Life Cycle Assessment of a chair seat by PaperShell

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Miljögiraff

Table of Contents

Ordered by: PaperShell AB
PaperShell AB was founded in 2021 but the idea behind PaperShell was born in 2018. We have the core belief that the solution to the climate crisis and a sustainable management of resources is found in nature. We're building paper back into a more resistant version of wood.

Our goal is to offer sustainable, high tech, long lasting and load bearing B2B components based on ingredients found in wood and plants. We're taking a pioneering role in the transformation towards a local and circular biobased society. PaperShell aims to replace fossil-based materials with bio-carbon solutions without compromising on nature's balance or performance.

We're a diverse and purpose-driven team cross breeding design, science and industrial technology. Inspired by nature's 3.8 billion years of bio intelligence we're creating high tech, artificially engineered wood components with the potential to replace bulk materials like press moulded veneer, plastics, fiber composites and even metals.

PaperShell is growing fast and organic. We work closely with scientists in EU with ongoing and deep collaboration with the research institute of Sweden (RISE). In Tibro, Sweden we have our pilot plant where we do co-development projects and R&D with a maximum capacity of 60 000 components per year. In 2023 we will launch our first highly automated and flexible factory with a maximum capacity of 700 000 components per year.

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

APOS – Allocation at the point of substitution (system model in ecoinvent)
CO_2 eq – Carbon dioxide equivalents
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.
EPD – Environmental Product Declaration
GFRP – Glass fibre reinforced polymer
GWP – Global Warming Potential
GLO – Global
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
PP - Polypropylene
RER – The European region
RoW – Rest of the world

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

Life cycle assessment (LCA) is a standardised 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.

This report presents the results for the environmental impacts calculated for a chair seat produced by PaperShell. The assessment is carried out according to a life cycle perspective using the ISO 14040 standard.

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 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

PaperShell aims to make components that are more environmentally friendly than press moulded veneer, weather resistant as plastic and strong as fiber composites. First out is a load bearing material solution that resembles an artificially engineered and exclusive wood.

The PaperShell components are made by press moulding, or inflation bladder moulding, to create 3D surfaces that are hard and load bearing for indoor and outdoor products. A natural fiber composite solution to replace press moulded veneer, plastic details, fiber composites or even press moulded metal. The solution is based on industry 4.0[1] production with advantages that enables a highly automated and flexible production.

The PaperShell material can be used for products in various shapes, for example flat, single curved, double curved/sphere. The material can also have properties such as heat resistance, UV resistance and scratch resistance etc. See the webpage papershell.se/material for more information on the material. Several pilot projects where the material is utilized are already ongoing, see papershell.se/news.

[1] https://en.wikipedia.org/wiki/Fourth_Industrial_Revolution

PaperShell's production is in early stages of scaling up production, with manufacturing facilities under construction. The pilot plant in Tibro has a maximum capacity of 60 000 components per year. In 2023 they will launch their first highly automated and flexible factory with a maximum capacity of 700 000 components per year. Hence, in the context of creating an LCA for the product the LCA model in this study represents the best estimates for what the production will look like based on PaperShell's current plans and existing test manufacturing.

Figure 1: Samples of the PaperShell material

Figure 2: Sample of a chair made of PaperShell material (image cropped due to confidentiality)

1.3 The sustainability challenge

Sustainability comprises meeting our own needs without compromising the ability of future generations to meet their own needs. Industrial and natural systems depend on a stable Earth system to function. A quantitative planetary boundary within which humanity can continue to develop and thrive for generations to come has been proposed (Steffen et al., 2015). These researchers describe nine processes that determine the resilience and stability of the Earth system, such as climate change, water use, and land use. Crossing these boundaries increases the risk of abrupt and irreversible environmental change, while staying within the boundaries represents a safe operating space for a sustainable society, see Figure 4.

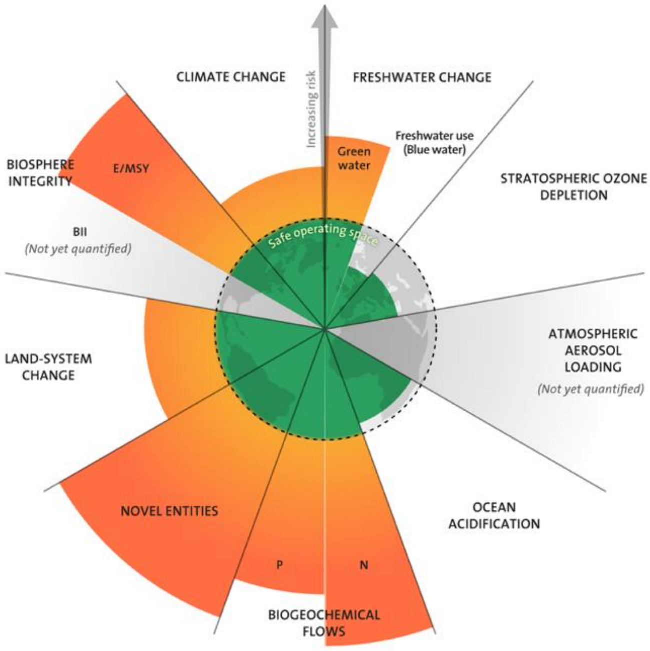

Figure 3: Shows the state of the planetary boundaries, where the green area represents a safe operating space. Credit: Azote for Stockholm Resilience Centre, based on analysis in Wang-Erlandsson et al 2022.

One critical environmental problem we face today is climate change. The latest report from the Intergovernmental Panel on Climate Change, shows that only the most ambitious of five scenarios for greenhouse gas emissions would result in a temperature increase within 2°C (IPCC, 2021a), see Figure 4. Considering that limiting temperature rise below 1.5°C is the ambition of the Paris Agreement 2016, it is evident that the available space for mitigating radical climate change is ever-shrinking, necessitating decisive action in all parts of society.

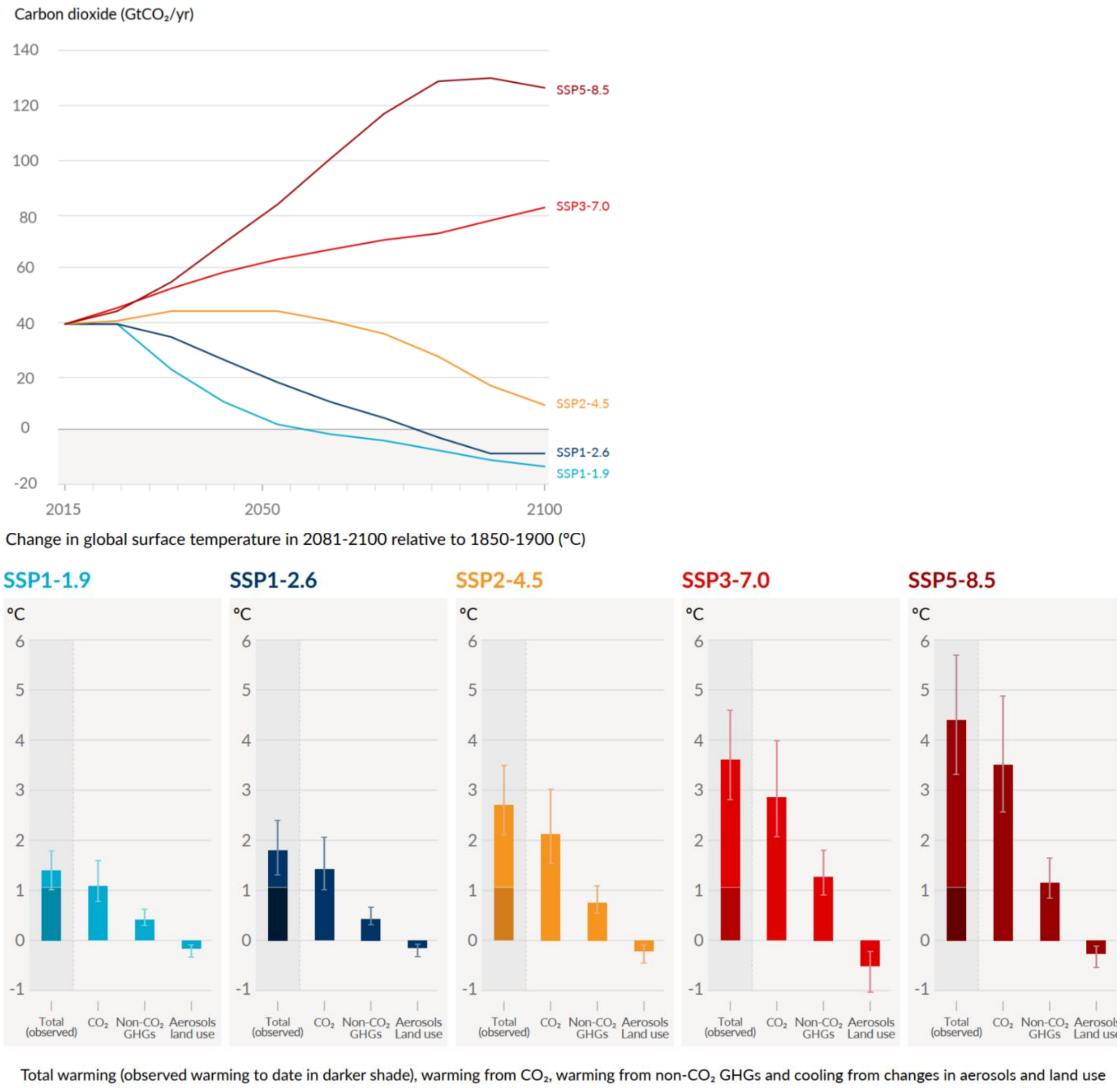

Figure 4: Future annual emissions of CO_2 (top) and contribution to global surface temperature increase from different emissions, with a dominant role of CO_2 emissions (bottom) across five illustrative scenarios. Image from IPCC (2021b).

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 standardised 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).

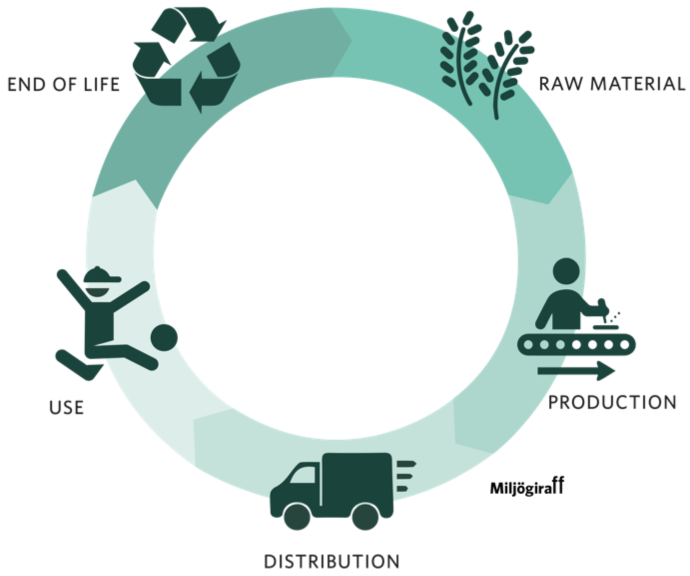

Figure 5: The Life Cycle concept, starting from raw material extraction, production, and distribution, followed by use and end-of-life.

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 6.)

Figure 6: 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, 2006a)
ISO 14044: 2006 – Requirements and guidelines (ISO, 2006b)

3 Goal and Scope

3.1 The aim of the study

The study's goal is to find metrics for the environmental impact of PaperShell's production from a life cycle perspective, according to the ISO 14040 and 14044 standards (ISO, 2006b, 2006c). Their production was exemplified by a chair seat, which was the foundation for the definition of the functional unit. Another goal was to provide PaperShell with a LCA result that can be reused for other products and sizes.

The report describes the results transparently and reproducibly according to the standard. The results are interpreted, followed by recommendations for mitigating the environmental impact. Note that PaperShell's production is in early stages of scaling up production, with manufacturing facilities under construction. Hence, the model in this study represents the best estimates for what the production will look like based on PaperShell's current plans and existing test manufacturing.

The purpose of the study is, through the LCA approach, to provide a transparent and objective assessment and characterisation of PaperShell's product for environmental communication intended for both internal and external audiences. An additional purpose is to provide PaperShell with an interactive LCA-model through SimaPro Share (a module on the SimaPro online platform) to be used in product development and communication.

