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Prolock
sustainable bank protection

LCA-report of MultiLock® & ProLock bank protection

Cat. 1 LCA, GWW Section 41.1

Public version

CE Delft
Committed to the Environment

Stimular
De werkplaats voor Duurzaam Ondernemen

LCA-report of Prolock bank protection

Cat. 1 LCA, GWW Section 41.1

Public version

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More information about the study is available from Maarten Bruinsma (CE Delft) and Willemien Troelstra (Stimular)

Contents

Stimular
De werkplaats voor
Duurzaam Ondernemen

1 Introduction

This report is the public version of the LCA report. Confidential business information has been removed from this version, which means that names of suppliers and production volumes have been removed. The annexes have also been removed.

Profextru Productie B.V. is the producer of Prolock plastic piling that are produced from recycled PVC. The sheet piling are, for example, used as revetments, sheetpile walls and seepage screens. There are four types of ProLock screens: MultiLock® Sigma, Omega, MultiLock® Delta and MultiLock® Diplo.

In 2017, a life cycle analysis (LCA; also referred to as a life cycle assessment) was performed for the Prolock range for inclusion in the Dutch National Environmental Database (in Dutch: *Nationale Milieudatabase*, NMD). This report updates the LCA of the Prolock sheet pile walls in accordance with the current requirements and guidelines within the LCA methodology that describes the basic assumptions and results for Prolock sheet pile walls of Profextru. The results in this report will be published as product cards in the National Environmental Database. The description of the various product cards for the end user are provided in Chapter 2.

The civil engineering data in the National Environmental Database is used for calculating the Environmental Cost Indicator (ECI) of materials, products and processes for the realisation of a civil engineering work. This ECI is calculated by means of the specifications in the Environmental Performance Assessment Method for Construction Works[1]. With software instruments such as DuboCalc[2], it is possible to calculate the ECI for a product, object and complete a project with the help of the National Environmental Database.

Clients in the civil engineering sector use these ECI calculations to make decisions about various materials or design options during the design phase of the project. They compare the ECI of the various solutions and can then choose the most sustainable material (the product with the lowest ECI). The invitation to tender for a project may also include an award criterion where the tenderer with the lowest ECI receives the highest fictional discount[3].

1.1 Objective and target group

We define environmental profiles of several ProLock sheetpile walls in this study. The objective of the study is:

— To determine the environmental impact of the Prolock sheet pile wall throughout the entire life cycle in various combinations (with softwood (conifers), hardwood and steel posts & tubes);

— To transfer the information about these products to the National Environmental Database (category 1 data, proprietary and tested by third parties) so that it becomes available in software such as in DuboCalc;

1 More information about the Assessment Method

2 More information about DuboCalc

3 More information about the use of the ECI as award criterion

— To inform clients and other relevant parties about the environmental impact of the products.

This report is meant to document the choices made in materials and environmental data in order to provide accountability. The contents of the report is confidential. The end results, the environmental profiles of the Prolock sheetpile walls and the environmental statements are available to external parties via the National Environmental Database and DuboCalc. Profextru Productie B.V. itself may also provide the environmental profiles to parties.

This study has been drawn up for the following target groups:
— Profextru Productie B.V. as the owner of the data;
— Stichting National Environmental Database (NMD) as the manager of the National Environmental Database;
- Distributors including THE Plastic Piling Company Limited
— Clients in the civil engineering sector as a basis for reference designs, exploratory (design) studies and for use in invitations to tender;
— Market parties such as engineering and consultancy firms and contractors active in the civil engineering sector as a source of information for the use of the National Environmental Database data via calculation instruments.

1.2 Accountability

We have performed the LCA in accordance with the requirements and guidelines in the *Environmental Performance Assessment Method for Construction Works (July 2020) including the amendment of 1 July 2019, the amendment of January 2020 and the amendment of February 2021 and the National Environmental Database testing protocol (version 1.0, July 2020 + Amendment 1, February 2021).* The Assessment Method is based on *ISO 14040 – ISO 14044* and *EN 15804:2012+A2 (2019)*[4].

The data was collected in the period from August 2021 to November 2021 after which the calculations were made and the LCA file was drawn up.

1.3 Verification

SGS assessed the file with the CE Delft & Stimular "LCA report of Prolock bank protection, Cat. 1 LCA, Civil engineering Chapter 41.1" (final draft version of 10 February 2022 and received on 22 February 2022). The report describes the basic assumptions, the modelling and the results.

The conclusion states: The methodology, data collection and report comply with the requirements of the "Environmental Performance Assessment Method for Construction Works of structures", version 1.0 – July 2020 with the amendments of October 2020 and February 2021, EN 15804 and underlying standards.

The 12 relevant product cards (5 Sigma, 4 Omega, 2 Aqua and 1 Delta) were published on 22 February 2022 and are available via the National Environmental Database.
Reader's guide

[4] The only thing not included in ISO 14044 is the adding up of the environmental impact scores to obtain a total score (the ECI, see Section 4.6).

Chapter 2 describes the method for the LCA. This is where we set the scope, system limits and functional unit.
Chapter 3 deals with the life cycle inventory. The product description, product composition and the inventory of the LCA are discussed in this chapter.
Chapter 4 presents the results and the sensitivity analysis.

2 Method

2.1 Approach

This report describes several ProLock sheetpile walls. These sheetpile walls are the main product, constructed from various semi-finished products (see Section 2.3). We describe the entire life cycle of these semi-finished products.

We perform the LCA calculation with SimaPro version 9.2.0.2 software. The reference databases used are:

- Processes database, National Environmental Database, version 3.4.
- Ecoinvent database, version 3.6.

In addition where possible, for materials that may be used, we use material-specific LCA data of the material producers.

2.2 CROW scope

The study focuses on Chapter 41.1 of the Standaard RAW Bepalingen (Standard RAW Provisions) 2020 (CROW, 2020).

This LCA concerns a cradle-to-grave study. This means that we include the production of the raw materials and components of the sheetpile wall, the installation in a work up to and including the removal of the sheetpile wall and the processing of the materials (Modules A1 to D).

This concerns Category 1 (cat. 1) LCAs. A cat. 1 LCA is defined on the basis of brand-related data from manufacturers and suppliers[5]. The results of this LCA study have been published as product cards in the National Environmental Database, but the content of this report is confidential. A description of the Prolock sheetpile walls is given below.

2.3 Product descriptions

Prolock sheet pile walls are used for the bank protection of canals, rivers, lakes and marinas. These sheet pile walls are composed of semi-finished products: a sheet pile of recycled PVC sheet piles and posts of softwood (mainly pine), hardwood or steel tubes. Depending on the application of the sheet pile wall, the sheet pile wall is also fitted with a hardwood wale. A wale serves as a bumper and is regularly added to the Sigma and Omega sheet pile walls.

The sheet pilesare built up from profiles that are 0.5 m wide with a variable length. By combining the plastic sheet pile and posts/tubes, relatively little plastic is needed. The length of the sheet pile is thus shorter than the length of, for example, wooden or steel sheet pile walls in the same application.

The sheet pile constructed of recycled PVC is produced by Profextru in the factory in Hardenberg. Profextru works together with several suppliers that produce the posts and

5 https://milieudatabase.nl/en/database/dutch-environmental-database/

transport them directly to the construction site where the posts are inserted in the Prolock & MultiLock® sheet piling. The components are fastened together at the construction site. The following section discusses the Prolock sheet piling in more detail.

The top side of the revetment can be finished with the beautiful Prolock Omega waling. It is also possible to install the sheetpile walls as freestanding or anchored. Choosing to add waling or anchoring has no effect on the sheetpile walls. The waling and anchoring are not an integrated part of the product and are not applied to most sheetpile walls. This is why these two complementary components are not included in this LCA.

2.3.1 Variants of ProLock brand of sheetpile walls

Profextru produces four types of Prolock profiles that can be used as sheet piling in sheetpile walls:

1. MultiLock® Sigma.
2. ProLock Omega.
3. MultiLock® Delta.
4. MultiLock® Diplo - this does not feature in this report

Table 1 gives the properties of four sheetpile walls per type of ProLock sheet piles.

Table 1 - Properties of Prolock sheetpile walls per type

	Sigma	Omega	Delta
Function	Bank protection for ponds and ditches	Bank protection for canals, rivers, lakes and marinas	Protection against seepage water and piping
Application	Revetments and light sheetpile wall structures	Heavy sheetpile wall structure	Dikes, aqueducts, dams, water level separations and soil remediation
Piles	Two or four piles per metre of bank length Thinner piles than with Omega	Two piles per metre of bank length	None
Length	The length of the screen and piles is variable and depends on the application	The length of the screen and piles is variable and depends on the application	Up to 12 metres
Other			Watertight sealing lip

The length of the screen and the dimensions of the posts varies and depends on the project-specific requirements and local conditions. The ratio of sheet pile length when compared to the pile length varies as well. In addition, piles can be made from hardwood, softwood and steel. Omega and Sigma are used in relation to posts while Delta is used when posts are not typically used.

In this LCA, we calculate the environmental profile of twelve Prolock sheet pile walls with the most common sheet pile length, post length and post diameters. These are given in Table 2. A translation of the sheet pile walls to one square metre is given in Section 3.2 (Table 7).

The information in Table 1 and Table 2 can be found in the description of the product cards in the National Environmental Database.

Table 2 - Prolock sheetpile wall systems chosen for the LCA per linear metre of sheetpile wall

Type	Screen	Piles				Wale		
	Height (m)	Type	Dimensions	Quantity per m[1]	Length (m)	Yes/no	Type	Dimensions
MultiLock® Sigma								
1 m, softwood pile, 3 m	1	Softwood	Ø of 100 mm	2	3	No		
1.5 m, softwood pile, 4 m	1.5	Softwood	Ø of 100 mm	4	4	No		
1.6 m, softwood pile, 4 m, wale	1.6	Softwood	Ø of 100 mm	2	4	Yes	Azobé	45 mm thick, 95 mm high
1 m, Azobé pile, 3 m, wale	1	Azobé	70 x 70 mm	2	3	Yes	Azobé	95 mm thick, 95 mm high
1 m, steel pile, 3 m	1	S235 steel	S3 Ø of 89 mm, 3 mm thick	2	3	No		
Omega								
2 m, softwood pile, 5 m	2	Softwood	Ø of 160 mm	2	5	No		
2 m, softwood pile, 5 m, wale	2	Softwood	Ø of 160 mm	2	5	Yes	Azobé	95 mm thick, 145 mm high
2 m, steel pile, 5 m	2	S235 steel	S4 Ø 140 mm, 5.6 mm thick	2	5	No		
3.5 m, Cloeziana pile, 6 m, wale	3.5	Cloeziana	Ø of 160 mm	2	6	Yes	Azobé	95 mm thick, 145 mm high
MultiLock® Delta								
5 m	5	None				No		

We give a few illustrations of the different types of sheetpile walls below. Figure 1 is a cross section of (the side view of) an entire sheetpile wall. As an example, here we are using the Prolock Omega sheet pile wall with softwood piles.

Figure 1 - Cross section of a Prolock Omega sheetpile wall with softwood piles

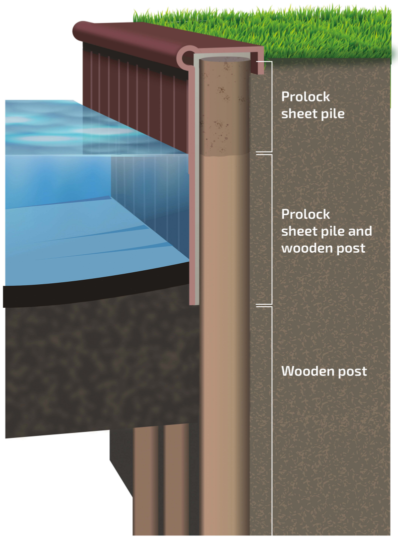


Figure 2 to Figure 5 is a cross section of (view from above) of the various types of Prolock sheetpile wall systems. We first show a profile on its own and, below, its application as a sheetpile wall.

Figure 2 - MultiLock¤4Sigma: single profile, as a screen in a functional application and as a screen in a functional application with a wale

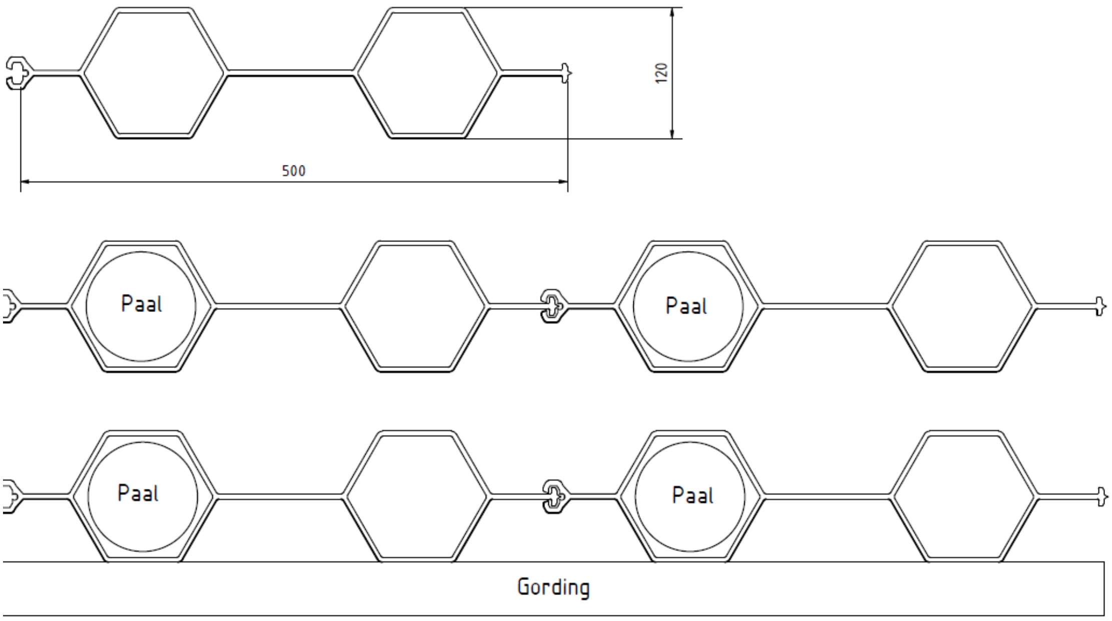


Figure 3 - Prolock Omega: single profile as a screen in a functional application and as a screen in a functional application with a wale

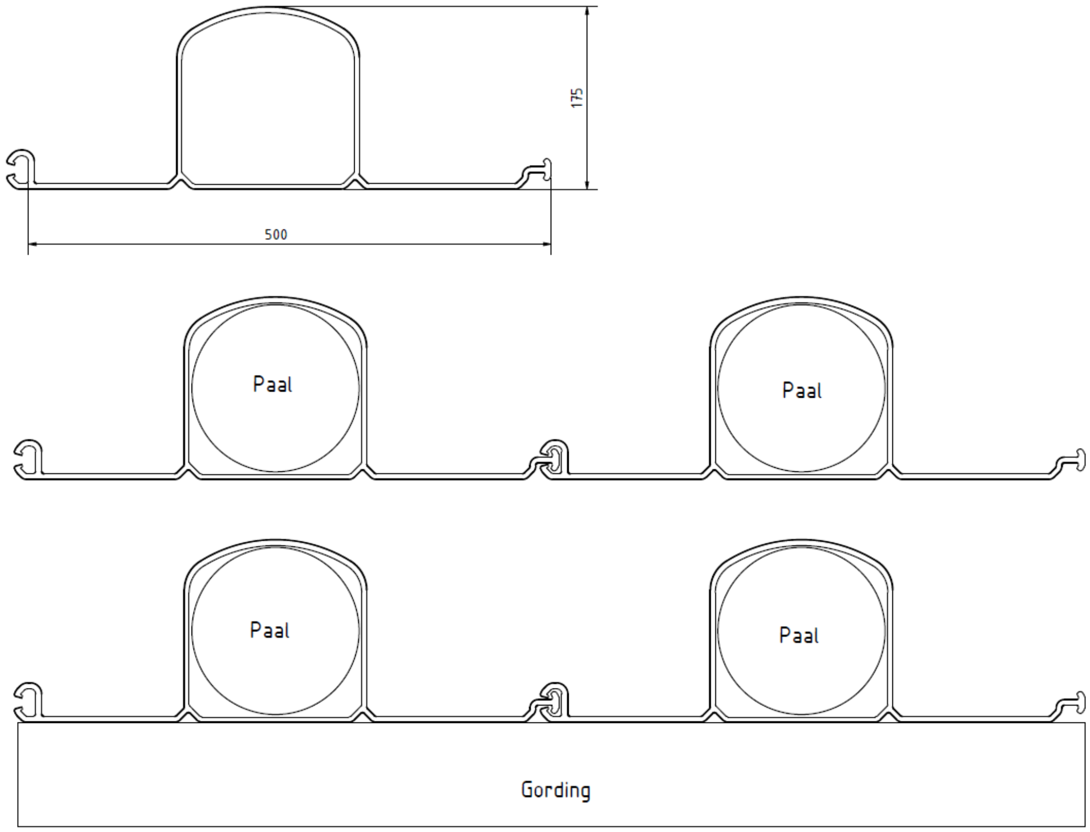


Figure 4 - MultiLock® Delta: as a single profile and as a screen in a functional application

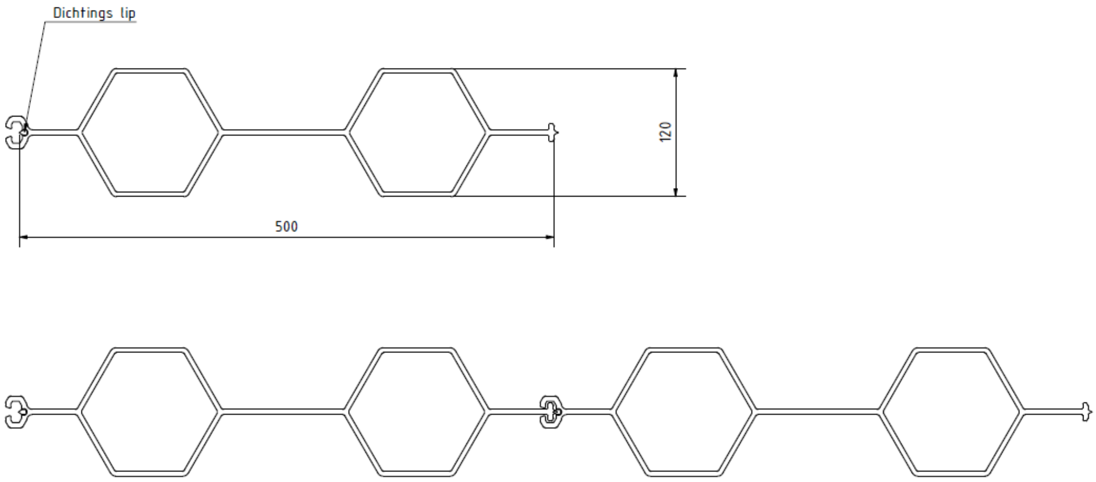


Figure 5

Figure 6 to Figure 9 show the front view of the various types of Prolock sheetpile wall systems.

