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Reduction of climate-damag- ing gases in geotechnical engineering by use of geosynthetics

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Abstract

At present, the political discussions around the globe are focused on sustainable development. Demand for reduction of energy consumption and emission of climate related gases like CO₂ and CH₄ are big challenges for the construction industry, too.

Economical and ecological advantages of construction methods with geosynthetics are already well known. Soil masses that need to be excavated, transported and installed can be dramatically reduced. The best examples are those of geosynthetic clay liners or geocomposite drains instead of clay or gravel layers. But also the avoidance of soil exchange in traffic areas and the improvement of soil at site with geogrids have to be mentioned as positive examples in this regard. This article will conduct a comparison between classical construction techniques and geosynthetic construction alternatives. The cumulated energy demand (CED) and climate related CO₂ emission for primary, prefinished and finished products, their transport to the manufacturer and to the construction site as well as their installation are determined. For both examples a considerably smaller cumulated energy demand (CED) and CO₂ emission is shown for the geosynthetic alternatives.

Introduction

The political discussion, but also research and science, are currently affected by the claim of "sustainable development". In the original context, "sustainable development" is not only restricted to the requirements of saving energy and raw materials, but comprises a model of a worldwide sustainable development based on the components protection of natural resources, social and economical balance worldwide as well as the future ability to develop with regard to education and economical scope of action.

The will and ability to achieve these sustainable aims will decide on our future – completely independent of hypothetical climate change scenario with more or less anthropogenic influence and hardly predictable regional impacts. The worldwide propagated climate protection approach to save energy and to reduce radically the emissions of the global warming gases CO₂ (carbon dioxide), but also CH₄ (methane) with its approx. 20 times higher damage to the climate compared to CO₂, are important components for a successful sustainable development and are therefore to be supported without restrictions.

The construction industry is as key industry responsible for 10% of the employees worldwide and 7% of the total economic performance. Round about 40% of the worldwide energy consumption and greenhouse gas emission, significantly influenced by buildings (heating and cooling) which are not energy efficient to a large extent, are to be assigned to the construction industry – a tremendous potential for sustainable developments in the construction industry including geotechnical, hydraulic and coastal engineering.

Innovations were and are essentially influenced by cost minimising. To encourage sustainable developments for constructions, sustainability components such as energy consumption or emission of greenhouse gases would have to be determined and calculated in offers. For two infrastructure projects – new construction of a district road and completion of a slope protection – Life Cycle Assessments (LCA) for alternative construction methods were made. As for these two examples from the construction industry the energy demand and associated emission of greenhouse gases demonstrate the decisive impacts on the environment, the cumulated energy demand (CED) and the CO₂ emission can be used as "short LCA" for the ecological evaluation.

Taking into account the extraction and production of the used construction materials, loading, transport and installation, the cumulated energy demand (CED) and CO₂ emissions are determined for each of the construction alternatives. For an environmentally friendly evaluation of the alternatives, the money equivalent of the CO₂ emissions would have to be determined and e.g. the costs for CO₂ emission certificates would have to be added to the quoted price for the construction work – thus the most sustainable offer could be accepted.

It is a challenging task for present research and development activities to support sustainable developments on the globe in favour of our future. Since many years already, it is reported about economical and ecological advantages of construction methods with geosynthetics in geotechnics and hydraulic engineering. Comparing traditional construction methods with those using geosynthetics, the latter result in considerable reduction of construction costs and/or construction time and considerably less masses that have to be excavated, transported and installed.

In addition, there are environmental advantages, for example due to the possibility of greening up geogrid reinforced slopes (Fig. 1) or the natural settlement of marine flora and fauna in coast protection measures, as for example shown at the artificial reef consisting of "geotextile containers" at the Gold Coast in Australia (Heerten et al, 2000).

Also the application of geogrids for base soil reinforcement in traffic areas instead of milling lime/cement binder into the soil is showing environmental advantages by having no groundwater impact and no air pollution due to lime/cement dust.



Fig. 1: City railway Stuttgart, Germany. Example of a greened up geogrid reinforced supporting structure (1990)

Present economical and ecological advantages of geosynthetic construction methods

The cover sealing of the old and closed landfill Neu Wulmstorf near Hamburg was one of the first big projects (320,000m²/32ha) in Germany where a classic/traditional cover system with clay liner and gravel drainage layer was replaced by a geosynthetic alternative. The cover system – consisting of a geosynthetic clay liner (GCL), a HDPE geomembrane and a geosynthetic drainage layer - was carried out on a mineral leveling layer permeable to gas placed on top of the waste. Fig. 2 shows the project in 1996.

