Carbon footprint in geotechnical constructions and geosynthetics impact on the environment

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ABSTRACT: The carbon footprint as the equivalent of the overall impact of human activity on the environment is a useful expression. Currently, high visibility require these values to determine the negative impact of human activities on the environment. In general, the term carbon footprint means the volume of gas emissions that affect the climate of the planet, while the emissions are caused by human activity. Even in our time is not uniform definition of carbon footprint, therefore it can be understood in different views. Also, in the article we will focus on the comparison of the various geotechnical structures and the impact of geosynthetics in these structures.

Keywords: carbon footprint, greenhouse gas, geotechnical construction, geosynthetics, CO_2, terrace wall, retaining wall

1 INTRODUCTION

In terms of the Regulation (EU) No 305/2011 of the European Parliament and of the Council Annex 1 every building must satisfy the essential requirements. These requirements in addition to mechanical resistance and stability of buildings and safety in case of fire are not least the requirement for the sustainable use of natural resources. And just today, when the climate impacts of human activity increasingly have been included in high-level European and global community, we the producers of designs building structures have to also begin to fulfil these requirements. Therefore, this article compare geotechnical structures regarding their impact on the environment.

2 ANTHROPOGENIC CARBON DIOXIDE EMISSIONS IN THE SLOVAK REPUBLIC

The share of the Slovak Republic in global anthropogenic greenhouse gas emissions is roughly 0.2%. The average annual emissions per capita currently are 6.5 tons of CO_2 (it was 11 tons in 1990). This is lower number than the average in OECD countries. Nevertheless, the Slovak Republic is among the twenty states with the highest CO_2 emissions per capita. Slovakia produces roughly 33,680,000 tons of CO_2 every year.

Compared to the steel industry, civil engineering is only the top of the glacier. The value of CO_2 emissions released in U.S Steel company (the biggest steelworks company in Slovakia) is between 8,0 and 9,0 million tons of CO_2 per year. In the case of the automotive industry (active producers are KIA, Hyundai, VW, Audi, Škoda and Land Rover starts production in the near future) the data are various, depending on the amount of input data. If only car production itself is taken into account, CO_2 emissions per car will reach around 89 kg. However taking into account the extraction and production of source materials, it is about 200 kg CO_2 per car. As 1 million vehicles every year are produced in Slovakia, the mass-produced emissions from this activity will reach about 200,000 tons.

Unfortunately, similar data as we have from the automotive or steel industry are not available obtained from construction industry during construction works. It is known how many emissions each building produces during its design lifetime, but it is unknown how many emissions are produced during construction. We want to change it, and we want to start with geotechnical constructions.

3 ASSESSMENT OF GEOTECHNICAL STRUCTURES

In terms of sustainable exploitation of natural resources, buildings must be designed, constructed and disposed in accordance with sustainability of natural resources. Particularly, to ensure the reuse or recycling of buildings and their parts after demolition, the durability of buildings and the use of ecological recycled materials in these buildings. Also, in terms of hygiene, health and the environment, buildings must be designed and constructed in such a way that during their life cycle they do not endanger the hygiene, health and safety of workers, residents or the environment. In the course of building life cycle, use, even during demolition, carbon dioxide has not unduly great impact on the quality of the environment or on the climate.

The designer should take into account all aspects of design, construction, construction use, and final demolition, taking into account their environmental aspects.

Life Cycle Assessment (LCA) involves the compilation and the evaluation of inputs and outputs of possible environmental impacts of the product system throughout its life cycle. The term product means any service or product. LCA takes into account the entire lifecycle of the product, from mining and raw material acquisition, through energy and material production, its use and recycling after the end of its lifetime to final disposal. According to such systematic overview and perspective, the potential environmental burden can be identified and then it is possible to avoid shifting it between the life cycle stages or the individual processes. LCA uses an iterative approach. This is a repetitive technique where the results of other phases are used in each LCA phase. The iterative approach within phases and between phases contributes to the completeness and consistency of the study and the results obtained.

