Life Cycle Assessment Of Inpipe Liner and Inpipe Freeliner

Title: Life Cycle Assessment of Inpipe Liner and Inpipe Freeliner
Date: 04/12/2023
Ordered by: Inpipe Sweden AB
Report number: 1043
Name and location of database: SimaPro@192.168.15.21\Default\MiljogiraffEmber; 1043 LCA + EPD Inpipe
LCA practitioner: Marcus Wendin and Karin Lagercrantz, Miljögiraff AB

Miljögiraff

Table of Contents

1 Introduction 6
1.1 Reading guide 6
1.2 General description of the product and its context 6
2 Life Cycle Assessment (LCA) 8
2.1 LCA Methodology background 8
2.2 Environmental product declaration 9
2.2.1 General Program Instructions (GPI) 10
2.2.2 Product Category Rules (PCR) 10
3 Goal and Scope 11
3.1 The aim of the study 11
3.2 Standards and frameworks 11
3.3 Scope of the Study 11
3.3.1 Declared unit 11
3.3.2 System Boundary 11
3.3.3 Cut-off criteria 12
3.3.4 Allocation procedure 13
3.3.5 Method of Life Cycle Impact Assessment (LCIA) 14
3.3.6 Other mandatory indicators to declare 15
3.3.7 Data requirements (DQR) 16
3.3.8 Type of critical review, if any 17
4 Life Cycle Inventory (LCI) 18
4.1 LCA Software 18
4.2 LCA database for generic data 18
4.3 Data collection 18
4.3.1 Supplier input data references 18
4.4 General modelling choices 19
4.5 Product content declaration 19
4.6 Raw materials (A1 + A2) 21
4.6.1 Polyester resin 22
4.6.2 Packaging from suppliers 22
4.7 Manufacturing (A3) 22
4.7.1 Energy 23
4.7.2 Direct emissions 23
4.7.3 Consumables 23
4.7.4 Packaging 23
4.7.5 Production waste 24
4.8 Transport of finished goods (A4) 25
4.9 Installation (A5) 25
4.9.1 Energy at installation 25
4.9.2 Waste treatment of packaging and installation waste 25
4.10 End-of-Life (C1-C4) 26
4.10.1 Dismantling or deconstruction (C1) 26
4.10.2 Transport to waste management (C2) 26
4.10.3 Waste treatment (C3) and final disposal (C4) 27
4.11 Benefits and loads from material recycling or energy recovery (D module) 27
4.12 Balancing of biogenic carbon dioxide 29
5 Result of Life cycle impact assessment (LCIA) 30

5.1 Environmental Footprint Midpoint 31
5.2 Environmental Footprint – Single score....34
5.3 Climate impact (EN15804) 38
5.4 Climate impact (GWP-GHG) 41
5.5 Use of resources and energy CED 1.11 43
5.6 Waste production and output flows 44
5.7 Biogenic carbon content....47

6 Interpretation 48

6.1 Key aspects of results 48
6.2 Sensitivity analysis....48
6.3 Data quality assessment 49
6.3.1 Uncertainty analysis....51
6.4 Limitations....52

7 Conclusions and recommendations 52

7.1 Recommendation on how to mitigate the hot spots....53
7.2 How to reduce uncertainties....53
7.3 Internal follow-up procedures 54

8 Bibliography 55

Appendix 1 Basics of Life Cycle Assessment 56
A. Goal and scope definition....56
i. System boundary 56
ii. Cut-off....58
iii. Allocation....58
iv. Data requirements (DQR) 58
B. Inventory analysis (LCI)....59
C. Impact assessment (LCIA) 59
i. Classification and characterisation 59
ii. Weighting.... 60
D. Interpretation.... 60
i. Evaluation of the results 60
Appendix 2 Environmental footprint 3.0 61
i. LCA impact categories vs planetary boundaries 63
Appendix 3 Cumulative Energy Demand, CED 65
Appendix 4 Guarantees of Origin 66
Appendix 5 Differences in inventory data and LCIA results for different liner dimensions....67

Ordered by: Inpipe Sweden AB
Inpipe offers innovative, strong, flexible, and environmentally friendly methods to repair laid pipes without excavation – so-called no-dig repair.
The company's market-adapted products contribute to a better environment and cost-saving solutions for line owners. At Inpipe, we work with our installation customers throughout the installation process – from the initial planning to on-site support and completion of the project. Today, we are the Nordic region's largest manufacturer of fiberglass-reinforced linings and installation equipment, with 35 years of experience. Our pipes have been installed around the world and yielded thousands of successful projects.

Issued by: Miljögiraff AB
Miljögiraff is an environmental consultant specialising in product Life Cycle Assessment and Life Cycle Design. We believe that combining analysis and creativity is necessary to meet today's challenges. Therefore, we provide Life Cycle Assessment to evaluate environmental aspects and design methods to develop sustainable solutions.

We create measurability in environmental work based on a life cycle perspective on ecological aspects. The LCA methodology establishes the basis for modelling complex systems of aspects with a credible assessment of potential environmental effects.

Miljögiraff is part of a global network of experts in sustainability metrics piloted by PRé Sustainability.

Abbreviations and expressions

Clarification of expressions and abbreviations used in the report

CO_2 eq – Carbon dioxide equivalents
EPD – Environmental Product Declaration
EoL – End of life (product End of life)
GWP – Global Warming Potential
ISO – International Organization for Standardisation
IPCC – Intergovernmental Panel on Climate Change
LCA – Life Cycle Assessment
LCI – Life Cycle Inventory Analysis
LCIA – Life Cycle Impact Assessment
PCR - Product Category Rules
RER – The European region
RoW – Rest of the world
GLO – Global
Cut-off in ecoinvent – Allocation cut off by classification (system model in ecoinvent)
Cut-off in general – Environmental impact that contributes insignificantly to the overall results.

Environmental aspect - An activity that might contribute to an environmental effect, for example, "electricity usage".

Environmental effect - An outcome that might influence the environment negatively (Environmental impact), for example, "Acidification", "Eutrophication", or "Climate change".

Environmental impact - The damage to a safeguarding object (i.e., human health, ecosystems, health, and natural resources).

Life Cycle Inventory (LCI) data – Inventory of input and output flows for a product system

1 Introduction

This report presents the results for the environmental impacts calculated for two types of liners produced by Inpipe – Inpipe Liner and Inpipe Freeliner.

The assessment is carried out according to a life cycle perspective using the ISO 14040 standard. Life cycle assessment (LCA) is a standardized method to quantify the potential environmental impact of a product or service from a holistic perspective. With its holistic perspective, LCA avoids the so-called burden-shifting from one part of the lifecycle to another or across impact categories. LCA results provide an understanding of a product's life cycle burdens and hotspots and allow for identifying opportunities to mitigate adverse effects.

1.1 Reading guide

Readers can select sections of the report depending on their time availability:

- 5 minutes
    - Section 7 gives the briefest summary of the most relevant conclusions and recommendations.
- 10 minutes
    - Section 7 and section 6 give the reader some more nuance and depth as it includes interpretation and sensitivity analysis that underpins the conclusions.
- 20 minutes
    - Section 7, section 6 and section 5 present detailed results through flowcharts or diagrams for the different impact categories that support the conclusion and recommendations.
- >30 minutes
    - For in-depth detail and transparent documentation on the modelling of each part of the life cycle, see section 4 ("Life Cycle Inventory")
    - For information about methodology, scope and functional unit, see sections 2 ("Life Cycle Assessment") and section 3 ("Goal and Scope")

1.2 General description of the product and its context

The products "Liner" and "Freeliner" are two glass fibre armed liners that are used for no-dig repair of pipes. They are made of different polyester resins. Liner uses a polyester without bisphenol, and Freeliner uses a polyester without bisphenol and styren. The liners are produced in Inpipes facilities in Vilhelmina and delivered to the customer in a wooden box and are hardened by the customer at the production site, using UV light.

Liner and Freeliner comes in different dimension. Freeliner vary from diameters 150mm to 500mm, and liner vary from diameters 150mm to 1800mm. This Life Cycle Assessment is regarding the environmental impact per kg liner for two of the most common liner dimensions, 225mm and 1100mm. Results are also calculated for 150mm and 1800mm to be able to cover the whole range in one EPD – these results are presented in Appendix 5. The difference per kg liner for the different dimensions lies in a slightly lower share of plastic film in the larger and heavier liners. Table 1 shows the different dimensions and SN classes available for Liner and Freeliner.

Table 1: Liner dimensions and weights, Liner and Freeliner

Dim. Ø (mm)	Weight / meter [kg/m] SN class 1	SN class 2	SN class 3	SN class 4	SN class 5
150					3.00
200			3.80	4.20	4.20
225			4.30	5.10	5.10
230			5.00	5.30	5.30
250	5.00	5.40	5.40	6.10	6.40
300	5.70	7.00	7.80	8.50	9.00
350	8.00	9.40	10.40	11.50	12.00
375	8.50	10.50	11.50	13.00	14.40
400	10.00	11.70	13.00	14.30	15.50
450	13.10	14.60	16.00	17.40	18.70
500	14.60	17.50	20.00	21.60	23.00
550	18.20	21.30	23.80	25.90	27.10
600	20.70	25.00	27.80	30.20	32.00
700	28.50	33.00	37.00	39.30	41.90
750	31.70	34.60	44.60	47.00	49.90
800	35.60	41.80	47.30	50.00	
900	45.70	50.80	56.80		
1000	51.40	61.50			
1100	69.60				
1200	80.4				
1300	88.5				
1400	99.6				
1500	102.2				
1600	112.7				
1700	118.5				
1800	132				

2 Life Cycle Assessment (LCA)

2.1 LCA Methodology background

Understanding the potential environmental impact in connection with the manufacture and use of products is increasingly important. LCA is an accepted standardized method that is applied to create this understanding. Being a quantitative tool, LCA can contribute to more sustainable development by identification of hotspots and by guiding actionable measures to reduce environmental impacts. A business can use the results of an LCA to develop strategy, management and communication of environmental issues related to products. By including environmentally relevant input and output flows through a product's entire supply chain, from raw material extraction to final disposal, LCA provides a comprehensive basis for the environmental impact of a product's supply chain (see Figure 3).

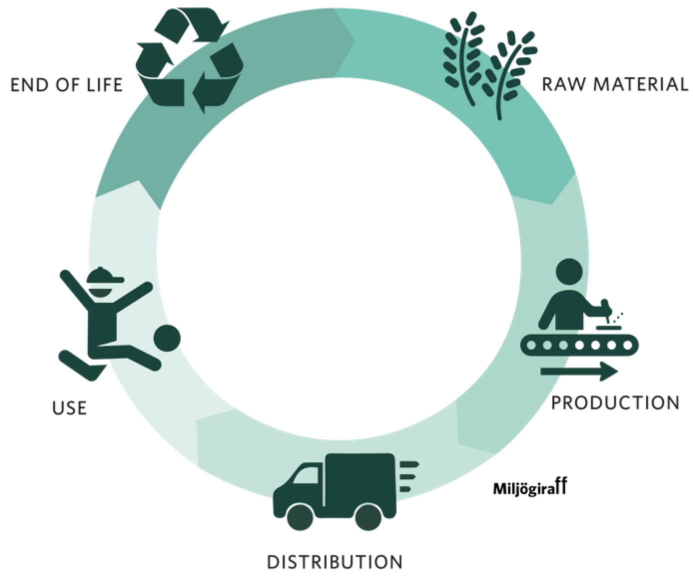


Figure 1: The Life Cycle concept, starting from raw material extraction, production, and distribution, followed by use and end-of-life.

Products' supply chains are complex and involve numerous connections. Therefore, in order to analyse a product's entire life cycle, LCA practitioners must simplify it into a model which involves limitations, as those as summarised by Guinée et al. (2002):

- Localised aspects are typically not addressed, and LCA is not a local risk assessment tool
- LCA is typically a steady-state approach rather than a dynamic approach
- LCA does not include market mechanisms or secondary effects on technological development
- Processes are considered linear, both in the economy and the environment, meaning that impact increases linearly with increased production.
- LCA involves several technical assumptions and value choices that are not purely science-based
- LCA focuses on environmental aspects and excludes social, economic, and other characteristics

The study presented in this report is a result of Miljögiraff's work which combines the confidence and objectiveness of the strong and accepted ISO standard with the scientific and reliable LCI data from ecoinvent and with the world-leading LCA software SimaPro for calculation and modelling (see Figure 2.)

Figure 2: ISO standard combined with reliable data from ecoinvent and the LCA software SimaPro.

Already in 1997, the European Committee for Standardisation published their first set of international guidelines for the performance of LCA. This ISO 14040 standard series has become widely accepted amongst the practitioners of LCA and is continuously being developed along with progressions within the field of LCA (Rebitzer et al., 2004). The guidelines for LCA are described in two documents; ISO 14040, which contains the main principles and structure for performing an LCA, and ISO 14044, which includes detailed requirements and recommendations. Furthermore, a document containing the format for data documentation (ISO/TS 14048) and technical reports with guidelines for the different stages of an LCA are available in ISO/TR 14047 and ISO/TR 14049 (ISO, 2012b, 2012a).

The environmental management method Life Cycle Assessment (LCA) is used in this study. The LCA has been performed according to the ISO 14040 series standards.
ISO 14040: 2006 – Principles and framework (ISO, 2006b)
ISO 14044: 2006 – Requirements and guidelines (ISO, 2006c)

2.2 Environmental product declaration

An Environmental Product Declaration (EPD) is defined by the International Organization for Standardization, ISO standard 14025 (ISO, 2006a) as a Type III declaration that "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function."

EPDs are primarily intended to facilitate business-to-business communication, although they may also benefit consumers who are environmentally focused when choosing goods or services. See Figure 3.

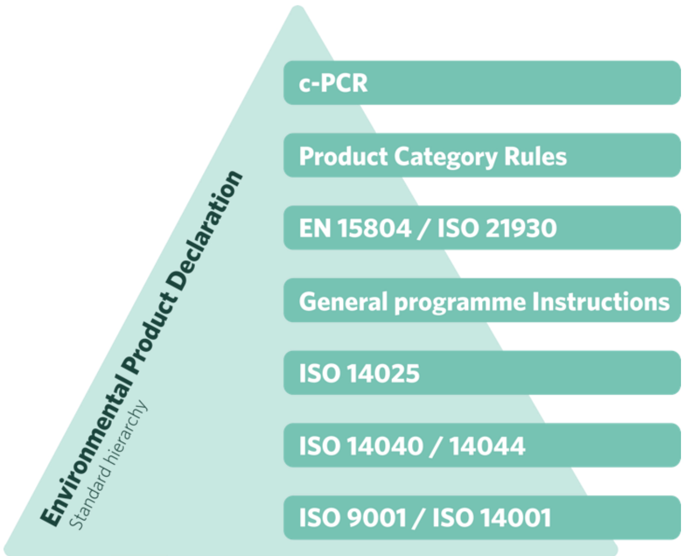


Figure 3 shows the hierarchy of standards used to create and EPD according to the International EPD system.

2.2.1 General Program Instructions (GPI)

General Program Instructions (GPI) of the International EPD® System form the basis of the overall administration and operation of a programme for Type III environmental declarations according to ISO 14025.

2.2.2 Product Category Rules (PCR)

Product Category Rules (PCRs) provide guidance that enables fair comparison among products of the same category. PCRs include the description of the product category, the goal of the LCA, functional units, system boundaries, cut-off criteria, allocation rules, impact categories, information on the use phase, units, calculation procedures, requirements for data quality, and other information. PCRs aim to help develop EPDs for products comparable to others within a product category. ISO 14025 establishes the procedure for creating PCRs and the required content of a PCR, as well as requirements for comparability.

3 Goal and Scope

3.1 The aim of the study

The study's goal is to find metrics for the environmental impact of Inpipe Liner and Inpipe Freeliner from a life cycle perspective. The study will be used for internal learning and external environmental communication (B2B) in the form of an Environmental Product Declaration (EPD).

3.2 Standards and frameworks

This is an attributional LCA approach (accounting) defined in the ISO 14040 standard.
The standards and frameworks guiding this LCA are presented in Table 2.

Table 2: Standards and framework conformance.

Standards conformance
ISO 14040 and 14044 (ISO, 2006b, 2006c)
General program instructions for the International EPD System, version 4.0 (EPD International, 2021)
PCR 2019:14 version 1.2.5 (EPD International, 2022)
EN 15804:2012+A2:2019 (CEN, 2019a)

3.3 Scope of the Study

In this section, the scope of the LCA is specified.

3.3.1 Declared unit

The functional/declared unit is the basis that enables alternative goods, or services, to be compared and analysed. The primary purpose of a functional unit is to provide a reference to which the result and the input and output data are normalised and can, therefore be compared.

For this study, a declared unit of 1 kg liner was used.
The geographical market is Global.

3.3.2 System Boundary

The system boundary determines which modules and activities are included within the LCA. The system boundary for the study is defined as (b) cradle-to-gate with options (A1-A3 + C + D and additional modules A4 and A5). All processes needed for raw material extraction, manufacturing, transport and end-of-life are included in the study. The use phase is excluded from the study.

Figure 4 shows an overview of the life cycle. The dotted lines (inside the system boundary) indicate aspects that have been included. The PCR for Construction Products also requires calculating benefits and loads outside the system boundary (module D). However, as it is outside the system boundary, it is reported separately and shall not be summed up with the rest of the results. A more detailed representation of the system's limitations is presented in Figure 5.

Environmental impacts from infrastructure, construction, personnel-related processes, production equipment, and tools not directly consumed in the production process are excluded, per the PCR for Construction Products.