For this project, it could be established that

- instead of 21,000 truck loads for clay and gravel only 165 truck loads were necessary for the supply of GCL and geosynthetic drainage layer,
- instead of the projected construction costs of approx. 36 million Euro only costs of approx. 25 million Euro occurred and thus 30% of the projected costs could be reduced,
- instead of a construction period of approx. 3 years the project could be completed within two years.



Fig. 2: Installation of the geosynthetic clay liner (GCL) as part of a geosynthetic cover system at the landfill Neu Wulmstorf near Hamburg, Germany, 1996/97

With another project carried out in 1999, the landfill Lichte near Stuttgart, Germany, a cost reduction of 47% could be achieved by using alternative geosynthetic construction methods. In this case a geocomposite drain was used as landfill gas collecting layer, a GCL and GM as combination sealing and a geocomposite drain again as drainage layer for seepage water out of the cover soil.

In addition to these savings and advantages, it has to be pointed out for cover systems in landfills that the landfill's climate damaging potential resulting from the possible emission of methane (CH_4) can be reduced by a factor of 20, if the methane (CH_4) is being collected and used for energy production or simply burnt off. Thus, only carbon dioxide (CO_2) would be emitted instead of methane (CH_4).

Also for geosynthetic reinforced steep walls or slopes, construction costs of 30 to 50% can be saved in comparison to classic construction methods (Fig. 3, Koerner et al., 1998).

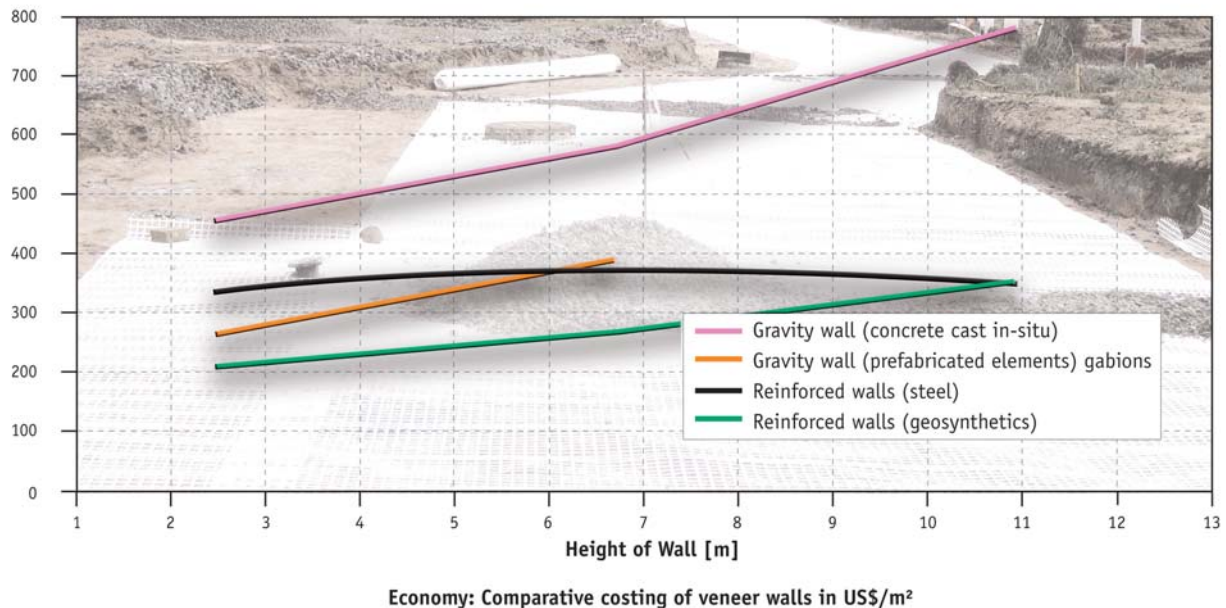


Fig. 3: The money challenge (MSE =Mechanically Stabilised Earth)

Life cycle assessment

A Life Cycle Assessment (LCA) denotes the systematic analysis of the environmental impact of products during their entire life cycle (excavation and treatment of raw materials, production, distribution and transport, use, consumption and disposal). This comprises any environmental impact during the production, utilization phase and disposal of the product as well as the upstream and downstream processes connected to that (e.g. production of raw and process materials). Environmental impact may include any ecologically relevant extraction from the environment (e.g. raw oil, soil, ore) as well as emission into the environment (e.g. waste, carbon dioxide emissions).