Figure 6 – Cross sections of a MultiLock® Sigma sheetpile wall system

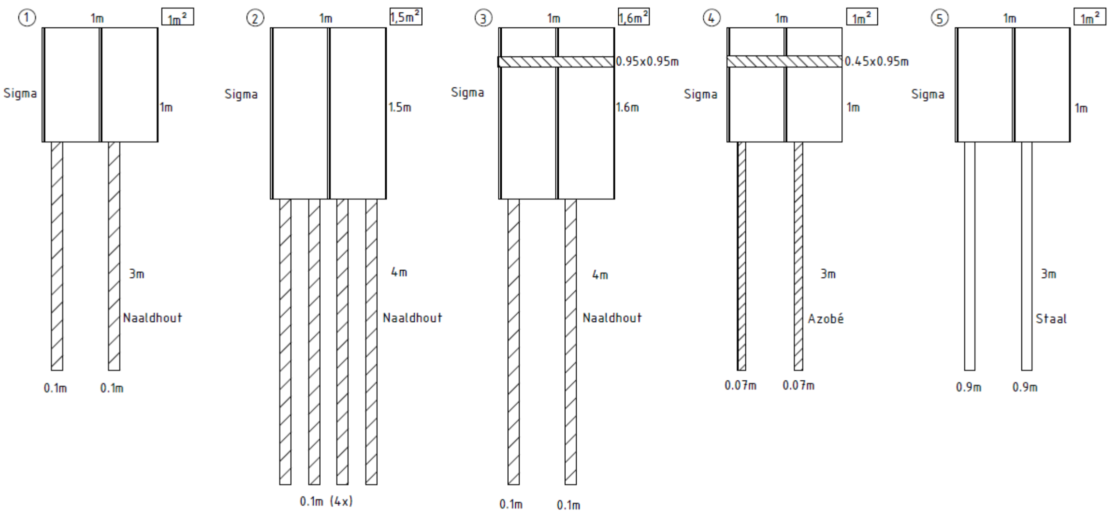


Figure 7 - Cross sections of a Prolock Omega sheetpile wall system

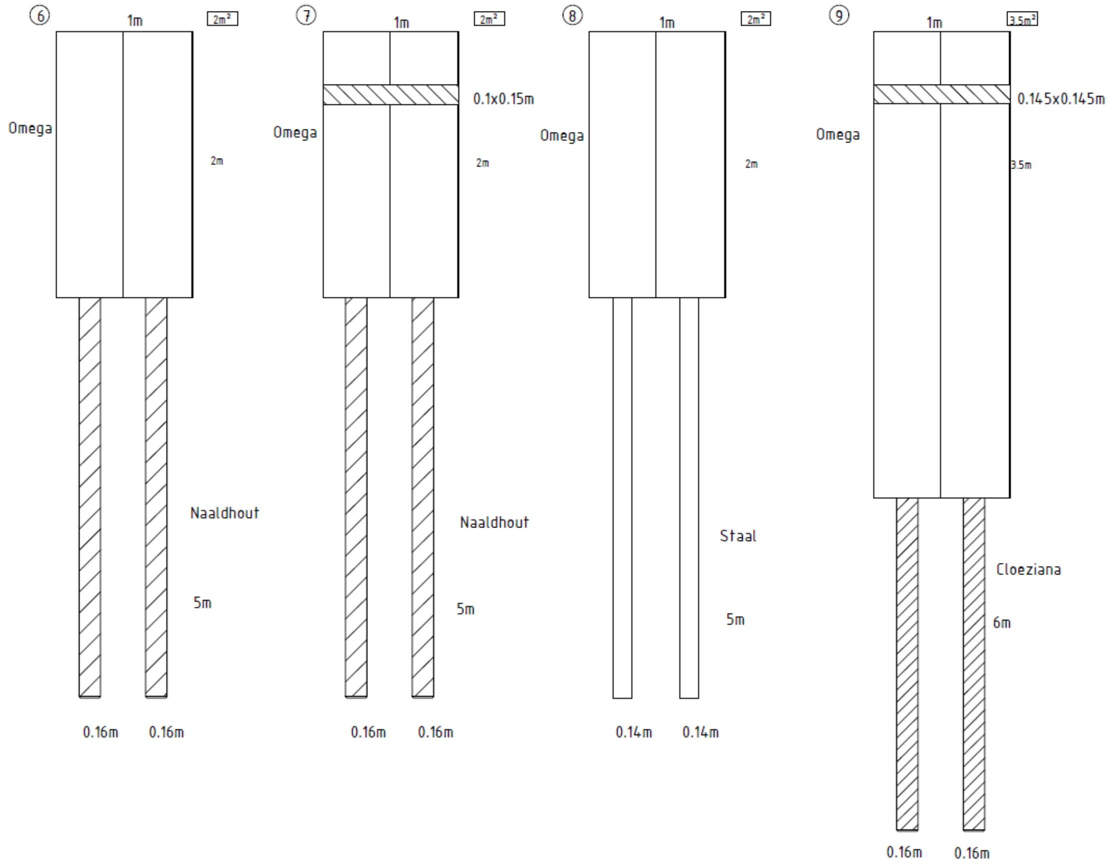
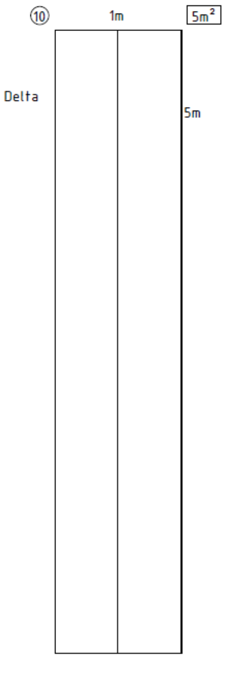


Figure 8 - Cross section of a MultiLock® Delta sheetpile wall system



2.3.2 Classification in accordance with the DEFP system

The main product (the sheet pile walls) can be divided into elements in accordance with the CEFP system (Construction, Elaboration, Finishing, Paintwork). This is given in Table 3.

Table 3 – Product elements within main Prolock d~brand MultiLock® Sigma, Omega and MultiLock® Delta sheetpile walls of one square metre

CEFP category	Element	Unit
C (construction)	Sheetpile wall screen	m
C (construction)	Piles	Item
E (equipment)	Wale	Item

This report is based on the main product while explicitly not distinguishing between the CEFP elements. The inventory describes the materials and components more in-depth. All results are given for the complete main produc, per sheetpile wall system.

2.4 Functional unit

The functional unit depends on the product. For sheet pile walls, a set functional unit of ‘m^2 of sheet pile wall’ is determined for inclusion in the National Environmental Database. This is why, in this LCA report, we calculated the environmental impact of the Prolock sheet pile walls **per m^2 of sheet pile wall** with a life cycle of 60 to 100 years. The life cycle is detailed further in Section 2.4.1.

The posts are longer than the sheet piles. For one m^2 of sheet pile wall, we use the area of the screen. The dimensions of the piles and wale are therefore not included in the total area of the sheetpile walls. The piles and wale are, of course, included in the environmental impact where we use one m^2 of sheetpile wall screen.

An example: Omega, 2 m screen, softwood pile*, 5 m, wale*
In 1 m of bank length of this sheetpile wall, there is a screen that is 2 m high or 2 m^2 of screen in total. This sheetpile wall also has 2 piles for every 5 m it is long and 1 m of wale. To connect to the functional unit of one square metre of sheetpile wall, we divide the size of all of these components by 2. Therefore, in 1 m^2 of sheetpile wall there is 1 m^2 of screen, 2 piles for every 2.5 m it is long and 0.5 m of wale.

At Profextru's request, the environmental profiles were also determined on the basis of the separate components of the sheetpile wall. If required, Profextru can provide clients (such as Rijkswaterstaat or a contractor) with these environmental profiles so that these clients can carry out project-specific calculations.

2.4.1 Life cycle of PVC and wood

The Prolock MultiLock® Sigma, and Omega sheet pile wall systems have a technical life cycle of at least 60 years. The life cycle applies to the PVC screen as well as the wooden piles since all of these are under the waterline. The MultiLock® Delta sheetpile wall system has a life cycle of 100 years because it is completely underground and is not subject to UV radiation. We base the life cycle on Profextru's experience and on the basis of literature research on the life cycle of PVC. This literature research is described below.

Life cycle of PVC sheet pile wall

The US Army Corps of Engineers (Dutta & Vaidya, 2003) did a study on the use of PVC sheet pile walls in the New Orleans area. The study involved sheet pile walls of new PVC without a coating. This study showed that the oldest PVC sheet pile walls that were placed 50 years ago in the boggy marsh soil of the river deltas in New Orleans were barely affected. The sheet pile walls showed little external wear and the impact resistance, flexibility and tensile strength of the material were still of good quality.

The results of the US Army Corps of Engineers were tested in 2007 by Profextru and a student at the HAN University of Applied Sciences using European standards. Lower temperatures occur more frequently in Europe than in New Orleans. The test showed that PVC in sheet pile walls do just fine well below zero degrees (-20 °C). Aging of the material is dealt with by applying a top coat that functions as a UV filter. In addition to sunlight, the material is also protected against other external influences (Feenstra, 2017).

The sheet pile walls in the tests described above were made of new (primary) PVC. In accordance with Profextru, the results also apply to recycled PVC. This is based on a study by Yarahmadi et al. (2001) where mechanically recycled PVC still had similar physical properties (strength, impact resistance) as new PVC after four recycling cycles and had a life cycle of more than 100 years. Only after a fifth recycling was the life cycle of PVC less than 50 years.

It is fair to assume that the recycled PVC with which Profextru is supplied has not been recycled five times already since PVC recycling is a relatively new development and the life cycle of most PVC products is generally long. An example of this is the PVC pipelines from the 1930s that are still used as sewer and drinking water pipelines (TEPPFA, 2019). It is for this reason that the life cycle of such PVC products has in the past been estimated at more than 100 years (TEPPFA, 2019, TNO, 2006).

Life cycle of piles and wales

In accordance with the Stichting Hout Research (Wood Research Foundation) (2016), the life expectancy of pine posts under water is 80 to 100 years, which means that their maximum life cycle falls within the 60-year life cycle of the sheet pile walls. The life cycle of hardwood and steel piles is comparable.

2.5 System limits

Table 4 shows what information per life cycle phase should be considered in accordance with EN 15804 and the Assessment Method. In this LCA, we calculated the environmental impact over the entire life cycle.

Table 4 - System limits

	Production phase			Construction phase		Use phase					Dismantling and processing phase				Subsequent production system
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
	Extraction of raw materials	Transport	Production	Transport	Construction and installation	Use	Maintenance	Repairs	Replacements	Renovations	Dismantling	Transport	Waste processing	Final waste processing	Opportunities for reuse, recovery and recycling
Cradle-to-gate with options	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X: Module included in the LCA study: module not declared (MND).

The selection of processes and determining cut-offs is done based on the description of system limits (Section 2.6.3.5. and Annex III of the Assessment Method) and cut-off criteria (Section 2.6.3.6. of the Assessment Method) in the Assessment Method. We do not suspect that relevant input and output have been omitted.

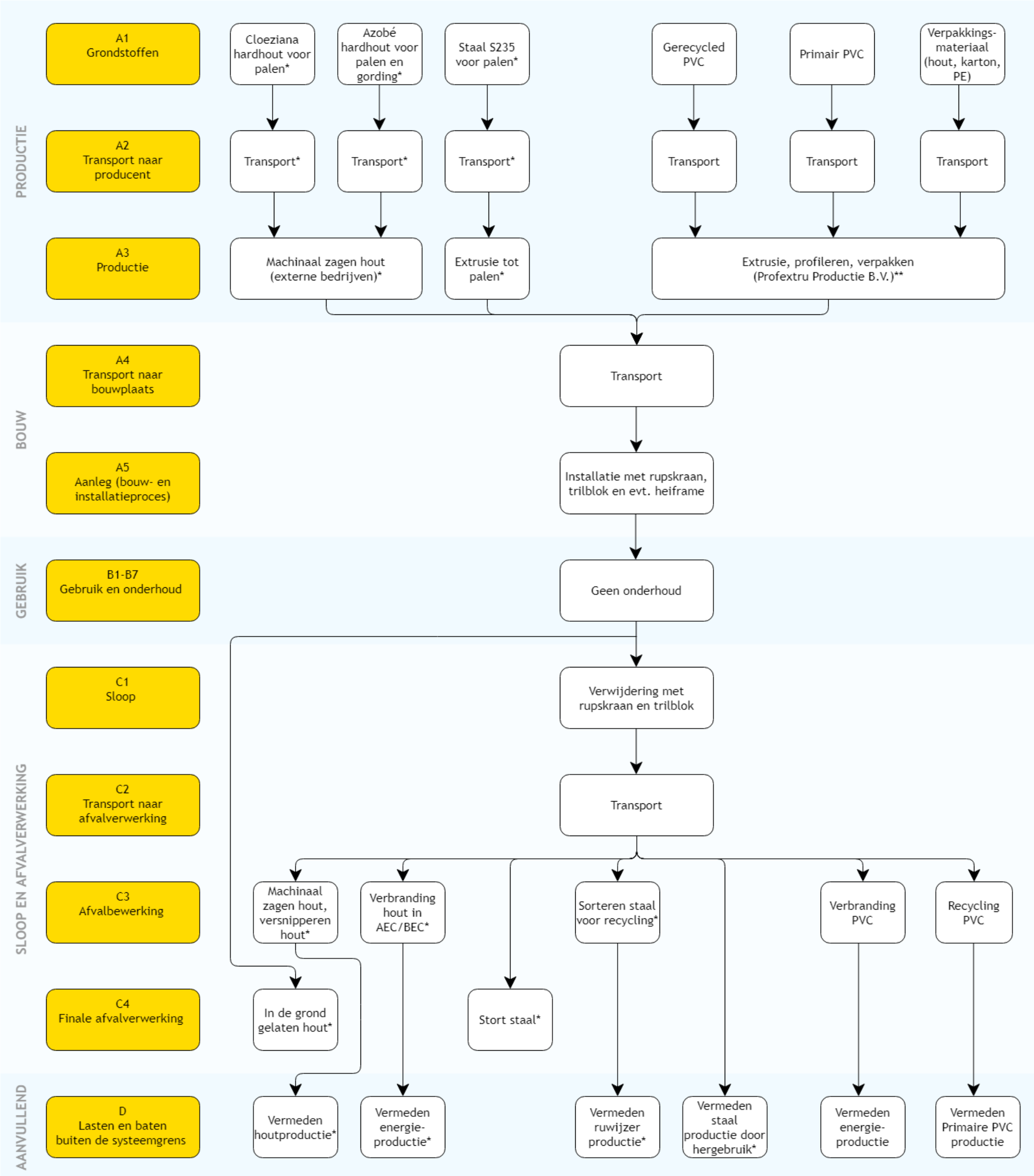
We also include the required emissions as stated in Section 2.6.4.1. of the Assessment Method. These emissions are part of the basic processes of the National Environmental Database and Ecoinvent:

- Emissions to air of CO_2, CO, NO_X, SO_2, C_XH_Y and particulate matter (PM_{10}: particles < 10 µm) with the use of thermal energy;
- Emissions of CVZ, BZV, P total, N total and fixed substances (PM_{10}: particles < 10 µm) to water;
- Emissions to soil of PAHs and heavy metals.

In accordance with EN 15804+A2, biogenic global warming potential (GWP) must be in balance throughout the life cycle – therefor 0. Where we modelled temporary storage of biogenic carbon in biomass in background processes, the emissions of this are also modelled at the end of the life cycle.

The life cycle phases and most important process steps of a Prolock sheet pile wall are given in Figure 10 including piles and wale.

