ArcelorMittal Sheet Piling

ArcelorMittal

Sustainable ports

Life Cycle Assessment

Executive Summary

Ports have been faced with quite many challenges in recent years. On the one hand, the sea traffic has steadily increased, modern vessels are getting bigger; on the other hand, our planet is struggling with the greenhouse gas emissions. Ports need to expand, to build new berths, but how to achieve these goals without harming the environment?

Before building a new structure, checking the possibility of extending the service life of existing structures makes sense. This is the best option from an environmental point of view, but most often, old structures need retrofitting. Hence, only an economic and environmental analysis can help the owner to make an informed decision. But when it comes to increasing the dredge level to welcome vessels with higher drafts, or when existing structures are close to failure, building a new quay wall may be the sole viable alternative.

The question is **how to build a sustainable port?** ArcelorMittal appointed *Tractebel*, an independent Belgian consulting engineering firm, to analyze this quite multifaceted topic [1]. The engineers proposed to focus on three key indicators: technical, financial and environmental criteria. Their task consisted in comparing three different technical solutions for above indicators. The selected structure is a cruise ship terminal capable of accommodating the largest cruise ships. It would be built in a Belgian port, with a draught of 42.65 ft in typical soil and load conditions for a Belgian port.

This brochure focuses on the environmental impact of the two most cost-effective solutions, and mainly on the Global Warming Potential (GWP)[i]. The **Life Cycle Analysis** (LCA) is based on the bill of quantities prepared by *Tractebel* and was performed by ArcelorMittal's R&D department [2]. It has been peer-reviewed by a panel of experts [3]. The objective was to compare the **Total Life Cycle Cost**, including the burdens or benefits of the end-of-life phase, which are dismantling and recycling of the building elements, but no reuse was considered.

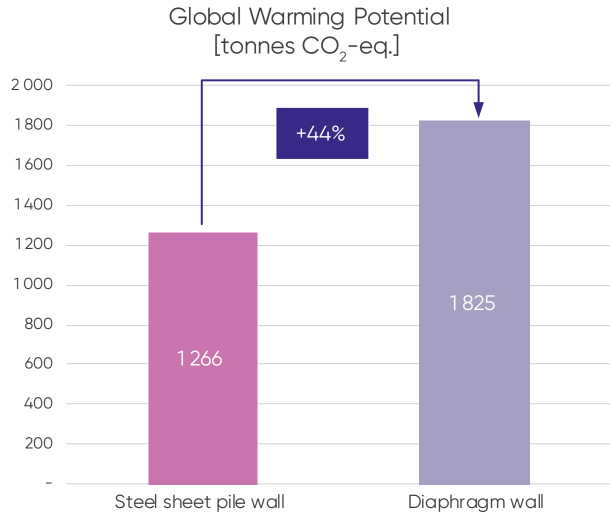
For this type of application, an LCA is a reasonably fair and transparent method to compare different solutions and suppliers. Although not required by ISO and EN standards, an LCA is more accurate and realistic when it uses specific **Environmental Product Declaration** (EPD) from the producers rather than generic data from databases.

The choice of a solution shall consider several key indicators, the principal one being the construction cost (including the design).

The key environmental indicator analyzed in this case is the carbon footprint; its impact for the base scenario is summarized in the graph below for a 650 ft long wall. This indicator can be included in a scheme to choose the most sustainable solution (most economically advantageous tender), such as the monetization method used in the Netherlands [4] which is based on multiple key indicators.

In this case study, the conclusion is that the **EcoSheetPile™** [ii] **steel sheet pile wall has the lowest carbon footprint, the difference being 44 % compared to the diaphragm wall.** A sensitivity analysis showed that modifying some of the parameters did not impact significantly the above-mentioned number, and in no case reversed the result.

Note:
The conclusions cannot be simply transposed to other situations, nor to other countries, without applying adequate correction factors.



Note: all weights in this document are expressed in metric tons. They are indicated either as "metric ton" or "tonne", or "t".

[i] The technical and financial indicators are handled in detail in another brochure.

[ii] The EcoSheetPile™ range is produced from 100% recycled steel through the Electric Arc Furnace route. These steel sheet piles can be reused several times and can be recycled after their service life.

