# Comparison of the $CO_2$ Record of Different Slope Stabilization Methods

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**Abstract.** In times of increasing concern for the environment, the $CO_2$-footprint method is widely accepted to evaluate the use of greenhouse emitting production processes for a given product. This allows for comparisons between products and makes environmentally friendly choices of a product more transparent to decision makers.

In the field of slope stabilization, the high tensile steel wire mesh TECCO® in combination with soil or rock nailing is the state of the art in many countries. Compared to shotcrete, load transfer capacity is equal or higher. The open mesh leaves enough space for plants to grow through the system.

Recent $CO_2$-footprint evaluation taking into account production and transport of the material of an equivalent slope stabilization measure shows that the TECCO® system has a very low $CO_2$-footprint. The methods used for assessing the impact were, the level of carbon dioxide emissions from burning of fossil fuels as well as all other emissions which contribute to climate change. These other emissions have been recorded and weighted according to their specific contribution to give an overall index, "Global Warming Potential" (GWP). Compared to shotcrete, the $CO_2$-footprint of the mesh solution is 4–5 times lower! One reason for the good result is the high $CO_2$-emitting level of concrete in general. Furthermore, less material weight and also transport costs for the same stabilizing effect of the product on the slope also account for a better $CO_2$ balance of the mesh solution.

## 1 Introduction

The flexible TECCO® slope stabilization system is a proven protection system using a high-tensile steel wire mesh in combination with soil or rock nails for stabilizing slopes endangered by slides and break-outs in loose and solid rock. Special spike plates actively brace the system against the subsoil, positively influencing the deformation behavior of the protection system. This is an open, transparent system with no possibility of hydrostatic water pressure building up behind the mesh covering (Tables 1, 2 and 3).

The TECCO® system offers an alternative approach for slope stabilization compared to anchored, reinforced shotcrete. Due to the fact that the TECCO® system requires less construction materials, it can be expected that this approach accounts less for climate change than regular methods do. This was clearly confirmed in a study done by the Institute of Civil and Environmental Engineering at the University of Applied Sciences Rapperswil (HSR), Switzerland.


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**Table 1.** Used materials in flexible facing solutions.

| TECCO – system | | Material | Weight (kg) |
|---|---|---|---|
| Pinning (WT 32 gross) | Nail = 4.0 m | Steel | 1817.3 |
| | Nail = 6.0 m | Steel | 4088.9 |
| | Injection for nails | Cement, w/c = 0.4 | 23400.0 |
| Wire mesh | TECCO mesh | High-strength wire | 1963.6 |
| | Corrosion protection: galvanization | Zinc | 169.6 |
| | Corrosion protection: galvanization | Aluminium | 8.9 |
| | Gripping plate | Sheet steel | 495.0 |
| | Corrosion protection for gripping plate | Zinc coating | 123.8 |
| | Press claws | Steel | |
| | Corrosion protection | Zinc coating | |
| | Stranded rope (as side guys, top/bottom) | High-strength wire | 100.0 |
| | Corrosion protection for stranded rope | Zinc coating | 0.5 |
| | Spiral rope anchor = 4.0 m (top/bottom) | High-strength wire | 42.4 |
| | Corrosion protection for spiral rope anchor | Zinc coating | 0.2 |
| | Injection for spiral rope anchors | Cement | 896.0 |
| Planting | TECMAT erosion protection mat | Polypropylene | 714.0 |
| **Total material weight** | | | 34 *t* |

Materials used for a slope stabilization structure constructed using flexible TECCO® wire netting for a slope 100 m long.

**Table 2.** Used materials in hard facing solutions.

| Shotcrete placement | | Material | Weight (kg) |
|---|---|---|---|
| Pinning (WT 28 gross) | Nails = 4.0 m | Steel | 1081.9 |
| | Nails = 5.0 m Nails | Steel | 6713.7 |
| | Injection for Nägel | Cement, w/c = 0.4 | 40350.0 |
| Shotcrete | Total shotcrete {spraying loss ∼25%) | | 564360.0 |
| | Clips | Steel | 6324.8 |
| | Top plate | Steel | 589.2 |
| | Corrosion protection for top plate | Zinc coating | |
| Drainage | Drainage pipes | PVC | 64.0 |
| **Total material weight** | | | 619 *t* |

Materials used for a slope stabilization structure constructed using shotcrete placement for a slope 100 m long.

