
# Life Cycle Assessment of Enduce E1 by Enduce AB

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# Table of Contents

Ordered by: Enduce AB

Enduce is a Swedish, Umeå based company, dedicated to driving the transition to environmentally friendly and climate-smart showers with its world-leading technology. Hot tap water heating represents the single largest energy consumer after space heating for residential and hotel buildings. The majority of hot tap water is used for showering.

Enduce has developed the world's most energy efficient shower floor drain, having an application-specific energy recycle efficiency of 71-75% at a shower flow of 10 l/min[1] (Passive House Institute, n.d.; Research Institutes of Sweden AB, 2022). The technology reduces hot water consumption and energy usage to as little as a quarter compared to traditional showers without compromising comfort, hygiene, or design. In addition to leading efficiency, Enduce has also developed a user-friendly cleaning system that prevents the clogging issues that have previously hindered energy recovery from greywater.

Overall, Enduce successfully combines leading efficiency with easy cleaning and an affordable price and an affordable price, making the product economically accessible and profitable. Enduce contributes an essential piece to the transition towards a more sustainable society.

The energy-saving potential for Enduce's technology amounts to approximately 12 TWh/year for Nordic households[2]. The equivalent saving potential for OECD countries is around 615 TWh/year, resulting in substantial potential emission reductions of greenhouse gases and environmental impact. Therefore, with its cost-effective and leading shower energy recovery technology, Enduce can significantly contribute to the fight against environmental and climate change.

Swedish translation:
Enduce driver med sin världsledande teknik omställningen till miljö- och klimatsmarta duschar. Uppvärmning av tappvarmvatten utgör den enskilt största energiförbrukaren efter lokaluppvärmning, för både bostäder och hotell. Det mesta av tappvarmvattnet används till just duschning.

Enduce har utvecklat världens effektivaste teknik för energiåtervinning ur duschvatten, med en energiåtervinningsgrad på 71-75% (verifierad av RISE, januari 2022). Tekniken minskar tappvarmvattenförbrukningen och energiåtgången ned till en fjärdedel jämfört med en traditionell dusch – utan att göra avkall på komfort, hygien, eller design. Utöver en ledande effektivitet har Enduce också utvecklat ett användarvänligt rengöringssystem som motverkar de igensättningar som tidigare har utgjort ett hinder för energiåtervinning ur gråvatten.

Sammantaget är Enduce ensamt om att lyckas kombinera en ledande effektivitet med enkel rengöring och ett överkomligt pris, som gör produkten ekonomiskt tillgänglig och lönsam. Enduce bidrar med en viktig pusselbit i omställningen till ett hållbarare samhälle.

Den totala nordiska energibesparingspotentialen för Enduce teknik uppgår till ca 14TWh/år. Motsvarande besparingspotential för OECD-länderna är ca 615 TWh/år, motsvarande ett utsläpp av 80 Mton fossil CO2 per år och enorma ingrepp i naturen. Enduce kan därmed – med sin kostnadseffektiva och ledande teknik för energiåtervinning i duschar – tillföra ett betydande bidrag till kampen mot miljö och klimatförändringarna.

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[1] The Passive House Institute presents "nominal efficiencies" which can be up to 78%, but in the underlying certificates the actual measured performances are presented which are at most 30-63%.

[2] Based on a warm water use in EU of 1000 kWh/person/year (Eurostat, 2019) and a use case of 60% of the warm water being used for showers, an Enduce E1 energy efficiency of 73% and a population in the Nordics of 27,4 million people (including only households, no commercial facilities or hotels)

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

Enduce E1 is an energy recycling shower drain with an energy-saving potential of ca 12 TWh/year for Nordic households. This LCA presents results for the life cycle impacts of Enduce E1, including the environmental benefits from avoided energy use for warm water heating during the product's use.

The climate impact from production, transportation and waste management of Enduce E1 is 126 kg CO2-eq. The product also has a significant impact on mineral and metal resource use. Impacts are cause by the production of stainless steel and copper and their alloying elements (mainly molybdenum, nickel and chromium).

The environmental benefit of the energy-saving ranges from ca 0,5 – 12 ton CO2-eq. over 30 years of use, depending on the energy system generating the energy being replaced. The net benefit can also be more, or less, with variations in household size, warm water use and net efficiency of the heat exchanger.

The net benefits can be increased e.g. through adapting the product design (reducing material in the product and production waste, using more recycled materials, prolong life), adapting the product life cycle (repair, upgrade, recirculate, make sure that suppliers use low-carbon energy sources) or by targeting customers with a high potential for environmental savings (applications with high energy use, low losses and/or high-carbon heating systems).

The report has been third-party verified and published as an EPD in the International EPD Programme.

# 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 Enduce E1 produced by Enduce. The assessment is carried out according to a life cycle perspective using the ISO 14040 standard and the product category rules (PCR) for construction products, PCR 2019:14 1.3.1 (EPD International, 2023), and forms the basis of an environmental product declaration (EPD).

This LCA presents results for the impacts from production, transportation and waste management of Enduce E1, as well as the benefits from avoided energy use for warm water heating during the product's use.

## 1.1 Reading guide

Readers can select sections of the report depending on their time availability, see list below. Of particular note is that the purpose of the product is to reduce the energy consumption. Scenarios regarding this matter can be found in section 6.3.

- 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. Particularly relevant is section 6.3 on the potential environmental benefits of Enduce E1.
- 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

Domestic hot water, i.e. the hot water we get from the tap, accounts for the largest part of our energy consumption. For newly built houses, this is between 35–45% and it is when we shower that the consumption is at its greatest (Energimyndigheten, 2009).

Used shower water is passed through a highly efficient industrial plate heat exchanger before being flushed down the drain. There, the heat is transferred to the incoming cold water of the shower.

This means that a significantly smaller percentage of hot water needs to be added to reach a comfortable shower temperature. In this way, large amounts of energy are saved.

The Enduce product has the potential to reduce the energy needed to heat the water. On markets where the energy used for heating water contains a lot of fossil fuels, the product has a higher potential to generate environmental benefits in the use phase. Scenarios showing the impact of the product in the use phase can be found in section 6.3 in this report.


Figure 1 Enduce E1 by Enduce.

## 1.3 The sustainability challenge

Sustainability comprises meeting our own needs without compromising the ability of future generations to meet their own needs. Industrial and natural systems depend on a stable Earth system to function. A quantitative planetary boundary within which humanity can continue to develop and thrive for generations to come has been proposed (Steffen et al., 2015). These researchers describe nine processes that determine the resilience and stability of the Earth system, such as climate change, water use, and land use. Crossing these boundaries increases the risk of abrupt and irreversible environmental change, while staying within the boundaries represents a safe operating space for a sustainable society, see Figure 3.

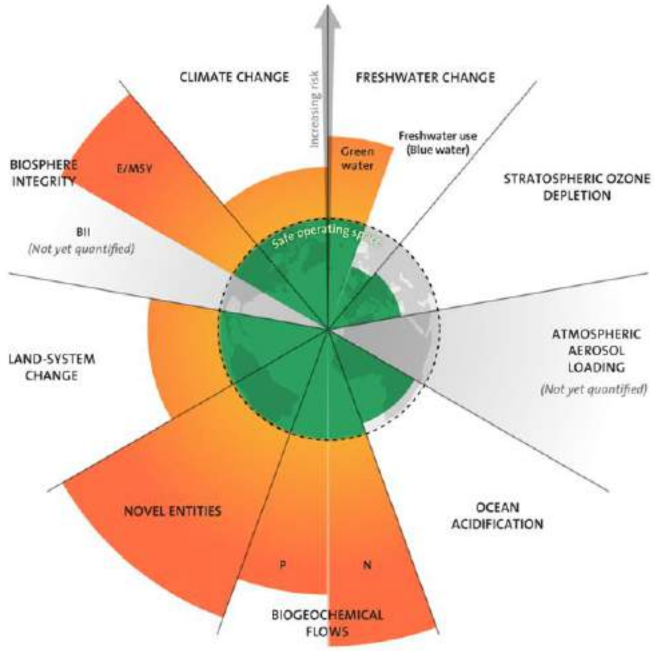


Figure 2: Shows the state of the planetary boundaries, where the green area represents a safe operating space. Credit: Azote for Stockholm Resilience Centre, based on analysis in Wang-Erlandsson et al 2022.

One critical environmental problem we face today is climate change. The latest report from the Intergovernmental Panel on Climate Change, shows that only the most ambitious of five scenarios for greenhouse gas emissions would result in a temperature increase within 2°C (IPCC, 2021a), see Figure 3. Considering that limiting temperature rise below 1.5°C is the ambition of the Paris Agreement 2016, it is evident that the available space for mitigating radical climate change is ever-shrinking, necessitating decisive action in all parts of society.

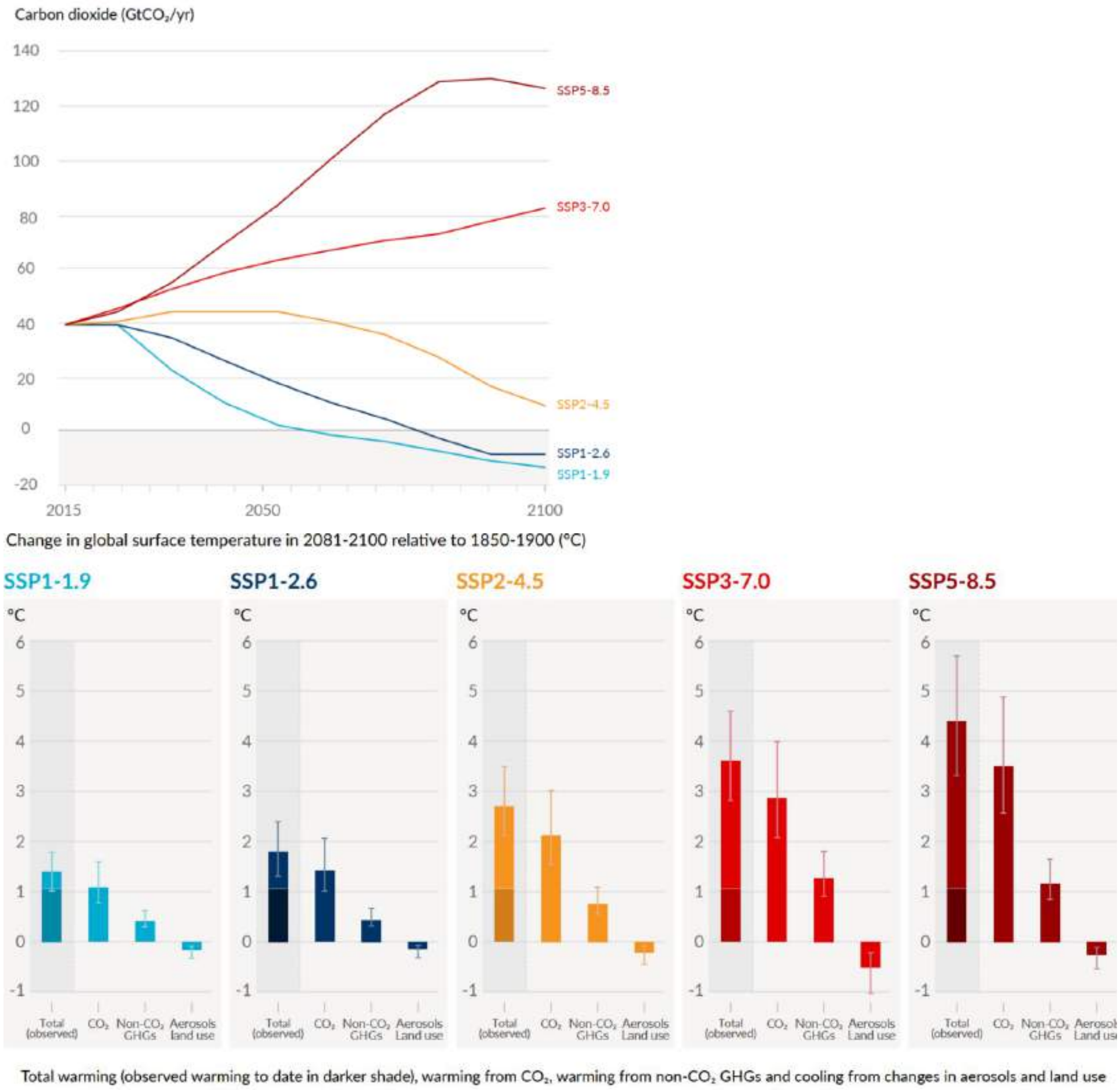


Figure 3: Future annual emissions of $CO_2$ (top) and contribution to global surface temperature increase from different emissions, with a dominant role of $CO_2$ emissions (bottom) across five illustrative scenarios. Image from IPCC (2021b).

# 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).

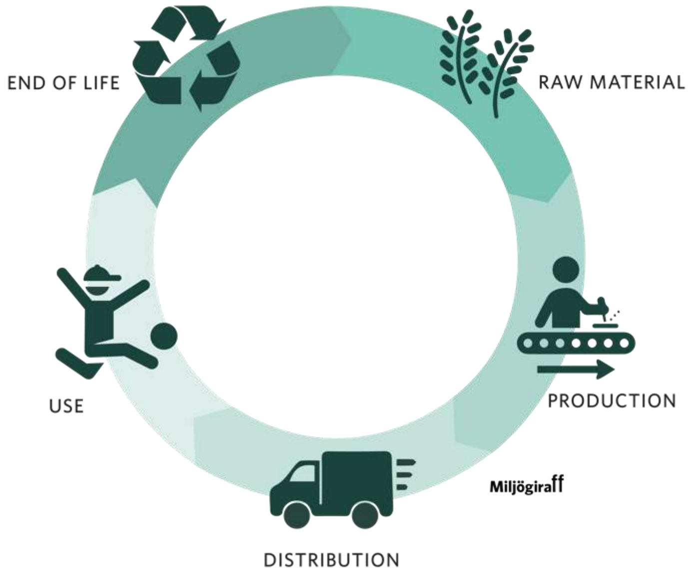


Figure 4: The Life Cycle concept, starting from raw material extraction, production, and distribution, followed by use and end-of-life.

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 5.)


Figure 5: ISO standard combined with reliable data from ecoinvent and the LCA software SimaPro.

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

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

## 2.2 Environmental product declaration

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

EPDs are primarily intended to facilitate business-to-business communication, although they may also benefit consumers who are environmentally focused when choosing goods or services. See Figure 6.

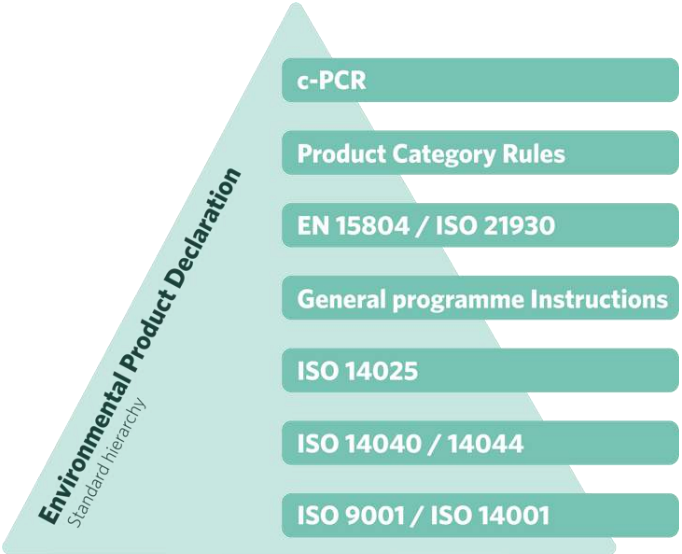


Figure 6 shows the hierarchy of standards used to create and EPD according to the International EPD system.

### 2.2.1 General Program Instructions (GPI)

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

### 2.2.2 Product Category Rules (PCR)

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

# 3 Goal and Scope

## 3.1 The aim of the study

The study's goal is to find metrics for the environmental impact of Enduce E1 produced by Enduce. from a life cycle perspective. The report describes the results transparently and reproducibly according to the standard. The LCA has been made according to the product category rules for construction products in the international EPD system. The results are interpreted, followed by recommendations for mitigating the environmental impact.

The purpose of the study is, through the LCA approach, to provide a transparent and objective assessment and characterisation of Enduce 's product to be used in product development and environmental communication in the form of an Environmental Product Declaration (EPD), being intended for both internal and external audiences.

## 3.2 Standards and frameworks

This is an attributional LCA approach (accounting) defined in the ISO 14040 standard. The standards and frameworks guiding this LCA are presented in Table 1.

