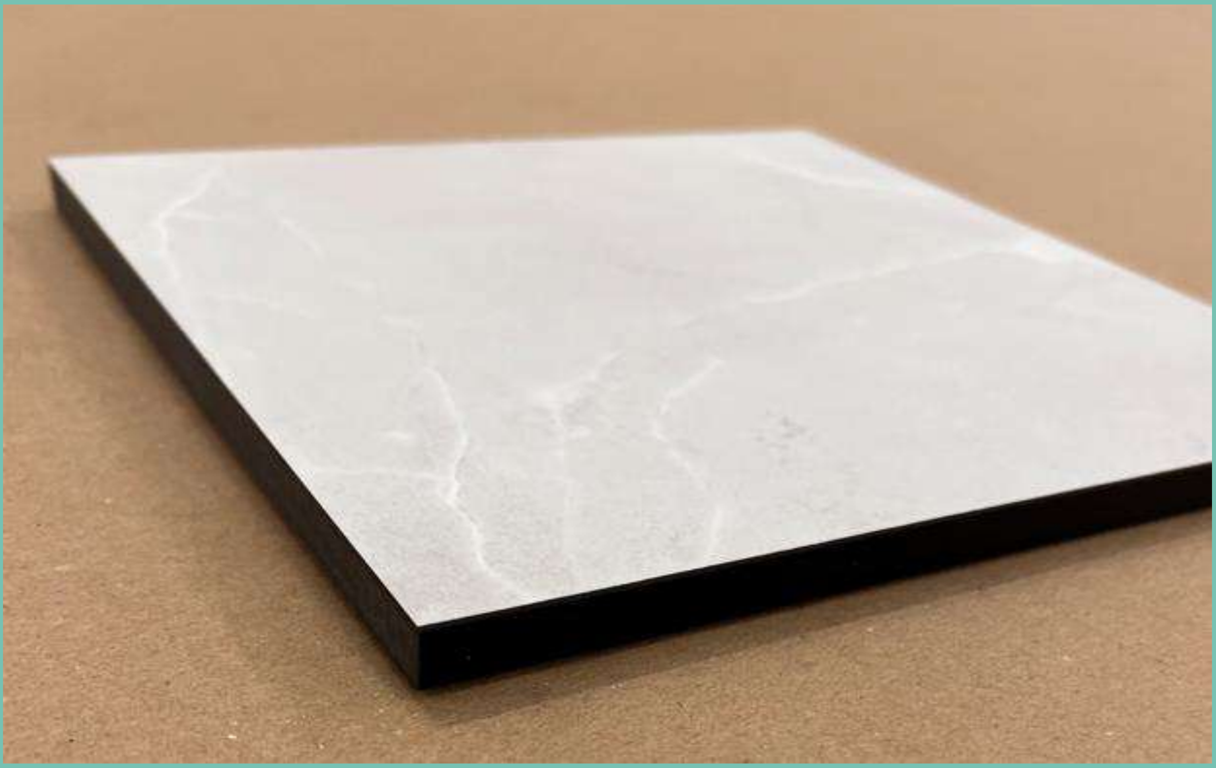

Life Cycle Assessment of Tabletops by DFI Geisler

Title: Life Cycle Assessment of Tabletops by DFI Geisler
Date: 10/04/2024
Ordered by: DFI Geisler
Report number: 1432
Name and location of database:
SimaPro@192.168.15.21\Default\MiljogiraffEmber; 1432 LCA and EPD DFI Geisler
LCA practitioner: Oline Haggren & Pär Lindman, Miljögiraff AB

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Ordered by: *DFI Geisler A/S*
DFI Geisler is Scandinavia's leading manufacturer of kitchen worktops in all materials. We are Danish
through and through, and, for decades, we have supplied worktops with personality to more than a million kitchens, mainly in Scandinavia.

DFI Geisler's mission is to "Develop, sell, produce and deliver a wide range of tabletops for kitchen and bath as efficiently as possible".

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

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

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

Abbreviations and Expressions

Clarification of expressions and abbreviations used in the report

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

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

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

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

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

Abstract

This Life Cycle Assessment (LCA) investigates the environmental impacts associated with the raw material acquisition, production, transportation and disposal of tabletops from DFI Geisler. The report can be used for internal communication and for ecodesign. The LCA study has been carried out according to ISO14040/44 and the product category rules for construction products, PCR 2019:14 v.1.3.1, in the International EPD system.

The report shows the environmental impact from a life cycle perspective the product Fibertops, the impact is shown per m2. The total climate impact is 26.9 kg CO2 eq per m2 tabletop. The biggest contributor to the climate impact is by far the raw materials, which stand for around 56% of the total impact. The manufacturing, transportation, and waste handling have a smaller but still relevant impact.

Looking at all impact categories, the most important impact categories for the Fibertops are “Climate change”, “Resource use fossils”, “Resource use minerals and metals”, according to the EF 3.1 single score method. The main impact for all impact categories originates from the raw materials, more specifically the CDF and laminate. For the impact category “Resource use minerals and metals”, the manufacturing at DFI Geisler has a big impact because of the use of a photovoltaic system for the production of electricity.

The most important life cycle stages are the raw materials, the manufacturing and the transportation of raw materials. Actions that have a potential to reduce the environmental impact are presented, these are:

- Investigate possibilities to dig deeper into the most contributing aspects of the raw materials CDF and laminate, where EPDs have been used, in order to see where efficient measures can be taken.
- Communicate to suppliers the importance of reducing waste and using energy with low environmental impact in production of the raw materials.
- The production waste for the manufacturing at DFI Geisler is now high, at 31%, if reduced this could lower the total impact of the product.
- Investigate the possibility to lower the total amount of energy used for the manufacturing at DFI Geisler in order to lower the impact.
- Investigate the possibility to use train instead of trucks for the transportation of the raw materials.

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 seven tabletops produced by DFI Geisler. 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 through flowcharts or diagrams for the different impact categories that support the conclusion and recommendations.
- >30 minutes
    - For in-depth detail and transparent documentation on the modelling of each part of the life cycle, see section 4 ("Life Cycle Inventory")
    - For information about methodology, scope and functional unit, see sections 2 ("Life Cycle Assessment") and section 3 ("Goal and Scope")

1.2 General Description of the Product and its Context

DFI Geisler is a Danish company that manufacturers kitchen worktops in all materials. In this study one LCA report is to be conducted for their product called Fibertops. DFI Geisler wants an LCA for their new product Fibertops which consists of the material melamine faced CDF and laminate, the report should be harmonized with PCR construction products.

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 (Richardson et al., 2023) . 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 1.

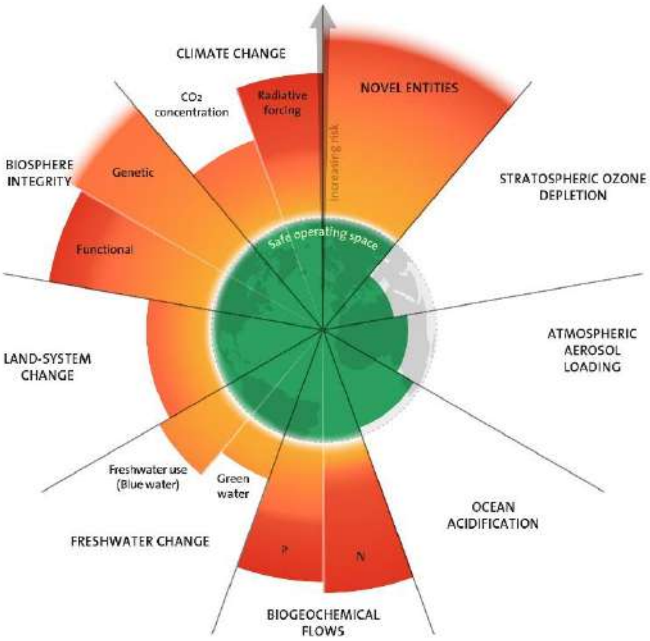

Figure 1: Shows the state of the planetary boundaries, where the green area represents a safe operating space. Credit: Azote for Stockholm Resilience Centre, based on analysis in (Richardson et al., 2023).

One critical environmental problem we face today is climate change. The report from the Intergovernmental Panel on Climate Change (IPCC), 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 2. 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. This is also evident in the latest report from IPCC (IPCC, 2022).

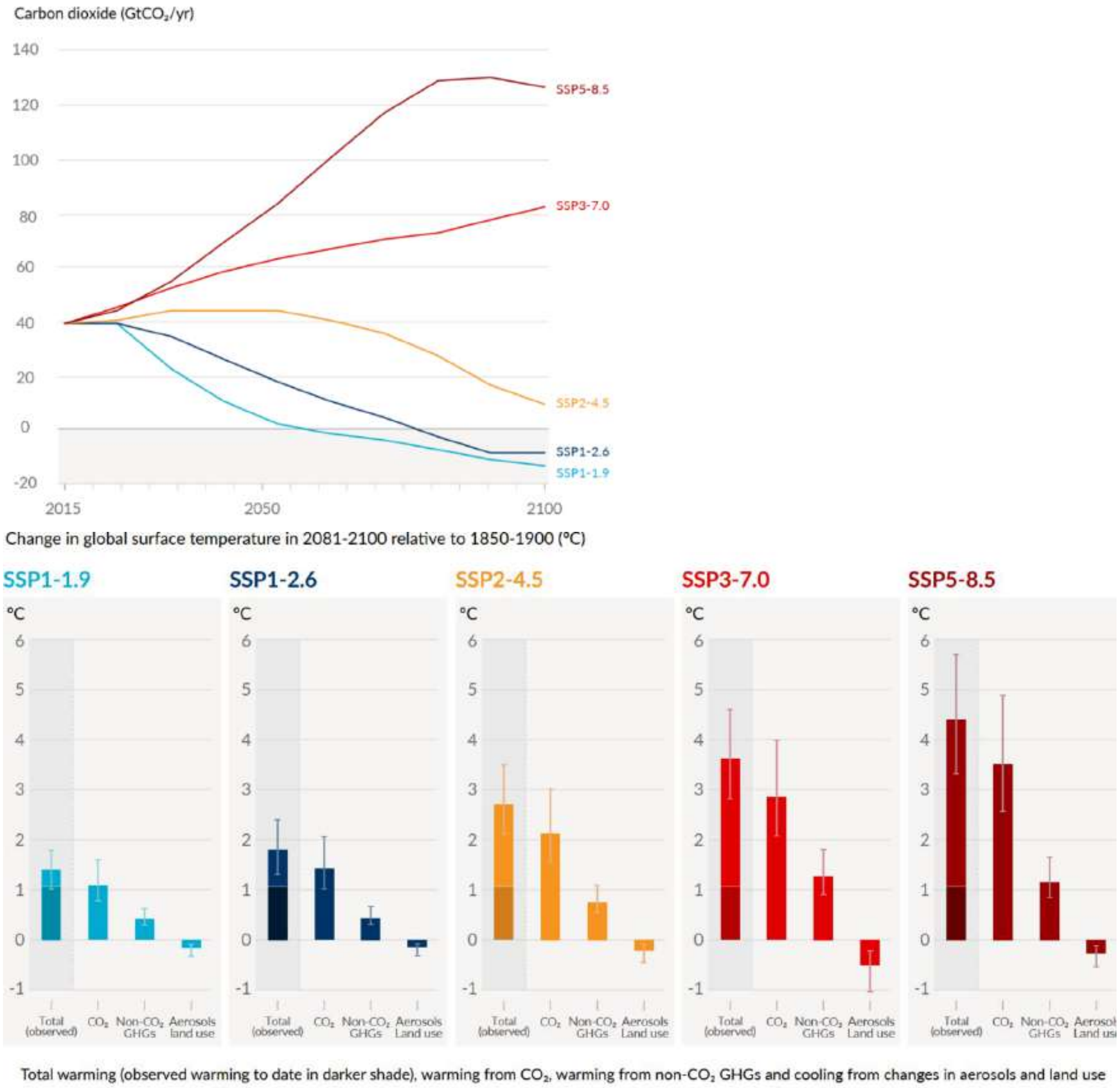

Figure 2: Future annual emissions of CO_2 (top) and contribution to global surface temperature increase from different emissions, with a dominant role of CO_2 emissions (bottom) across five illustrative scenarios. Image from IPCC (2021b).