1. Introduction

In order to provide a sound comparison of sheet piles with alternative solutions a simple but realistic case study was carried out. The case is based on a standard geometry of a 650 feet long cruise ship terminal that would be built in the port of Antwerp in Belgium, with a draft of -42.65 ft and the top of the quay at +16.4 ft. The cross section is shown in Figure 1.

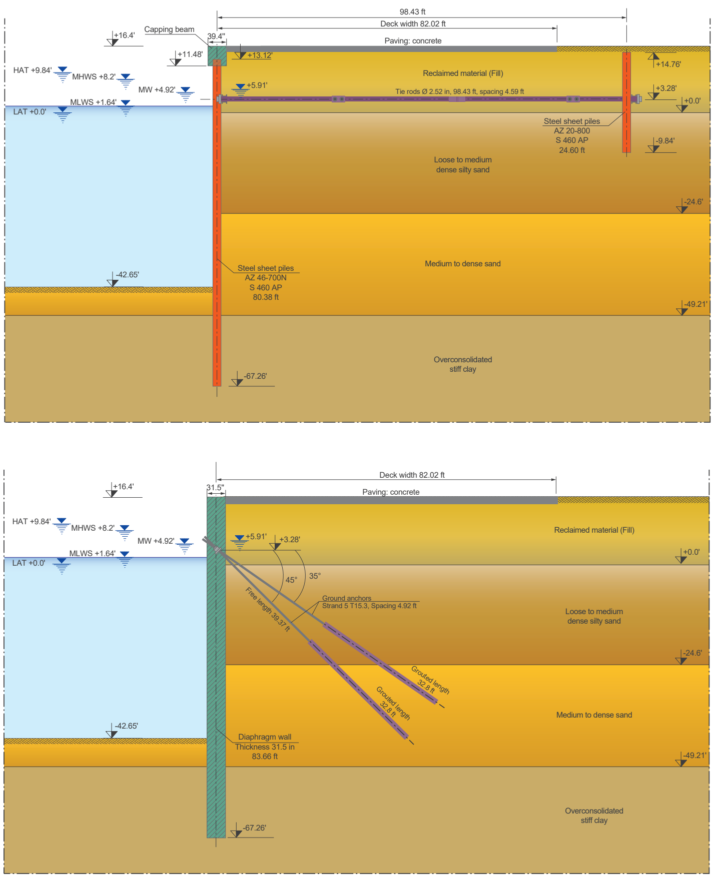


Figure 1. Cross section of the cruise ship terminal with steel sheet piles and with a diaphragm wall (design by *Tractebel Engineering*).

The following construction methods were analysed

- steel sheet pile wall (SSP),
- diaphragm wall (D-Wall),
- deck on piles.

The scope of the work from the Belgian engineering firm *Tractebel* was to design the three alternatives and to compare the overall construction cost of the walls, taking into account financial aspects linked to speed of execution and the return on investment (ROI), the end-of-life scenario where the structure should be demolished (whenever possible), and if applicable, the benefits of reuse or recycling of the structural elements.

The technical and financial aspects are dealt in detail in another brochure.

The sheet pile wall is designed with a 80.38 ft long standard AZ 46-700N section, in steel grade S 460 AP, and the anchor wall consists of a 24.60 ft long AZ 20-800 in S 460 AP. Both walls are connected with 98.43 ft long steel tie-rods of a diameter of 2.52 in, spaced at 4.59 ft (centerline).

The diaphragm wall is 83.66 ft high, with a thickness of 31.5 in, and with two 72.18 ft long active anchors located at the elevation +3.28 ft.

It turned out that under the chosen conditions and assumptions, **the SSP wall is around 20% more cost-effective than the D-Wal**l, and that the cost of the deck on pile structure is much higher compared to the two other alternatives. Hence, considering the significant differences, it was decided that the LCA would focus on the two solutions that were economically more attractive: SSP and D-Wall.

The Bill of Quantities obtained in this design project serves as the input for the Life Cycle Analysis.

The most sustainable structure can be determined in different ways. The *monetization* method used in the Netherlands [4] was chosen for this analysis.

There are several key environmental indicators that can be used to compare the most sustainable solutions, such as the MKI in the Dutch method. However, this LCA focuses on the Global Warming Potential (GWP) which is the main factor influencing the rise of the temperature on our planet. Other environmental parameters were analyzed and show similar trends as the GWP, with the exception of two parameters.

