Summary - Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials

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Executive Summary 2020

Goal and Scope Definition:

Geosynthetics are used in many different applications in civil engineering. In most cases, the use of geosynthetics replaces the use of other materials. In 2010, the European Association of Geosynthetic product Manufacturers (EAGM) commissioned ETH Zürich and ESU-services Ltd. to quantify the environmental performance of commonly used construction materials (such as concrete, cement, lime or gravel) versus geosynthetics.

To this end a set of comparative life cycle assessment studies was carried out concentrating on various application cases, namely filtration, sub-base stabilization, landfill construction and slope retention. The environmental performance of geosynthetics was compared to the performance of competing construction materials. The specifications of the four construction systems were established by the EAGM members representing the European market of geosynthetics. They represent best current practice.

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

The alternatives in each case were defined such that they can be considered technically equivalent or at least comparable. The geosynthetics used in the four cases represent a mix of different brands suited for the respective application. The conventional systems represent the most common type of construction.

Object of Investigation and Inventory Analysis:

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.

- *Filter layer:* The function of the first case is a combination of separation and filtration. A geosynthetic can serve as a separation and filter layer between a well compacted sub-base and the subgrade. This is essential to ensure that the sub-base retains its bearing capacity. The geosynthetic prevents on one hand the sub-base aggregate from sinking into the subgrade and on the other hand from pumping of fines from the subgrade into the sub-base. **The functional unit is thus defined as the construction and disposal of a filter with an area of 1 square meter, with a hydraulic conductivity (k-value) of 0.1 mm/s or more and an equal service life of 30 years.**

- *Foundation stabilization:* In the second case, concerning the improvement of weak soils, a conventional road, where no stabilisation is needed (case 2A), is compared to a geosynthetic reinforced sub-base (case 2B) and to a cement/quicklime stabilized road (case 2C). The function of the second case is the provision of a road class III on stabilized foundation. **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 an equal service life of 30 years.**

- *Landfill construction:* The third case compares the use of a geosynthetic drainage system (case 3B) with a gravel drainage system (case 3A) in a cap of a waste landfill site. A geosynthetic on top of the drainage gravel is often used to prevent moving of fines of the topsoil into the drainage, and a second geosynthetic is used below the drainage layer as a protection layer to ensure that the sealing element is not damaged by the drainage aggregate. Hence, in practice both solutions use geosynthetics - on top of and below the drainage layer. All the other layers in a landfill site change neither in thickness nor in material requirements. **The function of case 3 is to provide a drainage layer in the capping of a hazardous/non-hazardous waste landfill. 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 m2 of surface drainage layer with a hydraulic conductivity (k-value) of 1 mm/s or more and an equal service life of 100 years.**

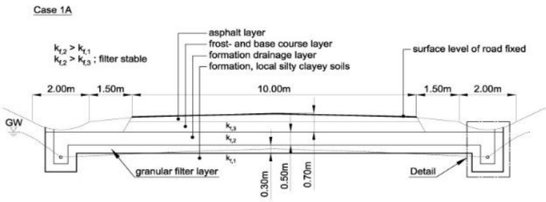
- *Slope retention:* It may be necessary in some cases, especially in the construction of traffic infrastructure, to stabilise embankments. To achieve this, supporting structures may be required. The design of these retaining walls ensures their ability to support the soil embankment. Retaining walls reinforced with concrete (case 4A) are compared to steep soil slopes reinforced with geosynthetics (case 4B). The function of the fourth case is to ensure slope retention with a stable retaining wall.
  The functional unit is defined as the construction and disposal of 1 m slope retention with a 3-meter high wall, referring to a standard cross-section. Thus, the functional unit is independent of the length of the wall. The service life of both designs is 100 years.

For all cases, data about geosynthetic material production were gathered at the numerous companies participating in the project. The company-specific life cycle inventories were used to establish average life cycle inventories of geosynthetic material. Average LCI were established per case on the basis of equally weighted averages of the environmental performance of the products manufactured by the participating member companies. The technical specifications of the four cases (e.g. how much gravel and diesel are required) were verified with civil engineering experts.