3.2 Scope of the Study

In this section, the scope of an LCA is specified, including a description of the functions (performance characteristics) of the system being studied.

3.2.1 Name and Function of the Product/System

In this study, the system studied was a chair seat and its function is represented by a certain area. The PaperShell material is a bio-based impregnated Kraft paper, with sufficient strength to substitute plastic and metal parts. The density is 1340 kg/m^3.

The chair seat was chosen as an example of a product that can be produced by PaperShell, which has been produced as a prototype and its characteristics have been tested. Note, however, that PaperShell plan to produce a wide range of components, covering a wide range of sectors.

3.2.2 The Functional Unit and reference flow

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

A PaperShell chair has an area of 0,327 m^2. However, the functional unit was defined differently, in order for PaperShell to easily be able to use the results of this LCA for different products with different surface areas. Hence, the functional unit was defined as "*a chair seat during 10 years of use, of size 0,187 m^2, of a thickness that gives a strength*[2] *equal to PaperShell material of 4 mm thickness*".

The specific area of 0,187 m^2 is smaller than a realistic chair seat, but it was chosen since it gives a weight of 1 kg for PaperShell's chair seat. For a more realistic seat size, it is possible to simply scale up all results accordingly, by multiplying the results with the factor 1,7487.

[2] The strength of the PaperShell material has been tested according to ASTM standards and is presented in detail on PaperShell's web page (https://papershell.se/material/).

The strength/thickness was included in the functional unit to allow for potential comparisons with other materials.

The period of 10 years was set to correspond to the warranty period for furniture. PaperShell's chair seat is meant for indoor use, but it can also be used outdoors (tests for heat aging and moisture aging show that the lifetime will still be at least 10 years[3]). The lifetime is estimated to be limited by the aesthetic rather than technical life length, and an estimated 10 years was thus used as the expected lifetime.

The equation below is used to calculate the amount of PaperShell chair seat required to fulfil the function. With the values above, it becomes 1 kg [4]:
area*thickness*density*(period/expected lifetime) =
= 0,187 m^2 * 0,004 m * 1340 kg/m^3 * (10 years / 10 years) =
= 1 kg of PaperShell chair seat

3.2.3 System Boundary

The system boundary for the study is defined as cradle-to-grave. All processes needed for raw material extraction, manufacturing, transport, usage, and end-of-life are included in the study. A simplified schematic representation of a cradle-to-grave system under study is presented in Figure 7.

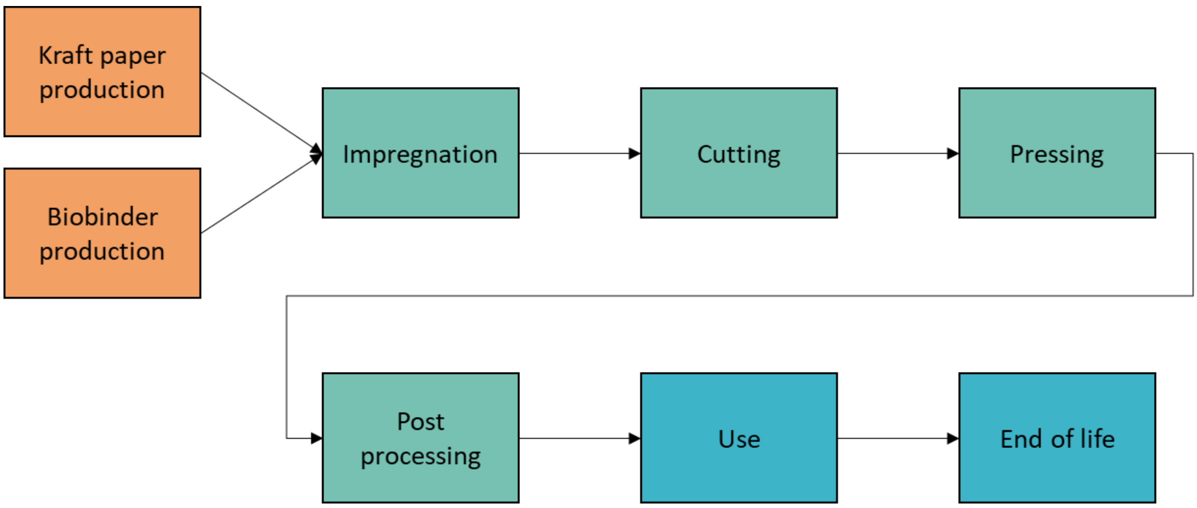

Figure 7: System boundaries for the model of the product system. Red represents production of raw materials, green represents production at PaperShell and blue represents downstream processes.

The raw material stage includes production of Kraft paper and biobinder. The Kraft paper is produced in Sweden. For details on the biobinder, see the confidential Appendix 3. Both are represented by specific data, while further upstream processes are represented by generic data.

Manufacturing occurs at PaperShell's facilities in Sweden and has been modelled with specific data.

The use phase of a chair contains no environmental aspects, while the end of life is modelled generically as incineration.

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[3] Details on the tests, such as heat aging according to STD 423-0055, can be found on PaperShell's web page (https://papershell.se/material/)
[4] For the full chair seat of 0,356 m^2, the amount becomes 1,7487 kg

3.2.4 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 applies 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. In addition to the cut-off of material- and energy flows, also life cycle stages can be excluded if they are deemed to be of low relevance or do not cause any adverse environmental effects.

In this study, the following have been cut off as they have been deemed of low relevance:

- Infrastructure and heating of PaperShell's facilities (heating is from district heating, which has low environmental impact per produced functional unit[5])
- Conversion losses from high to low voltage of the wind power used in PaperShell production (ca 3% losses according to ecoinvent processes[6])
- Transport of wood to Kraft paper supplier (because of locally sourced wood), of Kraft paper to PaperShell's facilities, of finished chair seats to the customer (because of short distances to potential customers, who are mainly located in Sweden) and of waste to waste processing
- Use phase (no environmental aspects during use phase)

3.2.5 Allocation procedure

When dealing with a multi-output process, in other words, if a process creates several products or one product along with by-products, this is referred to in LCA as an allocation problem. This is the case for materials like wool, for which production processes produce both meat and wool.

Allocation is described in ISO 14044 section 4.3.4.2 (ISO, 2006b). 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

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[5] PaperShell use the district heating system in Tibro, which is based on 99,7% renewable fuels (https://nevel.com/sv/fjarrvarme/tibro)
[6] Specifically, the processes "Electricity, medium voltage {SE}| electricity voltage transformation from high to medium voltage | Cut-off, U" and "Electricity, medium voltage {SE}| electricity voltage transformation from high to medium voltage | Cut-off, U", which show 0,6% and 2,8% losses, respectively.

physical relationship between products. This can be physical characteristics that are representative of 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 a relationship that can be used for allocating inputs and outputs of a process to its products.

Allocation of waste is described in ISO 14044 section 4.3.4.3.3 (ISO, 2006b) and uses the method of Allocation cut-off by classification per EPD guidelines (EPD International, 2021b). 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 the generating life cycle uses recycled material as input material will it account for the benefits of recycling.

In this report, no allocation has been done for specific data.

3.2.6 Method of Life Cycle Impact Assessment (LCIA)

The methods used to calculate the relevant environmental effect categories in this study are summarised in Table 1. The method follows the Environmental Footprint 3.0 methodology, which is one of the most commonly used impact assessment methods (European Commission, 2012a). For further details on the LCIA method, see Appendix 2.

All carbon in the product is biogenic (according to carbon-14 tests according to ASTM D6866-21 and elementary analysis showing a carbon content of 41%, see certificates in Appendix 6) and, according to the IPCC methodology, the characterization factor for both uptake and emissions of biogenic carbon is zero.

Table 1: Impact categories, indicators and methods used in the study. The chosen indicators follow Environmental Footprint 3.0 (EF3.0) (European Commission, 2012a).

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
Climate Change-fossil	GWP fossil	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2013
Climate Change-biogenic	GWP biogenic	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2013
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
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
Abiotic resource depletion, elements	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
Particulate Matter emissions	PM	Disease incidence	SETAC-UNEP, Fantke et al. 2016
Ionising radiation, human health	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)	ETP-fw	CTUe	USEtox 2.1. model (Rosenbaum et al, 2008)
Human toxicity, cancer effects	HTP-c	CTUh	USEtox 2.1. model (Rosenbaum et al, 2008)
Human toxicity, noncancer effects	HTP-nc	CTUh	USEtox 2.1. model (Rosenbaum et al, 2008)
Land-use-related impacts/Soil quality	SQP	dimensionless	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)

3.2.7 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 are well representative of the geography stated in the "location" indicated in the metadata**
- Technology representativeness: **Average technology or BAT**[7]
- Time-related coverage: **Specific data for PaperShell manufacturing represents 2023, Kraft paper production 2022 and background data represents < 5 years and later**
- Multiple output allocation: **Physical causality**
- Substitution allocation: Not applicable
- Waste treatment allocation: Not applicable
- Cut-off rules: **Less than 1% environmental relevance**
- System boundary: **Second order (material/energy flows including operations)**
- The boundary with nature: **Agricultural production is part of the production system**

[7] BAT (Best Available Technology or Best Available Techniques) signifies the latest stage in development of activities, processes and their method of operation which indicate the practical suitability of particular techniques as the basis of emission limit values, linked to environmental regulations, such as the European Industrial Emissions Directive (IED, 2010/75/EU). In determining whether operational methods are BAT, consideration is given to economic feasibility and the availability of techniques to carry out the required function. The BAT concept is closely related to BEP (Best Environmental Practice), which is the best environment-friendly company practice.

3.2.8 Type of critical review, if any

A critical review means that the study is reviewed by a third party. According to the standard, this is necessary if the result is to be communicated externally or if the result is to be compared with results from other studies.

A critical review will be carried out according to the International Standards ISO 14040 and 14044 (ISO 2006 b,c). 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
- 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.

This LCA report was reviewed by a third party, Martyna Mikusinska, senior environmental consultant at Sweco Sverige AB, a well-known LCA expert consultant with extensive experience in LCA.

4 Life Cycle Inventory (LCI)

In the life cycle inventory, the product system is defined and described. Firstly, the material flows and relevant processes required for the product system are identified. Secondly, relevant data (i.e., resource inputs, emissions and product outputs) for the system components are collected, and their amounts are related to the defined functional unit.

For data referring to processes beyond the control of the core production, the ecoinvent database 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.

4.1 Product content declaration

This part describes the different materials that PaperShell is made of. The products are packed in cardboard boxes, on wooden pallets. Note that the impregnation of the Kraft paper means that there is no need for a coating layer on the product, as shown by UV resistance (STD 423-0061) and scratch resistance (STD 423-0030) tests.

Table 2: Content declaration

Product components	Share of weight	Renewable material share
Kraft paper	70%	100%
Biobinder	30%	100%

4.2 Raw materials

This section describes the modelling of the Kraft paper and the biobinder.

4.2.1 Kraft paper

The Kraft paper is produced in Sweden (Munksjö), using a mix of Swedish wood, approximately 45% spruce, 45% pine and 10% birch. Data was collected directly from the Kraft paper supplier, see Table 3.

Note that the numbers for energy consumption provided by the supplier include the energy for impregnation, which was correct at the time of collecting the data in 2022. However, as of 2023, PaperShell have the capability to impregnate the paper at their site, the energy for which is included in the manufacturing model in section 4.3, meaning that the impregnation energy is double counted in the study. This is estimated to be an acceptable and minor error and it follows a conservative approach in the modelling of the raw materials and manufacturing in this study.

In the manufacturing at Munksjö, ca 8% of waste is generated. This was included as a yield factor which that scales the amounts needed so inputs needed for 1 kg of paper also covers the spillage and waste occurring in the production.