The LCA was performed by the R&D department of ArcelorMittal in 2020, and peer-reviewed by a panel of three independent experts [3]. The conclusion of the reviewers is that the LCA report has been performed in a professional and unbiased way, and that the conclusions are correct.

The variability of key parameters can significantly influence some results; hence a sensitivity analysis of key parameters was performed, and it confirms that their variation has a limited impact on the results, but never reversed the conclusion from the base scenario.

2. Goal, scope and assumptions

2.1. Goal of the study

The study was conducted to be compliant with ISO 14040 [5] and ISO 14044 [6]. The material data are based on EPDs compliant with EN 15804 [11] and the infrastructure global LCA, even if not applicable, is inspired by the EN 15978 [7] methodology.

The main objective of the study is to evaluate the influence of a structural solution on CO_2-eq. emissions considering the life cycle of a quay infrastructure. It proposes a comparison of two quay wall solutions through LCA.

The total life cycle cost is the main indicator, hence after the service life demolition, recovery of structural elements, reuse, recycling and landfill are to be taken into account.
The target group of the report include private investors, public authorities, engineers and architects that may not be familiar with the complexity of a LCA approach. The report was therefore written on purpose in a quite simple and clear form. More technical details on the background information and data can be obtained from ArcelorMittal's experts.

2.2. Infrastructure description and assumptions

The design of the structure was made according to European standards. Some loading parameters were taken from other international regulations and recommendations.
The geotechnical design was done according to EN 1997-1 [8], the steel sheet piles according to EN 1993-5 [9], and the concrete wall according to EN 1992-1 [10].

The execution of the wall is performed with land-based equipment. An alternative with equipment on barges would have increased the gap of the cost.

The service life of the structure was assumed to be 50 years, during which no major maintenance or repair works would be required for any of the structural solutions.

The main parameters that have an influence on the environmental impact during the usage phase are corrosion (loss of steel thickness), corrosion protection (coatings, cathodic protection), as well as the reuse and recycling rates assumed at the end of life.

For the steel structure, sacrificial thickness was the chosen solution. No coatings or cathodic protection was considered. According to EN 1993-5, the loss of steel varies with the exposed zone.

The maximum loss assumed per face is 0.148 in in the splash zone, 0.069 in in the permanent immersion zone, and 0.024 in in the buried zone.

The base scenario assumes that after the service life, steel sheet pile walls can be fully recovered, whereas for the concrete wall it is impossible.

The sensitivity analysis considered a few options

- recovering and recycling of a portion of the concrete wall (above the dredge level),
- different concrete strengths and EPDs,
- carbonation of concrete was analysed, although the phenomenon is highly improbable over the major length of the concrete wall,
- loss of steel thickness due to corrosion.

Use of low carbon cements was not analyzed in this case study as these cements are not recommended for use in contact with salt waters, and also due to the fact that the allocation method was under discussion at the European level at the time of the LCA analysis. The impact of bentonite was neglected due to the lack of reliable information available.

2.3. Environmental indicators

The different environmental impacts are characterized according to EN 15804 [11] based on CML 2001. For the steel Environmental Product Declaration (EPD), "CML 2001: April 2013" has been applied, following EN 15804+A1 and IBU PCR Part A [12]. For the concrete EPD, the same framework is applied. For non IBU Data, the extraction from the Gabi database [13] is done with the same EN 15804 method.

Only the date of CML 2001 method could vary but that might only slightly influence the results. Thus, this study can be considered as a carbon footprint assessment. GWP remains the most convenient indicator to quantify CO_2-eq. emissions. This indicator is calculated according to EN 15804 (23 flows) based on CML 2001: April 2013 method (235 flows) based on IPCC 2007. For all steel data, a physical allocation is applied to slag according to the EUROFER[iii] rules.

2.4. Functional unit

The LCA covers the entire quay wall structure (650 ft) and its effects over a time horizon of 50 years, the assumed lifetime of the structure. The quay wall structure fulfils the requirements of a retaining wall and a bearing foundation.

[iii] European Steel Association, www.eurofer.eu

3. Methodology

3.1. Data

Preference was given to the most relevant and recent sources. The database was built on the following elements

- Environmental Product Declarations (EPDs), following the standard EN 15804 and registered in IBU. Those data are public and peer reviewed,
- Gabi Database 2018 for transportation as well as construction site and in-use processes.

Representativeness and consistency of the data was checked, and whenever possible, Belgian, German or European EPDs and databases were used. Note that some inherent cut-off might be done in the data, but all the data in the EPDs are compliant with European standards.