Fig. 4 shows the phases of a life cycle assessment and the correlation between the terms life cycle inventory analysis, impact balance or impact assessment, respectively, and evaluation. Direct applications of life cycle assessments comprise for instance the development and improvement of products, strategic planning, political decision making processes or marketing etc.

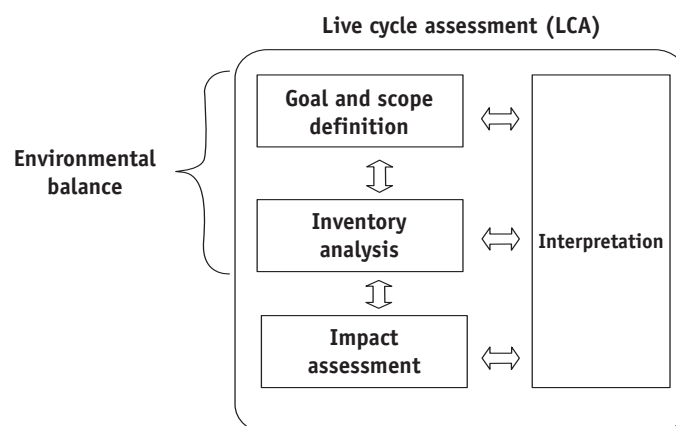


Fig. 4: Constituents of a life cycle assessment (pursuant to DIN EN ISO 14040 2006-10 / 14044, 2006-10)

In the interest of a subsequent, possibly comprehensive evaluation it is reasonable to conduct an impact related account between the sole life cycle inventory analysis and the evaluation of the balance. The flow and inventory parameters collected in the life cycle inventory analysis are described or assessed, respectively, with regard to their potential effects. Their impact on selected global and regional or local environmental factors are considered. The effects from the life cycle inventory analysis may be analysed with regard to the following environmental categories (SETAC, 1993):

1. Resource depletion
2. Land use
3. Global warming
4. Ozone depletions
5. Photochemical ozone creation
6. Acidification
7. Eutrophication, nitrification
8. Toxicological effects
9. Ecotoxicological effects
10. Waste
11. Modification of ecosystems and landscapes

To establish comparative life cycle balances for different products the following preconditions are necessary:

- same scope of use
- same state-of-the-art technology
- same range of functions

The comparison is conducted by means of the following balance factors:

1. Excavation of raw materials (e.g. soil, sand, gravel, limestone, marl, clay, iron ore, crude oil)
2. Transport of the raw materials to the site or the manufacturer
3. Production of the primary products (e.g. cement, lime, structural steel, PP granulate)
4. Transport of the primary products to the manufacturer or the construction site
5. Manufacturing of the products (e.g. concrete, geogrid, geotextiles)
6. Transport of the products to the construction site
7. Integration of the products (e.g. distribution, milling, consolidation, laying)

Considering these factors, it is possible to calculate the cumulated energy demand (CED) which can be stated with the following different units:

- MJ/kg in relation to the product, or
- MJ/m³ in relation to the compacted/stabilised soil, or
- MJ/m² in relation to the sealed surface.

As a representative for the environmental impact, the CO₂ emissions are indicated in kg per kg of the applied product or in kg per m³ of stabilised soil or in kg per m² of sealed area with regard to the global warming potential.

If a large part of the environmental effects results from the supply and consumption of energy, the CED may be used as a **first rough check** "Short life cycle assessment" in many cases. It provides at least first clues with regard to an ecological evaluation.

The CED is a first indicator for a **rough first evaluation** of the energy, transport and material services. Even though the CED also requires data, the energy data may be collected and standardised easily. The FFE (Research Institute for Energy Economy) in Germany offers a lot of these energy data.

