TECCO®Cell for shore protection against erosion: A comparative assessment of the potential for CO_2-footprint reduction of a new type of engineered solution

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1. Introduction

Many shorelines in Europe are subject to erosion. For example, of Great Britain's around 17'600 km of overall shoreline, at least 3'000 km are estimated to face erosion issues. Approximately 2'300 km of Great Britain's shorelines are artificially protected [1].
For many other countries in Europe with long shorelines, such as Norway, Greece, Italy, Croatia and Denmark (including Greenland) etc. [2], wave erosion and artificial protection against it is and will remain a major issue for local communities, politicians, researchers and planners.
Rising sea levels and the expected increase in extreme weather events such as storms may lead to an increasing demand of coastal management and artificial protection structures in the coming years. In accordance with international efforts to limit and reduce greenhouse gases (Paris Agreement, recent COP26 in Glasgow), the demand of low carbon footprint solutions for shore protection is expected to rise. Sound and sustainable shore management methods include spatial planning, but also new types of engineered solutions with a low carbon footprint.
This paper shows existing solutions for shore protection such as rock armour and concrete revetements and introduces a new type of specially engineered solution, i.e. an array of steel mesh cells filled with locally sourced blocks, stones and pebbles called TECCO®Cell. Using a qualitative comparison of CO_2-footprints based on literature, data and a case study in England, this paper aims to assess the potential reduction in CO_2-footprint of TECCO®Cell compared to existing solutions for a project appraisal stage. It also lists areas of interests for further studies such as recommendations for a better quantitative understanding of CO_2-footprints for specially engineered shore protection solutions such as TECCO®Cell.

2. Existing shore protection systems

Existing systems for shore protections include, but are not limited to (see also Figure 1):

1. Rock armour: This system consists mainly of large boulders installed on a relatively low gradient on the shore to dissipate energy and protect the shore from wave erosion (scour)
2. Precast concrete elements: As for rock armour, this type of revetement is often used on shallow slopes to protect the shore from wave erosion (scour).
3. Gabions filled with locally sourced blocks, stones and pebbles: They come in different sizes, are mostly rectangular shaped and are filled with local stones and pebbles.
4. Concrete or sheet pile seawalls: This type of wall, which are mostly horizontally installed, act as a barrier on the shore. These walls are sometimes back-anchored and vary in dimension and style.

1. Rock armour
Picture: [A]

2. Precast concrete elements
Picture: Coastalwiki [B]

3. Steel mesh cells filled with blocks, stones and pebbles
Picture: Geobrugg [C]

4. Curved concrete seawall
Picture: [D]

Figure 1: Different types of shore protection

All the above solutions are proven engineered solutions for coastal protection. Depending on site-specific conditions, the comparison of advantages and disadvantages of different engineered options will lead to the choice of the most adapted solution. In the case of shore protection, main factors to consider are:

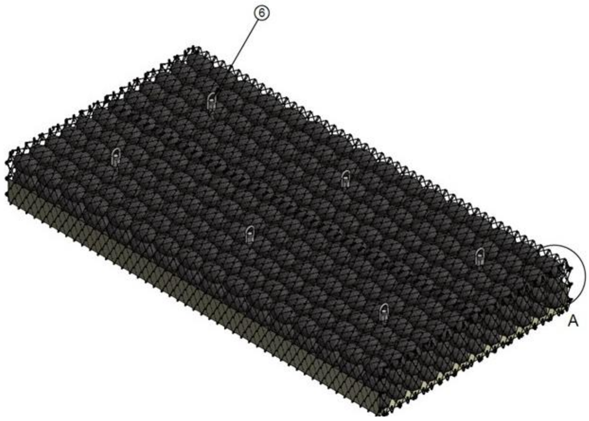
- Cost of material and transport
- Cost of installation
- Overall service life
- Resistance to scouring
- Maintenance costs
- Dismantling/recycling

CO_2-footprint assessments have become an important tool for decision makers from the beginning of this century. For example, the Environment Agency for England and Wales (EA) is requesting a carbon life cycle assessment for any newly funded shore protection structures. Many other countries with long shorelines have already adopted similar regulations or will probably establish them soon, considering the aim of the industrialized world to significantly cut back on CO_2 emissions.

3. TECCO®Cell

Commonly known gabions filled with stones and pebbles have been in use for several decades.