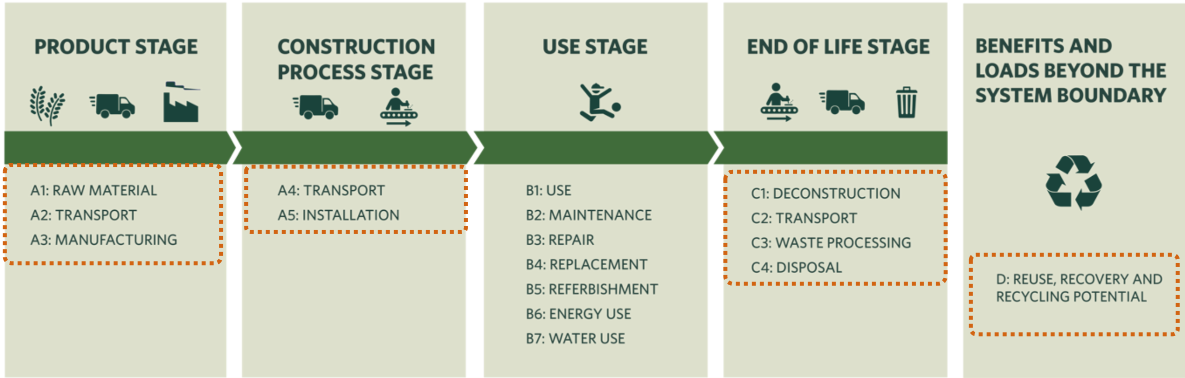


Figure 4: System boundaries of the study

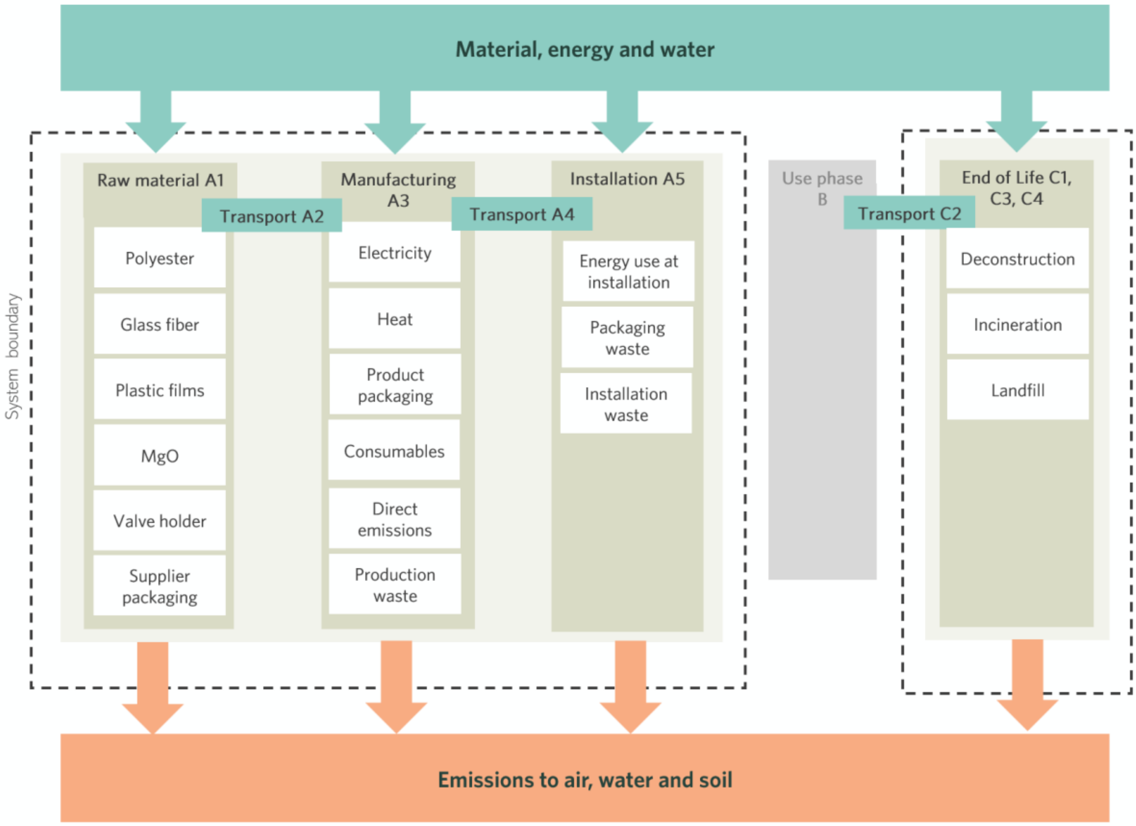


Figure 5: Model of the studied product system

3.3.3 Cut-off criteria

Life cycle assessment aims to include all relevant environmental flows related to a product's entire supply chain. Quantifying these impacts is done through a model, and simplification must be introduced, as it is impossible to obtain data and model every flow in practice. To maintain the comparability between products, a set of rules is applied. This study uses the following cut-off criteria:

Mass relevance
Applied if the mass flow was less than 1% of the cumulative mass of all the inputs and outputs of the LCI model.

Energy relevance

Applied if the energy flow was less than 1% of the cumulative energy of all the inputs and outputs of the LCI model.

Environmental relevance
If the flow met the above criteria for exclusion yet was thought to have a potentially significant environmental impact. The environmental relevance was evaluated with experience and relevant external research on similar products. If an excluded material significantly contributed to the overall LCIA, more information was collected and assessed in the system.

The sum of the neglected material flows did not exceed 5% of mass or 1% of energy.

An overview of processes that are excluded in this study is presented in Table 3.

Table 3: Overview of aspects that are excluded.

Excluded processes	Reason
Transport of manufacturing consumables (fosfor and aceton)	The amount of manufacturing consumables is less than 0.2 % of the total inputs, thus the transportation of these is well below the cut-off limit
Waste treatment of production waste of fosfor and aceton	The amount of manufacturing consumables is less than 0.2 % of the total inputs, thus their waste treatment is well below the cut-off limit
Transport of wooden box	The amount of wooden box is less than 2 % of the total inputs, thus its transportation is well below the cut-off limit

3.3.4 Allocation procedure

If a process creates several products and/or by-products, an allocation of inputs and outputs of that process is needed.

Allocation is described in ISO 14044 (ISO, 2006c). ISO 14044 recommends avoiding allocation whenever possible by division into subprocesses or expanding the product system. Where allocation cannot be avoided, it is recommended to base the allocation on the physical relationship between products. This can be physical characteristics that are representative for the quality of the function provided. Where the physical relationship between products is not suitable as the basis for allocation, other relationships between them can be used. Commonly the economic value is such relationship that can be used for allocating inputs and outputs of a process to its products.

In this LCA allocation in specific data was done for the use of energy, raw material spillage, product packaging and process consumables as well as the outputs of waste and emissions for Inpipe´s own manufacturing (A3). These inputs and outputs for 2022 were allocated per kg produced pipe during 2022. As Inpipe only produces pipes, this allocation is assumed to be a fair representation of the real inputs and outputs per kg pipe.

Allocation of waste uses the cut-off approach following the EPD guidelines (EPD International, 2021). In this approach, waste is the responsibility of the producer ("polluter pays") and recycleable materials are environmentally burden-free for those who uses it as a raw material.

3.3.5 Method of Life Cycle Impact Assessment (LCIA)

The LCIA method follow the standard for Construction Products EN15804:2012+A2:2019[1] (CEN, 2019b).

The methods are summarised in Table 4 and Table 5. For further details on the LCIA method and impact categories, see Appendix 2 - Appendix 3.

Table 4: Impact categories, indicators and methods used in the study. The chosen indicators follow the standard for Construction products EN 15804:2012+A2:2019.

Impact category	Abbreviation	Category indicator	Method
Climate Change-total	GWP total	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2013 (including biogenic uptake)
Climate Change-fossil	GWP fossil	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2013 (including biogenic uptake)
Climate Change-biogenic	GWP biogenic	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2013 (including biogenic uptake)
Climate Change-land use and land use change	GWP luluc	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2013 (including biogenic uptake)
Indicator for climate impact GWP-GHG	GWP-GHG	kg CO_2 equivalents	GWP total, excluding biogenic carbon dioxide emissions and uptakes
Ozone-depleting gases	ODP20	CFC 11-equivalents	Steady-state ODPs, WMO 2014
Acidification potential (fate not included)')	AP	mol H+ eq	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Eutrophication aquatic freshwater	EP-freshwater	kg P equivalents	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication aquatic marine	EP-marine	kg N equivalents	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication aquatic terrestrial	EP-terrestrial	mol N equivalents	Accumulated Exceedance, Seppälä et al. 2006, Posch et al.
Photochemical ozone creation potential	POCP	kg NMVOC eq.	LOTOS-EUROS, Van Zelm et al., 2008, as applied in ReCiPe

[1] In this LCIA method, removals of biogenic CO2 into biomass (with the exclusion of biomass of native forests) and transfers from previous product systems are characterised as –1 kg CO2 eq./kg CO2 when entering the product system. Emissions of biogenic CO2 from biomass and transfers of biomass into subsequent product systems (with the exclusion of biomass of native forests) are characterised as +1 kg CO2 eq./kg CO2 of biogenic carbon.

In addition to the climate impact indicator required in EN15804:2012+A2:2019, the PCR for Construction Products requires reporting of climate impact with the characterization factor for biogenic carbon dioxide set to zero (GWP-GHG). This is calculated with an adjusted version of the EN15804:2012+A2:2019 LCIA method, where the characterization factors related to biogenic carbon dioxide has been set to 0.

Abiotic resource depletion, minerals and metals	ADPe	kg Sb eq	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Abiotic resource depletion, fossil fuels	ADPf	MJ	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Water Depletion	WD	m3 world eq. deprived	Available WAter REmaining (AWARE) Boulay et al., 2018

Table 5: Additional environmental impact indicators and methods used in the study as described in EN 15804:2012+A2:2019.

Impact category	Indicator	Unit	Method
Particulate Matter emissions	Potential incidence of disease due to PM emissions (PM)	Disease incidence	SETAC-UNEP, Fantke et al. 2016
Ionising radiation, human health	Potential Human exposure efficiency relative to U235 (IRP)	kBq U235 eq.	Human health effect model as developed by Dreicer et al. 1995 and updated by Frischknecht et al., 2000
Eco-toxicity (freshwater)	Potential Comparative Toxic Unit for ecosystems (ETP-fw)	CTUe	USEtox 2.1. model (Rosenbaum et al, 2008)
Human toxicity, cancer effects	Potential Comparative Toxic Unit for humans (HTP-c)	CTUh	USEtox 2.1. model (Rosenbaum et al, 2008)
Human toxicity, noncancer effects	Potential Comparative Toxic Unit for humans (HTP-nc)	CTUh	USEtox 2.1. model (Rosenbaum et al, 2008)
Land-use-related impacts/Soil quality	Potential soil quality index (SQP)	dimensionless	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)

3.3.6 Other mandatory indicators to declare

Additional mandatory indicators to declare, according to the EPD Guidelines (EPD International, 2021) are presented in Table 6 - Table 8.

Table 6: Information on biogenic content.

Biogenic carbon content (1 kg = 44/12 kg CO2[2])	**Unit per FU or DC**
Biogenic carbon content in the product	Kg C
Biogenic carbon content in the accompanying packaging	Kg C

[2] Molar mass carbon dioxide (44g/mol) divided by molar mass of carbon (12g/mol)

Table 7: Resource use to be declared in the study.

Resource	Unit
Use of renewable primary energy excluding primary energy resources used as raw material (PERE)	MJ
Use of renewable primary energy resources used as raw material (PERM)	MJ
Total Use of renewable primary energy (PERT)	MJ
Use of non-renewable primary energy excluding primary energy resources used as raw material (PENRE)	MJ
Use of non-renewable primary energy resources used as raw material (PENRM)	MJ
Total Use of non-renewable primary energy (PENRT)	MJ
Use of recycled or recycled materials (secondary materials)	Kg
Use of renewable secondary fuels	MJ
Use of non-renewable secondary fuels	MJ
Net use of freshwater	m3

Table 8: Waste materials to be declared in the study.

Rest materials	Unit
Hazardous waste	Kg
Non-hazardous waste	Kg
Radioactive waste, disposed/stored	Kg
Outputs, secondary materials and exported energy	
Material for reuse	Kg
Recycling material	Kg
Material for energy recovery	Kg
Exported energy	MJ

3.3.7 Data requirements (DQR)

The following requirements are used for all the central LCI data. The more peripheral aspects may deviate from the DQI based on the rule for "cut off".

- Geographical coverage: The processes included in the data set should be well representative of the geography stated in the "location" indicated in the metadata
- Specific data should be used for at least the processes the producer of the specific product has influence over
- Technology representativeness: Generic data should represent the specific technology if known and if data is available, otherwise average technology
- Time-related coverage:
    - *Data of core processes*: The collected data should be representative for the last 12 months but not older than 5 years.
    - *Data of upstream and downstream processes*: The collected data should be as recent as possible but not older than 10 years. Generic datasets should be valid at the point of calculation.
- Multiple output allocation: Physical causality or economic allocation, depending on what is more reasonable for the products.
- Substitution allocation: Should not be used in the EPD
- Waste treatment allocation: Polluter pays and cut-off at point of substitution.
- Cut-off rules: See section 3.3.3

- The boundary with nature: Agricultural production should be part of the production system

The data quality and representativeness will be assessed in part 6.3 based on the guidelines established in the EN 15804:A2 standard.

3.3.8 Type of critical review, if any

A critical review will be carried out according to the International Standards ISO 14040 and ISO 14044 as well as the applied PCR. The LCA will be reviewed according to the following five aspects outlined in ISO 14040. It is assessed whether:

- the methods used to carry out the LCA are consistent with this International Standard and in line with the applied PCR.
- the methods used to carry out the LCA are scientifically and technically valid
- the data used are appropriate and reasonable in relation to the goal of the study
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The report will be reviewed Viktor Hakkarainen at VästLCA.

4 Life Cycle Inventory (LCI)

This chapter describes the modelling of the system;
- Software and LCA-databases that have been used
- Foreground LCI-data from Prototal on the resources and processes used in the two manufacturing techniques
- Background LCI-data from databases that have been used
- Modelling assumptions that have been made

4.1 LCA Software

The life cycle impact assessment (LCIA) was calculated using the LCA software SimaPro 9.5 (PRé Sustainability, 2022) . It allows access to databases with generic LCI data (e.g. ecoinvent) and several readymade LCIA methods.

4.2 LCA database for generic data

For data referring to processes beyond the control of the core production, the ecoinvent database version 3.9 (cut-off by classification) is used. Ecoinvent is one of the world's leading databases with consistent, open, and updated Life Cycle Inventory Data (LCI). With several thousand LCI datasets in the fields of agriculture, energy supply, transport, biofuels and biomaterials, bulk and special chemicals, construction and packaging materials, basic and precious metals, IT and electronics and waste management, ecoinvent offers the most comprehensive international LCI database. Ecoinvent's high-quality LCI datasets are based on industrial data and have been compiled by internationally recognized research institutes and LCA consultants.

4.3 Data collection

Data for the LCI has been collected from Inpipe. Inpipe has provided specific data on ingoing raw materials, the transport modes and distances of raw materials, and on resource use, waste and emissions related manufacturing in their own facilities (Inpipe, 2023). No specific data on supplier production could be gathered, but supplier specific compositions of the polyester resins was gathered from Inpipes supplier AOC resins. The data gathered from Inpipe is based on measurements representing 2022 year's production.

4.3.1 Supplier input data references

Table 9 shows the supplier contacts that have supplied the sources for data input.

Table 9 Input data references

Supplier	AOC resins
Name	**Rob van de Laarschot**
e-mail	rob.laarschot-van-de@aocresins.com
Position in company	Head of Technical service
Information regarding	Polyester resin recipes

4.4 General modelling choices

The scenarios included are currently in use and are representative of one of the most probable alternatives.

Modelling choices that are general to the entire LCA are:

- Choice of energy model: Residual electricity mixes on the market have been used when modelling specific data on electricity consumption, if no supplier specific electricity mix, proved by certificate of origin has been presented. Else regional averages obtained from the Ecoinvent LCI database are used. As no supplier specific data on production has been gathered from suppliers, upstream data is based on regional averages (as generic data is used).
- Choice of transport model: regional averages from Ecoinvent
- Raw material transport is modelled with the datasets *Transport, freight, lorry 16-32 metric ton, EURO6 {RER}| transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U* and *Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off*
- Ecoinvent processes that contain market funds such as "Diesel burned in building machine {GLO} | market for | Cut-off, U" includes generic shipments from producer to end customer. If available, market datasets are chosen in the modelling, so that upstream transportation in the supply chain is covered. Where no market dataset is available, transport upstream of first-tier supplier is excluded as it is assumed to be negligible.
- If nothing else is mentioned, generic datasets used are Ecoinvent 3.9 datasets (cut-off by classification).

4.5 Product content declaration

Table 10 and 11 describe the content in 1 kg liner delivered to the customer and the packaging per kg liner. The tables also present any substances of very high concern that exceeds 0.1 weight-%.

Table 10: Content declaration, 225mm, per kg liner

Product components	Weight (kg)	Post-consumer material (weight-%)	Renewable material (weight-%)
Polyester resin	0.454	0%	0%
Glass fibre	0.454	0%	0%
Film (polyethylene)	0.049	0%	0%
Film (polyamide)	0.028	0%	0%
Magnesium oxide	0.014	0%	0%
Total	1	0%	0%
Packaging materials			
Wooden box	0.02	0%	100%
Substances of Very High Concern (SVHC)[3] that exceeds 0.1 weight-%.	No substances of very high concern that exceeds 0.1 weight-%		

[3] SVHC and the Candidate List of SVHC are available via the European Chemicals Agency [Candidate List of substances of very high concern for Authorisation - ECHA (europa.eu)]

Table 11: Content declaration, 1100mm, per kg liner

Product components	Weight (kg)	Post-consumer material (weight-%)	Renewable material (weight-%)
Polyester resin	0.482	0%	0%
Glass fibre	0.482	0%	0%
Film (polyethylene)	0.014	0%	0%
Film (polyamide)	0.008	0%	0%
Magnesium oxide	0.014	0%	0%
Total	1	0%	0%
Packaging materials			
Wooden box	0.02	0%	100%
Substances of Very High Concern (SVHC)[4] that exceeds 0.1 weight-%.	No substances of very high concern that exceeds 0.1 weight-%		

[4] SVHC and the Candidate List of SVHC are available via the European Chemicals Agency [Candidate List of substances of very high concern for Authorisation - ECHA (europa.eu)]

4.6 Raw materials (A1 + A2)

This section describes the raw materials needed for the manufacturing of 1 kg liner (including spillage) and the transportation of these materials to the production site.

