Bentofix®

Environmental Product Declaration

Declaration number:
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NAUE

Environmental Product Declaration (EPD)
Bentofix®

Declaration holder
NAUE GmbH & Co. KG
Gewerbestraße 2
D-32339 Espelkamp
Phone: +49 5743 41-0
info@naue.com
www.naue.com

Declared product:
NAUE Bentofix®, geosynthetic clay liner for sealing

Data calculation by
treeze Ltd.
Kanzleistrasse 4
CH-8610 Uster
www.treeze.ch

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1 General aspects
This Environmental Product Declaration (EPD) is commissioned by NAUE GmbH & Co. KG and accomplished by treeze Ltd. in 2020. The study has been conducted according to the requirements of the standard EN 15804:2012+A2:2019 (EN 15804, 2019) and IES product category rules (IES 2018). The investigated products are the NAUE geosynthetic clay liners Bentofix® intended for the use in many fields of civil engineering.

This EPD is a revision and extension of a work done in 2017 for the same kind of geosynthetics (NAUE 2017). In comparison to 2017, the data are evaluated based on new background inventory where available. Furthermore, in this revision also the “end-of-life stage” (C1 – C4) is evaluated.

2 Product

2.1 Description and application

The investigated products belong to the NAUE product family Bentofix® intended for the use in many fields of civil engineering. The raw material and energy demands are based on the annual production of Bentofix® and do not reflect a specific product but the product family. The classification number according to the UN CPC classification system is 36950.

Figure 1
Bentofix® geosynthetic clay liner (GCL), also known as geosynthetic clay barrier (GBR-C)

The Bentofix® product line is mainly used for applications such as waste and contaminated soil caps, landfill base liners, gas and vapour seals, surface impoundment liners, secondary containment, dams, canals, water courses, tailings containment, groundwater protection, sorptive barriers, vertical barriers and waterproofing.

