COMPARATIVE LIFE CYCLE ASSESSMENT OF GEOSYNTHETICS VERSUS CONVENTIONAL CONSTRUCTION MATERIALS, A STUDY ON BEHALF OF THE E.A.G.M., GENERAL

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ABSTRACT: The European Association for Geosynthetic Products 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 (LCA) 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 (LCA) 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.

Case 1 Filtration
Case 2 Foundation stabilisation
Case 3 Landfill construction drainage layer
Case 4 Soil retaining wall

This paper presents the basis of the whole assessment, the detailed results of the four cases (Tab 1 shows the four cases and data) will be shown in further papers at this conference (see references).

Description	Alternatives	Case	Pro-ducers	Raw material	Value
Filter layer (ref. Case 1)	gravel based filter	1A			
	geosynthetics based filter	1B	13	PP	175g/m²
Road foundation (ref. Case 2)	conventional road	2A			
	geosynthetics based foundation	2B	7	PP and PET	250g/m² and 260g/m²
	cement/lime based foundation	2C			
Landfill construction (ref. Case 3)	gravel based drainage layer	3A			
	geosynthetics based drainage layer	3B	3	PP and HDPE	500g/m²
Slope retention (ref. Case 4)	reinforced concrete wall	4A			
	geosynthetics reinforced wall	4B	5	PET and HDPE	LTDS* 14kN/m

*) Long Term Design Strength

Tab.1: Overview of the objects of investigation

The study adheres to the ISO 14040 and 14044 standards. A critical review is performed by a panel of three independent experts. Data about geosynthetic material gathered by questionnaires refer to the year 2009 or, in a few exceptional cases, 2008.

The environmental performance is assessed with eight impact category indicators (see chapter 4).

The alternatives in each case are 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 types suited for the respective application. The conventional systems represent the most common type of construction.

Sensitivity analyses are carried out to further explore the reliability of the results. For example the thickness of the filter is varied in case 1 taking into account different technical specifications and four alternatives for road foundations are analysed in case 2. This includes two alternative road foundations using reinforcement with geosynthetics and two alternatives for the stabilisation of the road using cement or quick lime only.

For all cases, data about geosynthetic material production are gathered at the numerous companies participating in the project (see table 1). The company specific life cycle inventories are used to establish average life cycle inventories of geosynthetic material. Average Life Cycle Inventories (LCI) are 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 is required) were verified with civil engineering experts. The materials and processes needed to undertake the construction are modeled with generic, background inventory data. 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.

The study was commissioned by the European Association for Geosynthetic Manufacturers in January 2010. It is conducted by ESU-services Ltd. and ETH Zürich. Members of the project panel are:

- Henning Ehrenberg (Convener Working Group of EAGM)
- Dave Williams (Working Group of EAGM)
- David Cashman (Working Group of EAGM)
- Harry Groenendaal (Working Group of EAGM)
- Heiko Pintz (Working Group of EAGM)
- Heinz Homölle (Working Group of EAGM)
- Karl Wohlfahrt (Working Group of EAGM)
- Kjell De Rudder (Working Group of EAGM)
- Klaus Oberreiter (Working Group of EAGM)
- Nicolas Laidié (Working Group of EAGM)
- Massimo Antoniotti (Working Group of EAGM)
- Prof. Dr. Holger Wallbaum (ETHZ)
- Dr. Rolf Frischknecht (ESU-services Ltd.)
- Sybille Büsser (ESU-services Ltd.)
- René Itten (ESU-services Ltd.)
- Matthias Stucki (ESU-services Ltd.)

A critical review according to ISO 14040 and 14044 is being carried out by a panel of three independent external experts for LCA's:

- Hans-Jürgen Garvens, Falkensee, Germany (chair)
- Maartje Sevenster (MaS), Isaacs, Australia
- Lars-Gunnar Lindfors, IVL, Stockholm, Sweden

The whole study (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, Switzerland) including the results of the critical reviews is available on: http://www.eagm.eu/