Table 12: Raw materials and transport to the production site, per kg liner

Material	Weight (kg)	LCI database representation	Database	Origin	Transport type	Transport distance (km)	Comment
Polyester resin	0.478 (225mm) 0.506 (1100mm)	LCI Dataset 1	Own modelling, see confidential appendix	The Netherlands	Truck, Boat	602 (truck) 2185 (boat)	0.024 kg spillage in production
Glass fibre	0.455 (225mm) 0.482 (1100mm)	Glass fibre {RER}| glass fibre production | Cut-off, U	ecoinvent	Germany	Truck, Boat	1823 (truck), 155 (boat)	
Film (polyethylene)	0.065 (225mm) 0.029 (1100mm)	Nylon 6 {RER}| market for nylon 6 | Cut-off, U Extrusion, plastic film {RER}| production | Cut-off, U	ecoinvent	Italy	Truck	2974	0.016 kg spillage in production
Film (polyamide)	0.028 (225mm) 0.008 (1100mm)	Packaging film, low density polyethylene {RER}| packaging film production, low density polyethylene | Cut-off, U	ecoinvent	Italy	Truck	2974	
Magnesium oxide	0.014	Magnesium oxide {RER}| magnesium oxide production | Cut-off, U	ecoinvent	Germany	Truck	1646	
Valve holder (used in installation)	0.017	Polyoxymethylene (POM)/EU-27 Injection moulding {RER}| injection moulding | Cut-off, U	Industry data 2.0 ecoinvent	Sweden	Truck	270	Average per kg liner. Valve holder weight: 0.469 kg. Kg per m for 225mm (worst case) =4. Average length of liner: 67m

4.6.1 Polyester resin

Specific data has been given for the two polyester resins. This data is confidential and is presented in a confidential appendix sent to the verifier separately.

4.6.2 Packaging from suppliers

The amount of packaging has been calculated by dividing the total weight of supplier packaging during 2022 with the total weight of produced liners.

Table 13: Packaging from suppliers, per kg liner

Material	Weight (kg)	LCI database representation	Database
IBC-container (HDPE)	0.02	Polyethylene, high density, granulate {RER}| polyethylene production, high density, granulate | Cut-off, U Injection moulding {RER}| injection moulding | Cut-off, U	ecoinvent
IBC-container (metal)	0.02	Steel, low-alloyed, hot rolled {GLO}| market for steel, low-alloyed, hot rolled | Cut-off, U Metal working, average for steel product manufacturing {RER}| metal working, average for steel product manufacturing | Cut-off, U	ecoinvent
Wooden pallets	0.048	Sawnwood, softwood, raw, dried (u=20%) {RER}| market for sawnwood, softwood, raw, dried (u=20%) | Cut-off, U	ecoinvent
Plastic film (LDPE)	0.01	Polyethylene, low density, granulate {RER}| polyethylene production, low density, granulate | Cut-off, U Injection moulding {RER}| injection moulding | Cut-off, U	ecoinvent
Steel barrels	0.01	Steel, low-alloyed, hot rolled {GLO}| market for steel, low-alloyed, hot rolled | Cut-off, U Metal working, average for steel product manufacturing {RER}| metal working, average for steel product manufacturing | Cut-off, U	ecoinvent

4.7 Manufacturing (A3)

In this chapter, the activities carried out by Inpipe are presented. All activities are presented per kg liner.

4.7.1 Energy

The energy consumption of the manufacturing facility in 2022 was divided by the total weight of produced liners during 2022. Inpipe buys renewable energy, supported by certificates of origin, and intend to do so for the whole validity of the EPD.

Table 14: Energy use in production, per kg liner

Energy type	Energy source	LCI data representation in ecoinvent	Amount (kWh)	Comment
Electricity	93% hydro power, 5% biomass, 2% wind	Adjusted version of Electricity, high voltage {SE}| market for electricity, high voltage | Cut-off, U	0.06	Swedish production mix adjusted to represent 93% hydro power, 5% biomass and 2% wind power. For certificate, see Appendix 4
Heat	Industrial heating	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U	1.38	Industrial heating from Solör. 85% from biomass, 11% from flue gas condensation, 1.2 % from oil. Modelled as heat from wood chips

4.7.2 Direct emissions

Direct emissions from the manufacturing facility during 2022 was divided by the total weight of produced liners in 2022.

Table 15: Direct emissions, per kg liner

Emission	Amount (kg)	Compartment (Air, water, ground)
Styrene	0.002	Air
Acetone	0.004	Air

4.7.3 Consumables

Consumables used during 2022 was divided by the total weight of produced liners in 2022.

Table 16: Consumables used in production, per kg liner.

Type of consumable	Amount (kg)	LCI data representation in ecoinvent
Phosphoric acid (85% solution)	0.001	Phosphoric acid, industrial grade, without water, in 85% solution state {RER}| purification of wet-process phosphoric acid to industrial grade, product in 85% solution state | Cut-off, U
Acetone	0.004	Acetone, liquid {RER}| market for acetone, liquid | Cut-off, U

4.7.4 Packaging

Packaging used during 2022 was divided by the total weight of produced liners in 2022

Table 17: Packaging used for product, per kg liner

Type of Packaging	Material	Amount (kg)	LCI data representation in ecoinvent

Wooden box	Wood	0.02	Sawnwood, softwood, raw, dried (u=20%) {RER}| market for sawnwood, softwood, raw, dried (u=20%) | Cut-off, U. dataset per m3 - assumed density 500kg/m3.

4.7.5 Production waste

Data on production waste for 2022 was divided by the total weight of produced liners during 2022.

Table 18: Production waste types and treatment, per kg liner

Waste type	Amount (kg)	Dataset	Waste transport distance (km)	Transport type
Polyester	0.024	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration with fly ash extraction | Cut-off, U	227	Truck
Plastic film	0.016	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration with fly ash extraction | Cut-off, U	227	Truck
Packaging (wood, plastic, cardboard)	0.003 (0.001+0.001+0.001)	Waste wood, untreated {CH}| treatment of waste wood, untreated, municipal incineration with fly ash extraction | Cut-off, U Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration with fly ash extraction | Cut-off, U Waste paperboard {CH}| treatment of waste paperboard, municipal incineration with fly ash extraction | Cut-off, U	227	Truck

The transport to the waste treatment facility is modelled with the dataset *Transport, freight, lorry 7.5-16 metric ton, EURO6 {RER}| market for transport, freight, lorry 7.5-16 metric ton, EURO6 | Cut-off, U*

4.8 Transport of finished goods (A4)

The transport mode and distance to the customer depends on the customer. About 50% of Inpipes liners are delivered to customers in Sweden, but they also have customers in many European countries and globally. A Swedish distribution scenario is transport by truck from Inpipes facilities in Vilhelmina to Stockholm (675 km). A European distribution scenario is transport by truck from Inpipes facilities in Vilhelmina to Copenhagen (1320 km).
A Global distribution scenario is transport by truck from Inpipes facilities in Vilhelmina to Gothenburg (1028 km) further via ship to Mumbai (12409km) and truck to construction site (972km). The global scenario is used in the EPD.

Table 19: Distribution of products

Transport type	transport distance (km)	Dataset
Truck	2000	Transport, freight, lorry 16-32 metric ton, EURO6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, U
Ship	12409[5]	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U

4.9 Installation (A5)

4.9.1 Energy at installation

The liners are cured using UV radiation. This requires electricity, which can be provided in different ways. The most common, and most conservative, is through a diesel-electric generating set. The amount of electricity needed per kg pipe has been given by Inpipe and is based on the time that the generator is operating per m 225mm liner, and 1100mm liner, respectively. For the larger pipe (1100mm), a winch is used in installation.

Table 20: Energy at installation, per kg liner

Energy type	Amount	LCI data representation in ecoinvent	Comment
Electricity, from diesel generator	0.033 kWh (225mm) 0.013 kWh (1100mm)	Diesel, burned in diesel-electric generating set, 18.5kW {GLO}| market for diesel, burned in diesel-electric generating set, 18.5kW | Cut-off, U	Assuming 0.5 liters diesel/kWh electricity. Based https://www.bygghemma.se/reportage-och-guider/bast-i-test-elverk/
Diesel	0.427 MJ (1100mm only)	Diesel, burned in diesel-electric generating set, 18.5kW {GLO}| market for diesel, burned in diesel-electric generating set, 18.5kW | Cut-off, U	Winching

4.9.2 Waste treatment of packaging and installation waste

In the table below the waste treatment of the packaging that is delivered with the product, and other installation waste is presented.

[5] https://www.searates.com/services/distances-time/

Table 21: Disposal of installation waste, per kg liner

Type of Packaging	Material	Amount (kg)	Disposal method	LCI data representation in ecoinvent
Wooden box	Wood	0.02	Incineration	Waste wood, untreated {RoW}| treatment of waste wood, untreated, municipal incineration | Cut-off, U
Inner film	Plastic	0.039(225mm) 0.011(1100mm)	Incineration	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U
Valve holder	POM	0.0117	Incineration	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U

Assumed transportation by truck 50 km to a nearby incineration plant, modelled with the dataset *Transport, freight, lorry 7.5-16 metric ton, EURO5 {RoW}| transport, freight, lorry 7.5-16 metric ton, EURO5 | Cut-off, U.*

4.10 End-of-Life (C1-C4)

The end-of-life phase handles the product and the material it consists of after its use. The final handling includes dismantling of the product, transport to a facility for waste treatment, also energy and materials used for preparation for waste treatment and final waste treatment. If the material is recycled or reused into a new product, the environmental aspects of the processing of the secondary material are allocated to the life cycle of the new product. The end-of-life stage is divided into several modules, according to the requirements in the PCR; dismantling, transport to waste treatment, waste treatment and final disposal.

4.10.1 Dismantling or deconstruction (C1)

When a relined piped needs to be replaced, it is common that another relining is made on top of the first relining. If the pipes need to be removed from the area, the cement and relining pipe needs to be dug out and the cement pipe is crushed. The relining pipes can then be removed, as a whole. No specific data was available on this process, so instead, estimates where made. Per kg of pipe, it was assumed that 0.25 cubic meter needs to be dug out. This was modelled with an ecoinvent dataset for excavation with a hydraulic digger. The emissions from this process was divided by 3, to allocate the digging between the cement and relining pipes.

4.10.2 Transport to waste management (C2)

Transport to waste treatment management is assumed to be 50km and truck is assumed to be the transport mode.

Table 22: Transport to waste management site

Road transport type	Road transport distance (km)	Dataset used
Truck	50	Transport, freight, lorry 7.5-16 metric ton, EURO5 {RoW}| market for transport, freight, lorry 7.5-16 metric ton, EURO5 | Cut-off, U

4.10.3 Waste treatment (C3) and final disposal (C4)

Module C3 contains any energy and materials used for preparation for waste treatment and the environmental impact of waste incineration with energy recovery. Module C4 contains the environmental impact of incineration without energy recovery and of incineration of hazardous waste, and environmental impact of landfilling. The pipe is assumed to be sent to waste incineration with energy recovery, where everything but the glass fibre is incinerated. The remaining glass fibre is assumed to be landfilled. Table 23 shows the modelling details.

Table 23: Modelling details of waste treatment (C3 and C4), per kg liner

Module	Waste	Amount (kg)	Dataset used
C3	Polyester, PE film, PA film	0.492 (225mm) 0.493 (1100mm)	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U
C4	Glass fibre, magnesium oxide	0.469 (225mm) 0.496 (1100mm)	Inert waste {RoW}| treatment of inert waste, sanitary landfill | Cut-off, U

4.11 Benefits and loads from material recycling or energy recovery (D module)

Module D aims to describe potential benefits or loads that can be related to material and energy recovery as well as reuse outside the system boundary. Recycled material or energy has the potential to replace primary resources that would otherwise have been used in new products if the recycled material had not been available. This benefit is calculated with the D-module. For products that contain recycled material as raw material, the recycled share is deducted to avoid double counting.

In this study, no material is assumed to be recovered, but the plastic parts of the pipe is assumed to be incinerated with energy recovery. The wooden box that is delivered with the pipe and installation waste (see section 4.9.2) is also assumed to be incinerated with energy recovery.

The following formula is used to calculate the potential benefits of energy recovery from waste incineration:

$$e_{module\ D3} = -M_{INC\ out} \cdot \left(LHV \cdot X_{INC\ heat} \cdot E_{SE\ heat} + LHV \cdot X_{INC\ elec} \cdot E_{SE\ elec}\right)$$

where,

- M_{INCout} = The amount of material that leaves the product system and will be reused / recycled in subsequent systems. Calculated by subtracting the material that is sent to recycling from the amount in product and packaging, and multiplying with the incineration rate ($Share_{INCout}$)
- LHV = lower heating value of the material
- $X_{INCheat}$ = efficiency of the incineration process for heat
- E_{SEheat} = specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: heat
- $X_{INCelec}$ = efficiency of the incineration process for electricity

- E_{SEelec} = specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: electricity

In the incineration process with energy recovery, it is assumed that 30% becomes electricity and 70% becomes heat. The efficiency of the incineration process is assumed to be 80%. Table 24 shows the modelling details.

Table 24 Modelling details for module D, per kg liner

Material	Amount in product and packaging (kg)	Parameters for energy recycling (for remaining materials after material recycling)	Avoided process for production of electricity in ecoinvent	Avoided process for production of heat in ecoinvent
Plastic	0.572 (225mm) 0.517 (1100mm)	$Share_{INCout} = 100\%$ LHV = 31,00 MJ/kg	Electricity, high voltage {RER}| market group for electricity, high voltage | Cut-off, U	Heat, for reuse in municipal waste incineration only {RoW}| market for heat, for reuse in municipal waste incineration only | Cut-off, U
Wood	0.02	$Share_{INCout} = 100\%$ LHV = 19,00 MJ/kg	Electricity, high voltage {RER}| market group for electricity, high voltage | Cut-off, U	Heat, for reuse in municipal waste incineration only {RoW}| market for heat, for reuse in municipal waste incineration only | Cut-off, U

4.12 Balancing of biogenic carbon dioxide

Uptake of carbon dioxide from air and emissions of biogenic carbon dioxide is manually balanced over the life cycle. Uptake of carbon dioxide from air in material present in the product is balanced with an output in C3. Uptake of carbon dioxide from air in supplier packaging(A1) is balanced in A3, and from product packaging (A3) in A5. All carbon dioxide biogenic uptake and emissions in other modules are negligibly low and have not been balanced.

5 Result of Life cycle impact assessment (LCIA)

The estimated impact results are only relative statements which do not indicate the end points of the impact categories, exceeding threshold values, safety margins or risks.

In this section, the environmental impact results are presented. The difference in environmental impact for 225mm and 1100mm is less than 10% in all impact categories, thus only results for for the 225mm liner (worst case of the two) is presented in this section. Tables showing the difference in LCIA results for the whole range of liners (150mm – 1800mm) found in Appendix 5. Results are presented in the following order:

- Environmental Footprint per impact category – Tables
- Environmental Footprint – Single score
- Climate impact according to EN 15804:2012+A2:2019.
- Climate impact according to GWP-GHG
- Other mandatory indicators
  - Use of resources and energy
  - Waste production and output flows
  - Biogenic carbon content

Sankey diagrams are used to display the results as flow diagrams where the thickness of the arrows reflects the relative amount of that flow. All the nodes cannot be displayed simultaneously due to the vast amounts of background data. Therefore, only processes that contribute to a minimum of 5% of total impacts are shown in the diagram. For the impact category Eutrophication, freshwater, the result per unit kg P is used as basis for calculating the result per unit kg PO4-3 eq, using the factor 3,07.

Acronyms used in the result-tables: GWP: Global Warming Potential, LULUC: Land Use and Land Use Change, ODP: Ozone Depletion Potential, AP: Acidification Potential. EP: Eutrophication Potential, POCP: Photochemical Ozone Creation Potential, ADPE: Abiotic Depletion Potential – Elements, ADPF: Abiotic Depletion Potential – Fossil Fuels, WDP: Water Scarcity Footprint, PM: Particulate Matter, IRP: Ionizing Radiation - Human Health, ETP-FW: Ecotoxicity Potential – Freshwater, HTP-C: Human Toxicity Potential – Cancer, HTP-NC: Human Toxicity Potential – Non-Cancer, SQP: Soil Quality Potential Index

Disclaimer: The results of the environmental impact indicators for ADPE, ADPF, WDP, ETP-FW, HTP-C, and HTP-NC shall be used with care as the uncertainties of these results are high or as there is limited experience with the indicator. IR 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.

5.1 Environmental Footprint Midpoint

Table 25 shows the result per FU according to the LCIA methods stated in EN 15804:2012+A2:2019.