Figure 10 – Simplified process tree with life cycle phases, modules and the most important process steps of a Prolock sheet pile wall including the various types of piles and any wale



* These process steps do not apply to every sheet pile wall: the materialisation of the posts differs per sheet pile wall and not every sheet pile wall has a wale.

** Only the extrusion, profiling and packaging of the PVC profiles are carried out at Profextru. Profextru works together with several suppliers that produce the piles and transport them directly to the construction site where the posts are inserted in the Prolock sheet pile

3 Life Cycle Inventory (LCI)

This chapter describes the life cycle interpretation of the Prolock MultiLock® sheet pile walls. We discuss data collection in Section 3.1while also describing the modelling of all requested LCA data. We then, in Section 3.2, provide the composition of all sheet pile walls while making a distinction between the various components.

Finally, Sections 3.3 to 3.7 discuss how the materials, processes and activities of the different types of sheet pile walls and their components are modelled per life phase (Module A1 through D). We inventory how much and which materials, processes and references are used:
- 3.3: Production (Modules A1 and A3).
- 3.4: Transport (Modules A2 and A4).
- 3.5: Installation phase (Module A5).
- 3.6: Use phase (Modules B1-B5)..
- 3.7: Dismantelling and processing phase (Modules C1-D).

3.1 Data collection

To determine the LCA, data is collected about the different production processes that lie within the system limits of this LCA study. In the details, attention has been paid to the precision, completeness, representativity, consistency and reproducibility of the data.

To determine the product composition, material consumption and the accompanying processes, we use design and practical knowledge of experts at Profextru. Additionally, we have already requested plastic data about the production of these materials from Profextru's suppliers. The data collected as such is technologically, temporally and geographically representative of the production process of Profextru.

The production of the piles and wales is done by Profextru's suppliers. These suppliers transport the piles and wales directly to the construction site where the posts are inserted in the Prolock sheet piles. For the modelling of these components, Profextru requested information from the suppliers as to the origin, production method, properties and transport of the posts. For modelling these components, we used process maps from the National Environmental Database and Ecoinvent.

The Assessment Method also gives standard values and National Environmental Database processes for the most important background processes that must be taken into account when specific data is not available. This mainly concerns the processes for energy generation and transport. For activities outside of the Netherlands (such as production in Germany), we used process maps from Ecoinvent in the relevant country or region.

3.1.1 Data received

We received information from four suppliers of recycled PVC and from the supplier of primary PVC.

The modelling of recycled PVC is described in Section 3.1.2. The modelling of primary PVC is described in Section 3.1.3.

3.1.2 Modelling of recycled PVC

At the producers of recycled PVC, the information from two suppliers was detailed enough to include in this LCA study.

We assess recycled PVC from these two suppliers to be representative for all the recycled PVC within the scope of this study. Approximately 80% of all recycled PVC that Profextru processes for the production of Prolock sheet piles comes from these two suppliers. For the environmental impact of the recycled PVC, we used this ratio for 100% input of PVC distributed in accordance with the share of the supply from these two suppliers. The quality of this PVC granulate is identical to primary PVC granulate in accordance with Profextru. It is applied in the Prolock sheet pile walls without any additives.

The production of recycled PVC is a multi-output process. In addition to recycled PVC granulate, the production process also produces scrap metal for recycling. However, this metal is removed at the beginning of the production process together with the other impurities. The majority of the energy and water consumption only applies to the production of recycled PVC (melting, extrusion, etc.) after the metal has been removed. The exact distribution of this consumption over the different process steps is not known. The assumption is, however, that the energy and water consumption in this first step of the recycling process is negligible. We have therefore allocated all the consumption of energy and water to the main product of recycled PVC granulate.

We have allocated the waste processing of the remaining waste that becomes available during this first step in the recycling process to both the recycled PVC and the scrap metal. Since the value of the different co-products is not known, we have used the standard allocation formula from the Assessment Method (mass basis for multi-output processes) to allocate this impact. This is a worst-case scenario for the recycled PVC.

Within this study we set the end waste status at the time that PVC is sorted into a usable fraction for further recycling. All processing steps up to and including sorting is therefore included in the previous waste-producing product system. Sorted PVC therefore enters the product system of the Prolock sheetpile walls free of environmental impact. For this reason, all subsequent recycling and processing steps are included in the product system of the Prolock sheet pile walls.

The suppliers purchase sorted pre-consumer and post-consumer PVC as material for recycling. There is a market for this sorted PVC since this material can be applied directly for the production of PVC and complies with the technical regulations for the recycling process. Nor does, as far as we know, the use of sorted PVC for recycling have any unfavourable effects overall on the environment or human health.

For the transport of sorted PVC to recycling, we use the standard transport distance for materials in accordance with the Assessment Method: 150 km. For the transport of the waste, we use the standard transport distance for incineration in a waste incineration plant (WIP): 100 km.

All transport is done by truck. For this we use a standard truck from the National Environmental Database, since it is not exactly known which trucks will be used:

- 0001-tra&Transport, trucks (based on Transport, freight, truck, unspecified {GLO}| market group for transport, freight, truck, unspecified | Cut-off, U)

Supplier 1 of recycled PVC

For the production of recycled PVC by supplier 1, this study used an inventory of their production process carried out in 2016. An LCA report from 2017 turned out not to be sufficiently complete to reproduce in its entirety. Inventory data was missing, the method was not described clearly enough, the allocation to co-products was not specified and the process maps were missing from the report.

The output in 2016 had a ratio of 30:4 recycled PVC granulate and scrap metal. Since we allocate the waste processing arising from the production process to these two co-products on the basis of their mass, 88% of the waste processing impact is allocated to recycled PVC granulate and 12% to scrap metal.

The production of recycled PVC in 2016 is shown in Table 5 per kilogram of recycled PVC. The production location is in Germany.

Table 5 – Production of recycled PVC per kg of PVC (production in 2016)

Material/process	Quantity	Process map*	Explanation of choice of process map
PVC waste (industrial + domestic)	1.15 kg	N/A	Unprocessed secondary material, impact-free in accordance with the Assessment Method. Excluding secondary metal.
Electricity	0.28 kWh	Electricity, low voltage {DE}| market for	German electricity mix from Ecoinvent 3.6 cut-off.
Natural gas	1.33E-04 m^3	0111 pro&Natural gas, general use, per m^3**	Based on natural gas consumption from the National Environmental Database, since this process map uses average European natural gas.
Diesel	1.12E-03	0095 pro&Diesel, gas oil, consumption, litre**	Diesel for internal transport. Based on diesel from the National Environmental Database since this process map uses a global average for diesel.
Water	3.99E-02 kg	0289 fab&Water, drinking water**	Based on water consumption from the National Environmental Database since this process map uses average European tap water. 998 kg/m^3.
Wastewater	4.00E-05 m^3	XXXX Wastewater treatment, STP**	Based on wastewater treatment from the National Environmental Database since this process map uses a global average for wastewater treatment at a sewage treatment plant.
Waste: glass	1.44E-02 kg	0272-reC&Recycling flat glass**	Allocated waste processing part per 1 kg of recycled PVC (87% of total waste is allocated to recycled PVC, 13% to secondary metal). Waste processing part that is allocated to secondary metal is not shown here. 100% recycled in accordance with the supplier.
Waste: PVC	1.39E-01 kg	0265-avC&Incineration of PVC (21.51 MJ/kg)**	Allocated waste processing part per 1 kg of recycled PVC (87% of total waste is allocated to recycled PVC, 13% to secondary metal). Waste processing part that is allocated to secondary metal is not shown

Material/process	Quantity	Process map*	Explanation of choice of process map
			here. 100% incineration in accordance with the supplier.

* All process maps are from the National Environmental Database, version 3.4 unless indicated otherwise.
** The names of National Environmental Database process maps are abbreviated.

Supplier 2 of recycled PVC

For the production of recycled PVC by supplier 2, this study used an inventory of their production process carried out in 2020. Scrap metal and recycled PVC also become available in relation to this supplier. The ratio here is 15.5:1. Since we allocate the waste processing arising from the production process to these two co-products on the basis of their mass, 93.5% of the waste processing impact is allocated to recycled PVC granulate and 6.5% to scrap metal.

The production of recycled PVC for supplier 2 in 2020 is shown in Table 6 per kilogram of recycled PVC. The production location is in Belgium.

Table 6 – Production of recycled PVC for supplier 2 per kg of PVC (production in 2020)

Material/process	Quantity	Process map*	Explanation of choice of process map
PVC waste (industrial + domestic)	1.27 kg	N/A	Unprocessed secondary material, impact-free in accordance with the Assessment Method. Excluding scrap metal.
Electricity	0.41 kWh	Electricity, low voltage {BE}| market for	Belgian electricity mix from Ecoinvent 3.6 cut-off.
Diesel	3.28E-03 litres	0095 pro&Diesel, gas oil, consumption, litre**	Diesel for internal transport. Based on diesel from the National Environmental Database since this process map uses a global average for diesel.
Water	6.60E-01 kg	0289 fab&Water, drinking water**	Based on water consumption from the National Environmental Database since this process map uses average European tap water. 998 kg/m^3.
Wastewater	6.61E-04 m^3	XXXX Wastewater treatment, STP**	Based on wastewater treatment from the National Environmental Database since this process map uses a global average for wastewater treatment at a sewage treatment plant.
Waste: PVC	2.67E-01 kg	0265-avC&Incineration of PVC (21.51 MJ/kg)**	Allocated waste processing part per 1 kg of recycled PVC (93% of total waste is allocated to recycled PVC and 7% to secondary metal). Waste processing part that is allocated to secondary metal is not shown here. 100% incineration in accordance with the supplier.

* All process maps are from the National Environmental Database, version 3.4 unless indicated otherwise.
** The names of National Environmental Database process maps are abbreviated.

3.1.3 Modelling of primary PVC

For the primary PVC for the PVC top coat, the basis is the process map '0356-fab&PVC, granulate' from the section 3.4 of the National Environmental Database supplemented with data from the supplier. Additives are added to the primary PVC, which has been taken into account in the modelling.

3.2 Decomposition in materials and processes

Table 7 gives an overview of the weight of the sheet pile wall types per m^2 of sheet pile wall with a distinction made between the different components. For the weight of the sheet piles and fastening materials of the wale, we use the weights passed on by Profextru. We calculate the weight of the posts and the wale based on the description of the sheet pile walls and their components in Table 2. We calculate the weight of round posts using ∏ * r^2 * post height, the weight of square posts and the wale by thickness - width * height (length instead of height for the wale). For this we use the following specific weights:

- softwood: 460 kg/m^3;
- Azobé wood: 1,060 kg/m^3;
- Cloeziana wood: 860 kg/m^3;
- S235 steel: 7,850 kg/m^3.

Sections 3.3 to 3.7 discuss the inventory of these sheet pile walls and their components per life phase (Module A1 through D).

Table 7 - Mass of the screen, pile and wale per *m² of sheetpile wall*

No.	Sheetpile wall type	Screen (kg)	Pile (kg)	Wale (kg)	Fastening materials for wale (kg)	Total weight (kg)
1	MultiLock® Sigma recycled PVC, 1 m, softwood pile, 3 m	13.48	21.68	N/A	N/A	35.16
2	MultiLock® Sigma recycled PVC, 1.5 m, softwood pile, 4 m	13.48	38.54	N/A	N/A	52.02
3	Prolock Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	13.48	18.06	2.83	0.15	34.52
4	MultiLock® Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	13.48	31.16	9.57	0.15	54.36
5	Prolock Sigma recycled PVC, 1 m, steel pile, 3 m	13.48	19.42	N/A	N/A	32.90
6	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m	16.17	46.24	N/A	N/A	62.41
7	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m, wale	16.17	46.24	7.30	0.15	69.86
8	Prolock Omega recycled PVC, 2 m, steel pile 5 m	16.17	47.37	N/A	N/A	63.54
9	Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale	16.17	59.28	N/A	N/A	79.77
10	MultiLock® Delta recycled PVC, 5 m	13.68	N/A	N/A	N/A	13.68

3.3 Production (Modules A1 and A3)

The Prolock sheet pile walls consist of sheet piles of Prolock profiles, posts and, for part of the sheet pile walls, a wale. A Prolock sheet pile wall can be constructed using softwood, hardwood or steel posts/tubes.

The transport of the materials (Modules A2 and A4) is described separately from the production (Modules A1 and A2) in Section 3.4.

3.3.1 Prolock profiles

The Prolock sheet piles are constructed from PVC profiles. Sigma, Prolock Omega and Delta are constructed from recycled PVC and are fitted with a UV-resistant top coat of virgin PVC with additives. The production of recycled PVC and primary PVC is described in Sections 3.1.2 and 3.1.3. The quality of this PVC granulate is identical to primary PVC granulate in accordance with Profextru. It is applied in the Prolock sheetpile walls without any additives.

In the Profextru factory in Hardenberg (the Netherlands), the Prolock profiles are produced through extrusion of PVC granulate followed by a profiling step. The profiles are then packaged. For the production process at Profextru, we use production data from 2020.

For 2021, Profextru has a wind certificate from Powerhouse (Guarantee of Origin, GOO). This GOO guarantees that the production of 3,968 MWh of wind energy from Dutch onshore and offshore wind turbines are only allocated to Profextru's electricity consumption. This means that we deviate from the 2020 production year when 55% wind and 45% electricity from the grid was used. Since Profextru indicates that it will always produce with 100% wind from now on, 100% wind is more representative of Profextru's production processes.

Table 8 shows the weight per m^2 of the Prolock profiles in 2020.

Table 8 Weight per Prolock profile in 2020

Production data (gross)	Weight per m^2 of profile (kg)
Sigma production	13.48
Omega production	16.17
Delta production	13.68

Table 9 shows the consumption of energy, fuel and water and the production of waste at Profextru in 2020. Other than emissions due to the use of diesel in means of transport such as forklift trucks, there are no direct emissions of substances into the air, water or soil during the production of Prolock profiles.

Table 9 – Consumption of energy, fuel and water and production of waste at Profextru in 2020 per kg of product*

Energy/fuel/waste	Consumption (per kg of product)	Unit
Electricity	3.31E-01	kWh
Diesel (internal transport)	8.97E-04	litres
Water	9.21E-04	m^3
Wastewater	9.21E-04	m^3

* Consumption of gas and production of industrial waste not included. Gas is used to heat rooms and offices with industrial waste becoming available through office activities.

In order to allocate the total consumption of energy, fuel and water and the production of waste to the Prolock profiles, we calculated the consumption per 1 kg of product based on the total production at Profextru in 2020. Next, we allocated this to the Prolock profiles based on their weight per square metre (Table 9).

The Prolock profiles are also packaged prior to being brought to the work. For the packaging, figures from 2016 were used since this data is not available for 2020. In accordance with Profextru, the packaging method in 2020 has not changed compared to 2016.

The use of packaging materials is shown in Table 10 per kg of Prolock profile based on data in 2016.

Table 10 – Packaging for Prolock in 2016 per kg of profile

Packaging material	Packaging per kg of Prolock profile (kg)
Steel strapping	3.31E-03

Wooden frames	5.28E-02
Cardboard	1.43E-03
PE sheet	1.55E-03

Table 11 combines the data above and we provide an overview of all inputs and outputs of the production per square metre of the Prolock profile. We indicate the chosen process map here as well. In accordance with Profextru, all spoilage in the factory is recycled internally. This is why there is no waste with the production process that must be processed externally.

Table 11 - Production of Prolock profiles at Profextru per m^2 of profile

Material/ process	Sigma	Omega	Delta	Aqua	Process map*	Explanation of choice of process map
PVC recyclate	12.62 kg	15.39 kg	13.63 kg	13.05 kg	See Section 3.1.2	
PVC top coat (Coex)	0.86 kg	0.77 kg	0.05 kg	0 kg	See Section 3.1.3	
Electricity	4.46 kWh	5.35 kWh	4.52 kWh	4.32 kWh	63% of electricity, high voltage {NL}| electricity production, wind, 1-3 MW turbine, onshore 37% of electricity, high voltage {NL}| electricity production, wind, 1-3 MW turbine, offshore Electricity, low voltage {NL}| market for (for transmission and distribution)	Process maps from Ecoinvent 3.6 cut-off. 63% onshore, 37% offshore (CBS, 2021a). Average capacity of 2 MW in 2020 (CBS, 2021b). Transmission and distribution modelled based on Electricity, low voltage {NL}| market for
Diesel (internal transport)	1.21E-02 litres	1.45E-02 litres	1.23E-02 litres	1.17E-02 litres	0095 pro&Diesel, gas oil, consumption, litre**	
Water	12.41 kg	14.88 kg	12.59 kg	12.02 kg	0289 fab&Water, drinking water**	Water from the tap
Wastewater	1.24E-2 m^3	1.49E-2 m^3	1.26E-2 m^3	1.20E-2 m^3	XXXX Wastewater treatment, STP**	Wastewater treatment at a STP
Packaging: steel strapping	4.46E-02 kg	5.35E-02 kg	4.52E-02 kg	4.32E-02 kg	0317-fab&Staal, hot-rolled, flat and strip steel**	Material and processing into steel strapping
Packaging: wooden frames	7.11E-01 kg	8.53E-01 kg	7.22E-01 kg	6.89E-01 kg	0067-fab&Wood, softwood, pine, Scots pine, larch, Douglas**	Material and processing into frames
Packaging: cardboard	1.92E-02 kg	2.31E-02 kg	1.95E-02 kg	1.86E-02 kg	0058-fab&Paper/cardboard**	Material and processing into sheets
Packaging: PE sheet	2.09E-02 kg	2.51E-02 kg	2.12E-02 kg	2.03E-02 kg	0185-fab&Polythene, HDPE, extruded**	Material and processing into sheets

* All process maps are from the National Environmental Database version 3.4, unless indicated otherwise.