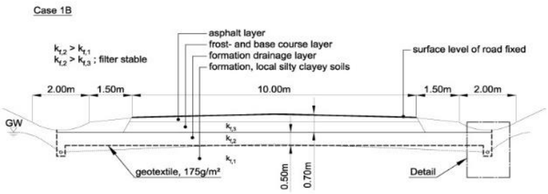
<u>Results:</u>

<u>Filter layer</u>:

A geosynthetic filter (case 1B) causes lower impacts compared to a conventional gravel filter layer (case 1A) with regard to all impact category indicators investigated. For all indicators the geosynthetic filter causes less than 25 % of the impacts of a conventional gravel filter.

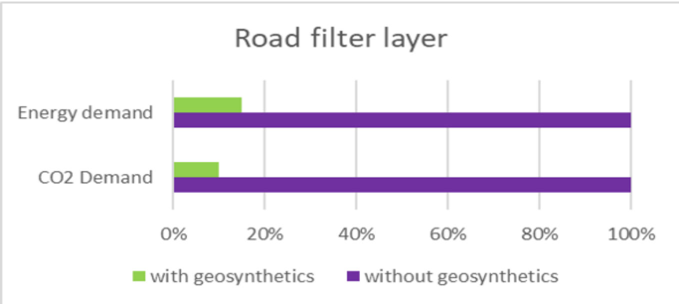


The non-renewable cumulative energy demand of the construction of 1 square meter filter with a lifetime of 30 years is 131 MJ-eq in case 1A and 19 MJ-eq in case 1B. The cumulative greenhouse gas emissions amount to 7.8 kg CO_2-eq/m2 in case 1A and 0.81 kg CO_2-eq/m2 in case 1B.



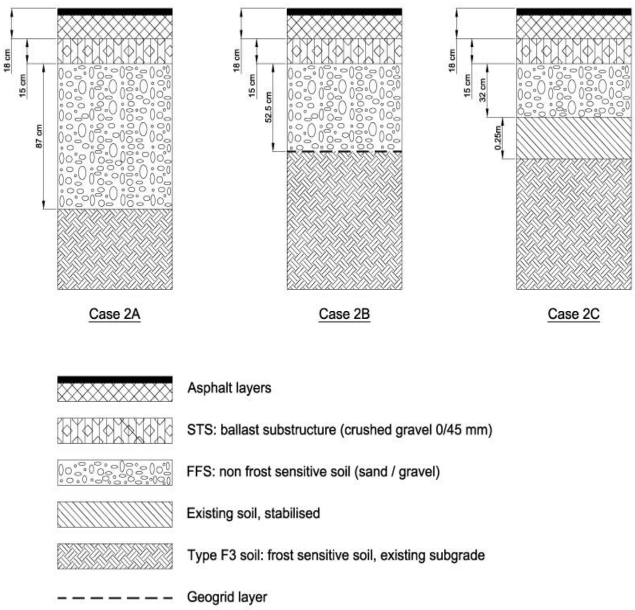
The use of geosynthetics leads to:

- 75 % (min.) lower environmental impact for all indicators.
- ~ 85 % lower non-renewable cumulative energy demand.
- ~ 90 % lower cumulative greenhouse gas emissions.



<u>Foundation stabilization</u>:

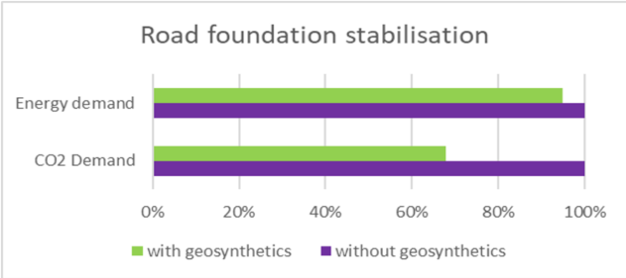
A conventional road (case 2A) causes higher impacts compared to a road reinforced with geosynthetics (case 2B) with regard to all impact category indicators. The higher impacts of case 2A are caused by the emissions and the resource consumption related to the production and transportation of the additional amount of gravel required.