2 SYSTEM BOUNDARIES

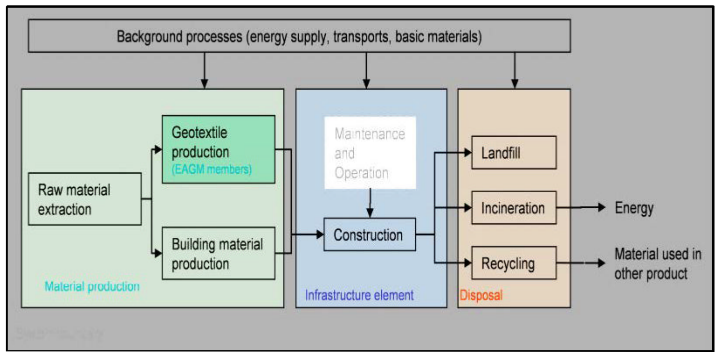

Figure 2: Simplified process flow chart. The simplified chart shows the most important process steps. Maintenance and Operation of the infrastructure element are not included in the system boundaries.

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. 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.

Not included are:

- Operation and maintenance of the infrastructure element (e.g. lightning, de-icing of roads, traffic), because these activities are outside the system analysed
- Manufacturing equipment (machinery) at the manufacturer's site, because of its minor importance
- Operation of the storage of raw and geosynthetic materials at the manufacturer's site, because the energy consumption is considered negligible
- Packaging of the geosynthetics, because they are of minor importance (less than 3% of mass contribution)

3 DATA GATHERING AND DATA QUALITY

Data about geosynthetic material production were gathered at the numerous companies participating in the project using pre-designed questionnaires. The company specific life cycle inventories were 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.). Qualitative information about reinforced concrete systems were collected from technical reference documents and expert knowledge. Average LCI are established per case on the basis of equally weighted averages of the environmental performance of the products manufactured by the participating member companies.

The primary source of background inventory data used in this study is the ecoinvent Data v2.2, which contains inventory data of many basic materials and services.

3.1 *Time reference*

Data about geosynthetic materials gathered by questionnaires refer to the year 2009 or, in a few exceptional cases, 2008. Data available about further material inputs and about the use of machinery are somewhat older. The characterisation of the four cases represents current best practice.

3.2 *Geographical coverage*

All data refers to European conditions. Some background data referring to Switzerland is used as estimation for European conditions, in particular regarding landfilling and incineration of wastes.

3.3 *Technical reference*

The alternatives in each case are 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 types suited for the respective application. The conventional systems represent the most common type of construction.

3.4 *Uncertainty assessment*

In order to evaluate the uncertainty of the data used, Monte Carlo analyses are performed. The Monte Carlo analysis is performed in a way that excludes depending uncertainties. The results of the analyses show the effects of the independent uncertainties of

4 LIFE CYCLE IMPACT ASSESSMENT

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

- **Cumulative Energy Demand – CED** (Primary Energy Consumption, split into non-renewable and renewable fractions) [CED describes the consumption of fossil, nuclear and renewable energy sources along the life cycle of a good or a service. The following two CED indicators are calculated; CED, non-renewable [MJ-eq.] – fossil and nuclear; CED, renewable [MJ-eq.] – hydro, solar, wind, geothermal, biomass],
- **Climate Change** (Global Warming Potential, GWP100) [All substances, which contribute to climate change, are included in the global warming potential (GWP) indicator. The residence time of the substances in the atmosphere and the expected emission design are considered to determine the global warming potentials. The potential impact of the emission of one kilogram of a greenhouse gas is compared to the potential impact of the emission of one kilogram CO_2 resulting in kg CO_2-equivalents. In this study a time horizon of 100 years is chosen, which is also used in the Kyoto protocol],
- **Photochemical Ozone Formation** [also known under “summer smog”],
- **Particulate Formation** [Particulate matter (PM) causes health problems as it reaches the upper part of the airways and lungs when inhaled],
- **Acidification** [Acidification describes a change in acidity in the soil due to atmospheric deposition of sulphates, nitrates and phosphates. Major acidifying substances are NOX, NH3, and SO2],
- **Eutrophication** [Eutrophication can be defined as nutrient enrichment of the aquatic environment],
- **Land competition** [Not all types of land occupation have the same effect on the biodiversity. However, this fact is not considered on this level of assessment. The land competition indicator includes the total, unweighted sum of the area occupied], and
- **Water use** [This indicator expresses the total amount of water used (excluding water turbined in hydroelectric power plants)].

