Environmental benefits by using construction methods with geosynthetics

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ABSTRACT: Geosynthetic materials are used in many different applications in the civil and underground engineering. In most cases, the use of geosynthetic material replaces the use of other materials. On behalf of the European Association for Geosynthetic Manufacturers (EAGM) the authors quantified 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, according to the ISO 14040 and 14044 standards, concentrating on various application cases, namely filtration, foundation stabilised road, landfill construction and slope retention. The environmental performance of geosynthetics is compared to the performance of competing construction materials used. The environmental impacts of the full life cycle of the four cases show overall the following results:

- A filter using a geosynthetic layer causes lower impacts compared to a conventional gravel based filter layer with regard to all impact category indicators investigated.

- A conventional road causes higher impacts compared to a road reinforced with geosynthetics with regard to all impact category indicators.

- A geosynthetic drainage layer causes lower environmental impacts compared to a gravel based drainage layer in all impact categories considered except land competition which is about the same in both cases.

- A geosynthetic reinforced wall causes lower environmental impacts compared to a reinforced concrete wall in all impact categories considered.

Keywords: Geosynthetic materials, LCA, ISO 14040/14044, environmental impacts, Global Warming Potential, GWP, Cumulative Energy Demand, CED, filter, road, drainage, reinforced wall

1 INTRODUCTION

Geosynthetic materials are used in many different applications in the civil and underground engineering. They are used 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.

1.1 Outline of the study

The European Association for Geosynthetic Manufacturers (EAGM) shall be provided with comprehensive qualitative and quantitative information of the environmental performance of commonly applied construction materials (such as concrete) versus geosynthetics. This is achieved by performing a set of comparative life cycle assessment studies concentrating on various application cases, namely road construction, foundation stabilisation, landfill construction and slope retention. The environmental performance of geosynthetics is compared to the performance of competing construction materials used. The study adheres to the ISO 14040 and 14044 standards. In the case of comparisons intended to be used in comparative assertions intended to be disclosed to the public, the ISO standards require a critical review performed by a panel of at least three independent experts.

1.2 Organisation of the study

The study was commissioned by the European Association for Geosynthetic Manufacturers (EAGM). It is conducted by ESU-services Ltd. (today most of the authors are with treeze Ltd.) and ETH Zürich, Switzerland (Prof. Wallbaum, today Chalmers University of Technology, Sweden). A critical review according to ISO 14040 and 14044 is being carried out by a panel of three independent external experts.

1.3 Use of the Study and Target Audience

Primarily, the study and its results are intended to be used within EAGM. They should assist the members of EAGM in their efforts to

- continuously improve the environmental performance of their products,
- formulate requirements to their upstream suppliers (of e.g. auxiliaries) and
- communicate the environmental information to customers, clients and other stakeholders involved (e.g. via Environmental Product Declarations (EPD) for the applications mentioned or for a product group).

1.4 Objects of investigation

Four construction systems are investigated in this comparative life cycle assessment (Table 1). The specifications of the four construction systems are established by the EAGM members representing approximately 80 % of the European market of geosynthetic materials. A detailed description of every construction system is provided in paragraph 2.

Table 1. Overview of the objects of investigation

Description	Alternatives	Case
Filter layer	gravel based filter	1A
	geosynthetics based filter	1B
Road foundation	conventional road (no stabilisation needed)	2A
	geosynthetics based foundation	2B
	cement/lime based foundation	2C
Landfill construction	gravel based drainage layer	3A
	geosynthetics based drainage layer	3B
Slope retention	reinforced concrete wall	4A
	geosynthetics reinforced wall	4B

1.5 Functional unit

The function of the constructed infrastructure elements differ from case to case, thus, the functional unit is defined for each case separately and described in the respective Chapters. The constructions are designed in a way that the two alternatives compared are technically equivalent. The infrastructure elements analysed represent new constructions (no refurbishments of existing constructions).

Reference flows quantify the function of the case studies. In these four case studies the quantification is given within the definition of the functional units.

The functional units of the four cases are distinctly different. That is why the results of the four cases should not be compared across cases.

1.6 System Boundaries and cut-off rules applied

1.6.1 System boundaries

The life cycle assessments carried out within this study follow a cradle to grave approach. The product systems of the infrastructure elements analysed in the four cases encompass the extraction of the raw materials, its processing to building materials, construction and disposal of the infrastructure elements (Figure 1). Operation and maintenance of the infrastructure element are excluded except for the land occupation. The difference in expected lifetimes is accounted for. Transport processes and infrastructure are included. All processes describe average European conditions.