Table 3: Modelling details for 1 kg of Kraft paper

	Database process used	Amount	Comment
Materials	Pulpwood, softwood, measured as solid wood under bark {SE}| softwood forestry, spruce, sustainable forest management | Cut-off, U	0,001047 m3	share_spruce*share_Kraft/density_spruce/yield 45% spruce. Assumes a (dry) density for spruce of 430 kg/m3, according to the ecoinvent-documentation
	Pulpwood, softwood, measured as solid wood under bark {SE}| softwood forestry, pine, sustainable forest management | Cut-off, U	0,000918 m3	share_pine*share_Kraft/density_pine/yield 45% pine. Assumes a (dry) density for pine of 490 kg/m3, according to the ecoinvent-documentation
	Pulpwood, hardwood, measured as solid wood under bark {SE}| hardwood forestry, birch, sustainable forest management | Cut-off, U	0,000156 m3	share_birch*share_Kraft/density_birch/yield 10% birch. Assumes a (dry) density for birch of 640 kg/m3, according to the ecoinvent-documentation
Processes	Electricity, medium voltage {SE}| market for | Cut-off, U	0,9859 kWh	75% of 1,3145 kWh 485 kWh/ton pulp (=339,5 kWh/ton paper) + 975 kWh/ton paper 339,5 + 975 = 1314,5 kWh/ton paper. 75% from grid, 25% from own renewable production
	Electricity, renewable fraction, high voltage {SE}| market for | Cut-off, U	0,3286 kWh	25% of 1,3145 kWh 485 kWh/ton pulp (=339,5 kWh/ton paper) + 975 kWh/ton paper 339,5 + 975 = 1314,5 kWh/ton paper. 75% from grid, 25% from own renewable production
	Heat, from steam, in chemical industry {RoW}| steam production, as energy carrier, in chemical industry | Cut-off, U (adapted)	13,354 MJ	Approximation for steam, ecoinvent process adapted to have no energy input, since it is from forestry waste (there is some fuel oil used, modelled separately above). Ecoinvent process assumes energy content of 2,75 MJ/kg, which corresponds to a temperature of ca 150 degrees C when looking at an enthalpy chart (e.g.: https://www.researchgate.net/publication/292947231_The_Lassen_hydrothermal_system)
	Heat, district or industrial, other than natural gas {SE}| heat production, propane, at industrial furnace >100kW | Cut-off, U	0,7945 MJ	18*LHV_propane/1000 18 kg propane per ton paper. 44,14 MJ per kg propane
	Heat, district or industrial, other than natural gas {Europe without Switzerland}| heat production, heavy fuel oil, at industrial furnace 1MW | Cut-off, U	0,933 MJ	Burning of fuel oil for steam. 33 dm3/ton pulp = 23,1 dm3/ton paper = 22,64 kg oil/ton paper= 0,933 MJ/kg paper . Assuming a density of 0,98 ton/m3 (https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html) and an energy density of 41,2 MJ/kg, according to ecoinvent documentation
Outputs	Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U	0,026 kg	share_binder/yield_Kraft -share_binder Represents waste from loss of binder during impregnation (i.e. process 1 in Table 4. Technically the waste of binder would now occur in the impregnation process at PaperShell. However, due to the structure of the model that was originally created for Munksjö it is kept here. The results will not be affected whether it lies here or in the manufacturing process at PaperShell.)
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,027 kg	share_spruce*share_Kraft/yield_Kraft - share_spruce*share_Kraft

			Adapted ecoinvent process to correct for the 10% water content stated in the ecoinvent documentation, by reducing output to 0,9 kg instead of 1 kg.
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,027 kg	share_pine*share_Kraft/yield_Kraft -share_pine*share_Kraft Adapted ecoinvent process to correct for the 10% water content stated in the ecoinvent documentation, by reducing output to 0,9 kg instead of 1 kg.
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,006 kg	share_birch*share_Kraft/yield_Kraft - share_birch*share_Kraft Adapted ecoinvent process to correct for the 10% water content stated in the ecoinvent documentation, by reducing output to 0,9 kg instead of 1 kg.
Parameters	yield	0,92	Ca 8% waste
	density_spruce	430	kg/m3
	density_pine	490	kg/m3
	density_birch	640	kg/m3
	share_spruce	0,45	
	share_pine	0,45	
	share_birch	0,1	
	LHV_propane	44,14	MJ/kg propane

4.2.2 Biobinder

The production of biobinder is confidential and is available as a separate confidential appendix (Appendix 3).

4.2.3 Packaging

PaperShell estimate the amount of packaging per kg of material to be 0,0075 kg cardboard and 0,0011 pcs of pallet (assuming it is reused 25 times). The cardboard was modelled with "Corrugated board box {RER}| market for corrugated board box | Cut-off, U", while the pallet was modelled as "EUR-flat pallet {RER}| market for EUR-flat pallet | Cut-off, U". Both are assumed to be incinerated at end of life, modelled with "Municipal solid waste (waste scenario) {Europe without Switzerland}| Treatment of municipal solid waste, incineration | Cut-off, U".

4.3 Manufacturing

In this section, the activities carried out by PaperShell are presented. All activities are presented per 1 kg of chair seat.

The manufacturing process can be divided into four steps:

- Process 1: Pre-processing
    - Impregnating Kraft paper with a biobinder
- Process 2: Blank preparation
    - Cutting the material into a desired 2D-shape using a digital cutter
- Process 3: Pressing
    - Heating up and forming the sheet into the desired 3D-shape
- Process 4: Milling or cutting
    - Finishing by Computer Numerical Control (CNC) machining

Data on electricity consumption is based on data from Papershell[8] about production according to measurements from suppliers of new machines. The machines are not yet in use but will soon be in Papershell's production. Amounts for process 1, 2 and 3 have been divided by 0,9 to account for a yield of 90% in cutting. This is a conservative estimate, since PaperShell have the capability to feed the production waste back into the process. Production waste is assumed to be incinerated. Conversion losses of high voltage to low voltage electricity has been cut off, see section 3.2.4.

Process 1, 2 and 4 are represented simply by electricity consumption, while process 3 is represented by an adapted ecoinvent process.

Table 4: Modelling details for manufacturing of 1 kg of PaperShell chair seat

	Database process used	Amount	Comment
Processes	Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0,2588 kWh	Impregnation[9] (Process 1, pre-processing). 0,2329 kWh /0,9
	Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0,1546 kWh	Papercutting by Zund digital cutter (Process 2, blank preparation) 0,1391/0,9
	Thermoforming of plastic sheets {FR}| processing | Cut-off, U (adapted)	1,111 kg	Approximation for pressing (Process 3) 1 kg /0,9 Process for thermoforming adapted by changing energy input to 0,65 kWh from Swedish wind power (according to data from PaperShell) and changing output from 1 kg to 0,946 kg according to instructions in ecoinvent documentation.
	Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0,4633 kWh	CNC cutting (Process 4).
Output	Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U	0,033 kg	Production waste from papercutting, biobinder fraction 0,3/0,9 kg

[8] Personal communication with Anders Breitholtz, founder and CEO, anders@papershell.se and Fredrik Westerberg, CPO, fredrik@papershell.se

[9] Note that there is some loss of binder during impregnation. Because of how the model was originally structured, the waste treatment of that can be found in Table 3 for the Kraft paper.

	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,035 kg	Production waste from papercutting, spruce fraction 0,315/0,9 kg
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,035 kg	Production waste from papercutting, pine fraction 0,315/0,9 kg
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,0077 kg	Production waste from papercutting, birch fraction 0,07/0,9 kg

4.4 End-of-Life

The end-of-life phase handles the product and the material it consists of after its use. The whole product is assumed to be incinerated.

Table 5: Modelling details for end of life for 1 kg of PaperShell chair seat

	Database process used	Amount	Comment
Outputs	Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U	0,3 kg	End of life waste, biobinder fraction
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,315 kg	End of life waste, spruce fraction
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,315 kg	End of life waste, pine fraction
	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U (adapted)	0,07 kg	End of life waste, birch fraction

5 Life cycle impact assessment (LCIA)

In this section, the results from the different environmental impact assessment methods are presented. All results are presented per functional unit, which corresponds to a chair seat of ca 0,182 m^2 and 1 kg of PaperShell material. The LCIA method used is Environmental Footprint 3.0 (EF 3.0). For further details on the LCIA method and the different impact categories, see Appendix 2.

The results are first presented per impact category, followed by a presentation of the climate impacts. Subsequently, the weighted single score is presented to show the most relevant impact categories according to EF3.0. Lastly, a hotspot analysis is presented for the five most relevant impact categories, showing what parts of the life cycle contribute the most. For detailed results and contributions in all impact categories, see Appendix 4.

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. Note also that the results of the environmental impact indicators for resource use (fossil, metal, water, land), freshwater eutrophication and toxicity 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.

5.1 Results per impact category

Table 6 shows the total result per functional unit according to the LCIA method Environmental Footprint 3.0 (midpoint level). For results per life cycle stage, see section 5.4 (and for further details, see Appendix 4).

Table 6: Environmental footprint midpoint results per functional unit

Impact category	LCIA result	Unit
Acidification	4,88E-03	mol H+ eq
Climate change - total	0,496	kg CO2 eq
Ecotoxicity, freshwater	17,0	CTUe
Eutrophication, freshwater	1,18E-04	kg P eq
Eutrophication, marine	9,99E-04	kg N eq
Eutrophication, terrestrial	0,0106	mol N eq
Human toxicity, cancer	1,11E-09	CTUh
Human toxicity, non-cancer	1,10E-08	CTUh
Ionising radiation	0,564	kBq U-235 eq
Land use	109	Pt
Ozone depletion	7,82E-08	kg CFC11 eq
Particulate matter	9,88E-08	p inc.
Photochemical ozone formation	3,09E-03	kg NMVOC eq

Resource use, fossils	13,9	MJ
Resource use, minerals and metals	4,84E-06	kg Sb eq
Water use	0,414	m3 depriv.

5.2 Climate impacts

The climate impacts according to the EF3.0 method is 0,496 kg CO2-eq. per functional unit. This corresponds to a climate impact of 0,496 kg CO2-eq. per kg of PaperShell material. Ca 98% of this comes from fossil climate emissions, while ca 1% comes from biogenic emissions and 1% from emissions due to land use and land use change.

The figure below shows that the raw material and biobinder are the largest contributors to the total climate impact, while the pressing is the most impacting step in PaperShell's own manufacturing.

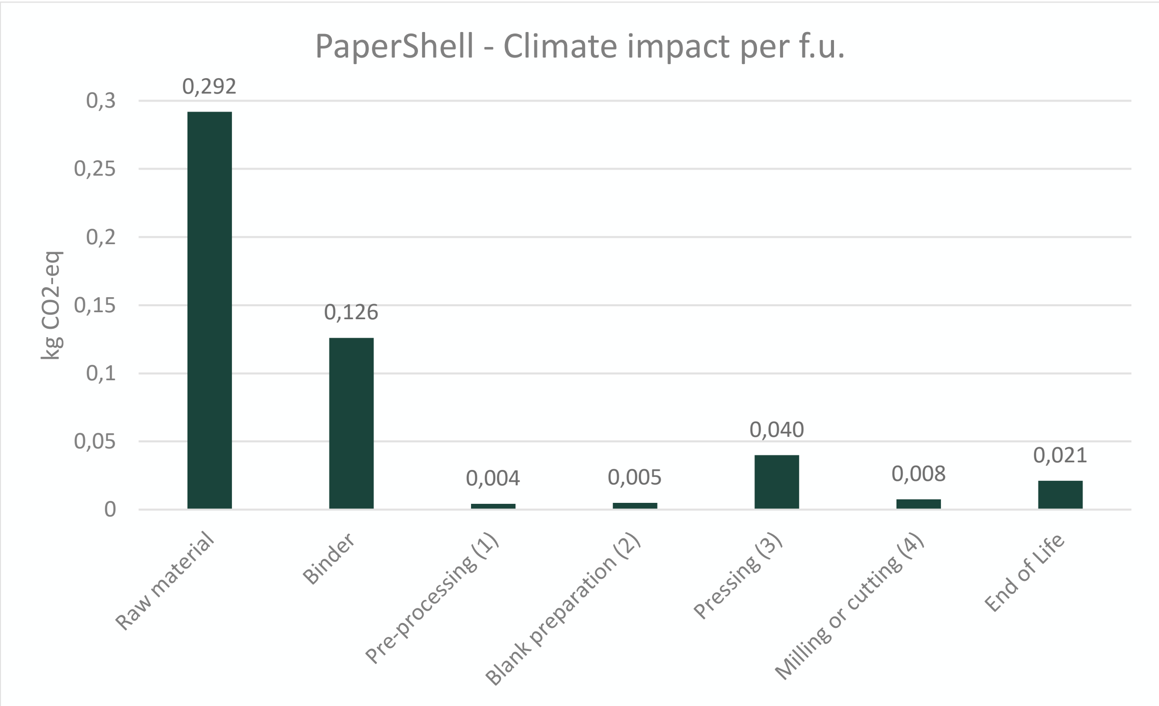

Figure 8: Climate impact per functional unit, divided into different life cycle stages. The method used is according to EF3.0.