Table 25: Environmental footprint midpoint results per kg liner (Liner), 225mm

Impact category	Unit	A1-C4	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
GWP Landuse	kg CO_2 eq	2,92E-03	2,28E-03	1,23E-04	2,03E-04	2,61E-03	2,80E-04	1,33E-05	6,72E-06	6,10E-06	8,88E-06	4,30E-06	-1,10E-03
GWP Fossil	kg CO_2 eq	5,19E+00	3,00E+00	2,43E-01	1,23E-01	3,36E+00	4,96E-01	8,96E-02	4,82E-02	1,22E-02	1,17E+00	5,87E-03	-4,38E-01
GWP Biogenic	kg CO_2 eq	0,0075	-5,36E-02	2,09E-04	3,11E-02	-2,23E-02	3,12E-04	2,93E-02	1,62E-05	6,17E-06	9,02E-05	4,76E-05	-1,12E-01
GWP Total	kg CO_2 eq	5,20E+00	2,94E+00	2,43E-01	1,54E-01	3,34E+00	4,96E-01	1,19E-01	4,82E-02	1,22E-02	1,17E+00	5,92E-03	-5,51E-01
ODP	kg CFC11 eq	1,93E-06	1,91E-06	5,20E-09	2,62E-09	1,92E-06	9,95E-09	7,86E-10	8,20E-10	1,76E-10	1,21E-09	1,39E-10	-7,49E-09
AP	mol H+ eq	2,38E-02	1,63E-02	8,64E-04	6,81E-04	1,78E-02	4,56E-03	5,87E-04	4,35E-04	4,19E-05	2,67E-04	4,18E-05	-2,18E-03
EP - Freshwater	kg P eq	8,75E-04	8,08E-04	1,68E-05	8,84E-06	8,34E-04	3,05E-05	2,84E-06	2,23E-06	9,78E-07	3,50E-06	1,54E-06	-4,08E-04
EP - Freshwater	kg PO4 eq	7,78E-03	2,45E-03	5,09E-05	2,68E-05	2,53E-03	9,23E-05	8,62E-06	6,75E-06	2,65E-03	2,45E-03	5,09E-05	2,68E-05
EP - Marine	kg N eq	5,28E-03	3,10E-03	2,17E-04	1,81E-04	3,50E-03	1,14E-03	2,64E-04	2,00E-04	1,35E-05	1,53E-04	1,57E-05	-4,03E-04
EP – Terrestrial	mol N eq	5,66E-02	3,24E-02	2,29E-03	2,84E-03	3,75E-02	1,24E-02	2,85E-03	2,17E-03	1,43E-04	1,30E-03	1,67E-04	-3,54E-03
POCP	kg NMVOC eq	2,10E-02	1,23E-02	1,05E-03	1,66E-03	1,50E-02	4,06E-03	7,93E-04	6,48E-04	5,52E-05	3,27E-04	5,66E-05	-1,13E-03
ADPE	kg Sb eq	1,58E-04	1,55E-04	7,65E-07	1,10E-07	1,56E-04	1,33E-06	1,67E-07	2,18E-08	3,81E-08	5,63E-08	1,19E-08	-3,75E-07
ADPF	MJ	7,28E+01	6,04E+01	3,42E+00	4,10E-01	6,42E+01	6,79E+00	6,13E-01	6,28E-01	1,68E-01	2,16E-01	1,27E-01	-1,01E+01
WDP	m3 depriv.	1,38E+00	1,26E+00	1,38E-02	1,02E-02	1,29E+00	2,51E-02	3,07E-03	1,56E-03	7,03E-04	5,32E-02	5,38E-03	-1,04E-01
PM	disease inc.	2,14E-07	1,40E-07	1,75E-08	8,85E-09	1,67E-07	3,12E-08	1,20E-09	1,21E-08	8,44E-10	1,34E-09	9,14E-10	-7,56E-09
IR	kBq U-235 eq	3,40E-01	3,25E-01	4,50E-03	1,88E-03	3,31E-01	7,85E-03	3,56E-04	4,28E-04	1,45E-04	4,33E-04	1,62E-04	-2,87E-01
ETP – FW	CTUe	5,21E+01	4,50E+01	1,25E+00	3,83E-01	4,67E+01	2,48E+00	3,03E-01	2,19E-01	7,03E-02	2,29E+00	4,13E-02	-4,83E-01
HTP - C	CTUh	5,04E-09	3,45E-09	1,10E-10	1,10E-09	4,66E-09	2,23E-10	1,85E-11	2,34E-11	5,04E-12	1,02E-10	3,35E-12	-1,28E-10
HTP - NC	CTUh	9,81E-08	8,53E-08	2,37E-09	1,98E-09	8,97E-08	4,17E-09	3,99E-10	1,21E-10	1,15E-10	3,61E-09	3,70E-11	-3,58E-09
Land use, SQP	Pt	3,44E+01	1,42E+01	1,99E+00	1,44E+01	3,05E+01	3,29E+00	5,34E-02	4,52E-02	8,65E-02	6,46E-02	2,90E-01	-1,52E+00

Table 26: Environmental footprint midpoint results per kg liner (Freeliner), 225mm

Impact category	Unit	A1-C4	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
GWP Landuse	kg CO_2 eq	6,11E-03	5,46E-03	1,23E-04	2,03E-04	5,79E-03	2,80E-04	1,33E-05	6,72E-06	6,10E-06	8,88E-06	4,30E-06	-1,10E-03
GWP Fossil	kg CO_2 eq	5,54E+00	3,35E+00	2,43E-01	1,23E-01	3,72E+00	4,96E-01	8,96E-02	4,82E-02	1,22E-02	1,17E+00	5,87E-03	-4,38E-01
GWP Biogenic	kg CO_2 eq	-1,92E-03	-2,65E-01	2,09E-04	1,48E-02	-2,50E-01	3,12E-04	2,93E-02	1,62E-05	6,17E-06	2,18E-01	4,76E-05	-1,12E-01
GWP Total	kg CO_2 eq	5,54E+00	3,09E+00	2,43E-01	1,38E-01	3,47E+00	4,96E-01	1,19E-01	4,82E-02	1,22E-02	1,39E+00	5,92E-03	-5,51E-01
ODP	kg CFC11 eq	2,18E-07	1,97E-07	5,20E-09	2,62E-09	2,05E-07	9,95E-09	7,86E-10	8,20E-10	1,76E-10	1,21E-09	1,39E-10	-7,49E-09
AP	mol H+ eq	2,93E-02	2,18E-02	8,64E-04	6,81E-04	2,34E-02	4,56E-03	5,87E-04	4,35E-04	4,19E-05	2,67E-04	4,18E-05	-2,18E-03
EP - Freshwater	kg P eq	1,13E-03	1,06E-03	1,68E-05	8,84E-06	1,09E-03	3,05E-05	2,84E-06	2,23E-06	9,78E-07	3,50E-06	1,54E-06	-4,08E-04
EP - Marine	kg N eq	6,30E-03	4,12E-03	2,17E-04	1,81E-04	4,51E-03	1,14E-03	2,64E-04	2,00E-04	1,35E-05	1,53E-04	1,57E-05	-4,03E-04
EP – Terrestrial	mol N eq	6,47E-02	4,05E-02	2,29E-03	2,84E-03	4,56E-02	1,24E-02	2,85E-03	2,17E-03	1,43E-04	1,30E-03	1,67E-04	-3,54E-03
POCP	kg NMVOC eq	2,24E-02	1,37E-02	1,05E-03	1,66E-03	1,65E-02	4,06E-03	7,93E-04	6,48E-04	5,52E-05	3,27E-04	5,66E-05	-1,13E-03
ADPE	kg Sb eq	1,67E-04	1,64E-04	7,65E-07	1,10E-07	1,65E-04	1,33E-06	1,67E-07	2,18E-08	3,81E-08	5,63E-08	1,19E-08	-3,75E-07
ADPF	MJ	7,23E+01	5,99E+01	3,42E+00	4,10E-01	6,37E+01	6,79E+00	6,13E-01	6,28E-01	1,68E-01	2,16E-01	1,27E-01	-1,01E+01
WDP	m3 depriv.	2,90E+00	2,79E+00	1,38E-02	1,02E-02	2,81E+00	2,51E-02	3,07E-03	1,56E-03	7,03E-04	5,32E-02	5,38E-03	-1,04E-01
PM	disease inc.	2,59E-07	1,85E-07	1,75E-08	8,85E-09	2,11E-07	3,12E-08	1,20E-09	1,21E-08	8,44E-10	1,34E-09	9,14E-10	-7,56E-09
IR	kBq U-235 eq	4,64E-01	4,48E-01	4,50E-03	1,88E-03	4,55E-01	7,85E-03	3,56E-04	4,28E-04	1,45E-04	4,33E-04	1,62E-04	-2,87E-01
ETP – FW	CTUe	4,59E+01	3,89E+01	1,25E+00	3,83E-01	4,05E+01	2,48E+00	3,03E-01	2,19E-01	7,03E-02	2,29E+00	4,13E-02	-4,83E-01
HTP - C	CTUh	4,23E-09	2,65E-09	1,10E-10	1,10E-09	3,86E-09	2,23E-10	1,85E-11	2,34E-11	5,04E-12	1,02E-10	3,35E-12	-1,28E-10
HTP - NC	CTUh	1,11E-07	9,79E-08	2,37E-09	1,98E-09	1,02E-07	4,17E-09	3,99E-10	1,21E-10	1,15E-10	3,61E-09	3,70E-11	-3,58E-09
Land use, SQP	Pt	3,98E+01	1,97E+01	1,99E+00	1,44E+01	3,60E+01	3,29E+00	5,34E-02	4,52E-02	8,65E-02	6,46E-02	2,90E-01	-1,52E+00

5.2 Environmental Footprint – Single score

In an LCA, several environmental impacts are calculated (climate impact, acidification, toxicity etc.). To identify which type of environmental impact that is most influential, a so-called weighting is applied. The calculated impact categories are weighted together to form a "single score", which describes the total environmental footprint. This study uses the weighting in the EF 3.0 Method in Simapro, which is based on a panel of experts. Figure 6 and 7, shows the contribution of each impact category to the total environmental impact, for Liner and Freeliner. It shows that most of the environmental impact is related to resource use (minerals and metals), resource use (fossils) and climate change. These impact categories are described in more detail below. Note that resource use (minerals and metals) and resource use (fossils) are impact categories with a high methodological uncertainty. In Figure 8 and Figure 9, Sankey diagrams show that glass fibre production, and production of polyester resins contribute most to the total environmental impact (single score).

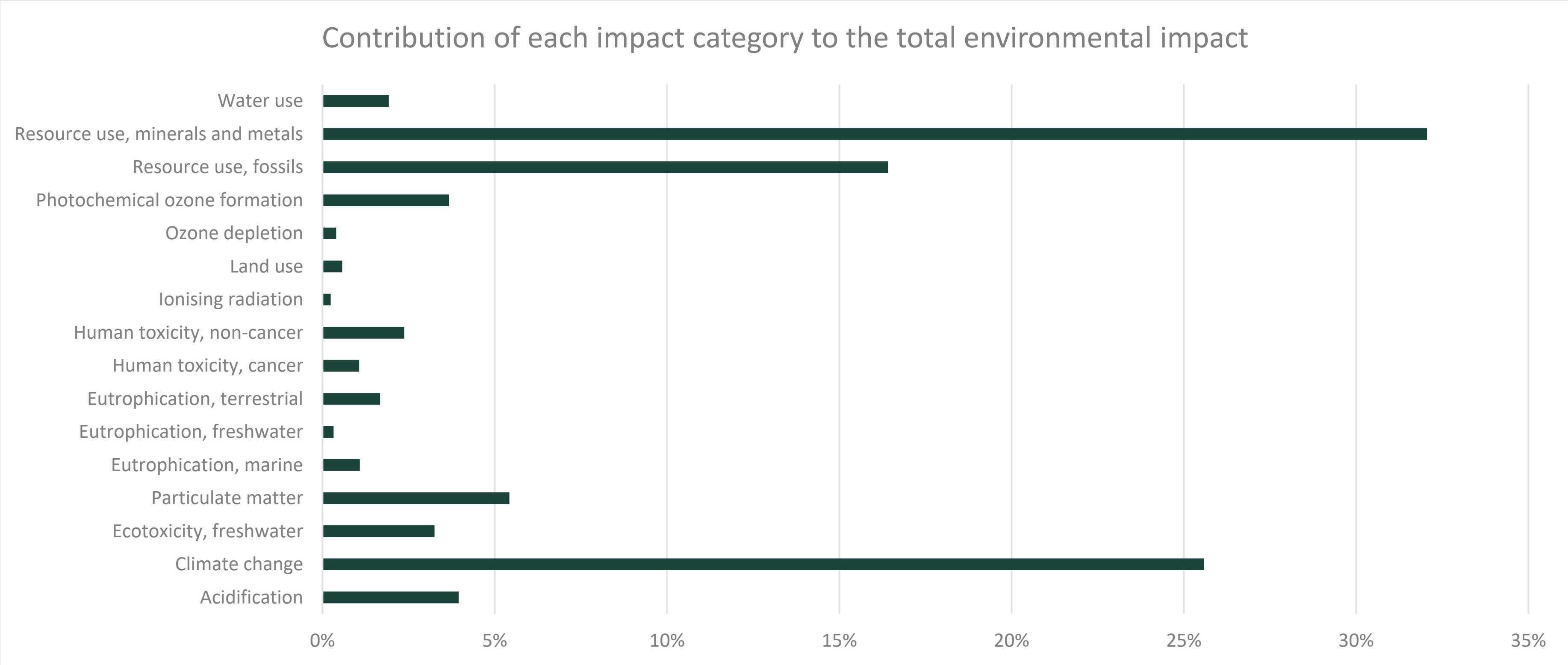


Figure 6: Share of environmental impact per impact category, Liner

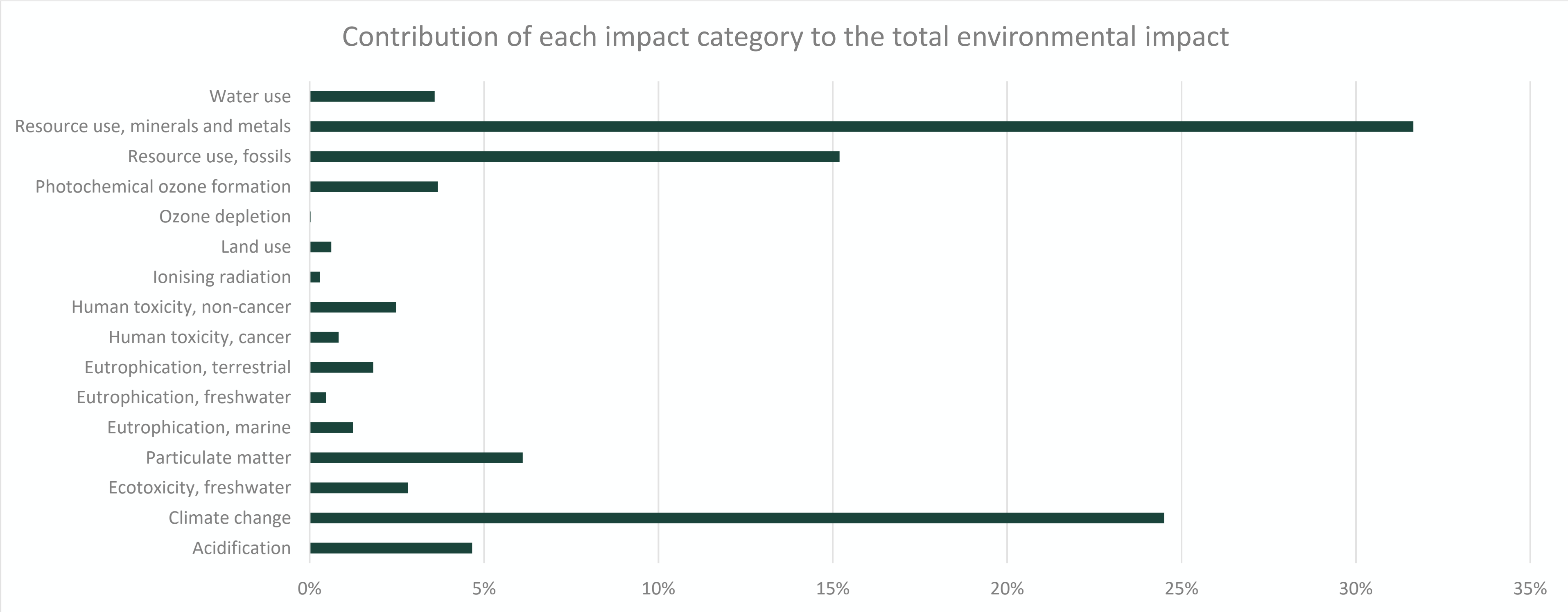


Figure 7: Share of environmental impact per impact category, Freeliner

Climate change

What it is: Climate change is defined as the warming of the climate system due to human activities. Human activities emitting greenhouse gases (GHG) are the leading cause of global warming. GHG emissions have the property of absorbing radiation, resulting in a net warming effect called the greenhouse effect. These will then perturb the Earth's natural balance, increasing temperature and affecting the climate with disturbances in rainfall, extreme climate events and rising sea levels. Climate change is an impact affecting the environment on a global scale.

GHG sources can be classified of three main types: fossil sources, biogenic sources, and land use change. Fossil sources are formed from the decomposition of buried carbon-based organisms that died millions of years ago. Burning fossil sources leads to an increase in GHG in the atmosphere. Biogenic sources are often considered natural and refer to carbon taken up during the cultivation of a crop, considering that there is no net increase of carbon dioxide in the atmosphere. Another source of carbon dioxide emissions is the effect of land use on plant and soil carbon. For example, carbon is stored naturally in nature, and by changing the characteristics of a land area, this carbon is then released. Land use change hence measures the GHGs emissions that occur when changing the vegetation or other characteristics of the land used for a product's lifecycle. The impact of climate gases is expressed as carbon dioxide equivalents, CO2 eq.

The cause of the climate impact of the technologies in this study will be explained in detail in coming sections.

Resource use (minerals and metals)

What it is: This impact category addresses the use of non-renewable abiotic natural resources (minerals and metals). When using these non-renewable resources, there is a decrease in the global stock. Depending on how large the global reserve is assessed to be and the extraction rate of the resource, this impact category regards how rare the mineral and metal are and how much is being used. Hence, this impact category measures the impacts on the global stocks of minerals and metals in the future. Note that this impact category has a high methodological uncertainty.

What causes it in this study: The main impact on resource use (minerals and metals) in this study comes from the glass fibre production and can be traced back to the calcium borate mine production. Calcium borates is used in the production of boric acid, and boric acid is used in the production of glass fibre.

Resource use (fossils)

What it is: This impact category addresses the use of non-renewable abiotic natural resources (fossil). Similar to resource use, minerals and metals, when using fossil fuels, there is a decrease in the global stock. Since the industrial revolution, we have created societies highly dependent on fossil resources. Fossil resources are today commonly used to power processes and transports throughout a product's lifecycle. This impact category aggregates this total use of fossil resources throughout the lifecycle. The use of fossil resources is strongly interlinked to many of the other impact categories like climate change, particulate matter formation, and acidification. Note that this impact category has a high methodological uncertainty.

What causes it in this study: The impact on resource use (fossils) in this study comes mainly from the use of fossil-based chemicals (styrene, polymers) and from the use of fossil energy in the production of raw materials.