With regard to global warming, the road construction with a cement/lime stabilized foundation (case 2C) causes higher impacts compared to cases 2A and 2B mainly because of the geogenic CO_2 emissions from the calcination process in the clinker and quicklime production. With regard to land use, the impacts of all three alternatives are more or less equal, with a maximal deviation in case 2C, using only 2.2 % less land than case 2A. Case 2C causes lower eutrophication and particulate matter emissions and requires less water compared to cases 2A and 2B.

The use of Geosynthetics leads to:

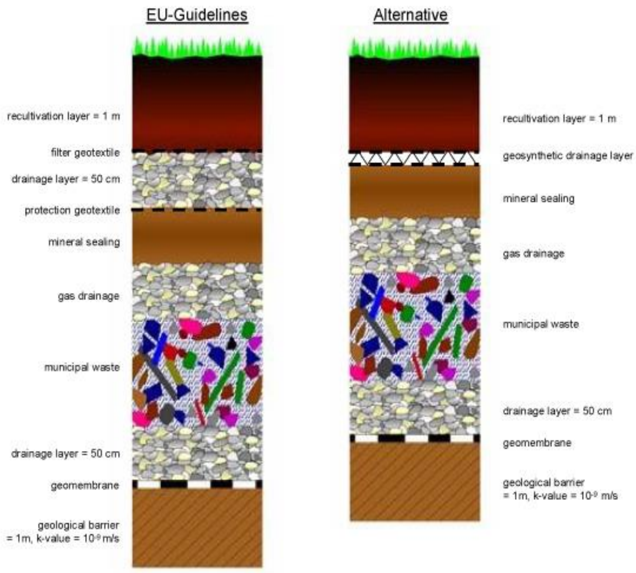
- lower impact concerning all indicators investigated compared to a conventional road.
- ~ 11% (or 800 tons) saving in CO_2 -equivalent per 10 km of road (12 m width).
- ~ 5% reduction in the non-renewable cumulative energy demand.



Note: When compared to lime/cement stabilization, a geosynthetic solution saves 30 % in CO_2 equivalent)

<u>Landfill construction:</u>

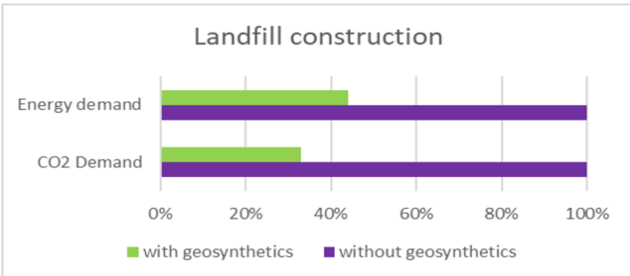
A geosynthetic drainage layer (case 3B) causes lower environmental impacts compared to a gravel drainage layer (case 3A) in all impact categories considered except land competition which is about the same in both cases. The non-renewable cumulative energy demand of the construction and disposal of 1 square meter drainage layer is 194 MJ-eq in case 3A and 86 MJ-eq in case 3B.



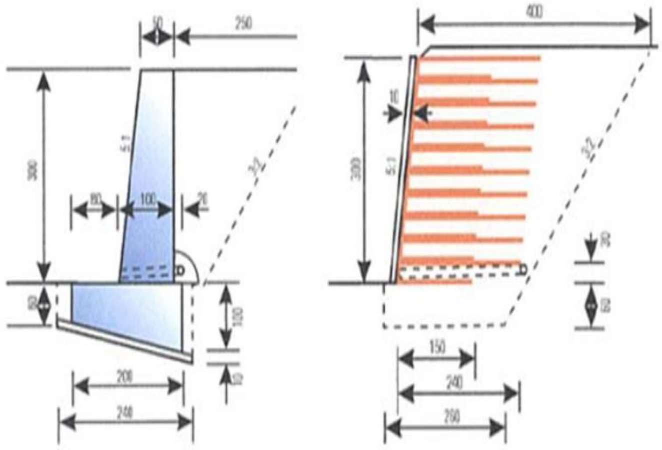
The cumulative greenhouse gas emissions amount to 10.9 kg CO_2-eq/m^2 in case 3A and 3.6 kg CO_2-eq/m^2 in case 3B. Correspondingly, the cumulative greenhouse gas emissions of the drainage layer of a landfill with an area of 30,000 m^2 are 330 t CO_2-eq in case 3A and 110 t CO_2-eq in case 3B respectively.