5.3 Environmental Footprint Endpoint

The environmental footprint endpoint shows the contribution of each environmental impact category to the total environmental impact. The total impact is calculated as a weighted single score according to the EF3.0 method. The five impact categories with the largest impact on the total environmental footprint are:

- Fossil resource use
- Particulate matter emissions
- Climate change
- Land use
- Freshwater ecotoxicity

These will form the basis of the hotspot analysis in section 5.4.

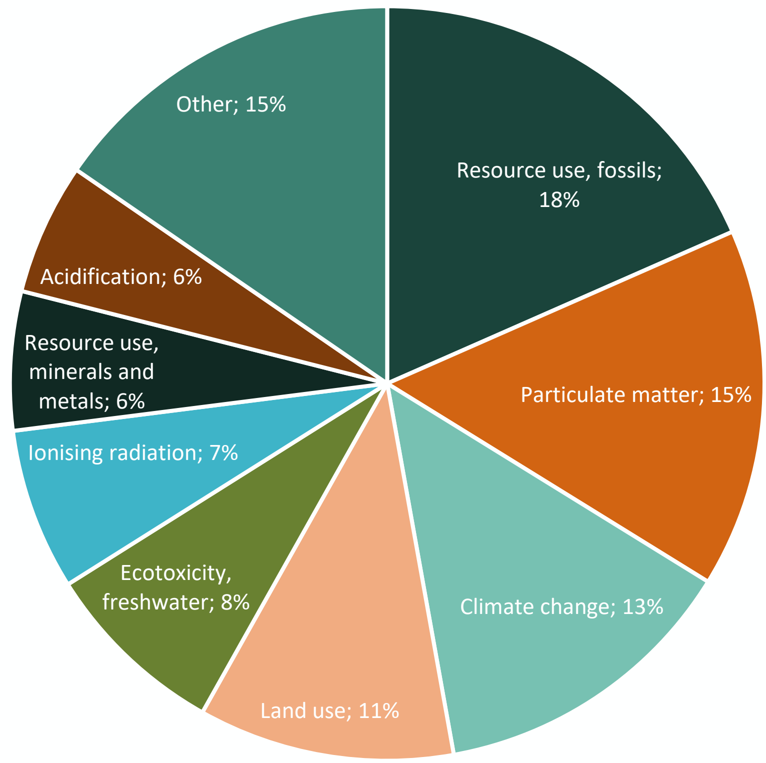

Figure 9: Contribution to weighted single score by impact category (single score according to EF3.0)

5.4 Hotspot analysis

For the five most relevant impact categories, a hotspot analysis is shown in the figure below. The raw material impacts are the most contributing to climate change, fossil resource use and land use. The production of the binder was the main contributor to ecotoxicity and particulate matter emissions.

For climate change and ecotoxicity, the pressing process and end of life had significant contributions to the total impact as well.

For detailed impact contributions for all impact categories, see Appendix 4.

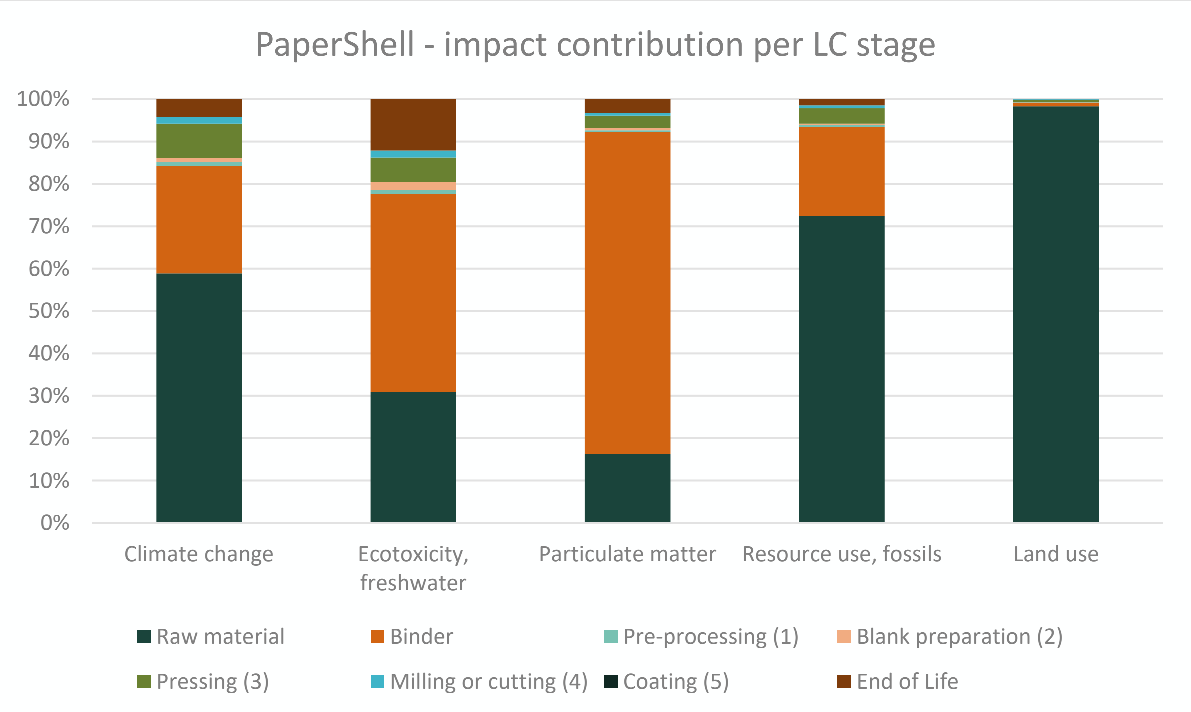

Figure 10: Hotspot analysis for the five most important impact categories identified in section 5.3

6 Interpretation

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

The quantitative impact assessment results are interpreted to understand the most effective ways of reducing environmental impacts.

6.1 Key aspects of results

The dominant phase of the lifecycle is the production of the raw materials, namely the Kraft paper production as well as the biobinder production (see section 7 for recommendations on how to mitigate the hotspots summarized below).

Kraft paper production has a high contribution to the total climate change, ecotoxicity, fossil resource use and land use:

- Climate impacts are caused mostly by electricity (average Swedish grid mix, ca 32% of the Kraft paper climate impact) and the propane used to provide heat (ca 45% of the Kraft paper climate impact)
- Ecotoxicity impacts are from the electricity production (average Swedish grid mix, ca 55% of the Kraft paper ecotoxicity impact)
- Fossil resource use is caused by the same processes as the climate impacts
- Land use impacts are from (sustainable) forestry to produce the pulp (97% of the Kraft paper land use impact)

Binder production has a high contribution to the total climate change, ecotoxicity, particulate matter emissions and fossil resource use.

- Climate impacts are caused mostly by heating with natural gas (ca 39% of the binder climate impact), production of catalyst (modelled approximately ca 15% of the binder climate impact) as well as transatlantic transport of the waste raw material (ca 18% of the binder climate impact)
- Ecotoxicity impacts are from the combustion of waste biomaterial for generating steam in the upstream processes of the biobinder production (ca 77% of the binder ecotoxicity impact)
- Particulate matter emissions are also from the combustion of waste biomaterial for generating steam in the upstream processes of the biobinder production (ca 93% of the binder particulate emissions)
- Fossil resource use is caused by the same processes as the climate impacts

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.

Transports to customer was one of the processes excluded in the model, because PaperShell's customers, at least initially, are located close to their production facility. To investigate the sensitivity to this parameter, a calculation was made adding 1000 km of transport by truck (32 ton, EURO6) to represent transport of the final product to a European customer. This increased the total climate impact by ca 22%, which means that the results can be significantly affected by long distance transports. Ca 9000 km of sea transport causes a similar level of increased climate impacts.

6.3 Comparison with other materials

In order to get an indication of how PaperShell performs compared to other materials that can fulfil the same function (of a chair seat), simple models were built for chair seats made out of veneer, polypropylene (PP), glass-fibre reinforced polymer (GFRP) and aluminium. The materials were modelled generically, meaning that the other materials are not represented by specific data, and the comparison is simply meant to be approximate and indicative, to provide context for PaperShell on their strengths and weaknesses in relation to other ways of fulfilling the same function.

The thickness of the material is adjusted to achieve a strength sufficient for a chair seat, namely 4 mm for PaperShell, 9 mm for veneer, 5 mm for PP, 4 mm for GFRP and 2,5 mm for aluminium (based on estimates by PaperShell which in turn are based on experience, industry praxis and testing in relation to test results for the PaperShell material[10]). Production of the chair seat itself is modelled similar to the PaperShell production, with some exceptions, see Appendix 5 for modelling details for each material.

Figure 11 shows that PaperShell fulfils the function of a chair seat with ca 50% less climate impact than veneer, due to the higher strength that allows less material to be used. PaperShell has ca 90% lower climate impact per functional unit than PP, and ca 98% lower impact than GFRP and aluminium.

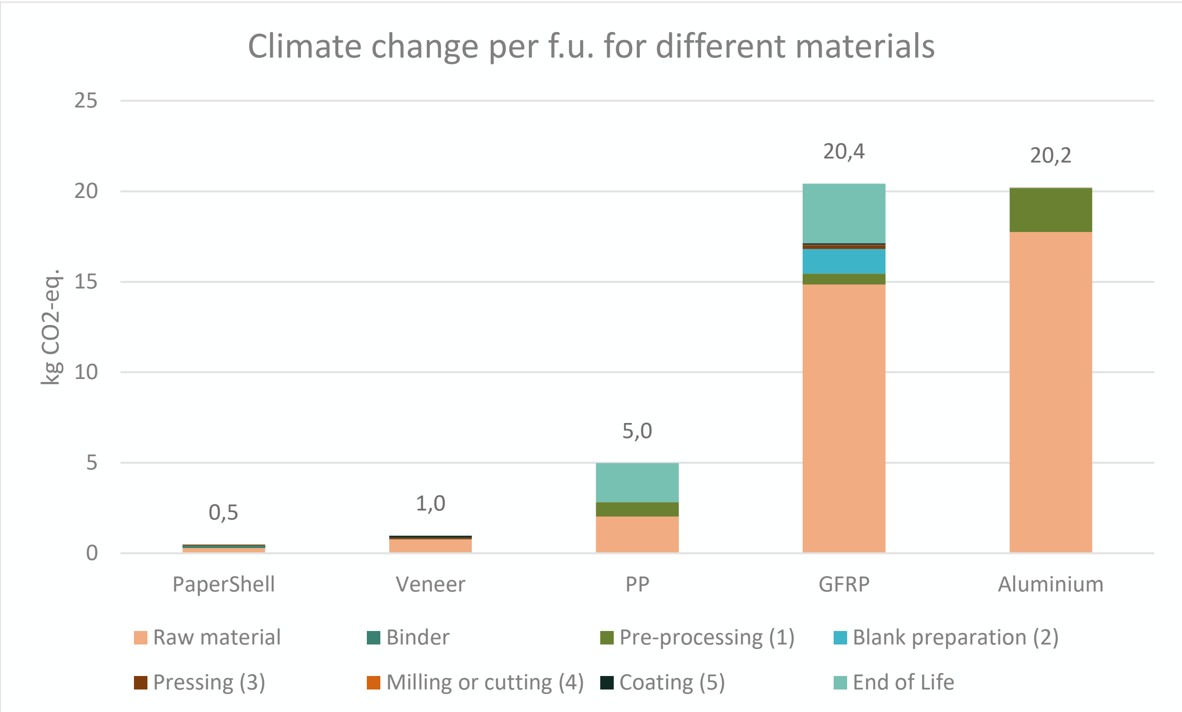

Figure 11: Rough comparison between PaperShell and four other materials, assuming that they should all fulfil the function of a chair seat (i.e. PaperShell has a thickness of 4 mm, veneer 9 mm, PP 5 mm, GFRP 4 mm and aluminium 2,5 mm)

[10] https://papershell.se/material/

6.4 Data quality and limitations

The data fulfil the quality requirements defined in section 3.2.7. The majority of the model in upstream production and in PaperShell's manufacturing being based on specific data, while the remaining parts of the model are built on generic data. The comparison with other materials in section 6.3 is based solely on generic data for the other materials.

Note that the data for PaperShell's manufacturing, although specific, represents manufacturing conditions in process of being implemented and scaled up, which means that there are inherent uncertainties in the data that should be further specified and verified once manufacturing has scaled up further. A further limitation is that most processing steps were represented simply by an electricity use, except the pressing process, which was represented by an adapted ecoinvent process. All processes should be modelled more comprehensively in future iterations.