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).

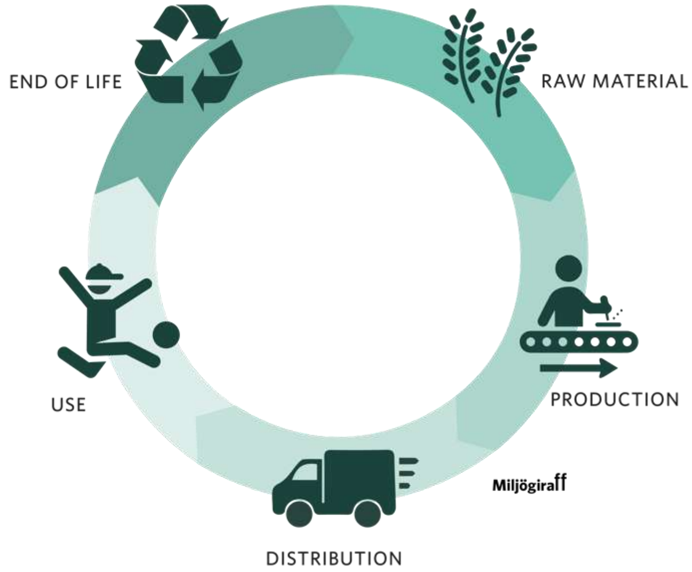

Figure 3: The Life Cycle concept, starting from raw material extraction, production, and distribution, followed by use and end-of-life.

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 4.)

Figure 4: 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 developing along with progressions within the field of LCA (Rebitzer et al., 2004). The guidelines for LCA are 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 method used in the study is Life Cycle Assessment (LCA) as described in:

- 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 aims to find metrics for the environmental impact of a tabletop called Fibertops produced by DFI Geisler from a life cycle perspective.

The purpose of the study is, through the LCA approach, to provide a transparent and objective assessment and characterization of DFI Geisler's product to be used in product development and environmental communication being intended for both internal audiences.

The study is done according to ISO14040/44 and the product category rules for construction products, PCR 2019:14 v.1.3.1, in the international EPD system.

The choice to harmonize with PCR is to make sure to follow industry consensus and prepare for the development of Environmental Product Declaration in the future.

3.2 Standards and Frameworks

The ISO 14040 and 14044 standards (ISO, 2006b, 2006c) guide this LCA. This study follows an attributional LCA approach (accounting) defined in the ISO 14040 standard.

The standards and frameworks guiding this LCA are in Table 1.

Table 1: Standards and framework conformance.

Standards conformance
ISO 14040 and 14044 (ISO, 2006a, 2006b)
General Programme Instructions for the International EPD System, version 4.0 (EPD International, 2021)
PCR 2019:14 Construction Products, version 1.3.1 (EPD International, 2023)
EN 15804:2012+A2:2019/AC:2021 (CEN, 2021)

3.3 Scope of the Study

This section specifies the scope of an LCA, including a description of the system's functions (performance characteristics).

3.3.1 Name and Function of the Product/System

In this study, one tabletop, caller Fibertops, are studied.

3.3.2 The Functional Unit and Reference flow

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

For this study, the functional unit used was 1 m2 tabletop during 20 years of usage.

3.3.3 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 5, where the dotted lines indicate aspects that have been included in this study.

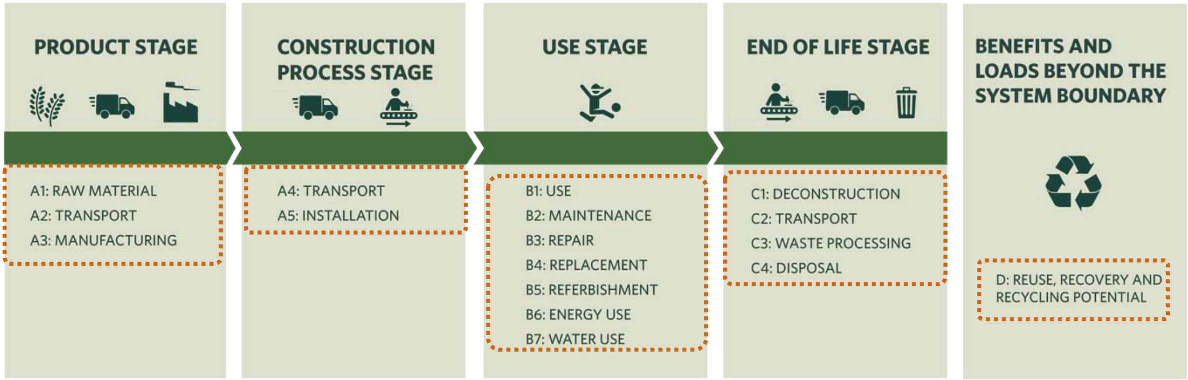

Figure 5: System boundaries for the model of the product system. The red dotted line marks the included modules.

3.3.4 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 simplified model, as it is too time-consuming to obtain data and model every flow in practice. Specific cut-off criteria facilitate the comparison of LCA for different products.

Mass relevance
Mass should be applied if the mass flow is less than 1% of the cumulative mass of all the inputs and outputs of the LCI model.

Energy relevance
Energy relevance should be applied if the energy flow is less than 1% of the cumulative energy of all the inputs and outputs of the LCI model.

Environmental relevance
Environmental relevance should be applied if the flow meets the above exclusion criteria but has 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 1% of mass or 1% of energy.

There can be other reasons to exclude activities or aspects of the life cycle. In this study, no activities or aspects of the life cycle have been excluded.

3.3.5 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 steel, for which the production processes produces both steel and pig iron or wool, for which production processes produce both meat and wool.

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 LCA, material for recycling leaves the product system from the manufacturing phase in the form of aluminium scrap. Following the cut-off approach, only the aluminium transport to the recycler has been included in the LCA (no burdens nor benefits of recycling). The same procedure applies to the packaging material sent to recycling.

3.3.6 Method of Life Cycle Impact Assessment (LCIA)

The methods used to calculate the relevant environmental effect categories in this study are summarised in Table 2 and Table 3. For further details on the LCIA method, see Appendix 2-Appendix 4.

Table 2: Impact categories, indicators and methods used in the study. The chosen indicators follow the standard for Construction products EN 15804:2012+A2:2019/AC:2021 (CEN, 2021).

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
Indicator for climate impact GWP-GHG	GWP-GHG	kg CO_2 equivalents	GWP total, excluding biogenic carbon dioxide emissions and uptakes, and biogenic carbon stored in the product
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, mineral and metals,	ADPe	kg Sb eq	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.

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

Note that for Climate Change Biogenic, removals of biogenic CO2 into biomass (with the exclusion of biomass of native forests) and transfers from previous product systems shall be characterised in the LCIA as –1 kg CO2 eq./kg CO2 when entering the product system. Emissions of biogenic CO2 from biomass and transfers of biomass into subsequent product systems (with the exclusion of biomass of native forests) shall be characterised as +1 kg CO2 eq./kg CO2 of biogenic carbon, see EN ISO 14067:2018, 6.5.2 (CEN, 2020).

Table 3: Additional environmental impact indicators and methods used in the study as described in EN 15804:2012+A2:2019/AC:2021 (CEN, 2021).

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

Table 4: Information on biogenic content.

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

Unit conversion for LCIA results.
Some methods report the LCIA results in different units then EF 3.0. Below some common unit conversions can be seen:
Acidification: 1.31 to report kg SO2,eq as mol H +,eq
Eutrophication: 0.33 to report kg PO$_4^{-3}$,eq. Kg P, eq

Photochemical Ozone Creation Potential: 1.69 to report kg C2H4, eq as kg NMVOC, eq

Table 5: Resource use to be declared in the study. The use of primary energy resources are calculated according to option B in Annex 3 in PCR Construction Products v.1.3.1

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

Table 6: Waste materials to be declared in the study.

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

3.3.7 Data requirements (DQR)

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

- Geographical coverage: The processes included in the data set are well representative of the geography stated in the "location" indicated in the metadata.
- Technology representativeness: Data of core processes: The collected data is representative for the technology used. Data of upstream and downstrean processes: Data is representative for the technology used (for example at suppliers) if possible. Otherwise, average technology in the relevant region.
- Time-related coverage: Data of core processes: The collected data is ideally representative for the last 12 months but not older than 5 years. Data of upstream and downstream processes: The collected data is as recent as possible but not older than 10 years.
- Multiple output allocation: Physical causality
- Substitution allocation: Not applicable
- Waste treatment allocation: Not applicable
- Cut-off rules: Less than 1% of mass or 1% of energy.
- System boundary: Second order (material/energy flows including operations)

- The boundary with nature: **Agriculztural production is part of the production system.**

The data quality and representativeness will be assessed in part 6.3 based on the guidelines established in the EN 15804: A2 standard (CEN, 2021).

3.3.8 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), as well as the applied PCR. The LCA will be reviewed according to the following five aspects outlined in ISO 14040. It is assessed whether:

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

This LCA report was internally reviewed by Pär Lindman, who was the project leader and involved in data inventory.

3.4 LCA Software

The life cycle impact assessment (LCIA) was calculated using the LCA software SimaPro 9.4 (PRé Sustainability, 2024) developed by PRé Consultants. SimaPro is a tool for calculations of complex product systems and comparisons of life cycles with documentation that conforms to the ISO 14000 standard. This software allows access to databases with LCI data (e.g. ecoinvent) and several readymade LCIA methods.

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 3.9 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 Assumptions

Assumptions that are general to the entire LCA are:

- choice of energy model: (e.g. regional averages obtained from the Ecoinvent LCI database or according to specific conditions);
- Choice of transport model: (e.g. regional averages from Ecoinvent) or according to specific conditions calculated according to the Network for Transport and the Environment (NTM).
- Transport distances have been based on Google Maps for road transportation and a port routing tool (e.g. Sea Distances or Port World) for sea transport. Possible deviating routes have not been included in the calculations.
- Ecoinvent processes that contain market funds such as "Diesel burned in building machine {GLO} | market for | Cut-off, U" includes generic shipments from producer to end customer. Therefore, these data sets have no further transport.
- Transport by truck is using emission standard Euro 6 and 16-32t truck if otherwise is not stated.

4.2 Input data references

Table 7 shows the supplier contacts that have supplied the sources for data input.

Table 7 Input data references

Main contact at DFI Geisler	
Name	Ane Vilsgaard
e-mail	av@dfi-geisler.com
Phone number	00 45 72 312 374
Supplier regarding the material melamine faced CDF	
Name	Bart Catteeuw
e-mail	bart.catteeuw@unilin.com
Phone number	+32 (0)478 74 71 16
Company	Unilin BV, division Panels

4.3 Raw material for Fibertops (A1 to A3)

The weight of the finished Fibertop is 13.27 kg per m2 and it has a thickness of 12 mm.
This product consists of 0.8mm top laminate, the CDF, and again a layer of top laminate of 0.8mm.

