Carbon Footprint Comparison of Geogrid Reinforced and Reinforced Concrete Retaining Walls in Turkey

D. Erten
Medipol University, Turkey (derten@medipol.edu.tr)
E. Güler*
Bogazici University, Turkey (eguler@boun.edu.tr)

ABSTRACT

Geosynthetics are playing an increasingly more important role in environmental and geotechnical applications, as local sources of natural barrier and drainage materials diminish. The purpose of this study is to compare the carbon footprint or equivalent greenhouse gas emissions of 3-meter, 4-meter and 5-meter high geogrid reinforced and reinforced concrete walls in kg of CO2 equivalents. The location of the wall is assumed to be in Turkey. The analysis found that, geogrid reinforced wall is expected to produce 69% less carbon for 3-meter high wall, 75% less for 4-meter high wall and 80% less for 5-meter high wall for average transportation distances. The largest component of the overall carbon footprint which creates the difference between two wall types is the amount of concrete and rebar used in the reinforced concrete wall. The production of concrete emits 55% and rebar emits 20% of total carbon footprint of reinforced concrete wall on average. The transportation footprint of two type of walls are almost identical.

1. INTRODUCTION

Nowadays, increasing the population of the world has a significant effect on raising the amount of greenhouse gases. Hence, beside the technical and economical items in a design, there is huge demand for a sustainable design which aimed for reduction of energy consumption and emission of climate related gases like CO2 and CH4. A material chosen for a sustainable construction techniques should ideally be available from a number of sources which the conventional material may not. Actually, a sustainable design aims to decrease the cost and pollution caused by a construction procedure and in the meantime, to increase the efficiency and lifetime of the projects.

In recent decades, geosynthetics have been considered as a proper material which can be useful for designing sustainable construction systems especially in the geotechnical applications. They are many types of geosynthetics which each one has its particular properties. Moreover, thanks to the polymer engineers, a civil engineer or contractor is able to demand a geosynthetic which is specially designed and prepared for a project with certain properties. For instance, we know that in a conventional method the clay core in a dam is a very critical part to prevent water flow. It is not easy to construct a clay core with exact desired properties and it is also expensive. Moreover, by the time the performance of the clay core may be decreased due to continues water seepage and change in the particle structures of the clay. In a new design with geosynthetics, the water flow can be stopped by putting a layer of geomembrane on the upper side of the dam. By this method, there is no need to clay core anymore, so it causes a huge save in the material, energy and cost.

For reduction of cumulated energy demand (CED) and CO_2 emission, and also for decreasing the costs, a system should be stabilized to determine the mentioned factors regarding the various materials and methods including both conventional methods and developed method by use of some new materials like geosynthetics. Life cycle assessment (LCA) and life cycle cost (LCC) are two major steps which make it possible to evaluate the various aspects of a design system.

In this study, the carbon footprint or equivalent greenhouse gas emissions of 3-meter, 4-meter and 5-meter high geogrid reinforced and reinforced concrete walls in kg of CO_2 equivalents per unit width of 1 m^2 will be compared. The location of the wall is assumed to be in Turkey.

2. LITERATURE REVIEW

Some studies on the sustainable design with geosynthetics were investigated. According to the results, by using geosynthetics in the design systems, the required material, cumulative energy demand, CO_2 emission and construction cost decrease significantly. In this literature review, the effect of sustainable design with geosynthetics has been investigated consisting of the following subjects: 1) Sustainable design and an introduction to the life cycle assessment and life cycle cost; 2) Design with geosynthetics for retaining walls; 3) Methodology to the CO_2 Calculations

2.1. SUSTAINABLE DESIGN AND AN INTRODUCTION TO THE LIFE CYCLE ASSESSMENT AND LIFE CYCLE COST

2.1.1. Sustainability Definition

Sustainability is a complex concept. The most often quoted definition comes from the UN Bruntland commission: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” In the charter for the UCLA Sustainability Committee, sustainability is defined as: “the physical development and institutional operating practices that meet the needs of present users without compromising the ability of future generations to meet their own needs, particularly with regard to use and waste of natural resources. Sustainable practices support ecological, human, and economic health and vitality. Sustainability presumes that resources are finite, and should be used conservatively and wisely with a view to long-term priorities and consequences of the ways in which resources are used.” In simplest terms, sustainability is about our children and our grandchildren, and the world we will leave them [web1].

2.1.2. Sustainable Design

In order to achieve a sustainable future in the building industry, Asif et al. (2007) suggest adoption of multi-disciplinary approach covering a number of features such as: energy saving, improved use of materials, material waste minimization, pollution and emissions control etc.. Peter (2012) suggests that there are many ways in which the current nature of building activity can be controlled and improved to make it less environmentally damaging, without reducing the useful output of building activities. A review of literature has identified three general objectives which should shape the framework for implementing sustainable building design and construction (Anon, 1998). These objectives are: 1) Resource conservation; 2) Cost efficiency; 3. Design for Human adaptation.