The life cycle assessment (LCA) of the product mainly uses scientific approaches. LCA decisions are therefore primarily based on natural sciences. However, where this is not possible, decisions shall be made on the basis of other scientific approaches or international conventions.

4 THE INFLUENCE OF GEOSYNTHETICS MATERIALS ON THE ENVIRONMENT

Even though we have not been accustomed to consider building structures with regard to the environment, it is good to know this impact. However we are not dealing only with geosynthetics materials today, I have aimed my attention to the environmental impact of these materials using the basic LCA methodology. The assessment was made on the basis of available data from the European Commission, producers of raw materials, generally known construction techniques and technical standards. Next, I will focus on basic geotechnical structures, which are most widely used in construction and where geosynthetics materials can be applied.

4.1 *Terrace wall and retaining wall*

As a model example, is chosen a support structure with a height of 6.0 m, which will serve to ensure the realization of a motorway in the slope (EN 14475). In order to comparison, I chose five basic and most widely used types of constructions:

- Type A: cantilever wall of reinforced concrete
- Type B: soil strengthened wall with semi-rigid facing (fittings)
- Type C: soil strengthened wall with semi-rigid facing (panels)
- Type D: gabion wall
- Type E: reinforced steep slope

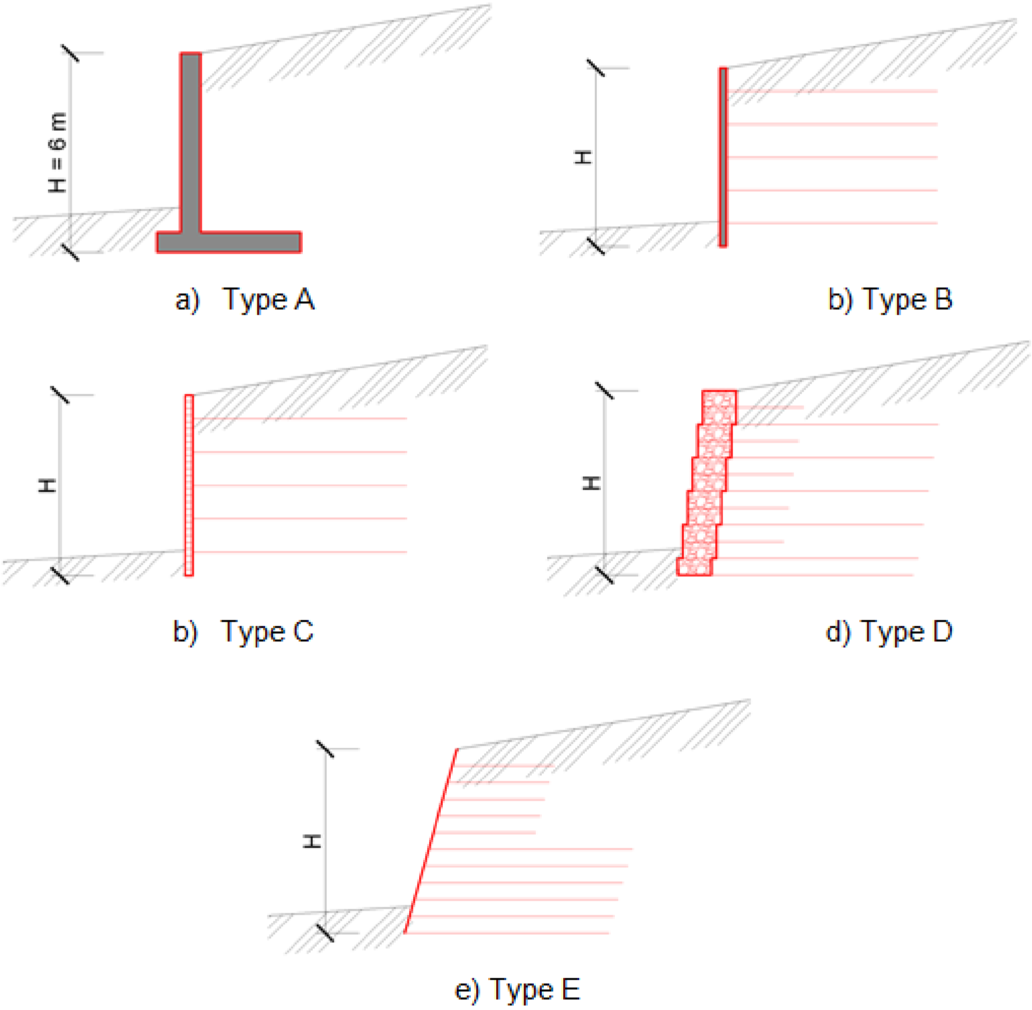

Figure 1. Supporting terrace / retaining constructions a) cantilever wall, b) soil strengthened wall with semi-rigid facing (fittings), c) soil strengthened wall with semi-rigid facing (panels), d) gabion wall, e) reinforced steep slope.