Table 1: Standards and framework conformance.

| Standards conformance |
|---|
| ISO 14040 and 14044 (ISO, 2006b, 2006c) |
| General program instructions for the International EPD System (EPD International, 2021a) |
| PCR 2019:14 version 1.3.1 (EPD International, 2023) |

## 3.3 Scope of the Study

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

### 3.3.1 Name and Function of the Product / System

In this study, the system studied was Enduce E1 and its function is to recycle energy from hot water in showers as an energy recycling floor drain.

### 3.3.2 The Declared Unit and reference flow

The declared unit is the basis that enables alternative goods, or services, to be compared and analysed. The primary purpose of a declared 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 declared unit is one Enduce floor drain in use for 30 years.

### 3.3.3 System Boundary

The system boundary for the study is defined as "Cradle to gate with options, module C1-C4, module D and optional modules". Modules A1 to A3, A4 and A5 as well as B1, B4, C1 to C4 and module D are included in the study.

All processes needed for raw material extraction, manufacturing, transport, usage, and end-of-life are included in the study. A simplified schematic representation of a cradle-to-grave system under study is presented in Figure 7, where the dotted lines indicate aspects that have been included in this study.

A more detailed representation of the system's boundaries is presented in Figure 8: A more detailed representation of the system boundaries of the product system.

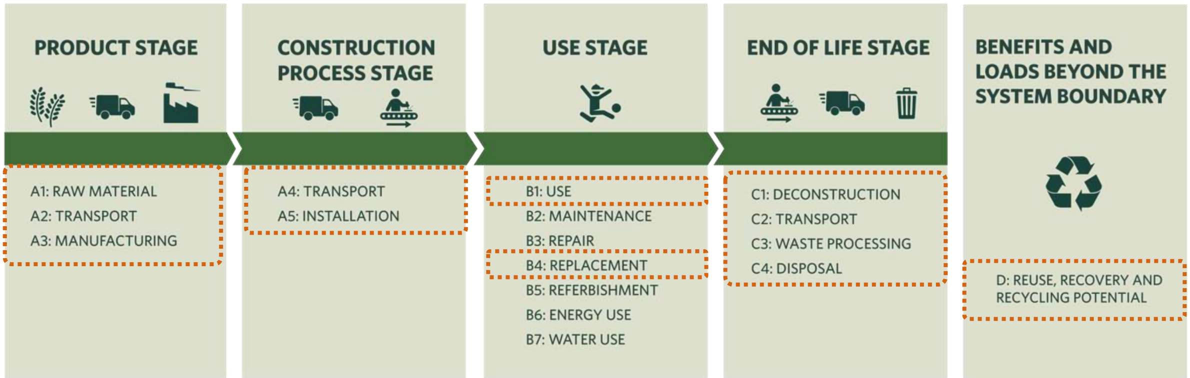


Figure 7: System boundaries for the model of the product system

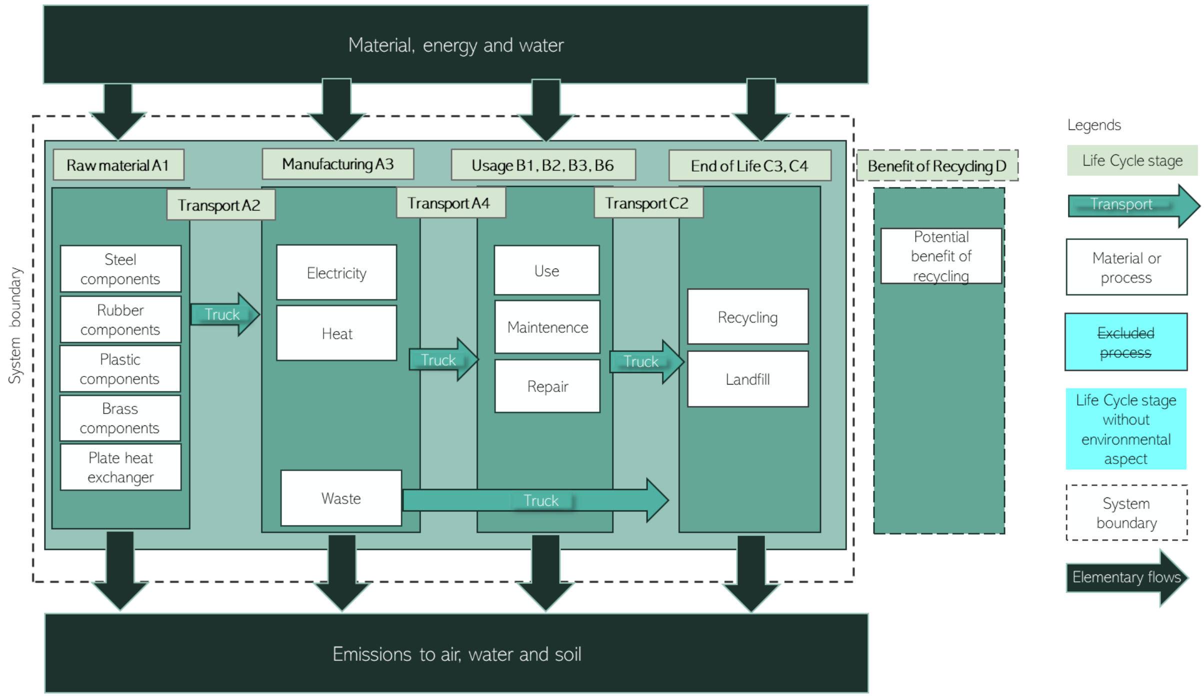


Figure 8: A more detailed representation of the system boundaries of the product system

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

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

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

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

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

In addition to the cut-off of material- and energy flows, also life cycle stages can be excluded if they are deemed to be of low relevance or do not cause any adverse environmental effects. An overview of processes that are excluded in this study is presented in Table 2.

Table 2: Overview of aspects that are excluded.

| **Excluded** processes | **Reason** |
|---|---|
| Assembly of products at Enduce in Umeå | Only manual labour, meaning that there are no relevant environmental aspects |
| Carton layers for separation of products when packaged in pallets | The amount of packaging material per product will be small and it is estimated to fall under the cut-off. |
| Waste of packaging material in the repackaging process at Enduce and its treatment with regards to the exchange process for non-stainless-steel components after 15 years. | Waste of packaging material in the repackaging process at Enduce and its treatment is estimated to fall under the cut-off. |
| Separation process for copper and steel in heat exchanger at end of life | Estimated to have a minor contribution to total impacts |
| Sorting and pressing of waste in C-module | Estimated to have a minor contribution to total impacts |

### 3.3.4 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 is described in ISO 14044 section 4.3.4.2 (ISO, 2006c). ISO 14044 recommends avoiding allocation whenever possible by division into subprocesses or expanding the product system. Where allocation cannot be avoided, it is recommended to base the allocation on the physical relationship between products. This can be physical characteristics that are representative of the quality of the function provided. Where the physical relationship between products is not suitable as the basis for allocation, other relationships between them can be used. Commonly the economic value is such a relationship that can be used for allocating inputs and outputs of a process to its products.

Allocation of waste is described in ISO 14044 section 4.3.4.3.3 (ISO, 2006c) and uses the method of Allocation cut-off by classification per EPD guidelines (EPD International, 2021b). Avoided materials due to recycling are typically not considered in the main scenario, per the International EPD system's recommendation of the Polluter Pays Principle. In other words, only if the generating life cycle uses recycled material as input material will it account for the benefits of recycling.

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

### 3.3.5 Method of Life Cycle Impact Assessment (LCIA)

The methods used to calculate the relevant environmental effect categories in this study are summarised in Table 3 and Table 4. Additionally, single score weighting according to EF 3.1 is applied. For further details on the LCIA method, see Appendix 2-Appendix 3.

Table 3: Impact categories, indicators and methods used in the study. The chosen indicators follow the standard for Construction products EN 15804:2012+A2:2019 (CEN, 2019).

| Impact category | Abbreviation | Category indicator | Method |
|---|---|---|---|
| Climate Change-total | GWP total | kg $CO_2$ equivalents | The baseline model of 100 years of the IPCC based on IPCC 2013 |
| 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, minerals and metals | ADPe | kg Sb eq | CML 2002, Guinée et al., 2002, and van Oers et al. 2002. |

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

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

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

Table 5: 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 6: 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 7: 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 |

### 3.3.6 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 for 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 downstream processes:* Data is representative for the technology used (for example at suppliers) if possible. Otherwise, average technology or BAT[3]
- Time related coverage:
  - *Data of core processes:* The collected data is ideally representative for the last 12 months but not older than 5 years.

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

  - *Data of upstream and downstream processes:* The collected data is as recent as possible but not older than 10 years.
- Precision:
  - *Data of core processes:* The collected data is ideally representative for a year of production covering the variability occurring during the time span.
  - *Data of upstream and downstream processes:* The variability present in background data should be accurately representative of the case in the study.
- Completeness: Data should account for all known sub-processes. The sum of the neglected material flows should not exceed 5% of mass or 1% of energy. If data is missing it should be clearly stated how it has been handled.
- Representativeness: The technological and geographical coverage of the data chosen should reflect the physical reality of the product system modelled.
- Consistency: The same methodology should be applied uniformly to each part of the analysis.
- Reproducibility: To ensure reproducibility of the study details regarding data collection, inventory and results should be available and clearly accounted for in the report.
- Sources of the data: The sources of data should be clearly stated in report.
- Uncertainty of the information: If a dataset has been specifically modelled, and/or certain assumptions have been made they should be stated.
- Allocation: Physical causality. See section 3.3.5 about details of allocation.
- Cut-off rules: See section 3.3.4 about cut-off criteria.
- System boundary: Second order (material/energy flows including operations)
- The boundary with nature: Agricultural production is part of the production system

The data quality and representativeness will be assessed in part 6.4 based on the guidelines established in the EN 15804:A2 standard (CEN, 2019).

### 3.3.7 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.

As this is a study also destined for external audiences with comparative assertions, the EPD and this underlying LCA report are reviewed by a third party, Viktor Hakkarainen, a verifier approved by the International EPD System.

### 3.3.8 LCA Software

The life cycle impact assessment (LCIA) was calculated using the LCA software SimaPro 9.4 (PRé Sustainability, 2022) developed by PRé Consultants. It is the world's leading LCA software chosen by industry, research institutes and consultants in more than 80 countries. SimaPro is a powerful tool for calculations of complex product systems and in-depth 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 declared 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.

For modules A4-D: the scenarios included are currently in use and are representative for one of the most probable alternatives.

## 4.1 Product content declaration

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

The packaging stated in the table below is the amount of packaging presented with the product when it is delivered to customer: wooden pallet + frames and carboard boxes.

There are no Substances of Very High Concern (SVHC)[4] exceeding the limits for registration with the European Chemicals Agency (i.e., if the substance constitutes more than 0.1% of the weight of the product).

Table 8: Content declaration

| Product components | Weight (kg) | Post-consumer material (weight-%) | Biogenic material, weight-% and kg C/kg |
|---|---|---|---|
| EPDM Rubber Hoses | 0,620 | Unknown | 0% |
| PP Plastics | 0,400 | Unknown | 0% |
| Brass components | 0,390 | Unknown | 0% |
| Stainless steel, box | 9,00 | 65,6% | 0% |
| Stainless steel, flange | 3,00 | 65,6% | 0% |
| Stainless steel, others | 4,84 | 65,6% | 0% |
| Plate heat exchanger | 12,8 | 66,7% | 0% |
| Total | 31,1 | 63,1% | 0% |
| Packaging materials | Weight (kg) | Weight-% (versus the product) | Weight biogenic carbon, kg C/kg |
| Cardboard boxes | 0,325 | 1% | 0,15 |

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

| | | | |
|---|---|---|---|
| Wooden pallet + wooden frames | 0,580 | 2% | 0,26 |
| Total | 0,905 | 3% | 0,41 |

## 4.2 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.
- Infrastructure processes are included.

## 4.3 Raw material (A1 + A2)

This section describes all the different raw materials needed for the manufacturing of the components needed for the final Enduce E1 product.

### 4.3.1 Supplier raw material extraction and production

The table below represents the components needed for the product. The transport route differs for the different components. Some of them are transported via the Enduce warehouse in Umeå before being sent to the client. The packaging of components for the transport to Umeå are included in A1. Other components are sent directly from the manufacturer of the component to the end-customer. For the components sent directly to the customer, the final packaging material to customer are included in A1.

Table 9: Raw materials and transport to Umeå or directly to end customer. See 4.3.2 for a detailed description of the steel models and 4.3.3 for the brass model.

| Component | Weight (kg) | LCI database representation | Origin | Transport type | Transport distance (km) | Comment |
|---|---|---|---|---|---|---|
| EPDM Rubber hose | 0,62 | Synthetic rubber {RER}\| synthetic rubber production \| Cut-off, U | Horda, Sweden | Road, truck, Euro 6, all sizes | 1045 | Energy for extrusion is included in material process for synthetic rubber<br>Transported from the supplier to the Enduce warehouse in Umeå. |
| PP Plastics | 0,4 | Polypropylene, granulate {RER}\| polypropylene production, granulate \| Cut-off, U<br>Injection moulding {RER}\| injection moulding \| Cut-off, U | Skellefteå, Sweden | Road, truck, Euro 6, all sizes | 135 | Injection moulding represents casting<br>Transported from the supplier to the Enduce warehouse in Umeå |
| Brass components | 0,39 | [1331] Brass CW724R, at manufacturer<br>Metal working, average for copper product manufacturing {RER}\| metal working, average for copper product manufacturing \| Cut-off, U | Lumezzane, Italy | Road, truck, Euro 6, all sizes | 2800 | Metal working is used as representation of manufacturing of the components<br>Transported from the supplier to the Enduce warehouse in Umeå |
| Stainless steel, box | 9 | [1331] Steel ASTM 304L \| Cut-off, U<br>Energy and auxilliary inputs, metal working factory {RER}\| market for | Ukmerge, Lithuania | N/A | N/A | Measurements from Enduce show a 25,5wt% spillage in the production of the box. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | energy and auxilliary inputs, metal working factory \| Cut-off, U | | | | This is added to the input of material in the model generating a total of 11,3 kg of raw material used.<br>Transport direct to customer, thus they are covered in module A4, see section further down |
| Stainless steel, flange | 3 | [1331] Steel ASTM 304L \| Cut-off, U<br>[MG] Metal working, average for steel product manufacturing {RER}\| processing \| Cut-off, U _ adapted for Sweden | Ulricehamn, Sweden | Road, truck, Euro 6, all sizes<br>Freight, sea, ferry, market | 523<br>405 | Transport from Ulricehamn to Lithuania for mounting on the steel box and then directly to customer, thus the transport to Lithuania is covered in A1 and the transport to the customer is covered in module A4, see section further down |
| Stainless steel, others | 4,84 | [1331] Steel ASTM 304L \| Cut-off, U<br>Metal working, average for steel product manufacturing {RER}\| metal working, average for steel product manufacturing \| Cut-off, U | Ukmerge, Lithuania | Road, truck, Euro 6, all sizes<br>Freight, sea, ferry, market | 1102<br>178 | Metal working is used as representation of manufacturing of the components<br>Transported from the supplier to the Enduce warehouse in Umeå |
| Plate heat exchanger | 12,8 | 3wt% Copper, cathode {GLO}\| market for copper, cathode \| Cut-off, U<br>9wt% Copper scrap, sorted, pressed {GLO}\| market for copper scrap, sorted, pressed \| Cut-off, U<br>19wt% [1331] Steel ASTM 304 \| Cut-off, U<br>69wt% [1331] Steel ASTM 316 \| Cut-off, U<br>[MG] Metal working, average for steel product manufacturing {RER}\| processing \| Cut-off, U _ adapted for Sweden | Ronneby, Sweden | N/A | N/A | Swedish market mix for low voltage electricity.<br>12wt% copper, 19wt% Steel ASTM 304, 69wt% Steel ASTM 316. 75wt% recycled content in the copper<br>Transport direct to customer, thus they are covered in module A4, see section further down |

### 4.3.2 Material 1 – Steel

Data is adapted to match the information for the specific steels. The ecoinvent dataset "Steel, chromium steel 18/8 {RER}| steel production, electric, chromium steel 18/8 | Cut-off, U" is used as a basis and modified. The composition of the steels are retrieved from searching on the name of the specific steel. For substances with a range, the average is used. Finally, iron is used to balance up to 100%.

| Product | Steel 304 [wt%] | Steel 304L [wt%] | Steel 316 [wt%] |
|---|---|---|---|
| Carbon | 0,07 | 0,03 | 0,08 |
| Manganese | 2,0 | 2,0 | 2,0 |
| Sulfur | 0,03 | 0,03 | 0,03 |
| Phosphorous | 0,045 | 0,045 | 0,045 |
| Silicon | 0,75 | 0,75 | 0,75 |
| Chromium | 18,5 (17,5 to 19,5) | 19,0 (18 to 20) | 17,0 (16,0 to 18,0) |
| Nickel | 9,25 (8,0 to 10,5) | 10,0 (8,0 to 12) | 12,0 (10,0 to 14,0) |
| Molybdenum | 0 | 0 | (2,0 to 3,0) |
| Nitrogen | 0,1 | 0,1 | 0,1 |
| Iron | 69,33 (0,393) | 68,08 (0,3508) | 65,58 (0,2664) |
| Source | https://nks.com/coil/304-stainless-steel/ | https://nks.com/coil/304-stainless-steel/ | https://nks.com/coil/304-stainless-steel/ |

The inputs of molybdenum etc are added to the dataset. The inputs of ferronickel and ferrochromium contain 25,5wt% Nickel and 68wt% chromium respectively, meaning that the amounts have to be adjusted to represent 9wt% nickel in the finished product.