Comparison of different construction methods based on two examples

Different building materials

When comparing traditional construction methods with the use of geosynthetics on the base of CED or CO₂ emission, one has to evaluate the excavation and production of all different construction materials needed. Transportation to the construction site and installation of the construction material or product has to be considered, too. For one example of slope protection and one example of road construction with involvement of NAUE geosynthetic products the details have been worked out by ICP Ingenieurgesellschaft Prof. Czurda und Partner mbH (geologists and engineers for water and soil), Karlsruhe, in collaboration with NAUE, and have been published with a lot of details by Egloffstein (2009). Detailed information of the special used geogrids, geotextiles, different soils,

fine ground lime, cement, ready-mixed concrete, structural steel have been collected and considered for CED and CO² emission comparison. The quantities of different materials have been considered as put out to tender or defined by special offer / construction proposal or as they are recommended by technical guidelines. More details are given again in Egloffstein 2009.

The slope protection example

In the vicinity of Frankfurt/Main, Germany, a new connecting road (Gänsbergspange Idstein) should improve the local traffic conditions. The design put out to tender was asking for a vertical gravity wall to support the road section. An alternative design with a geogrid reinforced slope was presented (Fig. 5) and finally built, giving the background to compare these alternatives with regard to their environmental impact.

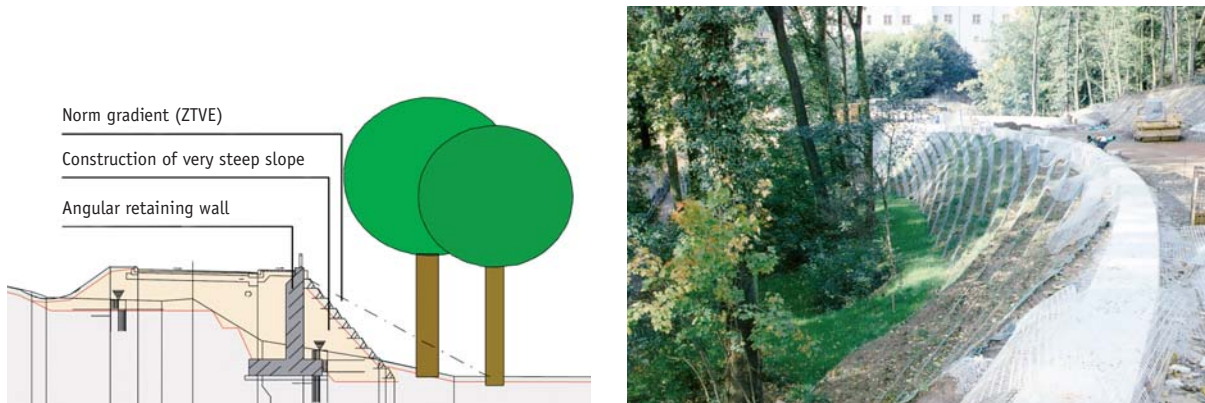


Fig. 5: Road construction alternatives at Gänsbergspange Idstein, Germany

Table 1: Cumulated energy demand (CED) for all components involved in the geogrid reinforced steep slope alternative (Project: Gänsbergspange near Frankfurt, Germany)

Project: Gänsbergspange Idstein

Geogrid-reinforced steep slope versus reinforced concrete construction (angular retaining wall)