** The names of National Environmental Database process maps are abbreviated.

3.3.2 Posts, softwood:

The softwood posts are supplied by Dutch timber merchants. The wood comes primarily from Belgium and, to a lesser extent, from the Netherlands and Germany. The wood is cut down in the country of origin and sawn into planks and planed onsite. The wood is primarily pine. The softwood piles are not treated since they will be completely submerged under water. The density is passed on by the supplier: 460 m^3/kg.

The process map chosen for both wood types is given in Table 12. The softwood posts is only available in a round shape. The weight and dimensions of the posts differ per sheet pile wall. This weight and the dimensions are given in Table 7.

Table 12 – Production of wooden pile, softwood

Material	Process map*	Explanation of choice of process map
Softwood post	0067-fab&Wood, softwood, pine, Scots pine, larch (based on Sawn wood, softwood, dried (u=10%), planed {RER}| production | Cut-off, U and 1 m^3 = 460 kg)	Softwood post for the European market

* The process map comes from the National Environmental Database, version 3.4.

3.3.3 Posts, hardwood (Azobé or Cloeziana)

The hardwood posts are supplied by Dutch timber merchants. Two types of wood, 100% FCS certified, are used for which the density is passed on by the supplier:
- Azobé (1,060 kg/m^3);
- Cloeziana (860 kg/m^3).

Both types of wood come from African countries. The trees are cut down in the country of origin and the wood is sawn to size. Planing is done in the Netherlands.

The process map chosen for both wood types is given in Table 13. The Azobé wooden post is only available in a square shape and the Cloeziana post only in a round shape. The weight and dimensions of the posts differ per sheetpile wall. This weight and the dimensions are given in Table 7.

Table 13 - Production of wooden pile, hardwood

Azobé wood Posts	0182-fab&Wood, tropical hardwood, African, sawn (based on Sawn wood, Azobé from sustainable forest management, planed, air dried {GLO}| market for | Cut-off, U + 7,000 km ocean transport and 1,150 kg/m^3)	Hardwood piles from sustainable managed forests in Africa. The density of the wood deviated from the density that the National Environmental Database has used. We have corrected this difference in SimaPro.
Cloeziana wood ost	0182-fab&Wood, tropical hardwood, African, sawn (based on Sawn wood, Azobé from sustainable forest management, planed, air dried {GLO}| market for | Cut-off, U + 7,000 km ocean transport and 1,150 kg/m^3)	Hardwood piles from sustainable managed forests in Africa. The density of the wood deviated from the density that the National Environmental Database has used. We have corrected this difference in SimaPro.

* The process map comes from the National Environmental Database, version 3.4.

3.3.4 Tubes, steel:

The steel tubes are supplied by Dutch steel structure companies. The piles are made of hot-rolled strip steel. No extra coating is applied.

The process map chosen for both wood types is given in Table 14. The weight of the piles differs per sheetpile wall. This weight is given in Table 7.

Table 14 - Production of steel pile

Material	Process map*	Explanation of choice of process map
Steel tube (S235 steel)	0318-fab&Steel, hot-rolled, tubular and rectangular profiles {GLO} (86.6% primary, 13.4% secondary)	Processing of steel into piles is included in the process map.

* The process map comes from the National Environmental Database, version 3.4.

3.3.5 Wale

The wale is made from FSC Azobé hardwood and is supplied by Dutch timber merchants. Not all Prolock sheetpile walls are fitted with a wale. The density is passed on by the supplier: 1,060 m^3/kg.

The hardwood comes from Africa. The trees are cut down in the country of origin and the wood is sawn to size. Planing is done in the Netherlands. The wale is fastened onsite with steel nuts and bolts onto the Prolock screens in the sheetpile wall.

The process map chosen for both wood types is given in

Table 15. Azobé hardwood has a density of 1,060 kg/m^3. The weight of the wale differs per sheet pile wall. The weight of the wood and the fastening materials used in the wale are given in Table 7.

Table 15 – Production of the wooden wale

Material	Process map*	Explanation of choice of process map
Azobé wood wale	0182-fab&Wood, tropical hardwood, African, sawn (based on Sawn wood, Azobé from sustainable forest management, planed, air dried {GLO}| market for | Cut-off, U + 7,000 km ocean transport and 1,150 kg/m^3)	Hardwood wale from sustainable managed forests in Africa. The density of the wood deviated from the density that the National Environmental Database has used. We have corrected this difference in SimaPro.
Steel nut and bolt	0416 fab&Steel, low alloy, galvanised (based on 98.6% Steel, low alloyed {GLO}| market for | Cut-off, U + Wire drawing; 1.4% Zinc {GLO}| market for | Cut-off, U + Zinc coat, coils)	Steel nuts and bolts are produced from galvanised steel. This process map comprises material production, processing of metal into, for example, nuts and galvanisation.

* All process maps are from the National Environmental Database, version 3.4.

3.4 Transport (Modules A2 and A4)

All transport is done by truck. For this we use a standard truck from the National Environmental Database, since it is not exactly known which trucks will be used:

- 0001-tra&Transport, trucks (based on Transport, freight, truck, unspecified {GLO}| market group for transport, freight, truck, unspecified | Cut-off, U)

3.4.1 Transport of materials

The transport distance of the materials in a Prolock sheetpile wall is estimated by Profextru in Table 16.

Table 16 - Transport distance per material

Material	Production location	Transport distance (km)
PVC recyclate	Belgium and Germany.	250
PVC top coat (Coex)	Hardenberg (the Netherlands), but the PVC comes from elsewhere.	3 + 150
Packaging: steel strapping	Dutch suppliers, standard transport distance chosen.	150
Packaging: wooden frames		
Packaging: cardboard		
Packaging: PE sheet		
Posts: Softwood	Production forest in Belgium and Germany.	130
Posts/wale: Azobé wood	Supplier in Belgium. Wood from Africa with transport up to Belgium is already taken into account in the National Environmental Database process map 0182.	130
Posts: Cloeziana wood	Supplier in Belgium. Wood from Africa with transport up to Belgium is already taken into account in the National Environmental Database process map 0182.	130
Tubes: S235 steel	Dutch suppliers, standard transport distance chosen.	150

3.4.2 Transport to construction site

Profextru's clients are responsible for the transport or outsource this. The Prolock profiles are transported from Hardenberg to the construction site. The posts/tubes and materials for the wale are transported directly from the suppliers to the construction site.

For the transport of the Prolock profiles, the posts/tubes and the wale to the construction site, we use the standard value for a single trip of products to the construction site from the Assessment Method: 150 km.

3.5 Installation phase (Module A5)

The Prolock sheet pile walls are placed at various locations in the Netherlands. During the installation, the packaging material is disposed of.

3.5.1 Installation

At the construction site, the profiles are installed next to one another to form the sheet pile of the sheetpile wall after which the posts are vibrated into the profiles with a tracked crane. The vibrator is driven by the engine of the tracked crane. Per Omega profile, one posts is used and, per Sigma or New Diplo profile, one or two posts. The Delta profiles are typically installed without posts.

The time required for the installation depends on the type of pile (material and thickness) and the number of posts. Profextru has estimated how many metres of sheet piles can be placed per hour based on the information provided by contractors that have installed Prolock sheet piles. This is how the time required per metre of bank length is estimated. This is given in Table 17.

Table 17 - Installation of sheetpile wall: time required per bank length

Type of screen	Type of pile	Number of piles	m of bank per hour	Time per m of bank (min.)
Sigma	Softwood	2	15	4.0
	Softwood	4	12	5.0
	Hardwood	2	15	4.0
	Steel	2	18	3.3
Omega	Softwood	2	10	6.0
	Hardwood	2	10	6.0
	Steel	2	12	5.0
Delta	N/A	0	12	5.0

In 2017, the construction company Stienstra van der Wal estimated the diesel consumption by a tracked crane for Profextru. In accordance with this contractor, a tracked crane uses approximately 10 litres of diesel per hour when installing sheetpile walls. For diesel, the National Environmental Database uses a lower heating value (LHV) of 35.9 MJ/litre, which means the hourly consumption of diesel is 359 MJ/hour. Per minute, this is 0.167 litres (5.98 MJ) of diesel.

Based on the sheet pile height per sheet pile wall in Table 2, we calculate in

Table 18 the quantity of a bank per m^2 of sheet pile wall. With the information in Table 17, we, next, calculate how much diesel per m^2 of sheet pile wall is used for all types of sheet pile walls during the installation.

Table 18 - Energy consumption per m² of sheetpile wall

Type of sheetpile wall	m of bank per m² of screen	Time (min.)	Energy (MJ)
Sigma recycled PVC, 1 m, softwood pile, 3 m	1.00	4.00	23.93
Sigma recycled PVC, 1.5 m, softwood pile, 4 m	0.67	3.33	19.94
Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	0.63	2.50	14.96
Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	1.00	4.00	23.93
Sigma recycled PVC, 1 m, steel pile, 3 m	1.00	3.30	19.75
Omega recycled PVC, 2 m, softwood pile, 5 m	0.50	3.00	17.95
Omega recycled PVC, 2 m, softwood pile, 5 m, wale	0.50	3.00	17.95
Omega recycled PVC, 2 m, steel pile, 5 m	0.50	2.50	14.96
Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale	0.29	1.71	10.26
Delta recycled PVC, 5 m	0.20	1.00	5.98

For the diesel consumption of the tracked crane we used the following process map in line with other diesel consumption by equipment in the National Environmental Database:
— 0114-pro&Dieselconsumption per MJ (1-on-1 reference to diesel, burned in a building machine {GLO}| market for | Cut-off, U).

A 'Prolock pile frame' was used specifically for the Omega sheet pile walls during the installation. Profextru owns eight of these pile frames that are lent out to contractors. These pile frames have been lent out since the formation of Prolock and are used for all sheetpile walls with Omega screens. Profextru assumes that the pile frames will last at least as long again as they have already been in use. Since these pile frames last so long and are used for all Omega screens, we estimate that the impact of their production on the functional unit is negligible (<<1%).

As far as is known, no waste is produced during installation.

3.5.2 Waste processing of packaging material

The packaging material of the Prolock screens is disposed of during the installation phase. Since this material becomes available during installation, it is part of Module A5. Benefits and any costs due to this waste processing of packaging material is declared in Module D[6] in accordance with the Assessment Method.

Table 19 shows the waste processing per packaging material including the choice of process map.

Table 19 - Waste processing of packaging material and choice of process map

Material	Waste processing	Process map*	Explanation
Packaging: steel strapping	100% recycled	0315-reC&Sorting and compressing old iron**	We assume that packaging material is recycled 100%. This is a rough assumption that has little impact on the
Packaging: wooden frames		0296-pro&Machining, wood, electric per kg**	

6 EN15804 2012+A2_2019: p. 32 & p. 40.

Packaging: cardboard		Waste paper, sorted {Europe without Switzerland}| treatment of waste paper, unsorted, sorting	total impact of the sheetpile walls (< 1%) For paper, a process map from Ecoinvent, version 3.6, was chosen.
Packaging: PE sheet		0286-reC&processing plastic for recycling**	

* All process maps are from the National Environmental Database, version 3.4 unless indicated otherwise.

** The names of National Environmental Database process maps are abbreviated.

3.6 Use phase (Modules B1-B5).

During the use phase of the Prolock sheet pile wall, no energy or water is used. No specific maintenance is necessary. The PVC top coat offers mechanical protection against weathering and wear. This top coat maintains its function throughout the life cycle of the Prolock sheet pile wall. As far as is known, there are no emissions into the soil, water or air.

No replacements are necessary during the function duration of the functional unit.

3.7 Dismantelling and processing phase (Modules C1-D)

At the end of the life cycle, the following processes take place:
- Dismantling of the sheet pile wall;
- Transport of the waste to the processor;
- Processing of the materials.

These processes will be detailed later. We will also discuss the benefits and costs in Module D.

3.7.1 Dismantling

The Prolock sheet pile wall is pulled out of the ground by machine and removed. We assume that the energy consumption for removal is equal to the energy consumption for installing the sheetpile wall. We described this in Section 3.5.1.

3.7.2 Transport of waste

Like the transport in Module A, all transport is done by truck. For this we use a standard truck from the National Environmental Database:
- 0001-tra&Transport, trucks (based on Transport, freight, truck, unspecified {GLO}| market group for transport, freight, truck, unspecified | Cut-off, U)

For the transport of waste materials, we use the standard value for a single trip of waste to the processing location from the Assessment Method:
- from dismantelling location to sorting and/or crushing plant: 50 km;
- from dismantelling or sorting location to disposal site: 50 km;
- from dismantelling or sorting location to waste incineration plant (WIP): 100 km.

3.7.3 Recycling, incineration and disposal

The waste processing of the materials used is based on standard waste scenarios of the Assessment Method.

For PVC sheet piles, we assume that the PVC sheet piles will at least be partially recycled. At this time, there is no system for recycling PVC sheet pile walls within the industry, but it is fair to assume that at least a part of the PVC will be recycled.

To make it as plausible as possible that the PVC will be recycled, Profextru has issued a take-back guarantee of their PVC products on their website and in the description of their products. This means that Profextru will organise the intake process and processing of its PVC products itself in the future. The entire industrial process of Profextru already focuses on the processing and marketing of plastic solutions made of recycled PVC. Moreover, with its current technical infrastructure, Profextru is able to break down PVC that has been taken back and use it directly in their products, which is a cost-efficient method for Profextru to obtain new raw materials. In addition, it has become more attractive for market parties to hand in PVC since Profextru offers a price per kg for returned PVC that is in line with market conditions.

Since Profextru offers a properly substantiated take-back guarantee that meets all requirements of Section 2.6.3.9 of the Assessment Method, we feel it is likely that the PVC sheetpile walls will be recycled in the future. This means that we base ourselves on the current standard waste scenario for PVC pipelines. This waste scenario is not the most optimistic standard scenario that is available (that is the waste scenario for PVC frame profiles) and therefore we purposely did not choose a best-case scenario.

Table 20 - Waste processing of materials and choice of process map

Material	Waste processing	Process map*	Explanation
PVC sheet pile (PVC recyclate)	70% recycled	0286-reC&processing plastic for recycling**	Waste processing in accordance with the standard scenario for PVC, pipelines.
	20% WIP	0265-avC&Incineration of PVC**	
	10% disposal	0252-sto&Waste PVC**	
PVC sheet pile (PVC top coat)	70% recycled	0286-reC&processing plastic for recycling**	Waste processing in accordance with the standard scenario for PVC, pipelines.
	20% WIP	0265-avC&Incineration of PVC**	
	10% disposal	0252-sto&Waste PVC**	
Wooden posts and wale (softwood and Azobé and Cloeziana hardwood)	Leave 10%	No impact	Waste processing in accordance with the standard scenario for wood, hydraulic engineering: sheetpile walls, duckboards, scaffolding and revetments.
	90% to WIP	0262-avC&Incineration of wood, 'clean' (13.99 MJ/kg)**	
Steel tubes (S235 steel)	12% reuse	No impact	Waste processing in accordance with the standard scenario for steel, light: including profiles, sheets, pipelines.
	87% recycled	0315-reC&Sorting and compressing old iron**	
	1% disposal	0253-sto&Disposal steel**	
Galvanised steel fastening materials	99% recycled	0315-reC&Sorting and compressing old iron**	Waste processing in accordance with the standard scenario for steel, fastening materials.
	1% disposal	0248-sto&Disposal of copper, lead, galvanised steel, zinc**	

* All process maps are from the National Environmental Database, version 3.4.

** The names of National Environmental Database process maps are abbreviated.

3.7.4 Module D: Benefits and charges

Through reuse and recycling, the production of primary materials is prevented. This is calculated on the basis of the net secondary output per material. For steel (piles, fastening materials) and the packaging material, we use the process maps of the National Environmental Database in which the secondary part is indicated in the name. For recycled PVC, 100% of the material is secondary and for primary PVC and wood products 0%.

Through incineration in a waste incineration plant, energy from the grid is avoided. This leads to benefits that we include in Module D. However, the PVC recyclate in the sheet pile walls already consists of 100% recycled material but is not fully recycled or reused after dismantling of the sheet pile walls. The part of this material that is not recycled (20% to a WIP and 10% disposal) is therefore lost. This loss is included as a cost in Module D. The benefits of incinerating PVC are also included but they do not compensate for the costs of the material lost.

Table 21 shows the applied process map for each material for Module D and indicates whether the process map concerns a net benefit or cost. This table also includes Module D of the packaging materials that are disposed of in Module A5.