Considering the engineering and technical aspects of design in a geotechnical application, resource conservation and cost efficiency should be mentioned as two major factors in which are required for sustainable design. These can be evaluated by Life Cycle Assessment and Life Cost Assessment respectively. The human adaption factor may be analyzed by specialists in social sciences and the results should be considered in the final design.

2.1.3. Life Cycle Assessment

Life cycle analysis (LCA) is the systematic approach of looking at a product's complete life cycle, from raw materials to final disposal of the product (Anon., 1998). It offers a "cradle to grave" look at a product or process, considering environmental aspects and potential impacts (Feng, 2009). LCA makes it possible to compare various environmental or ecological effects such as energy consumption, CO_2 emission, and etc. in different design alternatives to approach the best solution.

2.1.4. Life Cycle Cost

Life Cycle Cost (LCC) analysis is a tool or technique that enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement cost (Langdon, 2006). Some useful software for LCA, LCC, and carbon footprint analysis can be mentioned as openlca, GaBi 4, SimaPro 7.3, SPOLD Data Exchange Software, etc. [web2].

Chulski (2015) investigated the sustainability of four different design method of a retaining wall. Life cycle assessment (LCA) and life cycle cost (LCC) analysis were used to evaluate the sustainability of the various designs. A hypothetical case study was used to determine the best all-around design in terms of sustainability, cost, and function using a consistent methodology including LCA in conjunction with LCC, using specific geographical boundaries to address geographic specificity, and maintaining cradle-to-grave boundary conditions. A retaining wall case study is an excellent lens for examining traditional materials and geosynthetics. The retaining wall may require various geosynthetics including geogrid, geotextile, drainage pipe, potentially geofoam, and geonet. These geosynthetics can be categorized within the four functions (separation, reinforcement, drainage, and filtration) and are more easily exchangeable with conventional materials for the function they serve within a retaining wall problem.

In the Chulski (2015) study, the design scenario includes a four-story building to be constructed at top of an existing hill, at the base which is an existing road. It is assumed that the building is set back from the wall such that surcharge pressure from the building do not act on the wall. To maximize the use of the land and land acquisition fees, the slope will be removed and retaining wall will be constructed and backfilled, thus providing more space as necessary for recreation or for parking, for example. The construction steps is illustrated in Figure 1 and Table 1 shows the variables used within the case study design.

The analysis considers two primary in-situ soil types, loose sand or stiff clay. For the presence design case with an excavation greater than 20 feet in depth, shoring will be required according to standards set by the Occupational Safety and Health Administration (OSHA). Since the shoring is same and uniform for the all design scenarios, it is not analyzed within the scope of this for LCA and LCC.

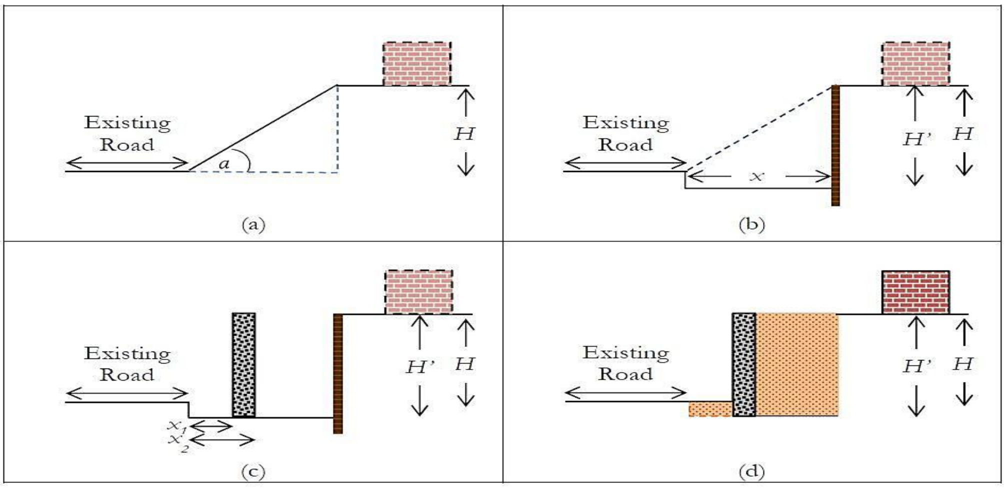

Figure 1: The retaining wall excavation illustrated in four stages: (a) prior to excavation, (b) excavation completed with temporary shoring, (c) wall constructed, and (d) temporary shoring removed and backfill placed (Chulski, 2015).

Table 1: Variables and constants used within the case study design (Chulski, 2015).