Other limitations include parts of the life cycle that are cut off, particularly transports. When PaperShell have reached the customers on the market, it will be important to estimate the transport distances to their average customer and to ensure that long distance transports are done with as little fossil fuels as possible.

7 Conclusions and recommendations

This section will highlight the most important aspects of the results and the interpretation. Recommendations will be presented as suggestions of how to mitigate the hot spots, how to communicate the results and how to reduce the uncertainties of the study.

Important environmental impact categories from a cradle-to-grave perspective on PaperShell's chair seat are climate change, ecotoxicity, fossil resource use and land use. The impact comes mainly from the production of raw materials, namely Kraft paper and biobinder, both from electricity use and the use of fossil fuels for heat and steam in their production.

The environmental impact of PaperShell is already low due to the use of renewable raw materials and the utilization of waste streams. However, the impacts can be reduced further, and the first priority should be to reduce the environmental impacts of the raw materials:

- For Kraft paper production:
    - Reduce electricity consumption or use renewable electricity.
    - Reduce the use of propane and fuel oil or use a renewable fuel.
    - Source the raw material for the pulp from waste streams instead of wood from trees.
- For binder production:
    - Reduce the use of natural gas or use a renewable fuel.
    - Minimise the use of catalyst.
    - Reduce the need for overseas transports, e.g. by sourcing the material from closer to Sweden.
    - Reduce the need for steam in the upstream chemical processes.
- For PaperShell manufacturing:
    - Reduce the use of electricity and the aluminium tool in the pressing process.
    - Ensure that the yield is as high as possible, e.g. by minimizing the cutting waste and reutilizing the waste that does occur. If PaperShell can confirm/prove a lower amount of waste than the assumed 10%, the overall results can be significantly improved.
- For end of life treatment:
    - Take steps to avoid the incineration of the product at end of life, for instance by prolonging the life and use of the product, e.g. through reuse and recycling.
- Other:
    - As indicated by the sensitivity analysis in section 6.2, avoid long-distance, fossil-based, transports. This will be more important in the future when PaperShell may start selling to more customers outside of Sweden.

7.1 How to communicate the results

This report represents the state of PaperShell's production and material as it is today. The report is third-party reviewed, which lends credibility to the study results. An interactive tool in SimaPro Share has been developed, which enables PaperShell to create scenarios for specific clients or quotations. It is recommended to use this tool in sales and quotation processes.

One of the key perspectives for communication is the fact that PaperShell can reduce environmental impacts by replacing other materials. This report provides guidance on this, as section 6.3 indicates that there are substantial benefits to replacing e.g. GFRP or aluminium, although it should be noted that the models for comparison are simplified and generic, and the comparison may look different in specific contexts.

It should be noted that the underlying data can be improved and other perspectives can be included if the model is expanded in the future, for instance regarding PaperShell's vision of using only waste streams as input and potentially creating carbon sinks at end of life.

A general recommendation regarding external communication of the results is to avoid using excessively precise numbers and instead use round numbers which would reflect the underlying uncertainties (see section 7.2 for how to reduce them). Furthermore, it is important to communicate about other environmental impacts in addition to climate change.

7.2 How to reduce uncertainties

The data underpinning the modelling of the biobinder is originally from 2014 and has significant uncertainties. The supply chain should be mapped more thoroughly and more up to date data should be collected in order to reduce the uncertainties in the model.

Since PaperShell is a young company in the process of scaling up production, there are also uncertainties in the data for the manufacturing processes like pressing and cutting. The model should be reevaluated at a later stage when production has reached a larger scale.

Parts of the model that are cut off (e.g. packaging, use phase etc.) or are represented by generic data (e.g. the pressing process and other parts of the manufacturing process) can be modelled more specifically in order to reduce uncertainties further.

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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 12. In sections Appendix 1A - Appendix 1D further details on each life cycle phase are presented.

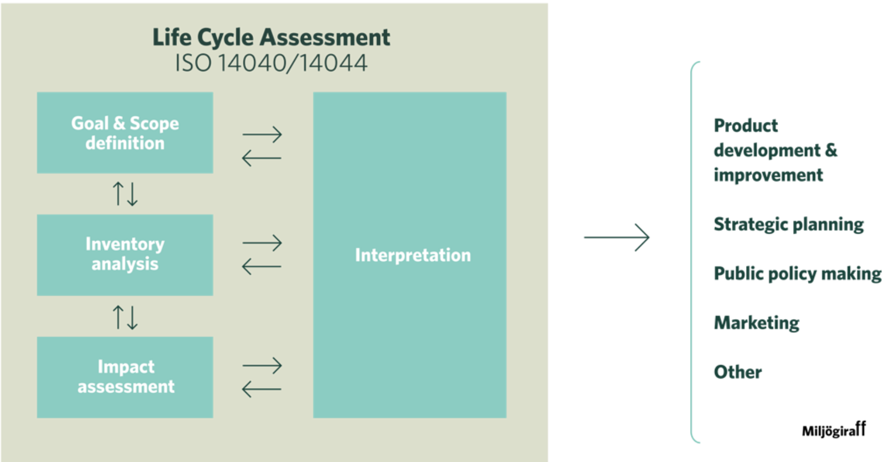

Figure 12. The four phases of the Life Cycle Assessment

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.

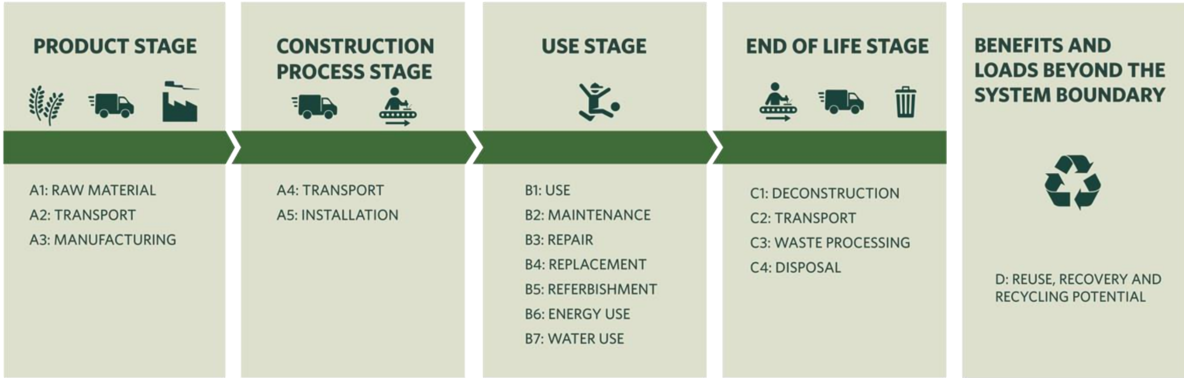

Figure 13: General summary of the modules included in an LCA, based on EN 15804.

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[11], 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 14). 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.

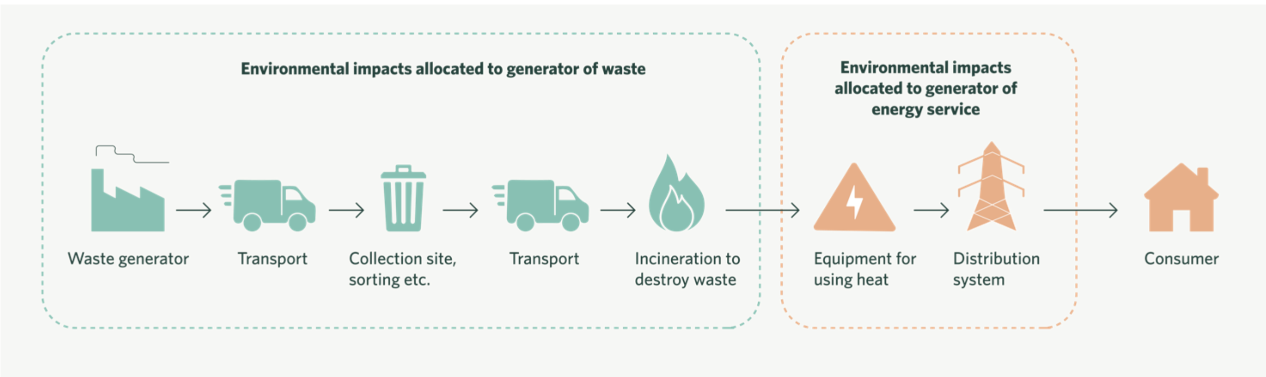

Figure 14: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here in regard to the incineration of waste and resulting energy products.

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

[11] 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 3.8.

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. One of the most common LCIA methods is presented in Appendix 2.

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 15 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.

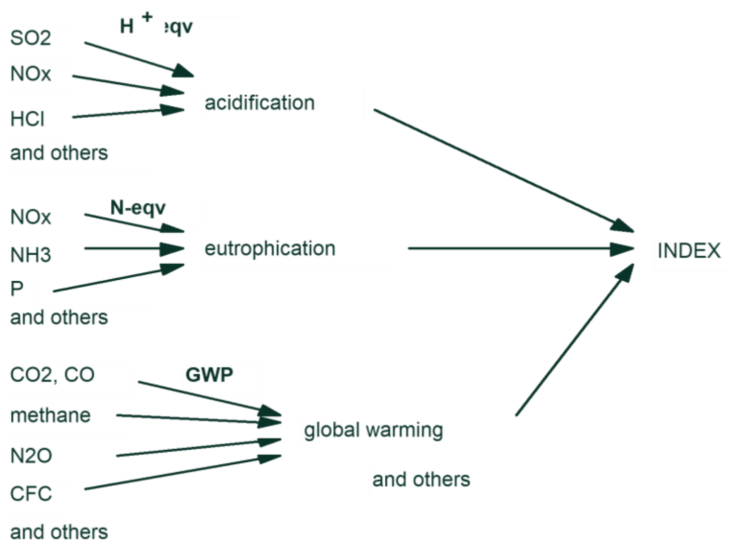

Figure 15: An illustration of the Impact Assessment of an LCA.

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 (European Commission, 2012b). 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 global 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 7 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 7: 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 Confidential appendix – Modelling details for binder (see separate file)

Appendix 4 Detailed results for all impact categories

The following table presents the result per functional unit for each impact category in EF3.0 for PaperShell and for the four other materials for comparison.

	PaperShell	Veneer	PP	GFRP	Aluminium
Particulate matter	p inc.				
Process	Value	Value	Value	Value	Value
Total	9,88E-08	2,31E-07	9,89E-08	9,24E-07	1,42E-06
Milling or cutting (4)	7,16E-10	1,07E-09		9,92E-10	9,02E-10
End of Life	3,17E-09	4,66E-09	2,22E-09	5,72E-09	0
Raw material	1,61E-08	2,13E-07	8,13E-08	8,73E-07	1,36E-06
Pre-processing (1)	4,00E-10		1,55E-08	2,20E-08	5,66E-08
Blank preparation (2)	5,91E-10	2,02E-09		2,79E-09	1,73E-09
Coating (5)		4,94E-09		4,58E-09	
Pressing (3)	2,83E-09	5,44E-09		1,51E-08	
Binder	7,50E-08				
Eutrophication, marine	kg N eq				
Process	Value	Value	Value	Value	Value
Total	0,000999	0,004001	0,002313	0,021871	0,019305
Milling or cutting (4)	9,42E-06	1,41E-05		1,30E-05	1,19E-05
End of Life	0,000212	0,000288	0,000135	0,000427	0
Raw material	0,000288	0,003438	0,001551	0,020439	0,017461
Pre-processing (1)	5,26E-06		0,000627	0,000528	0,001808
Blank preparation (2)	2,67E-05	0,000103		0,000183	2,45E-05
Coating (5)		8,49E-05		7,86E-05	
Pressing (3)	3,80E-05	7,30E-05		0,000203	
Binder	0,00042				
Eutrophication, freshwater	kg P eq				
Process	Value	Value	Value	Value	Value
Total	0,000118	0,000678	0,000855	0,000916	0,009094
Milling or cutting (4)	3,43E-06	5,13E-06		4,75E-06	4,32E-06
End of Life	8,72E-06	1,12E-05	2,30E-06	1,89E-05	0
Raw material	4,84E-05	0,000596	0,000339	0,000366	0,007725
Pre-processing (1)	1,92E-06		0,000513	0,000419	0,001349
Blank preparation (2)	2,11E-06	5,96E-06		9,85E-06	1,58E-05
Coating (5)		3,64E-05		3,37E-05	
Pressing (3)	1,19E-05	2,30E-05		6,38E-05	
Binder	4,10E-05				
Human toxicity, cancer	CTUh				
Process	Value	Value	Value	Value	Value
Total	1,11E-09	6,63E-09	1,26E-09	4,59E-09	4,52E-08
Milling or cutting (4)	4,06E-11	6,07E-11		5,62E-11	5,11E-11
End of Life	3,72E-10	5,56E-10	2,99E-10	6,57E-10	0
Raw material	2,82E-10	5,32E-09	5,95E-10	2,00E-09	4,39E-08