Geogrid-reinforced steep slope	Data [unit]	Mass [unit]	Data [unit]	CED [MJ]
Production Secugrid 60/60 Q6	built in area: 3.750 m ²			
	Mass per unit area: 0,62 kg/m ²	2.325 kg	78,70 MJ/kg	182.978
Production Secugrid 120/40 R6	built in area: 1600 m ²			
	Mass per unit area: 0,58 kg/m ²	928 kg	78,70 MJ/kg	73.034
Transport to construction site, distance to manufacturer in Adorf	400 km	3,253 t	1,5 MJ/tkm	1.952
Delta Green wire grating reinforcement system for outer slope	630 m ²			
Production geotextiles per m² slope reinforcement made of PP	0,16 kg/m ²	100,8 kg		
Production polypropylene granules	0,16 kg/m ²		65,50 MJ/kg	6.602
Production polypropylene fibres	0,16 kg/m ²		1,908 MJ/kg	192
Production non-woven polypropylene	0,16 kg/m ²		0,324 MJ/kg	33
Production wire grating reinforcement; front/bottom grating, press-lock, d = 5 mm, l x w = 3 m x 0,7 m = 2,1 m², 14,6 kg per element	6,95 kg/m ²	4.380 kg	27,69 MJ/kg	121.282
Transport non-woven to construction site, distance to manufacturer	270 km	0,1008 t	2,5 MJ/tkm	68
Transport wire grating to construction site, distance to manufacturer	220 km	4,38 t	1,5 MJ/tkm	1.445
Installation by excavator wheel loader (Secugrid + Delta Green)	5.980 m ²		1,04 MJ/m ²	6.219
Soil exploitation by backhoe 8.500 m³	8.500 m ³		7,6 MJ/m ³	64.600
Soil transport 17.000 t, transportation distance 15 km	15 km	17.000 t	2,5 MJ/tkm	637.500
Soil insertion by bulldozer, layer thickness 0,30 m	8.500 m ³		8,98 MJ/m ³	76.330
Soil compaction by roller compactor, layer thickness 0,30 m	8.500 m ³		4,80 MJ/m ³	40.796
Production anchored reinforced concrete ridgepole (0,5m x 0,5m x 140 m)	35 m ³	2,4 t/m ³	658 MJ/t	55.272
Production concrete reinforcing steel ST 500/550	77 kg/m ³	2,7 t	27.960 MJ/t	75.352
Transport concrete from concrete factory to construction site	20 km	84 t	2,5 MJ/tkm	4200
Transport structural steel to construction site	50 km	2,7 t	2,5 MJ/tkm	337
Production concrete ridgepoles (excavator, wheel loader, concrete pump etc.)	35 m ³	2,4 t/m ³	15 MJ/m ³	525
Faced brickwork of natural stones A = 41 m²; t = 0,2 m; density = 2,7 t/m³	41 m ²	8,2 m ³		
Exploitation faced brickwork of natural stones in quarry		22,14 t	40 MJ/t	886
Transport faced brickwork from quarry to construction site	35 km	22,14 t	2 MJ/tkm	44
Production faced brickwork (excavator, wheel loader etc.)	35 m ³		15 MJ/m ³	525

Total CED [GJ]

1350 GJ

The comparison between a slope protection system with geogrids including a vegetative steep slope protection system with anti-erosion mat and a vertical gravity retaining wall made of reinforced concrete also showed considerably better results for the geosynthetics solution with regard to both, the cumulated energy demand (CED) and the CO₂ emissions.

The geosynthetics solution requires not only 5350m² of geogrid layers made of propylene, but also a 0.5 x 0.5 x 140m long reinforced concrete top beam, forming the upper cover of the slope construction. In addition, 41m² of faced brickwork made of natural stone and 630m² of the slope protection system Deltagreen, with almost 7kg of steel wire per square metre as well as a 200g/m² non-woven made of PP had to be integrated into the slope protection system. Within the scope of an energy and CO₂ balance, the system components had to be considered individually for the comparison with the vertical gravity retaining wall construction. Furthermore, the geogrid reinforced embankment construction required approx. 40% more soil to be excavated, transported and installed compared to the vertical gravity retaining wall. The details are given in Table 1.

All this has proven not only considerably less energy consuming but also more ecological with regard to CO₂ emissions than the production, transport and installation of 1107m³ of concrete with approx. 77.5t of steel reinforcement. In this process, the steel reinforcement in the concrete contributed considerably to the higher CED and CO₂ emissions as can be seen in Table 2. The cumulated energy demand CED for the geosynthetics solution only amounted to approx. 30% and the CO₂ emissions to approx. 18% of the traditional alternative with vertical gravity retaining wall. Fig. 6 is giving more details showing the CED and CO₂ emissions of the alternative construction solutions. The cumulated energy demand (CED) is about 3.5 times and the CO₂ emission of the geosynthetic solution is about 5.4 times less than the traditional construction approach with a vertical gravity retaining wall construction.

Table 2: Cumulated energy demand (CED) for all components of the vertical retaining wall alternative (Project: Gänsbergspanne near Frankfurt, Germany)

Alternative: Reinforced concrete construction (angular retaining wall)