Symbol	Denotes	Equals
H	Height of initial slope	30 ft.
H'	Height of final retaining wall	35 ft. 4 in.
x	Distance from road to edge of excavation	90ft.
x_1	Distance from road to outside of retaining wall	Varies
x_2	Distance from road to inside of retaining wall	Varies
a	Angle of initial slope	18.4°

2.1.5. Design Alternatives

As it is shown in the Figure 2, design alternatives include traditional cast-in-place concrete gravity wall and mechanically stabilized earth (MSE) wall. In this study, the backfill material consists of sand placed and compacted in 8-inch lifts over a drainage system consisting of an underdrain surrounded by pea gravel wrapped in a geotextile to aid in filtering fines. Any additional materials (drain board, weep holes, waterproofing, etc.) will not be considered for this study because it is expected that the concrete required for the gravity retaining wall will drive the LCA in this case, likely making it the least sustainable case. The gravity retaining wall will serve as a basis for comparison among the studies. For the MSE wall granular backfill material is compacted in lifts over unidirectional geogrid reinforcement which anchors the block wall in place via the weight of the soil above it and the tension within the geogrid anchoring the wall in place. The MSE wall is vertical and the facing will be synonymous with the concrete blocks which anchor the reinforcement

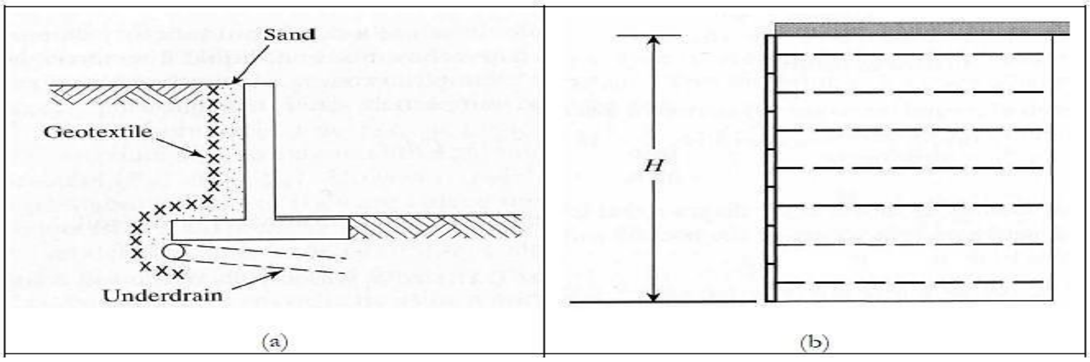

Figure 2: Retaining wall options using geosynthetics including (a) gravity retaining wall, (b) mechanically stabilized earth (MSE) wall.

For all cases, the excavated materials are assumed to be used as fill material in the rising of the slope to meet the new grades. The quantity of the excavated materials for a one foot of the wall length are shown in Table 2.

Table 2: Excavation and fill requirements (Chulski, 2015).

Wall Type	Soil Type	Required Excavation (cf/ft)	Additional Imported Backfill/Fill Required (cf/ft)
Concrete Gravity Retaining Wall	Sand	215	1555
	Clay	215	1567
MSE Wall	Sand	96	1535
	Clay	204	1555

2.1.6. Life Cycle Assessment

Considering the used materials in each design alternative, a life cycle assessment analysis has been conducted to make a comparison among the various methods. The analysis is based on the most comprehensive available resource for the used materials, ICE from the University of Bath. The geosynthetic properties including density, roll length, etc. will be determined using design parameters (i.e., tensile strength) and consider the median value in order to represent an "average" product. These have been found using GeosIndex [web3].

The main steps of the LCA briefly can be mentioned as below:

- Sensitivity Analysis: A sensitivity analysis will be performed in order to determine the most influential parameters within the LCA that drive the LCA. The input parameters observed for conducting the analysis are: 1) Impact of each material composition (embodied energy or embodied carbon); 2) Impact of location of refinery to manufacturer; 3) Impact of location of manufacturer to supplier; 4) Impact of location of supplier to site.

- Impact Assessment: The life cycle impact assessment (LCIA) is a necessary part of the LCA in order to understand the impacts to human and ecological health, as well as resource depletion.

2.1.7. Life Cycle Cost

In order to determine the economic costs of the retaining wall over its life cycle, a Life Cycle Cost analysis is required. The LCC can be broken down into subsets: cradle-to-factory gate, installation, maintenance, and end of life. The cost estimate for the materials and labor during the construction phase can be performed using construction estimating techniques. Because the retaining walls are free standing structures, they do not require energy, water, or operational costs. Maintenance and repair costs would be minimal, and are assumed to be relatively consistent across the four design options. Similarly, property taxes would be comparable for the four walls, and are not considered applicable for this study. Little data is available for the end-phase of the wall structure. Therefore, the dominant cost element is the cost of construction.

Chulski (2015) made a comparison based on the embodied energy, embodied carbon, cumulative energy demand by various materials, and total costs of each design alternative. Results show how the Geotextile A life cycle inventory was performed on the materials required for each wall type, and the results are presented in Figure 3. The gravity retaining wall contains more embodied carbon than the MSE wall.