Pre-processing (1)	2,27E-11		3,70E-10	5,27E-10	1,14E-09
Blank preparation (2)	5,49E-11	2,13E-10		2,96E-10	1,34E-10
Coating (5)		1,52E-10		1,41E-10	
Pressing (3)	1,73E-10	3,32E-10		9,22E-10	
Binder	1,63E-10				
Resource use, minerals and metals	kg Sb eq				
Process	Value	Value	Value	Value	Value
Total	4,84E-06	5,88E-06	1,44E-05	1,58E-05	4,68E-05
Milling or cutting (4)	3,65E-07	5,45E-07		5,05E-07	4,59E-07
End of Life	1,40E-07	6,22E-08	4,77E-08	5,33E-07	0
Raw material	1,53E-06	2,17E-06	1,20E-05	6,33E-06	3,19E-05
Pre-processing (1)	2,04E-07		2,37E-06	1,83E-06	1,11E-05
Blank preparation (2)	1,37E-07	2,55E-07		4,37E-07	3,39E-06
Coating (5)		9,35E-07		8,65E-07	
Pressing (3)	9,92E-07	1,91E-06		5,30E-06	
Binder	1,48E-06				
Ecotoxicity, freshwater - inorganics	CTUe				
Process	Value	Value	Value	Value	Value
Total	3,122924	2,266727	4,691663	24,59048	17,42865
Milling or cutting (4)	0,022397	0,033508		0,031026	0,028205
End of Life	1,76834	0,205902	0,339313	7,847489	0
Raw material	0,695017	0,986049	3,480862	11,2403	14,87768
Pre-processing (1)	0,01251		0,871488	0,946968	2,426688
Blank preparation (2)	0,203954	0,083467		3,26441	0,096075
Coating (5)		0,756145		0,700135	
Pressing (3)	0,104836	0,201656		0,560155	
Binder	0,31587				
Human toxicity, non-cancer	CTUh				
Process	Value	Value	Value	Value	Value
Total	1,10E-08	2,80E-08	2,29E-08	4,88E-08	6,73E-07
Milling or cutting (4)	3,35E-10	5,02E-10		4,65E-10	4,22E-10
End of Life	1,92E-09	1,62E-09	2,02E-09	6,14E-09	0
Raw material	3,65E-09	2,12E-08	1,45E-08	2,71E-08	6,46E-07
Pre-processing (1)	1,87E-10		6,34E-09	5,31E-09	2,50E-08
Blank preparation (2)	3,25E-10	7,59E-10		2,74E-09	2,12E-09
Coating (5)		2,08E-09		1,93E-09	
Pressing (3)	9,62E-10	1,85E-09		5,14E-09	
Binder	3,65E-09				
Acidification	mol H+ eq				
Process	Value	Value	Value	Value	Value
Total	0,004881	0,011367	0,012095	0,066413	0,13964
Milling or cutting (4)	4,66E-05	6,98E-05		6,46E-05	5,87E-05
End of Life	0,000421	0,000579	0,000277	0,000838	0
Raw material	0,001565	0,009177	0,008165	0,060239	0,128699
Pre-processing (1)	2,60E-05		0,003653	0,002925	0,010677

Blank preparation (2)	6,23E-05	0,000224		0,000375	0,000205
Coating (5)		0,000911		0,000844	
Pressing (3)	0,000211	0,000406		0,001127	
Binder	0,002549				
Climate change - Biogenic	kg CO2 eq				
Process	Value	Value	Value	Value	Value
Total	0,00286	0,008315	0,007143	0,018695	0,094196
Milling or cutting (4)	1,21E-05	1,81E-05		1,68E-05	1,52E-05
End of Life	0,000264	0,000417	9,56E-06	0,000114	0
Raw material	0,002138	0,007083	0,003786	0,014364	0,081555
Pre-processing (1)	6,76E-06		0,003348	0,002912	0,012477
Blank preparation (2)	3,33E-05	0,000148		5,43E-05	0,000149
Coating (5)		0,000306		0,000284	
Pressing (3)	0,000178	0,000343		0,000951	
Binder	0,000228				
Ionising radiation	kBq U-235 eq				
Process	Value	Value	Value	Value	Value
Total	0,563675	0,347135	0,354075	0,295784	3,095922
Milling or cutting (4)	0,000493	0,000737		0,000683	0,000621
End of Life	0,001398	0,000673	0,000513	0,005211	0
Raw material	0,531414	0,326389	0,052868	0,022373	2,3388
Pre-processing (1)	0,000275		0,300693	0,239766	0,755034
Blank preparation (2)	0,00032	0,000542		0,002452	0,001467
Coating (5)		0,014528		0,013452	
Pressing (3)	0,002217	0,004265		0,011848	
Binder	0,027558				
Human toxicity, non-cancer - metals	CTUh				
Process	Value	Value	Value	Value	Value
Total	8,73E-09	2,05E-08	1,80E-08	2,70E-08	4,72E-07
Milling or cutting (4)	2,76E-10	4,13E-10		3,82E-10	3,48E-10
End of Life	1,38E-09	1,05E-09	1,71E-09	4,40E-09	0
Raw material	2,65E-09	1,61E-08	1,10E-08	1,08E-08	4,48E-07
Pre-processing (1)	1,54E-10		5,24E-09	4,43E-09	2,09E-08
Blank preparation (2)	2,46E-10	5,29E-10		1,99E-09	1,94E-09
Coating (5)		9,74E-10		9,02E-10	
Pressing (3)	7,65E-10	1,47E-09		4,09E-09	
Binder	3,26E-09				
Ecotoxicity, freshwater - metals	CTUe				
Process	Value	Value	Value	Value	Value
Total	13,58213	46,54834	24,6648	23,51406	402,1226
Milling or cutting (4)	0,245288	0,36697		0,339787	0,308898
End of Life	0,296611	0,189604	0,177815	1,014772	0
Raw material	4,407302	42,5541	17,05602	9,370202	374,5298
Pre-processing (1)	0,137008		7,430968	6,177056	25,9599
Blank preparation (2)	0,114785	0,221024		0,566145	1,32397

Coating (5)		1,560071		1,444511	
Pressing (3)	0,861212	1,656571		4,601585	
Binder	7,519924				
Human toxicity, non-cancer - inorganics	CTUh				
Process	Value	Value	Value	Value	Value
Total	2,20E-09	1,34E-08	4,20E-09	2,06E-08	2,00E-07
Milling or cutting (4)	4,99E-11	7,46E-11		6,91E-11	6,28E-11
End of Life	5,99E-10	5,57E-10	2,96E-10	1,71E-09	0
Raw material	9,49E-10	1,11E-08	2,92E-09	1,53E-08	1,96E-07
Pre-processing (1)	2,79E-11		9,83E-10	8,12E-10	3,45E-09
Blank preparation (2)	8,32E-11	2,19E-10		7,38E-10	9,34E-11
Coating (5)		1,06E-09		9,86E-10	
Pressing (3)	1,68E-10	3,23E-10		8,98E-10	
Binder	3,28E-10				
Resource use, fossils	MJ				
Process	Value	Value	Value	Value	Value
Total	13,88605	17,23655	81,5609	221,9536	263,1569
Milling or cutting (4)	0,095494	0,142867		0,132284	0,120258
End of Life	0,209288	0,175827	0,10612	0,634273	0
Raw material	10,06599	14,24684	64,33686	205,2212	220,3264
Pre-processing (1)	0,053339		17,11792	11,49985	42,50948
Blank preparation (2)	0,055111	0,12028		0,319509	0,200744
Coating (5)		1,587011		1,469454	
Pressing (3)	0,501019	0,963728		2,677021	
Binder	2,905808				
Land use	Pt				
Process	Value	Value	Value	Value	Value
Total	109,3858	340,6879	12,08145	16,73756	54,90455
Milling or cutting (4)	0,158399	0,236978		0,219424	0,199477
End of Life	0,066643	0,055525	0,03978	0,202867	0
Raw material	107,4853	338,7023	5,980761	6,214241	48,07799
Pre-processing (1)	0,088475		6,060913	6,44901	6,468775
Blank preparation (2)	0,060247	0,120276		0,178159	0,158308
Coating (5)		0,483298		0,447498	
Pressing (3)	0,5664	1,08949		3,02636	
Binder	0,960388				
Human toxicity, non-cancer - organics	CTUh				
Process	Value	Value	Value	Value	Value
Total	2,30E-10	5,08E-10	1,35E-09	4,36E-09	3,67E-09
Milling or cutting (4)	1,04E-11	1,56E-11		1,44E-11	1,31E-11
End of Life	1,46E-11	1,82E-11	9,18E-12	3,25E-11	0
Raw material	8,23E-11	3,38E-10	1,15E-09	3,94E-09	2,77E-09
Pre-processing (1)	5,81E-12		1,85E-10	1,16E-10	7,97E-10
Blank preparation (2)	5,09E-12	1,28E-11		1,96E-11	9,09E-11
Coating (5)		5,69E-11		5,27E-11	

Pressing (3)	3,45E-11	6,63E-11		1,84E-10	
Binder	7,77E-11				
Photochemical ozone formation	kg NMVOC eq				
Process	Value	Value	Value	Value	Value
Total	0,003089	0,012335	0,008953	0,038207	0,063721
Milling or cutting (4)	3,48E-05	5,20E-05		4,82E-05	4,38E-05
End of Life	0,000544	0,000814	0,000388	0,000971	0
Raw material	0,000901	0,010361	0,006666	0,033711	0,057661
Pre-processing (1)	1,94E-05		0,001898	0,001389	0,005931
Blank preparation (2)	7,21E-05	0,000295		0,000423	8,48E-05
Coating (5)		0,00032		0,000296	
Pressing (3)	0,000256	0,000493		0,001368	
Binder	0,001261				
Human toxicity, cancer - inorganics	CTUh				
Process	Value	Value	Value	Value	Value
Total	0	0	0	0	0
Milling or cutting (4)	0	0		0	0
End of Life	0	0	0	0	0
Raw material	0	0	0	0	0
Pre-processing (1)	0		0	0	0
Blank preparation (2)	0	0		0	0
Coating (5)		0		0	
Pressing (3)	0	0		0	
Binder	0				
Water use	m3 depriv.				
Process	Value	Value	Value	Value	Value
Total	0,414336	1,790624	1,348698	17,01284	18,22785
Milling or cutting (4)	0,003414	0,005107		0,004729	0,004299
End of Life	0,030816	0,039116	0,01941	0,067673	0
Raw material	0,269431	1,622425	0,753987	15,79691	17,151
Pre-processing (1)	0,001907		0,575301	0,971279	1,064877
Blank preparation (2)	0,004563	0,015317		0,030064	0,007666
Coating (5)		0,086208		0,079822	
Pressing (3)	0,011671	0,02245		0,062361	
Binder	0,092534				
Ecotoxicity, freshwater - organics	CTUe				
Process	Value	Value	Value	Value	Value
Total	0,274941	0,929711	0,446634	1,083564	6,325222
Milling or cutting (4)	0,00862	0,012896		0,011941	0,010855
End of Life	0,003714	0,004121	0,002372	0,00931	0
Raw material	0,147544	0,341793	0,211454	0,30987	5,772769
Pre-processing (1)	0,004815		0,232809	0,152066	0,535256
Blank preparation (2)	0,003288	0,006914		0,008978	0,006341
Coating (5)		0,526625		0,487616	
Pressing (3)	0,019424	0,037362		0,103784	