The amount of nickel (or chromium) in finished steel is divided by the amount in the ferronickel (or ferrochromium).

This means that by mass balance, the amounts of ferronickel and ferrochromium is now larger than the input should be, to balance the output from the dataset. The amount of iron present in the ferronickel and ferrochromium is used fully in the process of creating the final steel. Hence the amount of iron as input is reduced with the amount of iron present in the ferronickel and ferrochromium.

As the inputs for the steel are now adjusted to match 1 kg of input, a further correction is needed to balance the output from the original ecoinvent dataset. The output from the dataset is summed up to approximately 19wt%. The input of quicklime in the datset is not adjusted as it is interpreted to be a catalyst for the process that does not end up in the final product. Therefore, the amount of quicklime input is subtracted from the waste output generating an estimation of 15,5wt% waste of other materials used as input. To adjust for the output, all inputs (except quicklime) are multiplied by a corrective factor of 1,155 to ensure mass balance in the dataset. A note here is that it is assumed that all inputs become waste to the same extent (15,5wt%).

An estimated 65,6wt% of the stainless steel is from post-consumer recycled steel. The amount was estimated based on one of the main stainless steel suppliers of Enduce's supplier in Lithuania, namely Outokumpu Abp. Their average rate of post-consumer recycled input over 2018-2022 is 65,6wt% (Outokumpu Abp, n.d.). In addition to this amount of post-consumer scrap, the statistics also show an amount of ca 19-23wt% pre-consumer scrap. However, it is not specified whether it is internal or external scrap, why it was conservatively assumed to be internal scrap (thus avoiding co-product allocation) with no environmental benefits.

The recycled content was modelled by creating one (separate) dataset representing 100% virgin steel and one for 100% recycled steel and combining them into the desired ratio of recycled steel. The model for the virgin steel is described above and the recycled steel is adapted from "Steel, chromium steel 18/8 {RER}| steel production, electric, chromium steel 18/8 | Cut-off, U", with material inputs being replaced with iron scrap as a proxy representing the input of post-consumer stainless steel. Similar to the virgin steel described above, the inputs are increased with a correction factor to ensure mass balance.

### 4.3.3 Material 2 – Brass

For brass CW724R, the Brass was modelled following the specification of this type of brass. The Swiss dataset for brass (Brass {CH}| brass production | Cut-off, U) was modified according to the specific composition. The energy was adapted to represent production in Italy with Italian electricity mix, medium voltage. The background datasets used for creating these processes are detailed in the table below:

Table 10: CW724R modelling details.

| Ecoinvent background data | CW614N composition in wt% |
|---|---|
| Copper, cathode {GLO}\| market for \| Cut-off, U | 76 |
| Silica sand {GLO}\| market for \| Cut-off, U | 3,1 |
| Phosphorus, white, liquid {RER}\| phosphorus production, white, liquid \| Cut-off, U | 0,06 |
| Lead {GLO}\| market for \| Cut-off, U | 0,1 |
| Zinc {GLO}\| market for \| Cut-off, U | 20,7 |

### 4.3.4 Packaging from supplier to Umeå

The components that are transported to the warehouse in Umeå are packaged at the supplier.

*Rubber hoses and plastic details:*
Packaged on a Euro pallet with frames and a lid. The total height of a pallet with frames is 130 cm. The lid is assumed to be wooden. To represent this case 4 Euro pallets are used to represent a pallet with frames and lid. The pallets are part of the reuse system, and 25 times reuse is used in the study following the suggestion of the recommendations from the European Commission (2021).

200 units of rubber hoses are packaged per pallet. Same for plastic details. For these components the amount of pallet is: 4/(25*200) = 0,0008 pieces of pallet per unit.

*Brass units:*
Packaged on a Euro pallet with frames and a lid. The total height of the pallet has not been possible for Enduce to estimate so the same assumption as for Rubber hoses and plastic is used. The lid is assumed to be wooden. To represent this case 4 Euro pallets are used to represent a pallet with frames and lid. The pallets are part of the reuse system, and 25 times reuse is used in the study following the suggestion of the recommendations from the European Commission (2021).

2000 units of brass units are packaged per pallet. For these components the amount of pallet is: 4/(25*2000) = 0,00008 pieces of pallet per unit.

*Steel, others*
Packaged in a cardboard box that is estimated to weigh 75 grams (measurements 30x68x3 cm). An estimation is made that 60 boxes are packaged on a Euro pallet with frames and a lid. The total height of a pallet with frames is 180 cm. The lid is assumed to be wooden. To represent this case 5 Euro pallets are used to represent a pallet with frames and lid. The pallets are part of the reuse system, and 25 times reuse is used in the study following the suggestion of the recommendations from the European Commission (2021).

For these components the amount of pallet is: 5/(25*60) = 0,003 pieces of pallet per unit.

### 4.3.5 Packaging from supplier to end-client (or via Ukmerge to end-client)

The components that are transported to the final client directly are presented below.

*Steel, Flange:*
The packaging of the flanges from Ulricehamn to Ukmerge, Lithuania for mounting on the steel box. For this transport they are packaged on a half pallet stacked on each other. It is assumed that fraes are used as well as a lid. The lid is assumed to be wooden. To represent this case 1 Euro pallet is used to represent a pallet with frames and lid. The pallets are part of the reuse system, and 25 times reuse is used in the study following the suggestion of the recommendations from the European Commission (2021).

90 units are packaged per pallet. For these components the amount of pallet is: 1,5/(25*90) = 0,0007 pieces of pallet per unit.

*Steel, Box (including mounted flange):*
The finished steel box with a mounted flange is packaged on a Euro pallet with frames and a lid. The total height of a pallet with frames is 180 cm. The lid is assumed to be wooden. To represent this case 5 Euro pallets are used to represent a pallet with frames and lid. The pallets are part of the reuse system, and 25 times reuse is used in the study following the suggestion of the recommendations from the European Commission (2021). Layers of carton is used to separate the boxes. These are assumed to fall under the cut-off in the study.

20 units of boxes are packaged per pallet. For these components the amount of pallet is: 5/(25*20) = 0,01 pieces of pallet per unit.

*Plate heat exchanger:*
The plate heat exchanger is packaged on a Euro pallet with frames and a lid. The total height of a pallet with frames is 40 cm. The lid is assumed to be wooden. To represent this case 2 Euro pallets are used to represent a pallet with frames and lid. The pallets are part of the reuse system, and 25 times reuse is used in the study following the suggestion of the recommendations from the European Commission (2021). Layers of carton is used to separate the boxes. These are assumed to fall under the cut-off in the study.

12 units are packaged per pallet. For these components the amount of pallet is: 2/(25*12) = 0,006 pieces of pallet per unit.

## 4.4 Manufacturing at Enduce (A3)

In this chapter, the activities carried out by Enduce are presented. Enduce purchases components and transports them for final installation at the customer's site. The transport route differs for the different components. The components passing Enduces site in Umeå are assembled and repackaged in cartons before being sent to the customer. Hence the operations covered by A3, the Enduce operations, are operations for packaging and distribution.

The activities include the delivery of components to the warehouse in Umeå, assembling of components as well as repackaging and storage of components.

All activities are presented per one product.

### 4.4.1 Energy

The assembling of the components that are mounted to each other is done by manual labour and the occasional use of a screwdriver. The amount of energy needed for the assembling is very small and estimated to fall under the cut-off for the product.

### 4.4.2 Internal transports

No internal transports have been reported by Enduce.

### 4.4.3 Production waste

The PP Plastics, Rubber hose and Brass components arrive in bulk packaging on pallets. The amount of pallets have been calculated in the A1 section in this report. The pallets and frames are part of a reuse system and are therefore reused. However, at some point they would be discarded and this is assumed to happen in A3. Therefore, the amount calculated in A1 is assumed to go to waste management in A3.

For the components called steel, others the pallet that they arrive on are also sent to waste management from Enduce. The cardboard packaging from the supplier is however kept as it is reloaded on a pallet with the other components that were assembled.

Table 11: Production waste types and treatment

| Waste type | Waste transport type | Waste transport distance (km) | Waste quantity (kg) | Waste treatment |
|---|---|---|---|---|
| Wooden pallet + frames | Truck | 50 | 0,13 | Recycling and incineration according to the waste scenario in the C module |

### 4.4.4 Packaging

At the Enduce warehose the products are mounted and repackaged. The components Rubber hose, PP plastics and brass components are assembled and packaged in a new cardboard box and then loaded on a pallet together with the smaller cardboard box containing the component stainless steel, others.

Table 12: Packaging used for product

| Type of Packaging | Material | Amount (kg) | LCI data representation in ecoinvent |
|---|---|---|---|
| Wooden pallet + frames + lid | Swedish wood | 0,58 | EUR-flat pallet {RER}\| market for EUR-flat pallet \| Cut-off, U |
| Cardboard box | Cardboard | 0,25 | Corrugated board box {RER}\| market for corrugated board box \| Cut-off, U |

## 4.5 Transport of finished goods (A4)

The transport route differs for the different components. The components passing Enduce's site in Umeå are repackaged and sent to the customer. The components that are sent directly to the customer from the supplier of the component are packaged there and sent to the customer.

The finished products are loaded on a truck and transported to a client. According to Enduce the end-client is usually located somewhere between Stockholm and Göteborg, Sweden. Therefore, Mjölby is used as the representative location of the client and distances from Umeå as well as suppliers of components that go directly to the client are assessed to Mjölby.

Table 13: Distribution of products

| Product | Road transport type | Road transport distance (km) | Sea transport type | Sea transport distance (km) | Comment |
|---|---|---|---|---|---|
| EPDM Rubber hose<br>PP Plastics<br>Brass components | Road, truck, Euro 6, all sizes | 862 | N/A | N/A | From Enduce in Umeå to customer as assembled part. |
| Stainless steel, box<br>Stainless steel, flange | Road, truck, Euro 6, all sizes | 617 | Ferry | 275 | From Ukmerge, Lithuania to customer |
| Stainless steel, others | Road, truck, Euro 6, all sizes | 862 | N/A | N/A | From Enduce in Umeå to customer as assembled part. |
| Plate heat exchanger | Road, truck, Euro 6, all sizes | 270 | N/A | N/A | Direct to customer |

## 4.6 Installation (A5)

Activities for installing the product are consisting of manual labour using for example a screwdriver. This installation work is estimated to fall under the cut-off in the study.

A description of the installation process is described below:
The final customer receives the components for installation. When the customer has mounted the steel box and finished building the sub-flooring in the bathroom it is time to mount the sealing layer, flooring and mount the technical part of the product in the steel box.

### 4.6.1 Disposal of packaging

In the table below, the disposal of the packaging that is delivered with the product to the final customer is presented.

Table 14: Disposal of packaging delivered with the product

| Type of Packaging | Material | Amount (kg) | Disposal method | Comment |
| --- | --- | --- | --- | --- |
| Cardboard box | Cardboard | 0,325 | Recycling, incineration, landfill | Recycling, incineration, landfill according to waste scenario in C module |
| Wooden pallet + frames + lid | Wood | 0,58 | Recycling, incineration, landfill | Recycling and incineration according to the waste scenario in the C module |

Assumed transportation by truck 50 km to a nearby incineration plant.

## 4.7 Usage (B1) and replacements (B4)

The Enduce product has a lifetime of 30 years. After 15 years, non-stainless-steel components are exchanged. Hence, the components rubber hose, PP plastics and brass components are exchanged after the product has been installed for 15 years. To account for this, the manufacturing of the products, transport to Enduce in Umeå, assembly and repackaging as well as transports to the customer are included in the model as an additional life cycle. See section 4.3 to 4.6 for detailed information on the components.

Potential waste of packaging material in the repackaging process at Enduce and its treatment is estimated to fall under the cut-off and are excluded from the model.

When installed, the product provides its function of reducing heating needs for showering. The benefits of this are calculated in the D-module (see section 4.9.2) and further explored in section 6.3. The usage does not affect module B1, except for the indicator for exported thermal energy, where the total avoided energy use over 30 years of use (43 470 kWh) is included, see section 5.5. The amount was calculated as 62 100 kWh of burden free energy entering the system as warm wastewater, of which 70% (43 470 kWh) is captured by Enduce E1 and sent into another system (energy exported into the shower system) and the remaining 30% (18 630 kWh) is lost with the exiting wastewater.

## 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 relevant environmental aspects have been identified in the dismantling phase. Most components can be manually separated into different material streams. Additionally, there is an industrial process for separating the copper and steel in the plate heat exchanger but it was cut off since it was estimated to have a minor total contribution.

### 4.8.2 Transport to waste management (C2)

The dismounted product is transported to the waste facility for waste treatment. Details regarding the transport can be found in the table below.

Table 15: Transport to waste management site

| Road transport type | Road transport distance (km) | Comment |
|---|---|---|
| Road, truck, Euro 6, all sizes | 50 | A distance of 50 km is assumed to the closest waste management facility. |

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

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

C3 and C4 are modelled by adjusting the Simapro waste scenario "Municipal solid waste (waste scenario) {EU27}| Treatment of waste | Cut-off, U" (which builds on recycling rates of packaging). Recycling rates have been adjusted according to post-consumer non-packaging recycling rates (R2) used in the Circular footprint formula of PEF, as found in Annex C[5]. The remaining waste is assumed to be incinerated (99%) and landfilled (1%), according to the Swedish average scenario stated in PEF Annex C. Details on the waste scenario can be found in Appendix 4. Environmental burdens from sorting and pressing was cut off as they were estimated to be of low importance to the total life cycle impacts.

## 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 of materials and energy 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.

Here, the D-module has been divided into two parts, the first in section 4.9.1 related to the material-related benefits from recycling and incineration of the product's waste flows leaving the system boundary. The second part in section 4.9.2 relates to the benefits of the function of Enduce E1 to reduce the energy consumption from heating of water in showers.

### 4.9.1 Material-related benefits

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

[5] R2 values, available at https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

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

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[6], 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
- $E_{SEheat}$ = 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

The amount of materials that are not material recycled, are either sent to incineration or landfill. The share that goes to incineration is based on the Swedish average scenario described in PEF Annex C[7] - See parameter $Share_{INCout}$ in table below for each material's incineration rate, the rest is going to landfill.