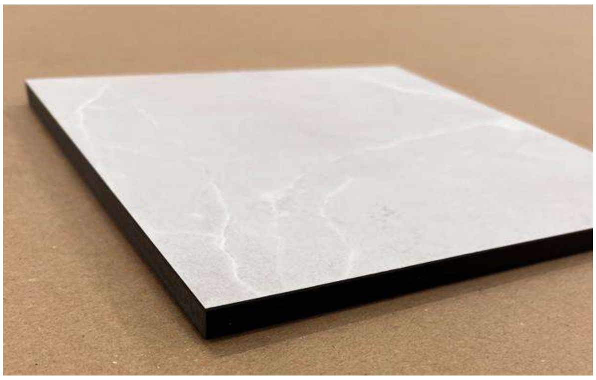

Figure 6 Picture of Fibertops

4.3.1 Product content declaration

This part describes all the different components, packaging materials and substances of very high concern.

Table 8: Content declaration

Product components	Weight (kg/m2)	Post-consumer material (weight-%)	Renewable material (weight-%)
Melamine Faced CDF	11.15	70%	70%
Laminate	1.92	57%	57%
Glue	0.2	0%	0%
Total	13.27		
Packaging materials			
EPS	0.2	0%	0%
LLDPE	0.105	0%	0%
Substances of Very High Concern (SVHC)[1].	Weight (mg)	Weight-% (versus the product)	exceeds 0.1%

No substances of very high concern have been reported by DFI Geisler.

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

4.3.2 Raw material (A1 + A2)

This section describes all the different raw materials needed for the manufacturing of Fibertops at DFI Geisler.

4.3.2.1 Supplier raw material extraction and production

The amounts are including waste and are specified per m2 of finished products. The transport distances are presented from the supplier to DFI Geisler.

Table 9: Raw materials and transport to the production site

Material	Weight (kg/m2)	LCI database representation	Origin	Transport type	Transport distance (km)	Comment
Melamine faced CDF	14.61	[EPD] Melamine faced CDF_Unilin Decorative Compact MDF_Unilin_Belgium_S-P-20230380	Unilin, Bazeilles, France	Truck	1100	Transport distance estimated distance with google maps
Laminate	2.52	[EPD] Laminate_EGGER Laminate_EGGER_Austria_S-P-20210049	Riisfort, Århus, Denmark	Truck	126	0.8mm top laminate x 2 => 1.6mm
PVAC Glue	0.26	See chapter 4.3.2.1.3	PKI Industrial Adhesives, Frederica, Denmark	Truck	173	The same type of glue for the regular laminate tabletop from DFI Geisler.

4.3.2.1.1 Melamine faced CDF

The melamine faced CDF has a thickness of 10mm and a weight of 11.15 kg/m2 (excluding the production waste). It is manufactured at the supplier Unilin in France, and then transported to DFI Geisler. The data for the raw material phase of the melamine faced CDF is retrieved from an EPD made by Unilin (Unilin B.V. Division Panels, 2023). Product packaging of the melamine faced CDF consists of wood-based chipboards, cardboard, stretch foil and PET packaging and the raw materials are included in the EPD, but not the end-of-life.

4.3.2.1.2 Laminate

The laminate is produced by Riisfort in Århus, Denmark. The data for the raw material phase of the laminate is retrieved from an EPD made by Eggers (Fritz EGGER GmbH & Co. OG Holzwerkstoffe, 2021). The EPD is used to provide data for the extraction/production of raw material, transport to production site and production of laminate. The laminate has a total thickness of 1.6mm and based on the density from the EPD the amount of laminate used for the fibertops is 1.92 kg/m2 (excluding the production waste).

4.3.2.1.3 PVAC Glue

The type of glue that is used for this product is the same type of glue that is used for the regular laminate tabletop that DFI Geisler produces, which is a PVAC glue. The PVAC glue is produced by PKI Industrial Adhesives in Frederica, Denmark, and it a polyvinyl acetate-based glue. The glue is modelled based on information from a safety data sheet by Franklin International. The data sheet presents the percentages of the toxic substances' formaldehyde, methanol and aluminium chloride. It is assumed that the glue is based on vinyl acetate since it is an industrial wood glue. The details are presented in Table 10. The glue is applied over and under the melamine faced CDF with a total weight of 0.2 kg/m2 (excluding the production waste).

Table 10: Raw materials for 1 kg of PVAC Glue used in the fibretops.

Product components	Amount (kg/m2)	LCI database representation
Ethylene vinyl acetate copolymer	0.9	Ethylene vinyl acetate copolymer {RoW}| ethylene vinyl acetate copolymer production | Cut-off, U
Formaldehyde	0.001	Formaldehyde {RER}| market for formaldehyde | Cut-off, U
Methanol	0.003	Methanol {GLO}| market for methanol | Cut-off, U
Aluminium chloride, anhydrous	0.03	Aluminium chloride {GLO}| aluminium chloride production | Cut-off, U

4.4 Manufacturing of Fibertops at DFI Geisler (A3)

In this chapter, the activities carried out by DFI Geilser are presented. The CDF core is glued to a top laminate and a bottom laminate in standard size. The tabletop is then formatted and processed to fixed dimensions with CNC machining. The finished tabletop is packaged with EPS packaging and plastic corner protectors. Finally, the tabletop is wrapped with stretch wrap.

4.4.1 Energy

In the manufacturing process 29.25 kWh of electricity and heat are used per m2 of tabletop. Both the electricity and heat come from 100% renewable energy by photovoltaic energy in Denmark, certificate can be seen in Appendix 5a.

Table 11: Energy use in production

Energy type	Energy source	LCI data representation in ecoinvent	Amount (kWh/m2)	Certificate?
Electricity and heat	Solar power	Electricity, low voltage {SE}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U	29.25	Yes, see appendix 5

4.4.2 Direct emissions

No direct emissions have been reported by DFI Geisler.

4.4.3 Consumables

No consumables have been reported by DFI Geisler.

4.4.4 Packaging of finished tabletop

The finished tabletop is packaged with EPS packaging and wrapped with stretch wrap. The packaging material is specified in Table 12.

Table 12: Packaging used for product

Type of Packaging	Material	Amount (kg/m2)	LCI data representation in ecoinvent	Transport type	Transport distance (km)
EPS packaging	EPS	0.2	Polystyrene, expandable {GLO}| market for polystyrene, expandable | Cut-off, U	N/A	N/A
Stretch wrap	LDPE	0.105	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate | Cut-off, U Extrusion, plastic film {GLO}| market for extrusion, plastic film | Cut-off, U	N/A	N/A

4.4.5 Internal transports

No internal transports have been reported by DFI Geisler.

4.4.6 Production waste

The production waste reported by DFI Geisler is material for energy recovery. The amount of waste is 31% per product, which in total represents around 4.11 kg/m2. The production waste is divided into the waste types of wood, paper, and plastic. The waste is transported 20 km to a waste treatment facility where the energy is recovered by incineration.

Table 13: Production waste types and treatment

Waste type	Waste quantity (kg/m2)	Waste transport type	Waste transport distance (km)	Waste treatment	Comment
Wood	3.46	Truck, EURO6	20 km	Waste wood, untreated {CH}| treatment of waste wood, untreated, municipal incineration | Cut-off, U	
Paper	0.339	Truck, EURO6	20 km	Waste paperboard {RoW}| treatment of waste paperboard, municipal incineration | Cut-off, U	The laminate consists of 57% paper
Plastic	0.318	Truck, EURO6	20 km	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U	The laminate consists of 43% plastic

4.4.7 Disposal of raw material packaging

Since the EPD used for the raw material melamine faced CDF and the laminate did not consider the end-of-life for the packaging materials it was added in the model. The amounts for the packaging materials have been gathered from the EPD for the melamine faced CDF and the EPD for the laminate. The disposal of the packaging of both raw materials are assumed to be incinerated. The disposed packaging is transported 20 km to a waste treatment facility where the energy is recovered by incineration.

Table 14: Disposal of packaging materials for the raw material melamine faced CDF.

Waste type	Waste quantity (kg/m2)	Waste transport type	Waste transport distance (km)	Waste treatment	Comment
Plastic	0.003	Truck, EURO6	20	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U	Packaging material for the CDF
Cardboard	0.004	Truck, EURO6	20	Waste graphical paper {CH}| treatment of waste graphical paper, municipal incineration | Cut-off, U	Packaging material for the CDF
Wood	0.41	Truck, EURO6	20	Waste wood, untreated {CH}| treatment of waste wood, untreated, municipal incineration | Cut-off, U	Packaging material for the CDF
Plastic	0.002	Truck, EURO6	20	Waste polyethylene {CH}| treatment of waste polyethylene, municipal incineration | Cut-off, U	Packaging material for the laminate
Cardboard	0.067	Truck, EURO6	20	Waste paperboard {RoW}| treatment of waste paperboard, municipal incineration | Cut-off, U	Packaging material for the laminate

4.5 Transport of Finished Fibertop to Customer (A4)

The finished tabletops are transported 400 km by truck to a customer in Copenhagen. This is a representation of the most common customer and transport distance since most of the DFI Geisler's
sales go to Copenhagen.

Table 15: Distribution of tabletops

Product	Road transport type	Road transport distance (km)
Tabletops	Truck	400

4.6 Installation of Tabletops (A5)

Below, the activities for installing the tabletop is presented. Installation activities include only manual labor, therefore the only relevant aspect that is included for the installation of the tabletops are the disposal of packaging.

4.6.1 Disposal of packaging

In the table below, the disposal of the packaging that is delivered with the finished tabletop is presented. The packaging of the tabletops contains of EPS and a stretch wrap, both plastic materials.

The main market is Copenhagen, Denmark and thereby statistics regarding plastic waste treatment in Copenhagen is used. The recycling rate of plastic packaging in Denmark during the year 2019 was less than 30 percent[2]. Therefore, it is assumed that 30 percent of the plastic is being recycled and the rest is incinerated.

Table 16: Disposal of packaging delivered with the product.

Type of Packaging	Material	Amount (kg/m2)	Disposal method	LCI data representation in ecoinvent	Comment
EPS & stretch wrap	Plastic	0.213	Incineration	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration | Cut-off, U	70% goes to incineration
EPS & stretch wrap	Plastic	0.0915	Recycling	Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U	30% goes to recycling

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[2] plast.dk/wp-content/uploads/2019/12/Design-Guide-Reuse-and-recycling-of-plastic-packaging-for-private-consumers-english-version-1.pdf

4.7 Usage (B1-B7)

For the use phase it is assumed that there is only an impact from the maintenance of wiping off the tabletops. The tabletops are cleaned with green soap and the assumed yearly consumption is 0.2 kg of soap per m2. The green soap is used together with water, 10% soap and 90% water, and therefore two datasets in ecoinvent is used to represent the green soap.

Table 17: Materials and energy consumed in the use phase.

Material or energy	Quantity (kg/m2)	Reference service life	LCI data representation in Ecoinvent	Comment
Soap	0.02	20 years	Soap {RER}| soap production | Cut-off, U	10% soap
Water	0.18	20 years	Tap water {Europe without Switzerland}| tap water production, conventional treatment | Cut-off, U	90% water

4.8 End-of-Life (C1-C4)

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

4.8.1 Dismantling or deconstruction (C1)

No dismantling or demolition is required for the tabletops.

4.8.2 Transport to waste management (C2)

The waste for the tabletops is transported by a smaller truck to a nearby waste management facility with a transport distance of 20km.

Table 18: Transport to waste management site

Road transport type	Road transport distance (km)	LCI data representation in ecoinvent
Truck, EURO6	20	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U

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

According to PCR, if the thermal efficiency for the incineration is assumed to be higher than 60%, the incineration process is an energy recovery process and shall be assigned to module C3. Incineration is assumed to have an 80% energy efficiency, the assumption is the global average for incineration. Due to this, all waste treatment falls under C3. 100% of the waste for the tabletops are assumed to be incinerated.

Module C3 hence contains any energy and materials used for preparation for waste treatment and the environmental impact of waste incineration with energy recovery. Module C4 contains the environmental impact of incineration without energy recovery and of incineration of hazardous waste, and environmental impact of landfilling.