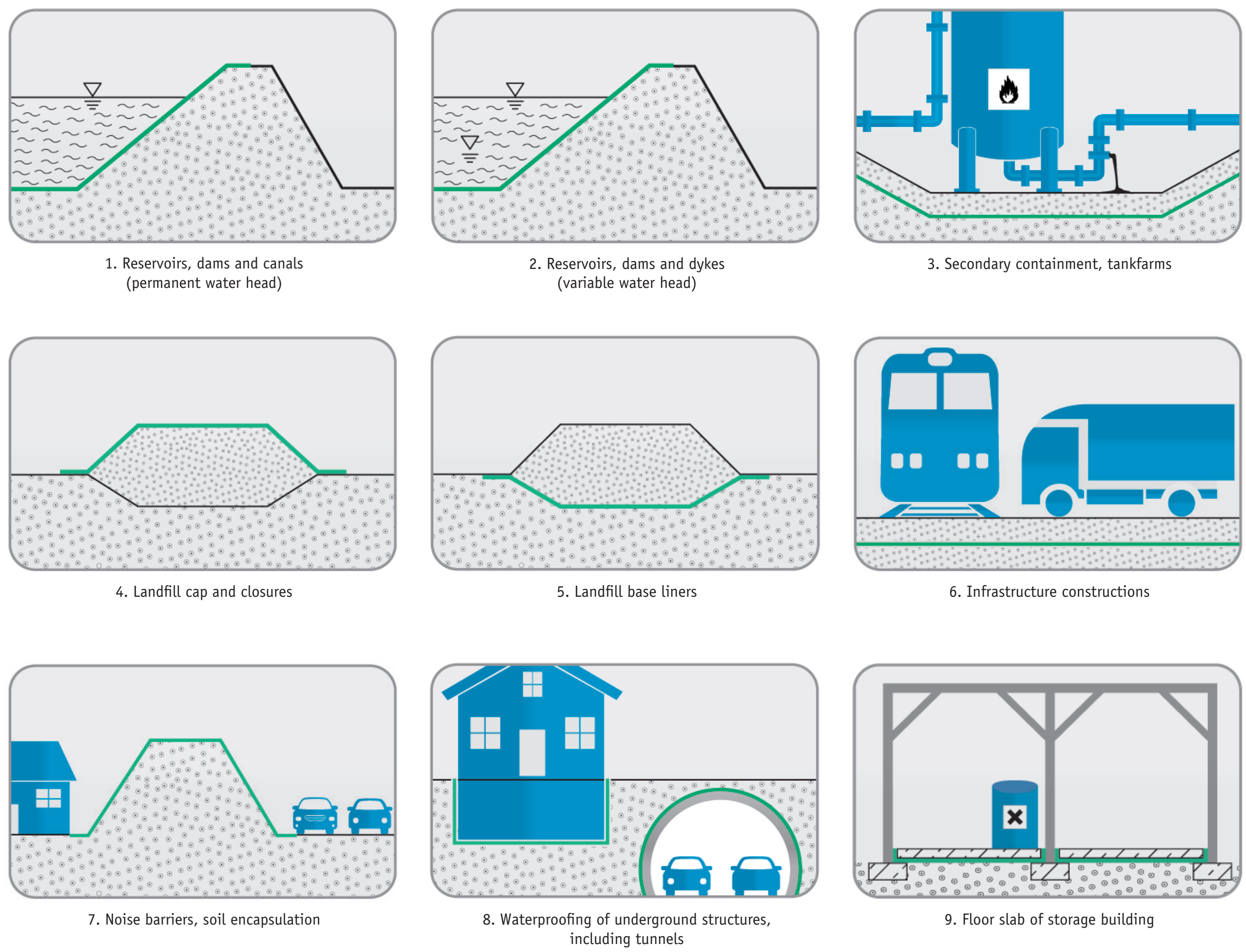

Figure 2
Typical Bentofix® applications

Product stage			Construction process stage		Use stage	End-of-life stage			
Raw material supply	Transport	Manufacturing	Downstream transport (to construction site)	Construction-Installation process	Use	Deconstruction, demolition	Transport	Waste processing	Disposal
A1	A2	A3	A4	A5	B1-B7	C1	C2	C3	C4
X	X	X	X	X	n.a.	X	X	X	X

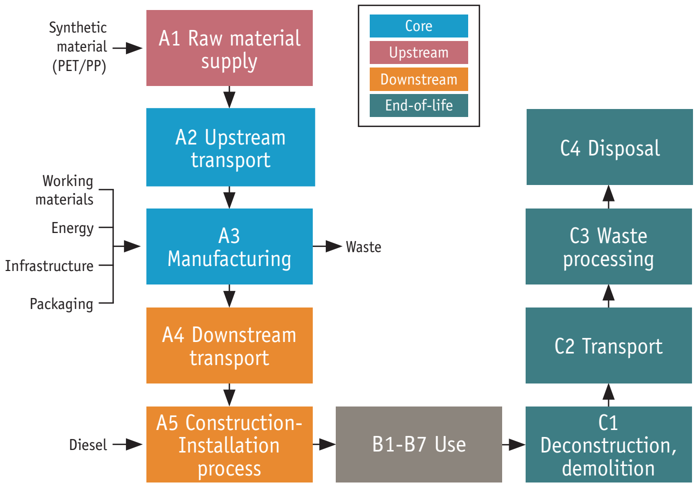

Figure 3
Graphical overview of the life cycle stages covered by the EPD of geosynthetics.

2.2 Raw material (A1)

The geosynthetic product Bentofix® is manufactured using polypropylene (PP) and bentonite as raw material. Occasionally, sand is used as an additional ballast material for underwater installation. The average geosynthetic clay liner for the Bentofix® product family consists of 89.8% bentonite, 7.4% PP, 1.6% HDPE and 1.1% sand. These shares describe the average production of the product family Bentofix® in the year 2019. More detailed information on the materials used is shown in Tab.1.