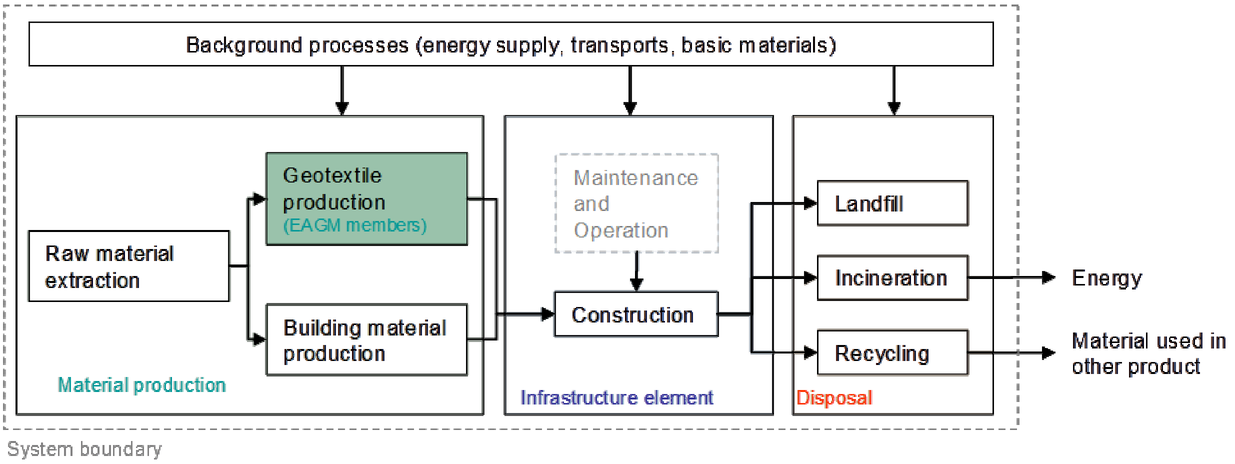

Figure 1. Simplified process flow chart. The simplified chart shows the most important process steps. Maintenance and Operation of the infrastructure element are not included in the system boundaries.

1.6.2 Cut-off rules

As far as possible all inputs are considered. In some cases data availability was limited. That is why packaging of the geosynthetics is not considered, because they contribute less than 3 % to the total mass. Capital goods are included, except for the equipment used in geosynthetics manufacture, which is excluded because of its low importance. Process specific emissions such as Non-methane volatile organic compounds (NMVOC) are included in the life cycle inventories as far as indicated by the companies. They are included independent of their contribution to the cumulative emissions of the respective substance (no threshold of a mass based cut-off is applied).

1.7 Data Gathering and Data Quality

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 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.

1.8 Allocation

1.8.1 Multi-output processes

No multi-output datasets are established in the foreground system. Thus multi-output processes only occur in the background system. In ecoinvent data v2.2 allocation based on exergy content is used for multi-output processes that produce heat and electricity. In most other cases, allocation based on economic revenues is used. Mass allocation is applied in the remaining multi-output datasets. In the product systems analysed, co-products in the background do not contribute significantly to the overall results. Hence, no sensitivity analyses related to allocation in multi-output processes are performed.

When plastics are disposed of in an incineration, heat and electricity can be produced as by-product to the waste treatment service. With the cut-off approach, those by-products leave the system without burdens. That is why the emissions from incineration are fully attributed to the product disposed of.

1.8.2 Recycling

Recycling of materials is modelled according to the recycled content approach. The recycled content approach represents the concept of strong sustainability (see also Frischknecht 2007, Frischknecht 2010). Materials to be recycled leave the system neither with burdens nor with credits. Materials made from secondary raw materials bear the loads of scrap collection, sorting and refining. This gives an incentive to use recycled materials in the product systems under study.

1.9 Allocation

The environmental performance is assessed with the following impact category indicators:

- Cumulative Energy Demand (Primary Energy Consumption, split into non-renewable and renewable fractions),
- Climate Change (Global Warming Potential, GWP100),
- Photochemical Ozone Formation,
- Particulate Formation,
- Acidification,
- Eutrophication,
- Land competition, and
- Water use.

2 CASE STUDY DESCRIPTIONS

2.1 Case 1 – Filter layer

Geosynthetics is used in soil engineering, where it 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

- filament,
- staple fibre, and
- woven grids

Polypropylene granules are used as basic material (in case 1B). 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 Table 2 and Figure 2. A more detailed description is available in the full report (http://www.eagm.eu/wp-content/uploads/2012/07/LCA-Study.pdf). The cases 1A and 1B compare the environmental impacts of one square meter of the filter area below the road. The deeper excavation needed at the boundary area for case 1A is not considered in the comparison.

Table 2. Overview of the objects of investigation

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	cm	30	0

From these parameters it is calculated that the required thickness D of the mineral filter (case 1A) is 300 mm and the one with the filter layer – i.e. with the geosynthetic, case 1B – is 1-2 mm.