Table 21 - Benefits and costs of waste processing of materials and packaging materials and choice of process map

Material	Waste processing	'Benefits and costs' process map*	Explanation
PVC sheet pile (PVC recyclate)	70% recycled	Cost: Polyvinyl chloride, suspension polymerised {RER}| polyvinyl chloride production, suspension polymerisation	Waste processing in accordance with the standard scenario for PVC, pipelines. 70% of the PVC recyclate is offered in Module C as 'material for recycling'. In this way, 30% of secondary material is lost. This is included as a cost in Module D.
	20% WIP	Benefit: 0267-avD&Prevented WIP energy production, based on FOSSIL raw materials, 18% electric and 31% thermal (per MJ LHV)	
	10% disposal	N/A	
PVC sheet pile (PVC top coat and primary PVC)	70% recycled	Benefit: Polyvinyl chloride, suspension polymerised {RER}| polyvinyl chloride production, suspension polymerisation Cost: recycling PVC to granulate in accordance with the process at suppliers. Modelled identical to that in Section 3.1.2	Waste processing in accordance with the standard scenario for PVC, pipelines. The PVC top coat is primary PVC in Module A1. Secondary PVC prevents 0.77 kg of primary PVC (1.31 kg of waste PVC per kg of recycled PVC). To be equal functionally to PVC granulate, the secondary PVC must first be recycled into granulate. This is included as a cost in Module D. For the following life phase, we used the recycling at the suppliers in line with Module A1. The quality of recycled PVC granulate is identical to primary PVC granulate (raw materials are equivalent) in accordance with Profextru (no quality factor).
	20% WIP	Benefit: 0267-avD&Prevented WIP energy production, based on FOSSIL raw materials, 18% electric and 31% thermal (per MJ LHV)	
	10% disposal	N/A	
Wooden posts and wale (softwood and Azobé and Cloeziana hardwood)	Leave 10%	N/A	Waste processing in accordance with the standard scenario for wood, hydraulic engineering: sheetpile walls, duckboards, scaffolding and revetments. Incinerating wood avoids energy from biogenic raw materials.
	90% to WIP	Benefit: 0268-avD&Prevented energy production at a WIP, based on RENEWABLE raw materials, 18% electric and 31% thermal (per MJ LHV)	
Steel tubes (S235 steel)	12% reuse	Benefit: 0318-fab&Steel, hot-rolled, tubular and rectangular profiles {GLO} (86.6% primary, 13.4% secondary)	Waste processing in accordance with the standard scenario for steel, light: including profiles, sheets, pipelines. The steel piles already have 13.4% secondary materials in Module A1.
	87% recycled	Benefit: 0282-reD&Module D, steel, per supplied NET kg of non-alloy scrap**	
	1% disposal	N/A	
Galvanised steel fastening materials	99% recycled	Benefit: 0282-reD&Module D, steel, per supplied NET kg of non-alloy scrap**	Waste processing in accordance with the standard scenario for steel, fastening materials.

Material	Waste processing	'Benefits and costs' process map*	Explanation
	1% disposal	N/A	Galvanised steel is 98.6% steel, 43% of which is secondary material in Module A1.
Packaging: steel strapping	100% recycled	Benefit: 0282-reD&Module D, steel, per supplied NET kg of non-alloy scrap**	We assume that packaging material is recycled 100%. This is a rough estimate that has little impact on the total impact of the sheetpile walls (< 1%). With steel strapping, 17.3% of the secondary materials are already present in Module A1. For paper, a process map of the raw materials for paper and cardboard from Ecoinvent, version 3.6, was chosen. Secondary paper pulp prevents 1.48 kg pulpwood, based on the fluting medium in Ecoinvent (1.88 kg pulpwood equals 1.09 kg secondary paper pulp for the production of 1 kg of the fluting medium. (1.16 kg of cardboard waste is needed per 1 kg of paper pulp.) Secondary PE prevents 0.91 kg of primary PE (1.10 kg of waste PE per kg of sorted PE).
Packaging: wooden frames		Benefit: 0276-reD&Module D, wood chips per supplied NET kg**	
Packaging: cardboard		Benefit: Pulpwood and softwood, measured as solid wood under bark {Europe without Switzerland}| market for	
Packaging: PE sheet		Benefit: 0278-reD&Module D, PE per supplied NET kg**	

* All process maps are from the National Environmental Database, version 3.4.

** The names of National Environmental Database process maps are abbreviated.

4 Results

4.1 Calculation of the environmental profile

This LCA uses the following calculation procedures:

- The calculations in this LCA are carried out in accordance with the requirements and guidelines of EN 15804:2012+A2 (2019) and the Environmental Performance Assessment Method for Construction Works (July 2020).
- The environmental interventions were calculated using characterisation factors from the CML-VLCA calculation method (version of Feb 2021, National Environmental Database 3.4). These results are marked as ‘set 1’.
- The environmental interventions were also calculated using the methods described in EN 15804:2012+A2 (2019). These results are marked as ‘set 2’.
- If applicable, we follow the rules for allocation with multi-output, recycling and reuse processes from EN 15804:2012+A2 (2019) in accordance with NEN-EN-ISO 14044.
- The LCA calculations were done with SimaPro 9.2.0.2.
- Ecoinvent processes were calculated by means of inclusive infrastructure processes and capital goods.
- Ecoinvent processes were calculated by means of exclusive long-term (> 100 years) emissions.

In accordance with section 3.5 of the Assessment Method, we converted the environmental impact categories from the CML-VLCA calculation method to an environmental cost indicator (ECI) in euros. The weighting factors for this conversion are given in Table 22.

Table 22 - Weighting factors of the ECI per environmental impact category

Environmental- mpact category	Unit	Weighting factor (€/kg unit)	
001. abiotic depletion, non-fuel (AD)	Sb eq.	€	0.16
002. abiotic depletion, fuel (AD)	Sb eq.	€	0.16
004. global warming potential (GWP)	CO2 eq.	€	0.05
005. ozone layer potential (ODP; ozone depletion potential)	CFC-11 eq.	€	30.00
006. photochemical oxidation (POCP; Photochemical Ozone Creation Potential)	C2H4 eq.	€	2.00
007. acidification potential (AP)	SO2 eq.	€	4.00
008. eutrophication potential (EP)	PO4 eq.	€	9.00
009. human toxicity (HT)	1.4-DCB eq.	€	0.09
010. Ecotoxicity, fresh water (FAETP)	1.4-DCB eq.	€	0.03
012. Ecotoxcity, marine water (MAETP)	1.4-DCB eq.	€	0.0001
014. Ecotoxicity, terrestric (TETP)	1.4-DCB eq.	€	0.06

4.2 Characterised results and parameters

The total characterised results are given for all Prolock sheetpile walls per m^2 of sheetpile wall in Table 23 and Table 24 for set 1 and in Table 25, Table 26, Table 27 and Table 28 for set 2. The quantity of biogenic carbon in the products is given in Table 29 and Table 30 calculated on the basis of the biogenic CO_2 in the products and their packaging material.

Table 23 - Total characterised results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 1 (part 1)

Impact category	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
001. abiotic depletion, non-fuel (AD)	Sb eq. kg	6.18E-04	7.76E-04	1.23E-03	1.22E-03	1.53E-03	9.24E-04
002. abiotic depletion, fuel (AD)	Sb eq. kg	2.11E-01	2.35E-01	2.01E-01	2.59E-01	3.05E-01	2.73E-01
004. global warming potential (GWP)	CO_2 eq. kg	34.85	38.09	33.59	44.29	49.32	44.46
005. ozone layer potential (ODP; ozone depletion potential)	CFC-11 eq. kg	8.44E-06	8.64E-06	8.21E-06	9.45E-06	9.48E-06	1.02E-05
006. photochemical oxidation (POCP; Photochemical Ozone Creation Potential)	C_2H_4 kg	1.58E-02	1.71E-02	1.44E-02	2.18E-02	2.78E-02	1.93E-02
007. acidification potential (AP)	SO_2 eq. kg	1.14E-01	1.18E-01	1.09E-01	2.02E-01	1.77E-01	1.32E-01
008. eutrophication potential (EP)	PO_4--- eq. kg	1.70E-02	1.54E-02	1.53E-02	2.48E-02	3.14E-02	1.65E-02
009. human toxicity (HT)	kg 1.4-DB eq.	1.26E+01	1.33E+01	1.29E+01	1.58E+01	2.23E+01	1.55E+01
010. Ecotoxicity, fresh water (FAETP)	kg 1.4-DB eq.	2.54E-01	2.74E-01	2.56E-01	2.92E-01	1.18E+00	3.20E-01
012. Ecotoxcity, marine water (MAETP)	kg 1.4-DB eq.	9.10E+02	1.02E+03	8.97E+02	1.16E+03	1.63E+03	1.19E+03
014. Ecotoxicity, terrestric (TETP)	kg 1.4-DB eq.	8.35E-02	8.76E-02	9.42E-02	9.21E-02	1.36E+00	1.05E-01

Table 24 - Total characterised results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 1 (part 2)

Impact category	Unit	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m, wale	Prolock Omega recycled PVC, 2 m, steel pile, 5 m	Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale	Delta recycled PVC, 5 m	
001. abiotic depletion, non-fuel (AD)	Sb eq. kg	1.59E-03	3.20E-03	1.43E-03	4.01E-04	
002. abiotic depletion, fuel (AD)	Sb eq. kg	2.90E-01	5.24E-01	3.43E-01	1.51E-01	
004. global warming potential (GWP)	CO_2 eq. kg	47.24	82.62	59.45	26.42	
005. ozone layer potential (ODP; ozone depletion potential)	CFC-11 eq. kg	1.04E-05	1.31E-05	1.18E-05	7.55E-06	
006. photochemical oxidation (POCP;	C_2H_4 kg	2.10E-02	5.06E-02	3.00E-02	9.82E-03	

Impact category	Unit	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m, wale	Prolock Omega recycled PVC, 2 m, steel pile, 5 m	Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale	Delta recycled PVC, 5 m
Photochemical Ozone Creation Potential)					
007. acidification potential (AP)	SO_2 eq. kg	1.52E-01	3.01E-01	2.94E-01	7.55E-02
008. eutrophication potential (EP)	PO_4--- eq. kg	1.83E-02	5.37E-02	3.23E-02	1.18E-02
009. human toxicity (HT)	kg 1.4-DB eq.	1.70E+01	3.99E+01	2.07E+01	1.00E+01
010. Ecotoxicity, fresh water (FAETP)	kg 1.4-DB eq.	3.41E-01	2.59E+00	3.84E-01	2.02E-01
012. Ecotoxcity, marine water (MAETP)	kg 1.4-DB eq.	1.28E+03	3.03E+03	1.59E+03	6.72E+02
014. Ecotoxicity, terrestric (TETP)	kg 1.4-DB eq.	1.17E-01	3.22E+00	1.14E-01	7.75E-02

Table 25 - Total characterised results of Prolock sheetpile walls per m² of sheetpile wall. Set 2 (part 1)

Impact category	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
051. Climate change	CO_2 eq. kg	35.31	38.60	33.87	42.44	50.21	45.06
052. Climate change - Fossil	CO_2 eq. kg	35.28	38.55	33.84	42.42	50.02	45.00
053. Climate change - Biogenic	CO_2 eq. kg	0	0	0	0	0	0
054. Climate change - Land use and LU ch	CO_2 eq. kg	0.03	0.05	0.03	0.01	0.20	0.06
055. Ozone depletion	CFC_{11} eq. kg	8.72E-06	9.00E-06	8.42E-06	1.00E-05	9.67E-06	1.05E-05
056. Acidification	H+ eq. mol	1.41E-01	1.42E-01	1.34E-01	2.49E-01	2.22E-01	1.58E-01
057. Eutrophication, fresh water	P eq. kg	1.09E-03	1.23E-03	1.08E-03	1.01E-03	2.71E-03	1.47E-03
058. Eutrophication, marine	N eq. kg	4.32E-02	4.37E-02	3.76E-02	7.32E-02	5.68E-02	4.72E-02
059. Eutrophication, terrestrial	N eq. mol	4.19E-01	3.82E-01	3.71E-01	7.09E-01	6.02E-01	4.00E-01
060. Photochemical ozone formation	NMVOC eq. kg	1.40E-01	1.46E-01	1.23E-01	2.32E-01	1.86E-01	1.59E-01
061. Resource use, minerals and metals	Sb eq. kg	6.18E-04	7.76E-04	1.23E-03	1.22E-03	1.53E-03	9.24E-04
062. Resource use, fossils	MJ	4.47E+02	4.92E+02	4.27E+02	5.48E+02	6.20E+02	5.74E+02
063. Water use	m^3 depriv.	1.78E+01	1.83E+01	1.79E+01	1.83E+01	3.18E+01	2.23E+01
064. Particulate matter	disease inc.	3.13E-06	3.79E-06	2.63E-06	3.48E-06	3.89E-06	4.23E-06

Impact category	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
065. Ionising radiation	kBq U-235 eq.	1.66E+00	1.85E+00	1.57E+00	2.12E+00	2.36E+00	2.16E+00
066. Ecotoxicity, fresh water	CTUe	8.95E+02	7.12E+02	9.02E+02	6.67E+02	1.62E+03	8.41E+02
067. Human toxicity, cancer	CTUh	2.30E-08	2.77E-08	2.47E-08	2.99E-08	2.09E-07	3.28E-08
068. Human toxicity, non-cancer	CTUh	5.13E-07	4.93E-07	5.54E-07	5.07E-07	5.86E-06	5.82E-07
069. Land use	Pt	4.54E+03	7.88E+03	4.74E+03	1.34E+04	3.49E+02	9.45E+03

Table 26 - Total indicator/parameter results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 2 (part 1)

Indicator/parameter	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
111. Energy, primary, renewable, excl.	MJ	2.37E+02	3.83E+02	3.07E+02	1.50E+03	7.31E+01	4.59E+02
113. Energy, primary, renewable, material	MJ	3.14E+02	5.49E+02	3.03E+02	5.80E+02	1.03E+01	6.59E+02
101. Energy, primary, renewable (MJ)	MJ	5.51E+02	9.32E+02	6.10E+02	2.08E+03	8.36E+01	1.12E+03
112. Energy, primary, non-renewable, excl.	MJ	4.74E+02	5.23E+02	4.53E+02	5.82E+02	6.60E+02	6.10E+02
114. Energy, primary, non-renewable, material	MJ	2.91E+02	2.91E+02	2.91E+02	2.91E+02	2.91E+02	3.49E+02
102. Energy, primary, non-renewable (MJ)	MJ	7.65E+02	8.14E+02	7.44E+02	8.73E+02	9.51E+02	9.59E+02
108. Secondary material (kg)	kg	1.26E+01	1.26E+01	1.27E+01	1.27E+01	1.52E+01	1.54E+01
109. Secondary fuel, renewable*	MJ	0	0	0	0	0	0
110. Secondary fuel, non-renewable*	MJ	0	0	0	0	0	0
104. Water, fresh water use (m^3)	m^3	3.11E-01	3.38E-01	3.12E-01	3.35E-01	6.74E-01	4.04E-01
106. Waste, hazardous (kg)	kg	7.90E-04	9.80E-04	7.97E-04	1.07E-03	1.26E-03	1.14E-03
105. Waste, non-hazardous (kg)	kg	8.29E+00	1.00E+01	8.28E+00	1.01E+01	1.28E+01	1.20E+01
107. Waste, radioactive (kg)	kg	1.84E-03	2.05E-03	1.70E-03	2.52E-03	2.31E-03	2.36E-03

Indicator/parameter	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
120. Components for reuse (kg)	kg	2.17E+00	3.85E+00	2.09E+00	4.07E+00	2.33E+00	4.62E+00
121. Materials for recycling (kg)	kg	1.02E+01	1.02E+01	1.04E+01	1.04E+01	2.71E+01	1.23E+01
122. Materials for energy recovery (kg)	kg	2.22E+01	3.74E+01	2.15E+01	3.94E+01	2.70E+00	4.49E+01
123. Exported energy, electric (MJ)	MJ	5.96E+01	9.78E+01	5.78E+01	1.03E+02	1.04E+01	1.17E+02
124. Exported energy, thermal (MJ)	MJ	1.05E+02	1.73E+02	1.02E+02	1.77E+02	1.80E+01	2.08E+02

*No direct use of secondary fuels is made in the foreground processes or in the process maps applied.