TECCO®Cell and TECCO®Cell mobile mattresses are extending the range of possible shore protection schemes using high-tensile steel wire mesh in stainless steel 1.4462 (AISI 318) [4]. The product is a specially designed array of steel mesh cells. According to the manufacturer Geobrugg, the stainless high tensile steel wire mesh (product name TECCO) is holding an European Assessment Document EAD [5] and the product is therefore entitled to wear the commonly known CE-marking. The CE-marking is assuring that the product is tested, and regular factory production control (FPC) is carried out according to latest European Standards.



Principal drawing of TECCO®Cell mobile mattress
Picture: [C]

TECCO®Cell installed as shore protection
Picture: [E]

Figure 2: TECCO®Cell principal drawing and installed as shore protecion

The following mains installation steps are necessary:

1. Earthworks with an excavator to prepare the terrain
2. Installation for geosynthetics as required for separation and filtering
3. Installation of the empty cell array, deploying the cell array on the ground
4. Filling of the cell array with locally sourced blocks, stones and pebbles
5. Closing of the cell array with clips and ropes
6. Finishing works with rock armour at the border of the cells to avoid scouring

The above steps will be considered for the CO_2-Footprint evaluation in chapter 6.

4. Case study TECCO®Cell in Beesands, Devon UK

In 2016, an installation of TECCO®Cell was realized at the beach of Beesands, Devon UK. According to the local contractor, the history behind the rehabilitation of eroded shore protections can be summarized as outlined below [7] :

The whole beach front at Beesands is protected by various types of sea defences. The part of the beach that has most residential properties and businesses has been defended by concrete revetment/walls and very large rock armour (each rock heavier than 5 tonnes). The lower (or Northern) section of

Beesands has the village green and around 15 properties behind it. This is the section the case study focuses on.
Severe storms early in 2014 caused the existing rock armour sea defence to fail along an approximately 150 m stretch of the beach. As a first measure, a geotextile mattress with rock revetment was installed. That solution failed due to exposure of the geotextile to UV-light and after severe storms. The rock armour revetement then collapsed.
The local authorities then published a tender to replace the damaged rock armour revetement including geotextiles and was also calling for innovative solutions for better type of shore protection.
In a joint venture between the contractor and the producer of TECCO®Cell, a custom-made solution was designed for first an area of 20 metres. The project was installed in 2016 after approval of the Environment Agency".

After successful installation of the 20 m stretch, another 70 linear metres were secured using TECCO®Cell in 2021. After storm DARCY, the contractor in 2021 published a video [8] showing that this construction has performed well in the years since installation and showed no damage or corrosion as of November 2021. [9]

TECCO®Cell: installation in 2021
Picture: [E]

Finished installation of shore protection in 2021
Picture: [E]

Figure 3: TECCO®Cell installation and finished work at Beesands, Devon UK

5. Estimative CO_2-Footprint comparison for engineered shore protection solutions

5.1 Engineered shore protection solutions compared

Carbon footprints are nowadays used to account for possible damages to the environment. For this study, a comparison of carbon footprint for three different types of shore protection is carried out:

- TECCO®Cell
- Rock armour
- Concrete revetement

For the comparison, the author chose to work with the site of Beesands, since it is well documented and two of the three selected revetements have been installed at the site (see chapter 5). A stretch of 70 m length and 12 m width was compared, which is the actual size of the project carried out in 2021.

5.2 Tools and data

For the estimation of a carbon footprint, the following tools and databases have been used:

- Shipping and construction documents provided by the contractor and the producer of TECCO®Cell
- Personal communication by the contractor of the Beesands Project
- Various literature values CO_2-footprint for the extraction of material, for example [15]
- An online carbon emission calculator for transport [14]
- The latest carbon modeling tool of the British Environment Agency EA [11]
- A paper by a specialized consultant for shore protection in the UK comparing the carbon footprint of two types of coastal constructions (concrete caissons and rubble mound breakwater) to compare and verify the data [10]

5.3 Type of assessment

The Environment Agency for England and Wales (EA) distinguishes between primarily two kind of assessment:

- For an early product appraisal stage: Carbon modelling using databases of existing projects as estimates. It is mainly used to identify possible alternatives in an early project stage.
- For a project undergoing official approval by the EA: Carbon calculation of the whole product cycle (whole life carbon assessment).

Since TECCO®Cell can be regarded as a valuable alternative to existing protection solutions, the following CO_2-footprint comparison is carried out for the product appraisal stage.
In the calculations, the author chose to use the data derived from literature and existing online carbon calculators. It was opted for a cradle-to-gate (for materials) and well-to-wheel (for transport) approach. For that, some adaptations of the values had to be made by hand.
The calculations were also compared with values from the latest EA carbon modeling tool [11]. Moreover, the values were also compared with an estimation of a local EA expert on CO_2-footprint for verification [13].