**Table 3.** Standard processes.

| Material | Description | Unit | C02 - fossil | GWP |
|---|---|---|---|---|
| *Steel* | | | | |
| Reinforcing steel | 63% converter steel, low-alloyed, 37% electric steel, unalloyed and low-alloy | [kg C02/kg] | 0.54 | 1.25 |
| Low-alloyed converter steel | This process produces primary steel | [kg C02/kg] | 0.72 | 1.7 |
| *Cement* | | | | |
| Portland cement, strength class Z 42.5, at plant | 90% clinker, 5% base additives, 5% plaster | [kg C02/kg] | 0.764 | 0.829 |
| *Shotcrete* | | | | |
| Concrete, exacting | 375 kg cement, 150 kg water, 1880 kg gravel | [kg C02/kg] | 0.121 | 0.135 |
| *Transport* | | | | |
| Truck, 28 t | | [kg C02/tkm] | 0.174 | 0.223 |
| Transoceanic freight | | [kg C02/tkm] | 0.0001 | 0.011 |
| *Coatings* | | | | |
| Zinc | Zinc for zinc coating | [kg C02/kg] | 0.483 | 2.46 |
| Aluminium | Aluminium for corrosion protection | [kg C02/kg] | 1.82 | 11.7 |
| *Others* | | | | |
| Drainage pipes for the shot-crete | Polyvinyl chloride pipes for draining the slope | [kg C02/kg] | 0.02 | 2.16 |
| Erosion protection mat | Liner to go underneath the Tecco mesh made of polypropylene | [kg C02/kg] | 0.002 | 2 |

List of the standard processes used as well as their environmental impacts.

## 2 The TECCO® High-Tensile Slope Stabilisation System

The use of wire meshes and wire rope nets for flexible slope stabilization has stood the test in many cases and frequently offers an alternative to solid concrete or shotcrete constructions. The open structure of meshes and nets enables the entire surface to be grassed over. Most often used for slope stabilization are wire meshes with a tensile strength of ca. 50 kN/m, respective wires from ca. 500 N/mm$^2$. Taking into account an economic nail spacing however, these are often unable to absorb the occurring forces and transfer them precisely to the nails.

The development of a wire mesh of high-tensile steel with a wire tensile strength of at least 1770 N/mm$^2$ offers an interesting possibility for efficient slope stabilization which can be dimensioned using adapted soil and rock static dimensioning models.

In principle the TECCO® slope stabilization system comprises the following elements:

- High-tensile TECCO® steel wire mesh
- TECCO® system spike plates
- Standard soil or rock nails available on the market, e.g. type GEWI, TITAN or IBO.

TECCO® high-tensile steel wire mesh used as standard for slope stabilization consists of a 3 mm thick high-tensile steel wire coated with aluminum-zinc for corrosion protection (GEOBRUGG SUPERCOATING®). The 83 mm × 143 mm diamond-shaped mesh forms are produced by a simple twisting process. The TECCO® steel wire mesh has a tensile strength of at least 150 kN/m. The three-dimensional structure of the mesh positively influences the mesh-subsoil interaction. Together with a resulting favorable friction this also offers a good basis for grassing over using hydro or spray seeding.

In form, size and bending strength, the diamond shaped system spike plates were adapted to the TECCO® mesh through numerous bending, punching and shearing tests to achieve optimal supporting behavior of the stabilization system. Close contact and where possible by lightly pressing-in the spike plates, the mesh can be optimally braced against the subsoil to be stabilized.

## 3 Method

### 3.1 Basic Principle

The basic principle for this study is the method of Life Cycle Assessment (LCA) which analyses the overall impact to the environment of a structure from the production of the raw materials to the disposal of the structure as described in ISO 12040:2006 and ISO 14044:2006. In contrast to LCA, our analysis focuses on emissions relevant for climate change, emissions characterized by their «Global Warming Potential» (according to Guinee et al. 2001). To indicate this focus we refer to our study as «$CO_2$ - Footprint».