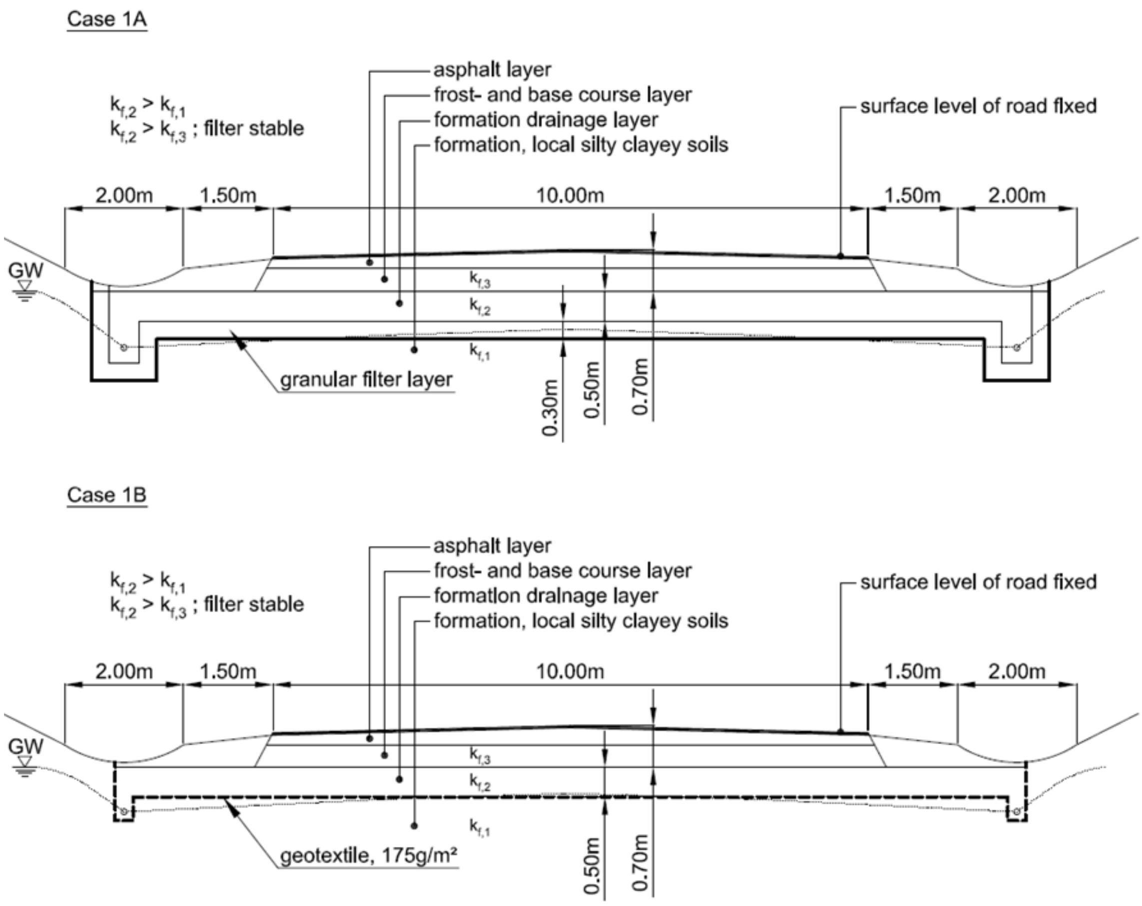

Figure 2. Cross section of the mineral filter (case 1A, top) and geosynthetic filter system (case 1B, bottom).

2.1.1 Functional unit

The functional unit of case 1 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.

2.2 Case 2 – Foundation Stabilisation

In road construction the sub-base needs to meet defined requirements for compaction and bearing capacity. Improvements of some soil characteristics may be necessary while building on weak soils. Besides the construction of a conventional road with a non frost sensitive gravel/sand layer (case 2A), soil improvement can be done with geosynthetic (case 2B) or by adding lime, cement or hydraulic binder (case 2C). Both cases 2B and 2C lead to a reduced thickness of the gravel/sand layer.

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

- extruded stretched grids,
- layed grids, and
- woven / knitted grids.

Polypropylene granulates are used as basic material to manufacture geogrids or wovens used in case 2B. The average weight of the polymer is 250 g/m^2. In alternative to that, also Polyethylene terephtalate (PET) grids, with a weight of 260 g/m² (30 kN/m in each direction) are used.

The case of a conventional road (2A) is compared to a road reinforced with geosynthetics (2B) and to a cement/lime stabilised road (2C). The example considered is a road class III with the same finished surface level in all cases. The road is built on frost-sensitive soil class F3. In regions where the frost penetration depth does not reach the frost-sensitive soil, this soil needs not being removed. This is considered the standard case 2B.

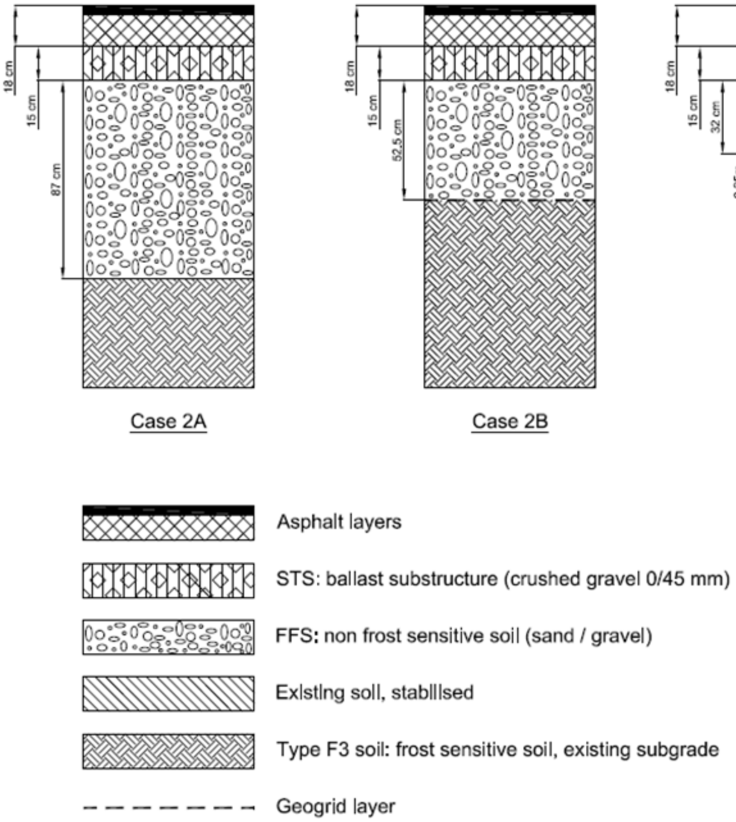

Figure 3. Scheme of the road profiles of a standard road (case 2A, left), a road using reinforcement with geogrid (case 2B, middle) and a road using soil improvement with lime/cement (case 2C, right).

Table 3 show specific values of the roads for all three alternatives in their base case analyses.