5.4 Process

To assess the CO_2-footprint of a shore protection system such as breakwaters and dams, one needs to identify the individual contributors to the total carbon emissions of the construction materials, the transport to the site, construction activities, operation and maintenance and disposal at the end of the constructions design life [13].

In short, generally the following stages are considered:

- Material production
- Transport
- Construction/installation
- Operation/maintenance
- Disposal

For this case study, it was the chosen to compare the first three stages only (material – transport – construction/installation), mainly for the following reasons:

- The first three stages account in most of the cases for the greatest part of the overall CO_2-footprint and would give a good first idea on a project appraisal stage, where options are evaluated.
- For operation and disposal, it is much harder to find robust data to compare. However, these stages will need to be accounted for in a whole life carbon assessment and are recommended to be included when seeking for approval from authorities for a specific project.
- For operation and disposal, a qualitative assessment will be given in chapter 7 (Evaluation of the results).

6. CO_2-footprint assessment: results

The calculations for the CO_2-footprint assessment have been made in an Excel-Sheet for the options outlined above (TECCO®Cell/rock armour/concrete revetement). A summary of the results is shown in Table 1 below. The detailed calculations have been carried out separately and can be received upon request.

Table 1: Results of CO_2-footprint calculations for three different options of the case study.

CO2-Footprint	**Example Beesands**	
L = 70 m, B = 12 m		
Option 1: TECCO®Cell		
Total Material + Transport [t CO_2]		38.8
Total Installation [t CO_2]		9.16
Total Material + Transport + Installation [t CO_2]		**48.0**
Option 2: Rock armour		
Total Material + Transport [t CO_2]		57.5
Total Installation [t CO_2]		17.09
Total Material + Transport + Installation [t CO_2]		**74.5**
Option 3: Concrete revetement		
Total Material + Transport [t CO_2]		199.6
Total Installation [t CO_2]		10.69
Total Material + Transport + Installation [t CO_2]		**210.3**

7. Evaluation of results

While the raw data of the calculations gives a good first impression on the different CO_2-footprints for the case study, the numbers will need to be put into context for a sound appreciation. Therefore, some general statements regarding quality of data, sensitivity of values to changes and whether the data can be generalized are given below.

7.1 Evaluation of data used

- Generally speaking, data on CO_2-footprint values may vary greatly for one specific value and assumptions needed to be made by the author.
- Operational data for the case study (material weight, transport distances, type of machinery used and operating hours) are considered to be of good quality, because two of the above options (TECCO®Cell and rock armour) where built at this site and reports and shipping documents are available.
- The data of carbon emissions for material extraction was sometimes hard to find and showed a wide range of values. This is often due to the fact that these values have not been assessed for the specific case (e.g. block extraction). For example, the material extraction cradle-to-gate for large blocks may vary greatly (by a factor 10 or more) whether the rock is extracted for that reason or is "leftover" material. [10]. In this case, the author chose the same value as other authors did in their study [10], where the material was locally sourced as "leftovers".
- The author needed to update and estimate the values to obtain cradle-to-gate or well-to-wheel values for some of the positions. For example, transport industry often gives "tank to wheel" values, which do not account for the extraction of the fuel itself and show a better result than in reality.
- The case study is representative, and results may be compared for similar shore-types, wave impacts, gradients, use of materials and transport distances. However, the case study is one data point of many to come and results cannot be generalized yet. With each project using this novel kind of approach, more information on CO_2-footprint will be gained and values of this case study should be confirmed and adopted.

7.2 Comparative evaluation of the results

The information gained from the result in Table 1 was normalized and compared with values from the EA's total carbon model (for rock armour vs. concrete revetement) and an EA expert estimation (for TECCO®Cell vs. rock armour, educated estimate according to [16]). Results are given in Table 2 below:

Table 2: Normalized values of the case study Beesands and comparison with other results

Comparison CO_2 Footprint Case study Beesands			
Evaluation method	TECCO®Cell	Rock armour	Concrete Revetement
Material+Transport+Installation, own model	64%	100%	282%
Total Carbon, Model EA		100%	209%
EA Expert estimation	80%	100%	
Range of Difference in CO_2 emissions	-20%....-36%	Reference 100%	+ 109%....+182%
Proposed wording until further knowledge is available	"up to 20 - 30% less CO_2 emissions than rock armour revetement in the case study"		"up to 2 -2.5 times more CO_2 emissions than rock armour revetements in the case study"

The results of the case study show that TECCO®Cell would result in a significantly smaller CO_2-footprint than rock armour and in a considerably smaller CO_2-footprint than a concrete revetement. The reasons for this result are mainly that

- TECCO®Cell would need significantly less and smaller sized stones that rock armour. This results in a smaller amount of overall material extraction (which can be easily locally sourced).