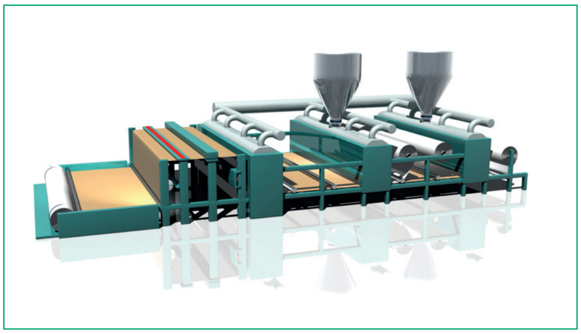

Figure 4
Bentofix® installation

2.3 Upstream transport (A2)

The transport to the manufacturer (A2) considers transports of raw materials to the NAUE manufacturing site. The raw materials are transported from the producer to the NAUE's production site by lorry. The average shipping distances for bentonite, sand and PP are 392km, 161km and 684km, respectively.

Specific material consumption	Specific material and energy use per m²	Unit	Bentofix®
Production volume and reference year	Annual production volume	tons	*
	Annual production volume	m²	*
	Reference year		2019
	Mass per unit area	g/m²	5'093
A1 Raw material	PP	g/m²	388.1
	Polyethylene (HDPE)	g/m²	86.6
	Sodium bentonite	g/m²	4'693.9
	Sand	g/m²	57.3
A2 Upstream transport	Lorry, 25 tons	tkm/m²	2.11E+00
A3 Manufacturing (working material and energy consumption)	**Working material**		
	Lubricating oil	kg/m²	1.99E-05
	Packaging		
	Paper case / cardboard	kg/m²	3.76E-03
	LLDPE (Packaging)	kg/m²	1.06E-02
	PVC	kg/m²	8.71E-02
	Steel core	kg/m²	8.07E-03
	Energy		
	Electricity	kWh/m²	1.61E-01
	Diesel	MJ/m²	2.15E-01
	Natural gas	MJ/m²	5.35E-01
	Waste		
	Municipal waste	kg/m²	9.66E-02
	Hazardous waste (machine oil)	kg/m²	2.98E-05
	PP to recycling	kg/m²	8.37E-03
	Bentonite to recycling	kg/m²	2.79E-02
	Land use		
	Total area	m²/m²	3.85E-04
	Factory halls	m²/m²	1.15E-04
	Office buildings	m²/m²	9.79E-06
	Other sealed areas	m²/m²	2.18E-04
	Share related to product	%	3%
A4 Downstream transport	Ship	tkm/m²	2.98E+01
	Lorry, 25 tons	tkm/m²	4.28E+00
A5 Construction and installation	Diesel consumption installation	MJ/m²	2.47E+00
C1 Deconstruction	Diesel consumption deconstruction	MJ/m²	1.01E+01
C2 End-of-life transport	Lorry, 25 tons	tkm/m²	1.08E-01
C4 Disposal	Municipal waste incineration, Talcum/Bentonite	kg/m²	4.63E-01
	Municipal waste incineration, PP	kg/m²	3.78E-02
	Municipal waste incineration, HDPE	kg/m²	8.44E-03
	Landfill, Talcum/Bentonite	kg/m²	4.17E+00
	Landfill, PP	kg/m²	3.40E-01
	Landfill, HDPE	kg/m²	7.59E-02

Table 1
Specific raw material, working material and energy consumption, wastes produced and infrastructure requirements per square meter of average clay liner of the product family Bentofix®.

* filed confidentially
** tkm/m² - ton-kilometer per m²

2.4 Manufacturing (A3)
Manufacturing includes energy and working materials consumption, a share of the infrastructure (factory halls and office buildings) as well as disposal of production wastes (scrap, lubricating oil, and municipal waste). The manufacturing site is in Germany. Therefore, the German consumption mix at low voltage level is used to model the electricity use in manufacturing. The consumption mix displays the electricity domestic net production including imports. No secondary plastics are used. The production wastes are reported to be about 0.7% relative to the material input.