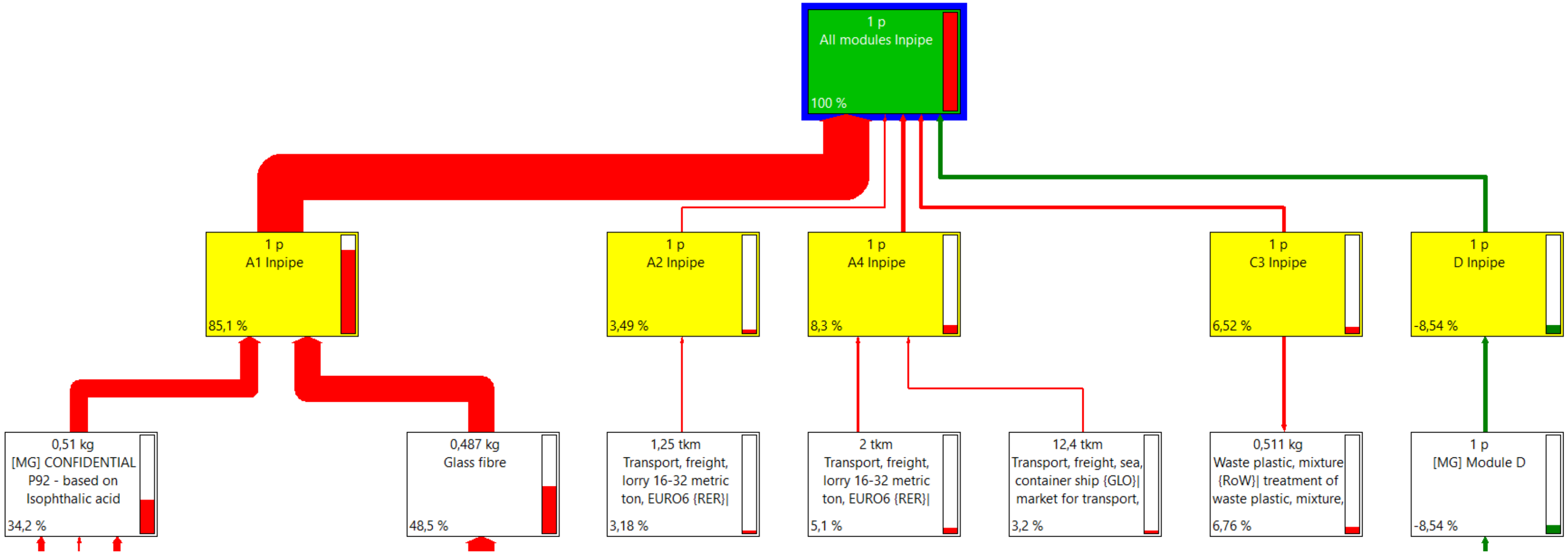


Figure 8: Sankey diagram over total environmental impact per kg liner, Liner. Cut-off level 5%

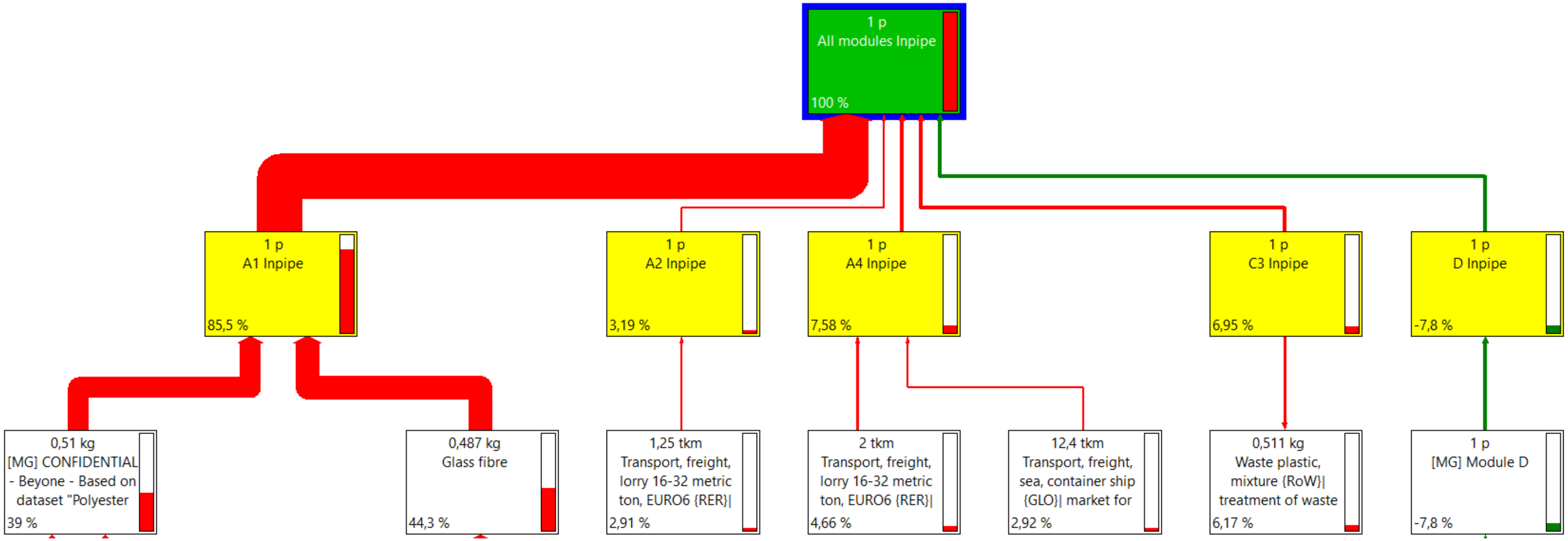


Figure 9: Sankey diagram over total environmental impact per kg liner, Freeliner. Cut-off level 5%

5.3 Climate impact (EN15804)

Figure 10 and Figure 11 show Sankey diagrams over the climate impact of Liner and Freeliner. They show that the main sources of the liner's climate impact is the production of the polyester resins, production of glass fibre and incineration of plastic at product end of life (C3). The green flows in module D represents the climate impact that is "saved" from the energy recovery of the incinerated of plastic. The other modules (A2, A3, A4, A5, C1, C2) has a rather small climate impact in comparison.

Polyester resins

As the content of the polyester resins are confidential, no detailed analysis of the origin of the climate impact can be given for the resins. However, we can see that the majority of the climate impact is related to production of the chemicals used in the resin, not the energy use in the resin production itself. This means that a majority of the climate impact lies further up in the supply chain than at the polyester resin producer. Note that no specific data for the *production processes* of the polyester resins, or the production of the chemicals used in the polyester resins, have been gathered – the conclusions are thus generic and should be interpreted as such: it is *likely* that the majority of the climate impact lies further up in the supply chain than at the polyester resin producer. In many cases, the climate impact of chemical production stems from the energy use (heat, electricity) in the processing – thus, in order to reduce the climate impact, one should strive for a supply chain with energy efficient suppliers that has a low use of fossil energy sources. One way to do this is to look for suppliers in regions with lower climate impact per produced kWh of electricity.

Glass fibre

Glass fibre production is an energy intensive process, and two thirds of the climate impact of glass fibre production comes from energy use. Thus, the climate impact can be substantially lowered if non-fossil energy sources are used in production, or if the supplier has an energy efficient production.

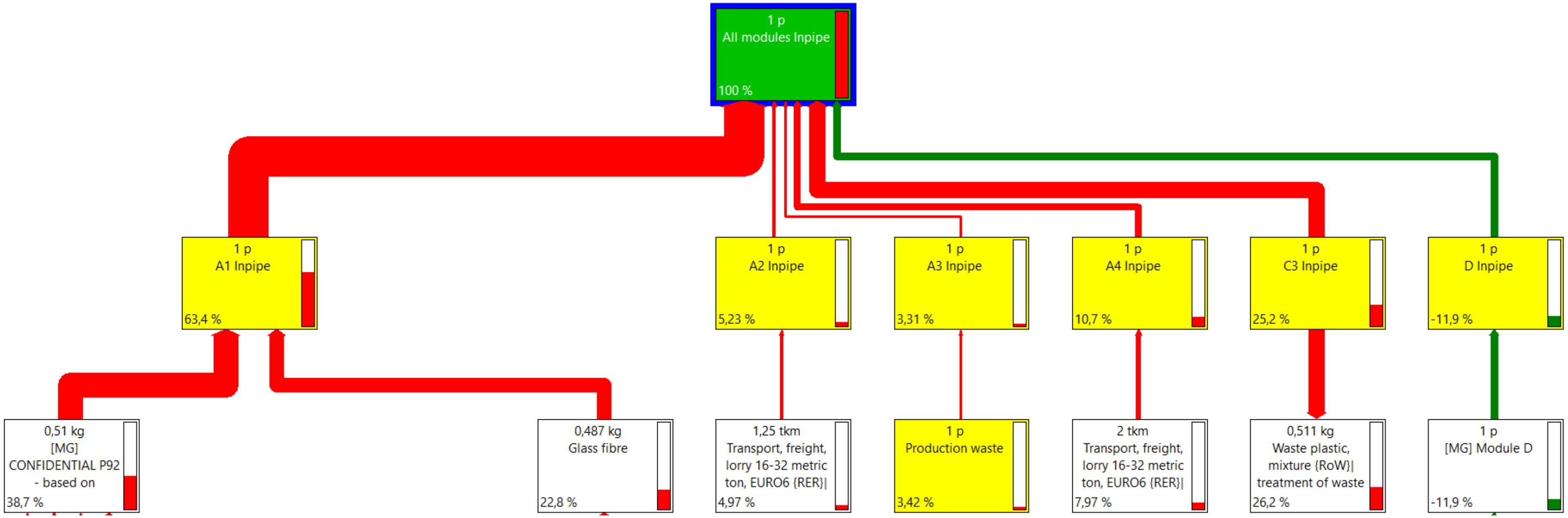


Figure 10: Sankey diagram over climate impact (total), per kg liner, Liner. Cut-off level 5%

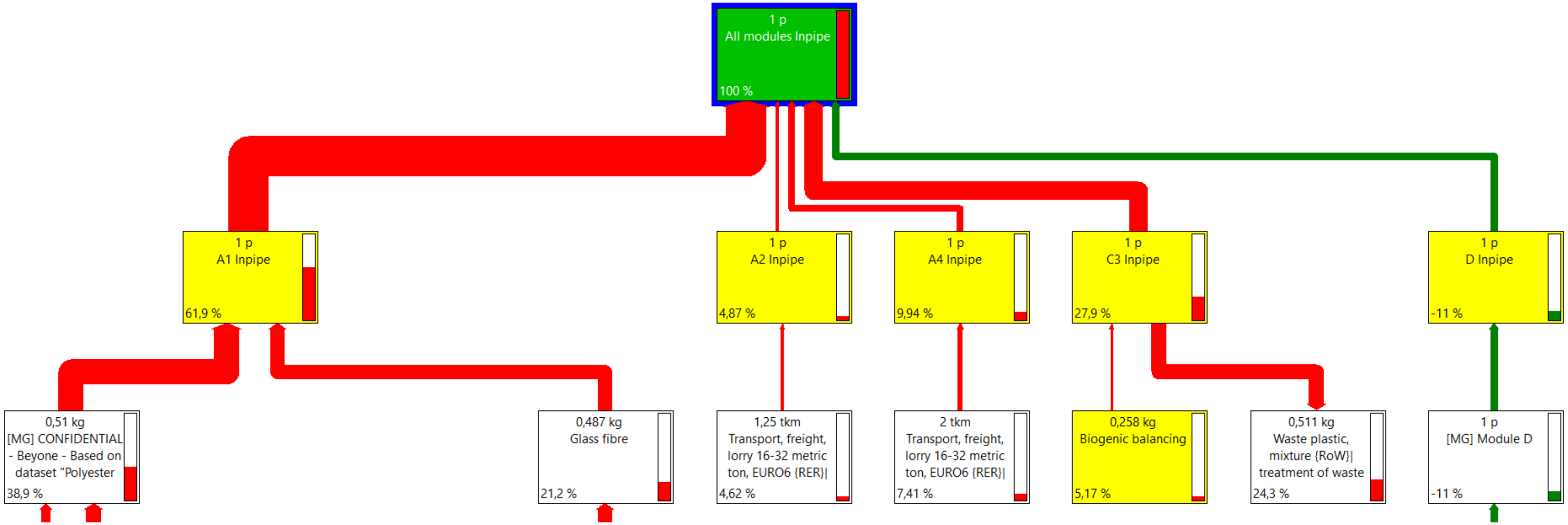


Figure 11: Sankey diagram over climate impact (total), per kg liner, Freeliner. Cut-off level 5%

5.4 Climate impact (GWP-GHG)

The climate impact measured with the method GWP-GHG is slightly higher in A1 than the climate impact calculated with the method stated in EN 15804:2012+A2:2019 (results shown above). This is because the two methods handle biogenic carbon dioxide emissions differently. The GWP-GHG method is mandatory in the EPD as it better harmonizes with older versions of the EPD system, and the method is especially useful for products containing biomass.

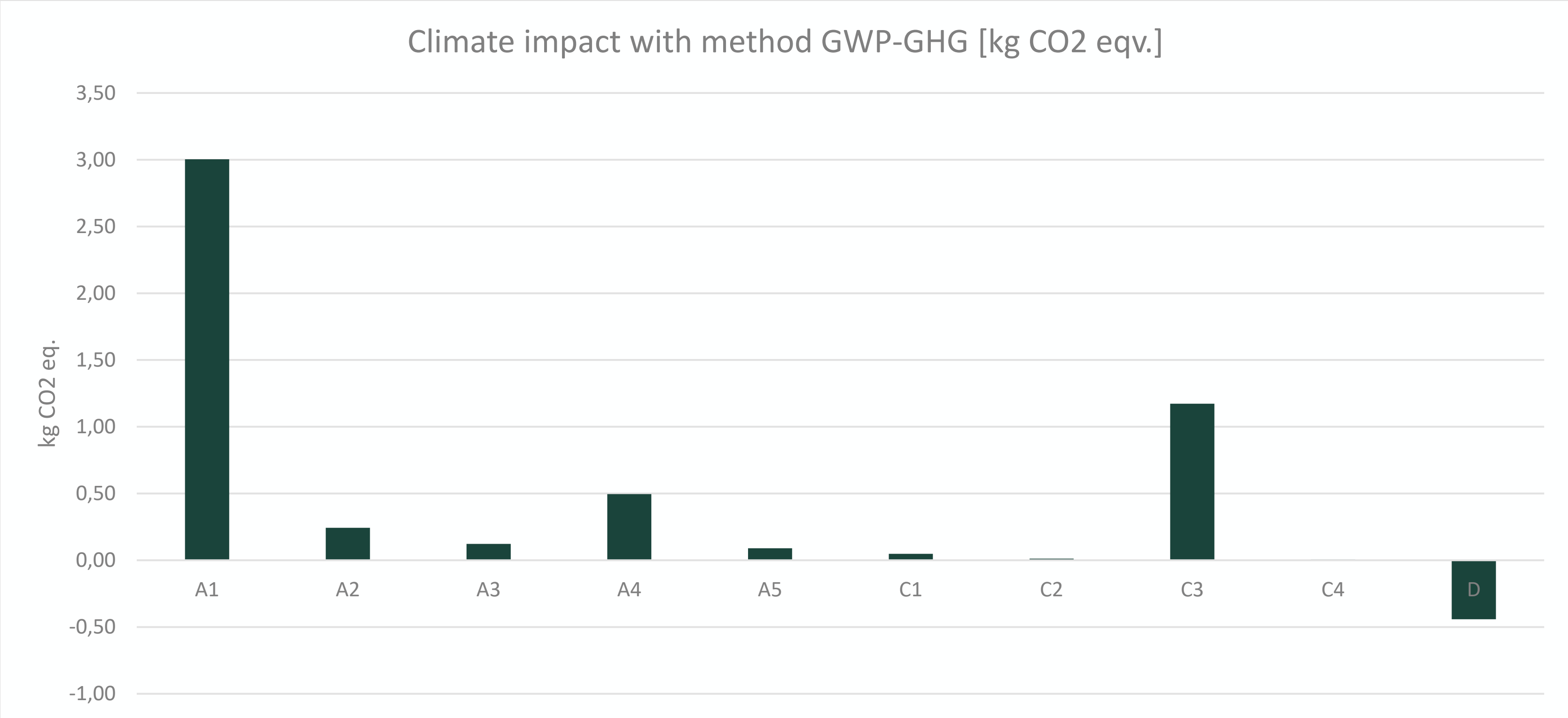


Figure 12: Climate impact per functional unit according to method GWP-GHG, per kg liner, Liner.