5 SENSITIVITY ANALYSES

Sensitivity analyses were conducted to verify the reliability of the results. The following scenarios were chosen:

- The average thickness of the gravel based filter in case 1A (30cm) is varied between 20 and 40cm to reflect different realistic technical specifications.
- Soil stabiliser material in case 2: In addition to the case 2C standard scenario with a 50/50% cement/lime stabiliser, scenarios with a 100% cement and a 100% quicklime stabiliser are considered.
- Frost sensitivity of soil in case 2: In regions where the frost penetration depth reaches frost-sensitive soil F3, an upgrade of the frost-sensitive soil F3 in case 2B to non-frost-sensitive soil F2 is required and the geosynthetic cannot directly be applied on the existing surface. Hence, in a sensitivity analysis a scenario is considered, where the foundation is stabilised by removing the soil and replacing it with non-frost-sensitive soil.
- Separation geosynthetic in case 2: In some cases no separation geosynthetic is needed in case 2B. Hence, a scenario is considered excluding the use of the separation geosynthetic.
- No allocation sensitivity is calculated for the recycling of concrete in the cases 4A and 4B, since recycled and primary concrete have about the same environmental impacts and hence, no credits can be given for recycled concrete. The same is true for recycled reinforcing steel, because reinforcing steel is made from scrap.

6 RESULTS AND CONCLUSIONS

- A filter using a geosynthetic layer (case 1B) causes lower impacts compared to a conventional gravel based filter layer (case 1A) with regard to all impact category indicators investigated. For all indicators the filter with geosynthetics causes less than 25% of the impacts of a conventional gravel based filter. The non-renewable cumulative energy demand of the construction of 1 square meter filter with a life time of 30 years is 85% lower for a geosynthetic filter compared with a gravel based filter (19MJ-eq in case 1B and 131MJ-eq in case 1A). The cumulative greenhouse gas emissions amount are almost 90% lower for a geosynthetic filter compared with a gravel based filter (0.81kg CO_2-eq/m^2 in case 1B and 7.8kg CO_2-eq/m^2 in case 1A .
- 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 non-renewable cumulative energy demand of the construction and disposal of 1 meter stabilised road with a width of 12 meters and a life time of 30 years is 25,200MJ-eq in case 2A, 23,900MJ-eq in case 2B and 24,400MJ-eq in case 2C (road stabilised with cement/lime). The cumulative greenhouse gas emissions amount to 0.73t CO_2-eq/m² in case 2A, to 0.65t CO_2-eq/m² in case 2B and to 0.95t CO_2-eq/m² in case 2C. Correspondingly, the cumulative greenhouse gas emissions of 1 km stabilised road are 730t CO_2-eq in case 2A, 650t CO_2-eq in case 2B and 950t CO_2-eq in case 2C - almost one third more than for a geosynthetic stabilised road.
- Using quicklime as stabiliser causes the highest environmental impacts with regard to global warming, photochemical oxidation, CED non-renewable, and CED renewable. Choosing cement as stabiliser leads to higher environmental impacts for global warming, CED renewable and water use compared to case 2B.
- A geosynthetic drainage layer (case 3B) causes lower environmental impacts compared to a gravel based 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 194MJ-eq in case 3A and 86MJ-eq in case 3B (56% lower). The cumulative greenhouse gas emissions amount to 10.9kg CO_2-eq/m² in case 3A and 3.6kg CO_2-eq/m² in case 3B (66% lower). Correspondingly, the cumulative greenhouse gas emissions of the drainage layer of a landfill with an area of 30,000m² are 330t CO_2-eq in case 3A and 110t CO_2-eq in case 3B respectively (66% lower).
- 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 12,700MJ-eq in case 4A and 3,100MJ-eq in case 4B (75% lower). The cumulative greenhouse gas emissions amount to 1.3t CO_2-eq/m in case 4A and 0.2t CO_2-eq/m in case 4B (85% lower). Correspondingly, the cumulative greenhouse gas emissions of 300m slope retention are 400t CO_2-eq in case 4A and 70t CO_2-eq in case 4B (82% lower).

The life cycle assessments of the four cases filter layer, foundation stabilisation, landfill construction and slope retention are defined in a way that they represent commonly applied new construction.

Nevertheless construction methods may vary from one EU member state to the other. Thus the cases should be perceived as typical models of common and frequent applications of geosynthetic materials.

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.

7 REFERENCES

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