Figure 5
Bentofix® loading

2.5 Downstream transport (A4)
Transportation from the manufacturer to the construction site, warehouse or the client's location is considered based on the current sales of NAUE. Shipping within Europe is done by lorry and to the rest of the world mainly by containers on freight ships. Containers are transported to port by lorry.

2.6 Construction and installation (A5)
The construction and installation stage considers the mounting of Bentofix®. Other processes such as excavation of foundation or ground compaction are outside the system boundary. The diesel consumption of mounting the geosynthetics amounts to 2.47MJ/m².

Figure 6
Bentofix® installation

2.7 Deconstruction (C1)
The deconstruction as part of the end-of-life processes (C1) covers the on-site dismantling of Bentofix®. The diesel consumption of dismantling the geosynthetics amounts to 10.1MJ/m².

2.8 Transport to product's waste processing (C2)
The end-of-life transport (C2) considers the transportation of the geosynthetics to a recycling site or disposal. On average, Bentofix® is transported 21km to the nearest waste incineration plant or landfill.

2.9 Waste processing (C3)
Bentofix® is directly disposed of. That is why no wasted processing is included in the assessment.

2.10 Disposal (C4)
The end-of-life disposal (C4) includes the emissions from waste disposal, physical pretreatment, and management of the disposal site. Bentofix® is disposed of 10% in municipal waste incineration plants and 90% in landfills.

3 LCA – Calculation rules
3.1 Declared unit
The declared unit is 1m² of clay liner of the product family Bentofix® with an average mass per unit area of 5.1kg/m².

3.2 System boundaries
This EPD is a cradle-to-grave declaration excluding the usage stage. The product system of geosynthetics comprises the product stage (manufacture and supply of raw materials including purchase and intercompany logistics, manufacture of the components and of the product), the construction stage (mounting of the product) and the end-of-life stage (deconstruction, end-of-life transport and disposal).

The comparison of products based on their EPD is defined by the contribution they make to the environmental performance of the building. Consequently, the comparison of the environmental performance of construction products using the EPD information shall be based on the product's use in and its impacts on the building and shall consider the complete life cycle (all information modules).

3.3 Allocation and recycling
Wastes that reach the end of waste state and that are recycled leave the product system without bearing a share of the environmental impacts of the first life cycle. No credits are given for potentially avoided production. Secondary raw materials bear environmental impacts caused by scrap collection and recycling activities. This is in line with the "polluter pays" principle (EN 15804, 2019; IES 2012).

Energy and working materials consumption as well as infrastructure requirements of Bentofix® manufacture are allocated according to the m² of the geosynthetics outputs.

3.4 Temporal and geographic validity
The life cycle assessment of Bentofix® describes the geosynthetics used worldwide. It is valid for the purchase, production, and distribution situation in the recent past (last two years). All product alternatives described in this report are currently available on the market.

3.5 Background data EN 15804

Foreground inventory data is mainly based on average annual production data provided by NAUE GmbH & Co. for the year 2019. The primary sources of background inventory data are the UVEK LCI data DQRv2:2018 (KBOB et al. 2018). These data are based on the ecoinvent data v2.2 (ecoinvent Centre 2010) and include updates of several background inventory data: electricity supply (Itten et al. 2014; Messmer & Frischknecht 2016a), natural gas supply (Schori et al. 2012), photovoltaics (Jungbluth et al. 2012; Frischknecht et al. 2015a), hydroelectric power generation (Flury & Frischknecht 2012), nuclear power and supply chain (Bauer et al. 2012), oil supply chain (Stolz & Frischknecht 2016a), wood products (Werner 2017), aluminium (Stolz & Frischknecht 2016b) and transportation (Stolz et al. 2016; Messmer & Frischknecht 2016b, c, d). The plastics inventory data of PET and PP refer to the years 1999/2000 and 1999, respectively and are based on data provided by PlasticsEurope (Boustead 2005-07).