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

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

The following formula is used to calculate the potential consequences of material recycling of the product and it´s packaging:

$$e_{module\ D1} = \sum_i (Y \cdot M_{MR\ out}|_i - Y \cdot M_{MR\ in}|_i) \cdot (E_{MR\ after\ EoW\ out}\Big|_i - E_{VMSub\ out}|_i \cdot \frac{Q_{R\ out}}{Q_{Sub}}\Big|_i)$$

Equation 1 describes how the potential consequences of material recycling has been calculated.

- **Y** is the material yield in the recycling process
- **MMR out** is the amount of material that leaves the product system and will be reused or recycled in subsequent systems. Amount of material in product and packaging multiplied with the recycling rate ($Share_{MRout}$)
- **MMR in** is the amount of secondary material that enters the product's system as raw material
- **EMR after EoW out** are specific emissions and the consumed resources that arise in the recycling process, up to the point where it is assume to substitute virgin material.
- **EVMSub out** are specific emissions and consumed resources that arise during the acquisition and pre-treatment of primary materials in the manufacturing process.
- **QR out** is the quality of the recycled material at replacement.
- **QSub** is the average quality of primary material that the recycled material substitutes.

$Share_{MRout}$ for the different materials are based on European average recycling rates (R2) used in PEF Circular Footprint Formula[3], and can be seen in the table below.

The following formula is used to calculate the potential benefits of energy recovery from waste incineration of the product and it's packaging:

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

where,
- M_{INCout} = The amount of material that leaves the product system and will be reused / recycled in subsequent systems. Calculated by subtracting the material that is sent to recycling from the amount in product and packaging, and multiplying with the incineration rate ($Share_{INCout}$)
- LHV = lower heating value of the material
- $X_{INCheat}$ = efficiency of the incineration process for heat

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[3] R2 values as stated in PEF Annex C available at https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

- E_{SEheat} = specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: heat
- $X_{INCelec}$ = efficiency of the incineration process for electricity
- E_{SEelec} = specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: electricity

In this study, only the potential benefits of energy recycling have been assessed since the products are assumed to be sent to incineration. In the incineration process with energy recovery, it is assumed that 20% becomes electricity and 80% becomes heat. The efficiency of the incineration process is assumed to be 80%. Since the main market is Copenhagen, Denmark, the LCI data representation is made with Danish electricity and heat. Based on information about energy in Copenhagen, 70% of the heat is assumed to be biomass and 30% is assumed to be oil, which represent an average emission of 65 kg CO2/MWh[4].

The lower heating value for wood is 19 MJ/kg[5], the lower heating value for plastic is 31 MJ/kg [6]and the lower heating value for the laminate is between 15-16 MJ/kg according to the EPD for laminate from EGGER, therefore the value for cardboard is used, which is 15,66 MJ/kg.

Below in Table 19, the calculations for the D-module for Fibertops are shown.

Table 19: Electricity and heat for D-module

Benefit	LCI data representation in ecoinvent (avoided activity)	Wood sent to incineration (weight*incineration rate)	Energy content of wood waste LHV (MJ/kg)	Plastic sent to incineration (weight*incineration rate)	Energy content of plastic waste LHV (MJ/kg)	Cardboard sent to incineration (weight*incineration rate)	Energy content of cardboard waste LHV (MJ/kg)	Total energy recovered
Energy recovery EPDM, production of electricity Denmark	Electricity, medium voltage {DK}| electricity voltage transformation from high to medium voltage | Cut-off, U	1.78	19	0.032	31	0.307	15.66	39.7
Energy recovery EPDM, production of heat Denmark	Heat, district or industrial, other than natural gas {DK}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U	5	19	0.0896	31	0.86	15.66	111
Energy recovery EPDM, production of heat Denmark	Heat, district or industrial, other than natural gas {DK}| heat and power co-generation, oil | Cut-off, U	2.14	19	0.0384	31	0.369	15.66	47.6

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[4] District Heating in the Copenhagen Region (stateofgreen.com)
[5] Energy Basics – Wood Energy (extension.org)
[6] Phyllis2 - ECN Phyllis classification

5 Result of Life cycle impact assessment (LCIA)

In this section, the result from the different environmental impact assessment methods will be presented. The LCIA method follow the standard for Construction Products EN15804:2012+A2:2019/AC:2021 (CEN, 2021). EN15804:2012+A2:2019/AC:2021 uses the impact categories and characterization factors of the LCIA methods used in Environmental Footprint 3.1 (EF 3.1), with the only difference that biogenic carbon dioxide uptake is calculated as -1 and biogenic carbon dioxide emissions as +1, where EF 3.1 calculates this as 0, 0. In addition to the climate impact indicator required in EN15804:2012+A2:2019/AC:2021 , the PCR for Construction Products requires reporting of climate impact with the characterization factor for biogenic carbon dioxide set to zero (GWP-GHG). This is calculated with the IPCC 2021 GWP 100 method. For further details on the LCIA method and impact categories, see Appendix 2 - Appendix 3.

First, the results from the method Environmental Footprint 3.1 (EF) with adaptation to EN15804:2012+A2:2019/AC:2021 , Midpoint and Endpoint are presented, second from the method IPCC GWP 2021 100 and third the inventory results based on the list of aspects required by the PCR. 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.

Sankey diagrams are used to display the results as flow diagrams where the thickness of the arrows reflects the relative amount of that flow. All the nodes cannot be displayed simultaneously due to the vast amounts of background data. Therefore, only processes that contribute to a minimum of 3% of total impacts are shown in the diagram.

Disclaimers and conversion factors

For the impact category Eutrophication, freshwater, the result per unit kg P is used as a basis for calculating the result per unit kg PO_4^{-3} eq, using the factor 3,07.

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

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

5.1 Environmental Footprint Midpoint

Table 20 shows the result per FU according to the LCIA method Environmental footprint 3.1 midpoint level.

Table 20: Environmental footprint midpoint results per functional unit

Impact category	Unit	A1-C4	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GWP Fossil	kg CO_2 eq	2,63E+01	1,50E+01	3,15E+00	4,20E+00	2,24E+01	2,99E-01	5,06E-01	0,00E+00	3,98E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,48E-01	2,54E+00	0	-5,04E+00
GWP Biogenic	kg CO_2 eq	2,28E-02	-2,05E+01	2,88E-03	6,30E+00	-1,42E+01	2,74E-04	6,70E-05	0,00E+00	-9,31E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,30E-04	1,51E+01	0	-1,79E-01
GWP LULUC	kg CO_2 eq	6,05E-01	3,01E-02	1,55E-03	5,19E-03	3,69E-02	1,48E-04	1,33E-05	0,00E+00	5,68E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,64E-05	9,53E-05	0	-1,05E-02
GWP Total	kg CO_2 eq	2,68E+01	-5,48E+00	3,15E+00	1,05E+01	8,18E+00	3,00E-01	5,06E-01	0,00E+00	3,52E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,48E-01	1,77E+01	0	-5,23E+00
ODP	kg CFC11 eq	1,73E-06	1,40E-06	6,85E-08	1,86E-07	1,65E-06	6,51E-09	3,06E-09	0,00E+00	4,15E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,21E-09	2,07E-08	0	-1,38E-07
AP	mol H+ eq	1,07E-01	6,89E-02	6,88E-03	2,08E-02	9,66E-02	6,54E-04	1,37E-04	0,00E+00	5,35E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,14E-04	4,34E-03	0	-5,63E-02
EP - Freshwater	kg P eq	6,44E-04	3,79E-04	2,56E-05	1,79E-04	5,83E-04	2,43E-06	3,74E-07	0,00E+00	5,27E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,42E-06	3,99E-06	0	-2,63E-04

EP - Marine	kg N eq	3,67E-02	2,35E-02	1,69E-03	3,81E-03	2,90E-02	1,61E-04	5,61E-05	0,00E+00	5,37E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,06E-05	2,01E-03	0	-7,64E-03
EP – Terrestrial	mol N eq	3,25E-01	2,19E-01	1,76E-02	4,34E-02	2,80E-01	1,68E-03	6,06E-04	0,00E+00	1,97E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,38E-04	2,27E-02	0	-1,06E-01
POCP	kg NMVOC eq	1,09E-01	7,20E-02	1,07E-02	1,59E-02	9,86E-02	1,02E-03	1,68E-04	0,00E+00	2,75E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,63E-04	5,99E-03	0	-2,71E-02
ADPE[7]	kg Sb eq	2,26E-04	1,07E-04	1,03E-05	9,91E-05	2,17E-04	9,78E-07	7,41E-08	0,00E+00	6,50E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,43E-07	5,62E-07	0	-1,20E-05
ADPF[7]	MJ	4,53E+02	3,40E+02	4,47E+01	5,51E+01	4,40E+02	4,25E+00	1,67E-01	0,00E+00	4,23E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,08E+00	1,74E+00	0	-7,09E+01
WSF[7]	m3 depriv.	1,57E+01	1,12E+01	1,84E-01	2,89E+00	1,43E+01	1,75E-02	5,67E-03	0,00E+00	1,29E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,58E-03	9,25E-02	0	-1,10E+00
PM	disease inc.	1,30E-06	6,92E-07	2,34E-07	2,22E-07	1,15E-06	2,22E-08	1,15E-09	0,00E+00	8,18E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,79E-09	3,46E-08	0	-4,63E-07
IR[8]	kBq U-235 eq	9,02E-01	7,88E-01	2,26E-02	7,68E-02	8,87E-01	2,15E-03	3,24E-04	0,00E+00	8,16E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,48E-03	2,65E-03	0	-3,81E-01
ETP – FW[7]	CTUe	1,44E+02	6,00E+01	2,21E+01	2,35E+01	1,06E+02	2,10E+00	1,29E+00	0,00E+00	2,46E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,10E+00	9,34E+00	0	-2,31E+01
HTP - C[7]	CTUh	4,84E-08	3,67E-08	1,43E-09	4,78E-09	4,30E-08	1,36E-10	9,90E-11	0,00E+00	1,30E-09	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,48E-11	3,85E-09	0	-2,60E-09

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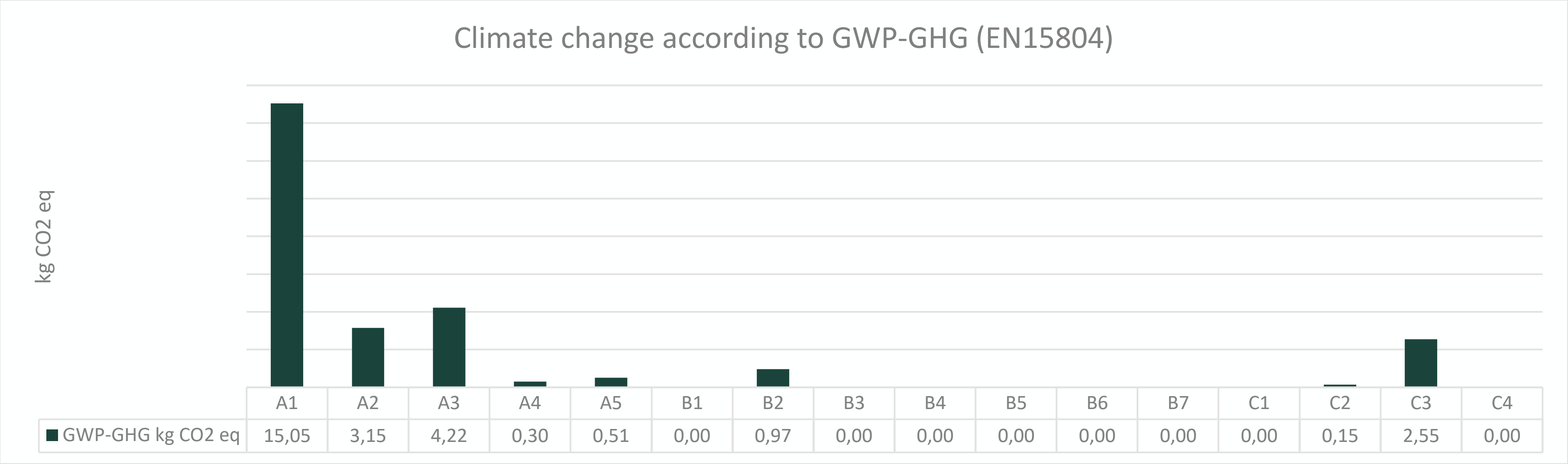
[7] **Disclaimer:** The results of this environmental impact indicator shall be used with care as the uncertainties of these results are high or as there is limited experience with the indicator.