Angular retaining wall	Data [unit]	Mass [unit]	Data [unit]	CED [MJ]
Total length	150 m			
Average height	5,5 m			
Angular retaining wall, average cross-sectional area (min. = 1,8 m²; max. = 9,5 m²)	7,38 m ²			
Production standard concrete C20/25	1.107 m ³	2,4 t/m ³	657 MJ/t	1.745.518
Transport concrete from concrete factory to construction site	20 km	2.657 t	2,5 MJ/tkm	132.840
Production concrete reinforcing steel ST 500/550, 70 kg/m³ for angular retaining wall	77,49 t		27.690 MJ/t	2.145.698
Transport structural steel to construction site	50 km	77,49 t	2,5 MJ/tkm	9.686
Production angular retaining wall (excavator, wheel loader, concrete pump etc.)	1.107 m ³		15 MJ/m ³	16.605
Soil exploitation by backhoe 8.500 m³	5.146 m ³		7,6 MJ/m ³	39.110
Soil transport 10.292 t, transportation distance 15 km	15 km	10.292 t	2,5 MJ/tkm	385.950
Soil insertion by bulldozer, layer thickness 0,30 m	5.146 m ³		8,98 MJ/m ³	46.213
Soil compaction by roller compactor, layer thickness 0,30 m	5.146 m ³		5,40 MJ/m ³	27.790
Total CED (GJ)				4549 GJ

The road construction example

A second example to compare traditional construction work with a modern geosynthetic solution is dealing with the subbase or base course improvement in road construction at a district road close to the city of Aix-la-Chapelle, Germany. Fig. 7 shows the base soil improvement by milling a little percentage of binder (lime/cement) into the soil. Fig. 8 demonstrates the geogrid alternative for base soil reinforcement.

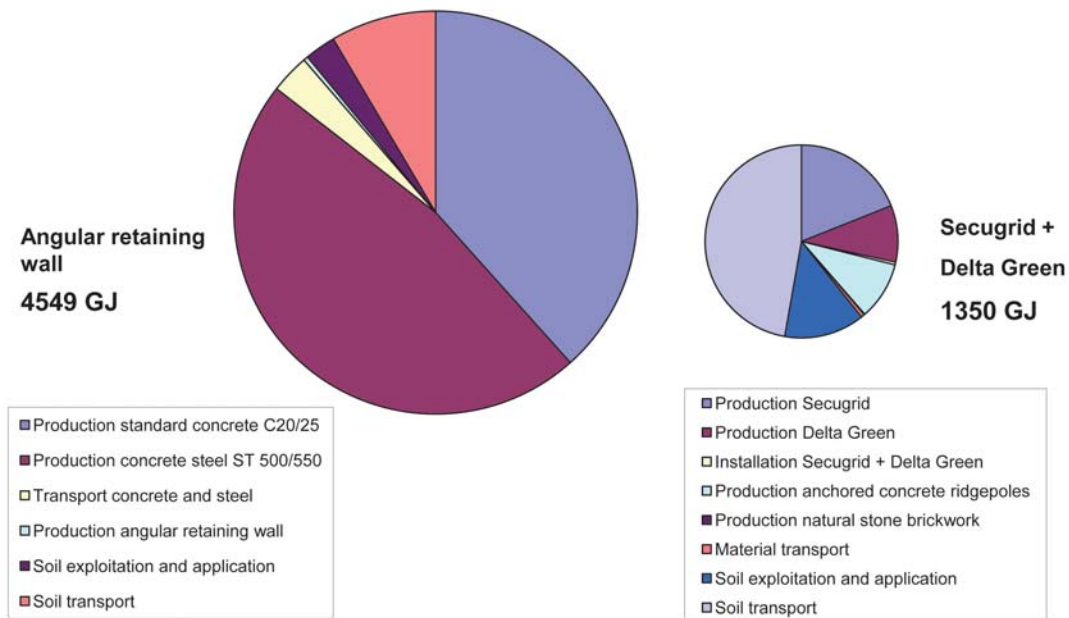
For the new construction of this district road, a considerable advantage of the geogrid solution in comparison to the use of lime, cement and concrete became apparent in the form of a considerably lower CED and CO₂ emission. One of the main reasons is the very small amount of geosynthetics made of polypropylene (PP) that was required, besides the high specific CED per kilogramme of PP. Only 0.67kg of PP per cubic metre of soil were required for the equivalent of one cubic metre of stabilised soil, on the basis of a mass per unit area of the geogrids of 200g/m² PP and a layer distance of the geogrid of 30cm.

In order to allow for a comparative assessment, an average value pursuant to the Recommendation 551 of the German Road and Transportation Research Association [FGSV-Merkblatt 551 (2004), in German] of 3.5% by mass was considered for the addition of fine ground lime and of 4% by mass for the addition of lime hydrate. This corresponds to a 70-80kg of fine ground lime or lime hydrate per m³ of soil at a moisture density of approx. 2000kg/m³. The production of the much larger amount of fine ground lime required has obviously negative effects on the cumulated energy demand and the CO₂ emission. The results for CED and CO₂ emission are shown in Fig. 9, giving an about 5.4 times less CED and an about 27(!) times less CO₂ emission of the geogrid alternative. Furtheron, there is no groundwater impact or air pollution caused by lime/cement dust when using geogrids for base soil reinforcement.