Table 27 - Total characterised results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 2 (part 2)

Impact category	Unit	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m, wale	Prolock Omega recycled PVC, 2 m, steel pile, 5 m	Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale	Delta recycled PVC, 5 m
051. Climate change	CO_2 eq. kg	47.44	84.30	55.64	26.77
052. Climate change - Fossil	CO_2 eq. kg	47.38	83.83	55.61	26.75
053. Climate change - Biogenic	CO_2 eq. kg	0	0	0	0
054. Climate change - Land use and LU ch	CO_2 eq. kg	0.06	0.46	0.02	0.02
055. Ozone depletion	CFC_{11} eq. kg	1.09E-05	1.33E-05	1,26E-05	7.52E-06
056. Acidification	H+ eq. mol	1.82E-01	3.73E-01	3.57E-01	9.46E-02
057. Eutrophication, fresh water	P eq. kg	1.51E-03	5.51E-03	1.33E-03	8.88E-04
058. Eutrophication, marine	N eq. kg	5.37E-02	8.78E-02	9.96E-02	2.29E-02
059. Eutrophication, terrestrial	N eq. mol	4.66E-01	9.14E-01	9.43E-01	2.49E-01
060. Photochemical ozone formation	NMVOC eq. kg	1.80E-01	2.94E-01	3.18E-01	7.36E-02
061. Resource use, minerals and metals	Sb eq. kg	1.59E-03	3.20E-03	1.43E-03	4.01E-04
062. Resource use, fossils	MJ	6.08E+02	1.04E+03	7.24E+02	3.30E+02
063. Water use	m^3 depriv.	2.26E+01	5.66E+01	2.29E+01	1.85E+01
064. Particulate matter	disease inc.	4.52E-06	6.78E-06	4.42E-06	1.10E-06
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]35E+00	1.20E+00

Impact category	Unit	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m, wale	Prolock Omega recycled PVC, 2 m, steel pile, 5 m	Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale	Delta recycled PVC, 5 m	
066. Ecotoxicity, fresh water	CTUe	7.72E+02	2.55E+03	6.54E+02	1.10E+03	
067. Human toxicity, cancer	CTUh	3.72E-08	4.88E-07	4.04E-08	1.58E-08	
068. Human toxicity, non-cancer	CTUh	6.23E-07	1.36E-05	5.88E-07	5.15E-07	
069. Land use	Pt	1.18E+04	5.39E+02	2.62E+04	2.48E+02	

Table 28 – Total indicator/parameter results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 2 (part 2)

Indicator/parameter	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
111. Energy, primary, renewable, excl.	MJ	7.19E+02	1.16E+02	3.25E+03	5.14E+01	2.36E+02	4.23E+02
113. Energy, primary, renewable, material	MJ	7.61E+02	1.23E+01	8.42E+02	1.04E+01	3.13E+02	6.16E+02
101. Energy, primary, renewable (MJ)	MJ	1.48E+03	1.28E+02	4.09E+03	6.21E+01	5.50E+02	1.04E+03
112. Energy, primary, non-renewable, excl.	MJ	6.46E+02	1.10E+03	7.69E+02	3.50E+02	4.59E+02	5.14E+02
114. Energy, primary, non-renewable, material	MJ	3.49E+02	3.49E+02	3.49E+02	2.95E+02	2.82E+02	2.82E+02
102. Energy, primary, non-renewable (MJ)	MJ	9.95E+02	1.45E+03	1.12E+03	6.45E+02	7.41E+02	7.96E+02
109. Secondary fuel, renewable*	kg	1.55E+01	2.18E+01	1.54E+01	1.37E+01	1.31E+01	1.31E+01
110. Secondary fuel, non-renewable*	MJ	0	0	0	0	0	0
110. Secondary fuel, non-renewable	MJ	0	0	0	0	0	0
104. Water, fresh water use (m^3)	m^3	4.18E-01	1.30E+00	4.30E-01	2.77E-01	3.01E-01	3.35E-01
106. Waste, hazardous (kg)	kg	1.30E-03	2.42E-03	1.47E-03	3.95E-04	7.82E-04	1.01E-03
105. Waste, non-hazardous (kg)	kg	1.28E+01	2.37E+01	1.44E+01	6.02E+00	8.02E+00	1.02E+01
[illegible]	[illegible]	[illegible]	[illegible]	40E-03	1.20E-03	1.83E-03	2.04E-03

Indicator/parameter	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
120. Components for reuse (kg)	kg	5.35E+00	5.68E+00	5.93E+00	0.00E+00	2.17E+00	4.34E+00
121. Materials for recycling (kg)	kg	1.24E+01	5.35E+01	1.23E+01	1.04E+01	9.91E+00	9.91E+00
122. Materials for energy recovery (kg)	kg	5.14E+01	3.23E+00	5.66E+01	2.74E+00	2.21E+01	4.16E+01
123. Exported energy, electric (MJ)	MJ	1.34E+02	1.25E+01	1.56E+02	1.06E+01	5.92E+01	1.08E+02
124. Exported energy, thermal (MJ)	MJ	2.36E+02	2.16E+01	2.69E+02	1.82E+01	1.05E+02	1.92E+02

* No direct use of secondary fuels is made in the foreground processes or in the process maps applied.

Table 29 - Biogenic carbon content at 'factory gate' per m^2 sheet pile wall (part 1)

Biogenic carbon content	Unit	Sigma recycled PVC, 1 m, softwood pile, 3 m	Sigma recycled PVC, 1.5 m, softwood pile, 4 m	Sigma recycled PVC, 1.6 m, softwood pile, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel pile, 3 m	Prolock Omega recycled PVC, 2 m, softwood pile, 5 m
Biogenic carbon content in product*	kg	17.45	31.36	16.36	22.91	0	38.18
Biogenic carbon content in packaging materials**	kg	0.58	0.58	0.58	0.58	0.58	0.70

* Wooden piles and wale.

** Wooden frames and cardboard.

Table 30 - Biogenic carbon content at 'factory gate' per m^2 sheetpile wall (part 2)

Biogenic carbon content	Unit	Prolock Omega recycled PVC, 2 m, softwood	Prolock Omega recycled PVC, 2 m, steel pile,	Prolock Omega recycled PVC, 3.5 m, Cloeziana	Delta recycled PVC, 5 m
					0
					0.59

Biogenic carbon content	**Unit**	**Prolock Omega recycled PVC, 2 m, softwood pile, 5 m, wale**	**Prolock Omega recycled PVC, 2 m, steel pile, 5 m**	**Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale**	**Delta recycled PVC, 5 m**	
content in packaging materials**						

*   Wooden posts and wale.

**   Wooden frames and cardboard..

4.3 Weighted results

Weighting the results is a process where the results of different environmental-impact categories are converted to a 1 point score so that they can be considered integrally. This study uses the Environmental Cost Indicator (ECI) to weigh the different effect categories into one final point in accordance with the Environmental Performance Assessment Method for Construction Works and civil engineering works. In the following two subsections, the weighted results are given per semi-finished product per functional unit and the quantities in which the semi-finished products are used in the main product.

The total weighted results are given for all Prolock sheet pile walls per m^2 of sheetpile wall in Figure 11, Table 31 and Table 32.

Figure 11 – Total weighted results of Prolock sheet pile walls per m^2 of sheetpile wall. Set 2 (ECI, €/m^2)

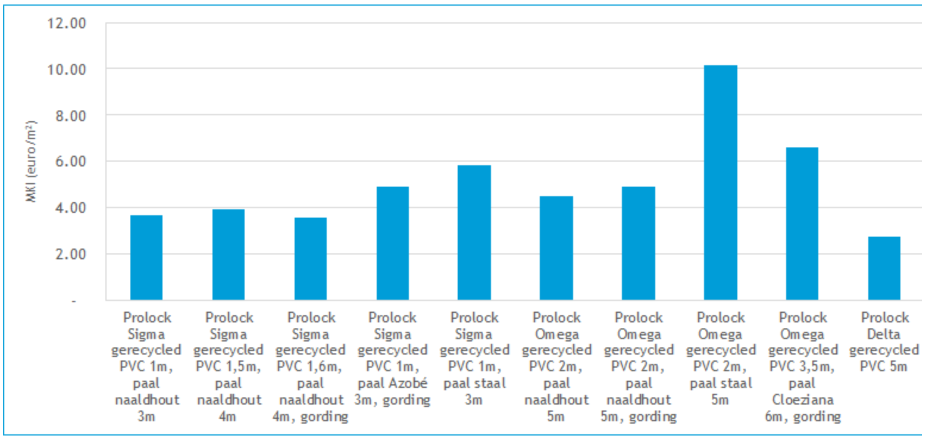


Table 31 – Total weighted results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 2 (part 1)

Impact category	Unit	Sigma recycled PVC, 1 m, softwood post, 3 m	Sigma recycled PVC, 1.5 m, softwood post 4 m	Sigma recycled PVC, 1.6 m, softwood post, 4 m, wale	Sigma recycled PVC, 1 m, Azobé pile, 3 m, wale	Sigma recycled PVC, 1 m, steel tube 3 m	Prolock Omega recycled PVC, 2 m, softwood post, 5 m
ECI (total)	**€**	**3.65**	**3.90**	**3.57**	**4.89**	**5.85**	**4.51**
001. abiotic depletion, non-fuel (AD)	€	9.89E-05	1.24E-04	1.97E-04	1.95E-04	2.44E-04	1.48E-04
002. abiotic depletion, fuel (AD)	€	0.03	0.04	0.03	0.04	0.05	0.04
004. global warming potential (GWP)	€	1.74	1.90	1.68	2.21	2.47	2.22
005. ozone layer potential (ODP; ozone depletion potential)	€	2.53E-04	2.59E-04	2.46E-04	2.84E-04	2.85E-04	3.05E-04
006. photochemical oxidation (POCP; Photochemical Ozone Creation Potential)	€	0.03	0.03	0.03	0.04	0.06	0.04
007. acidification potential (AP)	€	0.45	0.47	0.44	0.81	0.71	0.53
008. eutrophication potential (EP)	€	0.15	0.14	0.14	0.22	0.28	0.15
009. human toxicity (HT)	€	1.13	1.20	1.16	1.42	2.00	1.39
010. Ecotoxicity, fresh water (FAETP)	€	0.01	0.01	0.01	0.01	0.04	0.01
012. Ecotoxcity, marine water (MAETP)	€	0.09	0.10	0.09	0.12	0.16	0.12
014. Ecotoxicity, terrestric (TETP)	€	5.01E-03	5.25E-03	5.65E-03	5.53E-03	8.16E-02	6.28E-03

Table 32 - Total weighted results of Prolock sheetpile walls per m^2 of sheetpile wall. Set 2 (part 2)

Impact category	Unit	Prolock Omega recycled PVC, 2 m, softwood post, 5 m, wale	Prolock Omega recycled PVC, 2 m, steel tube, 5 m	Prolock Omega recycled PVC, 3.5 m, Cloeziana post, 6 m, wale	Delta recycled PVC, 5 m
ECI (total)	**€**	**4.90**	**10.17**	**6.60**	**2.75**
001. abiotic depletion, non-fuel (AD)	€	2.54E-04	5.13E-04	2.29E-04	6.41E-05
002. abiotic depletion, fuel (AD)	€	0.05	0.08	0.05	0.02
004. global warming potential (GWP)	€	2.36	4.13	2.97	1.32
005. ozone layer potential (ODP; ozone depletion potential)	€	3.13E-04	3.92E-04	3.54E-04	2.27E-04
006. photochemical oxidation (POCP; Photochemical Ozone Creation Potential)	€	0.04	0.10	0.06	0.02
007. acidification potential (AP)	€	0.61	1.20	1.17	0.30
008. eutrophication potential (EP)	€	0.16	0.48	0.29	0.11
009. human toxicity (HT)	€	1.53	3.59	1.87	0.90
010. Ecotoxicity, fresh water (FAETP)	€	0.01	0.08	0.01	0.01
012. Ecotoxcity, marine water (MAETP)	€	0.13	0.30	0.16	0.07
014. Ecotoxicity, terrestric (TETP)	€	7.05E-03	1.93E-01	6.86E-03	4.65E-03

4.4 Centre of gravity analysis

To study how the environmental impact of the Prolock sheet pile walls contribute to the total impact of the sheet pile walls, we look at the ECI. This means we examine the contribution of different facets.

4.4.1 Analysis of the contribution to impact categories

The contribution of the different impact categories to the total ECI for all Prolock sheetpile walls is given in Figure 12 and Figure 13.

Figure 12 - Contribution analysis of Prolock sheetpile walls per impact category per m² of sheet pile wall (Modules A1-D, part 1)

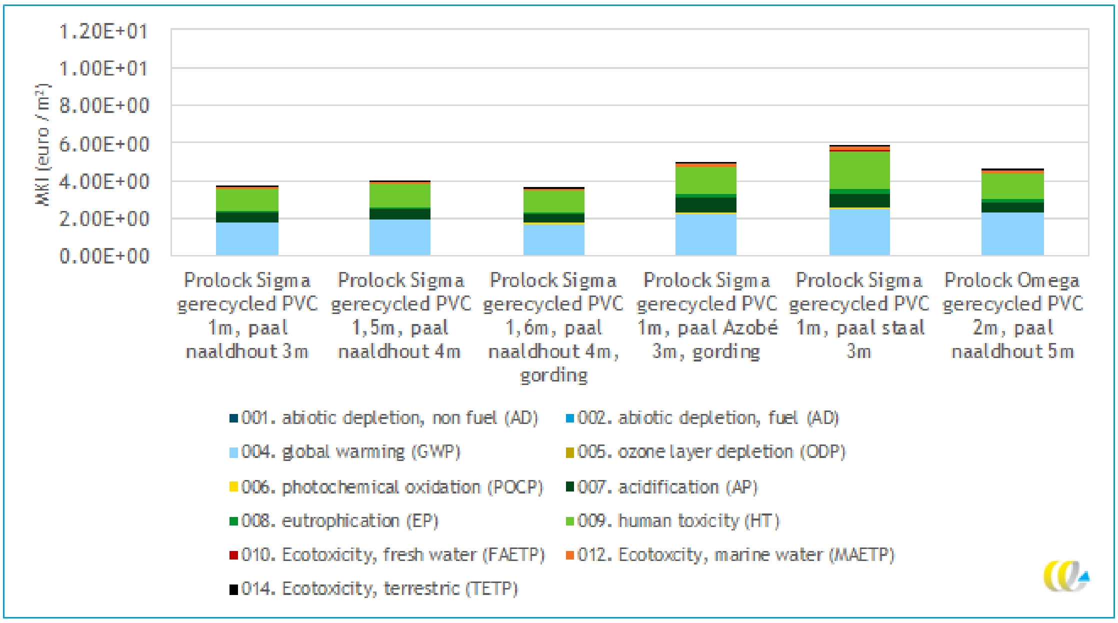
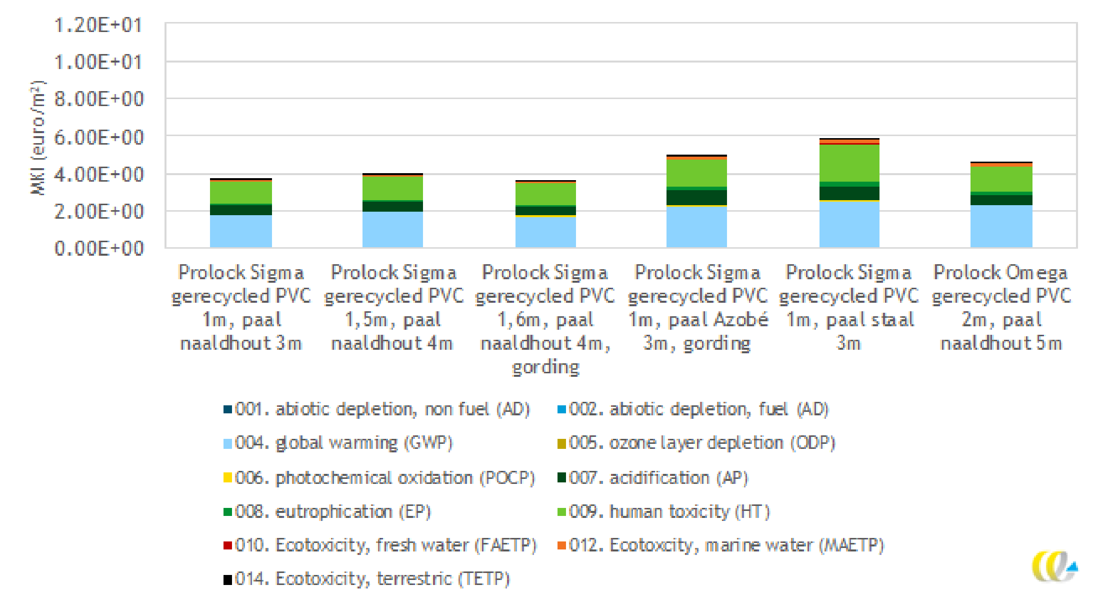


Figure 13 - Contribution analysis of Prolock sheet pile walls per impact category per m² of sheetpile wall (Modules A1-D, part 2)



From these figures, we conclude that climate change and human toxicity, in particular, contribute greatly to the total ECI of the Prolock sheet pile walls with a smaller contribution of acidification.

4.4.2 Analysis of the contribution of modules

The contribution of the different modules to the total ECI for all Prolock sheet pile walls is given in Figure 14 and Figure 15.