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

HTP-NC[7]	CTUh	2,69E-07	9,00E-08	3,17E-08	9,98E-08	2,21E-07	3,02E-09	7,29E-10	0,00E+00	2,92E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,44E-09	1,33E-08	0	-6,32E-08
Land use, SQP[7]	Pt	1,98E+03	1,56E+03	2,70E+01	3,51E+02	1,93E+03	2,57E+00	5,69E-02	0,00E+00	4,24E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,62E-01	5,05E-01	0	-2,75E+02
Acronyms	GWP: Global Warming Potential, LULUC: Land Use and Land Use Change, ODP: Ozone Depletion Potential, AP: Acidification Potential. EP: Eutrophication Potential, POCP: Photochemical Ozone Creation Potential, ADPE: Abiotic Depletion Potential – Elements, ADPF: Abiotic Depletion Potential – Fossil Fuels, WDP: Water Scarcity Footprint, PM: Particulate Matter, IRP: Ionizing Radiation - Human Health, ETP-FW: Ecotoxicity Potential – Freshwater, HTP-C: Human Toxicity Potential – Cancer, HTP-NC: Human Toxicity Potential – Non-Cancer, SQP: Soil Quality Potential Index																			
Legend	A1-C4: Sum of impacts inside system boundary, A1: Raw Material, A2: Raw Material Transport, A3: Manufacturing, A1-A3: Sum of A1-A3, A4 Transport to Customer, A5: Installation, B1: Use, B2: Maintenance, B3: Repair, B4: Replacement, B5: Refurbishment, B6: Operational Energy Use, B7: Operational Water Use, C1: Deconstruction, C2: Waste Transport, C3: Waste Processing, C4: Disposal, D: Reuse, Recovery, Recycling Potential																			

5.2 Climate impact (GWP) - IPCC GWP 2021 100

The climate impact according to GWP 2021 100 is presented in Figure 7. The biggest impact comes from life cycle stage A1.



	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
■ GWP-GHG kg CO2 eq	15,05	3,15	4,22	0,30	0,51	0,00	0,97	0,00	0,00	0,00	0,00	0,00	0,00	0,15	2,55	0,00

Figure 7: Climate impact per functional unit according to IPCC 2021 GWP 100

Figure 8 shows a Sankey diagram of the climate footprint. The figure shows that the highest impact comes from the raw materials. The manufacturing, transportation, and waste handling have a smaller but still relevant impact.

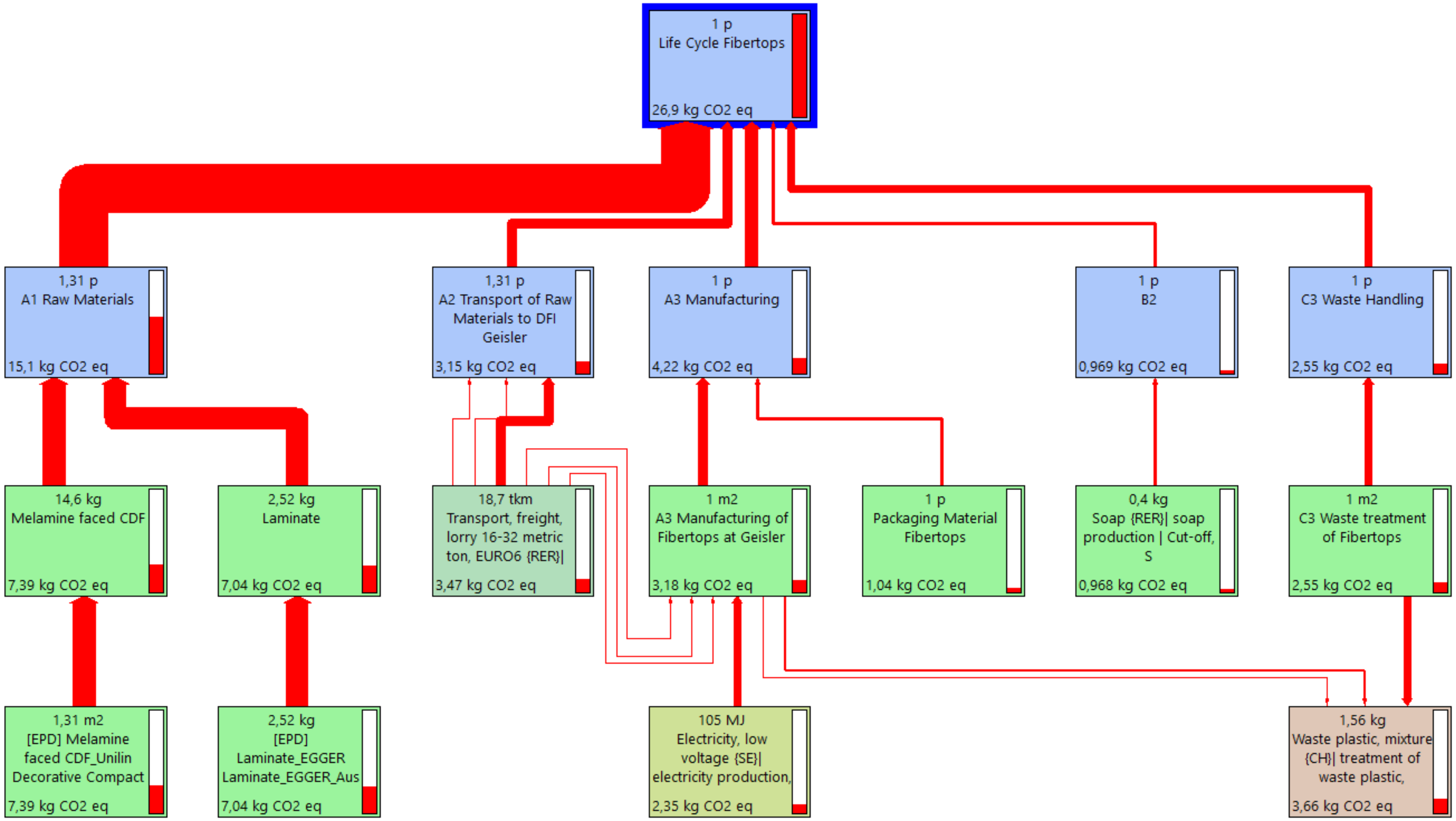


Figure 8: Sankey diagram over Environmental footprint climate impact per functional unit.

5.3 Environmental Footprint Endpoint

The environmental footprint endpoint shows the contribution of each environmental impact category to the total environmental impact. As seen in Figure 10, the most relevant impact categories are Climate change and Resource use fossils, followed by resource use minerals and metals.

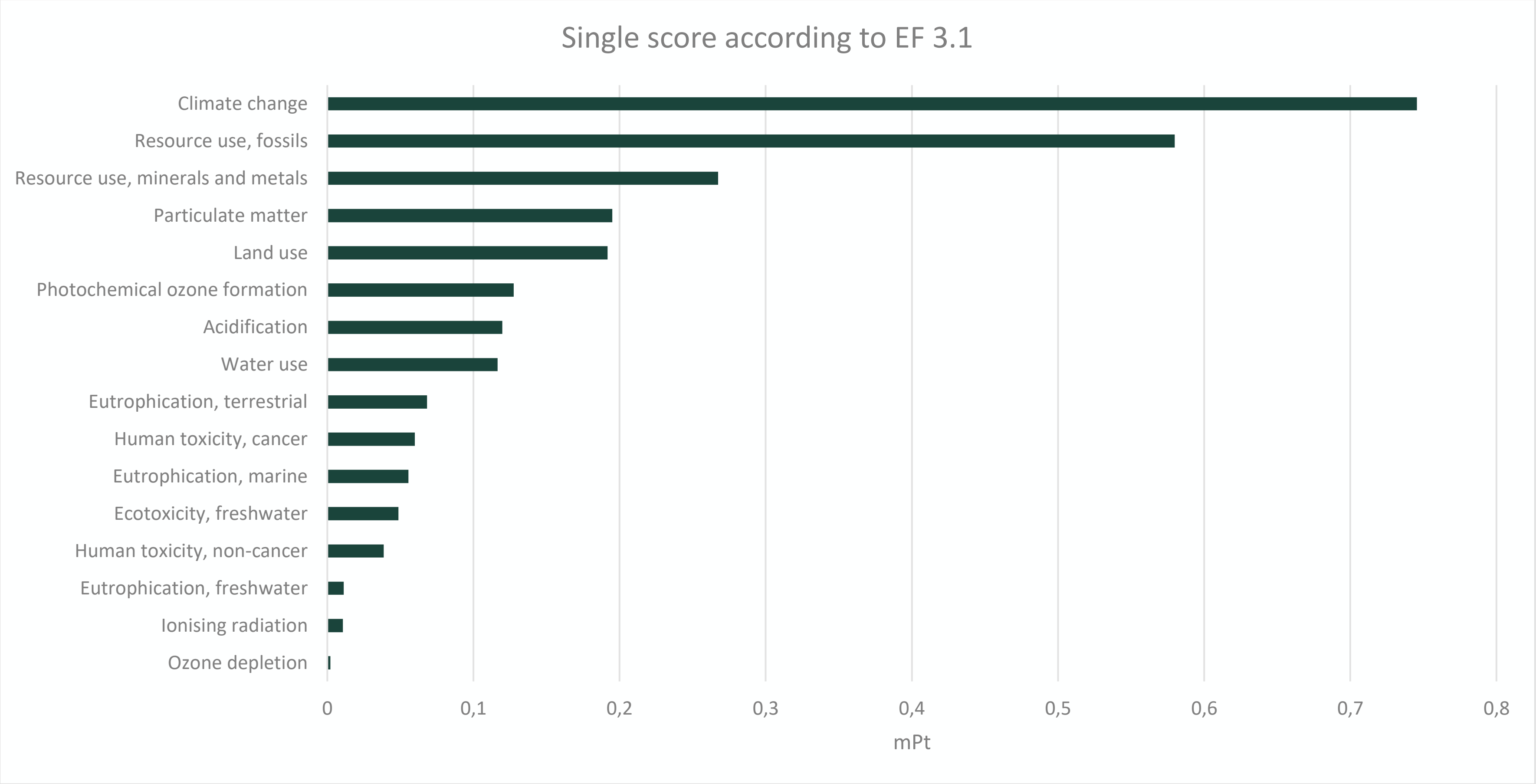


Figure 9: Share of environmental impact per impact category.

Figure 10 shows a Sankey diagram over the single score impact. The biggest impact comes from the raw materials, followed by the manufacturing and the waste handling. The transportation has a smaller but still relevant impact.