As it can be seen in the above sketches, these are really the most common structures that we have never thought of otherwise than economically. However, if we see discussed retaining walls in terms of their environmental impact by the LCA methodology described in EN ISO 14040 and EN ISO 14044 including the examples in TNI ISO / TR 14049, we will get the following results. The whole process from production to the end of the life of the structure was divided into three basic parts according to the methodology:

- Part 1: Acquisition of raw materials and production processes of basic materials,
- Part 2: Import of basic materials for the construction and realization of the construction,
- Part 3: Operation and removal of the construction.

In the first part of the calculation has been included the impact on the environment, that is the amount of CO_2 from the extraction of raw materials and the production of basic materials, including the import of material into the plant and the whole process of production of input materials, including hall heating, CO_2 generation in the electricity production process, etc. (Frischknecht, Büsser-Knöpfel, Itten, Stucki and Wallbaum, Paris 2013). From the given results (Figure 2) it is shown that the least efficient building construction in terms of the environment for the production of basic raw materials is a reinforced concrete wall. In the production of basic materials such as concrete and steel, approximately 75,000 g of CO_2 per meter of wall is produced. The most efficient construction of the wall is the use of a flexible front of geosynthetics materials, which produces approximately 3,500 g of CO_2 per meter of wall. Wall constructions made of semi-rigid facings or gabion structures have approximately the same CO_2 production at a level of 10,000 to 15,000 g of CO_2 per meter of wall.