The selected steel sheet piles are manufactured in ArcelorMittal's mill in Belval, Luxembourg. The data for steel sheet piles was extracted from ArcelorMittal's *EcoSheetPiles™* EPD [14]. Note that since this is an LCA being performed for a specific project, the values form the EPD were adapted to fit the project specific assumptions. Therefore, a simple tool was developed by the R&D department.

Rebars could be delivered from any mill in Europe, hence the difficulty in choosing a specific mill. The best option is to consider one EPD and to calculate an average distance from mills covered in the EPD to the jobsite.

Structural steel such as the waler beams are assumed to be fabricated in one of the mills in Luxembourg (Belval or Differdange). An EPD for steel beams manufactured in Differdange was selected.

Concrete is assumed to be fabricated in a plant close to the port of Antwerp. Specific EPDs for concrete, with and without module D, were used.

3.2. Transport

The environmental impact of the transport modes is taken from the Gabi database from 2018. It contains several categories for each transport mode, for instance an *"articulated lorry with a maximum payload of 27 metric tons, Euro 0-6 mix"*.

The LCA considers the following assumptions for the transport

- steel sheet piles: 155 miles by rail - from the mill in Belval (Luxembourg) to the port of Antwerp in Belgium,
- rebars: 870 miles by rail - average distance from the mills considered in the EPD to Antwerp,
- other steel elements: 155 miles by rail – from the mill in Belval or Differdange (LU) to Antwerp,
- concrete: 6 miles by truck - from a batch plant close to the port of Antwerp.

3.3. End of Life practices

Steel sheet piles and other steel elements from the steel solution are assumed to be recovered after the service life. It is quite rare to reuse sheet piles that have been used in a permanent wall for 50 years, hence two scenarios with 0 % reuse were analyzed:

- 95 % recycling and 5 % landfill,
- 99 % recycling and 1 % landfill.

In the *EcoSheetPiles* EPD, the chosen assumptions are that 25 % are reused, 74 % recycled and 1 % landfilled. The method used to adapt the values from the EPD to above scenarios is explained in detail in the report.

The diaphragm wall could only be partially demolished, so that only a portion could be recovered and recycled / landfilled. This distinction leads also to two different scenarios.

3.4. Bill of materials

The bill of quantities that was used for the analysis is detailed in the LCA report (please refer to the report for more details). It comprises the following items

- equipment mobilization and demobilization,
- preliminary works, clearance and construction site requirements,
- material quantity and specifications,
- earthworks and temporary works,
- structural works,
- disposal of (construction) material.

As can be seen on Figure 2, there is a significant difference on the total mass of the retaining walls, a little bit more than a factor 5. Although it can have a significant influence on the results, the mass is not considered as an environmental criterion. The criterion consists in multiplying each mass with the value of an environmental indicator, and to sum it up.

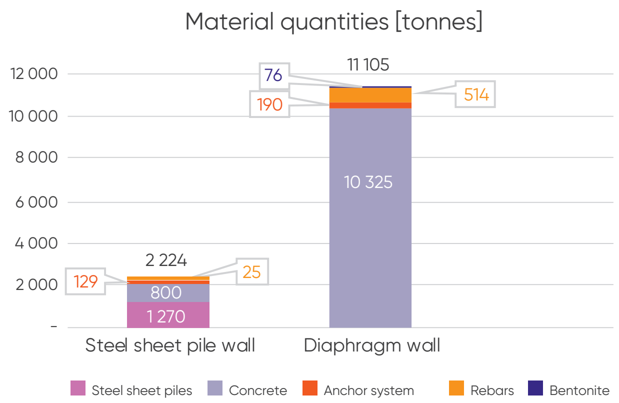


Figure 2. Mass of the retaining walls, excluding soil movements (dredging, back-filling,...).

However, the more material you need to deliver to the job-site, the more traffic will be generated, and in urban areas, it may increase traffic congestion or traffic jams. Choosing prefabricated light elements may be an environmental judicious choice too.

3.5. System boundary

The environmental impacts are calculated considering the following phases

- production of material, phase A1 – A3,
- transportation, phase A4,
- construction, phase A5,
- demolition and processing, phase C3,
- end of life and beyond life cycle, phase D.

Phases B are not included since they are assumed to be negligible in this infrastructure application.

