ArcelorMittal Sheet Piling

ArcelorMittal

Underground car parks

Detailed Design | The Netherlands

Part 2 | Life Cycle Assessment

Mobility Infrastructure Solutions

Disclaimer

The technical and economic analysis of this case study was performed by the Dutch consulting engineers *Witteveen & Bos* for *ArcelorMittal* in 2020. The design assumptions were determined for a two level below grade underground car park in soil conditions that are typical for the region of Amsterdam in the Netherlands. The design assumptions were the same for the four alternatives. 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 *Witteveen & Bos* 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 Witteveen & Bos* can be held responsible for choices made in specific projects based on the design or conclusions of the report prepared by *Witteveen & Bos*.

The Life Cycle Assessment (LCA) was performed in-house by the R&D department in 2020, and peer-reviewed in 2020 [3] by the Dutch independent research organisation TNO, acting as an independent expert. The conclusion of the reviewers is that the LCA report has been performed in a professional and unbiased way, and that the conclusions are exact. Key parameters were submitted to a sensitivity analysis that confirmed the basic scenario; the variation of the parameters did not reverse the results nor the conclusions from the basic scenario.

This brochure summarises above-mentioned reports. The text and structure were 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, the text and other elements from the original reports are binding.

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

Cover picture: Markthal | Rotterdam | NL

Table of content

PART 2 Life Cycle Assessment

Cities have grown substantially, resulting in higher building densities and a scarcity of space. In many European cities mobility still relies predominantly on individual cars and the associated inherent problem: traffic jams and scarcity of parking slots. Mindsets are changing, but currently, underground car parks (UCP) seem to be the adopted solution in densely populated urban areas.

A first market study performed by *Royal Haskoning DHV*, a Dutch consulting engineering firm, in 2018 compared several alternatives to build the surrounding retaining walls of an UCP in typical Dutch soil conditions. Their conclusion was that for a 2 to 3 level UCP, a permanent steel sheet pile wall is up to 50% more cost-effective than the second best in class, a secant pile wall, and even more compared to other alternatives (cutter soil mix, diaphragm wall). Besides its execution time is also significantly faster.

Later in 2019, ArcelorMittal contracted *Witteveen & Bos* (W+B), another Dutch engineering firm, to dive deeper into this topic and to prepare a more detailed analysis of four alternatives for building the retaining wall of a standard UCP. The results of the technical and financial analysis are detailed in Part 1 of this brochure.

This second part deals with the environmental impact of the alternatives, **focusing on the Global Warming Potential (GWP)**, which can be seen in this case equivalent to the carbon footprint. The environmental impact is determined through a **Life Cycle Assessment**[1] (LCA) based on the bill of quantities prepared by *Witteveen & Bos* [1] and was performed by ArcelorMittal's R&D department [2]. It was peer-reviewed by the Dutch research organisation TNO, acting as an independent expert [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. No reuse was considered.

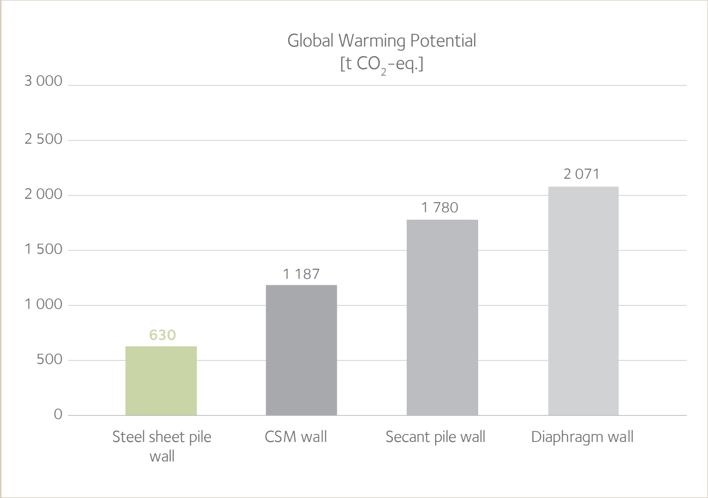
For this type of application, an LCA is a reasonably fair and transparent method to compare different solutions and suppliers. Although not required by ISO and EN standards, an LCA is more accurate and realistic when it uses specific **Environmental Product Declarations** (EPDs) from the producers rather 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 analysed in this case is the *carbon footprint*; its impact for the basic scenario is summarized in the graph below for a rectangular **UCP about 250 m x 30 m**.

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 environmental indicators.

In this case study, the conclusion is that the **EcoSheetPile™** [2] **steel sheet pile wall has the lowest carbon footprint, the difference being 88 % compared to the cutter soil mix wall (CSM), and much more compared to a secant pile wall and a diaphragm wall**. A sensitivity analysis showed that modifying some key parameters did not impact significantly the gaps, and in no case reversed the result.

	Sheet piles	CSM	Secant piles	Diaphragm
Global Warming Potential (t CO_2-eq.)	630	1 187	1 780	2 071
Difference	reference	+88 %	+182 %	+229 %



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

[1] Often also referred to as "Life Cycle Analysis".
[2] 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 a steel sheet pile wall with alternative solutions a simple but realistic case study was carried out. The case study is based on a hypothetical geometry of a 250 meter long by 30 meter wide underground car park (UCP), with two levels below grade that would be built in the city of Amsterdam in the Netherlands.

Following retaining structures were analysed

- steel sheet pile wall (SSP),
- cutter soil mix wall (CSM), also known as deep soil mix in other countries,
- secant pile wall,
- diaphragm wall (D-Wall).