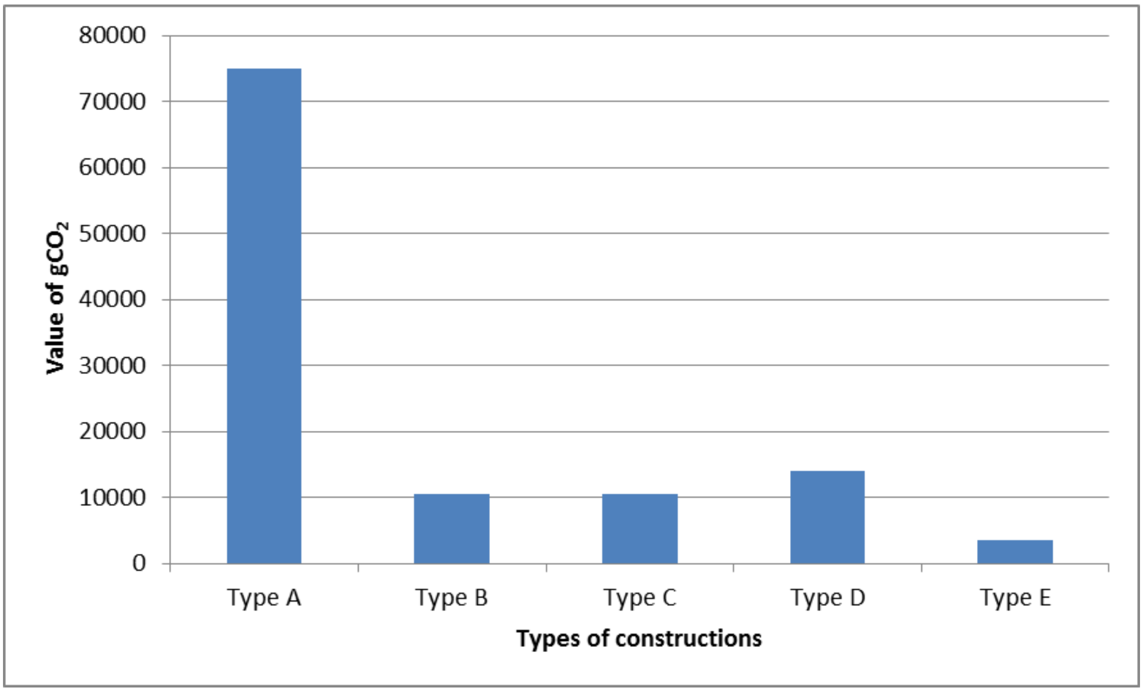

Figure 2. The value g of CO_2 in the extraction and production of raw materials and products of different types of terrace / retaining walls.

The impacts on the environment have been included in the calculation in the second part, that is the amount of CO_2 from imported raw materials and building materials, including their installation, in-site transport, excavation works and backfill up to final landscaping. The following formula was used to calculate CO_2 from transport:

$$CEDm = cm. \Sigma^{n}_{i=1}. Cedi. xi. Gi \qquad (1)$$

where CEDm = total carbon impact from transport of material from plant to construction in $kgCO_2$ per construction, cm = amount of building material in m3, i = type of transport (e.g. ship, truck, train, ...), CEDi = Carbon impact from transport in CO_2, xi = transport distance for specific type of traffic in km per amount, Gi = Fuel consumption for specific mode of transport in liter per km.

Figure 3. The value of gCO_2 in the transport and installation of basic materials and products of different types of terrace / retaining walls including earthworks.

From the given results (Figure 3) it is shown that the least efficient building construction in terms of environment for the transport of basic raw materials and construction is again reinforced concrete wall. During the import of concrete, steel, cladding and earthworks for the construction of a 6 meters high reinforced concrete wall length, about 33,000 gCO_2 per meter of wall is produced. The most efficient construction is the use of a semi-rigid face element - a piece of steel, where approximately 16,800 gCO_2 per meter of wall is produced for transport and construction. Following are the wall constructions made of semi-rigid facing elements - panels and reinforced slope (yielding cheeks), which have roughly equivalent CO_2 outputs of 18,600 gCO_2 per meter of wall. Less efficient in the given case are gabion structures with CO_2 production in the second phase at a level of about 28,400 gCO2 per meter of wall.

The impacts on the environment have been included in the calculation in part three. This is CO_2 from the operation of the structure to the removal of the structure after the end of its design life. Here, however, it must be remembered that this third part of the environmental impact is more interesting for building structures, not for geotechnical constructions. We assume that geotechnical constructions do not consume any energy during their lifetime and we also do not expect any necessary reconstruction work that would significantly affect the environment. From the given results (Figure 4) it is shown that the least efficient building construction from the point of view of operation and removal of the construction after the end of its lifetime is again a reinforced concrete wall. During the operation and removal of the structure, including the recovery of waste for further recovery and landfill, approximately 9,800 gCO_2 per meter of wall is produced. The most efficient wall constructions are the use of a semi-rigid face element - a fitting and a reinforced slope (pliable cheeks) in which approximately 5,000 gCO_2 per meter of masonry is produced and end-of-life. The following is the construction of a wall made of semi-rigid facing elements - panels having CO_2 production at a level of 6,000 gCO_2 per meter for the given phase 3. Less efficient in the present case are gabion structures with third stage CO_2 production at about 8,000 gCO_2 per meter of wall.