### 3.2 Example Slope

The climate relevant emissions were estimated for two comparable slope stabilization systems and an example slope with a height of 8.5 m and a length of 100 m: One with the TECCO® system and one with a conventional shotcrete cover. The analysis of the life cycle is limited to the production of the construction materials and their transport to the construction site since no significant differences in climate relevant emissions from construction, operation, maintenance, removal and disposal can be expected (Figs. 1 and 2).

**Fig. 1.** TECCO® mesh and system spike plates

**Fig. 2.** Example of application in Queensland, Australia

### 3.3 Used Materials

The materials listed in the tables below were used in these two structures. These quantities correspond to a stabilization structure consisting of a slope 100 m long in each case as represented in the diagrams shown in Fig. 3.

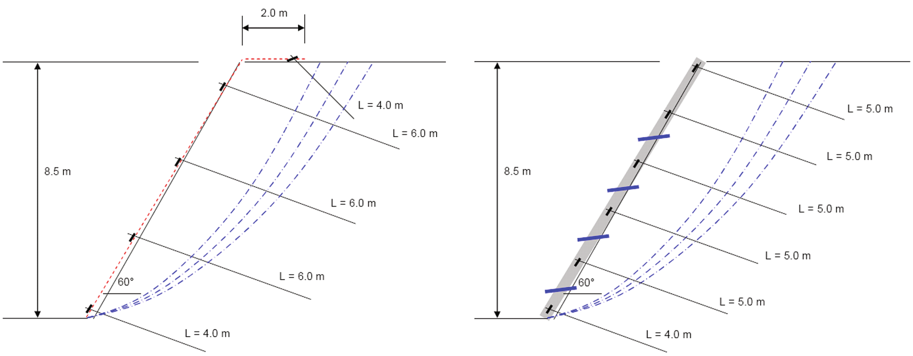


**Fig. 3.** Slope stabilization with flexible TECCO® mesh (left) and shotcrete (right)

### 3.4 System Definition

The service life analysis will be limited to the manufacture of the building materials and their transport to the construction site. Construction, operation, maintenance, removal and disposal will not be taken into consideration (see Fig. 4).