The cross section of the steel sheet pile solution is shown in Figure 1. The length of the retaining walls slightly varies by alternative. The strutting system and other elements (slabs,...) are quite similar for all the solutions, so that as a simplification, *Witteveen & Bos* selected the same elements for the four construction methods. Hence, only the retaining walls differ in this study.

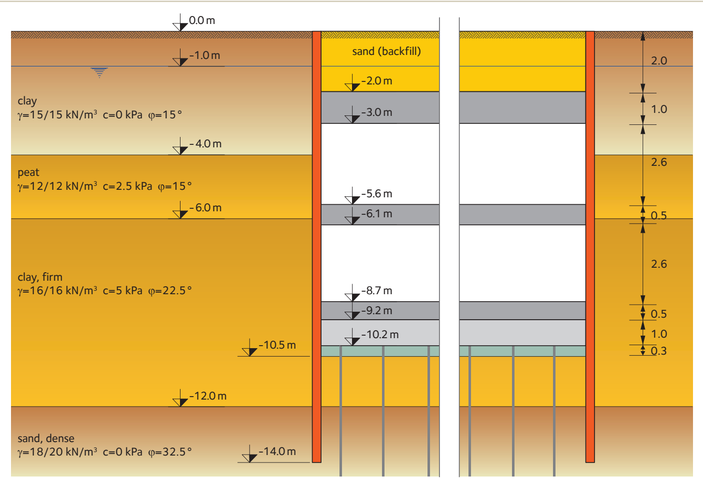


Figure 1. Cross section of the two-level underground car park – steel sheet pile solution (design by Witteveen & Bos).

The scope of the work from the Dutch engineering firm *Witteveen & Bos* was to design the four 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 Part 1 of this brochure.

The sheet pile wall is designed with a 14.0 m long standard **AZ 20-800 section**[3] , in steel grade S 355 GP. Using a higher steel grade would increase the resistance of the wall and consequently the safety on the steel stresses, but would not reduce the deflection / deformation of the wall, which is one key parameter in this case.

The CSM wall is 15.0 m high, with a thickness of 550 mm and reinforced with steel H-beams, whereas the secant pile wall is 14.0 m high with a diameter of the piles of 630 mm and with steel H-beams used as reinforcement of the main piles. The diaphragm wall is 14.0 m high and has a thickness of 800 mm.

It turned out that under the chosen conditions and assumptions, **the steel sheet pile wall is the most cost-effective solution: around 40 % more economical than the cutter soil mix wall.** The most expensive solution is by far the diaphragm wall, and the secant pile wall is slightly more expensive than the CSM wall. Despite the tremendous cost difference between the D-Wall and the other solutions in this specific case, the LCA covers the four alternatives to check if the carbon footprint might offset the financial weakness of one or another solution.

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

The most sustainable structure can be determined in different ways. Several key environmental indicators can be used to compare the most sustainable solutions, such as the MKI indicator (ECI in English) in the Dutch monetization 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 indicators were analysed and show similar trends as the GWP, except for one indicator. The monetization method used in the Netherlands [4] was chosen for this analysis.

The LCA was performed by the R&D department of ArcelorMittal in 2020, and **peer-reviewed by independent experts** [3] from the Dutch research organisation *TNO*. The conclusion of the reviewers is that the LCA report has been performed in a professional and unbiased way, and that the analyses are correct.

The variability of key parameters can influence significantly some results; hence a sensitivity analysis of key parameters was also performed. The alternative scenarios confirm that for most of the parameters, their variation has a limited impact on the results, but never reversed the conclusions from the basic scenario.

[3] The original design considered an AZ 20-700 for driving reasons, but in the meantime, new hydraulic presses allow the installation of the new AZ-800 range without any vibrations.

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 [7] and the infrastructure global LCA, although in principle not applicable, is inspired by the EN 15978 [8] 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 an underground car park structure. It proposes a comparison of four alternative 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 considered whenever technically feasible.

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 and the national application documents specific to the Netherlands. The geotechnical design was done according to EN 1997-1, Design Approach 1 [9], the steel sheet piles according to EN 1993-5 [10], and the concrete wall according to EN 1992-1 [11].

The execution of the wall would be done with standard equipment. As the project is in an urban area, noise and vibrations due to the execution of the walls need to be addressed. For the steel sheet piles, a vibrationless driving equipment (hydraulic press) was preferred by the design engineer, which had a slight influence on the choice of the sheet pile profile.

The service life of the structure was assumed to be 100 years, during which no major maintenance or repair works would be required for any of the structural solutions, except for the renewal after 50 years of the fire protection painting required for the SSP and the secant pile wall.

The basic scenario assumes that after the service life, the steel sheet pile wall can be fully recovered, whereas for the concrete wall solutions and the cutter soil mix wall dismantling is currently technically almost impossible.

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

Consequently, a sensitivity analysis considered a variation of a few parameters, for instance

- no deconstruction of any structure ⇒ exclusion of modules C3 and D,
- loss of steel thickness due to corrosion,
- recovering and recycling of a portion of the concrete wall (above the bottom slab level),
- influence of the choice of the sheet pile section,
- influence of the fire protection product.

For the steel structure, sacrificial thickness was chosen, so no coatings were considered except for a fire protection spray coating on the exposed face. According to EN 1993-5, the loss of steel varies with the exposed zone, but in the Netherlands, it is usual to refer to the CUR 166 [12]. The maximum loss assumed per face is 0.012 mm/year in the buried zone.

Use of low carbon cements was not analysed in this case study because the allocation method for this product was under discussion at the European level at the time where the LCA was drafted.