- TECCO®Cell and rock armour do not use concrete. The concrete’s cement, reinforcing steel and the overall weight of this option are the key factor for the much higher carbon footprint of the concrete revetement solution.

Other findings of the case study are:

- According to the contractor, the blocks for rock armour are often difficult to source locally. For the Beesands case study, the blocks could be sourced locally, which seems to be an optimum and rather exceptional case. For other projects with rock armour, blocks needed to be shipped from overseas Scandinavia or Belgium [9]. If this had been the case for Beesands, the option TECCO-Cell would be even up to 30 – 40% more CO_2-effective than the rock armour solution.
- For the TECCO®Cell, the metal mesh needed to be shipped from overseas (Switzerland). The rise in CO_2-footprint is compensated by the fact the filling was conducted using locally sourced small stones and pebbles.

For the stages maintenance and dismantling/recycling, which have not been considered in the calculations, a qualitative appreciation can be made:

- Generally speaking, the two stages maintenance and dismantling are estimated to account for less than 35% of the overall CO_2-footprint, for all 3 options. Yet, depending on site specific conditions, these stages cannot be neglected for an overall carbon footprint model and sound estimations of these values need to be found in future studies.
- According to the manufacturer, the metal mesh used for the cell array may be recycled after use. A value for recycling of stainless-steel wire mesh still needs to be established for further studies.
- According to installers, the rock armour solution in Beesands needed to be repaired each year due to heavy storms, and TECCO®Cell showed to be maintenance free in the first 5 years of service life [9]. This information would further increase the CO_2-footprint of the rock armour solution. While TECCO®Cell is showing promising results after 5 years in use regarding maintenance, long-term experience regarding service life and maintenance still needs to be gained.

7.3 Appreciation of the results and recommendations for their use

The case study gives a good impression on the CO_2-saving using TECCO®Cell of this specific project for the stages material extraction, transport and installation and enables evaluation of options at a project appraisal stage.

Please note that the results of the case study cannot be generalized. Other sites and conditions would need to be evaluated separately. It is recommended to carry out a separate CO_2-footprint assessment for each future coast protection project using TECCO®Cell or other technologies.

For the communication of the results of this paper until further knowledge is available, the author proposes a wording as shown it Table 2.

8. Recommendations for future studies

For further CO_2-footprint comparisons for TECCO®Cell compared to standard solutions it would be interesting to study whether:

- For other projects, the values of CO_2-footprints remain in the same range as for the case study Beesands
- For project parameters that differ significantly from the case study Beesands (e.g. steeper slopes), CO_2-footprint of TECCO®Cell including installation remains favorable compared to standard solutions
- CO_2-emission values for maintenance and dismantling/recycling of TECCO®Cell may be established and confirmed

9. Conclusions

The results of the CO_2-footprint assessment of a case study with TECCO®Cell show that this novel kind of high tensile stainless steel solution may help reducing carbon impact for shore protection. It also shows that the technology is less dependent on large blocks being transported very long distances to the construction sites and can use locally sourced material. The steel mesh for the cell array itself needs to be transported from abroad, but the overall savings in CO_2-emissions compared to standard solutions is significant, considering the parameters of the case study. The results of the case study may be adopted to similar kind of projects, but not be generalized for any type of project. Thus, it is strongly recommended (or, depending on the country, even required by law) to carry out similar CO_2-footprint assessments for future projects of a similar type.

Acknowledgements

The author would like to thank all researchers that have contributed to the study of engineered coastal protection so far, especially those listed in the references section.

This study has been established with financial support of Geobrugg AG. The author is holding neither any shares of companies nor rights on patents of products described in this article.

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Disclaimer

All values and calculations have been carried out to the best of knowledge of the author. Changes of materials used, or installation methods need to be communicated to the author. The use of the calculations or conclusions in this paper is only allowed with prior written consent of the author. The correct interpretation and use of the results of this paper lies with the reader and user of the products mentioned. The author is declining any legal responsibility for any use of these values without prior notice and written consent.

Citation proposed

Denk, M. (2022): TECCO®Cell for shore protection against erosion: A comparative assessment of the potential for CO2-footprint reduction of a new type of engineered solution. Company200 Matthias Denk, St. Gallen, Switzerland.

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