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

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

Table 16 Modelling details for module D with a Swedish scenario

| Material | Amount in product and packaging (kg) | Parameters material recycling | Avoided process in material recycling in ecoinvent | Process for material recycling in ecoinvent | Parameters for energy recycling (for remaining materials after material recycling) | Avoided process for production of electricity in ecoinvent | Avoided process for production of heat |
|---|---|---|---|---|---|---|---|
| Steel | 28,1 | $Share_{MRin}$= 65,6%<br>$Share_{MRout}$= 85%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 1<br>Y=0,958 | Steel, low-alloyed {Europe without Switzerland and Austria}\| steel production, electric, low-alloyed \| Cut-off, U | Steel, low-alloyed {Europe without Switzerland and Austria}\| steel production, electric, low-alloyed \| Cut-off, U (adapted by removing material inputs) | No energy recycling of this material | - | - |
| Copper | 1,54 | $Share_{MRin}$= 0%<br>$Share_{MRout}$= 90%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 1<br>Y=0,576 | Copper, cathode {GLO}\| electrorefining of copper, anode \| Cut-off, U | Copper, cathode {RER}\| treatment of copper scrap by electrolytic refining \| Cut-off, U (adapted by removing material inputs) | No energy recycling of this material | - | - |
| Brass | 0,39 | $Share_{MRin}$= 0%<br>$Share_{MRout}$= 95%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 1<br>Y=0,99 | [1331] Brass CW724R, at manufacturer | Copper, cathode {RER}\| treatment of copper scrap by electrolytic refining \| Cut-off, U (adapted by removing material inputs) | No energy recycling of this material | - | - |
| Cardboard | 0,325 | $Share_{MRin}$= 0%<br>$Share_{MRout}$= 75%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 0,8<br>Y=0,85 | Containerboard, fluting medium {RER}\| containerboard production, fluting medium, semichemical \| Cut-off, U | Containerboard, fluting medium {RER}\| containerboard production, fluting medium, recycled \| Cut-off, U (adapted by removing material inputs) | $Share_{INCout}$ = 99%<br>LHV = 15,66 MJ/kg | Electricity, high voltage {SE}\| market for electricity, high voltage \| Cut-off, U | [MG] Heat, from district heating Sweden 2022, cut-off |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Plastic (non packaging) | 0,4 | $Share_{MRin}$= 0%<br>$Share_{MRout}$= 0%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 0,8<br>Y=0,895 | Polyethylene, high density, granulate {RER}\| polyethylene production, high density, granulate \| Cut-off, U | Polyethylene, high density, granulate, recycled {Europe without Switzerland}\| polyethylene production, high density, granulate, recycled \| Cut-off, U | $Share_{INCout} = 99\%$<br>LHV = 31,00 MJ/kg | Electricity, high voltage {SE}\| market for electricity, high voltage \| Cut-off, U | [MG] Heat, from district heating Sweden 2022, cut-off |
| Wood | 0,58 | $Share_{MRin}$= 0%<br>$Share_{MRout}$= 0%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 0,8<br>Y=1 | No material recycling is assumed for this material | | $Share_{INCout} = 99\%$<br>LHV = 19,00 MJ/kg | Electricity, high voltage {SE}\| market for electricity, high voltage \| Cut-off, U | [MG] Heat, from district heating Sweden 2022, cut-off |
| Rubber | 0,62 | $Share_{MRin}$= 0%<br>$Share_{MRout}$= 0%<br>$Q_{Sub}$= 1<br>$Q_{Rout}$= 0,8<br>Y=1 | No material recycling is assumed for this material | | $Share_{INCout} = 99\%$<br>LHV = 32,06 MJ/kg | Electricity, high voltage {SE}\| market for electricity, high voltage \| Cut-off, U | [MG] Heat, from district heating Sweden 2022, cut-off |

The avoided process for production of heat was modelled to represent Swedish district heating, based on Swedish statistics (Energiföretagen, n.d.). The model is summarised below. Note that it includes infrastructure.

Table 17: [MG] Heat, from district heating Sweden 2022, cut-off. Model for Swedish district heating for use as replaced heating in module D. ("S" chosen instead of "U" in order to include infrastructure impacts)

| Fuel/input | Ecoinvent-process | Amount | Unit |
|---|---|---|---|
| Avfall• | Heat, for reuse in municipal waste incineration only {SE}\| market for heat, for reuse in municipal waste incineration only \| Cut-off, S | 0,212 | MJ |
| Rökgaskondensering• | Heat, for reuse in municipal waste incineration only {SE}\| market for heat, for reuse in municipal waste incineration only \| Cut-off, S | 0,106 | MJ |
| Återvunnen industriell restvärme• | Heat, for reuse in municipal waste incineration only {SE}\| market for heat, for reuse in municipal waste incineration only \| Cut-off, S | 0,083 | MJ |
| Returträflis• | Heat, for reuse in municipal waste incineration only {SE}\| market for heat, for reuse in municipal waste incineration only \| Cut-off, S | 0,077 | MJ |

| | | | |
|---|---|---|---|
| Värme från värmepumpar• | Heat, for reuse in municipal waste incineration only {SE}\| market for heat, for reuse in municipal waste incineration only \| Cut-off, S | 0,04 | MJ |
| Deponi- och rötgas samt avfallsgas från stålindustrin• | Heat, for reuse in municipal waste incineration only {SE}\| market for heat, for reuse in municipal waste incineration only \| Cut-off, S | 0,023 | MJ |
| Grot, sågspån, bark• | Heat, district or industrial, other than natural gas {SE}\| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 \| Cut-off, S | 0,251 | MJ |
| Stamvedsflis• | Heat, district or industrial, other than natural gas {SE}\| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 \| Cut-off, S | 0,067 | MJ |
| Förnybar el till elpannor mm• | Electricity, high voltage {SE}\| electricity production, wind, 1-3MW turbine, onshore \| Cut-off, S | 0,043 | MJ |
| Pellets, briketter, pulver• | Heat, central or small-scale, other than natural gas {RoW}\| heat production, wood pellet, at furnace 300kW, state-of-the-art 2014 \| Cut-off, S | 0,049 | MJ |
| Bioolja, Tallbeckolja• | Heat, district or industrial, other than natural gas {SE}\| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 \| Cut-off, S | 0,021 | MJ |
| Åkergrödor, främst Salix• | Heat, district or industrial, other than natural gas {RER}\| heat production, straw, at furnace 300kW \| Cut-off, S | 0,001 | MJ |
| Eldningsolja• | Heat, district or industrial, other than natural gas {SE}\| heat and power co-generation, oil \| Cut-off, S | 0,015 | MJ |
| Fossil el till elpannor, mm• | Electricity, high voltage {SE}\| electricity production, oil \| Cut-off, S | 0,001 | MJ |
| Naturgas• | Heat, district or industrial, other than natural gas {CH}\| refinery gas, burned in furnace \| Cut-off, S | 0,002 | MJ |
| Stenkol• | Heat, central or small-scale, other than natural gas {Europe without Switzerland}\| heat production, hard coal coke, stove 5-15kW \| Cut-off, S | 0,001 | MJ |
| Torv o Torvbriketter• | Heat, central or small-scale, other than natural gas {RoW}\| heat production, lignite briquette, at stove 5-15kW \| Cut-off, S | 0,0036 | MJ |
| El från kärnkraft till elpannor• | Electricity, high voltage {SE}\| electricity production, nuclear, boiling water reactor \| Cut-off, S | 0,0035 | MJ |

#### 4.9.2 Benefits from avoided energy use in showers

Once installed, Enduce E1 reduces the need for warm water heating. These benefits are represented by an avoided amount of an average Swedish heating mix according to Energimyndighetens statistics for energy for heating and hot water for 2002-2021 (Energimyndigheten, 2022). It is modelled in the following way (the numbers include heating of houses and apartment buildings):

- 0,91% oil: *Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, oil | Cut-off, U*
- 51,3% district heating: Modelled as in scenario S7, see section 4.9 (Table 17) for details
- 30,94% direct electricity: *Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S* ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
- 15,6% wood, wood chips, shavings and pellets: *Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U*
- 0,82% gas: *Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, U*
- 0,43% other: distributed evenly on the other heating sources by reducing the output of the process in SimaPro by 0,0043.

Note that an exception is made here to include infrastructure processes for the direct electricity use, since infrastructure is central to impacts of electricity production.

The amount of avoided warm water heating is calculated based on an average energy consumption in Swedish households of 1150 kWh per person and year (Energimyndigheten, 2009). Of these, an average of 60% is used for household showers (Energimyndigheten, 2009). An average household size among Enduce's customers is estimated to be 3 people (this estimate is based on the fact that the customer's economic savings increasing with more residents in the household and that an average Swedish family size is 3,5 people, or 2,5 people in a divorced family (Statistikmyndigheten, n.d.)). The net efficiency of Enduce E1 is 70% (Research Institutes of Sweden AB, 2022) and it's estimated lifetime is 30 years, meaning that 1150*0,6*3*0,7*30 = 43 470 kWh are avoided. For further details and scenarios for these parameters, see section 6.3.

# 5 Result of Life cycle impact assessment (LCIA)

The results and interpretation have been divided into parts relating to the product itself (production, transports, waste management etc.), and parts relating to the use of the product and potential environmental benefits thereof. In this section, the result from the different environmental impact assessment methods will be presented for the production and waste management of Enduce E1. Consequently, it excludes any potential benefits from reduced household energy consumption from bathing, which is presented separately in section 6.3.

The LCIA method follows the standard for Construction Products EN15804:2012+A2:2019 (CEN, 2019). EN15804:2012+A2:2019 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, the PCR for Construction Products requires reporting of climate impact (GWP-GHG) with the characterization factor for biogenic carbon dioxide set to zero. For further details on the LCIA method and impact categories, see Appendix 2 and Appendix 3.

First, the results from the method EF3.1 with adaptation to EN15804:2012+A2:2019, Midpoint and Endpoint are presented, second from the method GWP-GHG 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

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 18 shows the result per declared unit according to the LCIA method Environmental footprint 3.0 midpoint level. The potential benefits from reduced water heating during use is included in the D-module (see more details and scenarios in section 5.1.1 and section 6.3), as are benefits from recycling and energy recovery at the product's end of life. An uptake of ca 4,50 kg of biogenic CO2 has been manually added to A1 to balance the uptake and emission of biogenic CO2 over the entire life cycle.

Table 18: Environmental footprint midpoint results per declared unit.

| Impact category | Unit | A1-C4 | A1 | A2 | A3 | A1-A3 | A4 | A5 | B1 | B4 | C1 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GWP Fossil | kg $CO_2$ eq | 1,24E+02 | 1,07E+02 | 1,48E+00 | 2,30E-01 | 1,09E+02 | 2,48E+00 | 9,71E-03 | 0,00E+00 | 5,49E+00 | 0,00E+00 | 1,81E-01 | 6,26E+00 | 1,80E-03 | -1,07E+03 |
| GWP Biogenic | kg $CO_2$ eq | 1,84E+00 | 6,83E-02 | 4,18E-04 | 4,35E-03 | 7,31E-02 | 7,02E-04 | 9,72E-01 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 5,53E-05 | 7,93E-01 | 1,80E-02 | -2,08E+01 |
| GWP LULUC | kg $CO_2$ eq | 1,78E-01 | 1,66E-01 | 3,26E-05 | 4,24E-03 | 1,71E-01 | 5,43E-05 | 2,11E-06 | 0,00E+00 | 7,66E-03 | 0,00E+00 | 3,58E-06 | 3,09E-05 | 1,28E-07 | -4,80E+01 |
| GWP Total | kg $CO_2$ eq | 1,26E+02 | 1,08E+02 | 1,48E+00 | 2,39E-01 | 1,09E+02 | 2,48E+00 | 9,81E-01 | 0,00E+00 | 5,51E+00 | 0,00E+00 | 1,81E-01 | 7,05E+00 | 1,98E-02 | -1,14E+03 |
| ODP | kg CFC11 eq | 1,85E-06 | 1,66E-06 | 3,08E-08 | 7,75E-09 | 1,70E-06 | 5,17E-08 | 8,03E-10 | 0,00E+00 | 9,39E-08 | 0,00E+00 | 3,95E-09 | 7,06E-09 | 4,89E-12 | -4,84E-05 |
| AP | mol H+ eq | 1,19E+00 | 9,36E-01 | 9,01E-03 | 1,17E-03 | 9,46E-01 | 1,45E-02 | 2,08E-04 | 0,00E+00 | 2,26E-01 | 0,00E+00 | 2,28E-04 | 1,13E-03 | 3,87E-06 | -1,30E+01 |
| EP - Freshwater | kg P eq | 8,26E-03 | 7,21E-03 | 1,16E-06 | 1,79E-05 | 7,23E-03 | 1,94E-06 | 7,19E-08 | 0,00E+00 | 1,03E-03 | 0,00E+00 | 1,44E-07 | 1,16E-06 | 9,83E-08 | -8,13E-02 |
| EP - Marine | kg N eq | 1,36E-01 | 1,17E-01 | 2,27E-03 | 7,16E-04 | 1,20E-01 | 3,66E-03 | 9,92E-05 | 0,00E+00 | 1,21E-02 | 0,00E+00 | 5,60E-05 | 4,91E-04 | 2,82E-05 | -2,67E+00 |
| EP – Terrestrial | mol N eq | 1,57E+00 | 1,32E+00 | 2,46E-02 | 4,05E-03 | 1,35E+00 | 3,97E-02 | 1,11E-03 | 0,00E+00 | 1,67E-01 | 0,00E+00 | 5,44E-04 | 5,38E-03 | 1,42E-05 | -3,92E+01 |
| POCP | kg NMVOC eq | 5,23E-01 | 4,44E-01 | 8,48E-03 | 1,16E-03 | 4,54E-01 | 1,38E-02 | 2,98E-04 | 0,00E+00 | 5,37E-02 | 0,00E+00 | 4,28E-04 | 1,43E-03 | 9,47E-06 | -8,61E+00 |
| ADPE[8] | kg Sb eq | 1,38E-02 | 1,09E-02 | 4,60E-08 | 7,43E-08 | 1,09E-02 | 7,73E-08 | 1,07E-09 | 0,00E+00 | 2,89E-03 | 0,00E+00 | 6,29E-09 | 3,83E-08 | 1,85E-11 | -5,74E-02 |
| ADPF[8] | MJ | 1,63E+03 | 1,45E+03 | 1,97E+01 | 3,27E+00 | 1,47E+03 | 3,30E+01 | 1,14E-01 | 0,00E+00 | 1,21E+02 | 0,00E+00 | 2,43E+00 | 9,16E-01 | 4,55E-03 | -8,92E+04 |
| WDP[8] | m3 depriv. | 3,42E+01 | 2,92E+01 | 1,79E-02 | 1,27E-01 | 2,94E+01 | 3,00E-02 | 2,05E-03 | 0,00E+00 | 4,83E+00 | 0,00E+00 | 2,23E-03 | -1,83E-02 | 1,79E-05 | -1,14E+03 |
| PM | disease inc. | 9,24E-06 | 8,37E-06 | 8,58E-08 | 1,57E-08 | 8,48E-06 | 1,44E-07 | 1,81E-09 | 0,00E+00 | 5,96E-07 | 0,00E+00 | 1,16E-08 | 1,48E-08 | 7,08E-11 | -1,63E-04 |

[8] 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.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IR[9] | kBq U-235 eq | 8,61E+00 | 8,30E+00 | 2,99E-03 | 8,27E-03 | 8,31E+00 | 5,02E-03 | 8,14E-05 | 0,00E+00 | 2,96E-01 | 0,00E+00 | 3,87E-04 | 8,93E-04 | 1,69E-05 | -2,91E+03 |
| ETP – FW[8] | CTUe | 1,48E+03 | 1,15E+03 | 8,87E+00 | 2,00E+00 | 1,16E+03 | 1,48E+01 | 2,73E-01 | 0,00E+00 | 2,97E+02 | 0,00E+00 | 1,08E+00 | 9,11E+00 | 6,38E-02 | -1,18E+04 |
| HTP - C[8] | CTUh | 1,10E-06 | 1,06E-06 | 1,15E-10 | 2,17E-10 | 1,06E-06 | 1,91E-10 | 1,88E-10 | 0,00E+00 | 3,34E-08 | 0,00E+00 | 1,16E-11 | 4,89E-10 | 3,61E-11 | -2,23E-06 |
| HTP - NC[8] | CTUh | 1,09E-05 | 7,96E-06 | 9,97E-09 | 1,63E-09 | 7,97E-06 | 1,68E-08 | 4,71E-10 | 0,00E+00 | 2,88E-06 | 0,00E+00 | 1,36E-09 | 6,88E-09 | 2,48E-09 | -8,02E-05 |
| Land use, SQP[8] | Pt | 6,15E+02 | 5,25E+02 | 3,60E-02 | 1,93E+01 | 5,45E+02 | 6,03E-02 | 4,39E-03 | 0,00E+00 | 6,99E+01 | 0,00E+00 | 4,62E-03 | 4,99E-01 | 7,39E-03 | -1,36E+05 |
| GWP-GHG | kg CO2 eq | 1,26E+02 | 1,09E+02 | 1,48E+00 | 2,56E-01 | 1,11E+02 | 2,48E+00 | 1,16E-02 | 0,00E+00 | 5,53E+00 | 0,00E+00 | 1,81E-01 | 6,26E+00 | 1,65E-02 | -1,13E+03 |
| 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, GWP-GHG: Global Warming Potential – Greenhouse gases | | | | | | | | | | | | | | |
| 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 | | | | | | | | | | | | | | |

### 5.1.1 Benefits from avoided energy use in D module

The D-module includes benefits from avoided energy use for heating of water in showers. Table 19 presents these benefits in detail. The benefits are a factor of ca 2 - 340 times larger than the product impacts in modules A-C.