Binder	0,087537				
Ecotoxicity, freshwater	CTUe				
Process	Value	Value	Value	Value	Value
Total	16,97999	49,74477	29,8031	49,18811	425,8765
Milling or cutting (4)	0,276304	0,413374		0,382754	0,347958
End of Life	2,068665	0,399626	0,5195	8,871571	0
Raw material	5,249863	43,88194	20,74834	20,92037	395,1803
Pre-processing (1)	0,154332		8,535264	7,276091	28,92185
Blank preparation (2)	0,322027	0,311405		3,839533	1,426385
Coating (5)		2,842842		2,632261	
Pressing (3)	0,985472	1,895588		5,265523	
Binder	7,923331				
Human toxicity, cancer - metals	CTUh				
Process	Value	Value	Value	Value	Value
Total	5,09E-10	8,45E-10	7,28E-10	3,31E-09	2,38E-08
Milling or cutting (4)	2,83E-11	4,23E-11		3,91E-11	3,56E-11
End of Life	7,02E-11	3,48E-11	6,15E-11	2,60E-10	0
Raw material	1,26E-10	3,59E-10	4,40E-10	1,79E-09	2,31E-08
Pre-processing (1)	1,58E-11		2,26E-10	2,54E-10	6,42E-10
Blank preparation (2)	1,72E-11	2,98E-11		1,24E-10	1,12E-10
Coating (5)		1,17E-10		1,08E-10	
Pressing (3)	1,37E-10	2,63E-10		7,30E-10	
Binder	1,15E-10				
Climate change - Land use and LU change	kg CO2 eq				
Process	Value	Value	Value	Value	Value
Total	0,007121	0,006293	0,002271	0,003573	0,314764
Milling or cutting (4)	7,86E-06	1,18E-05		1,09E-05	9,90E-06
End of Life	1,64E-05	6,07E-06	4,94E-06	6,45E-05	0
Raw material	0,006846	0,006098	0,001017	0,001756	0,310915
Pre-processing (1)	4,39E-06		0,001249	0,0014	0,00382
Blank preparation (2)	4,44E-06	7,08E-06		3,14E-05	1,94E-05
Coating (5)		8,71E-05		8,07E-05	
Pressing (3)	4,29E-05	8,26E-05		0,000229	
Binder	0,000198				
Human toxicity, cancer - organics	CTUh				
Process	Value	Value	Value	Value	Value
Total	5,99E-10	5,79E-09	5,35E-10	1,29E-09	2,14E-08
Milling or cutting (4)	1,23E-11	1,84E-11		1,71E-11	1,55E-11
End of Life	3,02E-10	5,21E-10	2,37E-10	3,97E-10	0
Raw material	1,56E-10	4,96E-09	1,54E-10	2,01E-10	2,08E-08
Pre-processing (1)	6,88E-12		1,43E-10	2,73E-10	4,96E-10
Blank preparation (2)	3,77E-11	1,83E-10		1,72E-10	2,22E-11
Coating (5)		3,51E-11		3,25E-11	
Pressing (3)	3,61E-11	6,93E-11		1,93E-10	
Binder	4,78E-11				

Climate change	kg CO2 eq				
Process	Value	Value	Value	Value	Value
Total	0,495981	0,982454	4,978023	20,41623	20,20085
Milling or cutting (4)	0,007597	0,011366		0,010524	0,009568
End of Life	0,021285	0,017659	2,154922	3,291205	0
Raw material	0,291838	0,772537	2,035129	14,84258	17,7569
Pre-processing (1)	0,004244		0,787972	0,603706	2,418618
Blank preparation (2)	0,004899	0,010801		1,368013	0,015771
Coating (5)		0,093027		0,086136	
Pressing (3)	0,040064	0,077065		0,214069	
Binder	0,126054				
Climate change - Fossil	kg CO2 eq				
Process	Value	Value	Value	Value	Value
Total	0,486	0,967846	4,968608	20,39396	19,79189
Milling or cutting (4)	0,007577	0,011337		0,010497	0,009543
End of Life	0,021005	0,017235	2,154908	3,291027	0
Raw material	0,282853	0,759356	2,030326	14,82646	17,36443
Pre-processing (1)	0,004232		0,783375	0,599395	2,402321
Blank preparation (2)	0,004862	0,010646		1,367928	0,015603
Coating (5)		0,092633		0,085771	
Pressing (3)	0,039843	0,07664		0,212888	
Binder	0,125628				
Eutrophication, terrestrial	mol N eq				
Process	Value	Value	Value	Value	Value
Total	0,010645	0,042991	0,023685	0,1105	0,191786
Milling or cutting (4)	9,26E-05	0,000138		0,000128	0,000117
End of Life	0,002115	0,003113	0,001453	0,003812	0
Raw material	0,002926	0,036867	0,016386	0,096488	0,174379
Pre-processing (1)	5,17E-05		0,005846	0,005032	0,017024
Blank preparation (2)	0,000266	0,001104		0,001634	0,000266
Coating (5)		0,000813		0,000752	
Pressing (3)	0,000497	0,000955		0,002653	
Binder	0,004698				
Ozone depletion	kg CFC11 eq				
Process	Value	Value	Value	Value	Value
Total	7,82E-08	8,43E-08	1,39E-07	1,35E-07	1,56E-06
Milling or cutting (4)	5,70E-10	8,52E-10		7,89E-10	7,17E-10
End of Life	5,56E-09	2,00E-09	1,66E-09	2,20E-08	0
Raw material	3,67E-08	6,45E-08	3,98E-08	3,07E-08	1,32E-06
Pre-processing (1)	3,18E-10		9,77E-08	4,65E-08	2,37E-07
Blank preparation (2)	8,07E-10	1,04E-09		9,47E-09	1,05E-09
Coating (5)		1,01E-08		9,34E-09	
Pressing (3)	3,02E-09	5,80E-09		1,61E-08	
Binder	3,12E-08				

Appendix 5 Modelling details for veneer, PP, GFRP, aluminium

Part of the interpretation (section 6.3) was a rough comparison with other materials. This comparison was based on the parameters defined in Table 8 and Table 9 while the modelling details are described for each material in Table 10-Table 13. Note that the modelling is simplified and meant for a rough indication only of PaperShell's performance in relation to other materials. Packaging is identical to the PaperShell model.

The same conditions as for PaperShell manufacturing are assumed for all materials, with some differences described here. The thicknesses are estimated by PaperShell as the thickness needed to fulfil the function of a chair seat for each material. The density for PaperShell is measured. The expected life length is assumed as 10 years based on the warranty period for furniture in Sweden. For simplicity, end of life was modelled as incineration for all materials, except for aluminium which was assumed to be recycled. An average production waste from cutting is estimated as 30%, based on PaperShell's experience from cutting various components of different sizes. The exceptions are PaperShell (the waste can be fed back into the process, but still a conservative number of 10% was used for production waste) and PP (no cutting needed since it is assumed to be injection moulded. Due to the high density of GFRP, the energy required for pressing is estimated to be triple the energy for the other materials. Aluminium is assumed to not need any pressing, since it instead goes through sheet rolling and metal working, which are modelled as one process.

Table 8: Material and life cycle parameters for each material

	PaperShell	Veneer	PP	GFRP	Aluminium
Thickness to achieve similar strength/function (mm)	4	9	5	4	2,5
Density (kg/m3)	1340	900 [12]	910 [13]	1875 [14]	2700 [15]
Material needed for functional unit (kg)	1,0	1,51	0,85	1,4	1,26
Expected life length (years)	10	10	10	10	10
End of life scenario	Incineration	Incineration	Incineration	Incineration	Recycling
Production waste in process 2	10%	30%	0%	30%	30%
Relative energy for process 3 (pressing)	1	1	1	3	0

Table 9: How the processing steps were modelled for each material, based on experience from PaperShell on how the materials need to be processed to make a chair seat.

	PaperShell	**Veneer**	**Polypropylene (PP)**	**Glass fibre reinforced plastic (GFRP)**	**Aluminium**
Process 1 (pre-processing)	Impregnation of Kraft paper	-	Injection moulding of PP	Calendering	Sheet rolling and metal working of aluminium

[12] Density veneer: https://www.hordastans.se/a.350/material/fiber--trabaserade-material
[13] Density PP: https://www.lenntech.com/polypropylene.htm
[14] Density GFRP: https://www.sciencedirect.com/science/article/pii/S2214785320357618
[15] Density aluminium: https://sv.wikipedia.org/wiki/Aluminium

Process 2 (blank preparation)	Cutting (digital cutter)	Cutting (digital cutter)	-	Cutting (digital cutter)	Cutting (laser)
Process 3 (pressing)	Pressing (approx. with thermo-forming of plastic sheets)	Pressing (approx. with thermo-forming of plastic sheets)	-	Pressing (approx. with thermo-forming of plastic sheets)	- Pressing (approx. with sheet rolling of aluminium)
Process 4 (milling or cutting)	CNC	CNC	-	CNC	Metal cutting
Process 5 (coating)	-	Coating, approx. with TiO2 coating powder	-	Coating, approx. with TiO2 coating powder	-

Table 10: Manufacturing of 1 kg of veneer chair seat.

Processes	Amount	Unit	Comments
Inputs			
Plywood {RER}| plywood production | Cut-off, U	(1-share_coat)/ yield_veneer	kg	Proxy for veneer. Ecoinvent process adapted by removing inputs and outputs of steel, rubber and urea formaldehyde resin
Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0,1391/ yield_veneer	kWh	kWh Papercutting by Zund digital cutter (Process 2, blank preparation)
Coating powder {RER}| market for coating powder | Cut-off, U	share_coat	kg	Proxy for coating (process 5) - coat approximated by 1%
Thermoforming of plastic sheets {FR}| processing | Cut-off, U (with SE mix)	relative_press_energy_V* (1-share_coat)	kg	Proxy for pressing (process 3). Process for thermoforming adapted by changing energy input to 0,65 kWh from Swedish wind power (according to data from PaperShell) and changing output from 1 kg to 0,946 kg according to instructions in ecoinvent documentation.
Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	(1-share_coat)*0,4633	kWh	Proxy for CNC machining (process 4)
Outputs			
Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U	(1-share_coat)/ yield_veneer-1	kg	Production waste from cutting.
Parameters			
yield_veneer	0,7		30% waste in cutting
relative_press_energy_V	1		Standard, same as PS
share_coat	0,01		1% coat for veneer and GFRP

Table 11: Manufacturing of 1 kg of polypropylene chair seat

Processes	Amount	Unit	Comments
Inputs			
Polypropylene, granulate {GLO}| market for | Cut-off, U	1/yield_PP	kg	

Injection moulding {RER}| processing | Cut-off, U	1/yield_PP	kg	Process 1 according to the scenario-definition. Waste is assumed to be recycled and thus set to zero
Parameters			
yield_PP	1		0% waste

Table 12: Manufacturing of 1 kg of glass fibre reinforced polymer chair seat.

Processes	Amount	Unit	Comments
Inputs			
Nylon 6-6, glass-filled {RoW}| market for nylon 6-6, glass-filled | Cut-off, U	(1-share_coat)/ yield_GFRP	kg	Raw material approximated with glass-filled nylon
Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0,1391/ yield_GFRP	kWh	kWh Papercutting by Zund digital cutter (Process 2, blank preparation)
Coating powder {RER}| market for coating powder | Cut-off, U	share_coat	kg	Proxy for coating (process 5) - coat approximated by 1%
Thermoforming of plastic sheets {FR}| processing | Cut-off, U (with SE mix)	relative_press_energy_GFRP*(1-share_coat)	kg	Proxy for pressing (process 3). Energy is triple compared to other materials. Process for thermoforming adapted by changing energy input to 0,65 kWh from Swedish wind power (according to data from PaperShell) and changing output from 1 kg to 0,946 kg according to instructions in ecoinvent documentation.
Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	(1-share_coat)*0,4633	kWh	Proxy for CNC machining (process 4)
Outputs			
Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U	(1-share_coat)/ yield_GFRP-1	kg	Production waste from cutting.
Parameters			
yield_GFRP	0,7		30% waste in cutting
relative_press_energy_GFRP	1		Standard, triple compared to PS
share_coat	0,01		1% coat for veneer and GFRP

Table 13: Manufacturing of 1 kg of aluminium chair seat.