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 based on CML 2001. For the steel Environmental Product Declaration (EPD), "CML 2001: April 2013" has been applied, following EN 15804+A1 and IBU[4] PCR Part A [13]. For the concrete EPD, the same framework is applied.

For non IBU data, the extraction from the database Gabi [14] is done with the same EN 15804 method. Only the date of CML 2001 method could vary but that would 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[5] rules.

2.4. Functional unit

The LCA covers the entire underground car park (250 m x 30 m) and its effects over a time horizon of 100 years, the assumed lifetime of the structure.

The different retaining structures fulfil the requirements of a retaining wall (horizontal loads from the soil) and a bearing foundation (vertical loads from the structure).

UCP Miroir / Spiegel | Jette | BE

[4] IBU: Institut Bauen und Umwelt, Germany, https://ibu-epd.com/.
[5] 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, 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 [15]. Note that since this is an LCA being performed for a specific project, the values form the EPD were adapted to fit the project specificities. Therefore, an Excel 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. In that case, 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 H-beams used to reinforce the CSM wall and the secant pile wall would 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 city of Amsterdam. Specific German EPDs for concrete, with and without module D, were used. Using a Dutch EPD might introduce a bias because Dutch EPDs included in the official Dutch database (*Nationale Milieu Database*, NMD [16]) are generally elaborated with a different software and based on a different life cycle inventory (*ecoinvent* [17]).

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 tonnes, Euro 0-6 mix*".

The LCA considers following assumptions for the transport

- steel sheet piles: 410 km by rail – from the mill in Belval (LU) to Amsterdam (NL),
- rebars: 1 400 km by rail - average distance from the mills considered in the EPD to Amsterdam,
- steel H-beams: 410 km by rail – from the mill in Belval or Differdange (LU) to Amsterdam (NL),
- concrete: 10 km by truck - from a batch plant close to the jobsite in Amsterdam.

3.3. End of Life practices

Generally speaking, steel sheet piles are recovered after the temporary use, respectively after the service life. In the EPD EcoSheetPiles, the chosen assumptions are that 25 % are reused, 74 % recycled and 1 % landfilled. However, in the case of a UCP, it is quite rare to reuse sheet piles that have been used in a permanent wall for 100 years, hence the basic scenario considers that the sheet piles will be extracted and recycled after the service life. The more realistic end of life scenario is

- 99 % recycling, 0 % reuse and 1 % landfill.

The method used to adapt the values from the EPD to above scenario is explained in detail in the report.

In the basic scenario, the three concrete solutions are not demolished at the end of life, but one additional scenario deals with this topic.

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 following items

- equipment mobilization and demobilization,
- preliminary works, clearance and construction site requirements for the concrete solutions,
- 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 materials used to build the retaining walls, varying from a factor around 5 to almost 18. 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.

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 and lead to significant traffic jams, which has a substantial impact on the economy and the well-being of people living in the area. For this reason, choosing prefabricated light and compact elements may be an environmental judicious choice too.

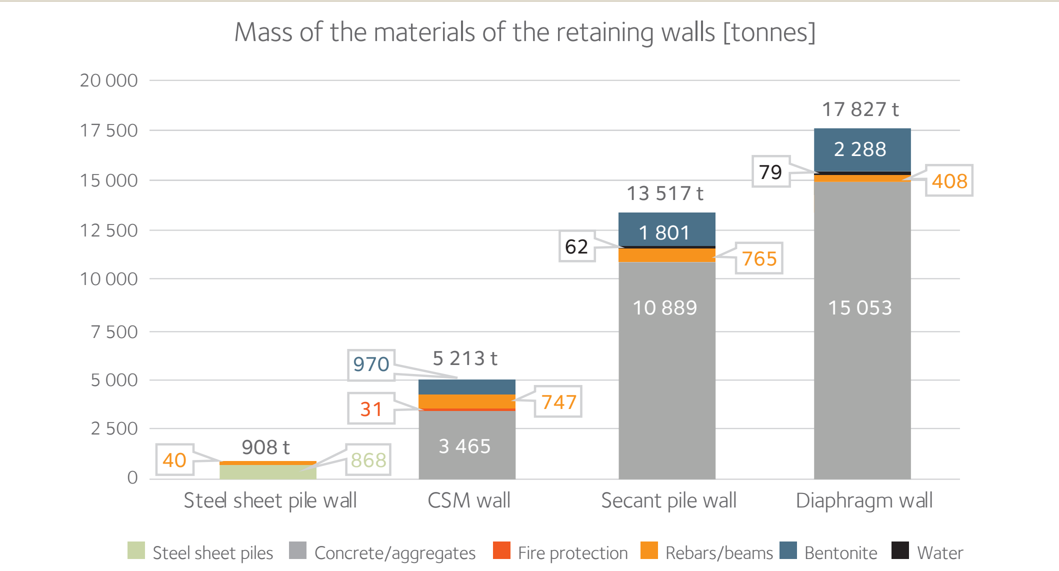


Figure 2. Mass of the materials used for the retaining walls, excluding soil movements (excavation, mixed soil, back-filling,...).

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,
- end of life, including demolition and processing, phase C3,
- benefits / loads beyond the product system boundary, phase D.

Phases B are not included since they are assumed to be negligible in this infrastructure application, except for phase B4 that considers the replacement of the fire protection coating after 50 years.

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, for A5, only the supply of bentonite and the site preparation (excavation) are included. No other installation processes are considered since not enough precise scenarios could be provided. Hence, 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
  - treatment of water to separate the bentonite,
  - disposal of separated bentonite.