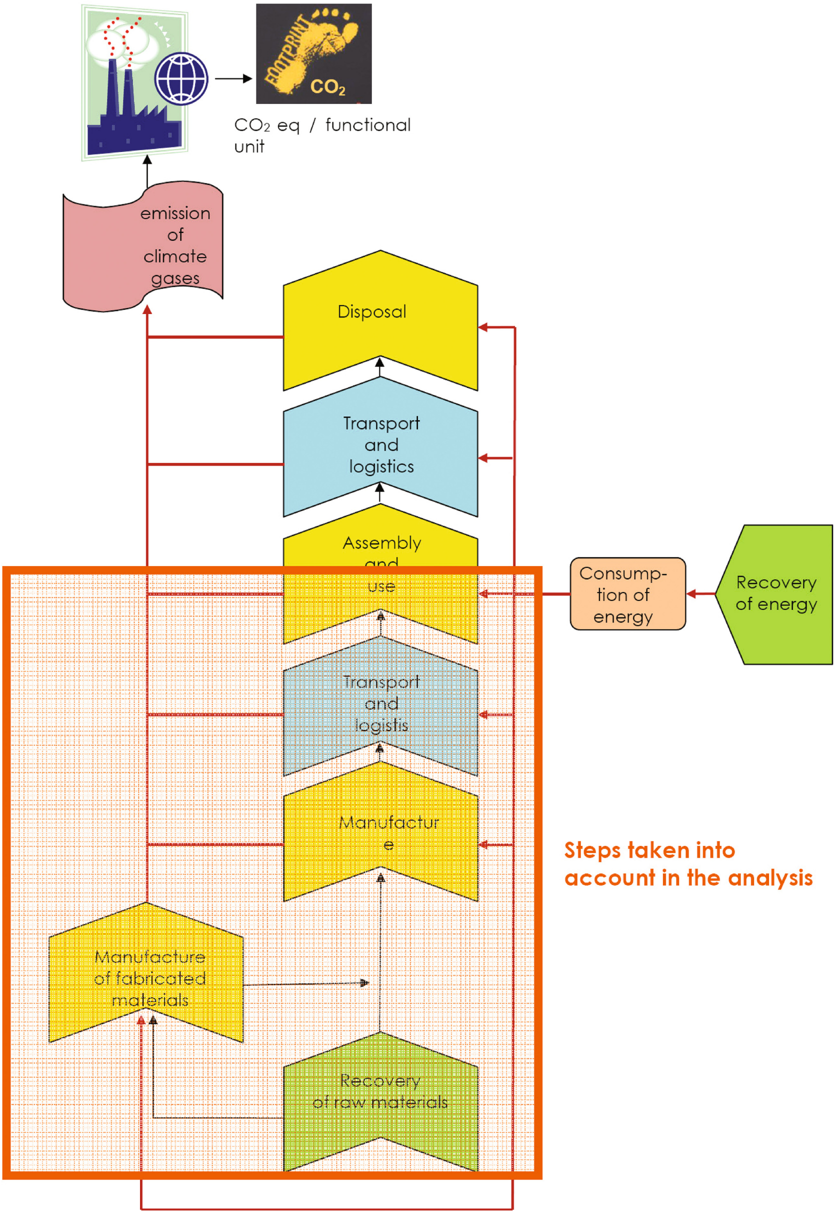


**Fig. 4.** Life cycle of a product and CO2 footprint (schematic diagram)

This definition is based on the following considerations:

- Studies published on life cycle assessment of structures are based on the assumption that the creation of the structure will only make a relatively small contribution towards the pollution of the environment. Kasser (1998) and Geiger and Fleischer (1997) come to the conclusion that in the case of residential buildings, less than 1% of the cumulative energy demand of a building can be attributed to construction. The construction of the structures considered here is not expected to result in (relatively) higher energy expenditure.
- It has been assumed that in general, there will be no expenditure on operation and maintenance.
- When the two structures are removed, it is mainly steel and concrete which will need to be dealt with. If these two waste materials are collected separately, then their processing and disposal will only result in very low energy consumption and thus only to a low level of emissions which might affect climate change.

In addition, the following processes involved in the manufacture of building materials were not taken into consideration:

- The galvanizing of the TECCO® mesh: here, only the manufacture of the zinc or aluminum coating has been taken into consideration. However, the energy consumption associated with galvanizing itself has not been taken into consideration.
- The refinement of the steel for the TECCO® mesh.

This simplification is necessary as these processes cannot be assessed using standard data.

However, it can be assumed that the energy consumption associated with galvanization and refinement is negligibly low compared to the energy consumption associated with the steel manufacturing process.

### 3.5 Data Used as a Basis for the Life Cycle Inventory Analysis

The following table provides information on the processes used and the associated environmental impacts.

The emissions from the manufacture of materials which might affect climate change (incl. the recovery of materials, the manufacture of fabricated materials and the supply of energy) as well as from transport processes have been taken from the Ecoinvent database from the Swiss Federal Institute of Technology (ETH) domain (see Ecoinvent center 2007).

Within the context of a conservative estimate of emissions (consideration of the “worst case scenario”), in case of doubt, processes which produce the highest level of environmental pollution will be chosen in each case. This includes above all:

- The selection of distances and means of transport. These have been based on an average distance of 100 km for suppliers from Switzerland, 500 km for suppliers from Germany and 700 km for suppliers from the rest of Central Europe. A (28 t) truck has been used as the means of transport for all journeys from European destinations. Transport from China has been based on a distance of 8000 km for transport by ship and 500 km for transport by truck.

- The selection of steel grades: as no information was available on the proportion of recycling and alloying, the process of manufacturing 'low-alloy oxygen steel' which creates a comparatively high level of emissions has been taken as a basis.