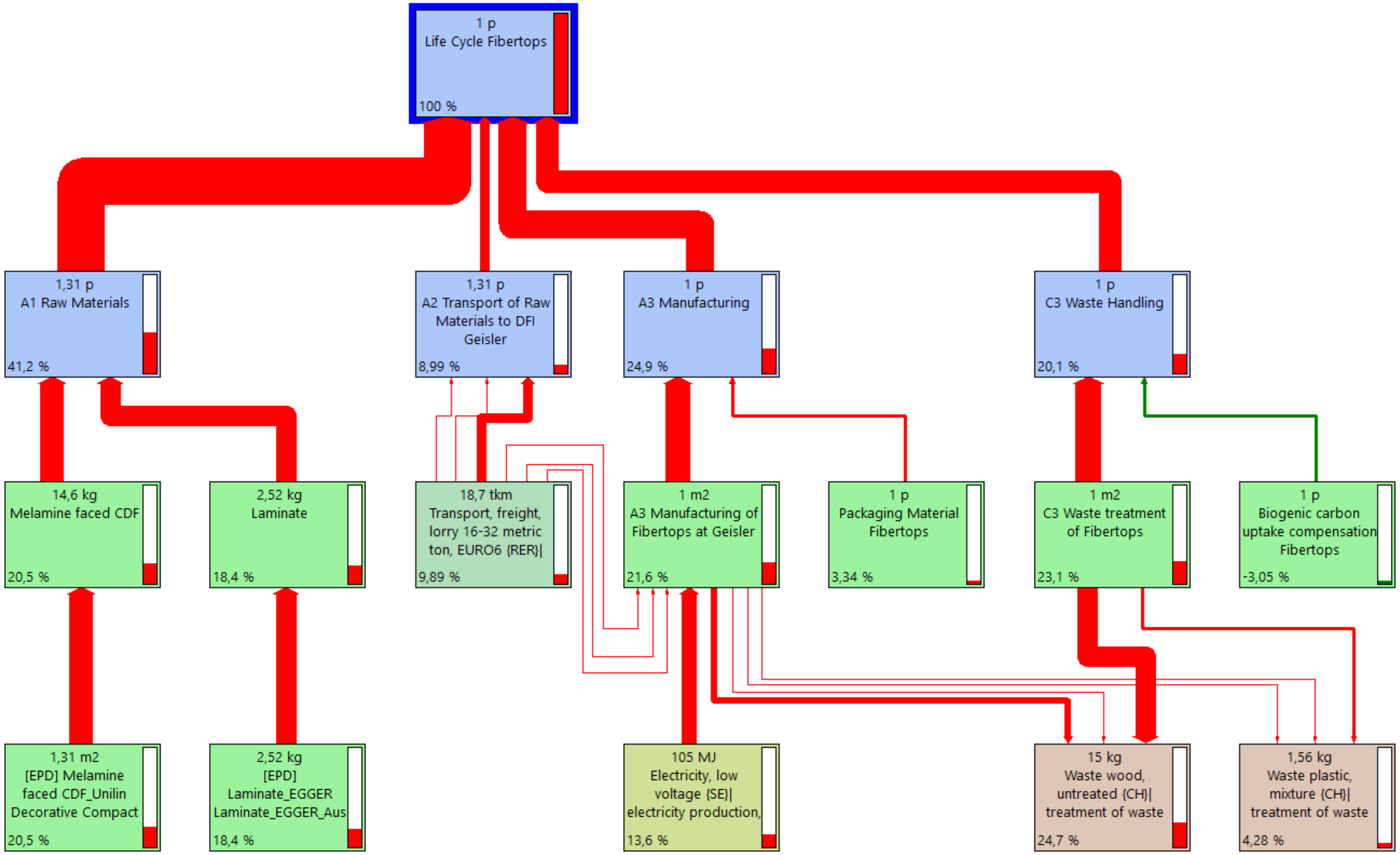


Figure 10: Sankey diagram over share of environmental impact contributions per module and per functional unit. The D-module is not included in the figure.

5.4 Use of resources and energy CED 1.11

The consumption of resources in terms of energy is measured as primary energy demand with the method Cumulative Energy Demand 1.11 (see Appendix 4).

Table 21: Use of resources and energy for module A-D, per functional unit

Parameter	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
PERE	MJ	1,25E+02	7,02E-01	1,18E+02	2,45E+02	6,68E-02	1,09E-02	0,00E+00	2,30E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,51E-02	1,03E-01	0,00E+00	-9,07E+01
PERM	MJ	2,17E+02	0,00E+00	0,00E+00	2,17E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-2,17E+02	0,00E+00	0,00E+00
PERT	MJ	3,42E+02	7,02E-01	1,18E+02	4,61E+02	6,68E-02	1,09E-02	0,00E+00	2,30E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	4,51E-02	-2,17E+02	0,00E+00	-9,07E+01
PENRE	MJ	2,34E+02	4,75E+01	4,95E+01	3,31E+02	4,52E+00	1,78E-01	0,00E+00	5,34E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,21E+00	1,87E+00	0,00E+00	-7,51E+01
PENRM	MJ	8,12E+00	0,00E+00	9,46E+00	1,76E+01	0,00E+00	-9,46E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-8,12E+00	0,00E+00	0,00E+00
PENRT	MJ	2,42E+02	4,75E+01	5,90E+01	3,48E+02	4,52E+00	-9,28E+00	0,00E+00	5,34E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,21E+00	-6,25E+00	0,00E+00	-7,51E+01
SM	kg	9,99E+00	0,00E+00	0,00E+00	9,99E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
RSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
NRSF	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
FW	m3	5,68E-03	7,48E-03	2,35E-02	3,67E-02	7,11E-04	2,86E-04	0,00E+00	1,13E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,46E-04	1,52E-02	0,00E+00	-1,57E-02

Abbr evi-ation s	PERE = use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total Use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total Use of non-renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels; FW = use of net fresh water

5.5 Waste production and output flows

The production of waste in terms of final waste and the output of materials for recycling, is measured from the calculation of selected inventory results with our own method[9]. Final waste and output flows, refers to flows that are leaving the system of the LCA. In this LCA only elementary flows (substances) are actually leaving the system.

Table 22: Waste production for module A1-D, per functional unit

Indicator	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Hazardous waste	kg	2,79E-01	0,00E+00	0,00E+00	2,79E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Non-Hazardous waste	kg	5,31E+00	0,00E+00	0,00E+00	5,31E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Radioactive waste	kg	2,34E-03	0,00E+00	0,00E+00	2,34E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Table 23: Output flows for module A-D, per functional unit

Indicator	Unit	A1	A2	A3	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

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[9] EPD (2018) EN15804 v3

Components for reuse	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Material for recycling	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Materials for energy recovery	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Exported energy, electricity	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,27E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,95E+01	0,00E+00	0,00E+00
Exported energy, thermal	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,29E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,39E+02	0,00E+00	0,00E+00

5.6 Biogenic carbon content

Equation 1 Biogenic carbon content according to EN 16449

$$\text{Biogenic carbon content} = \text{Biogenic carbon fraction} \bullet \frac{\text{Wet density of the biomass} \bullet \text{Wet volume of the biomass}}{1 + \frac{Moisture\ percentage}{100}}$$

Standard Values:
Moisture: 6% for wood (CDF), and 14% for cardboard (laminate).
Biogenic Carbon fraction: 50% for wood (CDF), and 50% for cardboard (laminate).

Table 24: Shows the biogenic carbon content of the product and the product packaging

Share of biogenic carbon	Unit	Amount
Biogenic carbon in the product	kg C	4,15
Biogenic carbon in the packaging	kg C	0,0

6 Interpretation

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

The quantitative impact assessment results are interpreted to understand the possibilities of reducing environmental impact most efficiently.

6.1 Key aspects of results

The dominant environmental impact categories for the product Fibertops are according to Figure 9 "Climate change" and "Resource use fossils", followed by "Resource use minerals and metals".

The product Fibertops have a total climate impact of 26.9 kg CO2 eq per m2 and the biggest contributor is the raw materials, which stands for around 56% for the total climate impact. The raw materials that contribute the most to the climate impact are the melamine faced CDF and the laminate, whereas the glue only stands for a relatively small impact. The transportation, manufacturing, and waste handling have a smaller but still relevant impact. The main impact from the transportation comes from the transport of the melamine faced CDF from France to DFI Geisler in Denmark, because of the long distance and the use of fossil fuels. The impact for the manufacturing mainly originates from the electricity use, more specially the use of fossil fuels for the construction of the photovoltaic system.

For the impact category, "Resource use fossils", the raw materials also have the highest impact, where the melamine faced CDF is the biggest contributor, followed by the laminate.

For the impact category, "Resource use minerals and metals", the life cycle stages that contribute the most to this impact are the raw materials and the manufacturing. The biggest impact for the raw materials comes from the melamine faced CDF and the impact from the manufacturing originates from the use of a photovoltaic system for the electricity production.

6.2 Sensitivity analysis

LCA provides a holistic perspective on an entire system. To succeed in this 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.

Waste treatment of the packaging of the raw materials

In this study, it was assumed that all the packaging for the raw material CDF and laminate goes to incineration when disposed. This was a conservative assumption and a sensitivity analysis have been made regarding this to analyse how the result would differ when altering the recycling share of the waste treatment for the packaging. The analysis covered 100% incineration, a share of incineration and recycling, and 100% recycling. The share of incineration and recycling is based on statistics regarding plastic and cardboard packaging waste treatment in Denmark. According to statistics the recycling rate of plastic packaging in Denmark during the year 2019 was less than 30 percent[10],and the recycling rate for paper and cardboard packaging during the year 2020 was 69.3

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[10] plast.dk/wp-content/uploads/2019/12/Design-Guide-Reuse-and-recycling-of-plastic-packaging-for-private-consumers-english-version-1.pdf

percent[11]. The result for the total climate impact is presented in Figure 11. As can be seen from the figure, the result for the total climate impact is barely affected at all.

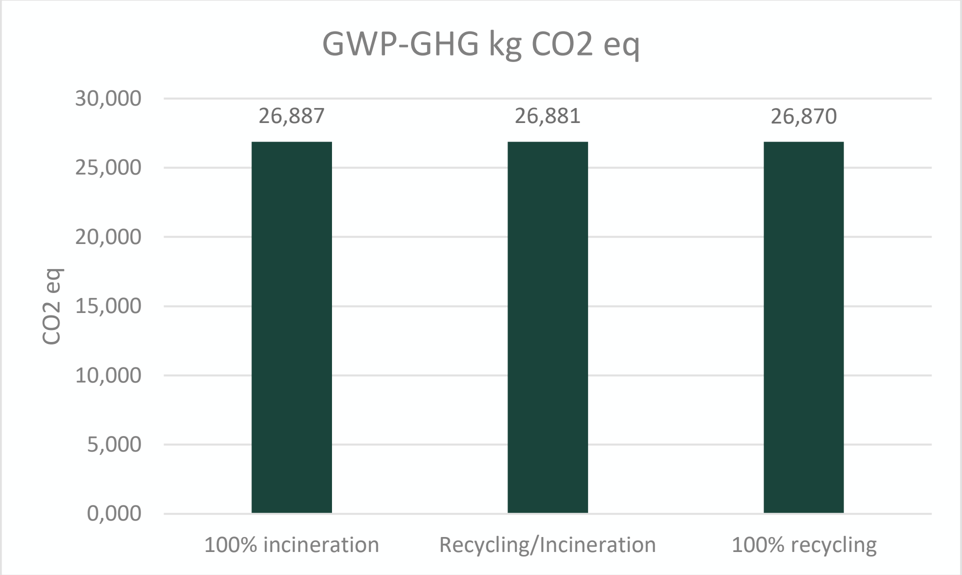

Figure 11: Sensitivity analysis: The climate impact of altering the recycling share for the waste treatment of the raw material packaging.

To evaluate the impact in all impact categories, a result presenting the weighted single score can be seen in Figure 12. As can be seen from the figure, the impact is not visibly affected when changing the recycling share for the waste treatment. This indicates that the share of recycling for the waste treatment of the packaging materials does not have an important impact on the result, which means that the assumption made is validated.