Note that phase A5 includes the construction site preparation. To distinguish "site preparation" and "material installation", both parts have been separated into

- A5 site preparation,
- A5 installation.

However, due to a lack of reliable data and information on the execution methods, the following elements were not considered in the LCA calculation

- steel sheet pile scenario
  - diesel consumption of equipment to install and to remove the sheet piles.
- concrete scenario
  - water volume to create the slurry wall (bentonite mix),
  - treatment of water to separate the bentonite,
  - disposal of separated bentonite.

Note:
According to the EFFC DFI Carbon Calculator [15] and some internal studies, an estimation of the installation processes' contribution to Global Warming Potential is around 2 % for a sheet pile solution and 10 % for a concrete solution.

3.6. Monetization

Monetization is a commonly and politically approved approach to reflect the economical actors' position to global warming and ecological issues. This approach is not compliant with ISO 14040-44 but is applied in Belgium and the Netherlands. This methodological process can address the issue of evaluating a fair and appropriate equilibrium between environmental impacts and costs.

For instance, the default value of 1 tonne of CO_2-eq. is taken as 50 € in the Netherlands, and within a range in Belgium (up to 100 €). The factor is used to multiply the calculated CO_2-eq. content.

In the Netherlands, the method leads to a global index called MKI. It considers several parameters that are not in the standard European EPDs (i.e. toxicological) and weighting factors for each parameter.

Additionally, the method subdivides the data for the LCA in three different categories. The first category corresponds to a specific EPD for a specific product (usually from a single manufacturer), whereas the third corresponds to generic data (average values from available databases or manufacturers) and is penalized by a specific weighting factor to take into account the averaging and spreading of generic data. Consequently, manufacturers that want their products to be part of "Category 1" data must develop a specific EPD for the Netherlands. Note however that this approach has a weakness: in specific cases it might be more favorable to use generic data than a specific EPD which has a very high environmental impact!

4. Results

The focus is on Global Warming Potential. In the base scenario, the **sheet pile wall shows the lowest environmental impact**. Compared to the diaphragm wall (concrete) the **difference of 44 % is quite significant**.

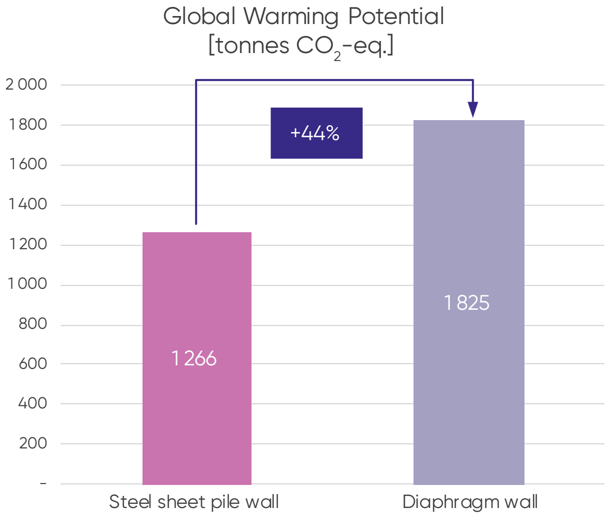


Figure 3. Global Warming Potential - Total impact for the quay wall (tonnes of CO_2-eq.).

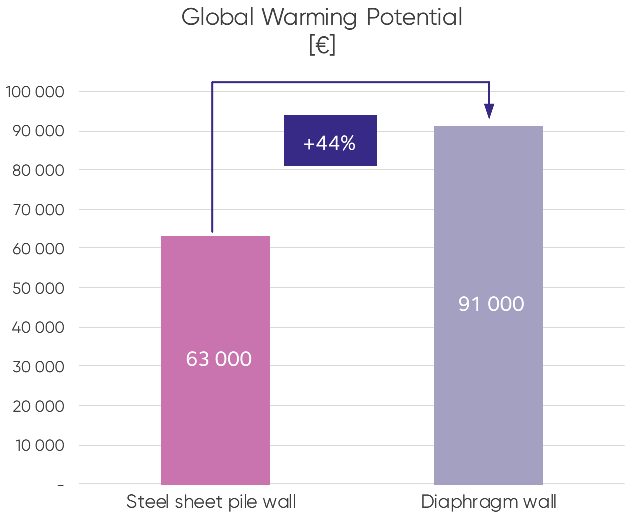


Figure 4. Monetization value of the Global Warming Potential indicator (€).