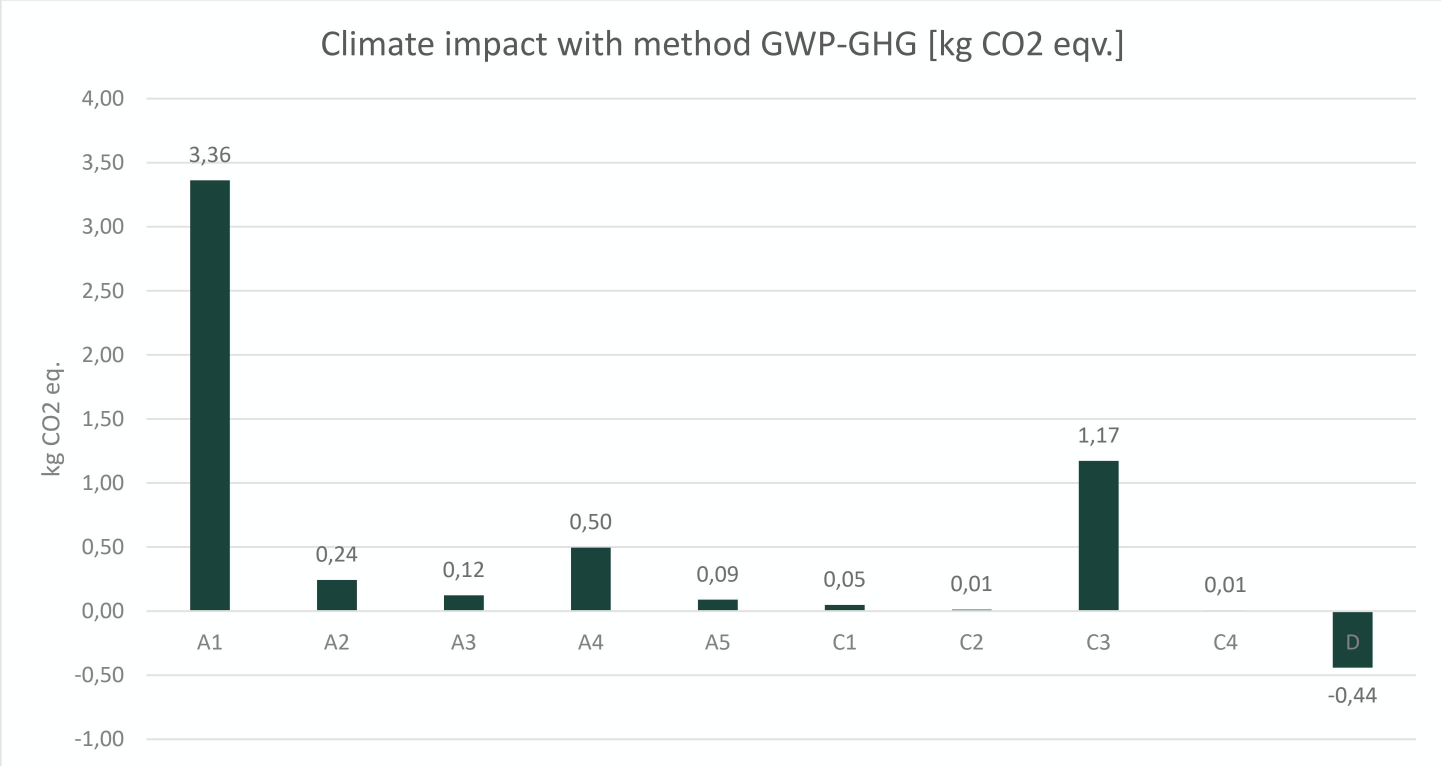


Figure 13: Climate impact per functional unit according to method GWP-GHG, per kg liner, Freeliner.

5.5 Use of resources and energy CED 1.11

The consumption of resources in terms of energy is measured as primary energy demand with the method Cumulative Energy Demand 1.11 (see Appendix 3).

Table 27: Use of resources and energy for module A-D, per functional unit, Liner, 225mm.

Para-meter	Unit	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
PERE	MJ	4,32E+00	5,25E-02	3,52E+00	7,89E+00	9,34E-02	6,80E-03	5,22E-03	2,26E-03	8,87E-03	2,16E-03	-1,94E+00
PERM	MJ	0,00E+00	0,00E+00	3,80E-01	3,80E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PERT	MJ	4,32E+00	5,25E-02	3,90E+00	8,27E+00	9,34E-02	6,80E-03	0,00E+00	2,26E-03	8,87E-03	2,16E-03	-1,94E+00
PENRE	MJ	6,48E+01	3,64E+00	4,38E-01	6,89E+01	7,22E+00	6,52E-01	6,68E-01	1,79E-01	2,35E-01	1,35E-01	-1,06E+01
PENRM	MJ	2,02E+01	0,00E+00	0,00E+00	2,02E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PENRT	MJ	8,50E+01	3,64E+00	4,38E-01	8,91E+01	7,22E+00	6,52E-01	0,00E+00	1,79E-01	2,35E-01	1,35E-01	-1,06E+01
SM	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	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
FW	m3	2,24E-02	6,14E-04	3,27E-04	2,33E-02	2,97E-04	2,18E-04	6,71E-05	2,87E-05	1,95E-03	1,31E-04	-3,41E-03
Abbrevi-ations	PERE = use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total Use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total Use of non-renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels; FW = use of net fresh water											

Table 28: Use of resources and energy for module A-D, per functional unit, Freeliner, 225mm.

Para-meter	Unit	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
PERE	MJ	7,93E+00	5,25E-02	3,52E+00	1,15E+01	9,34E-02	6,80E-03	5,22E-03	2,26E-03	8,87E-03	2,16E-03	-1,94E+00
PERM	MJ	0,00E+00	0,00E+00	3,80E-01	3,80E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PERT	MJ	7,93E+00	5,25E-02	3,90E+00	1,19E+01	9,34E-02	6,80E-03	0,00E+00	2,26E-03	8,87E-03	2,16E-03	-1,94E+00
PENRE	MJ	6,42E+01	3,64E+00	4,38E-01	6,83E+01	7,22E+00	6,52E-01	6,68E-01	1,79E-01	2,35E-01	1,35E-01	-1,06E+01
PENRM	MJ	2,02E+01	0,00E+00	0,00E+00	2,02E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
PENRT	MJ	8,44E+01	3,64E+00	4,38E-01	8,85E+01	7,22E+00	6,52E-01	0,00E+00	1,79E-01	2,35E-01	1,35E-01	-1,06E+01
SM	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	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
FW	m3	5,50E-02	6,14E-04	3,27E-04	5,59E-02	2,97E-04	2,18E-04	6,71E-05	2,87E-05	1,61E-03	1,31E-04	-3,41E-03
Abbrevi-ations	PERE = use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total Use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total Use of non-renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels; FW = use of net fresh water											

5.6 Waste production and output flows

Waste and other output flows that are leaving the system (for which the environmental impact of further processing is not included in the results) shall be declared. As all waste flows are included in the model, no values for waste flows leaving the system are presented here.

Table 29: Waste production for module A1-D, per functional unit, Liner, 225mm

Indicator	Unit	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
Hazardous waste	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Hazardous waste	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Radioactive waste	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 30: Waste production for module A1-D, per functional unit, Freeliner, 225mm

Indicator	Unit	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
Hazardous waste	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Hazardous waste	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Radioactive waste	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 31: Output flows for module A-D, per functional unit, Liner, 225mm

Indicator	Unit	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
Components for reuse	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Material for recycling	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Materials for energy recovery	kg	0.00	0.00	0	0	0.00	0	0.00	0.00	0	0.00	0.00
Exported energy, electricity	MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported energy, thermal	MJ	0.00	0.00	1,51	1,51	0.00	2,16	0.00	0.00	15,94	0.00	0.00

Energy recovery of waste has been adjusted using the specific heat capacity of the materials (wood 16,6 MJ/kg and plastic mix 36 MJ/kg) going the incineration and listing the results as export of thermal energy.

Table 32: Output flows for module A-D, per functional unit, Freeliner, 225mm

Indicator	Unit	A1	A2	A3	A1-A3	A4	A5	C1	C2	C3	C4	D
Components for reuse	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Material for recycling	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Materials for energy recovery	kg	0.00	0.00	0.04	0.04	0.00	0.07	0.00	0.00	0.44	0.00	0.00
Exported energy, electricity	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported energy, thermal	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5.7 Biogenic carbon content

The carbon content in the packaging (wood) is calculated based on an assumed moisture content of 12% and an and assumed carbon content of 50%.

Table 33: Shows the biogenic carbon content of the product and the product packaging, per kg liner.

Share of biogenic carbon	Unit	Amount
Biogenic carbon in the product	kg C	0,0
Biogenic carbon in the packaging	kg C	0,083

6 Interpretation

This section covers the key aspects of the results, sensitivity analyses and an evaluation of the model and underlying data.

6.1 Key aspects of results

The most influential impact categories are climate impact, resource use minerals and metals, and resource use fossils.

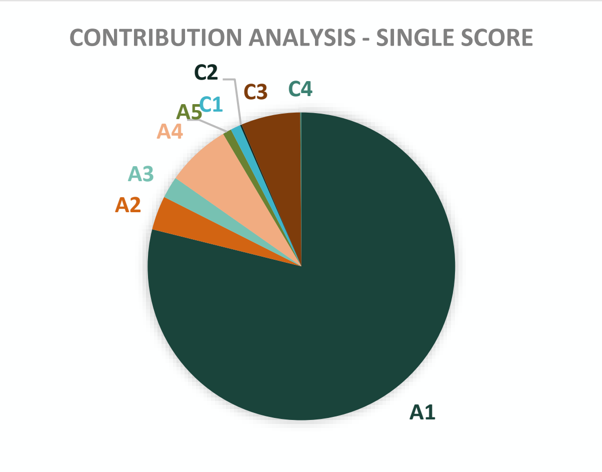


Figure 14: Contribution analysis - Single score. Based on results from Inpipe Liner, 225mm

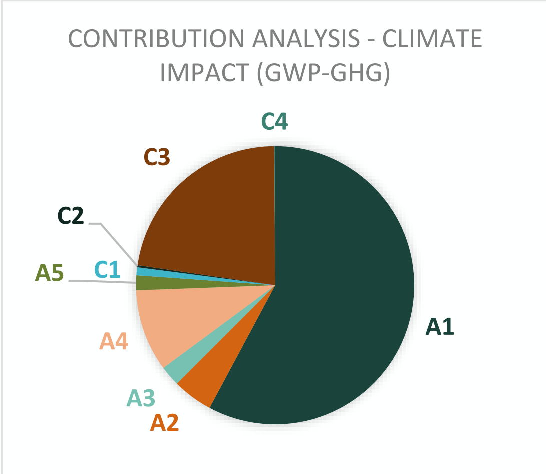


Figure 15: Contribution analysis - Climate impact (GWP-GHG). Based on results from Inpipe Liner, 225mm

Main environmental impact lies in production of raw materials used in the liner (module A1) - 90% of total environmental impact and around 70% of the climate impact. The majority of this stems from the production of glass fiber and the production of polyester. About 25% of the climate impact comes from incineration of polyester and plastic film at product EoL (C3). The environmental impact from transport of raw materials, manufacturing at Inpipe's facilities and transport to customer is small in comparison.

For the impact category resource use minerals and metals, the glass fiber production is responsible for most of the impact, whereas the polyester resins have a higher impact if we are looking at resource use fossils and climate impact (polyester production is responsible for around 40% of the climate impact). Resource use fossils and climate impact are both related to use of fossil resources. For chemicals the climate impact is often related to fossil electricity use in the production/processing throughout the value chain.

6.2 Sensitivity analysis

LCA provides a holistic perspective on an entire system. To succeed in this ambitious goal, certain simplifications and value-based choices to cover the entire system are required. By changing these choices, one can, based on the result, assess its relevance and whether there is a reason to revise the assumptions or choices that have been made.

For one of the chemicals used in production of the polyester in Freeliner, no generic data could be found. This chemical has been modelled based on literature, using a combination of generic datasets for other chemicals. A sensitivity analysis (available only in the confidential appendix) of the modelling assumptions shows that the uncertainty of modelling this chemical is high (the climate impact of that chemical varies with -24% to +36% from the result used in the study). This results in a variation of -8% to +12% for module A1. However, we argue that the baseline modelling is a reasonable modelling choice, as it is in the middle of the result span, is the most likely scenario with respect to large scale production and prices of input raw materials as well as giving a similar result compared to other similar substances. In further studies, specific data on the production of this chemical should be collected to decrease the uncertainty.

6.3 Data quality assessment

An evaluation of the model and underlying data is made by a data quality assessment which includes a completeness check, assessing validity of data and a consistency check. Further, the data quality is checked based on the data quality level and criteria of the UN Environment Global Guidance on LCA database development (as described in EN15804:2012+A2:2019, Annex E). The concluded results are found in Table 34.

Data for the LCI has been collected from Inpipe. Inpipe has provided specific data on ingoing raw materials, the transport modes and distances of raw materials, and on resource use, waste and emissions related manufacturing in their own facilities. No specific data on supplier production could be gathered, but supplier specific compositions of the polyester resins was gathered from Inpipes supplier AOC resins. The data gathered from Inpipe is based on measurements representing the last year's production.

Table 34: Data quality assessment for the study.

Aspect	Notes
Geographical coverage	Upstream data: Good (Generic data that represents the region of production) Core module (A3): Very good (site-specific)
Technological representativeness	Upstream data: Good (Raw materials are modelled with generic data based on average technology. The polyesters are modelled based on specific recipes and modelled with generic LCA data on ingoing substances and production) *Uncertainty regarding technological representativeness of upstream data (checked in sensitivity analysis):* - No match in generic data could be found for one of the chemicals used in the production of the Freeliner polyester. This chemical has been modelled based on literature, using a mix of other generic datasets. The modelling of this chemical induces an uncertainty of -8 to +12% (climate impact) in A1. Production at Inpipe: Very good (site-specific based on measurements and production data representative for the last year)
Time-related coverage	Upstream data: Poor-Very good (see also Table 35) . All datasets were valid at the point of calculation. - Freeliner polyester: Poor

Aspect	Notes
	- Liner polyester: Good-Very good - Glass fibre: Very good - PE film: Very good - PA film: Good Production at Inpipe: Very good (Based on current measurements and production data representative for the last year)
Validity	The technological and geographical coverage of the data chosen reflects the physical reality of the product system modelled. All the primary data from Inpipe has been validated by Inpipe.
Plausibility	The result has been compared to earlier EPDs on similar liners from other manufacturers, which give similar results.
Precision	Material and energy flow quantified based on generic data from the ecoinvent 3.9 database (one dataset from Industry Data 2.0)
Completeness	Data accounts for all known sub-processes within the system boundary, except for the exclusions mentioned in Table 3. Upstream processes were modelled using generic data from the ecoinvent 3.9 database, and one dataset from Industry data 2.0
Consistency, allocation method, etc.	Ecoinvent cut-off datasets were used – these datasets are consistent with the allocation regarding waste treatment and regarding multiple output specified in 3.3.4. One dataset from Industry data 2.0 was used – this data coheres with the system boundaries of Ecoinvent.
Completeness and treatment of missing data	No data is found missing.
Final result of data quality assessment	Data quality as required in EN15804 is met.

Table 35: Data quality assessment of main raw materials

	Geographical coverage	Technological representativeness	Time-related coverage
Polyester resin "Freeliner"	Good (average data from larger area in which the area under study is included)	Good. Generic data on average technology	Poor. Most influential chemicals: Poor (about 60% of climate impact). Good (17%). Very good (8%)
Polyester resin "Liner"	Good (average data from larger area in which the area under study is included)	Good. Generic data on average technology	Good-Very good. Most influential chemicals: Very good (42% of climate impact).Good (36%). Poor (11%)
Glass fibre	Good (average data from larger area in which the area under study is included)	Good. Generic data on average technology	Very good. Last edited 2022
Film (polyethylene)	Good (average data from larger area in	Good. Generic data on average technology	Very good. Last edited 2022.

	Geographical coverage	Technological representativeness	Time-related coverage
	which the area under study is included)		
Film (polyamide)	Good (average data from larger area in which the area under study is included)	Good. Generic data on average technology	Good. Last edited 2019

6.3.1 Uncertainty analysis

Uncertainty analysis is performed in two ways. Monte Carlo analysis will be performed to take into account the uncertainty in the inventory data obtained from the ecoinvent database. Uncertainty concerning specific data and assumptions are analysed in a sensitivity analysis described under 6.2.

Monte Carlo simulation was performed using the SimaPro software. For each inventory input or output that contains a distribution and standard deviation, a random value that falls in the distribution range is selected in numerous iterations. The LCA results are recalculated for each iteration. A histogram showing the probability of the results of the climate change impact (GWP-GHG), performed with 1000 iterations and presented in Figure 16 and details in Table 36.

Figure 16: Show the distribution of results from the Monte Carlo analysis, for Freeliner 225mm

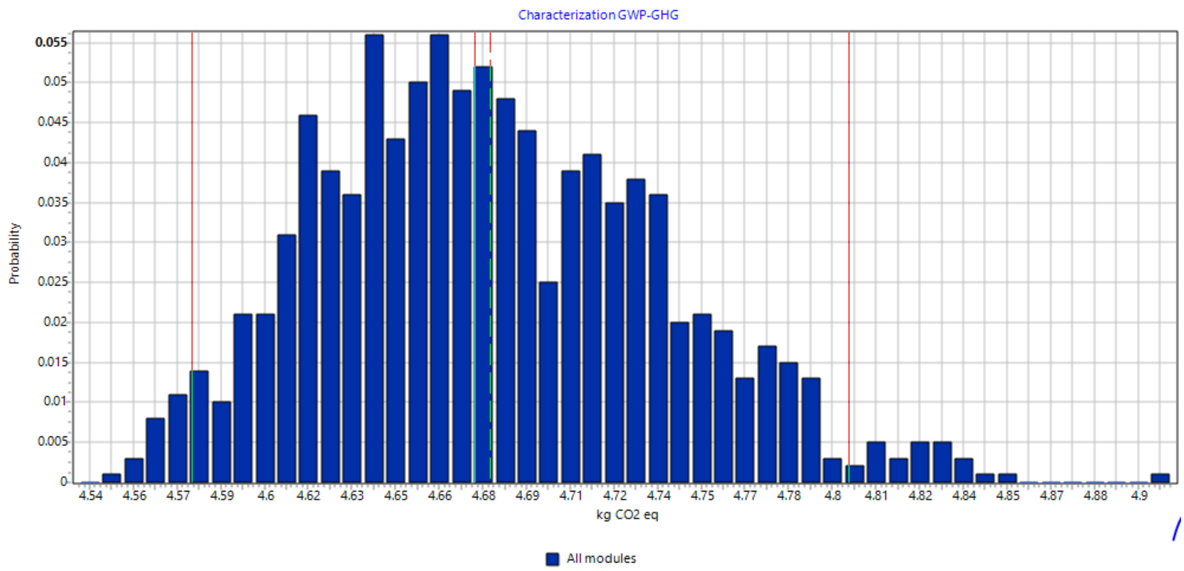


Table 36: Details concerning the Monte Carlo analysis, for Freeliner 225mm

Mean	Median	Standard deviation	Coefficent of variation %	Low 2.5%	High 97.5%	Standard error of mean
4.68	4.67	0.0575	1.23	4.58	4.8	0.00182

The uncertainty is considered good for a complex LCA study.