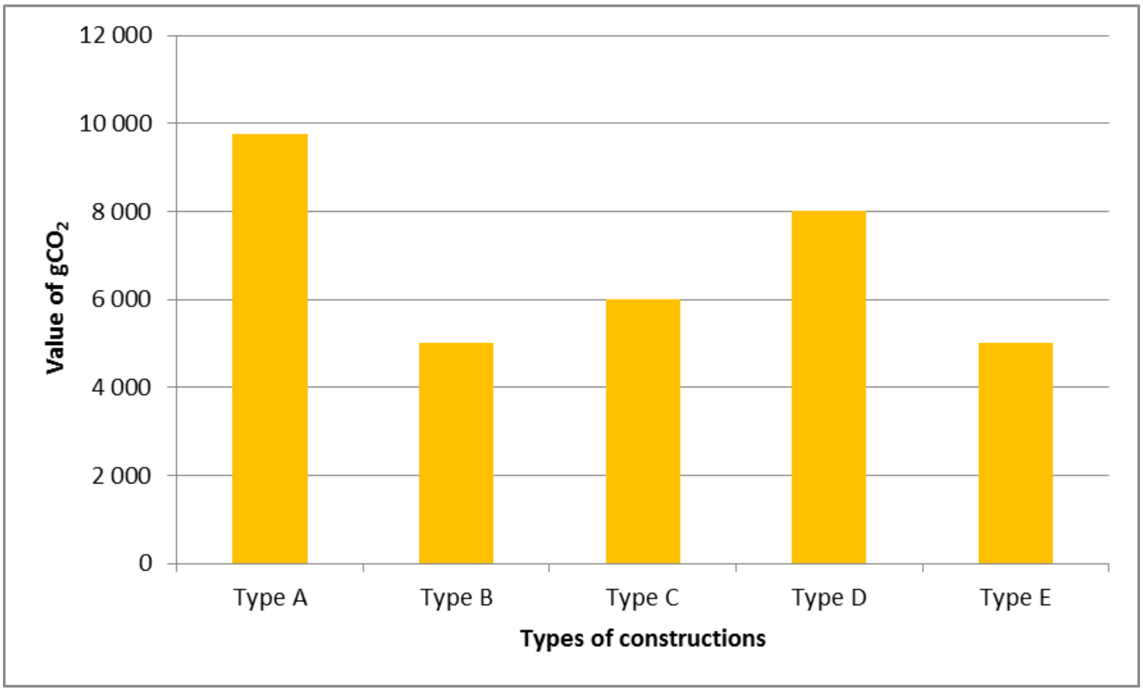

Figure 4. The value of gCO_2 over the life of a removal at the end of life of the various types of terrace / retaining walls including earthworks.

Taking into account all three previous stages where the selected structures are evaluated, from the extraction of the raw materials through the implementation to the end-of-life removal, we obtain the overall results. It follows from the sum of the partial results of phases 1 to 2 (Figure 5) that the least efficient building structure from the environmental point of view is a reinforced concrete wall. Throughout the lifetime, construction and removal of one 6 meters high reinforced concrete wall length, is produced about 117,800 gCO_2 per meter of wall. The construction of a wall using a geosynthetic reinforcement (flexible facing fortification) is the most effective, with a lifetime is produced approximately 27,100 gCO_2 per meter of wall, including construction and removal. The following are wall constructions made of semi-rigid facing elements - panels and fittings that have roughly equivalent CO_2 production at 32,400 to 34,900 gCO_2 per meter of wall. Less efficient are gabion structures with CO_2 production in all three phases at the level of about 50,400 gCO_2 per meter of wall.