The modelling and all calculations are performed with the LCA software SimaPro v9.1 (PRé Consultants 2020).

4 LCA – Results

LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. Impact category indicators required by the environmental product declaration standard were modelled as follows:

- Climate change – total: Global warming potential total (GWP-total), Baseline model of 100 years of the IPCC based on IPCC (2013).
- Ozone depletion: Depletion potential of the stratospheric ozone layer (ODP), steady state ODPs (WMO 2015).
- Acidification: Acidification potential, Accumulated exceedance (Seppälä et al. 2006, Posch et al. 2008).
- Eutrophication aquatic freshwater: Eutrophication potential, fraction of nutrients reaching freshwater end compartment (EP-freshwater), EUTREND model (Struijs et al. 2009).
- Eutrophication aquatic marine: Eutrophication potential, fraction of nutrients reaching marine end compartment (EP-marine): EUTREND model (Struijs et al. 2009).
- Eutrophication terrestrial: Eutrophication potential (EP-terrestrial), Accumulated exceedance (Seppälä et al. 2006, Posch et al. 2008).
- Photochemical ozone formation: Formation potential of tropospheric ozone (POCP), LOTOS-EUROS (Van Zelm et al. 2008).
- Depletion of abiotic resources – minerals and metals : Abiotic depletion potential for non-fossil resources (ADP-minerals & metals), CML 2002 (van Oers et al. 2002).
- Depletion of abiotic resources – fossil fuels1: Abiotic depletion potential for fossil resources (ADP-fossil), CML 2002 (van Oers et al. 2002).
- Water use1: Water (user) deprivation potential, deprivation weighted water consumption (WDP), Available WAter REmaining (AWARE, Boulay et al. 2017).
- Particulate Matter (PM) emissions: Potential incidence of disease due to PM emissions, SETAC-UNEP (Fantke et al. 2016).
- Ionising radiation, human health: Potential human exposure efficiency relative to U235 (IRP), human health effect model as developed by Dreicer (1995) update by Frischknecht (2000).
- Ecotoxicity (freshwater)1: Potential comparative toxic unit for ecosystems (ETP-fw), USEtox model (DG-JRC 2015).
- Human toxicity, cancer effects1: Potential comparative toxic unit for humans (HTP-c), USEtox model (DG-JRC 2015).
- Human toxicity, non-cancer effects1: Potential comparative toxic unit for humans (HTP-nc), USEtox model (DG-JRC 2015).
- Land use related impacts / soil quality1: Potential soil quality index (SQP), soil quality index based on LANCA.
- Use of renewable and non-renewable energy (cumulative energy demand, CED): reported in net calorific value, as demanded in the product declaration guidelines. For each the total and the two sub-categories “primary energy resources used as raw material” (feedstock) and “primary energy resources excluding use as raw material” are reported.
- The “CED, raw materials used” was assessed on product basis, i.e. the net calorific value of the materials contained in the geosynthetics.
- The “CED total, renewable” and “CED total, non-renewable” are calculated with the method published in ecoinvent version 2.0 and expanded by PRé Consultants for resources available in SimaPro 9 database (Frischknecht et al. 2007; Frischknecht et al. 2015b; PRé Consultants 2015).
- Use of secondary materials: based on the feedstock used in the production of the geosynthetics.
- Use of renewable secondary fuels and use of non-renewable secondary fuels. Electricity is assumed to contain no secondary fuels.
- Use of net fresh water: Evaporated water is considered with 100%; elementary flows in the background system are accounted for as follows: 10% of water extracted from water bodies and 10% of process water used (e.g. Water, lake; Water, process, drinking) and 5% of cooling water used (e.g. water, cooling, surface).
- Waste, life cycle based: “Hazardous waste” covers hazardous waste deposited in underground storage facilities and is accounted for via the elementary flow of volume occupied in an underground deposit. The density of hazardous waste for the conversion to kg is taken from the ecoinvent report 13-III (Doka 2009). “Radioactive waste” covers low radioactive waste and high and medium radioactive waste. It is assessed likewise via the elementary flows “volume occupied, final repository for radioactive waste” and “volume occupied, final repository, low-active waste”, respectively. The density of radioactive waste is taken from Dones (Dones 2007). Non-hazardous waste covers all waste going to landfills. The conversion of the land transformation elementary flows “transformation, to dumpsite” for slag compartment (22’500kg/m^2), inert material landfill (22’500kg/m^2), sanitary landfill (20’000kg/m^2) and residual material landfill (16’000kg/m^2) is conducted according to the average depth of the landfill sites and average waste densities given in Doka (2007).
- Materials for recycling: based on the materials wasted in production, i.e. PET and PP sold to the recycling company. The share of the waste for PP is 3.15% relative to the material input.
- Materials for energy recovery: weight of materials sent to municipal waste incineration plant, i.e. municipal waste.
- Long-term emissions are not included in the assessment because of implausible results of the indicator eutrophication.