The use of Geosynthetics leads to lower impact in nearly all categories:

- ~ 69 % lower overall climate change impact of the construction and disposal efforts of a conventional drainage layer.
- ~ 67 % reduction in CO_2 emissions, which is equivalent with savings of 220 tons CO_2 -equivalent for a typical landfill site (30,000 m^2).



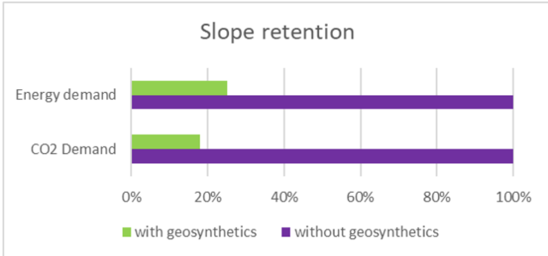
Slope retention:



A geosynthetic reinforced wall (case 4B) causes lower environmental impacts compared to a reinforced concrete wall (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 CO_2-eq/m in case 4A and 0.2 t CO_2-eq/m in case 4B. Correspondingly, the cumulative greenhouse gas emissions of 300 m slope retention are 400 t CO_2-eq in case 4A and 70 t CO_2-eq in case 4B respectively.

The use of geosynthetics leads to:
- lower impact in all categories
- ~ 75 % reduction of Nonrenewable cumulative energy demand (CED)
- ~ 85 % reduction of cumulative greenhouse gas emissions



Note: Each 3 linear meters soil retaining wall (3 m high) saves 30,000 MJ-eq, which is equivalent to the energy consumption of one household per year!

Conclusion:

A geosynthetic **filter** has lower environmental impacts than 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 geosynthetic replaces gravel, which causes considerably higher impacts when extracted and transported to the place of use. A layer of at least 8 cm of gravel must be replaced by a geosynthetic filter in order to cause the same or lower environmental impacts with regard to all indicators.

When comparing the use of **geosynthetics in road construction** to reinforce the sub-base (case 2B) and the conventional road construction (case 2A), the environmental impacts are reduced for all indicators when using geosynthetics. When road construction with geosynthetics (case 2B) and road construction with cement/lime stabilisation (case 2C) are compared, a trade-off between cases 2B and 2C can be observed. On the one hand, the use of a cement/lime stabiliser causes higher climate change impacts, mainly because of the geogenic CO_2 emissions from the production process of cement and quicklime.

On the other hand, the use of a geosynthetic stabiliser shows higher results for the environmental indicators eutrophication, water use and particulate matter because of the emissions and the resource consumption related to the production and transportation of the additional amount of gravel required. The use of quicklime only (case 2CS1) causes higher environmental impacts than the use of cement (case 2CS2) for the stabilisation of the road foundation. A layer of at least 25 cm of gravel in a conventional road must be replaced by geosynthetics used in the sub-base in order to cause the same or lower environmental impacts with regard to all indicators.

The main driving forces for the difference between the geosynthetic **drainage layer in a landfill** 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 compared to the impacts from the geosynthetic drainage layer. The Monte Carlo simulations show that differences can be considered reliable and significant with regard to all indicators except land competition. Regarding the latter, the two alternatives can be considered as equivalent.

Compared to the conventional slope retention, the **geosynthetic reinforced wall** substitutes the use of concrete and reinforcing steel, which results in lower environmental impacts of between 52 % and 87 %. The uncertainty analysis shows that it is reliable that the use of geosynthetics causes lower environmental impacts than a conventional slope retention.