Table 3. Specification of three alternative road foundations

Parameter	Unit	Case 2A conventional road	Case 2B Reinforced with geosynthetic	Case 2C Stabilised with cement/lime
road width	m	12	12	12
geogrid	g/m²	-	250 (PP) or 260 (PET)	-
separation and filtration geosynthetic	g/m² (geosynthetic from case 1)	-	150 (PP)	-
stabiliser : cement/quicklime	weight-%	-	-	2.25 / 3.75
existing soil stabilised	cm	-	-	25
grade and subgrade FSS	cm	87	52.2	32
ballast substructure (0/45mm), STS	cm	15	15	15
asphalt layer	cm	18	18	18
- surface layer	cm	4	4	4
- binder course	cm	14	14	14

2.2.1 Functional unit and Definition of the System

The function of case 2 is the provision of a road class III on a stable foundation. The stability is either reached by using a stabiliser (cement/quicklime), a geogrid or is given without particular measures. The functional unit is thus defined as the construction, and disposal of a road class III with a length of 1 meter, a width of 12 meters and a lifetime of 30 years.

2.3 Case 3 – Landfill construction

The European Regulation specifies 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 moving of fines of the top soil into the drainage, as also a second geosynthetic is used below the drainage as a protection layer to secure that the sealing element was not damaged to the drainage. Instead of the conventional gravel drainage layer a geosynthetic drainage layer is used. In practice both solutions use geosynthetics - on top and below of the drainage layer. 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 4.

The average of 2 types of different geosynthetics are used to represent its' performance, namely

- drainage nets and
- drainage 3D filament.

Polypropylene or polyethylene granulates are used as basic material in case 3B. The average weight of the drainage polymer is 500 g/m^2 (excluding 2 geosynthetic filters). Gravel with a rather uniform grain size of 16-32 mm and a layer thickness of 50 cm is used in case 3A.

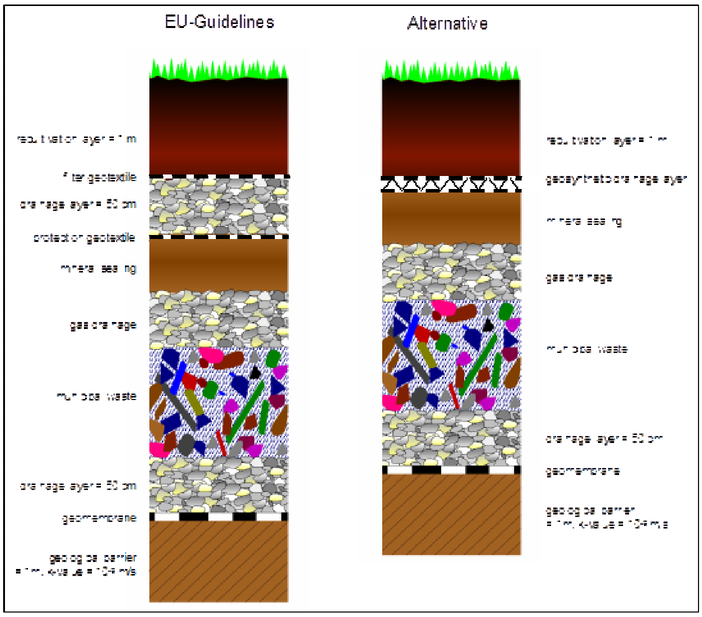

Figure 4. Cross section of the mineral filter (case 1A, top) and geosynthetic filter system (case 1B, bottom).

Table 4 shows specific values of the drainage layer for both alternatives.

Table 4. Specification of three alternative road foundations

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

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

2.3.1 Functional unit and Definition of the System

The function of case 3 is to provide a drainage layer in a landfill cap of hazardous/non-hazardous waste landfill site. The purpose of this drainage layer is to discharge infiltrating rainwater from the surface. The functional unit is defined as the construction and disposal of 1 m^2 surface area drainage layer with a hydraulic conductivity (k-value) of 1 mm/s or more and an equal life time of 100 years.

2.4 Case 4 – Slope retention

It may be necessary in some cases, especially in the construction of traffic infrastructure, to build-up very steep batters or walls. For such walls, supporting structures are necessary. The retaining walls need to meet defined tensile and shear strengths. Retaining walls reinforced with concrete (case 4A) are compared to soil slopes reinforced with geosynthetics (case 4B). In Figure 5 the retaining wall is 50 meters long and

3 meters high with a steepness of 5:1. In fact, the length of the wall has no influence on the LCA as the functional unit refers to 1 meter standard cross section.

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

- extruded stretched grids,
- layed grids, and
- woven / knitted grids.

Polyethylene and PET granules are used as basic material in case 4B. In this case a long-term strength of 14 kN/m must be achieved. Back calculated from that and applying the typical reduction factor A1-A4 per raw material the average weight of the polymer is defined as:

- Polyethylene (100kN/m) with 750 g/m²
- PET (35kN/m) with 280 g/m²

The concrete used in case 4A is classified in the strength class B300.