Figure 17: Show the distribution of results from the Monte Carlo analysis, for Liner 225mm

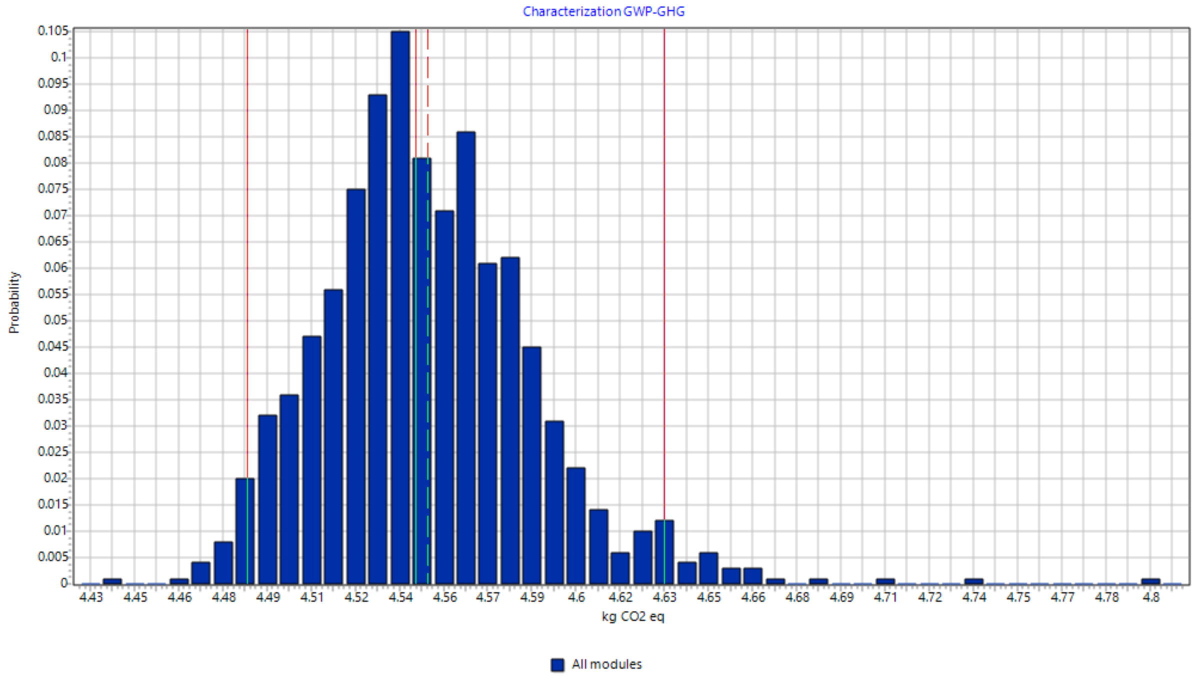


Table 37: Details concerning the Monte Carlo analysis, for Liner 225mm

Mean	Median	Standard deviation	Coefficent of variation %	Low 2.5%	High 97.5%	Standard error of mean
4.55	4.55	0.0368	0.808	4.49	4.63	0.00116

The uncertainty is considered good for a complex LCA study.

6.4 Limitations

Notes and disclaimers:

- Note that the LCIA results are relative expressions, which means that they do not predict impacts on category endpoints or the exceeding of thresholds, safety margins or risk.
- The results of the environmental impact indicators for ADPE, ADPF, WDP, ETP-FW, HTP-C, and HTP-NC shall be used with care as the uncertainties of these results are high or as there is limited experience with the indicator.
- The impact category for IR deals mainly with the eventual impact of low dose ionising 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 ionising radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

7 Conclusions and recommendations

This section highlights the most important aspects of the results and the interpretation, as well as recommendations on how to mitigate the hot spots.

1. The most influential impact categories are climate impact, resource use minerals and metals, and resource use fossils.

2. The main environmental impact of the liners comes from production of raw materials (module A1)
    a. Raw material production is responsible for around 90% of the total environmental impact (single score) and around 70% of the climate impact.
        i. Glass fiber production is responsible for most of the impact of the impact category resource use minerals and metals
        ii. The production of polyester resins is responsible for most of the impact on resource use fossils and climate impact
        iii. About 40% of the climate impact is related to the polyester production, about 25% from glass fibre production and 6% of the climate impact is related to plastic film production.
3. The life cycle phase with the second highest climate impact is waste treatment (C3)
    a. About 25% of the climate impact comes from incineration of polyester and plastic film at product EoL.
4. The environmental impact from the other life cycle phases (such as transport of raw materials, manufacturing at Inpipe's facilities and transport to customer) is small in comparison to raw material production (A1) and waste treatment (C3).
5. The largest uncertainty in the study regards the modelling of the Freeliner polyester – a sensitivity analysis showed that the modelling assumption can affect the climate impact results for A1 with -8 to +12%.

7.1 Recommendation on how to mitigate the hot spots

For a product such as Inpipe's liners where the main environmental impact is related to the raw material, reducing material use and reducing spillage is the most certain way to reduce the environmental impact – it reduces the impact of production of the material as well as the impact from waste treatment of the material. Another very efficient measure is to work with prolonging the life of the product – this requires less material for the same functionality.

Another important aspect for Inpipe is to work with suppliers with low environmental impact. The impact categories "Resource use fossils" and climate impact are both related to use of fossil resources. For resins this is often related to petroleum-based substances (styrene, polymers) but also to a large extent to fossil electricity use in the production/processing throughout the value chain. The impact can be lowered by sourcing from suppliers in regions with lower climate impact per produced kWh electricity and by making sure that your suppliers also work with suppliers with low climate impact in their production. One way to work with lowering the environmental impact from purchased goods is to look for suppliers with a product with proven low environmental impact (supported by for example a third party reviewed LCA or EPD). Glass fibre production is an energy intensive process, and two thirds of the climate impact of glass fibre production comes from energy use. Thus, the climate impact can be substantially lowered if non-fossil energy sources are used in production, or if the supplier has an energy efficient production.

The incineration of the polyester and plastic films at the product end of life causes about 25% of the climate impact. Finding a solution that makes it possible to recycle more material in EoL would mean that the impact of incineration would be lowered and would most likely result in a higher credit in module D – a lower environmental impact for the future user of the recycled material.

7.2 How to reduce uncertainties

The uncertainty of the study can be lowered with more specific data on the production of the polyester resins and, especially, specific or better generic data on the chemicals used in the production of the Freeliner polyester. Specific data on the glass fibre production would also increase the precision of the study.

7.3 Internal follow-up procedures

For EPDs, internal follow-up procedures shall be established to confirm whether the information in the EPD remains valid or if the EPD needs to be updated during its validity period. The GPI state that the main parameters that may mandate an update shall be identified through a sensitivity analysis. The established procedure may or may not involve a contracted verifier. The follow-up shall be at least annually and should be made with a frequency that will allow for an acceptable coverage of changes that might occur.

The procedure should include how the organisation monitors any significant changes that have taken place in the information submitted as input data for the information in the EPD, such as raw material acquisition, transportation modes, manufacturing processes, changes in product design, or updated legislation. The follow-up procedure may be made part of an existing quality or environmental management system.

8 Bibliography

Böckin, D., Goffetti, G., Baumann, H., & Zobel, T. (2020). *Environmental assessment of two business models Division of Environmental Systems Analysis.*
CEN. (2019a). *EN 15804:2012+A2:2019, Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.*
CEN. (2019b). *EN 15804:2012+A2:2019, Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.*
EPD International. (2021). *General Programme Instructions for the International EPD® System. Version 4.0.*
EPD International. (2022). *PCR 2019:14, Construction Products, version 1.2.5.* www.environdec.com.
Frischknecht, R., Jungbluth, N., Althaus, H. J., Doka, G., Dones, R., Hischier, R., Hellweg, S., Humbert, S., Margni, M., Nemecek, T., & Spielmann, M. (2007). *Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3.*
Guinée, J., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Koning, A., Oers, L., Wegener Sleeswijk, A., Suh, S., Haes, H., Bruijn, H., van Duin, R., & Huijbregts, Mark. (2002). *Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards.*
Inpipe. (2023). *Inpipe LCA Datasheet P92 - 2023-04-26.*
ISO. (2006a). *ISO 14025:2006, Environmental labels and declarations – Type III environmental declarations – Principles and procedures.*
ISO. (2006b). *ISO 14040:2006, Environmental management — Life cycle assessment — Principles and framework.*
ISO. (2006c). *ISO 14044:2006, Environmental management — Life cycle assessment — Requirements and guidelines* (pp. 1–54).
ISO. (2012a). *ISO/TR 14049:2012, Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis.*
ISO. (2012b). *ISO/TS 14047, Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situations.*
PRé Sustainability. (2022). *SimaPro* (9.4). PRé Sustainability B.V. https://simapro.com/
Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W. P., Suh, S., Weidema, B. P., & Pennington, D. W. (2004). Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, *30*(5), 701–720. https://doi.org/10.1016/j.envint.2003.11.005
Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223). https://doi.org/10.1126/science.1259855
Tillman, A.-M., Ljunggren Söderman, M., André, H., Böckin, D., & Willskytt, S. (2020). *Circular economy and its impact on use of natural resources and the environment - Chapter from the upcoming book “Resource-Efficient and Effective Solutions – A handbook on how to develop and provide them.”*

Appendix 1 Basics of Life Cycle Assessment

There are four phases in an LCA study; the goal and scope definition phase, the inventory analysis phase, the impact assessment phase and the interpretation phase. Below is a conceptual picture of this in Figure 18. In sections Appendix 1A - Appendix 1D further details on each life cycle phase are presented.

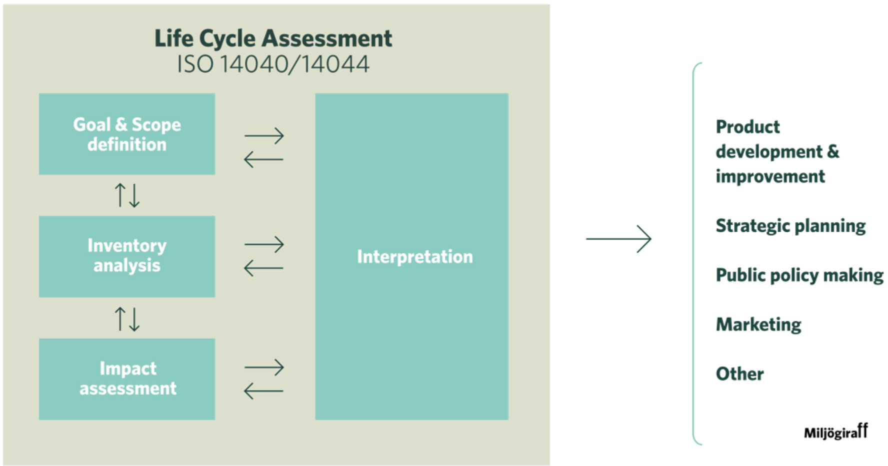


Figure 18. The four phases of the Life Cycle Assessment

A. Goal and scope definition

The first phase is the definition of goal and scope. The goal and scope, including system boundary and level of detail, of an LCA depend on the subject and the intended use of the study. The depth and breadth of LCA can differ considerably depending on the goal of a particular LCA. The goal also affects the choice of system boundaries and data requirements. See further details below.

i. System boundary

The system boundary determines which modules and activities are included within the LCA. The selection of the system boundary shall be consistent with the goal of the study. A system boundary chosen to include all contributing processes for the system while facilitating the modelling and analysis of the system. Therefore, there may be reasons to exclude activities that contribute insignificantly to the environmental effects (so-called "cut-off"). However, the omission of life cycle stages, processes, inputs, or outputs is permitted only if it does not significantly change the study's overall conclusions. It should be clearly stated if life cycle stages, processes, inputs, or outputs are not included; and the reasons and implications for their exclusion must be explained.

When the life cycle is defined by the system boundary, the environmental aspects included, and the data used to represent the different aspects is in detail described under the LCI part.

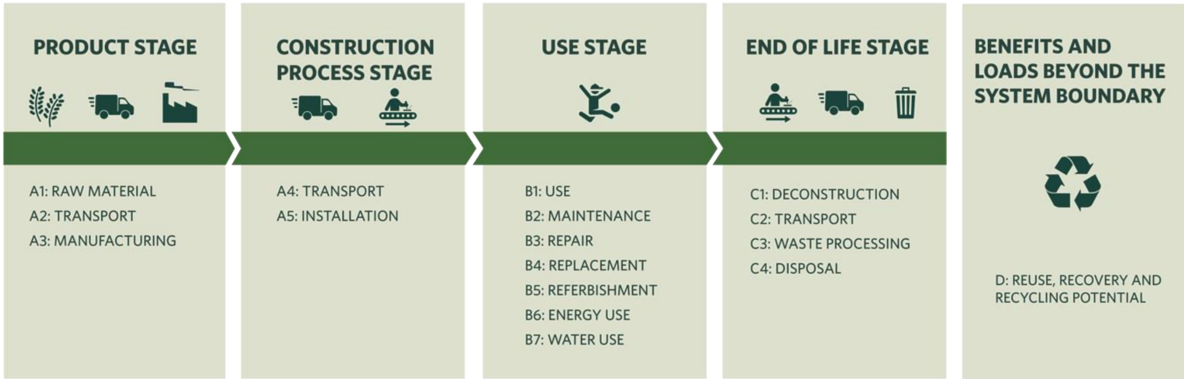


Figure 19: General summary of the modules included in an LCA, based on EN 15804.

In this LCA, boundaries with other systems, and the allocation of environmental burdens between them, are based on the recommendations of the international EPD system[6], which are also in line with the requirements and guidelines of the ISO14040/14044 standards. Following these recommendations, the Polluter Pays (PP) allocation method is applied (see Figure 20). For the allocation of environmental burdens when incinerating waste, all processes in the waste treatment phase, including emissions from the incineration, are allocated to the life cycle in which the waste is generated. Subsequent procedures for refining energy or materials to be used as input in a following/receiving process are allocated to the next life cycle.

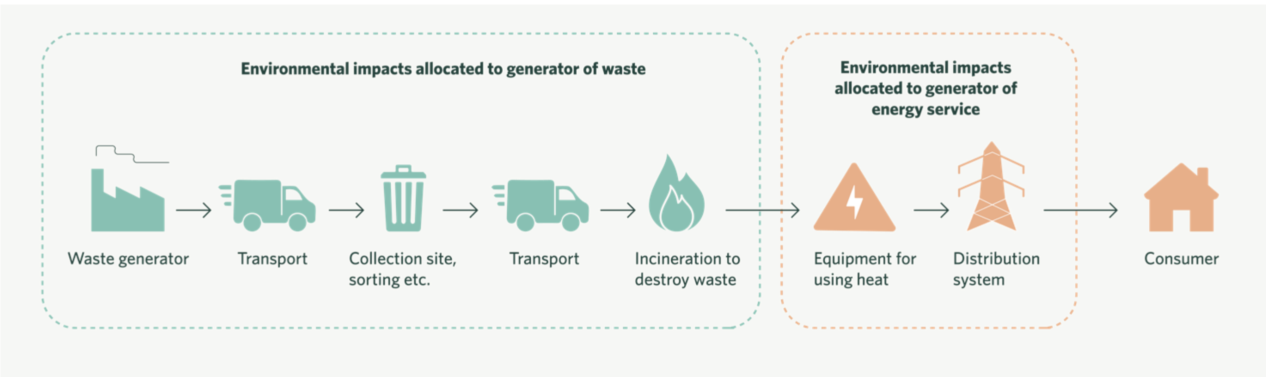


Figure 20: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here in regard to the incineration of waste and resulting energy products.

In the case of recycling, environmental burdens are accounted for outside of the generating life cycle. They have thus been allocated to the subsequent life cycle, which uses the recycled materials as input.

Avoided materials due to recycling are typically not considered in the main scenario, per the International EPD system's recommendation of the Polluter Pays Principle. In other words, only if

[6] EPD (Environmental Product Declarations) by EPD International®

the generating life cycle uses recycled material as input material will it account for the benefits of recycling.

ii. Cut-off

It is common to scan for the most important factors (a "cut off" of 95% is a minimum) to avoid putting time and effort into irrelevant parts of the life cycle. In general, LCA focuses on the essential material and energy flows, while the flows that can be considered negligible are excluded. By setting cut-off criteria, a lower limit is defined for the flows to be included. Flows below the limit can be assumed to have a negligible impact and are thus excluded from the study. For example, cut-off criteria can be determined for inflows concerning mass, energy, or outflows, e.g., waste.

iii. Allocation

The study shall identify the processes shared with other product systems as co-products, and deal with them according to the stepwise procedure presented below:

- **Step 1**: Wherever possible, the allocation should be avoided by dividing the unit process into two or more sub-processes and collecting the input and output data related to these sub-processes or expanding the product system to include the additional functions related to the co-products.
- **Step 2**: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e., they should reflect how the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.
- **Step 3**: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

When other allocation methods are used, it should be documented and assessed whether it may be significant to the results.

iv. Data requirements (DQR)

General LCI databases contain a large amount of third-party reviewed LCI data compiled according to the ISO 14048 standard. Certified LCI data forms a basis for a robust and transparent study. However, it is crucial to understand that specific producers may differ considerably from general practice and average data.

The LCI data can be either specific or general. Specific data means that all data concerning material, energy and waste are specifically modelled for the conditions at the manufacturing facility and the technology used. Generic data means that material or energy are represented using average LCI data from ecoinvent.

Specific data
1. Environmental Product Declarations (type III)
2. Collected data (web format, site visits and interviews).
3. Reported data (EMS, Internal data systems or spreadsheets)

Selected generic data
1. Close proxy with data on a similar product
2. Statistics
3. Public documents

Generic data
1. Public and verified libraries with LCI data

2. Trade organisations' libraries with LCI data

Sector-based IO data, national

B. Inventory analysis (LCI)

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.

C. Impact assessment (LCIA)

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance. Mandatory steps in the lifecycle impact assessment are classification and characterisation. An optional step is weighting.

Readymade methods for classification, characterisation and weighting have been used to evaluate environmental effects (either from a broad perspective or for a single issue) and find the categories or parts of a system with the most potential impact. Some of the most common LCIA methods are presented in Appendix 2 - Appendix 3.

Classification, characterisation and weighting will here be briefly explained.

i. Classification and characterisation

The process of determining what effects an environmental aspect can contribute to is called classification, e.g. that the use of water contributes to the environmental effect of water depletion, see Figure 21 for an illustration. The characterisation, in turn, means defining how much an environmental aspect contributes to the environmental impact category to which it is classified, e.g. the use of 1 tonne of river water contributes a factor of 0.5 to water depletion. Evaluating how critical it is in a specific area depends on the current environmental impact, the pressure from resource consumption and the ecosystem's carrying capacity. This is done through normalisation.

