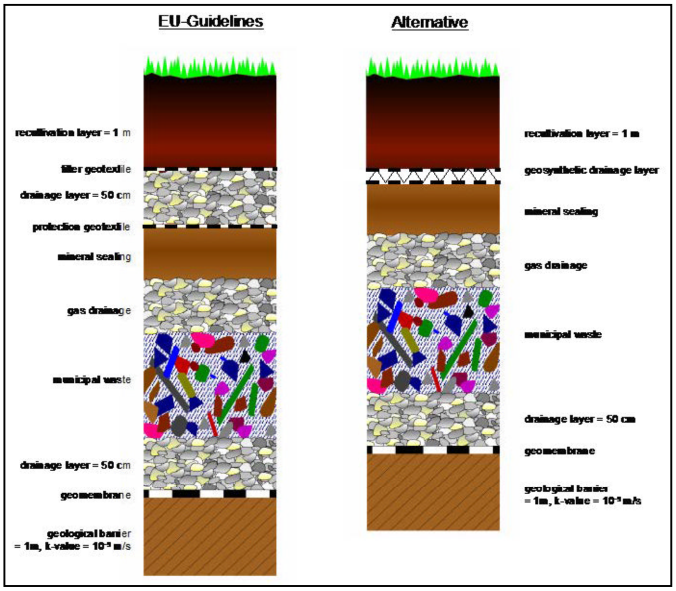

Fig.1: Scheme of the profile of waste landfill site class 2 according to EU guidelines (case 3A, left) and with a drain core as an alternative drainage layer in the cap (case 3B, right)

According to the European Council Directive 1999/31/EC a mineral drainage layer with a thickness of 0.50m is required and the hydraulic conductivity of the drainage layer (k-value) has not been defined. All countries in the European Union have to comply with these Directives. At present some countries in the European Union have additional requirements. In Germany for example requirements for the drainage layer are documented in the German landfill ordinance, German Federal Government 2009 ("Verordnung über Deponien und Langzeitlager (Deponieverordnung – DepV, BMU"). The hydraulic conductivity is required to be ≥ 1mm/s (k-value) and the thickness to be ≥ 0.30m for capping sealing systems. Similar requirements have been used in the Netherlands for years.

When alternative drainage layers are planned to be used, a sufficient long term drainage performance has to be demonstrated. For geosynthetic drainage layers this applies.

Several calculations and practical cases all over Europe have shown that geosynthetic drainage layers with a core weight of an average of 500g/m² are suitable for final capping sealing systems. Table 1 shows specific values of the drainage layer constructions for both alternatives.

Parameter	Unit	EU-Guidelines	Alternative geosynthetic
Landfill size	m^2	100000	100000
Drainage layer			
- gravel thickness (16/32mm)	cm	50	
- drainage core weight	g/m^2		500

Tab.1 Characteristics of two alternative landfill drainage constructions.

The typical life time can be assumed to be similar in both cases (100 years).

3 LIFE CYCLE IMPACT OF A DRAINAGE LAYER

Case 3A and case 3B differ in the design of the drainage layer. The material and energy consumption, which is related to the construction and disposal of the other parts of the landfill capping construction (e.g. the gas drainage, the mineral sealing and the recultivation layer) are equal in both cases and are not considered in this study. Hence, the difference between the two cases lies in the amount of primary gravel and geosynthetics that are used in the drainage layer and the energy consumption that is related to material transportation, excavation etc. The use of recycled gravel is not considered, since usually no onsite recycled gravel is available when covering a landfill site. In case 3A three process steps are required to build up the drainage layer (filter layer, gravel layer, protection layer) whereas in case 3B only one process step is needed as the protection and filter geotextiles are already connected to the drain core of the geocomposite drain.

Some important key data for the construction of case 3A and case 3B drainage layer are summarized in table 2. The information refers to one square meter drainage layer, since the hydraulic conductivity is equal in both cases. The life time in both cases is the same (100 years). The data for the particulate emissions refer to emissions from mechanical processes.

	Unit	Case 3A	Case 3B
Gravel	t/m^2	0.90	-
Geosynthetic filter layer	m^2/m^2	1	-
Geosynthetic protection layer	m^2/m^2	1	-
Geosynthetic drainage core[1]	m^2/m^2	-	1
Diesel used in building machines	MJ/m^2	4.5	3.8
Transport, lorry	tkm/m^2	45.1	0.2
Transport, freight, rail	tkm/m^2	0.1	0.3
Land use	m^2/m^2	1	1
Particulates, > 10 µm	g/m	6.3	-
Particulates, > 2.5 µm & < 10 µm	g/m	1.7	-

Tab.2: Selected key data referring to the construction of one square meter of a case 3A and case 3B drainage layer with a hydraulic conductivity of at least 1 mm/s (lifetime = 100a)

4 LIFE CYCLE IMPACT OF GEOSYNTHETIC

In total 3 questionnaires concerning the production of geosynthetic drainage layers used in landfill sites are included in the assessment. Despite its low number, the responding three companies represent a significant market share of this type of geosynthetic product. The quality of the data received is considered to be accurate. Table 3 shows important key data for the production of an "average" geosynthetic drainage layer.

	Unit	Value
Raw materials	kg/kg	1.03
Water	kg/kg	44
Lubricating oil	kg/kg	$8.05*10^{-5}$
Electricity	kWh/kg	1.00
Thermal energy	MJ/kg	0.03
Fuel for forklifts	MJ/kg	0.08
Factory	m^2/kg	$8.59*10^{-6}$

Tab.3: Selected key data referring to the production of 1kg geosynthetic drainage layer used in landfill sites

5 LIFE CYCLE IMPACT ASSESSMENT

In this section the environmental impacts of $1m^2$ drainage layer in a landfill are evaluated. The life cycle includes the provision of raw materials as well as the construction and disposal phases.