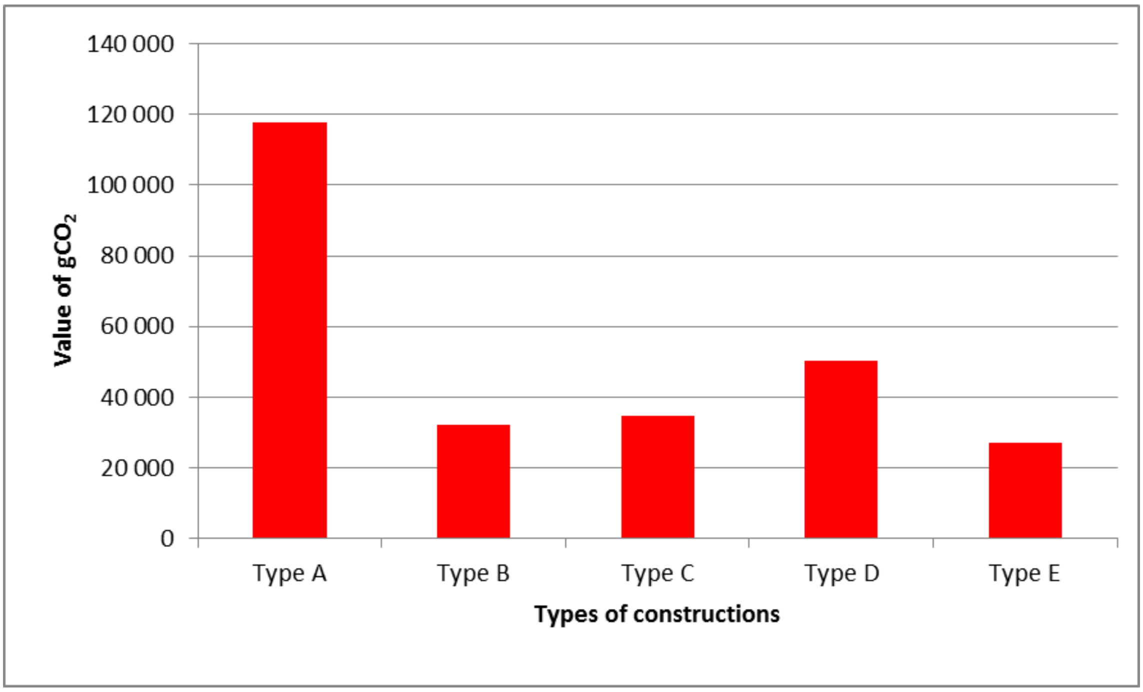

Figure 5. The total value of gCO_2 for all the processes of different types of terrace / retaining walls including earthworks.

At the same time, the following assumptions that have affected the previous calculations should be noted:

- For the calculation, input production values were used as input averages from producers,
- Data from the EURO IV emission standard (2005) was used to calculate the CO_2 production of construction machines, since not all construction machines follow the valid EURO VI (09/2014) emission standard,
- Standard transport distances were used to calculate the traffic, and in none of the examples were exceeded the standards set for transport distances.

The results above are, however, only indicative, as it is necessary to know the exact constructional procedures and traffic distances for accurate real results. Nevertheless, we can still create a vision of CO_2 production for a uniform methodology for assessing alternative designs.

4.2 *Geosynthetics clay layer*

The application of sealing of building structures or waste dumps is one of the best examples of efficient use of geosynthetics material. Figure 6 shows the amount of CO_2 produced in the production of geosynthetics clay mat (GCL) and the generation of CO_2 from the transport of material over long distances (Chulski, 2015). For comparison, the value of CO_2 production for the mining and import of natural clay material is given. It is clear from the chart that the impact on the environment is significantly lower at GCL imports from a distance of 3,000 km as compared to imports of clay material from a distance of 25 km. The unit of measurement in this case is kg CO_2 and hectare of the sealing area.