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[11] EU: paper packaging recycling rate by country | Statista

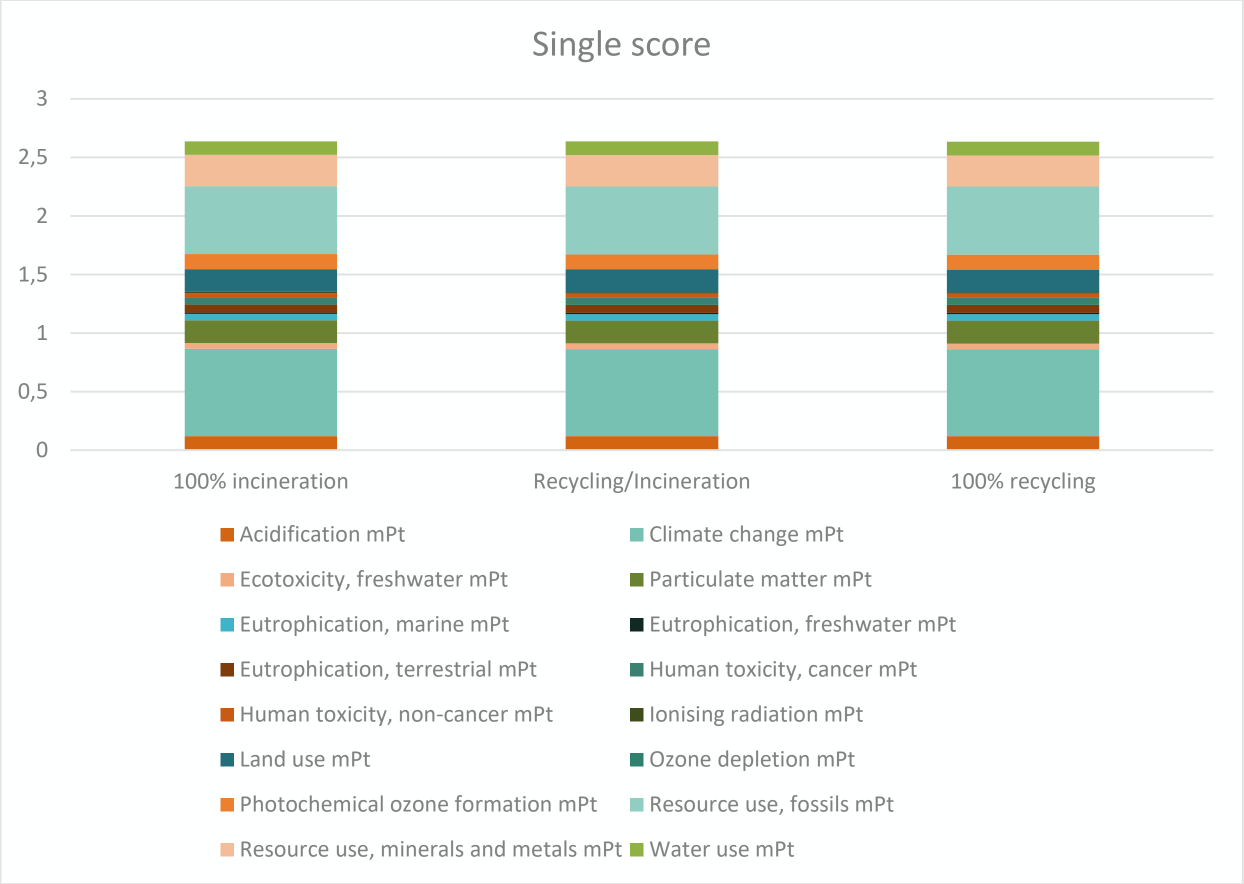

Figure 12: Sensitivity analysis: The single score of altering the recycling share for the waste treatment of the raw material packaging.

6.3 Data quality assessment

The data is valid for the specific product assessed by DFI Geisler. An evaluation of the model and underlying data is made by a data quality assessment which includes a completeness check, assessing the validity of data and a consistency check.

The data are assessed according to the DQR defined in part 0. The data quality assessment is based on the requirements in the ISO 14044 standard.

Table 25: Data quality assessment for the study.

Aspect	Notes
Data quality assessment scheme	The data quality level and criteria from the product category rules have been applied in this study
Geographical coverage	Upstream data: Very good (country-specific) Core module (A3): Very good (Nordic data)
Technological representativeness	Upstream data: Very good (Specific data from most suppliers) Core module (A3): Very good (site-specific)
Time-related coverage	Upstream data: Very good (data from 2021 and 2023) Core module (A3): Very good (2023 data)
Validity	The technological and geographical coverage of the data chosen reflects the physical reality of the product system modelled.
Plausibility	The data used for the core process and most upstream processes (component productions) have been checked for plausibility,

	using as reference EPDs for similar products. The product has been converted to per m2 for the plausibility comparison.
Precision	Very good. Two of the three raw materials have been modelled based on EPDs. The third raw material, the glue, and the energy and energy flow quantified based on generic data from the ecoinvent database.
Completeness	Data accounts for all known sub-processes. All upstream processes were modelled using generic data from the ecoinvent database, using country-specific datasets whenever available, otherwise using European datasets.
Consistency, allocation method, etc.	Allocation follows a physical causality in line with EN 15804.
Completeness and treatment of missing data	No data is found missing.
Final result of data quality assessment	Data quality as required in EN15804 is met.

6.3.1 Uncertainty analysis

Uncertainty analysis is performed in two ways. Monte Carlo analysis will be performed to take into account the uncertainty in the inventory data obtained from the ecoinvent database. Uncertainty concerning specific data and assumptions are analysed in a sensitivity analysis described under 6.2. Monte Carlo simulation was performed using the SimaPro software. For each inventory input or output that contains a distribution and standard deviation, a random value that falls in the distribution range is selected in numerous iterations. The LCA results are recalculated for each iteration. A histogram showing the probability of the results of the climate change impact using the EF 3.1 method, performed with 1000 iterations and presented in Figure 13 and details in Table 26.

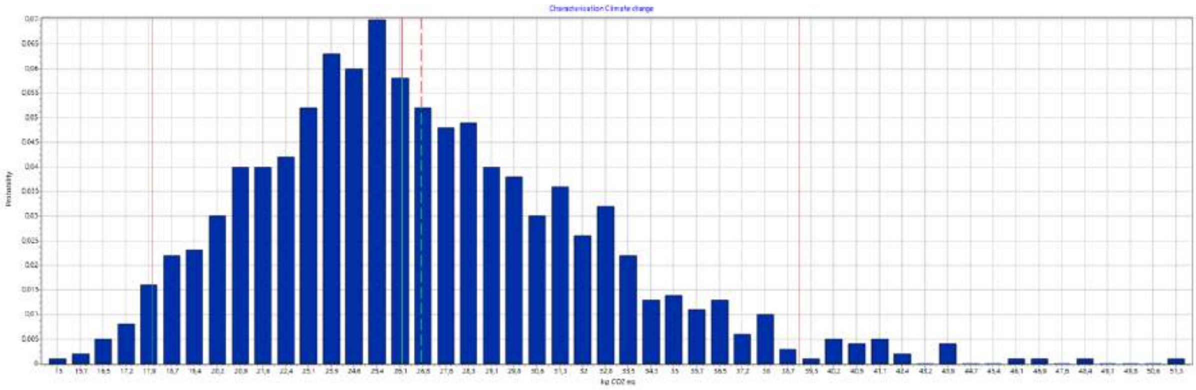

Figure 13: Shows the distribution of results from the Monte Carlo analysis.

In Table 26 it can be seen that the mean value is 26,8 kg CO2 eq per m2, which corresponds roughly to the total climate impact for the Fibertops which was presented in Chapter 5.1.

Table 26: Details concerning the Monte Carlo analysis.

Mean	Median	Standard deviation	Coefficent of variation %	Low 2.5%	High 97.5%	Standard error of mean
26,8	26,2	5,36	20,1%	18,1%	39,1%	0,171

The uncertainty is considered acceptable for a complex LCA study.

6.4 Limitations

In this study, two of the raw materials, melamine faced CDF and laminate, have been modelled with the use of EPDs. Since the raw materials stood for most of the impact it is in some ways a limitation that EPDs were used when modelling the raw materials. EPDs give a more precise result than generic datasets. However, they do not give a result which it Is possible to find out which processes that stand for most of the impact, which could have been interesting in this case, since the raw materials was the life cycle phase with the biggest impact.

7 Conclusions and recommendations

This section will summarise the conclusions from the study in terms of highlighting the most important aspects of the results and the interpretation. Recommendations will be presented in suggestions of how to mitigate the hot spots, how to communicate the results and how to reduce the uncertainties of the study.

The environmental impact of the product Fibertops from a cradle-to-grave perspective comes mainly from the production of **raw materials**, where the melamine faced CDF are a hotspot, closely followed by the laminate. Other life cycle phases that also have an important impact are the manufacturing, the waste handling and the transportation of raw materials. The impact for the manufacturing originates from the electricity use and the impact from the waste handling originates from the waste treatment of wood.

The climate impact from a lifecycle perspective for 1m2 of Fibertops is 26,9 kg CO2 equivalents.

Important impact categories are "Climate change", "Resource use, fossils", and "Resource use, minerals and metals". The impact originates mainly from the raw materials but for the impact category "Resource use, minerals and metals" the electricity for the manufacturing is a big contributor because of the use of a photovoltaic system.

The overall environmental impact comes mainly from the raw materials and the electricity in the manufacturing. The transportation of raw materials has a smaller but still relevant impact.

7.1 Recommendation on how to mitigate the hot spots

To mitigate the environmental impact of materials, one would have to improve the information about the critical materials and develop more specific data. It is also recommended to do a user-study to investigate the actual service life by different users and if reuse can be applied.

The life cycle phase with the biggest overall impact is the raw materials, followed by the manufacturing and the transportation of raw materials. Recommendations to reduce the impact for these life cycle phases are presented below.

- Investigate possibilities to dig deeper into the most contributing aspects of the raw materials CDF and laminate, where EPDs have been used, in order to see where efficient measures can be taken.
- Communicate to suppliers the importance of reducing waste and using energy with low environmental impact in production of the raw materials.
- The production waste for the manufacturing at DFI Geisler is now high, at 31%, if reduced this could lower the total impact of the product.
- Investigate the possibility to lower the total amount of energy used for the manufacturing at DFI Geisler in order to lower the impact.
- Investigate the possibility to use train instead of trucks for the transportation of the raw materials.

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

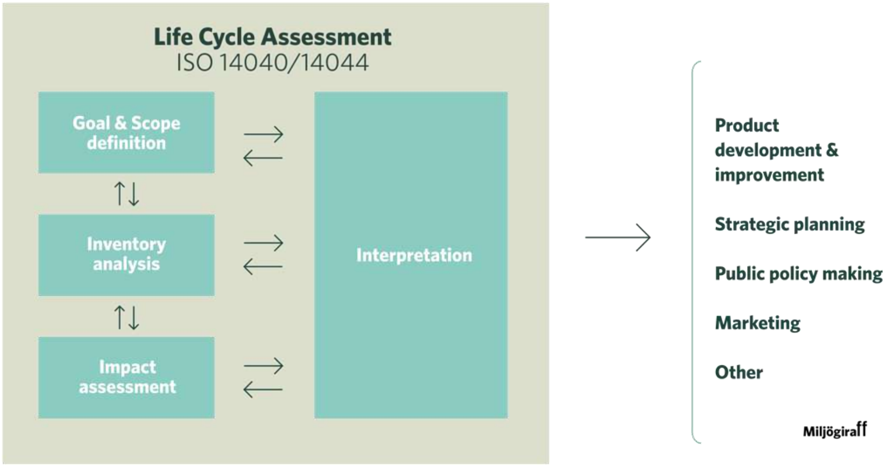

Figure 14. The four phases of the Life Cycle Assessment

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.