Table 19: Benefits per impact category from avoided energy use.

| Impact category | Unit | D module (benefits from reduced water heating) | D-module (other benefits) |
|---|---|---|---|
| GWP Fossil | kg CO2 eq | -2,66E+00 | -1,07E+03 |
| GWP Biogenic | kg CO2 eq | 2,37E-01 | -2,10E+01 |
| GWP LULUC | kg CO2 eq | -1,80E-02 | -4,80E+01 |
| GWP Total | kg CO2 eq | -2,44E+00 | -1,14E+03 |
| ODP | kg CFC11 eq | -3,25E-08 | -4,83E-05 |

[9] 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.

| | | | |
|---|---|---|---|
| AP | mol H+ eq | -2,23E-01 | -1,28E+01 |
| EP - Freshwater | kg P eq | -8,66E-04 | -8,04E-02 |
| EP - Marine | kg N eq | -1,04E-02 | -2,66E+00 |
| EP – Terrestrial | mol N eq | -1,53E-01 | -3,90E+01 |
| POCP | kg NMVOC eq | -4,36E-02 | -8,56E+00 |
| ADPE | kg Sb eq | -3,07E-03 | -5,43E-02 |
| ADPF | MJ | -5,18E+01 | -8,92E+04 |
| WDP | m3 depriv. | -3,62E+00 | -1,14E+03 |
| PM | disease inc. | -6,71E-07 | -1,62E-04 |
| IR | kBq U-235 eq | -8,69E-01 | -2,91E+03 |
| ETP – FW | CTUe | -2,65E+02 | -1,15E+04 |
| HTP - C | CTUh | -4,27E-08 | -2,19E-06 |
| HTP - NC | CTUh | -3,01E-06 | -7,71E-05 |
| Land use, SQP | Pt | -1,04E+02 | -1,35E+05 |
| GWP-GHG | kg CO2 eq | -2,67E+00 | -1,13E+03 |

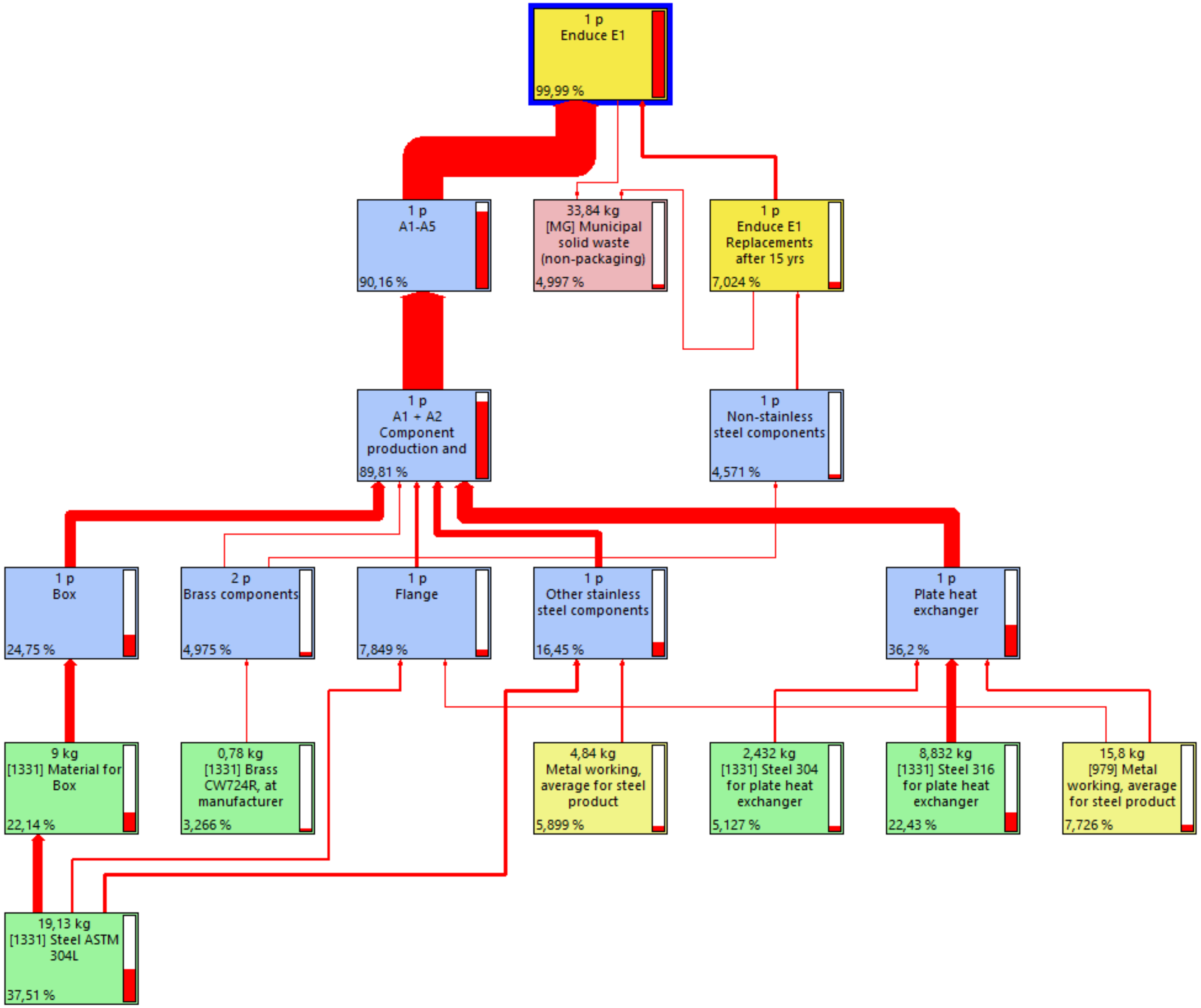

Figure 9: Sankey diagram over Environmental footprint climate impact (GWP-GHG) per declared unit, the figure is hiding all contributions below 3%. Note that these results excludes any potential benefits from reduced water heating during use.

## 5.2 Environmental Footprint Endpoint

The environmental footprint endpoint shows the contribution of each environmental impact category to the total environmental impact. Note that these results exclude any potential benefits from reduced water heating during use (see section 6.3 for details and scenarios). See Table 20 for weighting and normalization factors for each impact category, used to calculate the single score. According to the (value based) weighting method applied (EF 3.1), resource use (minerals and metals) and climate change are the largest contributors to the total environmental impact of Enduce E1.

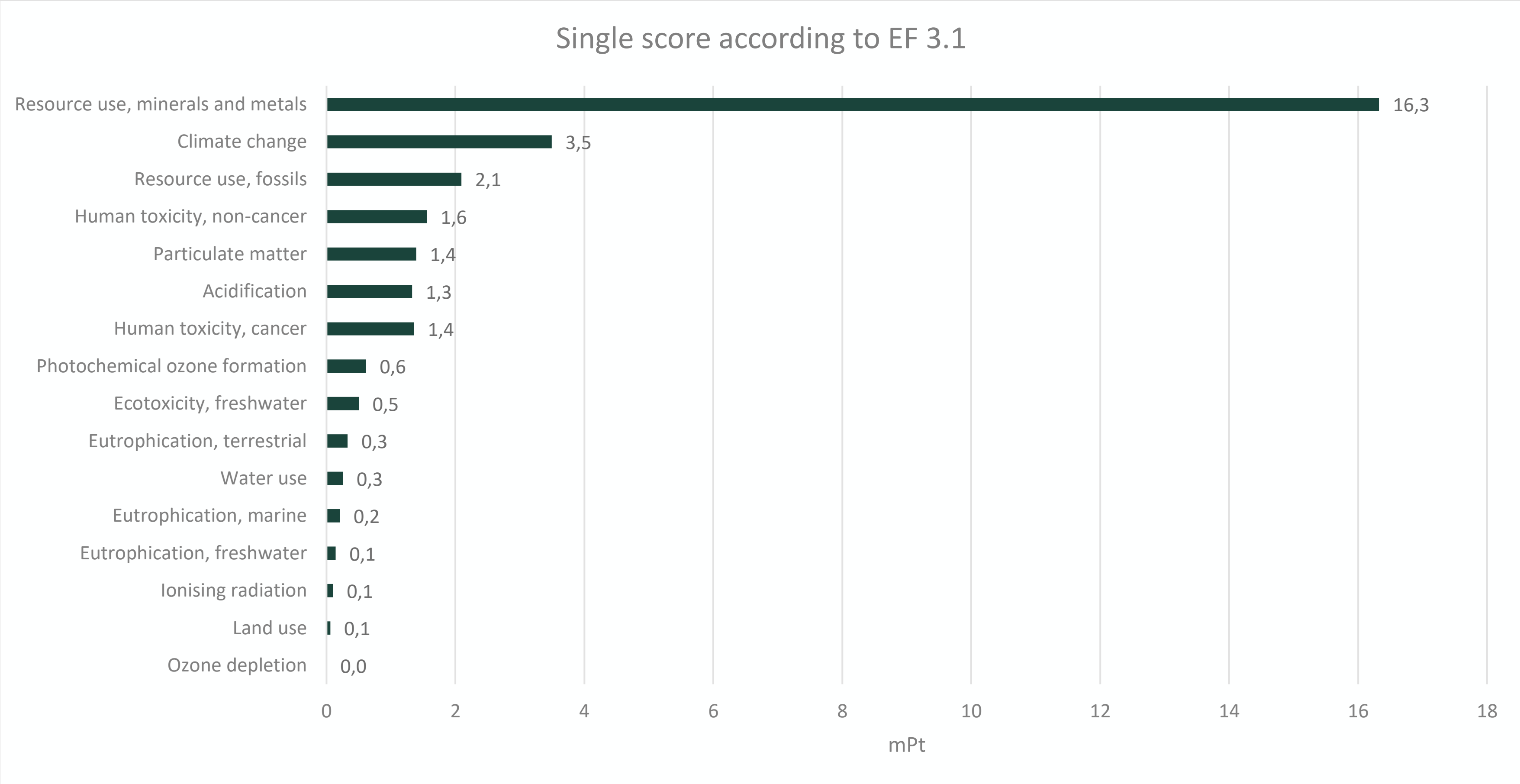


Figure 10: Share of environmental impact per impact category. Note that these results exclude any potential benefits from reduced water heating during use.

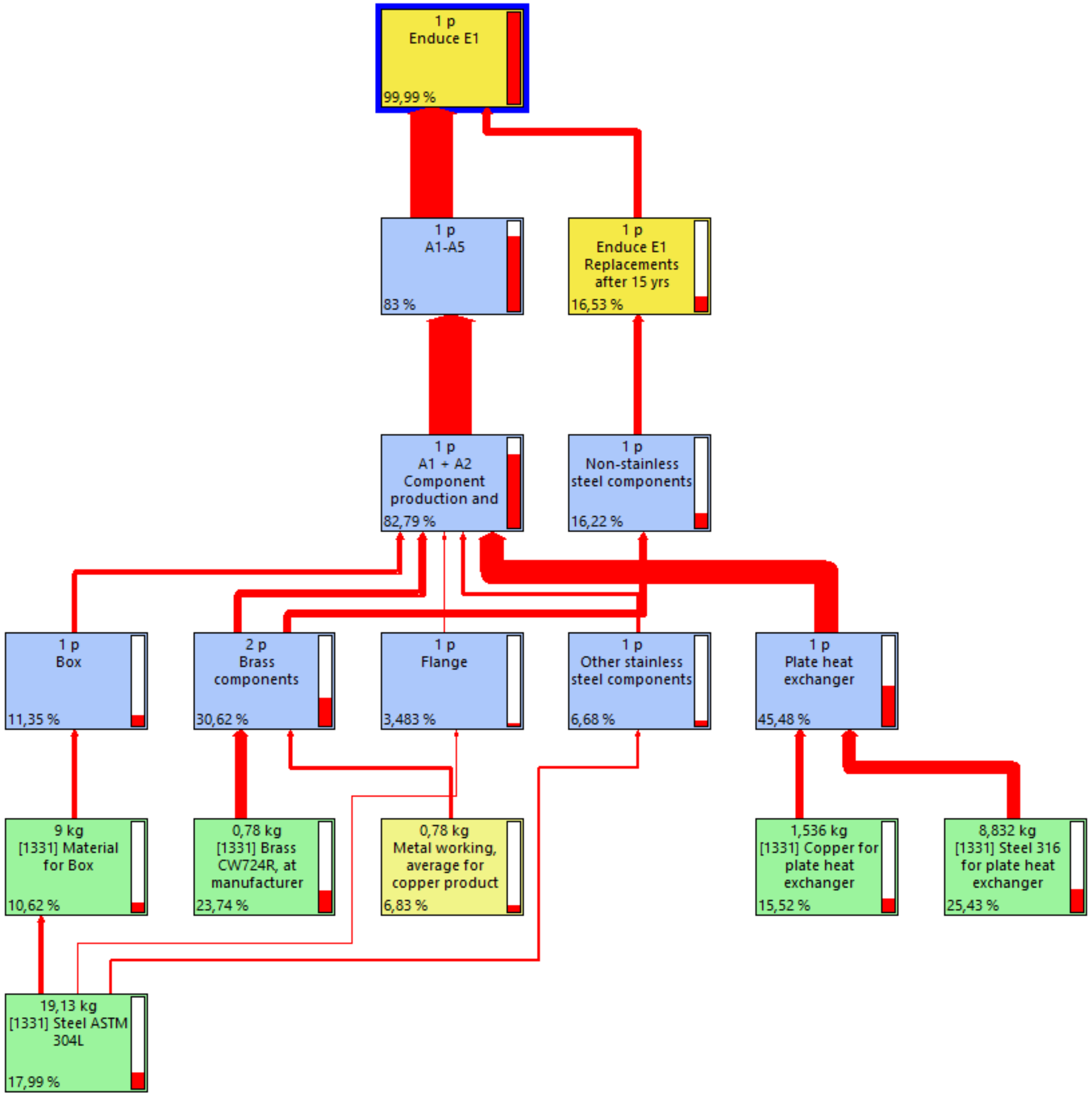

Figure 11: Sankey diagram over share of environmental impact contributions per module and per declared unit, the figure is hiding all contributions below 3%. Note that these results excludes any potential benefits from reduced water heating during use.

Table 20: Normalization and weighting factors used for calculating the single score according to EF 3.1. The mid-point impacts in Table 18 are multiplied by the normalization- and weighting factor to produce the single score.

| EF 3.1 | Normalization | Weighting |
|---|---|---|
| Acidification | 1,80E-02 | 0,062 |
| Climate change | 1,32E-04 | 0,2106 |
| Ecotoxicity, freshwater | 1,76E-05 | 0,0192 |
| Particulate matter | 1,68E+03 | 0,0896 |
| Eutrophication, marine | 5,12E-02 | 0,0296 |
| Eutrophication, freshwater | 6,22E-01 | 0,028 |
| Eutrophication, terrestrial | 5,66E-03 | 0,0371 |
| Human toxicity, cancer | 5,80E+04 | 0,0213 |
| Human toxicity, non-cancer | 7,77E+03 | 0,0184 |
| Ionising radiation | 2,37E-04 | 0,0501 |
| Land use | 1,22E-06 | 0,0794 |
| Ozone depletion | 1,91E+01 | 0,0631 |
| Photochemical ozone formation | 2,45E-02 | 0,0478 |
| Resource use, fossils | 1,54E-05 | 0,0832 |
| Resource use, minerals and metals | 1,57E+01 | 0,0755 |
| Water use | 8,72E-05 | 0,0851 |

## 5.3 Climate impact – GWP-GHG

The climate impact according to the GWP-GHG indicator (PCR 2019:14) is 126 kg CO2-eq. and the figure below shows the contribution to the total climate impact over the life cycle of the product. Note that these results excludes any potential benefits from reduced water heating during use, see section 6.3.

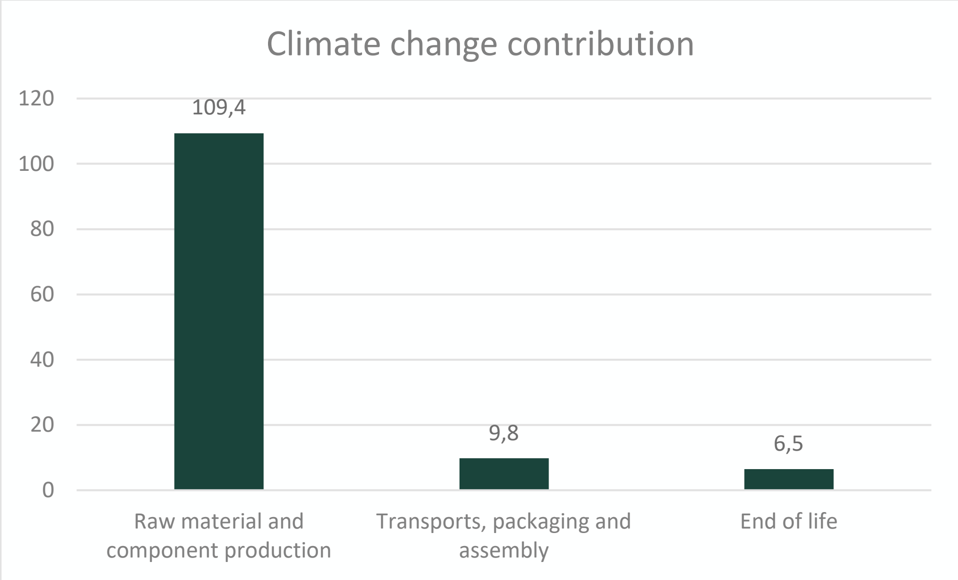


Figure 12: Climate impact per declared unit according to GWP-GHG (PCR 2019:14). Note that these results excludes any potential benefits from reduced water heating during use.