[1] The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

[2] This impact category deals mainly with the eventual impact of low dose ionizing radiation on human health of the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities. Potential ionizing radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

4.1 Life cycle impact assessment results

Environmental Impact 1m² Bentofix® 5093g/m²	**Unit**	**A1 Raw material**	**A2 Upstream transport**	**A3 Manufacturing**	**A4 Downstream transport**	**A5 Construction and installation**	**C1 Deconstruction**	**C2 End-of-life transport**	**C4 Disposal**
Climate change - total	kg CO_2-eq.	3.37E+00	2.64E-01	5.19E-01	7.42E-01	2.53E-01	1.03E+00	1.35E-02	2.40E-01
Ozone depletion	kg CFC-11-eq	7.41E-07	1.39E-08	1.23E-08	3.45E-08	1.18E-08	4.80E-08	7.13E-10	6.76E-09
Acidification (AP)	kg H^+-eq	2.61E-02	1.15E-03	1.15E-03	9.32E-03	1.22E-03	4.98E-03	5.89E-05	3.67E-04
Eutrophication aquatic freshwater	kg PO_4^{3-}-eq	5.44E-04	4.04E-06	1.81E-05	1.14E-05	1.60E-06	6.52E-06	2.07E-07	1.03E-06
Eutrophication aquatic marine	kg N-eq	2.29E-03	2.72E-04	2.69E-04	2.28E-03	3.93E-04	1.60E-03	1.39E-05	1.06E-04
Eutrophication terrestrial	kg N-eq	2.70E-02	3.00E-03	2.93E-03	2.53E-02	4.32E-03	1.76E-02	1.54E-04	1.07E-03
Photochemical ozone formation	kg NMVOC-eq	1.06E-02	1.03E-03	1.31E-03	7.00E-03	1.28E-03	5.21E-03	5.28E-05	3.71E-04
Depletion of abiotic resources - minerals and metals	kg Sb-eq	9.91E-06	6.19E-07	3.55E-07	1.27E-06	6.43E-08	2.62E-07	3.17E-08	7.67E-08
Depletion of abiotic resources - fossil fuels	MJ oil-eq	8.50E+01	4.10E+00	8.59E+00	1.13E+01	3.45E+00	1.41E+01	2.10E-01	1.56E+00
Water use	m^3 world eq. deprived	3.35E+02	1.34E+01	2.59E+01	3.99E+01	5.49E+00	2.24E+01	6.89E-01	6.83E+00
Particulate matter emissions	disease incidence	2.11E-07	1.94E-08	9.63E-09	4.54E-08	6.26E-09	2.55E-08	9.94E-10	4.03E-09
Ionising radiation, human health	kBq U235-eq	1.97E-01	6.71E-03	1.26E-02	2.20E-02	2.61E-03	1.06E-02	3.44E-04	3.06E-03
Ecotoxicity (freshwater)	CTUe	3.69E+01	3.00E+00	3.63E+00	7.86E+00	2.08E+00	8.47E+00	1.54E-01	9.56E-01
Human toxicity, cancer effects	CTUh	1.32E-09	8.17E-11	2.65E-10	2.25E-10	1.38E-10	5.64E-10	4.18E-12	4.11E-11
Human toxicity, non-cancer effects	CTUh	1.54E-07	4.58E-09	6.42E-09	1.06E-08	3.03E-09	1.24E-08	2.34E-10	1.28E-09
Land use related impacts / soil quality	-	6.12E+01	7.81E-01	1.10E+00	1.99E+00	3.77E-01	1.54E+00	4.00E-02	2.82E+00