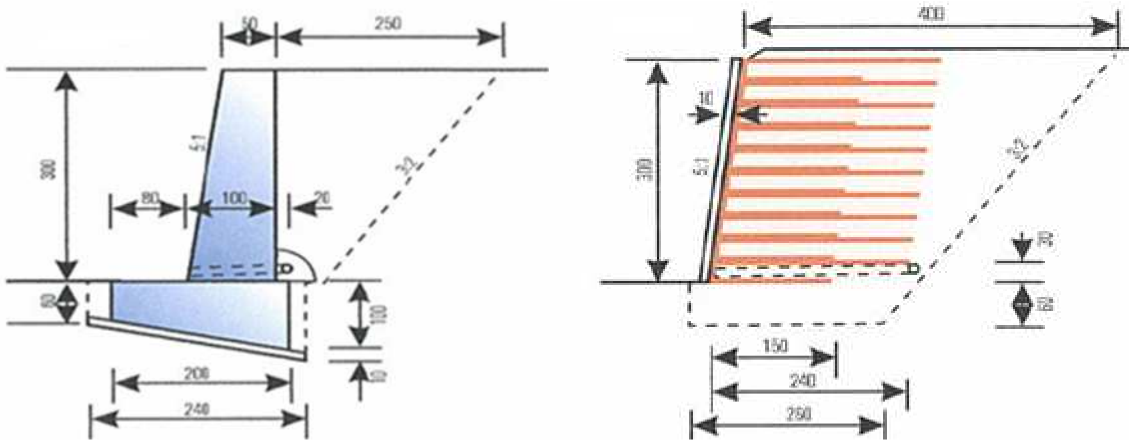

Figure 5. Scheme of retaining walls: the concrete reinforced wall (case 4A, left) versus the geosynthetics reinforced wall (case 4B, right).

Tab. 5.1 shows specific values of the retaining walls for both alternatives. The material on site is used as fill material, wall embankments and cover material in case 4B. A drainage layer made of gravel with a thickness of at least 30 cm behind the concrete lining is necessary. To be consistent with case 4A, a gravel layer thickness of 80 cm is assumed in both cases. Round gravel is used for drainage purposes.

Table 5. Specification of reinforced concrete wall (case 4A) and geosynthetic reinforced soil supporting structure (case 4B)

Description	Unit	Case 4A	Case 4B	Material
length of the wall	m	50	50	
height of the wall	m	3	3	
excavation fundament	m^3	109		
base compaction	m^2	121	262	On-site material
formwork fundament	m^2	83		Laminated board
cleanness layer	m^2	120		Lean mix concrete
concrete fundament	m^3	80		Concrete, sole plate
reinforcement fundament	kg	2400		Reinforcing steel
formwork wall face work	m^2	153		Laminated board
formwork wall coarse	m^2	150		Laminated board
concrete wall	m^3	105		Structural concrete, with de-icing contact
reinforcement wall	kg	5250		Reinforcing steel
Building gaps	m^2	21		Polystyrene foam slab
insulating coat cold	m^2	154		Bitumen
drainage	m	62	72	Polyethylene HDPE
filter gravel	m^3	10	11	Gravel
frost wall backfilling	m^3	219		Gravel and on-site material
compaction backfilling	m^2	500		Gravel and on-site material
excavation sub-base	m^3		79	On-site material
sub-base fill material	m^3		79	On-site material
form work, support	m^2		153	Laminated board
geosynthetics delivery and laying	m^2		1960	Geosynthetic
wall embankment	m^3		480	On-site material
compaction layers	m^2		1550	Gravel and on-site material
Sprayed-concrete lining	m^2		155	Structural concrete, with de-icing contact
covering material	m^3		45	On-site material

The typical life time is estimated in both cases with 100 years. This is in line with EBGEO (Deutsche Gesellschaft für Geotechnik 2010) and the British Standard “Code of practice for strengthened/reinforced soils and other fills” (British Standard 1995).

2.4.1 Functional unit and Definition of the System

The function of the fourth case is to provide a slope retention with a very steep and stable wall. The functional unit is defined as the construction and disposal of 1 m slope retention with a 3 meters high wall, referring to a standard cross-section. Thus, the functional unit is independent of the length of the wall.

3 RESULTS

3.1 Case 1 – Filter layer

In this Subchapter 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.

Figure 6 shows that case 1B causes lower impacts compared to case 1A with regard to all indicators investigated. 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 1A and 19 MJ-eq in case 1B. The cumulative greenhouse gas emissions amount to 7.8 kg CO_2-eq in case 1A and to 0.81 kg CO_2-eq in case 1B.