Project: Gänsbergspange Idstein

Cumulated energy demand (CED)

Comparison: Concrete angular retaining wall and Secugrid + Delta Green



Project: Gänsbergspange Idstein

CO₂-emissions

Comparison: Concrete angular retaining wall and Secugrid + Delta Green

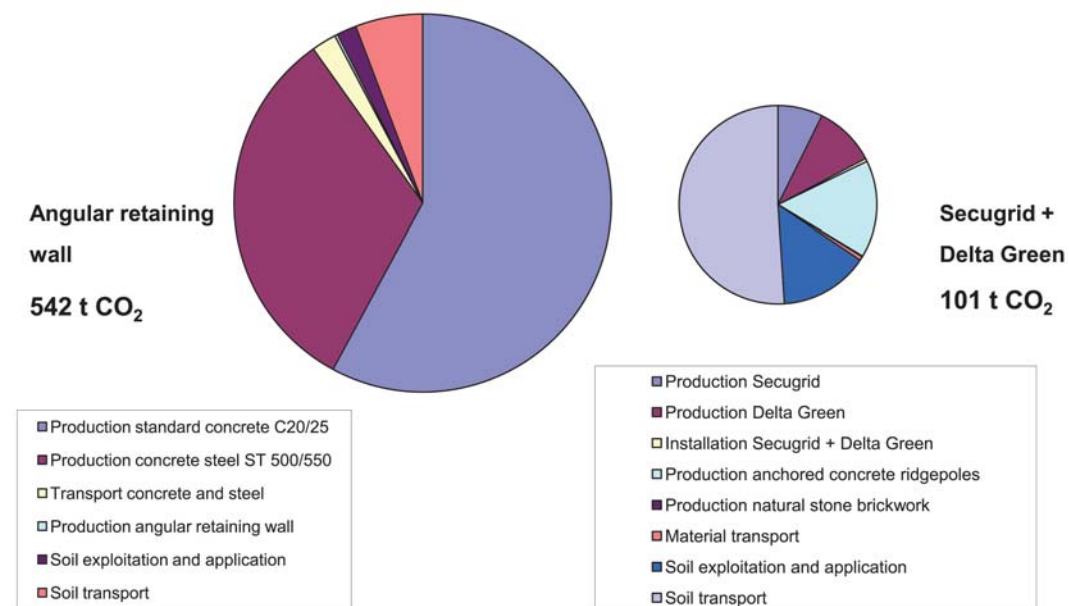


Fig. 6: Cumulated energy demand (CED) and CO₂ emissions at Gänsbergspange near Frankfurt, Germany



Fig. 7: Example of base soil improvement by milling of binder (lime/cement) into the soil