Processes	Amount	Unit	Comments
Inputs			
Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| market for | Cut-off, U	1/yield_alu	kg	
Energy and auxilliary inputs, metal working machine {RER}| market for energy and auxilliary inputs, metal working machine | Cut-off, U	1/yield_alu	kg	Proxy for rolling and pressing (process 1 and 3)

Sheet rolling, aluminium {RER}| processing | Cut-off, U	1/yield_alu	kg	Proxy for rolling and pressing (process 1 and 3)
Laser machining, metal, with CO2-laser, 1000W power {RER}| laser machining, metal, with CO2-laser, 1000W power | Cut-off, U	0,452	min	Approximation for laser cutting of aluminium, 1 chair seat (2,21 kg) requires 1 minute of 1 kW laser. Thus, 1 kg aluminium chair requires ca 1/2,21 = 0,452 minutes. (not scaled with yield, since laser time does not depend on yield). This gives an error because circumference does not scale linearly with weight, but good enough approximation)
Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	0,4633	kWh	Proxy for CNC machining (process 4)
Outputs			
Aluminium (waste treatment) {GLO}| recycling of aluminium | Cut-off, U	1/yield_alu-1	kg	Production waste from cutting.
Parameters			
yield_alu	0,7		30% waste in cutting

Appendix 6 Certificates

Below can be found two certificates. The first is a determination of PaperShell's biogenic carbon content. The second is an elementary analysis.

REPORT

Contact person RISE
Conny Haraldsson
Division Materials and Production
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conny.haraldsson@ri.se

Date
2022-06-13

Reference
P112413-01

Papershell
Anders Breitholz

Determination of Biogenic Content

Sample and assignment

A material sample labelled: PS 22-KF

Date of arrival 2022-04-20

Date of Analysis 2022-04-25

The assignment was to determine biogenic and fossil fraction of carbon in the material.

RISE Research Institutes of Sweden AB

Postal address	Office location	Phone / Fax / E-mail
Box 857	Brinellgatan 4	+46 10-516 50 00
501 15 BORÅS	504 62 Borås	+46 33-13 55 02
SWEDEN	SWEDEN	info@ri.se

Method

The biogenic fraction is determined based on the C-14 content of the materials using the method described below.

Modified ASTM D6866-21, the modification consists of using Saturated Cavity Ringdown Spectroscopy (SCAR) instead of the instrumental techniques for isotope ratios mentioned in the standard. Before measurement of ^{14}C content the samples are combusted in an elemental analyser, the CO_2 formed is trapped and used for the determination of the ^{14}C content in the SCAR spectrometer.

Results

The carbon in the sample is 100% biogenic.

RISE Research Institutes of Sweden AB
Chemistry and Applied Mechanics - Chemical Problem Solving

Performed by	Examined by
Conny Haraldsson	Eskil Sahlin

Verifikat

Transaktion 09222115557471293033

Dokument

Determination of Biogenic Content
Huvuddokument
2 sidor
Startades 2022-06-13 13:00:09 CEST (+0200) av Conny Haraldsson (CH)
Färdigställt 2022-06-13 13:03:06 CEST (+0200)

Signerande parter

Conny Haraldsson (CH)	Eskil Sahlin (ES)
RISE Research Institutes of Sweden AB Org. nr 556464-6874 *conny.haraldsson@ri.se* *Signerade 2022-06-13 13:00:12 CEST (+0200)*	RISE *eskil.sahlin@ri.se* *Signerade 2022-06-13 13:03:06 CEST (+0200)*

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Denna rapport ersätter tidigare utfärdad rapport med samma nummer

Analyscertifikat

Ordernummer	: **LE2301861**	Sida	: 1 av 4
Version	: **1**		
Kund	: **PaperShell AB**	Projekt	: ----
Kontaktperson	: Anders Holmkvist	Beställningsnummer	: Engineering - EA23
Adress	: Järnvägsgatan 15 543 50 Tibro Sverige	Provtagare	: ----
		Provtagningspunkt	: ----
		Ankomstdatum, prover	: 2023-02-10 14:36
E-post	: holmkvist@papershell.se	Analys påbörjad	: 2023-02-21
Telefon	: ----	Utfärdad	: 2023-03-16 08:43
C-O-C-nummer (eller Orderblankett-nummer)	: ----	Antal ankomna prover	: 2
Offertnummer	: ----	Antal analyserade prover	: 2

Generell kommentar

Denna rapport ersätter eventuella tidigare rapporter med denna referens. Resultaten gäller för de inskickade proverna. Alla sidor i denna rapport har kontrollerats och godkänts före utfärdande av rapporten.

Denna rapport får endast återges i sin helhet, om inte utfärdande laboratorium i förväg skriftligen godkänt annat. Resultatet gäller endast materialet såsom det har mottagits, identifierats och testats. Laboratoriet tar inget ansvar för information i denna rapport som har lämnats av kunden, eller resultat som kan ha påverkats av sådan information. Beträffande laboratoriets ansvar i samband med uppdrag, se vår webbplats www.alsglobal.se

Orderkommentar

Version 1 - Ändring gäller systemfel, det påverkar inte resultaten.

Signatur	*Position*
Ilia Rodushkin	Laboratoriechef

Ilia Rodushkin

Laboratorium	: ALS Scandinavia AB	hemsida	: www.alsglobal.se
Adress	: Aurorum 10 977 75 Luleå Sverige	E-post	: info.lu@alsglobal.com
		Telefon	: +46 920 28 99 00

Analysresultat

Matris: INDUSTRI FASTA	Provbeteckning	Prov 1						
	Laboratoriets provnummer	LE2301861-001						
	Provtagningsdatum / tid	ej specificerad						
Parameter	Resultat	MU	Enhet	LOR	Analyspaket	Metod	Utf.	
Oorganiska parametrar								
Kol i torrsubstans C (d)	41.1	± 6.16	% TS	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Kol (ar)	39.7	± 5.96	%	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Väte i torrsubstans H (d)	4.80	± 0.72	% TS	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Väte (ar)	4.64	± 0.70	%	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Kväve i torrsubstans N (d)	1.03	± 0.17	% TS	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Kväve (ar)	1.00	± 0.16	%	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Syre i torrsubstans O (d)	37.0	----	% TS	5.0	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Syre (ar)	35.8	----	%	5.0	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Brännbar svavel i torrämne S (d)	0.17	± 0.07	% TS	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Svavel Brännbart Original S (ar)	0.17	± 0.07	%	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ELEM-TCDS	CS	
Fysikaliska parametrar								
Aska (ar) vid 550°C	15.4	± 1.54	%	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ASH550GRS	CS	
Aska Analytisk A(ad) vid 550 °C	15.4	± 1.54	%	0.10	Elementaranalys C, H, N, S, O (fast matrl)	I-ASH550GRS	CS	
Provberedning								
Preprep special	Ja *	----	-	-	PP-spec	S-PP-spec	LE	

Matris: **INDUSTRI FASTA**

Provbeteckning	**Prov 2**						
Laboratoriets provnummer	*LE2301861-002*						
Provtagningsdatum / tid	*ej specificerad*						
Parameter	**Resultat**	MU	*Enhet*	*LOR*	*Analyspaket*	*Metod*	*Utf.*
Provberedning							
Uppslutning	Ja *	----	-	-	P-HNO3HF-UC	I-PI58-UC	LE
Metaller och grundämnen							
Al, aluminium	14.5 *	----	mg/kg	5.00	I-5	I-SFMS-58	LE
As, arsenik	<0.1 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Ba, barium	7.61 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Be, beryllium	<0.1 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Ca, kalcium	908 *	----	mg/kg	50.0	I-5	I-SFMS-58	LE
Cd, kadmium	<0.02 *	----	mg/kg	0.0200	I-5	I-SFMS-58	LE
Co, kobolt	4.56 *	----	mg/kg	0.0200	I-5	I-SFMS-58	LE
Cr, krom	0.264 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Cu, koppar	3.58 *	----	mg/kg	0.500	I-5	I-SFMS-58	LE
Fe, järn	20.1 *	----	mg/kg	2.00	I-5	I-SFMS-58	LE
Hg, kvicksilver	<0.05 *	----	mg/kg	0.0500	I-5	I-SFMS-58	LE
K, kalium	104 *	----	mg/kg	50.0	I-5	I-SFMS-58	LE
Mg, magnesium	129 *	----	mg/kg	5.00	I-5	I-SFMS-58	LE
Mn, mangan	18.9 *	----	mg/kg	0.200	I-5	I-SFMS-58	LE
Mo, molybden	0.130 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Na, natrium	910 *	----	mg/kg	50.0	I-5	I-SFMS-58	LE
Nb, niob	<0.1 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Ni, nickel	<0.2 *	----	mg/kg	0.200	I-5	I-SFMS-58	LE
P, fosfor	10.9 *	----	mg/kg	5.00	I-5	I-SFMS-58	LE
Pb, bly	<0.2 *	----	mg/kg	0.200	I-5	I-SFMS-58	LE
S, svavel	814 *	----	mg/kg	50.0	I-5	I-SFMS-58	LE
Sb, antimon	<0.1 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Sn, tenn	<0.1 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Sr, strontium	4.24 *	----	mg/kg	0.500	I-5	I-SFMS-58	LE
Ti, titan	1.01 *	----	mg/kg	0.500	I-5	I-SFMS-58	LE
V, vanadin	0.158 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
W, volfram	0.138 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Y, yttrium	0.529 *	----	mg/kg	0.100	I-5	I-SFMS-58	LE
Zn, zink	1.48 *	----	mg/kg	1.00	I-5	I-SFMS-58	LE
Zr, zirkonium	9.94 *	----	mg/kg	0.500	I-5	I-SFMS-58	LE
Provberedning							
Preprep special	Ja *	----	-	-	PP-spec	S-PP-spec	LE

Metodsammanfattningar

Analysmetoder	Metod
I-SFMS-58	Bestämning av metaller i polymerer och plast med ICP-SFMS enligt SS-EN ISO 17294-2:2016 och US EPA Method 200.8:1994 efter uppslutning enligt I-PI58-UC.
S-PP-spec*	Provberedning special. Kontakta laboratoriet för information.
I-ASH550GRS	Bestämning av aska genom gravimetri och bestämning av glödförlust genom beräkning från uppmätta värden enligt CSN EN 15403, CSN EN ISO 18122.
I-ELEM-TCDS	CZ_SOP_D06_07_121.A (CSN ISO 16994, CSN EN ISO 16948, CSN EN 15407, CSN ISO 19579, CSN EN 15408, CSN ISO 10694, CSN EN 13137) Bestämning av totalt kol (TC), totalt organiskt kol TOC), total svavel och väte genom förbränningsmetod med IR, bestämning av total kväve genom förbränningsmetod med användning av TCD och bestämning av syre genom beräkning och totalt oorganiskt kol (TIC) och karbonater genom beräkning från uppmätta värden.

Beredningsmetoder	Metod
I-PI58-UC	Uppslutning i salpetersyra/vätefluorid i UltraClave enligt SE-SOP-0055.
S-PPHOM.07*	Torkning, siktning och och malning av prov till partikelstorlek < 0.07 mm.
S-PPHOM0.3*	Torkning, siktning och malning av prov till partikelstorlek <0,3 mm.

Nyckel: **LOR** = Den rapporteringsgräns (LOR) som anges är standard för respektive parameter i metoden. Rapporteringsgränsen kan påverkas vid t.ex. spädning p.g.a. matrisstörningar, begränsad provmängd eller låg torrsubstanshalt.

MU = Mätosäkerhet

* = Asterisk efter resultatet visar på ej ackrediterat test, gäller både egna lab och underleverantör

Mätosäkerhet:

Mätosäkerheten anges som en utvidgad osäkerhet (enligt definitionen i "Evaluation of measurement data- Guide to the expression of uncertainty in measurement", JCGM 100:2008 Corrected version 2010) beräknad med täckningsfaktor lika med 2 vilket ger en konfidensnivå på ungefär 95%.
Mätosäkerhet anges endast för detekterade ämnen med halter över rapporteringsgränsen.

Mätosäkerhet från underleverantör anges oftast som en utvidgad osäkerhet beräknad med täckningsfaktor 2. För ytterligare information kontakta laboratoriet.

Utförande laboratorium (teknisk enhet inom ALS Scandinavia eller anlitat laboratorium (underleverantör)).

	Utf.
CS	*Analys utförd av* ALS Czech Republic s.r.o Česká Lípa, Bendlova 1687/7 Česká Lípa Tjeckien 470 01 Ackrediterad av: CAI Ackrediteringsnummer: 1163, CSN EN ISO/IEC 17025:2018
LE	*Analys utförd av* ALS Scandinavia AB, Aurorum 10 Luleå Sverige 977 75 Ackrediterad av: SWEDAC Ackrediteringsnummer: 2030, ISO/IEC 17025