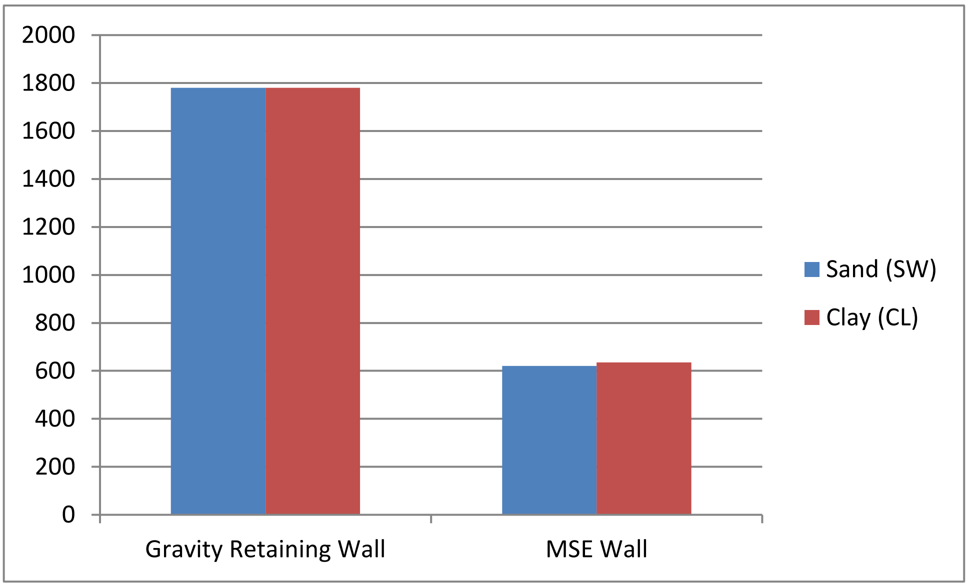

Figure 3: Comparison of embodied carbon from cradle to factory gate for each of four wall types (Chulski, 2015).

To further understand the contribution from each material to the total cradle-to-factory gate Cumulative Energy Demand (CED) for each wall type, the data was normalized by dividing the amount of CED from each individual material by the total CED for the entire wall unit.

As it is mentioned before, the dominant cost element is the cost of construction. Based on construction costing estimates, the total cost for wall materials are shown in Figure 6. The concrete gravity retaining wall is the most expensive wall, followed by the gabion wall. The geotextile wrap-around wall and the MSE wall have very similar costs associated with the materials required for construction.

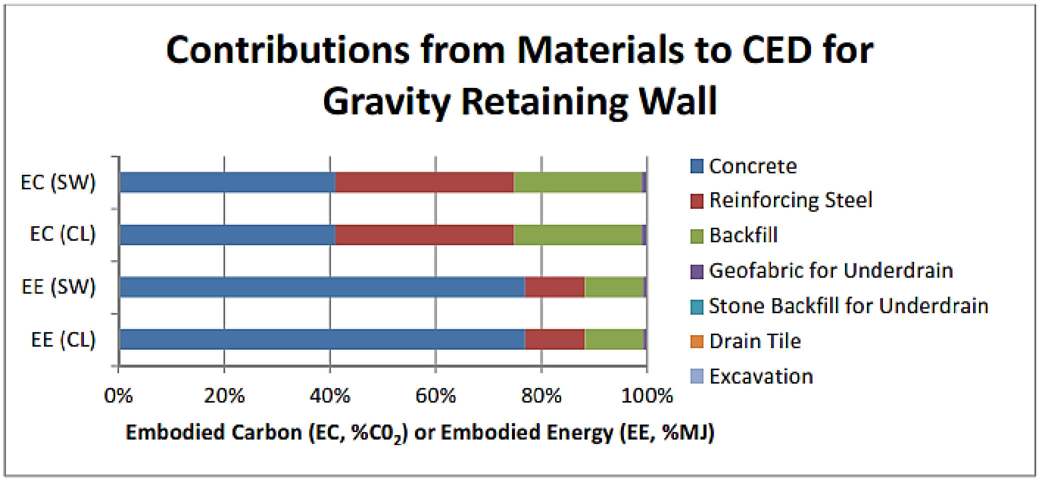

Figure 4: Contribution from each material used for a concrete gravity retaining wall toward total embodied carbon and embodied energy. Abbreviations "SW" and "CL" refer to sand or clay subgrade sites, respectively Chulski, 2015).