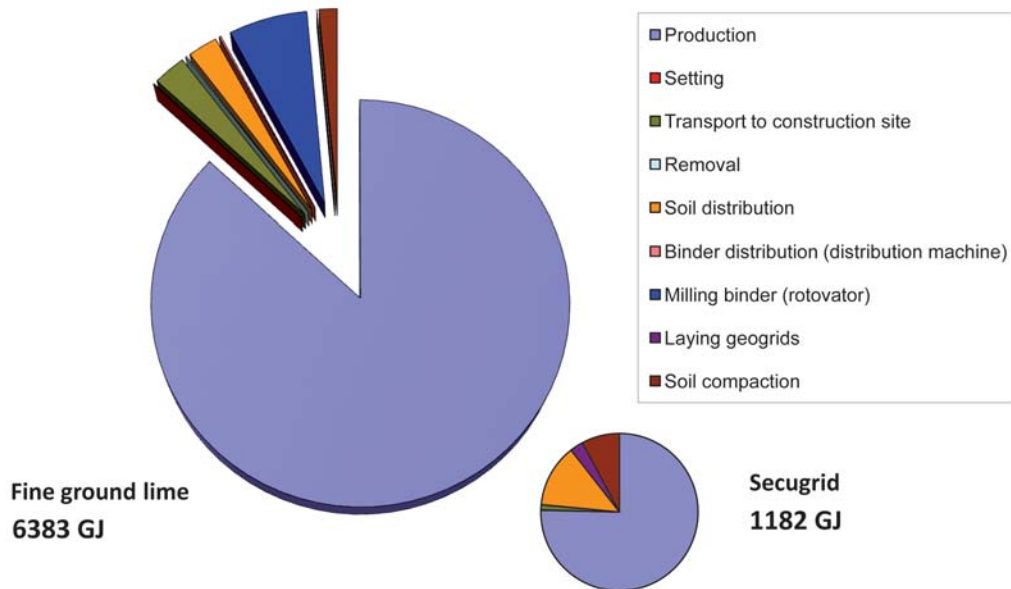


Fig. 8: Example for base soil reinforcement with a biaxial polypropylene geogrid

New construction of the district road K34 (bypass between K30 and B264 Würselen), district Aachen, 2008

Cumulated energy demand (CED):

Comparison: Soil compaction with fine ground lime versus geogrid solution



New construction of the district road K34 (bypass between K30 and B264 Würselen), district Aachen, 2008

Cumulated CO₂-Emissions: Comparison

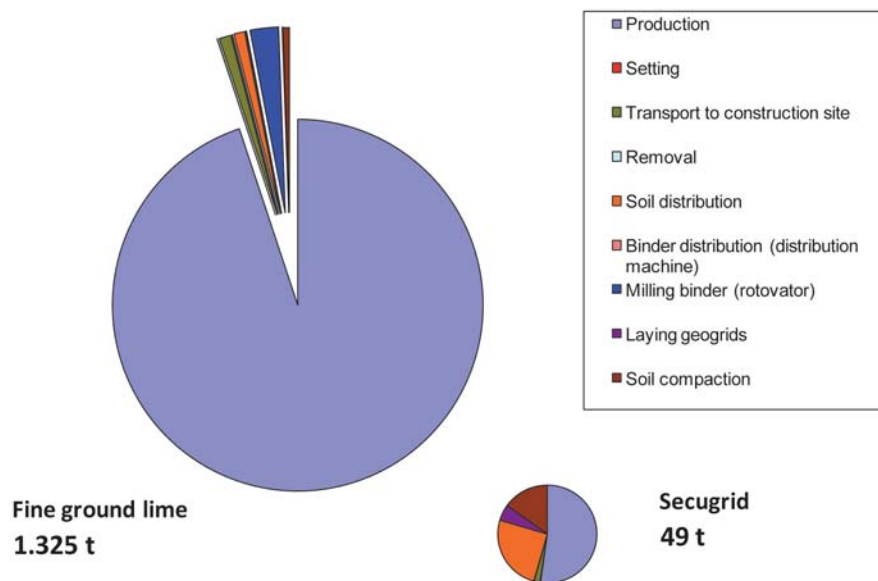


Fig. 9: Cumulated energy demand (CED) and CO₂ emissions at district road K34, district Aix-la-Chapelle, Germany, 2008

Conclusion

The global demand for reduction of energy consumption and reduced emission of climate related gases like CO₂ and CH₄ are big challenges for the construction industry, too. Economical and ecological advantages based on cost savings and dramatical reduction of handling of soil masses or "green" solutions by using construction methods with geosynthetics are already well known. A next step to demonstrate ecological advantages is given by comparing two infrastructure construction examples which document that the geosynthetic alternatives have a lower environmental impact due to much less cumulated energy demand (CED) and CO₂ emissions. These results are site, product and construction specific. But there is a good chance that the comparison of other construction solutions will show the same advantages. For the future it is recommended to consider the costs of CO₂ emission certificates when comparing different offers for a construction job to identify the most suitable solution for the environment.

Acknowledgement

The author thanks Dr. Thomas Egloffstein for his detailed work on the ecological comparison and evaluation of traditional construction methods and alternative designs with geosynthetics. On the basis of two NAUE projects, he has investigated the cumulated energy demand (CED) and the CO₂ emission of the traditional construction and of an alternative geosynthetic solution. The original work has been published by Dr. Thomas Egloffstein in the journal "geotechnik" of the German Geotechnical Society – geotechnik 32 (2009) Nr. 3. The tables in this paper are taken from Dr. Egloffstein's presentation at a Geotechnical Seminar on Geosynthetics Applications in September 2009 at the University of Gdansk.

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