Figure 14 - Contribution analysis of Prolock sheet pile walls per impact category per m² of sheetpile wall (Modules A1-D, part 1)

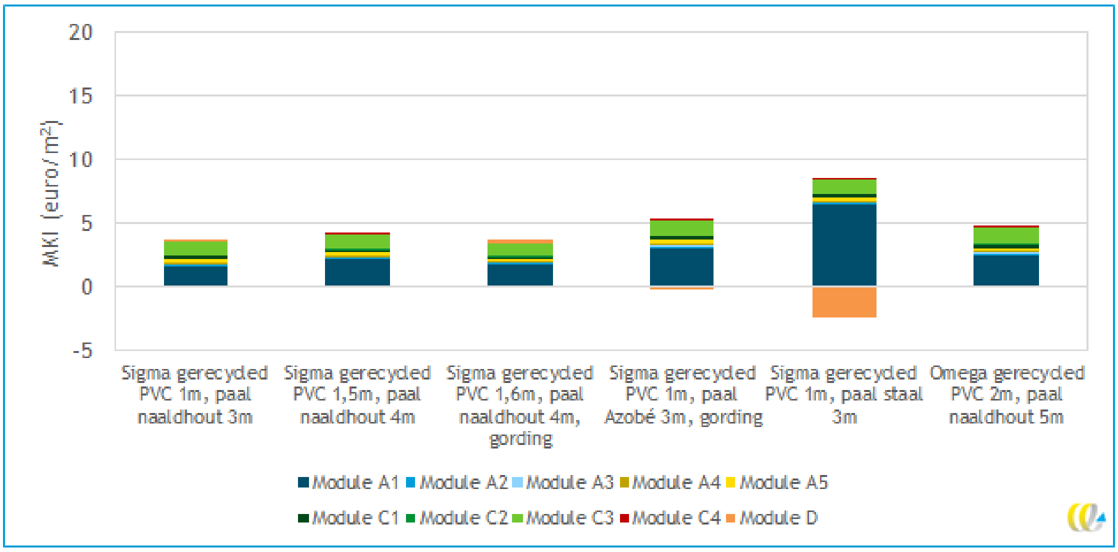
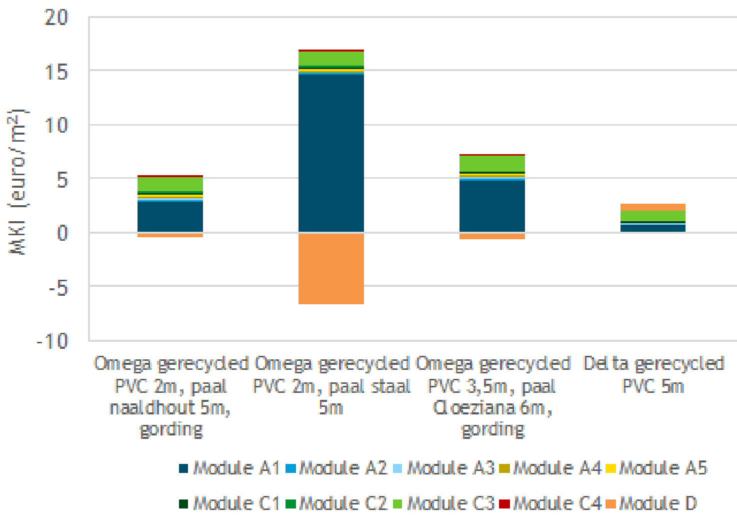


Figure 15 – Contribution analysis of Prolock sheetpile walls per impact category per m² of sheetpile wall (Modules A1-D, part 2)



From these figures, it emerges that Module A1, Module A3 and Module D, in particular, affect the total ECI of the Prolock sheet pile walls. It is striking that the ECI of Module A1 is considerably larger in sheet pile walls with steel tubes because the ECI of steel is relatively high. However, for sheet pile walls with steel tubes, Module D is also strongly negative (net benefit) because steel is recycled for the most part and even partially reused after dismantling of the sheet pile walls. The production of the Prolock sheet piles in Module A3 has a less major impact and is mainly caused by electricity consumption. Since Profextru uses wind energy, the impact of this electricity consumption is limited.

4.4.3 Analysis of the contribution of materials and Profextru's production process

The contribution of the different materials and of the production process of Profextru sheet piles at Profextru to the total ECI for all Prolock sheet pile walls is given in Figure 16 and Figure 17.

Figure 16 - Contribution analysis of Prolock sheetpile walls per material and activity per m² of sheetpile wall (Module A1-D, part 1)

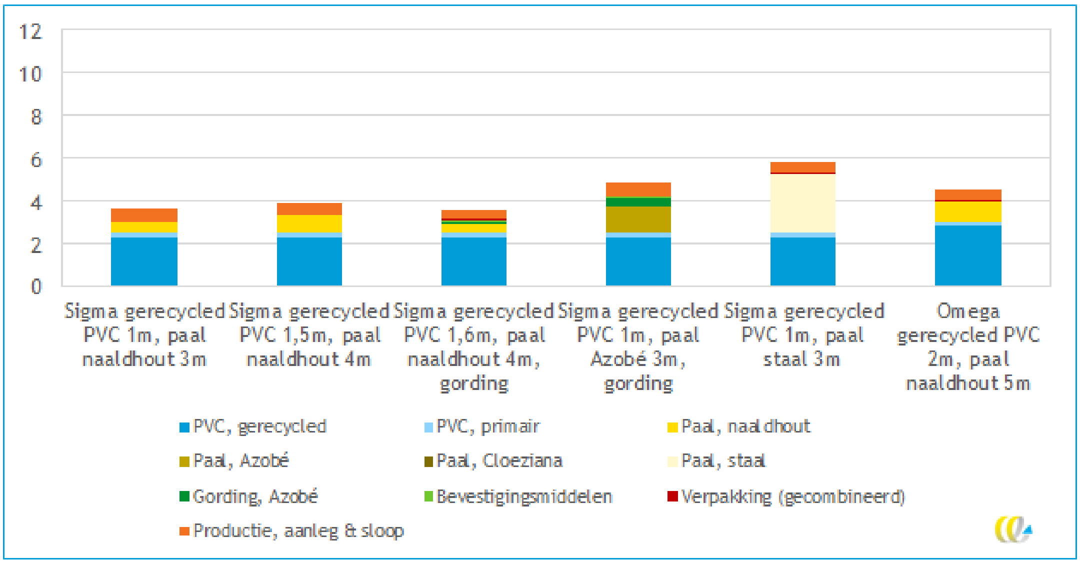
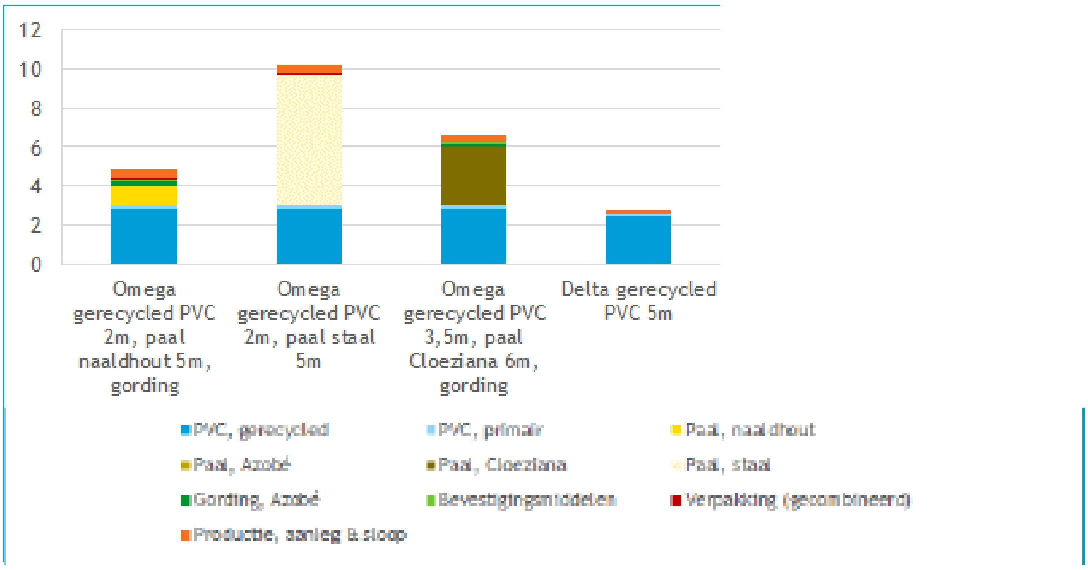


Figure 17 - Contribution analysis of Prolock sheetpile walls per material and activity per m² of sheetpile wall (Module A1-D, part 2)



The figures above clearly show that the recycled PVC of the Prolock sheet pilescontributes, in particular, to the ECI of the Prolock sheet pile walls. The production process of the Prolock sheet piles plays only a minor role in this. It is the material itself that leads to a major contribution. As was noticeable in Figure 14 and Figure 15, the impact of the steel tubes is also major. The figures above show the impact of the steel tubes to be even greater than the recycled PVC. For sheet pile walls with hardwood posts, the contribution is already less but, with Cloeziana posts, approximately equivalent to the contribution of the recycled PVC. For sheet pile walls with softwood piles, the contribution of the piles is considerably less. However, the figures above still do not allow us to determine from where the impact of recycled PVC comes. In Figure 18 we therefore look specifically at the impact of 1 kg of recycled PVC split into modules. This includes only modules that are material specific: Modules A1, A2, A4, C2, C3, C4 and D. Product-specific modules (A3, A5 and C1) have been omitted since these modules depend on the type of product rather than the type of material.

Figure 18 – Contribution analysis of recycled PVC (70% supplier 1, 30% supplier 2) per module per kg PVC

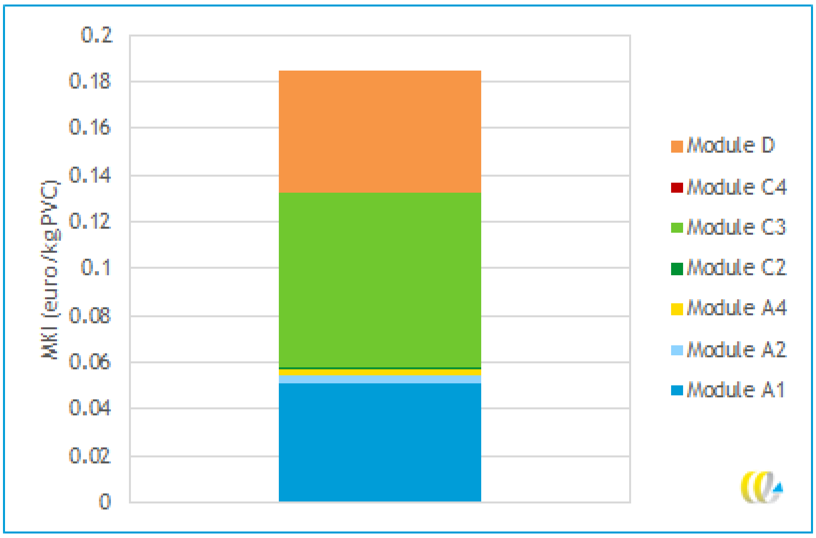


Figure 18 shows that the impact of recycled PVC comes largely from Module C3 (recycling and incineration after dismantling) and Module D (lost recycled PVC). Module C3 contributes more than a third to the total ECI and Module D almost a third. Module A1 (production of recycled PVC) is responsible for approximately a quarter of the total ECI.

Approximately half of the impact in Module C3 comes from the incineration of 20% of the recycled PVC. The other half comes from sorting 70% of the recycled PVC so that it can be recycled again.

The impact in Module D comes entirely from the loss of 30% of recycled PVC (cost in Module D). This loss is partially compensated for by the PVC that is incinerated for recovering energy (benefit in Module D), but this benefit is six times lower that the cost of the lost material.

4.4.4 Module D analysis structure

If we look at only Module D, we can see in Figure 14 and Figure 15 that there are huge differences between the different Prolock sheet pile walls in this module. Recycled PVC plays a major role in this since recycled PVC is lost. We can already see in Figure 18 that this use of recycled material results in a cost in Module D. With all other materials, less material is lost than recycled, so Module D is a sum of all sheet pile walls of the net costs of recycled PVC and the benefits of the other materials.
To examine from where this difference comes, we look in Figure 19 and Figure 20 specifically at Module D of each Prolock sheet pile wall to see how this module is built up.

Figure 19 - Contribution analysis of Prolock sheetpile walls per material per m² of sheetpile wall (Module D, part 1)

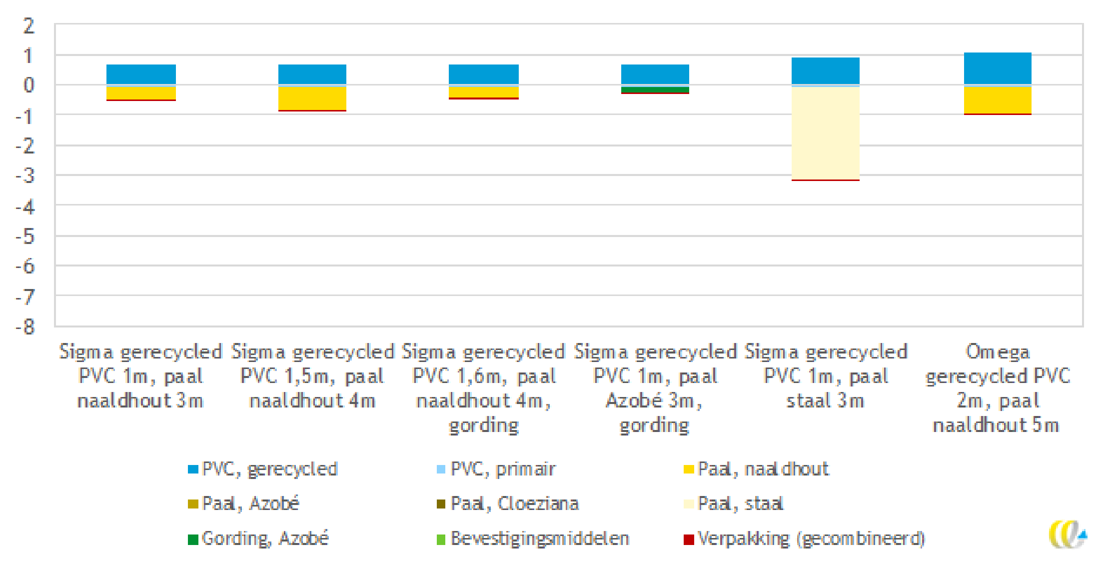
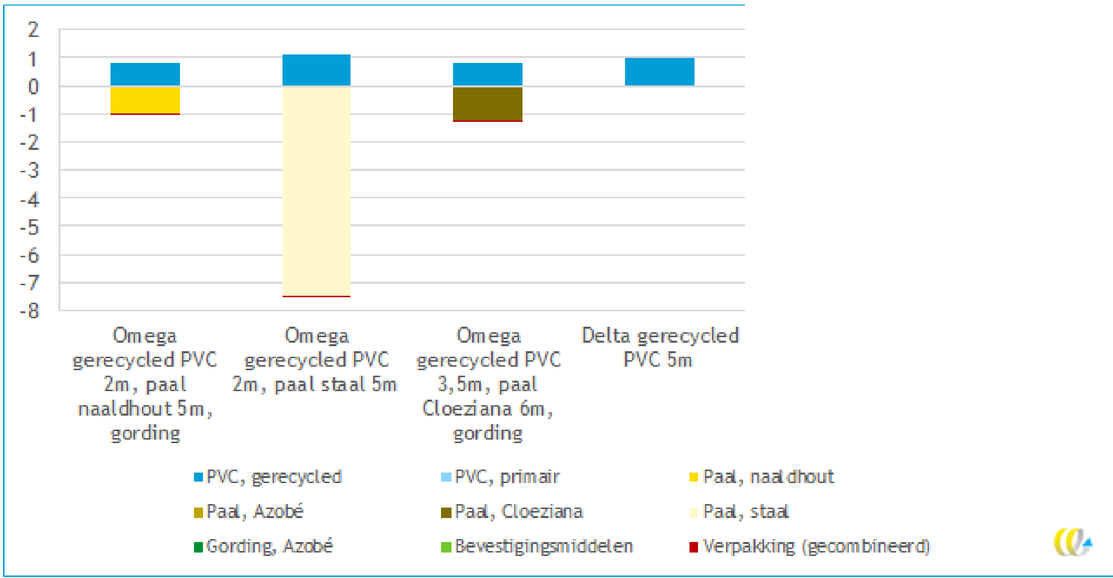


Figure 20 - Contribution analysis of Prolock sheetpile walls per material per m² of sheetpile wall (Module D, part 2)



The figures above reveals that the cost of recycled PVC in Module D is quite similar to the different types of Prolock sheet piles. In the sheet pile walls, the benefit of the posts or tubes in Module D have a major impact on the total ECI of Module D. Steel tubes ensure a major benefit in Module D as became clear from the analysis of the modules in Section 4.4.2. It must be remembered that the steel tubes greatly increase the total ECI of the sheet pile walls with respect to sheetpile walls with wooden posts because the ECI of steel tubes in Module A1 is higher than the impact prevented in Module D.

For sheet pile walls with wooden posts, the variation can be seen in the benefits in Module D. This is due not because of the type of wood, but the size and number of these wooden posts. All wooden posts are, for the most part, incinerated, which means that energy production is prevented elsewhere. The more wood is incinerated, the more energy is generated and therefore prevented. Here, too, it applies that more and larger wooden piles increase the total ECI of the sheetpile walls because their ECI in Module A1 is higher than the impact prevented in Module D.

4.5 Sensitivity analysis

To determine the effect of different assumptions and underlying data, we carried out a sensitivity analysis. This means we examine the following variables:

- The production of recycled PVC;
- Waste processing of PVC;
- The source of Profextru's electricity;
- Installation and dismantling.

4.5.1 Recycled PVC: 100% supplier 1 or 100% supplier 2

For recycled PVC, we used the ratio of the amounts supplied by the two suppliers.

Production years are different so it is possible that 100% recycled PVC is used from either supplier. This is why we have analysed what effect this would have. In addition, we have analysed the effect that using 100% PVC from supplier 1 would have if we used data from 2017. This data is incomplete, but it can be used if additional assumptions are made.

The analyses are given in Figure 21, Figure 22 and Figure 23.