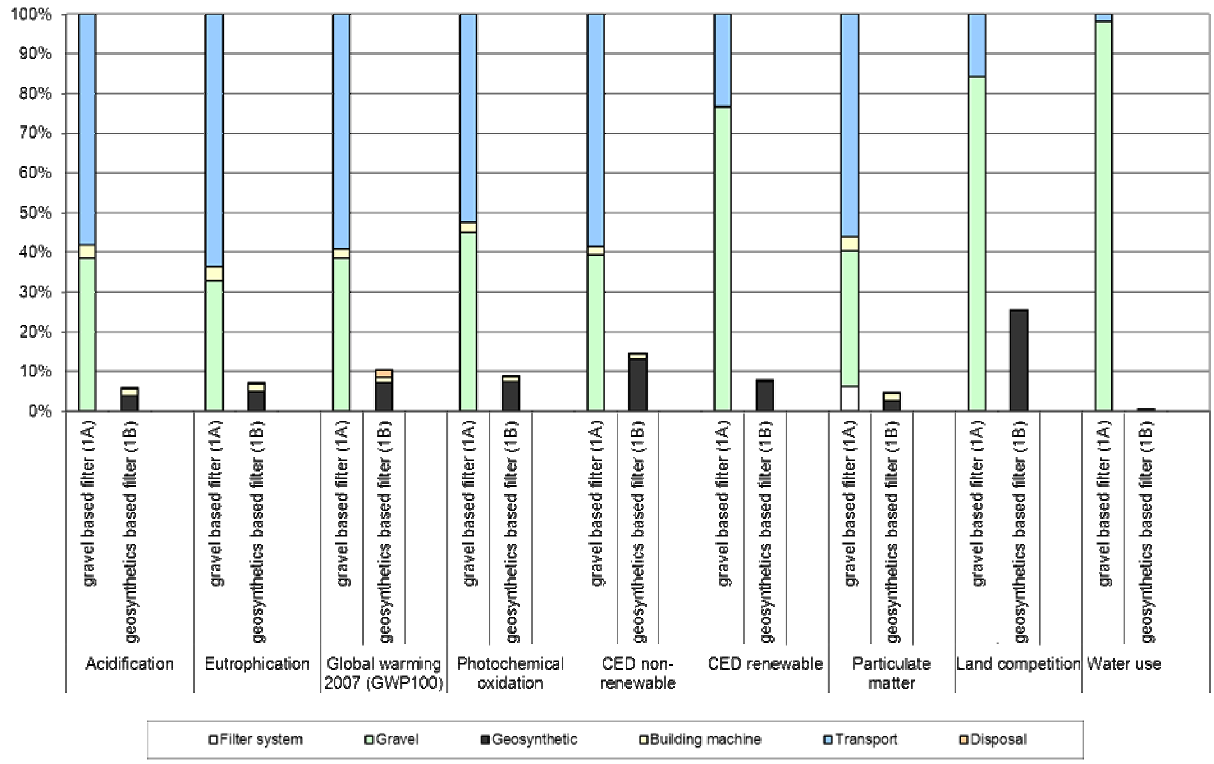

Figure 6. Scheme of retaining walls: the concrete reinforced wall (case 4A, left) versus the geosynthetics reinforced wall (case 4B, right).

The use of geosynthetics leads to lower environmental impacts of filter layer construction in case more than a layer of 8 cm gravel is saved. 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.

3.2 Case 2 – Foundation stabilisation

In this Subchapter the environmental impacts over the full life cycle of 1 meter road class III are evaluated.

In Figure 7 the environmental impacts over the full life cycle of the road are shown. A significant share of the environmental impacts is equal for all three cases, because the asphalt layers and the ballast substructure are identical. Thus the differences in results are less pronounced as compared to cases 1, 3 and 4.

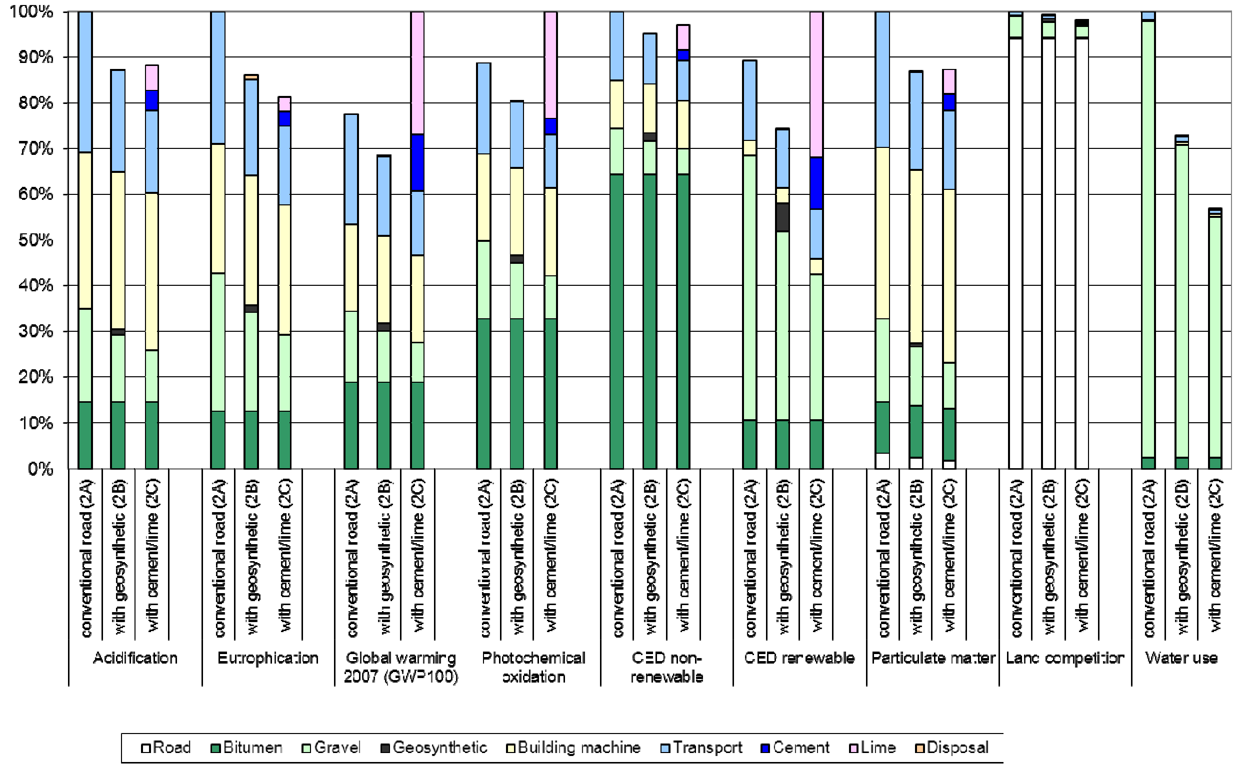

Figure 7. Environmental impacts of the life cycle of 1 m road with different foundations, cases 2A, 2B and 2C. For each indicator, the case with highest environmental impacts is scaled to 100°%.

The use of geosynthetics leads to lower environmental impacts of filter layer construction in case more than a layer of 8 cm gravel is saved. 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.

Compared to a conventional road (case 2A), the use of geosynthetics leads to lower environmental impacts concerning all indicators investigated (case 2B). At least a layer of 25 cm of gravel in a conventional road must be replaced by geosynthetics used in road foundation in order to cause the same or lower environmental impacts regarding all indicators. The comparison between a road stabilised with geosynthetics (case 2B) and a road stabilised with cement/lime (case 2C) is less clear-cut.