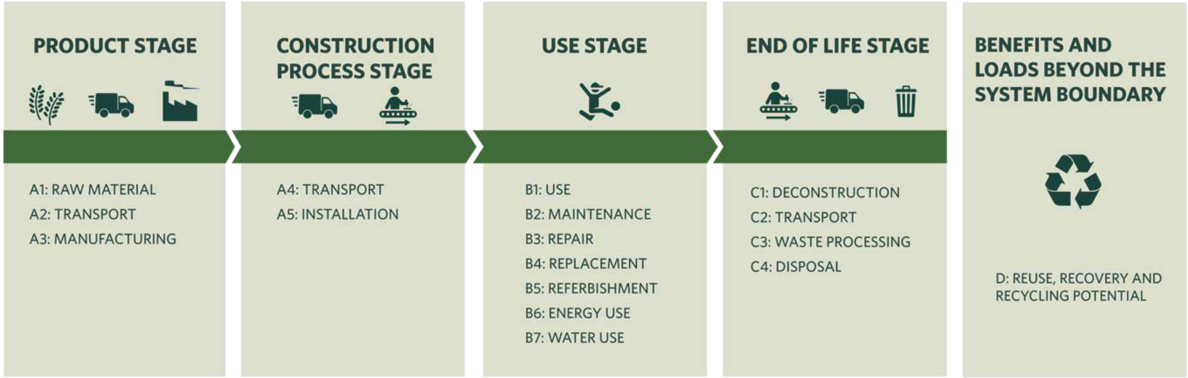

Figure 15: General summary of the modules included in an LCA, based on EN 15804.

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[12], 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 16). 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.

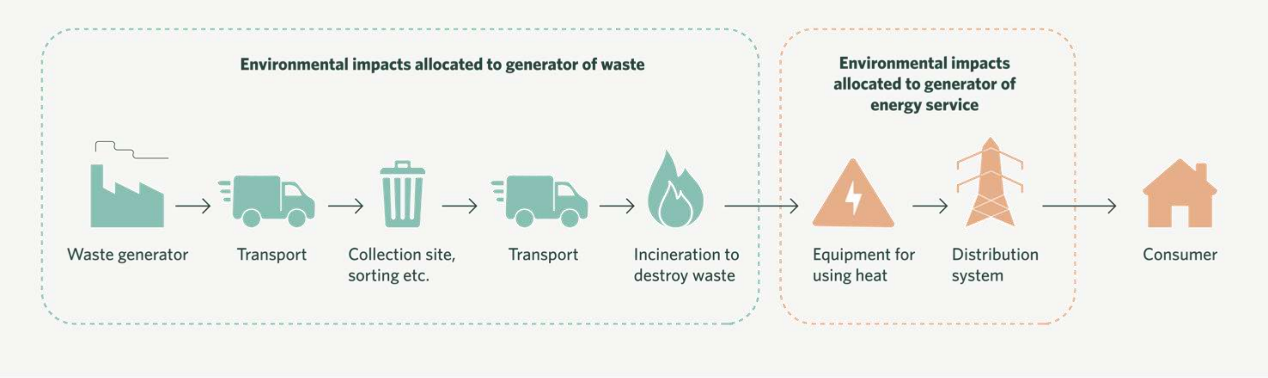

Figure 16: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here in regard to the incineration of waste and resulting energy products.

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 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

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

material and energy flows, while the flows that can be considered negligible are excluded. By setting cut-off criteria, a lower limit is defined for the flows to be included. Flows below the limit can be assumed to have a negligible impact and are thus excluded from the study. For example, cut-off criteria can be determined for inflows concerning mass, energy, or outflows, e.g., waste.

iii. Allocation

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

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

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

iv. Data requirements (DQR)

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

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

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

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

Generic data
1. Public and verified libraries with LCI data
2. Trade organisations' libraries with LCI data

Sector-based IO data, national

B. Inventory analysis (LCI)

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

C. Impact assessment (LCIA)

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

Readymade methods for classification, characterisation and weighting have been used to evaluate environmental effects (either from a broad perspective or for a single issue) and find the categories or parts of a system with the most potential impact. Some of the most common LCIA methods are presented in Appendix 2 - Appendix 4.

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 17 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.

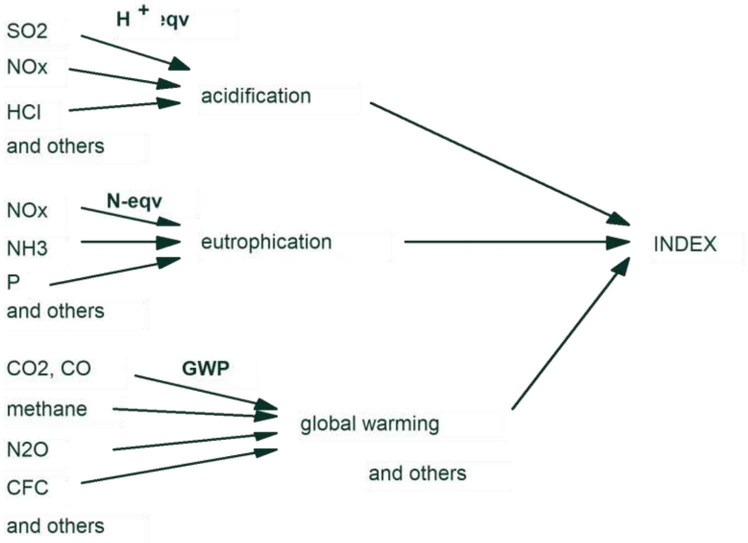

Figure 17: An illustration of the Impact Assessment of an LCA.

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 3.1

One of the most commonly used LCIA methods is the Environmental footprint 3.1 (EF3.1) method (European Commission, 2012). It includes classification, characterisation and optional normalisation and weighting as well as the possibility to calculate a single score including all weighted impacts.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

i. LCA impact categories vs planetary boundaries

Global environmental impacts are sometimes discussed in terms of planetary boundaries (Steffen et al., 2015). It can be relevant to note that the impact categories used in LCA do not have a one-to-one correlation with the planetary boundaries as described by Steffen et al.
Table 27 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 27: 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 IPCC 2021

Direct solar radiation heats the Earth. The heated crust emits heat radiation, is partially trapped by gases, in the Earth's atmosphere. These gases are known as greenhouse gases. Some of this heat radiation radiates back to Earth and heats it. This natural greenhouse effect is essential for life on Earth. However, because of human activity, the concentration of greenhouse gases in the atmosphere, such as carbon dioxide, methane, and nitrous oxide, has increased. This affects the natural radiation balance, which leads to global warming and climate change.

The potential impact on the climate is calculated using the IPCC 2021 GWP 100 v.1.0 model for Global Warming Potential, GWP. The impact of climate gases is expressed as carbon dioxide equivalents, CO2 eq. It is the most established scientific method and has been implemented (with adaptations) in other methods, such as the GHG protocol and EF3.0.

Appendix 4 Cumulative Energy Demand, CED

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

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

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

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

Appendix 5 Guarantees of Origin and other certificates

a. Certificate for renewable energy at DFI Geisler

Bevis for køb af
Miljøvenlig El

Miljøvenlig El sikrer, at VE-oprindelsesgarantierne kommer fra danske solcelleanlæg.

Energi Danmark A/S' revisor PWC dokumenterer i forbindelse med revidering af regnskabet balance mellem købt og solgt Miljøvenlig El.

Virksomhedsnavn	Adresse	Postnr.	By
DFI-Geisler	Bagsværd Hovedgade 172	2880	Bagsværd
DFI-Geisler	Industrivej 21	7900	Nykøbing M

Energi Danmark A/S bekræfter hermed, at **DFI-Geisler** har købt sin andel af elforbruget i perioden 01.01.2023 - 31.12.2023 som Miljøvenlig El produceret på danske solcelleanlæg.

Forventet forbrug i perioden 2.048.825 kWh	CO_2 udledning ved køb af miljøvenlig el 0 g/kWh i alt 0 ton CO_2	Virksomheden har sparet i alt 824 ton CO_2 ved køb af miljøvenlig el

Ægtheden af Miljøvenlig El dokumenteres af Energi Danmark A/S' revisor PWC.

Energi Danmark

Appendix 6 Waste treatment modelling details

[MG] Municipal solid waste (non-packaging) (waste scenario) {EU27}| Treatment of waste | Cut-off, U			
Separated waste		%	
Core board (waste treatment) {GLO}| recycling of core board | Cut-off, U	Cardboard	75	In PEF Annex> Paper > Packaging - carton board (Is almost always a packaging, and even if in a product, it is assumed to be recycled as a packaging cardboard. Therefore, it is included in this waste scenario, in addition to waste scenario for packaging)
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	Paper	62	In PEF Annex: Paper > paper > MATERIAL =0,62. This number probably also includes paper in packaging. All products with specific data was packaging, except tissues.
Packaging glass, white (waste treatment) {GLO}| recycling of packaging glass, white | Cut-off, U	Glass	0	In PEF Annex: Glass > glass > MATERIAL. (only packaging glas has a recycling rate above 0)
Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Cut-off, U	Ferro metals	85	In PEF Annex: Metals > Steel > MATERIAL =0,85
Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Cut-off, U	Steel	85	See comment for ferro metals above.
[MG] Copper (waste treatment) {GLO}| recycling of copper | Cut-off, U	Coppers	90	In PEF Annex: Metals > Coppers > Approx. average of the different copper products. Obs! Recylign rate of copper in photovolataic panel is 0.
Aluminium (waste treatment) {GLO}| recycling of aluminium | Cut-off, U	Aluminium	85	In PEF Annex: Metals > Aluminum > MATERIAL =0,85. Obs! Aluminium alloy used in in photovoltaic panels has a recycling rate of 0
Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U	Plastics	0	In PEF Annex: Plastic > 0 is chosen as most non-packaging products, except for a few, for all plastics has a recycling rate of 0. For uniterruptible power supply = 0.7 for most plastics, for PVC in building and construction 0.32, PP in building and constructions 0.18, PE (LD and HD) in building and construction 0.28 and 0.23.
PE (waste treatment) {GLO}| recycling of PE | Cut-off, U	PE	0	See comment for mixed plastics
PET (waste treatment) {GLO}| recycling of PET | Cut-off, U	PET	0	See comment for mixed plastics

PP (waste treatment) {GLO}| recycling of PP | Cut-off, U	PP	0	See comment for mixed plastics
PS (waste treatment) {GLO}| recycling of PS | Cut-off, U	PS	0	See comment for mixed plastics
PVC (waste treatment) {GLO}| recycling of PVC | Cut-off, U	PVC	0	See comment for mixed plastics
Biowaste {RoW}| treatment of biowaste, industrial composting | Cut-off, U	Compost	40.2	Not from PEF. This % remains from original dataset, see original documentation.
[MG] Batteries (waste treatment) {GLO}| recycling of batteries | Cut-off, U	Batteries	45	In PEF Annex > Batteries > unspecified > cordless power tool and ICT =0.45 (for electric vehicles the recycling rate is 0.95). This refers to amount that goes in to the recycling process. See comment box in PEF annex for more detailed information.
[MG] Textiles (waste treatment) {GLO}| recycling of textiles | Cut-off, U	Textile	11	In PEF Annex > Textiles > T-shirts (only available recycling rate for textiles)
Remaining waste		%	
Municipal solid waste (waste scenario) {Europe without Switzerland}| Treatment of municipal solid waste, incineration | Cut-off, U		54	Share going to incineration based on EU27 statistics for 2013, as found in PEF Annex C (See documentation tab). For Sweden, it is 99%
Municipal solid waste (waste scenario) {Europe without Switzerland}| Treatment of municipal solid waste, landfill | Cut-off, U		46	Share going to landfill based on EU27 statistics for 2013, as found in PEF Annex C (See documentation tab). For Sweden, it is 1%