The split in the different phases is shown in Figure 5.

The biggest gap between both solutions is observed on the phases A1-A3, in favor of EcoSheetPile™ quay.

The burden in module D of the EcoSheetPiles EPD can be explained as follows: the manufacturing of steel in an Electric Arc Furnace (EAF) requires more scrap than the recycled material available at the end of the life cycle. This leads to a negative net scrap value and creates a burden.

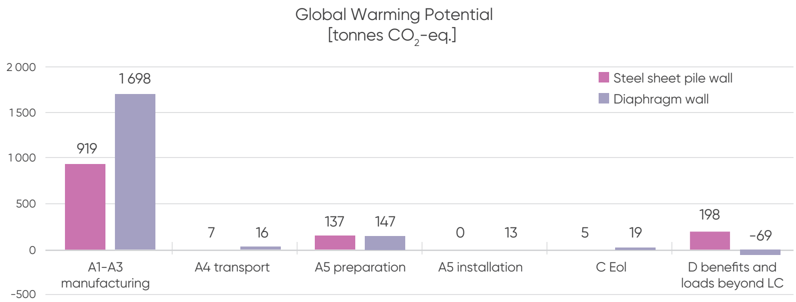


Figure 5. Global Warming Potential - Phase by phase contribution to the life-cycle

Moreover, the contribution of phases A1-A3 to the whole life cycle is more than 70 % in both cases (around 70 % for the sheet pile solution, around 90 % for concrete).

Additional indicators were analyzed: *Acidification Potential, Abiotic Depletion Potential Elements*, etc. Please refer to the report for more details. The trend is similar to the GWP except for *Use of Fresh Water* and *Abiotic Depletion Potential Fossil* where the environmental impact is larger for the steel solution.

The comparison of the indicators shows a sufficient difference between the two alternatives to justify the statement that **"the environmental impact of steel sheet piles is lower than that of the diaphragm wall"**. Indeed, assuming a 5 % uncertainty on each input of the study, **a difference of minimum 10 % is essential to demonstrate a clear difference between alternative solutions.** This condition is observed for the indicators that were analyzed.

5. Sensitivity analysis

5.1. Concrete carbonation at use phase

Carbonation in Module D is taken into account, but it was excluded in Module B1 because the main portion of the concrete is submerged, so that concrete carbonation during the use phase in this particular application is highly improbable.

Nevertheless, an evaluation of this parameter was performed. The conclusion is that applied to the whole concrete volume, the gap between the steel solution reduces from 44 % to 41 %.

5.2. Concrete EPD

Different EPDs for concrete were considered in this sensitivity assessment, and to confirm that the electricity mix has no or limited influence on the GWP of concrete, a set of EPDs from France and from Germany for different concrete strengths was chosen: C 30/37 up to C 50/60. Higher strength concrete increases the gap between the steel solution and the concrete solution, lower strength concrete reduces the gap.

Note: a comparison with concrete based on CEM III cement was not analyzed due to the current inconsistency of slag allocation between steel and cement industries.

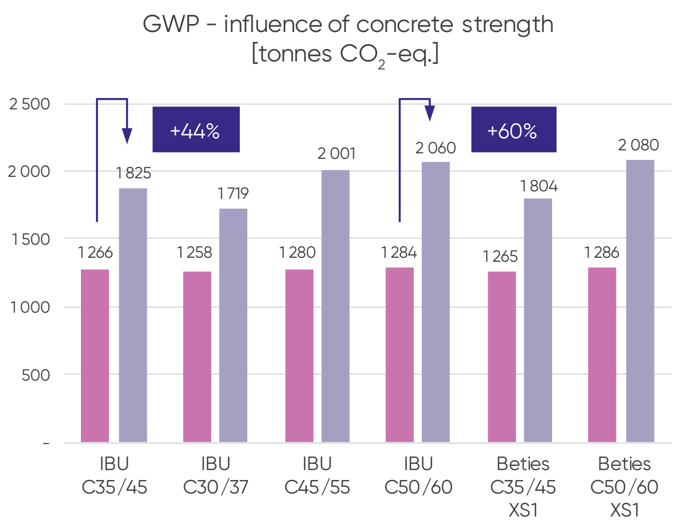


Figure 6. Global Warming Potential - Total value (tonnes of CO_2-eq.) Scenario with different concrete strengths.