Figure 21 - Sensitivity analysis for 100% recycled PVC from supplier 2 (€/m² sheetpile wall, Modules A1 through D)

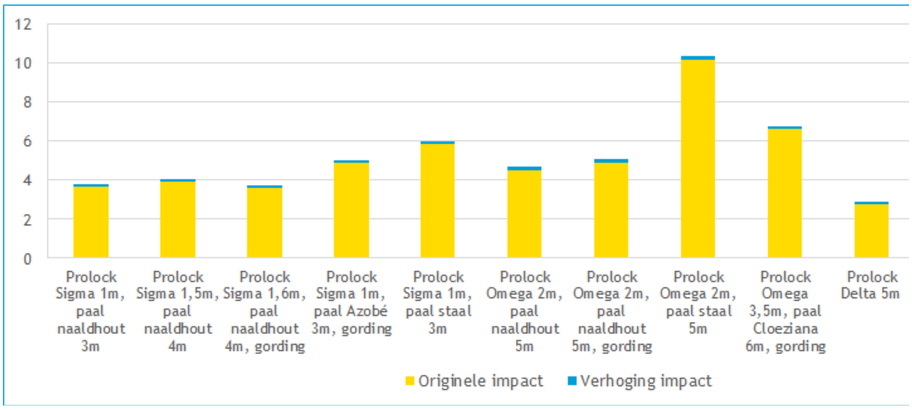


Figure 22 - Sensitivity analysis for 100% recycled PVC from supplier 1 (2016 data) (€/m² sheetpile wall, Modules A1 through D)

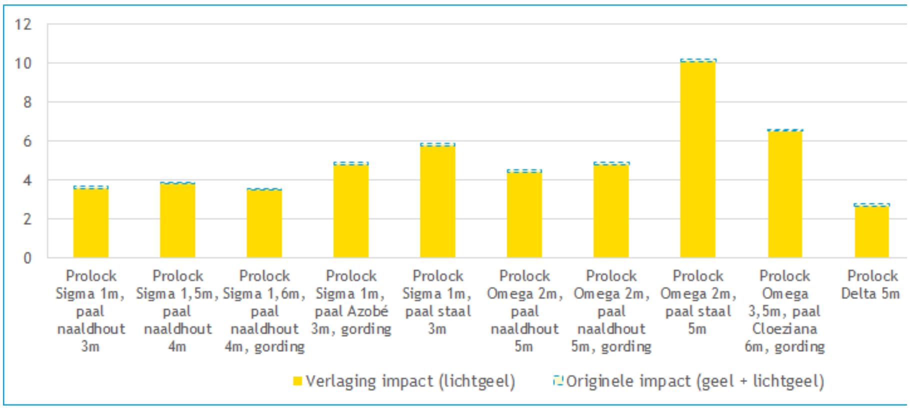
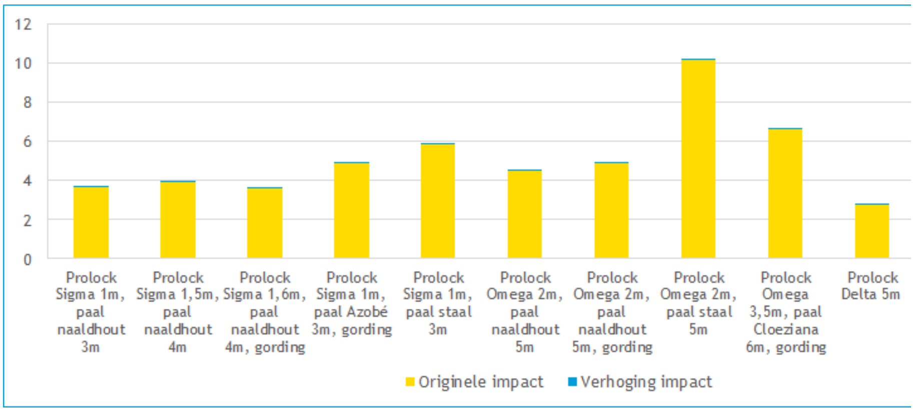


Figure 23 - Sensitivity analysis for 100% recycled PVC from supplier 1 (2017 data) (€/m² sheetpile wall, Modules A1 through D)



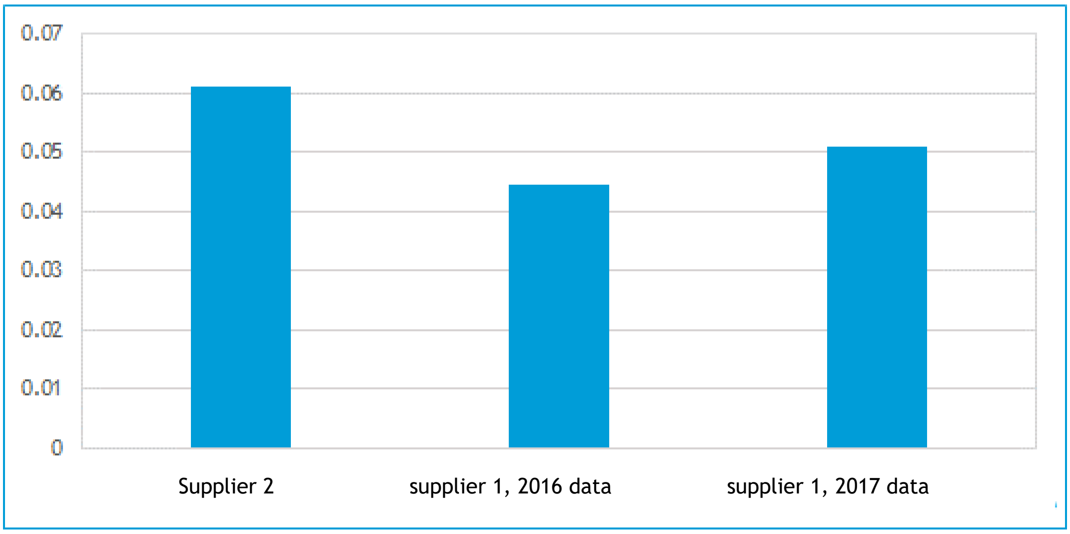
The effect differs per variant, but this difference is not great. It is striking that the effect of 100% recycled PVC from the supplier with data from 2017 results in almost exactly the same impact as the current modelling. The difference is less than € 0.01 and has been rounded off to 0%.

The difference is greatest with the use of 100% recycled PVC from supplier 2, amounting to an increase of 2% (Prolock Omega recycled PVC, 2 m, steel WXEH, 5 m) to 5% (Delta recycled PVC, 5 m). This means an increase of € 0.14/m² for Sigma sheet pile walls, € 0.15/m² for Omega sheet pile walls, € 0.14/m² for the Delta sheet pile wall.

When using 100% recycled PVC from the supplier with data from 2016, there is a decrease of 1% (Sigma, 1 m, steel pile, 3 m) to 3% (Delta recycled PVC, 5 m). This means a decrease of € 0.08/m² for Sigma sheetpile walls, € 0.10/m² for Omega sheetpile walls, € 0.08/m² for the Delta sheetpile wall.

The difference between the three options for recycled PVC is given in Figure 24.

Figure 24 - Impact of recycled PVC (€/kg PVC)



The fact that the differences are so small can be explained by the fact that the ECI of production is relatively close to one another for all options. Moreover, the ECI of recycled PVC comes mainly from waste processing (Modules C3 and D, see Figure 18) and not from the production process that we have examined.

4.5.2 Waste processing of PVC: 100% recycled

The previous sensitivity analysis showed that the effect of PVC production is limited because the ECI of recycled PVC is essentially related to waste processing. In the current scenario, we used 70% recycling, 20% WIP and 10% waste. In this analysis, we look at the effect of this scenario by calculating a hypothetical scenario with 100% recycling.

The analysis is given in Figure 25 for 100% recycling and Figure 26 for 100% WIP.

Figure 25 - Sensitivity analysis for waste scenario, 100% rather than 70% recycling (€/m² sheetpile wall, Modules A1 to D)

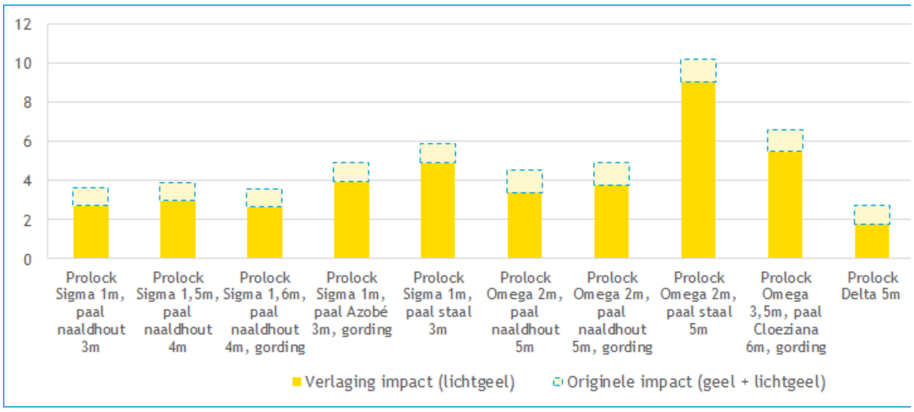
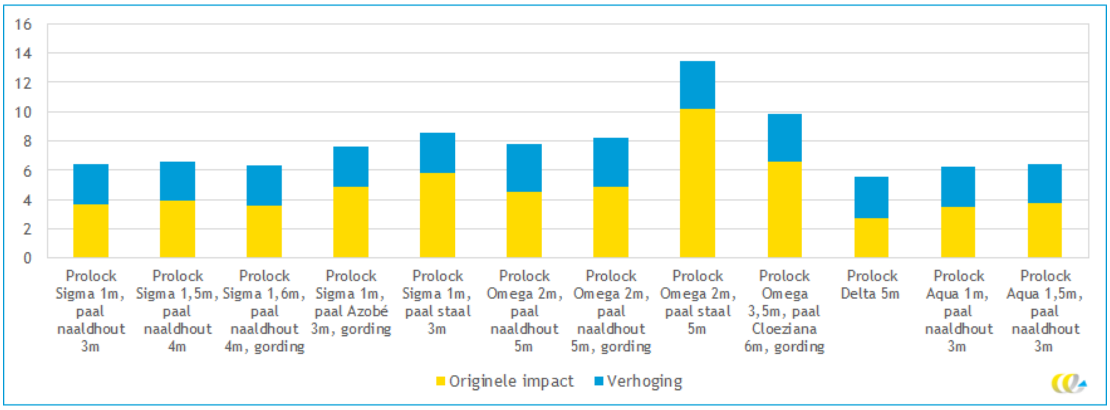


Figure 26 – Sensitivity analysis for waste scenario, 100% WIP rather than 70% recycling (€/m² sheetpile wall, Modules A1 to D)
A1 to D)



The effect in the waste scenario is huge. 100% recycling would mean a decrease from 11% (Prolock Omega recycled PVC, 2 m and steel pile, 5 m) to 35% (Prolock Delta recycled PVC, 5 m). This means a decrease of € 0.94/m² for Sigma sheetpile walls, € 1.13/m² for Omega sheetpile walls, € 0.98/m² for the Delta sheetpile wall and € 0.93/m² for Aqua sheetpile walls.

100% WIP is even more extreme and would mean an increase from 32% (Prolock Omega recycled PVC, 2 m, steel pile, 5 m) to 102% (Prolock Delta recycled PVC, 5 m). This means a decrease of € 2.72/m² for Sigma sheetpile walls, € 3.28/m² for Omega sheetpile walls, € 2.82/m² for the Delta sheetpile wall and € 2.69/m² for Aqua sheetpile walls.

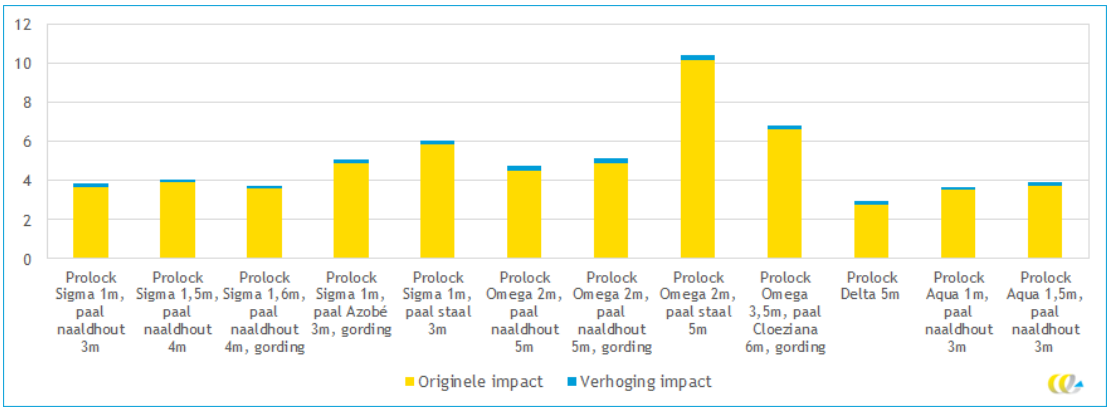
If therefore there is a guarantee that Profextru's sheetpile walls will be recycled, the impact can be lower. If, however, the sheetpile walls are not incinerated, their ECI can more than double.

4.5.3 Profextru's electricity: from the grid

For Profextru's electricity consumption, we have used 100% wind energy. This, however, only concerns production year 2021 and for the rest of the data we used the data from production year 2020. This is why we have analysed what the effect would be if we would use 'normal' electricity from the Dutch electricity grid for production at Profextru. We would then use the National Environmental Database process map for electricity: '0124-pro&1 kWh, from the socket (based on Electricity, low voltage {NL}| market for | Cut-off, U)'.

The analysis is given in Figure 27.

Figure 27 - Sensitivity analysis of source of electricity at Profextru, electricity from the grid rather than wind energy (€/m² sheetpile wall, Modules A1 through D)



The effect of grey electricity is relatively low and amounts to an increase of 2% (Prolock Omega recycled PVC, 2 m, steel pile, 5 m) to 6% (Prolock Delta recycled PVC, 5 m). This means an increase of € 0.18/m² for Sigma sheetpile walls, € 0.21/m² for Omega sheetpile walls, € 0.18/m² for the Delta sheetpile wall and € 0.17/m² for Aqua sheetpile walls.

Electricity consumption at Prolock is also relatively low with grey electricity with respect to the impact of material production and waste processing.

4.5.4 Installation and dismantling: 50% more and 50% less time required

The time required to install and dismantle is estimated by contractors and is therefore relatively uncertain. This is why we have analysed what the effect would be if this estimate would be 50% higher or lower.

The analyses are given in Figure 28 and Figure 29.

Figure 28 - Sensitivity analysis, 50% less time for installation and dismantling (€/m² sheetpile wall, Modules A1 through D)

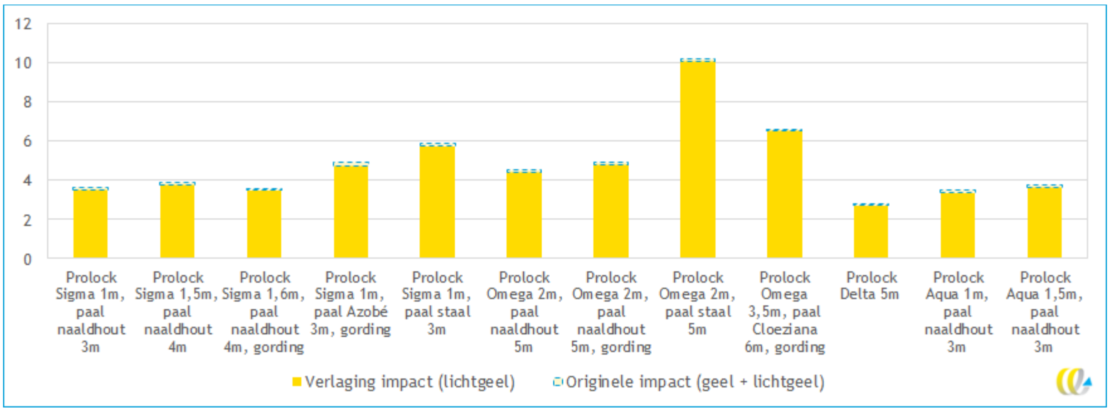
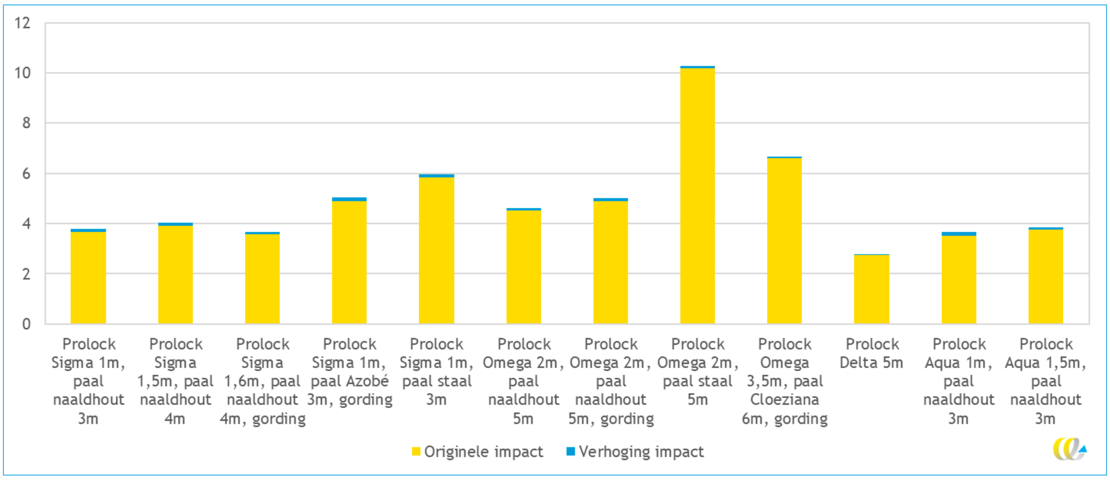


Figure 29 – Sensitivity analysis, 50% more time for installation and dismantling (€/m² sheetpile wall, Modules A1 through D)



The effect of 50% more or less time for installation and dismantling is small and amounts to an increase or decrease of 1% (Prolock Omega recycled PVC, 3.5 m, Cloeziana pile, 6 m, wale) to 4% (Prolock Aqua recycled PVC, 1 m, softwood pile, 3 m). This means an increase or decrease of € 0.06/m² to € 0.15/m².

The impact of installing and dismantling is relatively low with respect to the impact of material production and waste processing.

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