Consequently, to be coherent, phases C1 and C2 were also excluded.

Note: according to the EFFC DFI Carbon Calculator [18] and some internal studies, an estimation of the installation processes contribution to Global Warming Potential is around 2 % for a steel sheet pile structure and 10 % for a concrete based structure.

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 for 1 tonne of CO_2-eq. is taken as 50 € in the Netherlands, and within a range in Belgium (up to 100 €). This weighting factor is used to multiply the calculated CO_2-eq. content.

In the Netherlands, the method leads to a global index called MKI (ECI in English). It considers a total of 11 environmental indicators, including some that are not required in standard European EPDs (i.e. toxicological indicators) and weighting factors for each indicator. Additionally, the method subdivides the environmental 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 an additional weighting factor to take into account the averaging and spreading of generic data. In the Netherlands, the penalization factor is 30 %. Consequently, manufacturers that want their products to be part of Category 1 data must develop a specific EPD for the Netherlands.
Category 2 data contains for instance collective EPDs, i.e. data for one specific product but produced by several manufacturers, or an EPD covering several products produced by a single manufacturer. Note however that this approach has a weakness: in specific cases it might be more favourable to use generic data (category 3) than a specific EPD which has a very high environmental impact!

4. Results

The focus of the LCA is on the Global Warming Potential. In the basic scenario, the **sheet pile wall shows the lowest environmental impact**. Compared to the second most environmentally-friendly solution, the CSM (soil mix), the **difference of 88 % is pretty high**.

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

The biggest gap between both solutions is observed in the phases A1-A3, in favour of the *EcoSheetPile* steel sheet pile solution.

The burden in module D of the *EcoSheetPile* structure can be explained as follows: the manufacturing of steel in an Electric Arc Furnace (EAF) requires more scrap than the quantities of recycled material available at the end of the life cycle. Using the methodology recommended by the *Worldsteel Association*, this leads to a negative "Net Scrap Value" and creates a burden, hence a positive emission of CO_2-eq.

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

Additional indicators were analysed: *Acidification Potential, Abiotic Depletion Potential Elements*, etc. Please refer to the report for more details. The trend is similar to the GWP for the additional indicators, except for the *Ozone layer Depletion Potential* where the environmental impact of the steel solution is higher, mainly due to the fire protection painting layer.

The comparison of the indicators shows a sufficient difference between the four alternatives to justify the statement that "**the environmental impact of steel sheet piles is lower than that of other solutions**". 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 analysed.

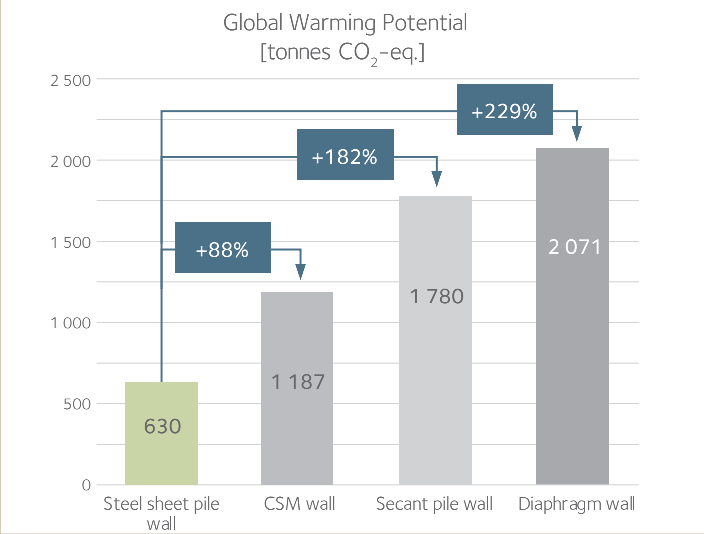


Figure 3. Global Warming Potential - Total impact for the UCP (t of CO_2-eq.).

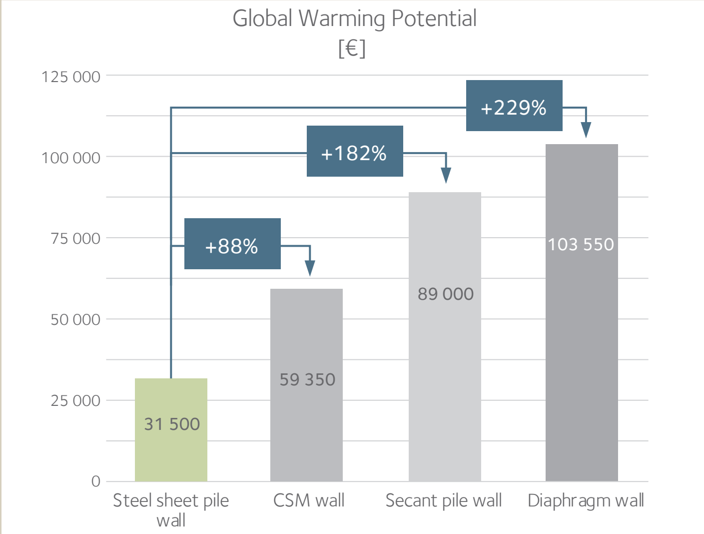


Figure 4. Monetization value of the Global Warming Potential indicator (€) according to the Dutch method.