## 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 3). Note that these results excludes any potential benefits from reduced water heating during use (except the exported energy which is included under module D, split into renewable and non-renewable energy according to the heating scenario described in section 4.9.2)

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

| Para-meter | Unit | Tot A1-C4 | A1 | A2 | A3 | A1-A3 | A4 | A5 | B1 | B4 | C1 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PERE | MJ | **3,39E+02** | 3,21E+02 | 4,90E-02 | 3,93E+00 | **3,25E+02** | 8,22E-02 | 2,45E-03 | 0,00E+00 | 1,40E+01 | 0,00E+00 | 6,40E-03 | 3,30E-02 | 6,55E-04 | -8,58E+04 |
| PERM | MJ | **0,00E+00** | 0,00E+00 | 0,00E+00 | 1,61E+01 | **1,61E+01** | 0,00E+00 | -1,61E+01 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 |
| PERT | MJ | **3,39E+02** | 3,21E+02 | 4,90E-02 | 2,00E+01 | **3,41E+02** | 8,22E-02 | -1,61E+01 | 0,00E+00 | 1,40E+01 | 0,00E+00 | 6,40E-03 | 3,30E-02 | 6,55E-04 | -8,58E+04 |
| PENRE | MJ | **1,70E+03** | 1,51E+03 | 2,10E+01 | 3,53E+00 | **1,53E+03** | 3,51E+01 | 1,22E-01 | 0,00E+00 | 1,29E+02 | 0,00E+00 | 2,59E+00 | 9,89E-01 | 4,81E-03 | -7,09E+04 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PENRM | MJ | **0,00E+00** | 3,23E+01 | 0,00E+00 | 0,00E+00 | **3,23E+01** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | -3,23E+01 | 0,00E+00 | 0,00E+00 |
| PENRT | MJ | **1,70E+03** | 1,54E+03 | 2,10E+01 | 3,53E+00 | **1,56E+03** | 3,51E+01 | 1,22E-01 | 0,00E+00 | 1,29E+02 | 0,00E+00 | 2,59E+00 | -3,13E+01 | 4,81E-03 | -7,09E+04 |
| SM | kg | **1,97E+01** | 1,97E+01 | 0,00E+00 | 0,00E+00 | **1,97E+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 |
| 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 |
| 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 |
| FW | m3 | **1,24E+00** | 1,11E+00 | 1,73E-03 | 8,57E-03 | **1,12E+00** | 1,62E-03 | 2,87E-03 | 0,00E+00 | 1,03E-01 | 0,00E+00 | 1,28E-04 | 7,56E-03 | 5,86E-07 | -1,26E-01 |
| Abbrevi-ations | PERE = use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total Use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total Use of non-renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels; FW = use of net fresh water | | | | | | | | | | | | | | |

## 5.5 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[10]. 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. This means that no waste (hazardous, non-hazardous or radioactive) is actually leaving the system boundaries and they are thus declared as zero.

Table 22: Output flows for module A-C, per declared unit

| Indicator | Unit | A1 | A2 | A3 | Tot.A1-A3 | A4 | A5 | B1 | B4 | C | C2 | C3 | C4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Components for reuse | kg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Material for recycling | kg | 4,89 | 0 | 0 | 4,89 | 0 | 0 | 0 | 0 | 0 | 0 | 25,6 | 0 |
| Materials for energy recovery | kg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Exported energy, electricity | MJ | 0 | 0 | 0 | 0 | 0 | 2,95 | 0 | 0 | 0 | 0 | 7,75 | 0 |

[10] EPD (2018) EN15804 v3

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Exported energy, thermal | MJ | 0 | 0 | 0 | 0 | 0 | 6,88 | 156492 | 0 | 0 | 0 | 18,1 | 0 |

## 5.6 Biogenic carbon content

Equation 1 Biogenic carbon content according to EN 16449 (chapter 4)

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

Standard Values:
Moisture: 12% for wood standard, 10% for cardboard
Biogenic Carbon fraction: 0,5 for wood (0,45 softwood and 0,55 hardwood). 50% for cardboard.

Table 23: 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 | 0,0 |
| Biogenic carbon in the packaging | kg C | 0,4 |

# 6 Interpretation

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

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

## 6.1 Key aspects of results

Weighting of all impact categories into a single score indicates that the most important type of impact is resource use of minerals and metals (55% of total single score), followed by climate change (12% of total single score). Mineral and metal resource use is mainly caused by the extraction of alloying elements for stainless steel, chiefly molybdenum, nickel and chromium, as well as the extraction of copper for the plate heat exchanger. Climate change is mainly caused by electricity use and heating during the mining, beneficiation and refining of ferronickel (which causes a total of 32% of all climate impacts) as well as the use of electricity and coke during the reduction of chromite into ferrochromium (which causes a total of 13% of all climate impacts).

It follows that the dominant phase of the lifecycle is the production of components and materials, particularly the plate heat exchanger (ca 36% of total climate impact and 45% of total single score) and the stainless steel box (ca 22% of total climate impact and 11% of total single score).

## 6.2 Sensitivity and scenario analysis

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

Furthermore, LCA provides the means to test different scenarios in order to indicate possible pathways towards reducing environmental impacts. Figure 13 shows the effects of changing certain parameters in the model, compared to the baseline results (presented in section 5):

- Increased share of post-consumer recycled stainless steel input
  - Changing from 65,6% recycled to 90% reduced total climate impact to ca 79 kg CO2-eq.
  - Conversely, changing to 40% recycled increases total climate impact to ca 174 kg CO2-eq.
- Green energy in ferronickel production
  - Changing to 100% hydropower and biomethane in all ferronickel production reduced its climate impact from 8,2 kg CO2-eq./kg to 1,86 kg CO2-eq./kg, which in turn reduced the total impacts to ca 94 kg CO2-eq.
- Green electricity in ferrochromium production
  - Changing to 100% hydropower in all ferrochromium production reduced its climate impact from 4,91 kg CO2-eq./kg to 2,15 kg CO2-eq./kg, which in turn reduced the total impacts to ca 116 kg CO2-eq.
- Eliminate production waste for steel box
  - Changing from 25,5% to 0% production waste for steel box production in Ukmerge, Lithuania reduced the total impacts to ca 120 kg CO2-eq.
- Change to polypropylene box
  - Changing from 9 kg stainless steel box to 4 kg polypropylene (PP) box reduced the total impacts to ca 105 kg CO2-eq.

- Scenario considers change in material, processing, transportation and waste management, but not whether the box has to be replaced before the 30 year lifetime of Enduce E1

These scenarios show that there is a large potential for mitigating the impacts from the production of Enduce E1. The ferronickel and ferrochromium production are several steps upstream from Enduce and consequently may be difficult to influence. In contrast, the recycled content and the production waste in Ukmerge, Lithuania, may be possible for Enduce to affect due to the direct contact between the organisations. In particular, the share of post-consumer recycled content is a crucial parameter, since it has the potential to either reduce or increase climate impacts significantly. Note also that the scenario with reduced waste only shows the effects of reducing production waste for one component. This means that there is a large improvement potential from reducing production waste for more components, e.g. by closed-loop recirculation of the production waste or by using inputs sourced from post-consumer recycling.

Lastly, the scenario with a PP box rather than a stainless steel box shows that there is a large potential in substituting impacting materials where possible without affect the efficiency or durability of the product. Using recycled PP could reduce total impacts further.

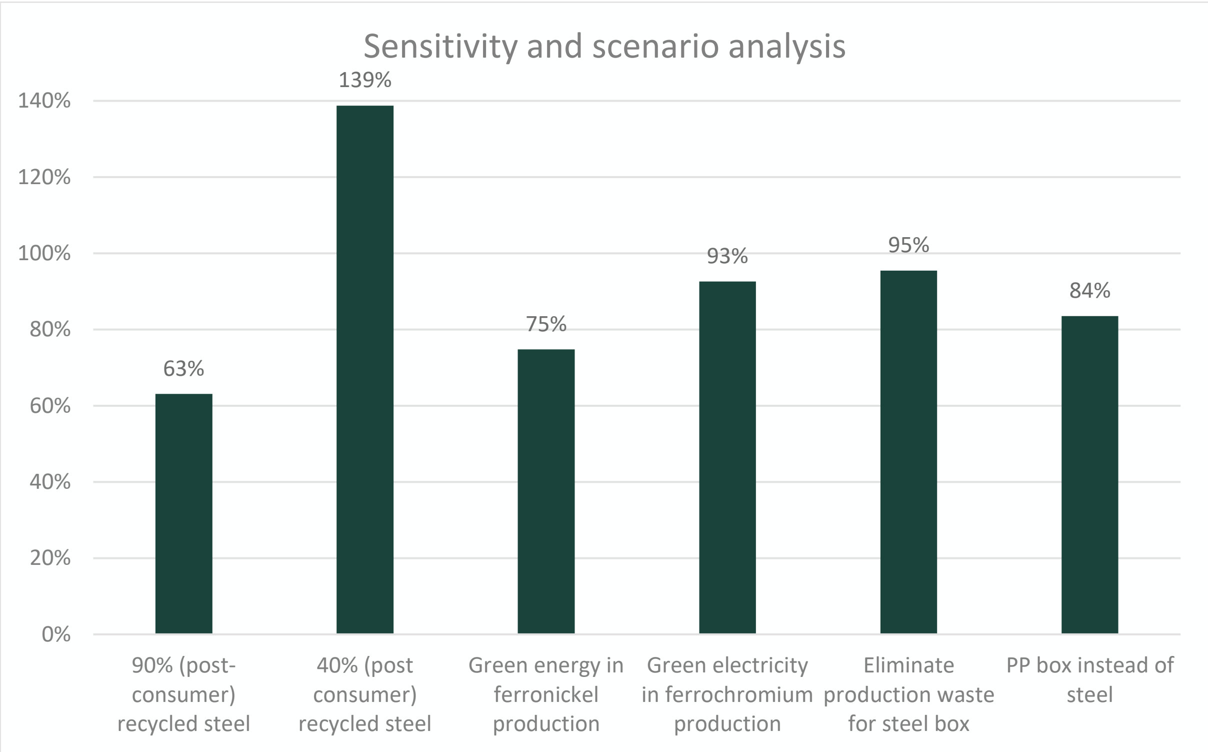


Figure 13: Sensitivity and scenario analysis. The baseline, i.e. the product as described in section 5, makes out 100%.

The scenario results are summarised in Table 24.

Table 24: Summary of sensitivity and scenario analysis

| | Result [kg CO2-eq.] | Result [% compared to baseline] | Comment |
|---|---|---|---|
| Baseline | 125,6 | 100% | |
| 90% (post-consumer) recycled steel | 79,2 | 63% | Changed to 90% post-consumer recycled steel |
| 40% (post consumer) recycled steel | 174,3 | 139% | Changed to 40% post-consumer recycled steel |

| | | | |
|---|---|---|---|
| Green energy in ferronickel production | 93,9 | 75% | Calculated according to a reduction of ferronickel production impacts from 8,2 kg CO2-eq./kg to 1,86 kg CO2-eq./kg due to changing to 100% hydropower and biomethane |
| Green electricity in ferrochromium production | 116,3 | 93% | Calculated according to a reduction of ferrochromium production impacts from 4,91 kg CO2-eq./kg to 2,153 kg CO2-eq./kg due to changing to 100% hydropower |
| Eliminate production waste for steel box | 120,0 | 95% | Changed from 25,5% to 0% production waste for steel box production in Ukmerge |
| PP box instead of steel | 104,9 | 84% | Changed from 9 kg steel box to 4 kg PP box |

## 6.3 Benefits from reduced household energy consumption

The results and interpretation thus far have focused on the production impacts of Enduce. However, the function of Enduce E1 is to reduce the energy consumption from heating of water in showers. The benefits of this avoided energy consumption will be analysed here and compared to the life cycle environmental impact of the product. Note that the energy systems modelled here are modelled as System-processes instead of Unit-processes, in order to include infrastructure.

### 6.3.1 Parameters deciding Enduce E1's environmental benefits

The potential benefits depend on a number of parameters, summarised here and described below.

- Energy consumption for warm water use per person, EC
- Share of warm water energy used for showers, SH
- Household size, H
- Net efficiency of Enduce E1, NE
- Heat losses in shower, L
- Energy system used for heating, ES

According to a study measuring the energy consumption in 44 Swedish households (Energimyndigheten, 2009), the average energy consumption for warm water use in apartment buildings, EC, is 1150 kWh per person.

Of the 1150 kWh, between 25% and 80% is used for household showers (Energimyndigheten, 2009). Looking at the data for the last 10 years, the average is SH=60%, meaning that the average yearly energy consumption for a Swedish person is 690 kWh. Assuming that an average household is 2-4 people, the total yearly energy consumption for warm water use would be 2070 kWh for a household of H=3 people.

Enduce E1 can mitigate a maximum of 73% of the warm water energy use in the shower. However, there are losses of heat from when the warm water exits the shower head until it enters the shower well. Taking these losses into account, the net efficiency of Enduce E1 is NE=70% (in showers without walls/curtains, there are large losses and the efficiency can go down to ca NE=50%).

Baseline parameters are defined as EC = 1150 kWh, SH = 60%, H = 3 people and NE = 70%, as described in section 4.9.2, which result in an avoided amount of heat energy of 43 470 kWh.

Lastly, the savings in environmental impact depends on the energy system used for heating, where higher savings can be achieved in a system using fossil fuels such as oil or natural gas for heating. Conversely, the energy saving results in a lower benefit in systems being heated by renewable energy. The energy system parameter is here defined as ES, examples include district heating, heat pumps, direct electricity and heating by burning fuel such as natural gas.

### 6.3.2 Scenarios

We can define scenarios spanning the variations in the parameters described above. The scenarios used are described in Table 25 and the parameter values are chosen so that S1 is the least conservative (giving the highest benefits) and S8 is the most conservative (giving the lowest benefits). Scenarios S2-S7 use baseline parameter values (estimated to be most likely in a Swedish setting), while S1 and S8 represent extreme scenarios (maximising or minimising each parameter). In each scenario, Enduce E1 is used for 30 years. S1 and S6 are also explored with five people per household instead of the default of three.

Table 25: Scenario definition

| | EC (energy consumption) | SH (share of bath energy) | H (ppl / household) | NE (net efficiency) | ES (energy system) |
|---|---|---|---|---|---|
| S1 – Extreme scenario - Heating with natural gas in Germany | 1150 | 80% | 3 | 73% | Natural gas |
| S2 – Heating with natural gas in Germany | 1150 | 60% | 3 | 70% | Natural gas |
| S3 – Heating with heat pump using Swedish electricity mix | 1150 | 60% | 3 | 70% | Heat pump |
| S4 – Heating with direct electricity using Swedish electricity mix | 1150 | 60% | 3 | 70% | Direct electricity |
| S5 – Heating with Swedish district heating (Hässleholm) | 1150 | 60% | 3 | 70% | District heating |
| S6 – Heating with average mix of Swedish heating sources | 1150 | 60% | 3 | 70% | Average SE mix |
| S7 – Heating with Swedish district heating (average) | 1150 | 60% | 3 | 70% | District heating |
| S8 – Extreme scenario - Heating with Swedish district heating (average) | 1150 | 25% | 2 | 50% | District heating |
| S1 – 5 - Extreme scenario - Heating with natural gas in Germany and 5 ppl / household | 1150 | 80% | 5 | 73% | Natural gas |
| S6 – 5 - Heating with average mix of Swedish heating sources and 5 ppl / household | 1150 | 60% | 5 | 70% | Average SE mix |

The energy systems are modelled in the following way:

- Natural gas in Germany was represented with the ecoinvent process "Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, S" (average for Europe) ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
- Swedish direct electricity was simply represented with the process "Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S" ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
- Swedish heat pumps are represented with the ecoinvent process "Heat, air-water heat pump 10kW {Europe without Switzerland}| heat production, air-water heat pump 10kW | Cut-off, S" ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
    - The electricity source in the process was changed to "Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S" ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
    - The coefficient of performance (COP) for warm water heating was adjusted to account for the frequent use of direct electricity required for tap water heating during the transient high power demand of showering - when heat pumps cannot deliver enough power to fulfil the warm water requirements. The COP was reduced

from 2,8 (the default in the ecoinvent heat pump process) to 2, according to (Benson, 2012). This was done by changing the amount of electricity input to 0,13889 kWh per MJ

- Swedish district heating is represented in two ways, to illustrate the potential variation in climate impact
    - In S5: district heating is represented by an EPD of Hässleholm (S-P-05636), with a carbon footprint of 0,0355 kg CO2-eq/kWh
    - In S7: district heating is represented by the model of average Swedish district heating, presented in section 4.9 (Table 17), with a carbon footprint of 0,0135 kg CO2-eq/kWh.
- Average Swedish heating is represented by Energimyndighetens statistics for energy for heating and hot water for 2002-2021 (Energimyndigheten, 2022). It is modelled in the following way (the numbers include heating of houses and apartment buildings):
    - 0,91% oil: Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, oil | Cut-off, S ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
    - 51,3% district heating: Modelled as in scenario S7, see section 4.9 (Table 17) for details
    - 30,94% direct electricity: Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
    - 15,6% wood, wood chips, shavings and pellets: Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, S ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
    - 0,82% gas: Heat, central or small-scale, natural gas {RER}| market group for heat, central or small-scale, natural gas | Cut-off, S ("S" chosen instead of "U" in order to include infrastructure impacts in this case)
    - 0,43% other: distributed evenly on the other heating sources by reducing the output of the process in SimaPro by 0,0043.