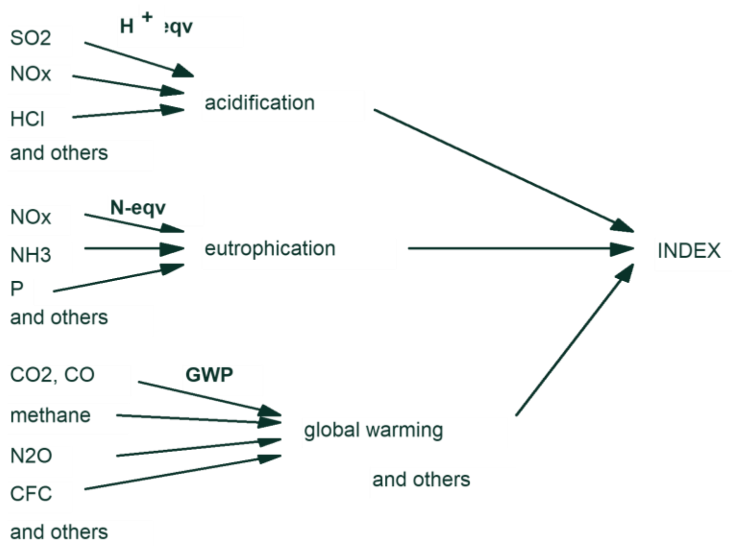


Figure 21: An illustration of the Impact Assessment of an LCA.

ii. Weighting

To compare different environmental effects and to identify "hot spots", so-called *weighting* is applied. The calculated environmental effects are weighted together to form an index called a "*single score*" which describes the total environmental impact.

Because weighting involves subjective weighting (e.g. by an expert panel), it is recommended for internal communication only. Otherwise, there is a risk of mistrust if the choice of weighting method used leads to results that emphasise the "upsides" and hide the "downsides" of the analysed product. For external communication, only *Single issues* should be communicated.

D. Interpretation

The life cycle interpretation phase of an LCA or an LCI study comprises several elements:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA
- an evaluation that considers completeness, sensitivity and consistency checks
- conclusions, limitations, and recommendations.

The interpretation of the results in this study is carried out by first identifying the aspects that contribute the most to each individual environmental effect category. After that, the sensitivity of these aspects is evaluated, and the completeness and consistency of the study are assessed. Conclusions and recommendations are then based on the results and a clear understanding of how the LCA was conducted with any subsequent limitations.

i. Evaluation of the results

The objectives of the evaluation element are to establish and enhance confidence and the reliability of the results of the LCA or the LCI study, including the significant issues identified in the first element of the interpretation. The evaluation should use the following three techniques:

- Completeness check
  The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete. If any relevant information is missing or incomplete, the necessity of such information for satisfying the goal and scope of the LCA shall be considered. This finding and its justification shall be recorded.
- Sensitivity check
  The objective of the sensitivity check is to assess the reliability of the final results and conclusions by determining how they are affected by uncertainties in the data, allocation methods or calculation of category indicator results, etc.
- Consistency check
  The objective of the consistency check is to determine whether the assumptions, methods and data are consistent with the goal and scope.
- Uncertainty check
  Is a systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability

Appendix 2 Environmental footprint 3.0

One of the most commonly used LCIA methods is the Environmental footprint 3.0 (EF3.0) method . It includes classification, characterisation and optional normalisation and weighting as well as the possibility to calculate a single score including all weighted impacts.

To give a brief description of each type of environmental impact, the impact categories from EF3.0 will now be summarised:

Acidification – EF impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

Climate change - Climate change is defined as the warming of the climate system due to human activities. Human activities emitting greenhouse gases (GHG) are the leading cause of global warming. GHG emissions have the property of absorbing radiation, resulting in a net warming effect called the greenhouse effect. These will then perturb the Earth's natural balance, increasing temperature and affecting the climate with disturbances in rainfall, extreme climate events and rising sea levels. Climate change is an impact affecting the environment on a global scale.
GHG sources can be classified of three main types: fossil sources, biogenic sources, and land use change. Fossil sources are formed from the decomposition of buried carbon-based organisms that died millions of years ago. Burning fossil sources leads to an increase in GHG in the atmosphere. Biogenic sources are often considered natural and refer to carbon taken up during the cultivation of a crop, considering that there is no net increase of carbon dioxide in the atmosphere. Another source of carbon dioxide emissions is the effect of land use on plant and soil carbon. For example, carbon is stored naturally in nature, and by changing the characteristics of a land area, this carbon is then released. Land use change hence measures the GHGs emissions that occur when changing the vegetation or other characteristics of the land used for a product's lifecycle.

Ecotoxicity, freshwater – Environmental footprint impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

Eutrophication – Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland and this affects the nutrient cycling in the aquatic and terrestrial ecosystems. Three EF impact categories are used to assess the impacts due to eutrophication: Eutrophication, terrestrial; Eutrophication, freshwater; Eutrophication, marine. In aquatic bodies, this accelerates the growth of algae and other vegetation in the water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Terrestrial vegetation can be affected by excess nitrogen, which can lead to changed tolerance to disease or other stressors like drought and frost. The three impact categories hence communicate which environment compartment the eutrophication occurs. Regardless of where it occurs, it changes the structure and function of ecosystems which may result in overall biodiversity and productivity changes.

Human toxicity, cancer – Impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food and water ingestion, penetration through the skin insofar as they are related to cancer.

Human toxicity, non-cancer– Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food and water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

Ionising radiation, human health – EF impact category that accounts for the adverse health effects on human health caused by radioactive releases.

Land use – The land use impact category reflects the damage to ecosystems due to the effects of occupation and transformation of the land. Although there are many links between the way land is used and the loss of biodiversity, this category concentrates on the following mechanisms:

1. Occupation of a certain area of land during a certain time;
2. Transformation of a certain area of land.

Both mechanisms can be combined, often occupation follows a transformation, but often occupation occurs in an area that has already been converted (transformed). In such cases, the transformation impact is not allocated to the production system that occupies an area.

Ozone depletion – EF impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example, long-lived chlorine and bromine-containing gases (e.g. CFCs, HCFCs, Halons).

Particulate matter formation – Fine Particulate Matter with a diameter of smaller than 10 µm (PM10) represents a complex mixture of organic and inorganic substances. PM10 causes health problems as it reaches the upper part of the airways and lungs when inhaled. Secondary PM10 aerosols are formed in the air from emissions of sulphur dioxide (SO2), ammonia (NH3), and nitrogen oxides (NOx), among others (World Health Organisation, 2003). Inhalation of different particulate sizes can cause different health problems.

Photochemical ozone formation – EF impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.
Resource use, fossil: Impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).

Resource use, minerals and metals: Impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals). When using these non-renewable resources, there is a decrease in the global stock. Depending on how large the global reserve is assessed to be and the extraction rate of the resource, this impact category regards how rare the mineral and metal are and how much is being used. Hence, this impact category measures the impacts on the gobal stocks of minerals and metals in the future.

Resource use, fossil: Impact category that addresses the use of non-renewable abiotic natural resources (fossil). Similar to resource use, minerals and metals, when using fossil fuels, there is a decrease in the global stock. Since the industrial revolution, we have created societies highly dependent on fossil resources. Fossil resources are today commonly used to power processes and transports throughout a product's lifecycle. This impact category aggregates this total use of fossil resources throughout the lifecycle. The use of fossil resources is strongly interlinked to many of the other impact categories like climate change, particulate matter formation, and acidification.

Water use – It represents the relative available water remaining per area in a watershed after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived (see also http://www.wulca-waterlca.org/aware.html).

i. LCA impact categories vs planetary boundaries

Global environmental impacts are sometimes discussed in terms of planetary boundaries (Steffen et al., 2015). It can be relevant to note that the impact categories used in LCA do not have a one-to-one correlation with the planetary boundaries as described by Steffen et al.
Table 38 maps the planetary boundaries to mid-point indicators in LCA (when possible) and classifies whether there is a high or low level of correspondence between the indicators.

Climate change, ozone depletion, eutrophication and human- and ecotoxicity are included in similar ways in the two frameworks (Böckin et al., 2020). However, the impact categories of photochemical ozone creation potential and respiratory effects in EF3.0 are meant to represent direct human health impacts. The corresponding planetary boundary is atmospheric aerosol loading, but this is instead mainly meant to represent the effects of monsoon rains. Furthermore, acidification in EF3.0 represents impacts from, e.g., nitrogen and sulphur oxides on land and water ecosystems, while ocean acidification in the planetary boundaries instead represents the effects of carbon dioxide being dissolved in oceans, thus lowering pH levels and affecting marine life. Moreover, the impact categories in EF3.0 does not include an indicator that matches the planetary boundary of biospheric integrity, while the closest category can be said to be land use since it is a driver of biodiversity loss. Lastly, there are some differences between land system change and freshwater use in the planetary boundaries and land use and water use in EF3.0, while the planetary boundaries do not include a category for abiotic resource depletion.

Table 38: Planetary boundaries and mid-point environmental impact indicators in LCA recommended by EF3.0. Adapted from (Tillman et al., 2020).

Planetary boundaries	Mid-point indicators in LCA as per EF3.0	Level of correspondence between impact categories
Climate change	Climate change	High level of correspondence
Stratospheric ozone depletion	Ozone layer depletion	
Biogeochemical flows (nitrogen and phosphorus cycles)	Freshwater, marine and terrestrial eutrophication	
Novel entities (chemical pollution)	Freshwater ecotoxicity	
	Human toxicity (cancer and noncancer)	
Atmospheric aerosol loading	Photochemical ozone creation	Some correspondence
	Respiratory effects, inorganic	
Ocean acidification	Freshwater acidification	
Biospheric integrity (biodiversity loss)	Resources land use	

Land system change	Resources land use	
Freshwater Use	Resources dissipated water	
-	Resources minerals and metals	No correspondence
-	Resources fossils	
-	Ionising radiation	

Appendix 3 Cumulative Energy Demand, CED

Cumulative Energy Demand (CED) is a method to calculate direct and indirect use of energy resources, commonly referred to as *primary energy*. Characterisation factors are given for the energy resources divided into five impact categories:

- Non-renewable, fossil
- Non-renewable, nuclear
- Renewable, biomass
- Renewable, wind, solar, geothermal
- Renewable, water

Some studies also add energy from waste as an indicator. This is not done here, since waste is not considered to be primary energy, and thus the input of energy resources may be less than the final energy (heat and electricity) delivered by the system.

Normalisation is not a part of this method. To get a total ("cumulative") energy demand, each impact category is given the weighting factor 1 (Frischknecht et al., 2007)

Appendix 4 Guarantees of Origin

Nordic Green Energy

BOX 4013, STOCKHOLM 10261
Switch Nordic Green AB

Specifikation 2(2)
Kundnummer: 291459
Fakturanummer: 1004292842
OCR-nummer: 1291459000100283
Fakturadatum: 2023-04-03

ERT AVTAL
Avtalstid, t o m 2026-12-31

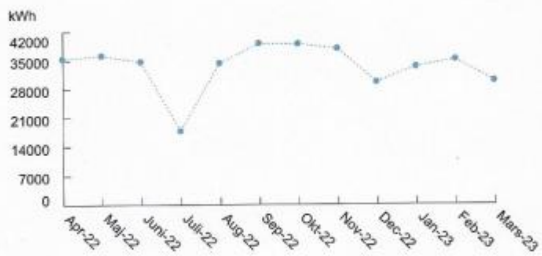
Se din avtalsinformation på Mina sidor
minasidor.nordicgreen.se

ANLÄGGNINGSUPPGIFTER
Anläggningsid: 735 999 100 056 756 923
Adress: INDUSTRI EKORRV. 12 VILHELMINA, 91232 VILHELMINA
Nätområde: VMA
Elprisområde: SE2 Sundsvall
Beräknad årsförbrukning: 405 062 kWh
Mätarnummer: 887624210073978

Specifikation

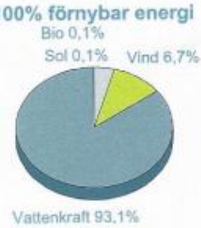
Energi	Antal	Pris exkl moms	Belopp
Förbrukning, 2023-03-01-2023-03-31	30 006 kWh	29,54 öre/kWh	8 863,78 kr
Svk volymavgift & effektreserv, 2023-03-01-2023-03-31	30 006 kWh	0,40 öre/kWh	120,02 kr
		Summa energi	**8 983,80 kr**
		Moms (25% momsgrundande belopp 8 983,80 kr)	**2 245,95 kr**
		Totalt	**11 229,75 kr**

HISTORIK FÖRBRUKNING



ENERGIMIX NORDIC GREEN ENERGY

100% förnybar energi



0g CO2 utsläpp av försåld el

Appendix 5 Differences in inventory data and LCIA results for different liner dimensions

This section describes the differences in inventory data for different liner dimensions, as well as the difference in environmental impact results between the two extremes – 150mm and 1800mm.

The following differences exists:

- Raw materials: The amount of film per kg liner is lower for thicker liners, as the film thickness is the same in all liners. This means that the raw material composition per kg is slightly different.
- Transport of raw materials: Changes slightly as the raw material composition changes.
- Installation:
  - Energy in installation: For the 1100 mm and 1800mm liner, a diesel fuelled winch is used in installation and the electricity use per kg is lower, as the relation between liner weight and curing area differs with sizes
  - Installation waste: The amount of film disposed of in the installation is lower in thicker liners, per kg liner.
- End-of-life:
  - C3 and C4: The amount of glass fibre per kg liner is slightly higher for the thicker liners, whereas the amount of plastic film is slightly lower. As these two almost cancel each other out, the amount of material going to sanitary landfill (glass fibre) and to incineration (polyester and plastic film) is almost identical for the different dimensions.
  - D: Adjusted according to the difference in C3 and C4 described above.

The difference in environmental impact between a liner with dimension 150mm and 1800mm is shown in the tables below. The difference in impact for A1-C4 is below 10% in all impact categories.

Table 39: Comparison of results for dimensions 150mm and 1800mm – Freeliner

	150	1800	150/1800
Climate change	5,15E+00	5,17E+00	99%
Climate change - Fossil	5,14E+00	5,17E+00	99%
Climate change - Biogenic	-2,19E-03	-2,12E-03	103%
Climate change - Land use and LU change	5,71E-03	5,89E-03	97%
Ozone depletion	2,00E-07	2,10E-07	95%
Acidification	2,46E-02	2,50E-02	98%
Eutrophication, freshwater	1,60E-04	1,63E-04	99%
Eutrophication, marine	4,81E-03	4,99E-03	96%
Eutrophication, terrestrial	5,09E-02	5,29E-02	96%
Photochemical ozone formation	1,84E-02	1,88E-02	98%
Resource use, minerals and metals	1,58E-04	1,66E-04	95%
Resource use, fossils	6,94E+01	6,72E+01	103%
Water use	2,85E+00	2,88E+00	99%
Particulate matter	2,38E-07	2,34E-07	102%
Ionising radiation	1,48E-01	1,52E-01	98%
Ecotoxicity, freshwater - part 1	4,18E+01	4,41E+01	95%
Ecotoxicity, freshwater - part 2	7,49E+00	7,70E+00	97%
Ecotoxicity, freshwater - inorganics	4,44E+01	4,66E+01	95%
Ecotoxicity, freshwater - organics - p.1	3,00E+00	3,15E+00	95%

Ecotoxicity, freshwater - organics - p.2	1,94E+00	2,02E+00	96%
Human toxicity, cancer	3,96E-09	4,06E-09	97%
Human toxicity, cancer - inorganics	1,79E-09	1,86E-09	96%
Human toxicity, cancer - organics	2,17E-09	2,20E-09	98%
Human toxicity, non-cancer	1,03E-07	1,08E-07	95%
Human toxicity, non-cancer - inorganics	9,96E-08	1,05E-07	95%
Human toxicity, non-cancer - organics	3,22E-09	3,25E-09	99%
Land use	3,76E+01	3,76E+01	100%
GWP-GHG	5,15E+00	5,18E+00	99%

Table 40: Comparison of results for dimensions 150mm and 1800mm – Liner

	150	1800	150/1800
Climate change	5,02E+00	4,82E+00	104%
Climate change - Fossil	5,01E+00	4,81E+00	104%
Climate change - Biogenic	7,20E-03	7,30E-03	99%
Climate change - Land use and LU change	2,70E-03	2,71E-03	100%
Ozone depletion	1,82E-06	1,92E-06	95%
Acidification	1,94E-02	1,95E-02	99%
Eutrophication, freshwater	8,47E-04	8,53E-04	99%
Eutrophication, marine	4,11E-03	4,21E-03	98%
Eutrophication, terrestrial	4,35E-02	4,49E-02	97%
Photochemical ozone formation	1,71E-02	1,73E-02	99%
Resource use, minerals and metals	1,49E-04	1,57E-04	95%
Resource use, fossils	6,99E+01	6,78E+01	103%
Water use	1,42E+00	1,36E+00	104%
Particulate matter	1,99E-07	1,92E-07	103%
Ionising radiation	3,30E-01	3,35E-01	99%
Ecotoxicity, freshwater - part 1	4,80E+01	5,02E+01	96%
Ecotoxicity, freshwater - part 2	5,11E+00	5,18E+00	99%
Ecotoxicity, freshwater - inorganics	5,23E+01	5,45E+01	96%
Ecotoxicity, freshwater - organics - p.1	2,81E-01	2,80E-01	100%
Ecotoxicity, freshwater - organics - p.2	6,05E-01	6,12E-01	99%
Human toxicity, cancer	4,74E-09	4,87E-09	97%
Human toxicity, cancer - inorganics	1,65E-09	1,69E-09	97%
Human toxicity, cancer - organics	3,09E-09	3,18E-09	97%
Human toxicity, non-cancer	9,15E-08	9,52E-08	96%
Human toxicity, non-cancer - inorganics	8,91E-08	9,28E-08	96%
Human toxicity, non-cancer - organics	2,38E-09	2,36E-09	101%

Land use	3,24E+01	3,21E+01	101%
GWP-GHG	5,02E+00	4,82E+00	104%