5.3. End-of-life scenario

The assessment of the influence of the end-of-life scenario is performed by ignoring the deconstruction/demolishing of the structure for each alternative. Hence the system boundaries are modified by removing phases C3 and D.

Figure 7 shows an increase of the difference between the steel and the concrete solution. This is mainly due to the fact that for the *EcoSheetPiles™* Module D leads to a burden, due to the negative *"Net Scrap Value"* (more scrap is consumed in the EAF production process than is available for recycling at the end of life), whereas for the concrete it is beneficial through carbonation at the end of life.

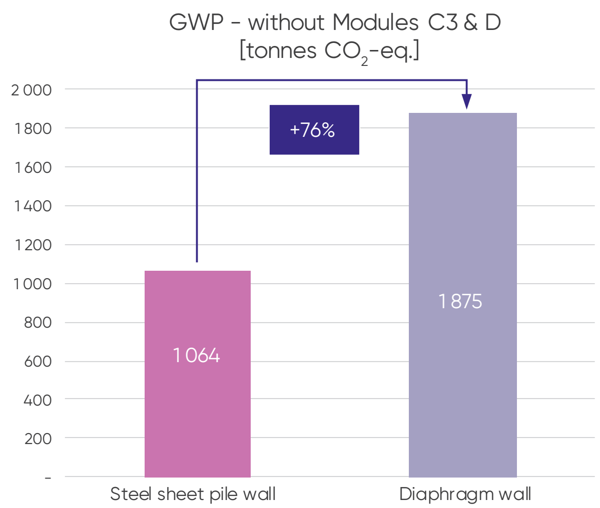


Figure 7. Global Warming Potential - Total value (tonnes of CO_2-eq.) Scenario without Modules C3 and D

5.4. Corrosion losses

A precise loss of steel mass due to corrosion is hardly predictable because the corrosion phenomenon differs by exposure zone and by location.

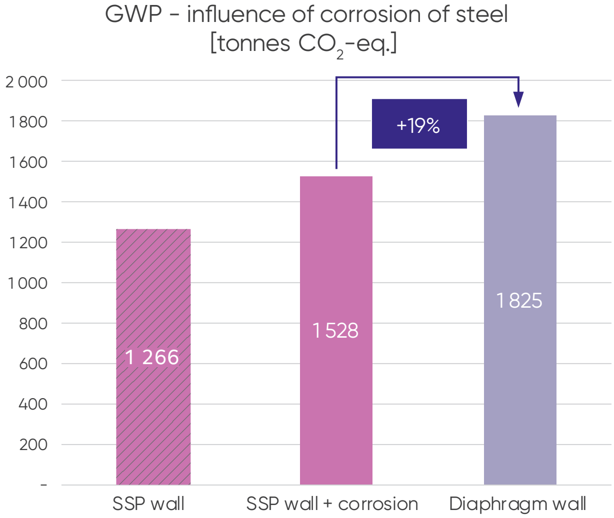


Figure 8. Global Warming Potential - Total value (tonnes of CO_2-eq.)
Scenario with corrosion of steel sheet piles

Several effects during the use phase may have a significant influence on this parameter. When more accurate long-term local measurements are not available, it is usual to assume the corrosion rates proposed in Chapter 4 of the standard EN 1993-5.

Based on this standard, the total loss of steel due to corrosion adds up to around 136 tonnes. Hence, the reuse and recycling rates were adapted to 0 % reuse, 88.3 % of recycling, and 11.7 % landfill.

If the concrete structure would not suffer any similar damage (corrosion of the rebars for instance) during the service life, this worst-case scenario for the steel solution leads to a difference in GWP of +19 %, less than the +44 % from the base scenario (see Figure 8).

5.5. Conclusion

The sensitivity analysis confirms the results from the base scenario in all the cases: the GWP of the concrete structure (D-Wall) is significantly higher than that of the steel sheet pile solution, varying from +19 % to more than +76 % for the extreme scenarios.

6. Conclusions, limitations & general comments

6.1. Conclusions

From this LCA it can be concluded that the quay wall executed with steel sheet piles retaining wall has a lower carbon footprint (expressed in CO_2-eq. emissions) than an equivalent diaphragm wall in concrete. In the base scenario the difference is 44 %, but it depends on the variation of some parameters.