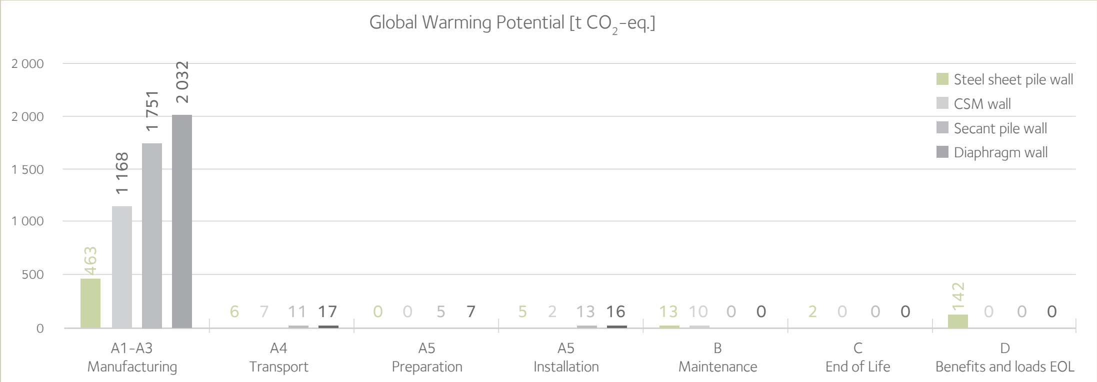


Figure 5. Global Warming Potential - Phase by phase contribution to the life cycle.

5. Sensitivity analysis

5.1. Bentonite

The water volume used to create the bentonite to support the temporary trenches / holes of the D-Wall and secant pile wall is considered in the phase A5 (installation).

Due to the lack of data and information, the water treatment on site after extraction of bentonite was not included in the current calculations.

The results were reassessed without considering the water volumes, and lead to a reduction of the gap between the CO_2-eq. emissions of less than 1 %.

5.2. Transport distance for concrete

The transport A4 module contributes to less than 1 % of the total value on the considered perimeter. Although 10 km of delivering distance for the concrete may be on the low side, doubling or even tripling the distance would not have changed the conclusion between the concrete solutions and the steel solution.

5.3. End-of-life scenario – excluding modules C3 & D

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. Fact is that for the concrete solutions and the CSM, the basic scenario already disregarded modules C3 and D because these structures would not be demolished.

Figure 6 shows an increase of the difference between the steel solution and the three other alternatives, for instance rising from 88 % to 144 % compared to the CSM wall. This is mainly due to the fact that for the sheet piles *EcoSheetPile*, module D leads to a burden, whereas for the other solutions, it was already ignored.

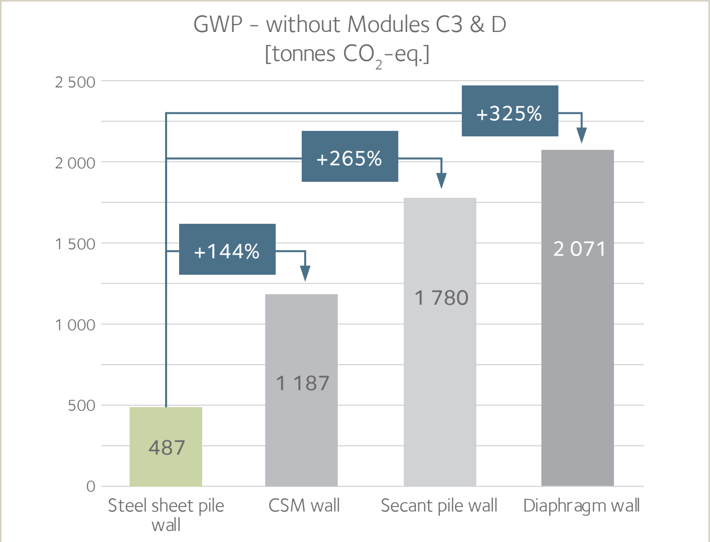


Figure 6. Global Warming Potential - Total (t of CO_2-eq.)- Scenario without modules C3 and D.

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

However, in the Netherlands it is standard practice to use the values recommended in the CUR 166 manual. For steel buried in the soil, the corrosion loss per face can be estimated as 0.012 mm / year, leading to a loss of approximately 137 tonnes of steel over the service life of 100 years (no corrosion occurs on the surface protected by the painting).

Hence, the reuse and recycling rates of the EPD *EcoSheetPiles* were adapted to 0 % reuse, 84.2 % of recycling, and consequently 15.8 % landfill.

This worst-case scenario for the steel sheet pile wall (SSP-wall) reduces the gap in the GWP between the steel sheet pile wall and the alternatives, i.e. falling from +88 % (basic scenario) to +35 %, see Figure 7.

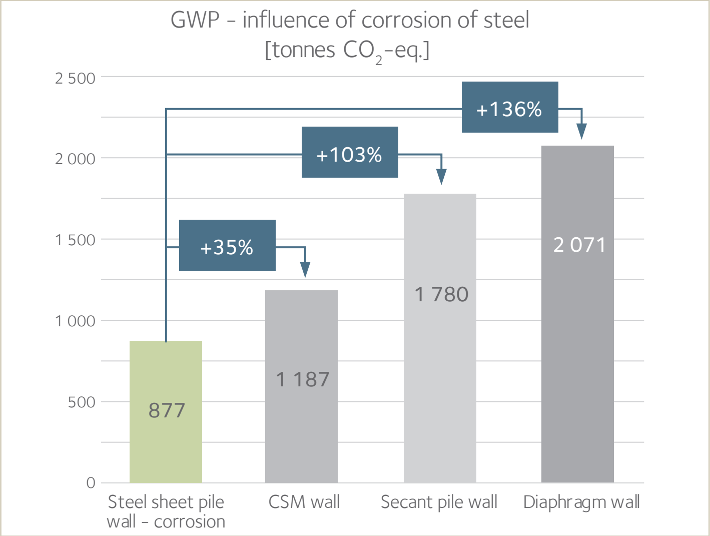


Figure 7. Global Warming Potential - Total (t of CO_2-eq.) - Scenario with corrosion of steel sheet piles.