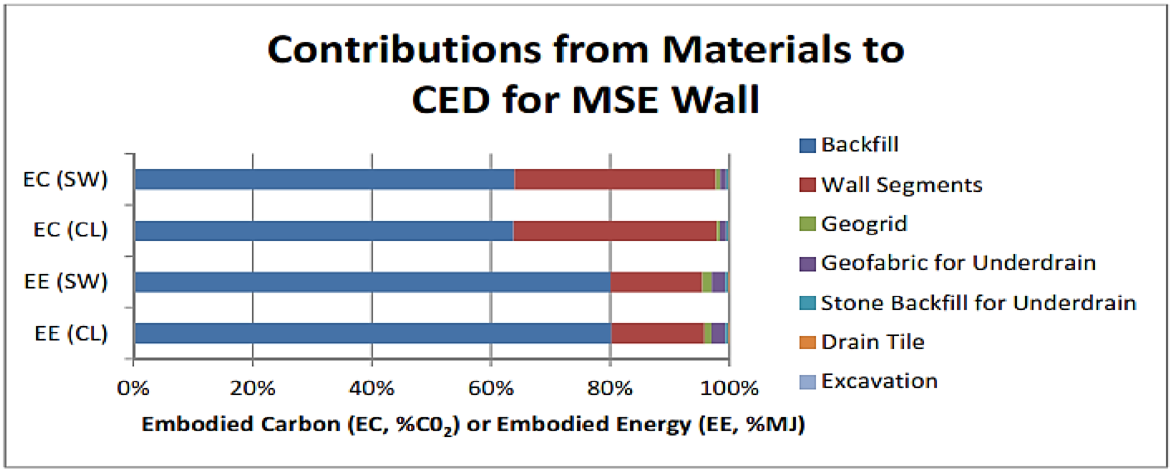

Figure 5: Contribution from each material used for a MSE wall toward total embodied carbon and embodied energy. Abbreviations "SW" and "CL" refer to sand or clay subgrade sites, respectively (Chulski, 2015).

Frischkenecht (2013) has compared the results of a life cycle assessment (LCA) between a concrete reinforced retaining wall (CRRW) and geosynthetic reinforced retaining wall (GRRW). One meter of a three meters high retaining wall forms the basis for comparison. The two walls have same technical performance and an equal life time of 100 years. The environmental performance is assessed with eight impact category indicators which are: 1) Cumulative Energy Demand (CED); 2) Climate Change (Global Warming Potential); 3) Photochemical Ozone Formation; 4) Particulate Formation; 5) Acidification; 6) Eutrophication (effect of nitrate and phosphate accumulation on aquatic systems); 7) Land competition; 8) Water use.

The functional unit is defined as the construction and disposal of 1 m slope retention with a 3 meters high wall, referring to a standard cross-section. A scheme of retaining walls are shown in Figure 1

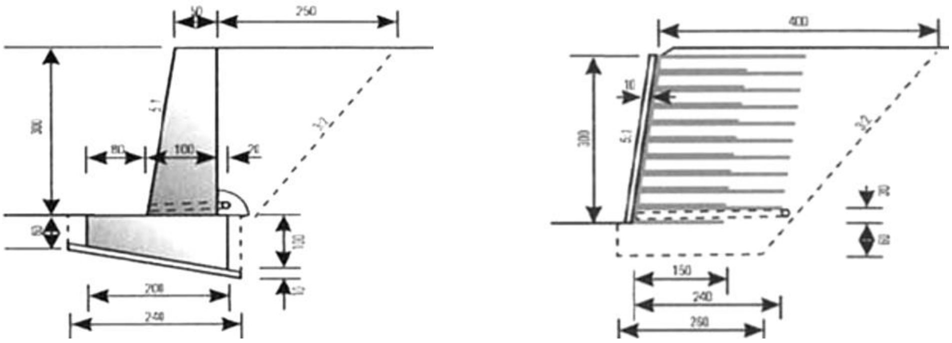

Figure 6: Scheme of concrete reinforced retaining wall (CRRW, left) and the geosynthetic reinforced retaining wall (GRRW, right) (Frischkenecht, 2013)

Table 3 shows specific values of the retaining walls for both alternatives. The information refers to one meter of slope retention infrastructure and a time period of 100 years. Diesel is used in building machine for the excavation of the foundation and the compaction of the ground. In the case of concrete wall, bitumen used to seal the concrete wall. The use of recycled gravel is not considered, since usually no onsite recycled gravel with specific properties is available when building reinforced retaining wall for the first time. Unlike the concrete wall, the material on site is used as fill material, wall embankment and cover material in the case of GRRW. The geogrid has to achieve a long-term strength of 14 kN/m. Polyethylene and PET granules are used as basic material of the geogrid.

Table 3: Selected key figures describing the two constructions of one meter reinforced retaining wall (Frischkenecht, 2013).

	Unit	CRRW	GRRW
Concrete	m^3/m	1.6	-
Lean mix concrete	m^3/m	0.24	-
Structural concrete	m^3/m	2.1	0.31
Reinforcing steel	kg/m	153	-
Gravel	t/m	4.3	4.3
Bitumen	kg/m	2.84	-
Three layered laminated board	m^3/m	0.01	-
Geosynthetic	m^3/m	-	39.2
Polystyrene foam slab	m^3/m	0.25	-
Polyethylene	kg/m	1.74	2.02
Diesel in building machine	MJ/m	11.6	53.9
Transport, lorry	tkm/m	701	265
Transport, freight, rail	m2/m	33.2	6.9
Land Use	m2/m	1	0.6
NMVOC	g/m	20	-

A drainage layer made of gravel with a thickness of at least 30 cm behind the concrete lining is necessary. To be consistent with the CRRW, a gravel layer thickness of 80 cm is assumed in both cases. Round gravel is used for drainage purpose.