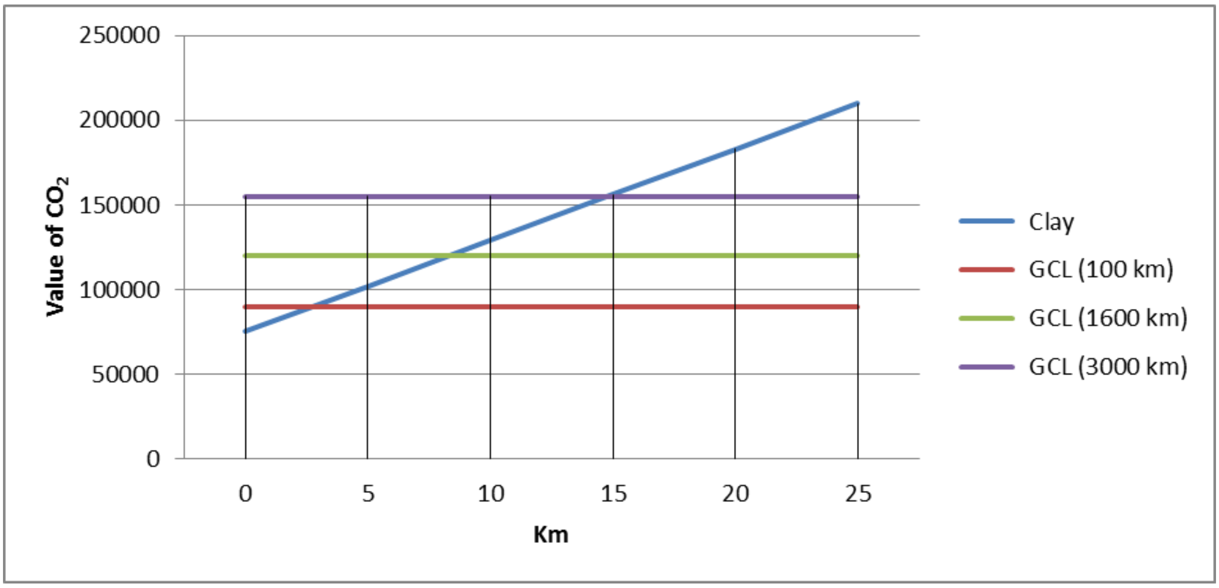

Figure 6. Comparison kgCO_2 emissions value for the clay seal and GCL.

4.3 *Other applications*

In the case of other applications (mentioned in Slovak Technical Standard STN 73 3040) this article does not refer to the least used geosynthetics materials, but because of the scope of the article there are graphically summarized all the other most widely applied applications of geosynthetics materials from separating and filtering geotextiles, through reinforcing geogrids to drainage geocomposites (www.fibertex.com).