5.5. End-of-life scenario – deconstruction and recycling of the D-Wall and secant pile wall

This scenario considers that the portion of the concrete wall and its reinforcement above the excavation level (-10.5 m) will be demolished after the service life, and that the portion completely embedded (3.5 m) will be left in place. Currently this scenario is technically improbable but might be imaginable in the future. It applies to the diaphragm wall and to the secant pile wall.
The cutter soil mix wall cannot be demolished since it consists in strengthening the existing soil; although a technique to extract the reinforcing steel beams may be developed in the future, it was not considered as an option in this study.

Considering the end of life and the recycling modules of the EPDs of the concrete solutions decreases the gap between the sheet pile wall and the concrete structures by roughly 5 % to 10 %, see Figure 8.

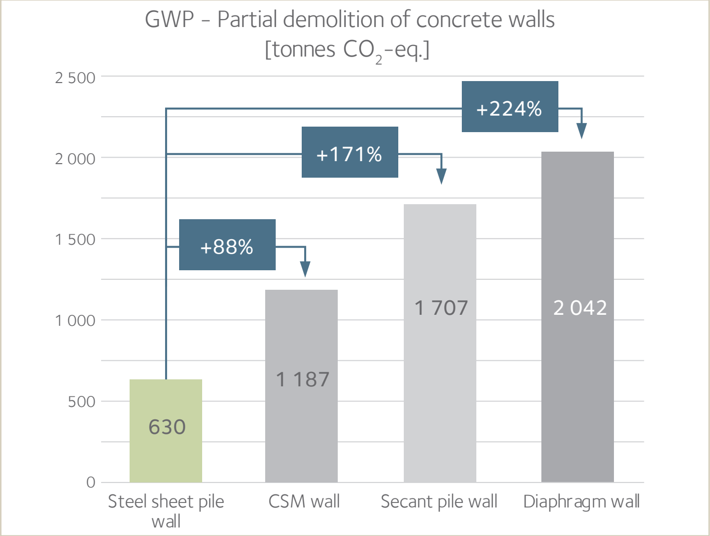


Figure 8. Global Warming Potential - Total (t of CO_2-eq.) - Scenario with partial demolition of the diaphragm wall and secant pile wall.

5.6. Influence of the steel sheet pile profile

This scenario analyses the influence of the chosen sheet pile section on the results. Currently, several equivalent profiles from different sheet pile series can be used for the same retaining structure. Wider profiles from the AZ-800 range are lighter and can usually be installed faster, but the choice needs also to consider driveability criteria, which depend mainly on the soil conditions, length of the pile, etc. The study compared two profiles, the AZ 20-800 and the AZ 20-700 (original choice in the report of *Witteveen & Bos*). The following Table 1 shows the bill of materials for both profiles. Note that the AZ 20-800 is 800 mm wide compared to 700 mm for the AZ 20-700, and has a different height; this leads to a difference in seal-welding length and coating area (and its mass).

Parameter	AZ 20-800	AZ 20-700	Unit	Difference in %
Mass of steel sheet piles	867.9	896.2	t	+3.3 %
Mass of fire protection painting	39.7	40.7	t	+2.5 %
Length of interlock seal-welding	6 300	7 200	m	+14.3 %

Table 1. Steel sheet pile wall – bill of quantities of equivalent profiles.

The gap between the steel sheet pile wall and the other solutions shrinks by less than 10 %, confirming the global trend of the basic scenario.

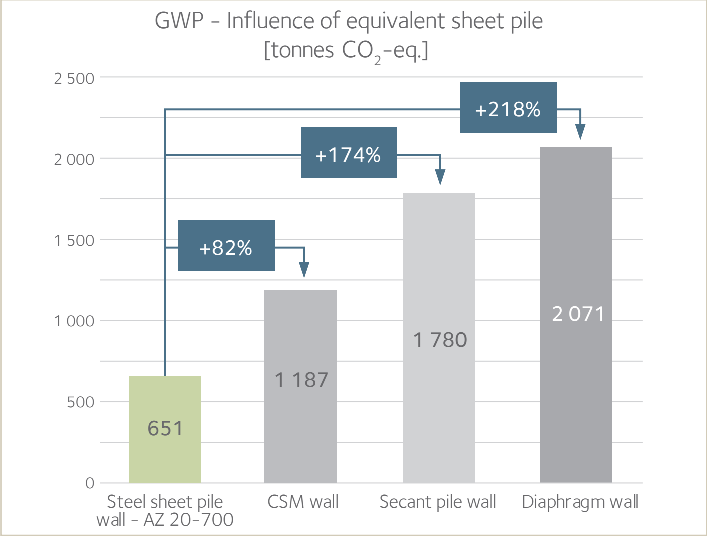


Figure 9. Global Warming Potential - Total (t of CO_2-eq.) - Scenario with the equivalent sheet pile profile AZ 20-700.

5.7. Influence of the fire protection painting

This scenario analyses the influence of the chosen fire protection painting on the results. The basic scenario uses PROMASPRAY® P300, and FIBROFEU® is a spray coating with an equivalent fire protection performance. The spray coating is also applied to the CSM, so that the impact on both solutions is quite similar, see Figure 10.