In figure 2 the environmental impacts (detailed description see paper "Ehrenberg H. & Mermet J.P." under References) over the full life cycle of the landfill drainage layer are shown. The higher environmental impacts (case 3A) are scaled to 100%. The total impacts are divided into the sections landfill, raw materials (gravel, geosynthetic layers), building machine (construction requirements), transports (of raw materials to construction site) and disposal of the landfill (includes transports from the construction site to the disposal site and impacts of the disposal of the geosynthetic materials).

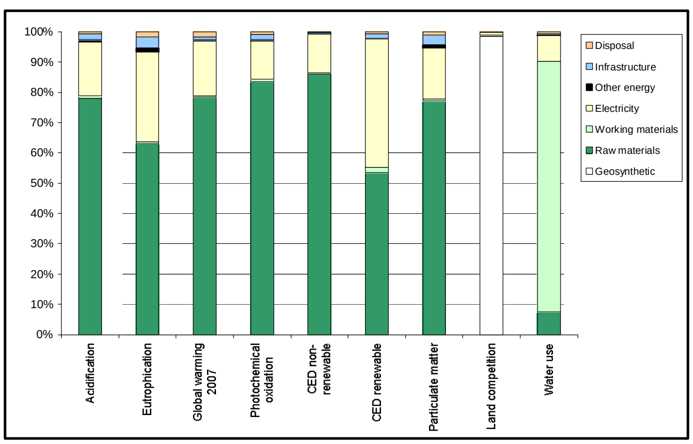

Fig.2: Environmental impacts of the life cycle of 1m² mineral drainage layer (case 3A) and a geosynthetic drainage layer (case 3B). For each indicator, the case with highest environmental impacts is scaled to 100%.

Case 3B causes lower environmental impacts compared to case 3A in all categories considered. The non-renewable cumulative energy demand of the construction and disposal of 1 square meter drainage layer is 194MJ-eq in case 3A and 86MJ-eq in case 3B. The cumulative greenhouse gas emissions amount to 10.9kg CO_2-eq in case 3A and 3.6kg CO_2-eq in case 3B. Correspondingly, the cumulative greenhouse gas emissions of the drainage layer of a landfill with an area of 30,000m² are 320t in case 3A and 90t in case 3B respectively.

The main driving forces for the difference between cases 3A and 3B are extraction and transportation of gravel used in case 3A. For all indicators except land competition, the environmental impacts of the conventional drainage layer are more than twice those from the geosynthetic drainage layer.

6 CONTRIBUTION ANALYSIS GEOSYNTHETIC DRAINAGE LAYER

In this section the environmental impacts of 1kg geosynthetic drainage 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 figure 3 comprises the direct impacts of the geosynthetic production. This includes land occupied to produce 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.

In figure 3 the environmental impacts of the geosynthetic drainage layer are shown. The cumulative greenhouse gas emission amounts to 2.7kg CO_2-eq per kg.

Environmental impacts are mostly dominated by the raw material provision and electricity consumption. Raw material includes plastics and chemicals. Plastic raw materials are responsible for between 0.1% (land competition) and 85% (CED non-renewable) of the overall impacts. The impacts of chemicals are negligibly small.

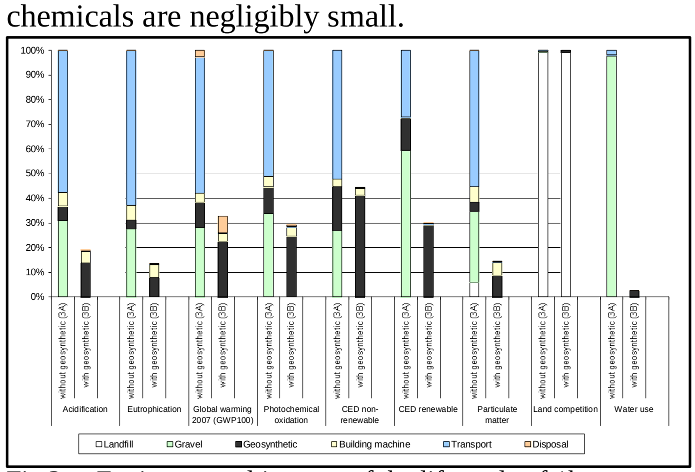

Fig.3: Environmental impacts of the life cycle of 1kg geosynthetic drainage layer. Geosynthetic includes direct impacts of

the geosynthetic production. Raw materials include plastic, their extrusion if necessary and additives, working materials include water (tap and deionised) and lubricating oil, other energy includes thermal energy and fuels, infrastructure concerns the production plant and disposal comprises wastewater treatment and disposal of different types of waste.

7 CONCLUSION

Compared to a conventional drainage layer in a landfill, the use of a geocomposite drain leads to lower environmental impacts of the construction in all indicators investigated, except land competition. The specific climate change impact of the construction of a landfill site's drainage layer (1m^2 surface area with a hydraulic conductivity (k-value) of 1mm/s or more and life time of 100 years) using geosynthetics is about 7.8kg CO_2-eq per m^2 lower compared to a conventional alternative. This difference is equal to about 69% of the overall climate change impact of the construction and disposal efforts of a conventional drainage layer.

Landfills constructed within Europe may differ in design and materials used depending on the wastes landfilled. Thus, generalising assumptions are necessary to model a typical drainage layer. Data about gravel extraction and the use of building machines are based on generic data and knowledge of individual civil engineering experts.

Based on the uncertainty analyses, it can be safely stated that the geosynthetics drainage layer solution shows lower environmental impacts than the gravel drainage level. Despite the necessary simplifications and assumptions, the results of the comparison are considered to be significant and reliable.

8 REFERENCES

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