Table 2
Environmental impact caused by the production of 1 square meter of average clay liner of the product family Bentofix®.

Energy demand 1m² Bentofix® 5093g/m²	**Unit**	**A1 Raw material**	**A2 Upstream transport**	**A3 Manufacturing**	**A4 Downstream transport**	**A5 Construction and installation**	**C1 Deconstruction**	**C2 End-of-life transport**	**C4 Disposal**
CED, non-renewable, total	MJ oil-eq	8.50E+01	4.09E+00	8.56E+00	1.12E+01	3.45E+00	1.41E+01	2.09E-01	1.56E+00
CED, non-ren., w/o raw mat. use	MJ oil-eq	7.24E+01	4.09E+00	6.37E+00	1.12E+01	3.45E+00	1.41E+01	2.09E-01	1.56E+00
CED, non-ren., raw mat. use	MJ oil-eq	1.26E+01	0.00E+00	2.20E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CED, renewable, total	MJ oil-eq	2.43E+00	6.75E-02	4.19E-01	2.07E-01	2.60E-02	1.06E-01	3.46E-03	3.15E-02
CED, renew., w/o raw material use	MJ oil-eq	2.43E+00	6.75E-02	4.19E-01	2.07E-01	2.60E-02	1.06E-01	3.46E-03	3.15E-02
CED, renew., raw material use	MJ oil-eq	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable secondary fuels	MJ oil-eq	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of non-renewable secondary fuels	MJ oil-eq	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of electricity	MJ	0.00E+00	0.00E+00	5.79E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 3
Cumulative energy demand and energy use caused by the production of 1 square meter of average clay liner of the product family Bentofix®.

Material use 1m² Bentofix® 5093g/m²	**Unit**	**A1 Raw material**	**A2 Upstream transport**	**A3 Manufacturing**	**A4 Downstream transport**	**A5 Construction and installation**	**C1 Deconstruction**	**C2 End-of-life transport**	**C4 Disposal**
Use of net fresh water	m^3	1.64E-02	1.80E-04	2.64E-03	5.06E-04	8.11E-05	3.31E-04	9.21E-06	1.76E-04
Hazardous waste	kg	5.32E-02	5.01E-06	6.89E-06	1.14E-05	1.54E-06	6.28E-06	2.57E-07	1.00E-06
Non-hazardous waste	kg	6.34E-01	3.15E-02	4.18E-02	6.60E-02	4.01E-03	1.63E-02	1.62E-03	5.13E+00
Radioactive waste	kg	1.64E-04	4.70E-06	1.40E-05	1.58E-05	1.94E-06	7.91E-06	2.41E-07	2.10E-06
Use of material	kg	5.23E+00	0.00E+00	1.18E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of secondary material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable secondary material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for recycling	kg	0.00E+00	0.00E+00	3.63E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for energy recovery	kg	0.00E+00	0.00E+00	9.66E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 4
Material use and waste flows caused by the production of 1 square meter of the average Bentofix®.