According to the Table 3, the difference between CRRW and GRRW lies in the amount of concrete, steel and bitumen use, the energy consumption that is released to the slope retention used (material, transportation, excavation etc.), and the use of geosynthetics. Table 4 show a summary of LCA for both cases.

Table 4: Summary of LCA between CRRW and GRRW (Frischkenecht, 2013).

	Reinforced Concrete Retaining Wall (CRRW)	**Geosynthetic Reinforced Retaining Wall (GRRW)**
Analysis type	Life cycle assessment	Life cycle assessment
Used software for LCA	SimaPro	SimaPro
Project life time (year)	100	100
Height of wall (m)	3	3
Width of wall (m)	1	1
Main material	Concrete, steel, Bitumen	Geosynthetic (geogrid)
Cumulative greenhouse gas emission (ton)	1.3 CO_2-eq	0.2 CO_2-eq
Cumulative greenhouse gas emission of 300 m (ton)	400	70
Cumulative energy demand (MJ)	12700	3100

Conclusions derived in the study of Frischkenecht (2013) can be summarized as follows:

- The specific climate change impact of the construction of the slope retention using geosynthetics is about 1 ton CO_2-eq per meter lower compared to a conventional alternative. This difference is equal to about 84% of the overall climate change impact of construction and disposal efforts of an entire conventional slope retention system during its 100 years life time.
- According to the sensitivity analysis, if a Euro5 lorry with lower exhaust emissions than an average fleet lorry is used for the transportation of material, the environmental impacts of both cases are somewhat reduced regarding some indicators. However, this does not affect the overall conclusion of the comparison.
- Compared to the conventional slope retention, the geosynthetic reinforced wall substitutes the use of concrete and reinforcing steel, which results between 63% and 87% lower environmental impacts.

2.2. METHODOLOGY TO THE CO_2 CALCULATIONS

One major step of the Life Cycle Assessment (LCA) is to measure the CO_2 emission of the used materials. This paper propose some methods for determining CO_2. The methodology used to calculate the embodied CO_2 of the material is based on the Inventory of Carbon & Energy (ICE) (Hammond, 2013). The document provides the embodied energy and the embodied CO_2

of many every day materials. The embodied CO_2 of a material is a calculated value of the quantity of carbon derived due to the extraction, processing and transportation of the material to the product. This value is typically expressed as the mass in kg of embodied CO_2 from producing 1 kg of material, shown as kg CO_2 /kg.

One remarkable point is that, the more processing required to produce the material, the higher the embodied CO_2 is. For materials such as virgin metals, the embodied CO_2 is much higher than that of recycled metals as much more energy is used in the extraction process. This must be taken in to consideration when reviewing some of the geosystem methods used, as some of the metal based geocomponents may appear to have very high embodied CO_2 values compared to others, but this is likely to be due to only virgin metals been used for the products.

Generally, three main method can be considered for CO_2 calculation:

- Method 1 – Embodied energy of single material type: To ascertain the carbon footprint, it is necessary to calculate the embodied carbon of the materials being used. This involves several calculations and reference to the ICE document. The first stage is to calculate the total amount of material used in each component part of the case study. For example if there is a need for 10m^3 of aggregate fill, it would be necessary to calculate the weight of the material.

- Method 2 – Embodied energy of multiple materials in one product: This method involves breaking down each element of the product. For example gabion mesh comprises several different materials, so to calculate the embodied CO2 of 100m2 of gabion mesh the first calculation would be to break down the products in the mesh into each component part.

- Method 3 – CO2 emissions associated with the transport of materials: These calculations included reference to values given by Defra in relation to CO_2 emissions from vehicles. The average fuel consumption for trucks was taken from the manufactures specification documents and truck trader.

3. RESULTS

3.1. Design Calculations

The load calculations are made according to live load of 1500 kg/m^2 on the ground and ground bearing capacity of 1,0 kg/cm^2.

Option 1: Geogird Reinforced Retaining Wall (1 meter wide)

Tensile strength of the reinforcement is 50 kN/m and weight is 100 g/m^2. Each facing block has dimensions 20x20x40 cm and weighs 20 kg. Other variables are given in Table 5.

Table 5. Details of the geogrid reinforced retaining wall

Height (m)	Number of Reinforcement Rows	Length of Reinforcement (m)	Number of Concrete Blocks
3	14	2.69	37.5
4	20	3.23	50
5	25	4.64	62.5

Option 2: Reinforced Concrete Retaining Wall (1 meter wide)

C25 Concrete was used for all types. The reinforcement details and volume of concrete necessary are given in Table 6.

Table 6. Details of the reinforced concrete retaining wall

Height (m)	Volume of Concrete (m)	Length of Rebar (m)				
		Ø8	Ø10	Ø12	Ø14	Ø16
3	1.78	35.25	54.7	29.5	-	-
4	2.8	47.75	44.4	20.5	41	-
5	4.24	7.8	72	32.75	25.75	98.5

3.2. Carbon Emission Calculations

<u>Material Production:</u>

The carbon footprint values of material production are estimated as below:

Carbon footprint of woven geotextile production: 2,36 tCO2-e / t

Carbon footprint of concrete production: 0,18 tCO2-e / t

Carbon footprint of rebar production: 2,68 tCO2-e / t

Emission results are calculated according to amount of materials used in the design multiplied by assumed carbon footprint per unit. Emissions of material production are given as tones of CO2 equivalent in Table 7.

