

COMPARATIVE LIFE CYCLE ASSESSMENT OF GEOSYNTHETICS VERSUS CONVENTIONAL CONSTRUCTION MATERIALS, A STUDY ON BEHALF OF THE E.A.G.M., CASE 3, LANDFILL CONSTRUCTION DRAINAGE LAYER

K. Werth

NAUE GmbH, Espelkamp-Fiestel, Germany, on behalf of E.A.G.M.

S. Höhny

Colbond bv., Arnhem, The Netherlands, on behalf of E.A.G.M.

M. Stucki, S. Büsser, R. Itten, R. Frischknecht

ESU-services Ltd., Uster, Switzerland

H. Wallbaum

ETH Zürich, Zürich, Switzerland

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 slope retention 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.

1. Filtration
2. Foundation stabilisation
3. Landfill construction drainage layer
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 is used. In fact the gravel drainage layer also uses geosynthetics - on top as a filter and below as a protection. 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 2 types of different geosynthetics are used to represent its performance, namely

- drainage nets and
- drainage 3D filmant.

Polypropylene or polyethylene granulates are used as basic material in case 3B. The average weight of the drainage polymer is 500g/m² (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.

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 (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 layer are already glued to the main drainage layer.

Some important key figures of the construction of the 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 figures shown regarding 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 -m	g/m	6.3	-
Particulates, > 2.5 -m & < 10 -m	g/m	1.7	-
The core consists of the drainage layer, geosynthetic filter and protection layer. The latter two are glued on the drainage layer.			

Tab.2: Selected key figures 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)

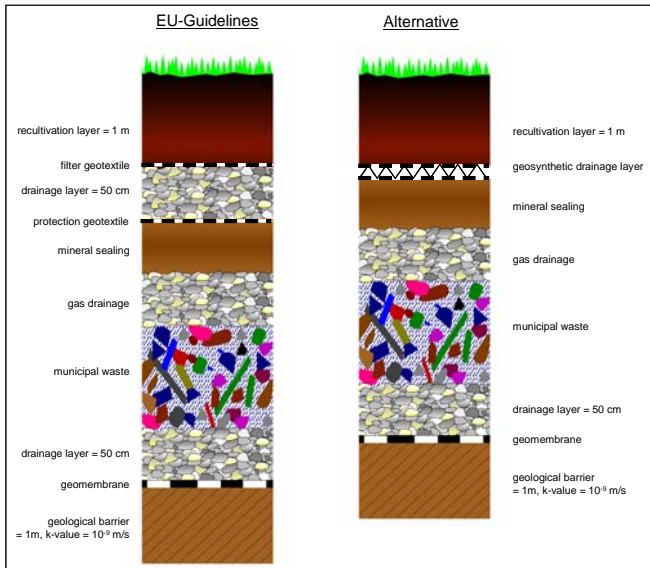


Fig.1: Scheme of the profile of waste landfill site class 2 according to EU guidelines (case 3A, left) and with a geosynthetic as an alternative drainage layer in the cap (case 3B, right)

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 German Federal Government 2009. The hydraulic conductivity is required with ≥ 1 mm/s (k-value) and the thickness is defined to be sufficient with ≥ 0.30 m 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 for both alternatives.

4 LIFE CYCLE IMPACT OF GEOSYNTHETIC

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

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

Tab.3: Selected key figures 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 1m² 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).

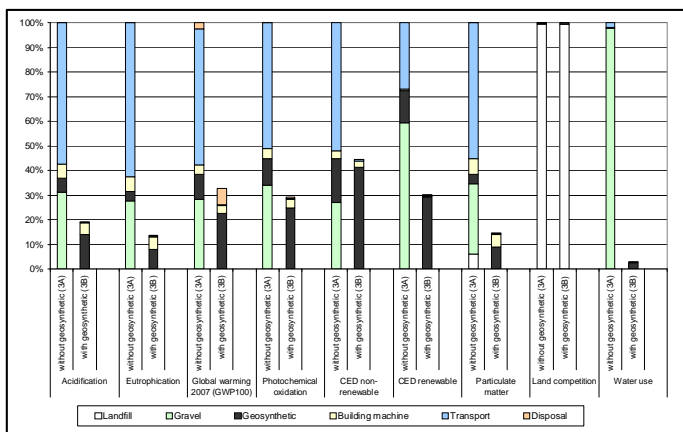


Fig.2: Environmental impacts of the life cycle of 1m² mineral drainage layer (case 3A) and a geosynthetic drainage layer (case 3B). For each indicator, the case with higher environmental impacts is scaled to 100%.

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 CO₂-eq in case 3A and 3.6kg CO₂-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 layer are shown. The cumulative greenhouse gas emissions amount to 2.7kg CO₂-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.

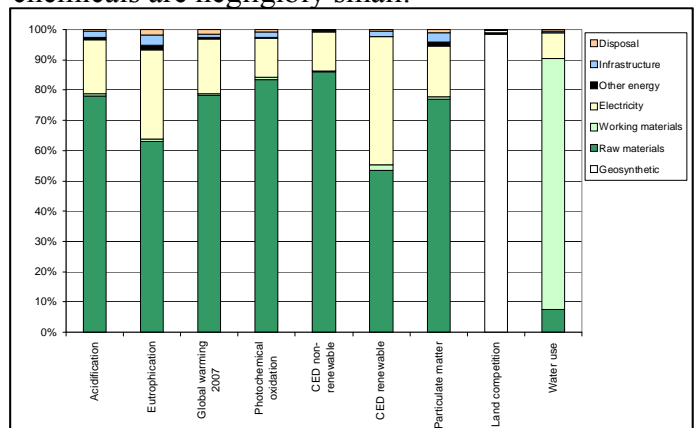


Fig.3: Environmental impacts of the life cycle of 1kg geosynthetic drainage layer. Geosynthetic includes direct impacts of the geosynthetic production. Raw materials include plastic, extrusion if necessary and additives, working materials include water

(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 geosynthetics leads to lower environmental impacts of construction in all indicators investigated, except land competition. The specific climate change impact of the construction of a landfill site's drainage layer (1m² 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 CO₂-eq per m² 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 cross section 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

- Ehrenberg H. & Mermet J.P. (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., General, EUROGEO 5, Valencia, Spain
- Elsing A. & Fraser I., (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., Case 2, Foundation Stabilization, EUROGEO 5, Valencia, Spain
- Fraser I. & Elsing A. (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., Case 4, Soil Retaining Wall, EUROGEO 5, Valencia, Spain
- Laidié N. & Shercliff D. (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., Case 1, Filter Function, EUROGEO 5, Valencia, Spain
- Stucki M. et al. (2011), Stucki M., Büsser S., Itten R., Frischknecht R. and Wallbaum H., Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Material. ESU-services Ltd. commissioned by European Association for Geosynthetic Manufacturers (EAGM), Uster and Zürich, CH.
- Wallbaum H. et al. (2012), Wallbaum H., Stucki M., Büsser S., Itten R., Frischknecht R., Comparative Life Cycle Assessment of retaining walls in traffic infrastructure, 12th Baltic Sea Geotechnical Conference, Rostock, Germany