### 3.6 Method for Assessing Impact

The emissions which might affect climate change have been shown by the level of carbon dioxide emissions from the burning of fossil fuels (in kg of "$CO_2$ - fossil") on the one hand. On the other hand, all the emissions which contribute towards climate change have been recorded and weighted according to their specific contribution - relating to carbon dioxide as a reference variable - and added together to give an overall index. This overall index is known as the "Global Warming Potential" ("GWP" for short); the unit in which it is measured is kg $CO_2$ equivalent. This method of assessment has been used as part of the Life Cycle Assessment in many studies and is internationally recognized (see Guinee et al. 2001 and Frischknecht et al. 2003).

## 4 Results

The comparison of the total climate relevant emissions during the life cycle of the two structures clearly shows that the TECCO® system accounts significantly less for the greenhouse effect than the anchored shotcrete cover (see Fig. 5). This is the case for both

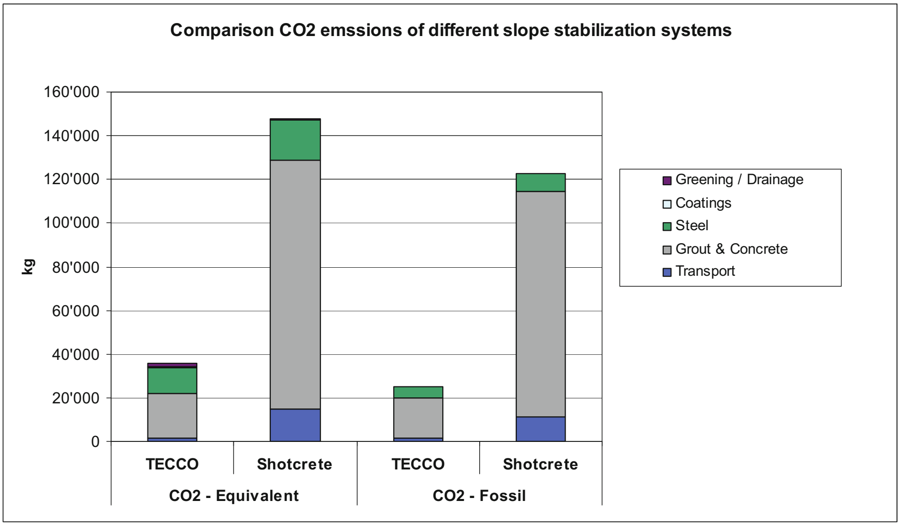


**Fig. 5.** Climate relevant emissions during the life cycle of two comparable slope stabilization structures built with two different methods.

«$CO_2$ - fossil» and the «Global Warming Potential (GWP)». The environmental impact of the TECCO® system is approx. 4–5 times smaller with both evaluation methods.

The difference can be explained with the differences in the used quantities of materials. In the structure executed with anchors and shotcrete, approx. 14’700 kg of steel, 40’300 kg of cement and 564’000 kg of concrete are required. For the same slope with the TECCO® system, approx. 8’100 kg of steel and 23’400 kg of cement are used. These differences have a big effect on the environmental impact due to both the production of the materials and also their transport to site.

For the TECCO® system it can be concluded that:

- The anchorage accounts more for the greenhouse effect than the mesh and the greening.
- The used cement has the biggest contribution to the total environmental impact, followed by the steel (in relation 3 to 1).
- The effect of the transport is relatively small with 5% of the total impact.

For the system with the anchored shotcrete cover:

- The shotcrete cover accounts more to the greenhouse effect with 70% of the total environmental impact than the anchorage with approx. 30%.
- The used cement has the biggest contribution to the total environmental impact, followed by the steel (in relation 12 to 1).
- The effect of the transport is with approx. 9% more significant than the impact of the steel.

## 5 Conclusion

On the base of these results, it can be concluded that the TECCO® system accounts less for the greenhouse effect than a comparable slope stabilization system executed with anchored shotcrete. The difference between the two systems is significant as the here presented study shows. The environmental impact of the slope stabilization with a TECCO® system is approx. 4–5 times smaller than with shotcrete.

Since the difference between the two systems is quite big, a detailed analysis considering all the processes during the life cycle and a more detailed examination of the steel production and the transports would not lead to fundamentally new findings. This can be stated for the assumptions of life span, maintenance and repair. The result is robust here as well.

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