The gap between the steel sheet pile wall and the other concrete solutions shrinks by 30 % to 40%. Despite the quite higher carbon footprint of this alternative product, the global trend of the basic scenario would not be altered.

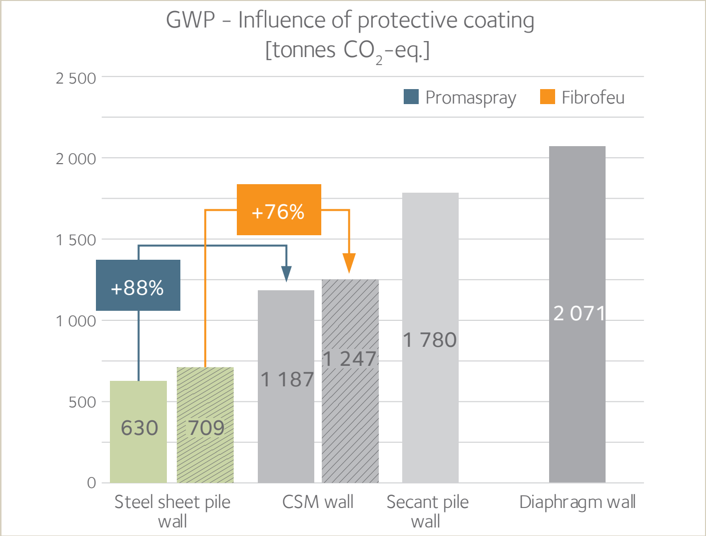


Figure 10. Global Warming Potential - Total (t of CO_2-eq.) - Influence of the fire protection system (paintings).

5.8. Influence of the different scenarios on the GWP of the sheet pile wall

This section summarizes the variation of the GWP of the steel sheet pile wall with the assumptions of the different scenarios. In Figure 11, it is clearly visible that for the type of structure under assessment, the loss of steel thickness due to corrosion has the major influence. The increase of the GWP due to corrosion amounts to almost 40%.

Note: for steel manufactured through the secondary route (recycling of steel scrap in an Electric Arc Furnace), omitting the stage beyond End-of-Life (module D) can lead to a significant reduction of its carbon footprint (-23% in this case study)! This is a drawback of some LCA models.

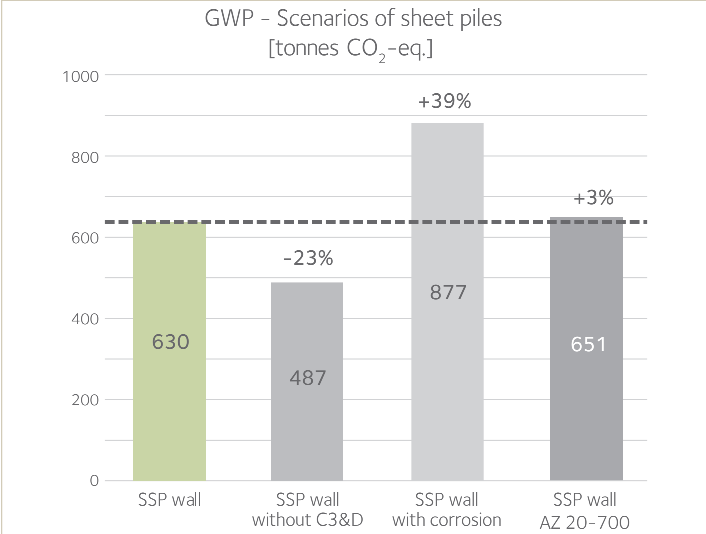


Figure 11. Global Warming Potential - Total (t of CO_2-eq.) – Influence of the scenarios on the GWP of the steel sheet pile wall.

5.9. Conclusions

The sensitivity analysis that was conducted confirms the robustness of the models and of the assumptions made in the basic scenario. **In all the cases, the carbon footprint (expressed as the GWP) of the steel sheet pile solution is always lower.** The difference varies by alternative and depends also on the scenario.

Compared to the steel sheet pile walls, the range of the increase in GWP for the extreme scenarios is shown in Table 2.

Retaining wall	GWP - difference in %	
	Basic scenario	Other scenarios
Steel sheet pile wall	Reference	Reference
CSM wall	+88 %	+35 % up to +144 %
Secant pile wall	+182 %	+103 % up to +265 %
D-Wall	+229 %	+136 % up to +325 %

Table 2. GWP – variation for all the scenarios.

6. Conclusions of the LCA

6.1. Conclusions

The aim of this Life Cycle Assessment (LCA) was to compare the environmental impact of several alternatives for the execution of the retaining wall of an underground car park (UCP) in an urban area. The design of a specific case study was performed by the Dutch design engineering firm *Witteveen & Bos*, assuming the structure would be built in the city of Amsterdam (NL). Although the LCA focused on the Global Warming Potential (GWP), other environmental indicators were examined, and a sensitivity analysis of key parameters was also done.

The key conclusions of this LCA for this specific case study is that **the underground car park executed with a steel sheet pile retaining wall has a much lower carbon footprint (expressed in emissions of CO_2-eq.) than equivalent alternatives in concrete (diaphragm wall, secant pile wall) and a deep soil mix wall (cutter soil mix)**. In the **basic scenario the minimum difference is 88 %** and varies for additional scenarios from +35 % up to +325 %.

Compared to the concrete solutions (D-Wall, secant pile wall) and to a cutter soil mix wall, the carbon footprint of the EcoSheetPile™ solution (SSP) is by far lower.