Compared to the concrete solution (D-Wall), the **carbon footprint of the EcoSheetPile™ solution (SSP) is by far lower.** In the base scenario the difference is 44 %.

6.2. Limitations

It is important to note that from a technical point of view, both the steel (SSP) and the concrete (D-Wall) solutions are equivalent. They have been designed by *Tractebel* to perform at a similar safety level during the whole service life.

The results and conclusions from this Life Cycle Assessment (LCA) illustrate a specific case study, and they cannot be extrapolated to other situations (i.e. soil conditions, countries,...) without further analysis (no generalization of the conclusions). The LCA is a snapshot of a specific space and time combination, based on EPDs available at the time of analysis. Technology can evolve quite fast.

The LCA focuses on the Global Warming Potential (GWP) indicator, which highlights the emissions of greenhouse gas emissions of both solutions, but other relevant indicators or/and technical aspects may lead to different conclusions about the most environmentally-friendly and sustainable solution.

Specific site or local conditions may have larger influence on the results in other situations. Particularly, transport to more remote locations may increase the contribution of Module A4, and although its contribution to the total GWP is in many cases quite small, it must be checked. Local conditions such as shortage of sand, potable water, aggregates, etc. could create a more unfavorable situation for the D-Wall, and could lead to a higher influence of the transport module for instance.

Finally, some elements (processes or materials) have not been considered in the LCA. Please refer to the system boundary description in previous chapters, or to the LCA report for more details. This omission is basically due to the fact that the assumptions would be too gross, but based on past experience and available literature, these parameters would not reduce significantly the difference of the GWP between the steel and concrete solution, and would not change the conclusions.

6.3. General comments

EPDs are currently a tool that in a certain way guarantee a quite fair and transparent assessment of the environmental impact of a specific product or service. As a manufacturer, we believe that if it is used in a correct manner, it is an excellent tool to compare different products and different alternatives. It will incentivize manufacturers to improve their productivity and reduce their environmental impact.

However, we have also noticed that not all EPDs have the same quality and fair assessment, and can sometimes be misleading. EPDs should be worked out by environmental experts that are also specialized in the industry for which the EPD is applicable to prevent wrong assumptions or to miss some key processes.

Generic EPDs are a nice tool to compare different alternatives, like in our example, a steel structure versus a concrete structure, at a feasibility stage or design stage for instance. But when it comes to the comparison of the proposed solution for a tender, a specific EPD from one manufacturer for the proposed product should be required. A product that has a major impact on the LCA result but which is not covered by a specific EPD should be penalized, for instance by using a weighting factor relative to the best-in-class product with a specific EPD.

7. References

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Note:
References [1], [2] and [3] are unpublished reports prepared by / for ArcelorMittal.

Disclaimer

The technical and economic analysis of this case study was performed by the Belgian consulting engineers *Tractebel* for ArcelorMittal in 2018. The design assumptions were determined for a cruise ship terminal in soil conditions that are typical for Belgian ports. From an engineering point of view, such simplified assumptions for a soil can be used for a feasibility study or for a comparison of different alternatives.

ArcelorMittal emphasizes on the fact that *Tractebel* has performed an objective and unbiased case study. The analysis is a purely hypothetical case study with its limitations on reliability on costs and techniques, since these aspects can be very dynamic in markets and different subsoils.

This case study is not a project specific design, therefore neither ArcelorMittal nor *Tractebel* can be held responsible for choices made in specific projects based on the design or conclusions of the report prepared by *Tractebel*.
The Life Cycle Assessment (LCA) was performed inhouse by the R&D department in 2020, and peer-reviewed by a panel of three independent experts in 2020 [3]. The conclusion of the reviewers is that the LCA report has been performed in a professional and unbiased way, and that the conclusions are correct. Key parameters were submitted to a sensitivity analysis that confirmed the base scenario; the variation of the parameters did not reverse the results and conclusions of the base scenario.

The text in this brochure is a summary of these two reports. It was edited in order to focus on the key points of the reports with a minimum of technical explanations. Although the content and conclusions are in line with the original reports, ArcelorMittal's engineers added some remarks and comments which complement the information contained in the original reports. Some figures, tables and sketches were edited, removed or replaced by new ones prepared by ArcelorMittal. In case of errors in the transcription, only the text and other elements from the original reports are binding.

The technical report from *Tractebel* and the peer-reviewed LCA report are available on request.

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