3.3 Case 3 – Landfill construction

In this section the environmental impacts of 1 m^2 drainage layer in a landfill are evaluated.

In Figure 8 the environmental impacts over the full life cycle of the landfill drainage layer are shown. Case 3B causes lower environmental impacts compared to case 3A in all impact categories considered. The non-renewable cumulative energy demand of the construction and disposal of 1 square meter drainage layer is 194 MJ-eq in case 3A and 86 MJ-eq in case 3B. The cumulative greenhouse gas emissions amount to 10.9 kg CO_2-eq in case 3A and 3.6 kg CO_2-eq in case 3B. Correspondingly, the cumulative greenhouse gas emissions of the drainage layer of a landfill with an area of 30’000 are 320 t in case 3A and 90 t in case 3B respectively.

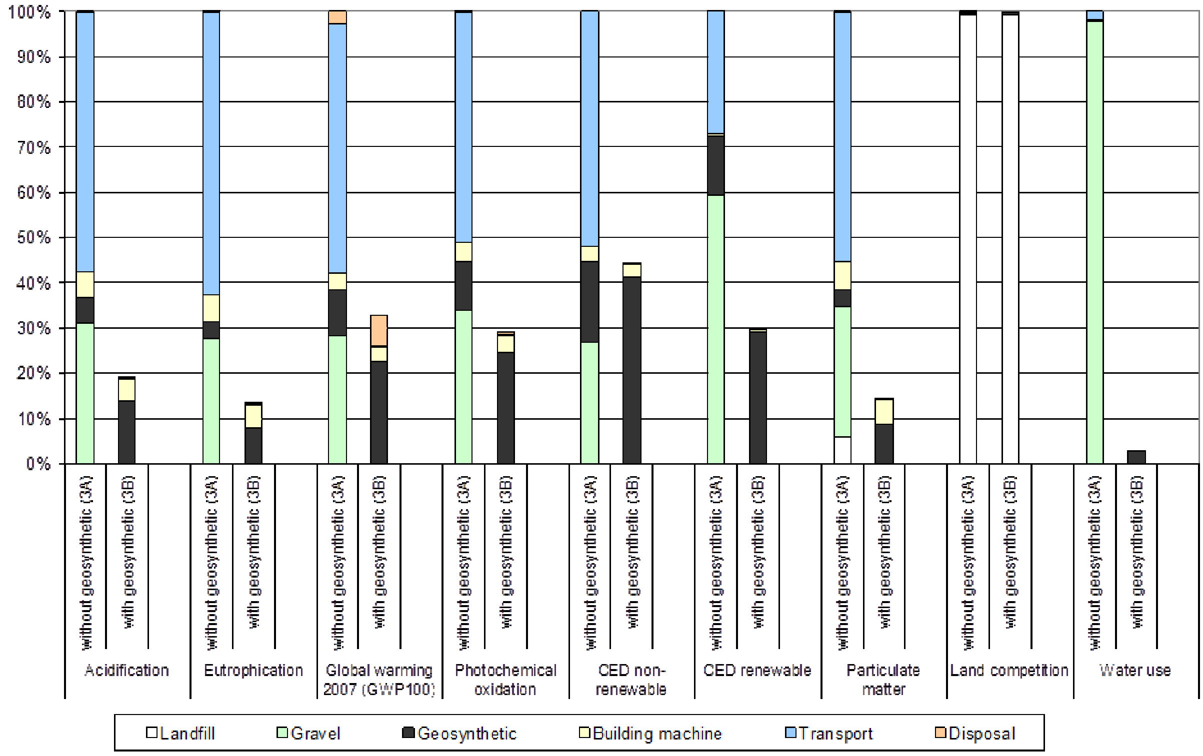

Figure 8. Environmental impacts of the life cycle of 1 m^2 mineral drainage layer (case 3A) and a geosynthetic drainage layer (case 3B). For each indicator, the case with higher environmental impacts is scaled to 100°%.

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

3.4 Case 4 – Slope retention

In this section the environmental impacts of 1 m slope retention with a height of 3 m over the full life cycle are evaluated.

In Figure 9 the environmental impacts over the full life cycle of the slope retention are shown. Case 4B causes lower environmental impacts compared to case 4A in all impact categories considered. The non-renewable cumulative energy demand of the construction and disposal of 1 meter slope retention with a height of 3 meters is 12'700 MJ-eq in case 4A and 3'100 MJ-eq in case 4B. The cumulative greenhouse gas emissions amount to 1.3 t CO2-eq in case 4A and 0.2 t CO2-eq in case 4B. Correspondingly, the cumulative greenhouse gas emissions of 300 m slope retention are 400 t in case 4A and 70 t in case 4B, respectively.