In the basic scenario the minimum difference is 88 %

6.2. Limitations

It is important to note that from a technical point of view, all the four retaining wall solutions are equivalent. They have been designed by *Witteveen & Bos* 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 environmental indicator Global Warming Potential (GWP), which highlights the greenhouse gas emissions of the solutions, but other relevant indicators and / or technical aspects may lead to different conclusions on 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 unfavourable situation for the structures using large quantities of concrete, 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 solutions and would not change the conclusions.

As a reminder, the execution of the retaining walls has not been considered in the phase A5 due to a lack of reliable data. For instance, the influence of the driving of steel sheet piles will depend mostly on the chosen driving equipment. A rough estimation with a third-party calculation tool lead to a contribution to the GWP of only 2 % for the steel sheet piles, and 10 % for a diaphragm wall. This contribution is quite small, in the same range as the transport module A4, and hence would not change the conclusions.

6.3. General comments

EPDs are currently a tool that in a certain way enable 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 way, an LCA based on peer-reviewed EPDs according to EN 15804 is an excellent method to compare different products and/or several alternatives. Investors can undoubtedly encourage manufacturers to improve their competitiveness (i.e. productivity, new production technologies) in order to reduce their environmental impact by awarding a financial incentive to the solutions with the lowest environmental impact for each project. This approach is already implemented in some European countries for public procurement.

Unfortunately, we have also noticed that not all EPDs have been drafted with the quality and fair assessment that can be expected from such a document, and even worse, in some cases it can be misleading. EPDs should be worked out by environmental experts that are also specialized in the industry for which the EPD is applicable to avoid wrong assumptions or to miss some key processes.

Generic EPDs are a nice tool to compare alternatives, like in this UCP case study, a steel structure versus concrete structures and a soil mix structure, at a feasibility stage or design stage for instance. But when it comes to the comparison of alternatives at the tender stage, a specific EPD from the manufacturer of the product is the most appropriate and 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 on its environmental impact indicators relative to a specific EPD from a product produced with the same process, or relative to the best-in-class product.

7. References

[1] Witteveen + Bos, "Underground Car Parks Design - Ref. 111629/20-002.313," Deventer, 2020.

[2] ArcelorMittal Global R&D, LCA methodological report - Comparative study of Steel Sheet pile, Diaphragm wall, Secant Piles and Cutter Soil Mix walls in Underground Car Parks application, Luxembourg, 2020.

[3] TNO innovation for life, "Review letter LCA UCP - Ref. 100339373," Utrecht, 2020.

[4] Stichting Bouwkwaliteit, Determination Method - Environmental performance - Buildings and civil engineering works, Rijswijk, 2019.

[5] ISO, ISO 14040:2006-07 - Environmental management - Life cycle assessment - Principles and framework, 2006.

[6] ISO, ISO 14044:2006+A1:2018 - Environmental management - Life cycle assessment - Requirements and guidelines, 2018.

[7] CEN, EN 15804:2012+A1:2013. Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products, Brussels, 2013.

[8] CEN, EN 15978:2011. Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method, Brussels, 2012.

[9] CEN, EN 1997-1:2004+A1:2013. Eurocode 7. Geotechnical design. General rules, Brussels, 2013.

[10] CEN, EN 1993-5:2007. Eurocode 3. Design of steel structures. Part 5: Piling., Brussels, 2007.

[11] CEN, EN 1992-1 (series). Eurocode 2. Design of concrete structures, Brussels, 2004-2019.

[12] CROW, CUR 166 Damwandconstructies, Ede: CROW, 2012.

[13] IBU - Institut Bauen und Umwelt e.V., PCR for Building-Related Products and Services. Part A - Calculation rules for the Life Cycle Assessment and Requirements on the Project Report - v 1.7, Berlin, 2018.

[14] Thinkstep (Sphera), Gabi database, Berlin, 2018.

[15] IBU - Institut Bauen und Umwelt e.V., EPD "EcoSheetPiles™" - EPD-ARM-20180069-IBD1-EN, Berlin, 2018.

[16] Nationale Milieu Database, 2021. [Online]. Available: https://milieudatabase.nl/. [Accessed 2021].

[17] Ecoinvent, 2021. [Online]. Available: https://www.ecoinvent.org. [Accessed 2021].

[18] EFFC - DFI, EFFC DFI Carbon Calculator Methodological & User Guide v2.1, 2013.

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

Disclaimer

The data and commentary contained within this steel sheet piling document is for general information purposes only. It is provided without warranty of any kind. ArcelorMittal Commercial RPS S.à r.l. shall not be held responsible for any errors, omissions or misuse of any of the enclosed information and hereby disclaims any and all liability resulting from the ability or inability to use the information contained within.
Anyone making use of this material does so at his/her own risk. In no event will ArcelorMittal Commercial RPS S.à r.l. be held liable for any damages including lost profits, lost savings or other incidental or consequential damages arising from use of or inability to use the information contained within. Our sheet pile range is liable to change without notice.

Printed on FSC paper. The FSC label certifies that the wood comes from forests or plantations that are managed in a responsible and sustainable way (the FSC principles promote the social, economical, environmental and cultural needs of today's and the next generations). www.fsc.org

Part2_Edition 7.2021

ArcelorMittal Commercial RPS S.à r.l.
Sheet Piling

66, rue de Luxembourg
L-4221 Esch-sur-Alzette (Luxembourg)

E sheetpiling@arcelormittal.com
sheetpiling.arcelormittal.com

UCP W+B_Part 2_-EN

Hotline: (+352) 5313 3105

ArcelorMittalSP

ArcelorMittal Sheet Piling (group)