### 6.3.3 Net climate benefits per scenario

The potential climate benefits should be weighed against the life cycle climate impacts of producing Enduce E1. In each of the eight scenarios, Figure 14 shows the potential climate benefits from reduced energy consumption due to the avoided need for heating warm water. Using baseline parameters (scenarios S2-S7), the net benefits range from ca 0,5 ton – 11,5 ton CO2-eq. over 30 years.

Considering the extremes in scenario S1 and S8, under the highly favourable conditions in scenario S1 the net benefits can be ca 16 tons CO2-eq. over 30 years. Conversely, under the highly unfavourable conditions in scenario S8, the product does not even reach climate break-even (note, however, that there are other environmental benefits than purely climate, see section 6.3.4). The (net) benefits are summarised in Table 26.

Table 26: Summary of production impacts, benefits and net benefits (i.e. subtracting production impacts) in each scenario

| Climate savings (kg CO2-eq. according to GWP-GHG) | Production impacts | Benefits | Net benefits |
|---|---|---|---|
| S1 (73% energy saving, 80% share of bath energy, 3 ppl/household, natural gas in DE) | 126 | -16158 | -16032 |
| S2 (baseline parameters, natural gas in DE) | 126 | -11620 | -11495 |

| | | | |
|---|---|---|---|
| S3 (baseline parameters, heat pump w/ SE electricity mix) | 126 | -1933 | -1807 |
| S4 (baseline parameters, direct heating w/ SE electricity mix) | 126 | -1930 | -1804 |
| S5 (baseline parameters, Hässleholm district heating) | 126 | -1543 | -1418 |
| S6 (baseline parameters, avg SE heating) | 126 | -1129 | -1004 |
| S7 (baseline parameters, SE district heating) | 126 | -588 | -462 |
| S8 (50% energy saving, 25% share of bath energy, 2 ppl/household, SE district heating) | 126 | -117 | 9 |

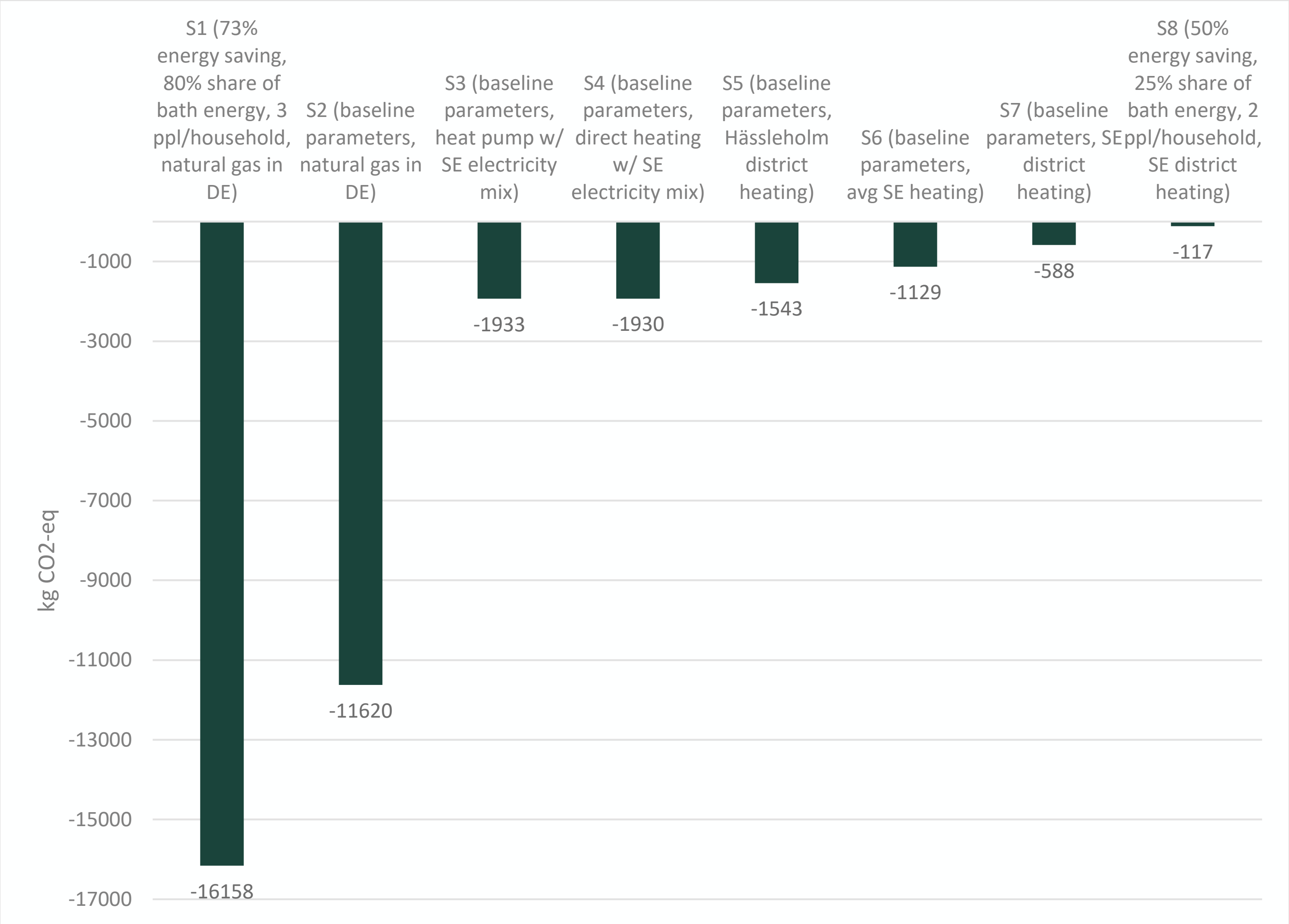


Figure 14: Potential climate benefits of avoided energy consumption (kg CO2-eq. according to GWP-GHG). Note that S7 (Swedish district heating) is built on a model where no environmental burden is assigned to the combustion of waste (that burden is instead assigned to the waste generator upstream) which gives a low environmental footprint for waste incineration.

In order to show the potential climate benefits for larger household, two additional scenarios were calculated, namely S1 and S6 above but with five people per household. This shows increased benefits to 1,6 ton CO2-eq. in the Swedish average heating case and 26,7 ton CO2-eq. in the case with natural gas used in Germany.

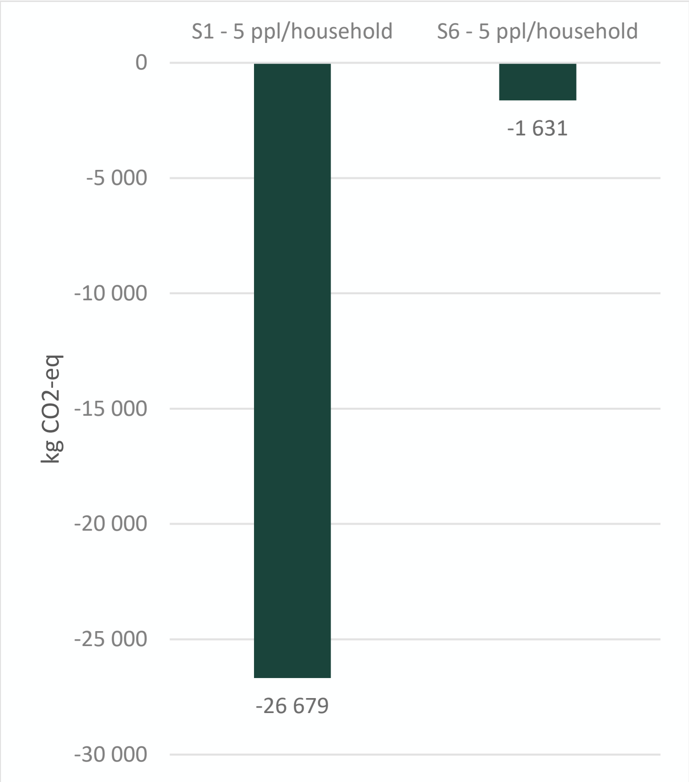


Figure 15: Potential climate benefits of avoided energy consumption (kg CO2-eq. according to GWP-GHG). These scenarios are copies of S1 and S6 above, but with five people per household

### 6.3.4 Total environmental benefits

Climate impact is only one of many impact categories. All impact categories can be analysed at once by using the weighted single score when calculating the potential benefits. Figure 16 compares the total single score from producing Enduce E1 to the potential benefits in scenarios S2, S3, S4, S6 and S6-5 (which is S6 but with 5 people per household). For simplicity and clarity, all other scenarios have been excluded[11].

The figure shows significant benefits compared to production impacts. In S2, the benefits are largely from avoided climate impact and fossil resource use. This is true also for S3, S4 and S6, but mineral and metal resource use contributed there as well.

Note that while the climate benefit in scenario S4 (direct electricity) is lower than in scenario S3 (heat pump), see section 6.3.3, the single score benefits are significantly higher when avoiding direct electric heating than avoiding heating by heat pump. This is mainly due to large reductions in the extraction of fossil, metal and mineral resources. Lastly, while the lowest benefits can be found in S7, they still outweigh the production impacts by a factor of more than 3 and the benefits are largely from avoided land use and particulate matter emissions.

[11] The extreme scenarios, S1 and S7, have been excluded. Additionally, scenario S5 is based on an EPD that does not cover all of the impact categories of the EF3.1 method used here, which would give an incomplete comparison.

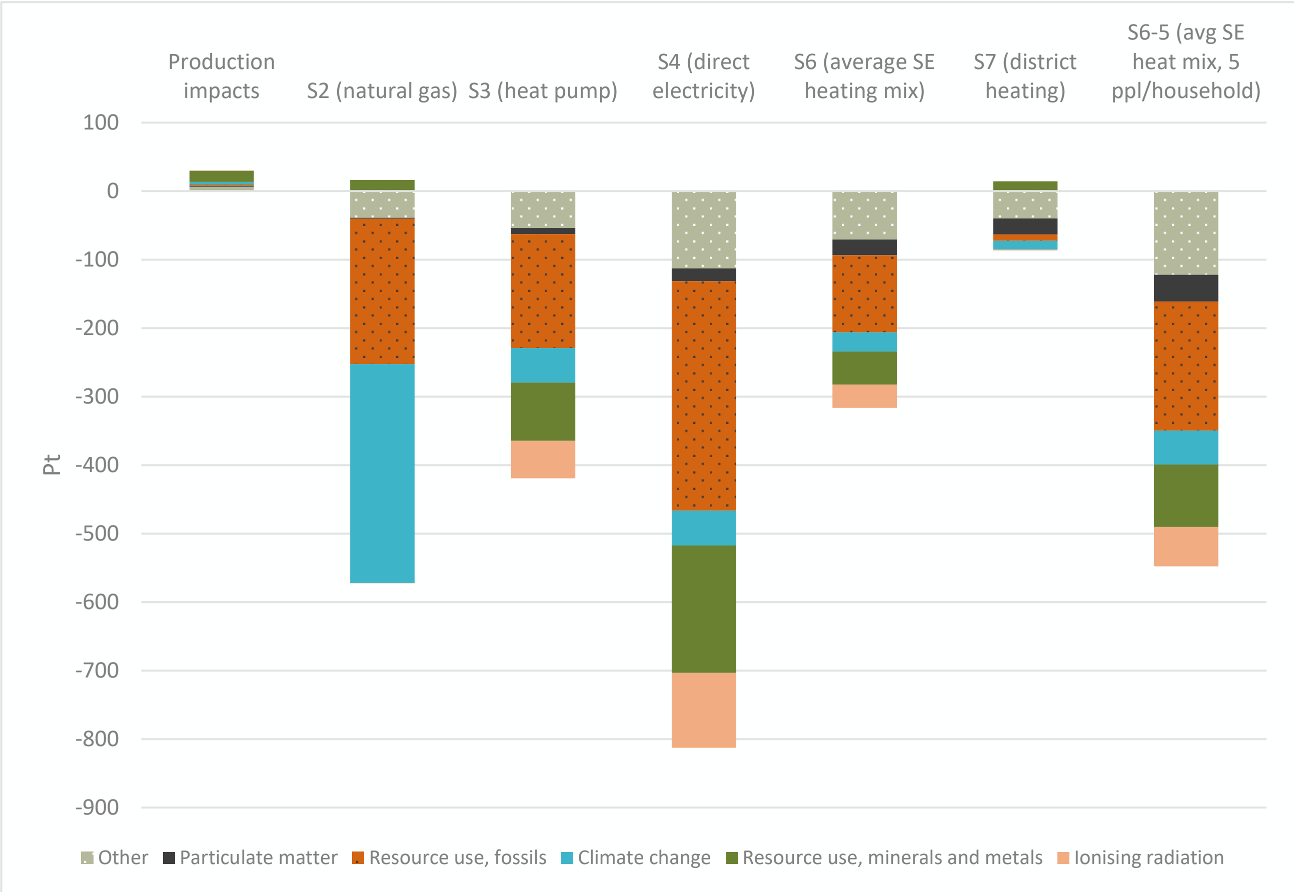


Figure 16: Single score of production impacts and net potential environmental benefits from avoided energy use in scenarios S2 (natural gas in Germany), S3 (Swedish electricity mix for heat pump), S4 (direct electricity heating with Swedish electricity mix), S6 (average Swedish heating mix), S7 (Swedish district heating) and S6-5 (scenario S6 but with 5 people per household instead of 3), expressed in single score per impact category (EF3.1, for weighting factors, see Table 20 in section 5.2). For clarity, Resource use (fossils) and Other has a dotted pattern. Note that S7 (Swedish district heating) is built on a model where no environmental burden is assigned to the combustion of waste (that burden is instead assigned to the waste generator upstream) which gives a low environmental footprint for waste incineration.

To show further details for benefits specifically from avoided heating with district heating, we compare scenario S6 to the baseline production impacts by considering the contributions for each impact category in Figure 17. Again, there are significant savings in climate change, land use and all other impact categories, except for two where there are actually net environmental impacts, namely mineral and metal resource use and human toxicity (cancer). Of these, only the mineral and metal resource use is significant. Consequently, installing an Enduce E1 in a shower heated by district heating can be said to reduce overall total environmental impact at the cost of extracting minerals and metals.