Table 7. Emissions of material production are given as tones of CO2 equivalent:

Geogrid wall	3m	4m	5m
Woven Geogrid	0,009	0,015	0,027
Concrete blocks	0,135	0,180	0,225
Total (tCO2-e)	**0,144**	**0,195**	**0,252**
Reinforced Concrete	**3m**	**4m**	**5m**
Concrete	0,737	1,161	1,757
Rebar	0,198	0,401	0,706
Total (tCO2-e)	**0,935**	**1,562**	**2,463**

<u>Transportation:</u>

Transportation distances are taken according to material availability in Turkey. The production of concrete blocks and geotextile are mainly located in the Marmara region of Turkey. The largest distance occurs between Marmara and South-east regions. The production of concrete is spread in all regions. Rebar production exists in Marmara, Akdeniz and Karadeniz regions. The results will be compared in order to show the impact of distances.

Transportation distance of woven geotextile: 1000 - 100 km

Transportation distance of precast concrete blocks: 1000 - 100 km

Transportation distance of concrete: 200 - 20 km

Transportation distance of rebar: 500 - 50 km

Emission per tonnes per km: 0,204 kgCO2-e / t

Transportation of the materials are calculated together with the weight of the trucks. The return distances of the trucks are also incorporated. Trucks are assumed to be fully loaded with the related material and total amount is divided into the material weight achieve unit footprint (per ton). Emissions for maximum distances given as tones of CO2 equivalent are given in Table 8. Emissions for minimum distances given as tones of CO2 equivalent are given in Table 9.

Table 8. Emissions for maximum distances given as tones of CO2 equivalent

Geo-grid wall	3m	4m	5m
Woven Geo.	0,007	0,011	0,020
Concrete	0,383	0,510	0,638
Total (tCO2-e)	0,389	0,521	0,658
RC	3m	4m	5m
Concrete	0,418	0,658	0,996
Rebar	0,038	0,076	0,134
Total (tCO2-e)	0,455	0,734	1,130

Table 9. Emissions for minimum distances are given as tones of CO2 equivalent:

Geo-grid wall	3m	4m	5m
Woven Geo.	0,001	0,001	0,002
Concrete	0,038	0,051	0,064
Total (tCO2-e)	0,039	0,052	0,066
RC	3m	4m	5m
Concrete	0,042	0,066	0,100
Rebar	0,004	0,008	0,013
Total (tCO2-e)	0,046	0,073	0,113

Calculations show that carbon emission of transportation of reinforced concrete is larger than geo-grid wall. The difference increases when the wall height increases.

Emissions not considered:

This study did not focus on a comprehensive “organizational” calculation, but instead, provides a comparison of the GHG emissions attributable to two retaining wall systems. Selected emission sources were excluded from the study, since they represent a very small percentage of the overall total carbon footprint and are difficult to estimate. Excluded sources include: 1)

Emissions associated with the exploration/extraction/production and transport of the fuels themselves; 2) Emissions associated with the construction site activities, such as formwork, soil works, wastes etc.; 3) Emissions associated with commuting/business travel of employees of the material suppliers, engineers, and contractors working on the project.

This approach was considered to be reasonable, since they would have little impact on the comparison, and therefore would not change the findings or conclusions of this study.

Results:

Total emissions for minimum and maximum transportation distances (Table 10):

Table 10. Total emissions for minimum and maximum transportation distances

CO2-e tonnes for 1 m width wall types (min-max distance)			
	3 meter	4 meter	5 meter
Geo-Grid	0,18 - 0,53	0,25 - 0,72	0,32 - 0,91
Reinforced Concrete	0,98 - 1,39	1,64 - 2,30	2,58 - 3,59

Calculations clearly show that the transportation distances do not affect the comparison of the wall types. Emissions of geo-grid wall with maximum distance are still very low compared to emissions of reinforced wall with minimum distances.

3.3. Comparison

Comparison of 3-meter-high geo-grid and reinforced concrete wall with average transportation distance is given in Figure 7.