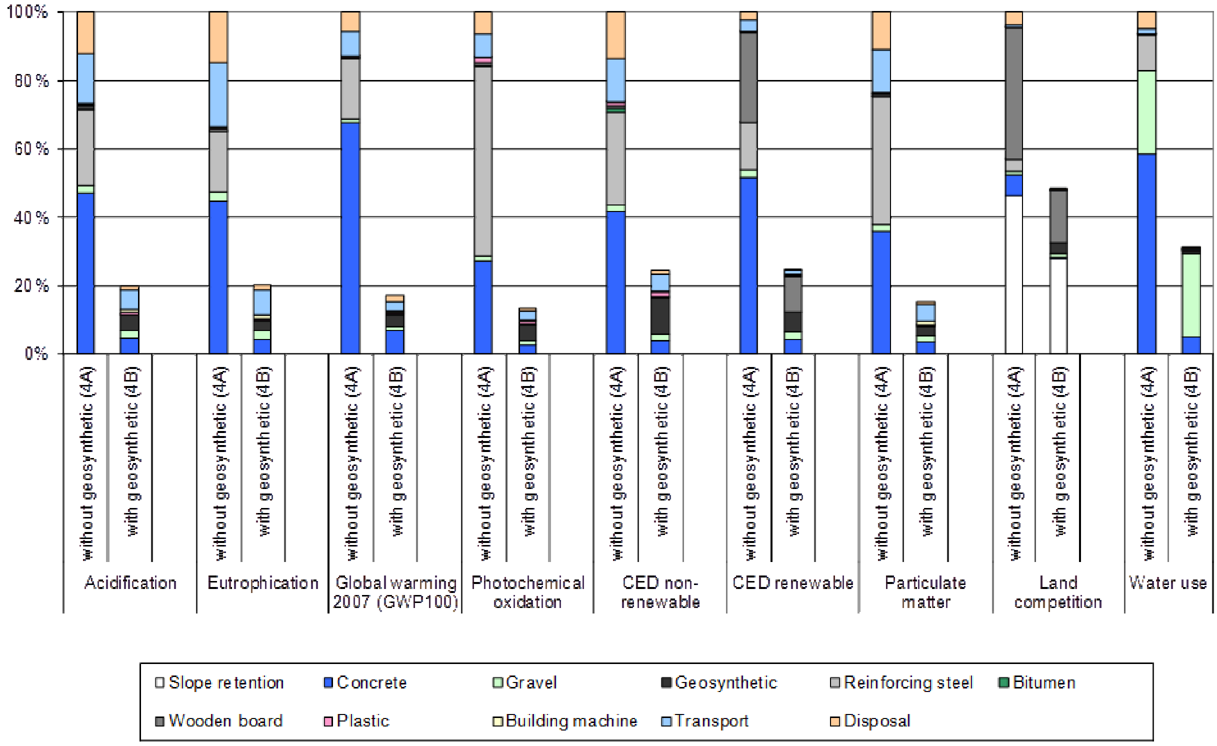

Figure 9. Environmental impacts of the life cycle of 1 m slope retention, cases 4A and 4B. For each indicator, the case with higher environmental impacts is scaled to 100°%.

The use of geosynthetics leads to lower environmental impacts of slope retention in all indicators investigated. The specific climate change impact of the construction of the slope retention (1 m slope retention with a 3 meters high wall) using geosynthetics is about 1 ton CO_2-eq per meter lower compared to a conventional alternative. This difference is equal to about 84 % of the overall climate change impact of the construction and disposal efforts of an entire conventional slope retention system during its 100 years lifetime.

4 OVERALL CONCLUSIONS AND RECOMMENDATIONS

Geosynthetic layers and geogrids can contribute to civil engineering constructions causing significantly lower climate change impacts in all cases considered. The use of geosynthetic layers also leads to lower environmental impacts such as acidification, eutrophication, and to lower cumulative energy demands, compared to conventional solutions.

A filter layer with geosynthetics has lower environmental impacts compared to a conventional alternative (gravel). The difference is considerable for all indicators (more than 85 %) and reliable. The difference in the environmental impacts arises mainly because the applied geosynthetic substitutes gravel, which causes considerably higher impacts when extracted and transported to the place of use.

When comparing the use of geosynthetics in road construction in order to reinforce the road foundation (case 2B) and the conventional road construction (case 2A), the environmental impact is reduced for all indicators when using geosynthetics. The uncertainty analysis shows that results are reliable for all indicators when comparing case 2A and 2B and that the results are stable for the indicators photochemical oxidation, global warming, land competition and CED renewable when comparing the case 2B and 2C. Regarding the other indicators the difference is not reliable.

The main driving forces for the difference between the geosynthetic drainage layer in a landfill site and the conventional gravel drainage layer is the extraction and transportation of gravel used in the conventional case. For all indicators except land competition, the impacts of the conventional drainage layer are more than twice as high as compared to the impacts from the geosynthetic drainage layer. From the uncertainty analysis it can be concluded that the results are reliable regarding all indicators except land competition.

A geosynthetic reinforced wall used for slope retention constitutes a different system compared to a concrete reinforced wall. Nevertheless, both systems provide the same function by enabling the build-up of steep walls. Compared to the conventional slope retention, the geosynthetic reinforced wall substitutes the use of concrete and reinforcing steel, which results between 63 % and 87 % lower environmental impacts. Compared to the use of geosynthetics as foundation stabiliser and separator, the geosynthetic used for slope retention has a considerably higher share in the total environmental impacts of the system between 3 % and 44 %. The Monte Carlo analysis reveales a high confidence in the higher environmental impacts of the conventional slope retention with regard to all indicators.

The results of the LCAs do not allow answering the question whether or not constructions based on geosynthetic materials are generally the environmentally preferable option. The specific situation and the particular construction in which the geosynthetic material is being used and the particular alternative options available should be taken into account.

Key parameters influencing the overall environmental performance of foundation stabilisation such as amounts of cement or lime, and of gravel needed, and transport distances should be investigated, when deciding about the environmentally appropriate construction in a particular case.

It is recommended to establish key parameter models for each of the four cases, which allow for an individual assessment of alternatives of any particular construction. This is particularly true for case 4, where actual situations may ask for highly specific technical solutions. In such key parameter models the main determining factors such as amount of gravel, cement, concrete or geosynthetics needed, can be entered to calculate the environmental impacts of the construction alternatives at issue.

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