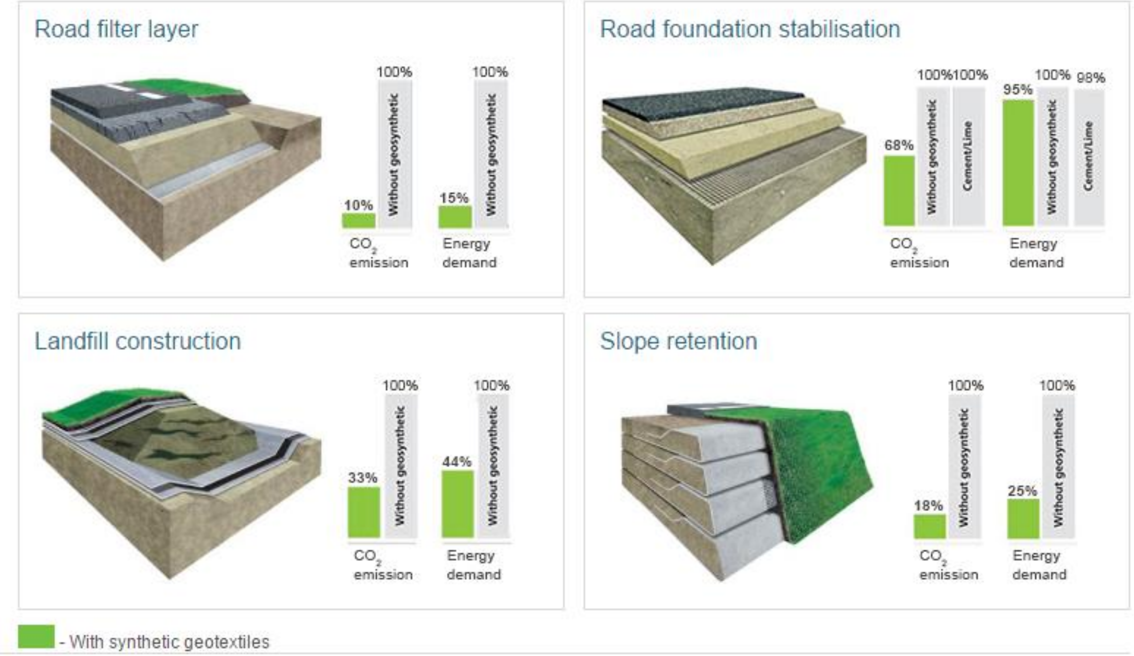

Figure 7. Summary of savings in CO_2 emissions and energy intensity structures in % with and without the use of geosynthetics.

5 SUMMARY

For the CO_2 production report, we prepared a table of average CO_2 production values for individual raw materials used in construction and geotechnics:

Table 1. Summary of CO_2 production of selected materials used in construction and geotechnics.

Raw Material / Product / Primary Material	Produce CO_2 in kg per 1 ton of material
Steel reinforced concrete	900 kg
Cement	900 kg
Concrete	400 kg
Steel	2,300 kg
Recycled steel	200 kg
Polypropylene (PP), Polyethylene (PE), Polyvinylchloride (PVC)	3,200 kg
Polyethylene (PET)	4,200 kg
Polystyrene (PS)	3,900 kg
Polycarbonate (PC)	9,000 kg

6 CONCLUSIONS

Geosynthetics materials have been used for decades to reduce construction costs. The benefits of these materials are also noticeable in their impact on the environment. Geosynthetics have not only lower CO_2 production to produce a comparable quantum of material than "standard" materials, but also lower transport consumption for construction, construction, and demolition after the end of their life.
Table 2 compares constructional constructions using "standard" and natural materials versus geosynthetics. The comparison refers to production, respectively. Savings of CO_2 produced from CO_2 from the exhaust gas of the vehicle. A passenger car with a gasoline engine and a consumption of 6.3 l per 100 km was considered as a vehicle.

Table 2. Comparison of CO_2 production versus transport.

Type of construction	Quantity	Saved kg of CO_2	Comparison with vehicle
Reinforcement wall vs. Concrete wall Height = 6.0 m	150 m	12,750 kg	86,732 km
Geosynthetics vs Nature material Lindfield	6,000 m2	72,150 kg	490,816 km
Geosynthetics vs Gravel Reinforcement of subsoil under embankment	20,000 m2	8,210 kg	55,850 km

Dioxide carbonate, mentioned in this article, is not only harmful gas produced during construction. Quantities of gases and solids such as hydrocarbons (HC), oxides of nitrogen (NOX), particulate matter (PM) and others are not mentioned because of the cell range. However, the more detailed values are evident from the EURO emission standards for construction machines and company literature of the producers of basic raw materials.
To conclude, I would like to summarize the basic knowledge from the field of geosynthetics with respect to the environment:
- The above comparisons show that geosynthetics have a significant impact on the reduction of the carbon footprint in construction,
- Geosynthetics have a higher CO_2 production compared to "standard" and natural materials (compared to tCO_2 per t units) but can significantly reduce their use,
- Also practice has shown that the use of geosynthetics materials reduces the cost of building structures.

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Web server www.fibertex.com.