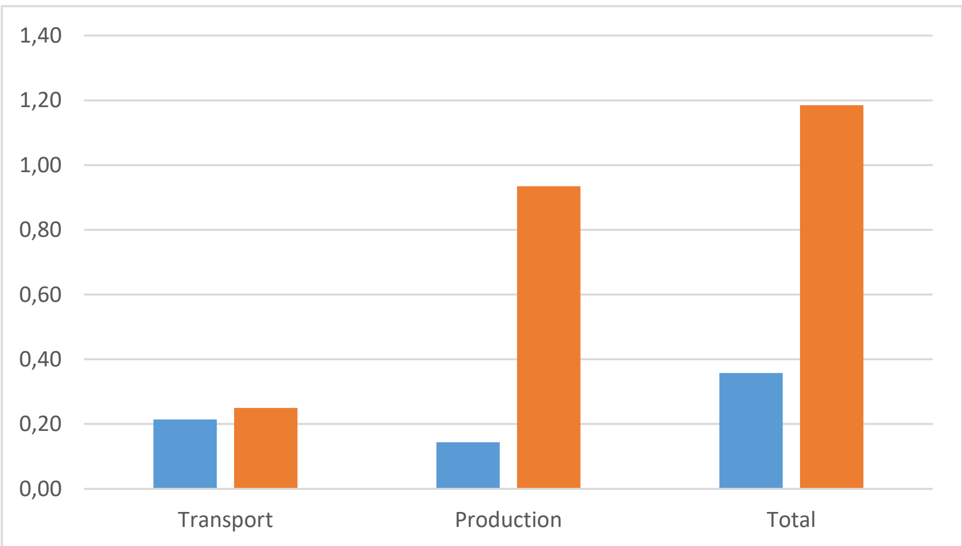

Figure 7. Comparison of 3-meter-high geo-grid and reinforced concrete wall with average transportation distance

Comparison of 4-meter-high geo-grid (blue) and reinforced concrete (orange) wall with average transportation is given in Figure 8.

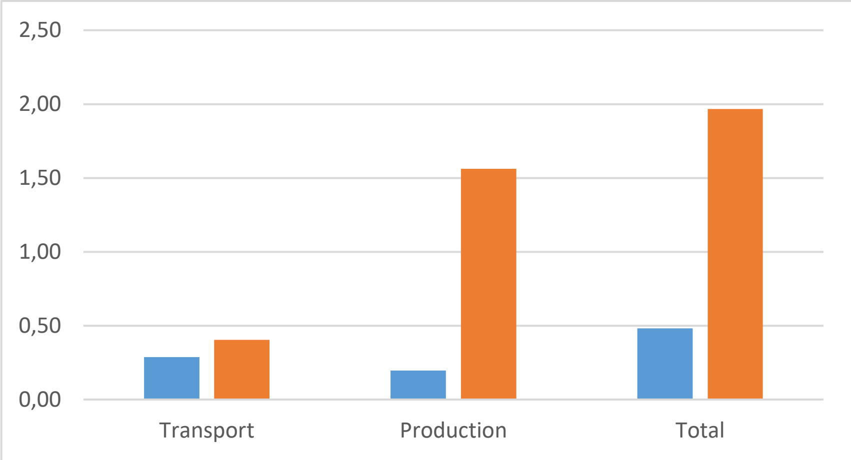

Figure 8. Comparison of 4-meter-high geo-grid and reinforced concrete wall with average transportation distance

Comparison of 5-meter-high geo-grid (blue) and reinforced concrete (orange) wall with average transportation is given in Figure 9.

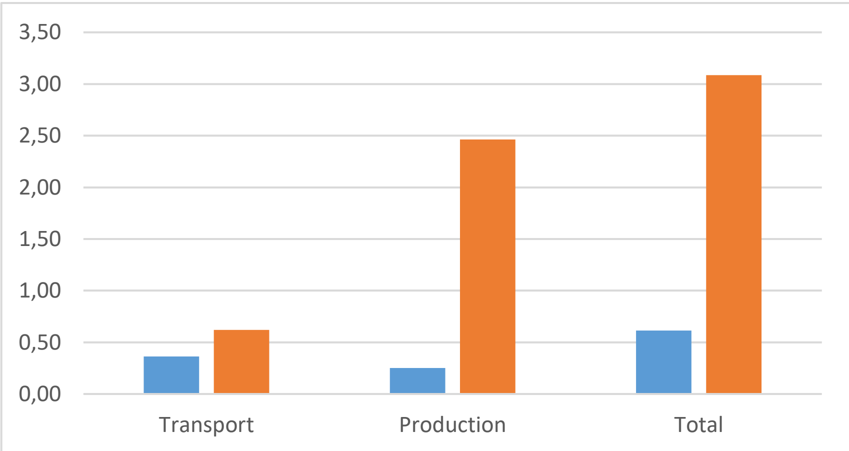

Figure 9. Comparison of 5-meter-high geo-grid and reinforced concrete wall with average transportation distance

4. CONCLUSION

The analysis found that, geogrid reinforced wall is expected to produce 69% less carbon for 3-meter high wall, 75% less for 4-meter high wall and 80% less for 5-meter high wall for average transportation distances. The largest component of the overall carbon footprint which creates the difference between two wall types is the amount of concrete and rebar used in the reinforced concrete wall. The production of concrete emits 55% and rebar emits 20% of total carbon footprint of reinforced concrete wall on average. The transportation footprint of two type of walls are compared for minimum and maximum distances and it is found that the difference between transportation footprint does not have a significant impact to the comparison since it is a small portion of total.

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