4.2 Relative contribution of life cycle stages

Fig. 7 shows the relative contribution of the different life cycle stages (A1 – A5) to the total impact of the product and construction process stage A of Bentofix® geosynthetic clay liners. The contribution is shown for the ten core indicators: Climate change – total, ozone depletion, acidification (AP), eutrophication aquatic freshwater, eutrophication aquatic marine, eutrophication terrestrial, photochemical ozone formation, depletion of abiotic resources – minerals and metals, depletion of abiotic resources – fossil fuels. According to the EPD of 2017 (NAUE 2017) and for comparison purposes, the end-of-life stage C is not included in Fig. 7.

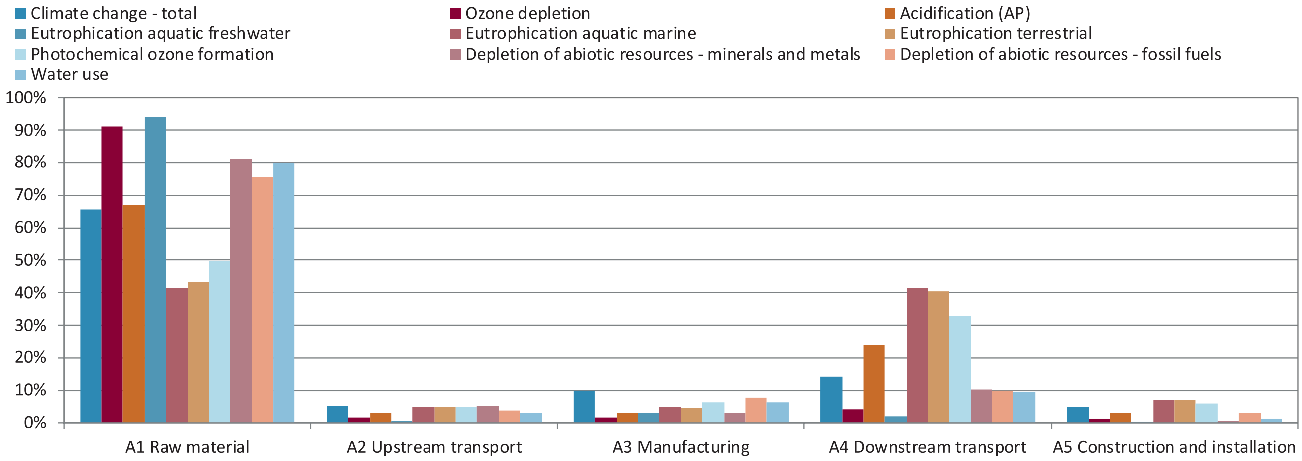

Figure 7
Relative contribution of the different life cycle stages (A1 – A5) to the total impact of the product and construction process stage A of Bentofix®.

4.3 Data quality

The quality of the data used to model geosynthetics produced by NAUE GmbH & Co. KG is high regarding the material composition, the transport logistics and the manufacture of components. Data are provided by NAUE GmbH & Co. KG and are reliable and detailed. The manufacturer's data are less than three years old and based on annual averages. The data representing the end-of-life stage are mainly based on assumptions and thus the data quality is considered to be low. The material supply of plastics is represented by best available data provided by the European Plastics association PlasticsEurope.

The UVEK LCI data DQRv2:2018 (KBOB et al. 2018) are used as background inventory data to complement the product system of geosynthetics. The UVEK LCI data DQRv2:2018 are based on the ecoinvent data v2.2 (ecoinvent Centre 2010) and contain inventory data of many basic materials and services. The database includes the most recent datasets of plastic feedstock. Most of the important background data are less than 10 years old.

Additional data quality considerations are documented within the KBOB LCI and ecoinvent database. A Monte Carlo analysis to assess uncertainties was not conducted. The overall background data quality is appropriate for the use in this LCA.

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NAUE GmbH & Co. KG
Gewerbestr. 2
32339 Espelkamp
Germany

Phone +49 5743 41-0
Fax +49 5743 41-240
info@naue.com
www.naue.com