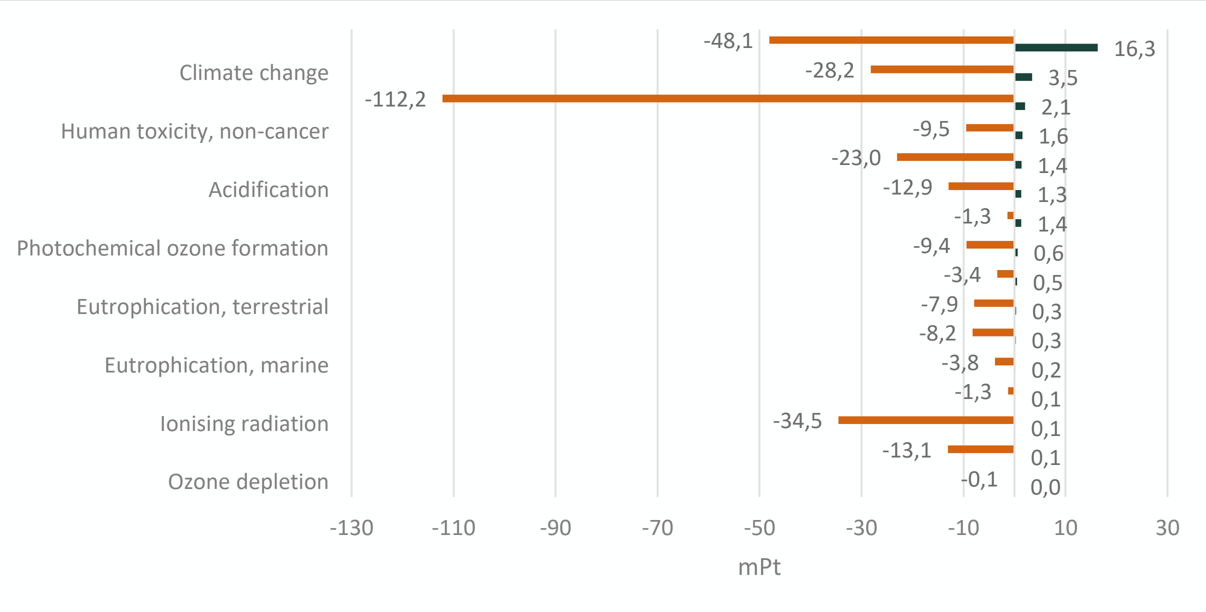


Figure 17: To the right are production impacts and to the left potential benefits from avoided energy use in scenario S6 (Swedish average heating mix), expressed in single score per impact category (EF3.1)

### 6.3.5 Break-even analysis

To illustrate the potential environmental benefit in relation to the life cycle impacts of Enduce E1, a break-even analysis was done, showing how many years the product needs to be used in each scenario to reach climate- or environmental break even.

Table 27: Break-even analysis showing the number of years that Enduce E1 needs to be used in order to reach climate break-even and total single score break-even, respectively. Note that no single score break-even was calculated for scenarios S1, S5 and S8 because the single score could not be calculated for various reasons.

| | Years to climate break even | Years to single score break-even |
|---|---|---|
| **S1 (73% energy saving, 80% share of bath energy, 3 ppl/household, natural gas in DE)** | 0,2 | - |
| **S2 (baseline parameters, natural gas in DE)** | 0,3 | 1,5 |
| **S3 (baseline parameters, heat pump w/ SE electricity mix)** | 1,9 | 2,0 |
| **S4 (baseline parameters, direct heating w/ SE electricity mix)** | 2,0 | 1,1 |
| **S5 (baseline parameters, Hässleholm district heating)** | 2,4 | - |
| **S6 (baseline parameters, avg SE heating)** | 3,3 | 2,6 |
| **S7 (baseline parameters, SE district heating)** | 6,4 | 8,8 |
| **S8 (50% energy saving, 25% share of bath energy, 2 ppl/household, SE district heating)** | 32,3 | - |
| **S1-5 (S1 with 5 ppl/household)** | 0,1 | - |
| **S6-5 (S6 with 5 ppl/household)** | 2,1 | 1,5 |

### 6.3.6 Take-aways

The most significant parameter is the energy system, meaning that the benefits of Enduce E1 are the largest in applications and markets where fossil-based energy is replaced, such as natural gas in

Europe. Furthermore, the larger the energy use for showering in a household, the larger the potential benefits of Enduce E1. This means that considerably larger benefits may be found in applications using more warm water, such as gyms, bath houses or large households (although this has to be weighed against the net efficiency of Enduce E1 which is reduced in showers with large losses, such as in gyms and baths where showers may not have walls/curtains).

The results also show that climate benefits are not the only aspect to consider and that there can be significant benefits (or burden shifting) to other impact categories.

Table 28 summarises the most important parameters and suggests actions for maximising benefits or reducing environmental impacts. Actions related to system properties, such as the amount of losses in a customer's shower, are more difficult to address than factors related to product design or supply chain management, but the analysis above shows that the system properties are at least as important to consider when trying to maximise environmental benefits.

Table 28: Summary of how to increase environmental benefits, with examples and an indication whether the action is related to product design or system properties.

| How to increase environmental benefits | Examples of actions | Is the action related to product design or system properties? |
|---|---|---|
| Less heat loss in the shower increases the net efficiency of Enduce | Make sure that customers have shower walls/curtains preventing heat losses in the shower | System properties |
| The higher the energy use per person for showering, the larger the potential energy savings | Target customers/applications with high energy demand | System properties |
| The larger the number of people utilizing the product, the larger the potential energy savings | Target customers/applications where more people are using the product | System properties |
| The more fossil-based and inefficient heating is replaced, the larger the environmental savings | Target customers/applications where water heating is not based on fossil-free technologies | System properties |
| Reducing production impacts increases environmental savings – reach environmental break-even faster | Reduce the amount of metal in the product<br>Use more recycled stainless steel<br>Reduce production waste<br>Make sure that green energy is used in production of alloying elements<br>Maximize the product reliability and lifespan to minimize the number of repairs and product replacements. | Product design and supply chain management |

## 6.4 Data quality assessment

The data is valid for the Enduce value chain and production in Sweden or Lithuania. 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 3.3.6. The data quality assessment is based on the requirements in the ISO 14044 standard. A data quality assessment of individual datasets covering more than 80% of impact across all impact categories is presented in Appendix 5.

Table 29: Data quality assessment for the study.

| Aspect | Notes |
|---|---|
| Data quality assessment scheme | The data quality level and criteria from the product category rules for construction products (Table E.2 with PEF guidance in EN1504) have been applied in this study. The classification levels according to these criteria are for geographical, technological and time related coverage: very good, good, fair, poor and very poor. |
| Geographical coverage | Upstream data: Good (Generally, good. Some of the incoming raw materials and components have been represented with specific data. The incoming raw materials has been represented with data for the specific region whenever available, otherwise using Global or European datasets to reflect the geography of the process.)<br>Core module (A3): Very good (site-specific) |
| Technological representativeness | Upstream data: Good (Generic data based on plant averages)<br>Core module (A3): Very good (site-specific) |
| Time-related coverage | Upstream data: Good<br>Core module (A3): Very good (2022 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 some upstream processes have been checked for plausibility, using as reference LCAs or EPDs for similar products. |
| Precision | Material and energy flow quantified based on generic data from the ecoinvent 3.9 database. |
| Completeness | Data accounts for all known sub-processes. Upstream processes were modelled using specific data when availably and generic data from the ecoinvent 3.9 database when specific data was not available. Regarding the general data country-specific datasets were used whenever available, otherwise using Global or European datasets to reflect the geography of the process. |
| Consistency, allocation method, etc. | Allocation follows a physical causality in line with EN 15804. The same methodology and approach has been uniformly applied in all parts of the study. |
| Completeness and treatment of missing data | Specific data for the manufacturing of some of the components are missing, this data has been represented with proxy data and is documented in the report. |
| Final result of data quality assessment | Data quality as required in EN15804 is met. |

### 6.4.1 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.

All known sub-processes have been accounted for. In reference to the goal and scope of the report, the report is complete. Missing or incomplete information has been documented and ways of handling this has been described in the study.

### 6.4.2 Validation of data

The data collected is often linked to a specific context, a certain facility size, etc. This may mean that data needs to be adjusted to represent the system being studied. It is also common for data to be reported in units or quantities that require recalculations. All such adjustments are documented in the software used for LCA calculation, SimaPro. The data has been validated by double-checking with the providers of data at Enduce.

### 6.4.3 Consistency check

The objective of the consistency check is to determine whether the assumptions, methods and data are consistent with the goal and scope.

In reference to the goal and scope assumptions, methods and data is considered to have been handled consistently throughout the study.

### 6.4.4 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 (fossil) impact using the EF3.0 method, performed with 1000 iterations and presented in Figure 18 and details in Table 30.

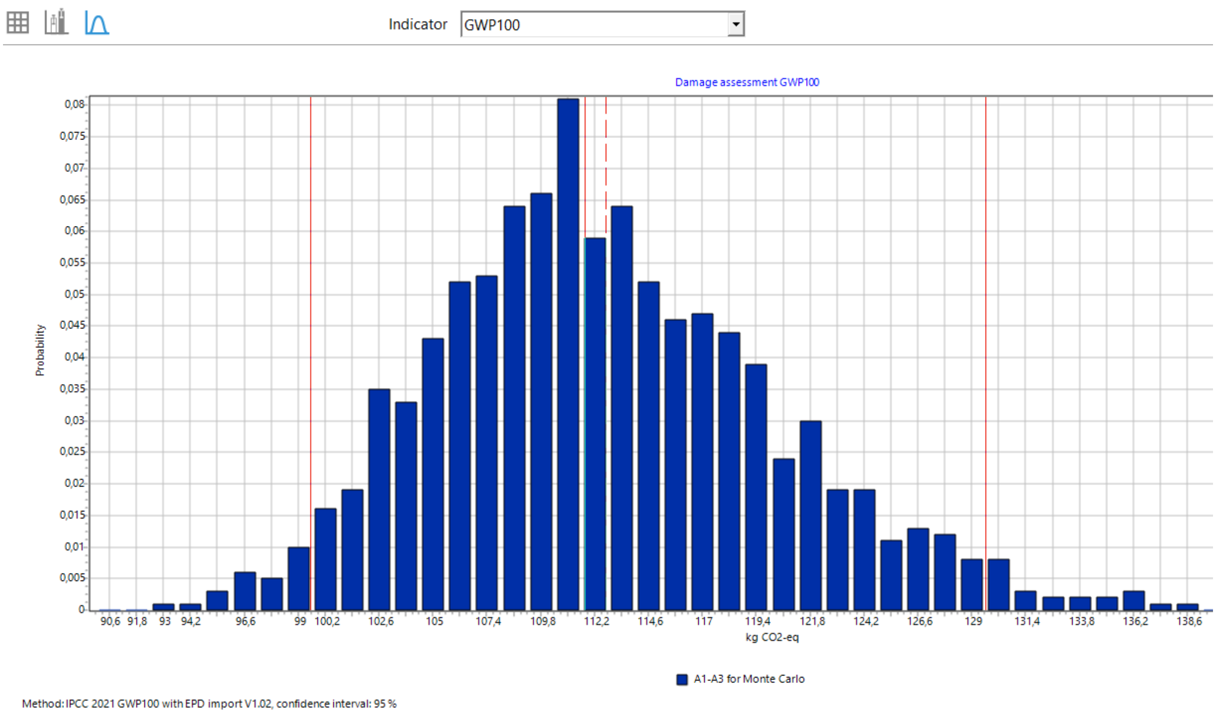


Figure 18: Show the distribution of results from the Monte Carlo analysis. 70% of the model contained uncertainty data. 1000 runs were performed.

Table 30: Details concerning the Monte Carlo analysis

| Mean | Median | Standard deviation | Coefficent of variation % | Low 2.5% | High 97.5% | Standard error of mean |
|---|---|---|---|---|---|---|
| 112,7 | 111,8 | 7,729 | 6,858 | 99,53 | 129,6 | 0,2444 |

The uncertainty is considered acceptable for a complex LCA study.

# 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 results can be divided into the product of Enduce E1 on the one hand and the potential environmental benefits of reduced energy consumption on the other.

The life cycle environmental impacts of Enduce E1 can be attributed to the production of the stainless steel components and their alloying elements (mainly molybdenum, nickel and chromium), as well as the copper for the plate heat exchanger. These cause resource use of minerals and metals and climate impacts from energy use in upstream production. The climate impact is 126 kg CO2-eq.

Once installed, Enduce E1 can reduce the energy consumption from heating of warm water by ca 70%. The resulting environmental benefits depend on the behaviour of the users of the product as well as the characteristics of the installation site and the energy system used for heating the water. The net benefits range from ca 0,4 – 11,5 ton CO2-eq. over 30 years, depending on the energy system generating the energy being replaced. Two extreme scenarios were also formulated showing a net benefit of ca 16 tons CO2-eq. over 30 years in the most favourable extreme, down to a net impact of ca 20 kg CO2-eq. in the least favourable extreme. The benefit can be maximized by minimizing production impacts, or by installing the product in a location with a large need for warm water such as a gym (but ideally with small heat losses from the shower head to the well), or in a location that relies on fossil energy for its warm water, or by improving the efficiency and lifetime of the product.

## 7.1 Recommendation on how to mitigate the hot spots and maximize benefits

Based on the results and sensitivity analysis, we make a number of recommendations for how to reduce environmental impacts and increase environmental benefits.

The first measure is to reduce the amount of material used in the product and reduce production waste, which in turn reduces the production and use of raw materials. The second measure is to use recycled input materials of stainless steel and copper, particularly post-consumer recycled stainless steel which reduces the need for new production of alloying elements of nickel, chromium, molybdenum. The third recommended measure is to choose suppliers that use green electricity in ferrochromium production and green electricity and heating in ferronickel production. The fourth measure is to prolong the life of the product by ensuring a durable design, which postpones the time for replacing the product and increases the period during which it contributes to reduced energy consumption. A combination of all measures has a large potential for significantly reducing the life cycle impacts of Enduce E1.

In the long term, there are also benefits to be gained by prolonging the life of the product with repairs or upgrades, or by recirculating the product at its end of life and remanufacturing it or reusing the parts or materials. These measures would also reduce the need for new raw material production.

We also argue that the maximum benefit of Enduce is found in applications using larger volumes of warm water, such as gyms and bath houses (although these applications tend to have large heat losses from shower head to well, somewhat reducing potential benefits). If the goal is to maximise environmental benefits, then it is important to find ways to enter such markets.

The table below summarises the suggested actions to reduce the environmental impact of the product. A priority ranking is presented. Actions which can result in a reduction in the environmental impact have been identified and presented in the table.

Table 31 Summary of actions in each life cycle phase and their priority

| Life cycle phase | Priority | Action 1 | Action 2 | Action 3 | Action 4 |
|---|---|---|---|---|---|
| Raw materials | High | Reduce material in product and production waste | Use more recycled materials | Choose suppliers using low-carbon energy sources | Prolong life (durable design) |
| Transports | Low | Minimize transportation distances and weights | x | x | x |
| Operations in Umeå | Low | Minimize energy and waste | x | x | x |
| Packaging | Low | Minimize packaging | x | x | x |
| Installation and use | High | Install in applications with high energy use, low losses and/or high-carbon heating systems | Prolong life (repair or upgrade) | Recirculate (remanufacture, reuse parts) | x |
| End of life | Medium | Make sure that the product is disassembled and recycled | x | x | x |

## 7.2 How to communicate the results

The report shows that two categories are the main contributors to the environmental burden of Enduce E1. It is, therefore, important to communicate about all these effects and keep not only climate impacts in mind but also resource consumption.

The study and report were carried out following the standards provided in ISO and is part of the publication of an environmental product declaration. LCA studies used to support assertation made public must be subjected to external review according to ISO14040 (ISO, 2006b):
*"When results of the LCA are to be communicated to any third party (i.e. interested party other than the commissioner or the practitioner of the study), regardless of the form of communication, a third-party report shall be prepared. The third-party report can be based on study documentation that contains confidential information that may not be included in the third-party report. The third-party report constitutes a reference document, and shall be made available to any third party to whom the communication is made"*.

Overall, a critical review gives credibility to the study results, and it may assist in discovering errors or perhaps more reasonable assumptions, as well as generally ensuring the integrity of a study, in addition to preventing abuse and unsubstantiated claims, hence encouraging the LCAs robustness and increasing confidence in its findings and recommendations (Rosenbaum & Olsen, 2018). The results of this report were third-party reviewed and may be communicated externally.

## 7.3 How to reduce uncertainties

The main uncertainty is related to the potential benefits Enduce depending on the application where it is installed and used. The benefits depend highly on the energy source for the warm water heating, the losses in the shower and the behaviour and number of users. These uncertainties are difficult to reduce, but they can be taken into account in e.g. market communication.

Considering only production impacts, the main uncertainty is instead the amount of recycled stainless steel input used and whether it is from post-consumer sources or not. If not, it is relevant whether the steel is from internal pre-consumer scrap (in which case there is not linked to any environmental benefit) or external pre-consumer scrap (in which case it is subject to co-product allocation). These uncertainties can be reduced by collecting specific data from suppliers.

Another uncertainty is what happens to the product at the end of its life. It is possible to dismantle and recycle it but, without retaining control of the product, it is not possible to know for certain what actually happens to it, which is why end of life has to be modelled with a generic waste scenario. With more specific data on the end of life, the model can be made more specific.

## 7.4 Internal follow-up procedures

Procedure for follow-up the validity of the EPD is at minimum required once a year with the aim of confirming whether the information in the EPD remains valid or if the EPD needs to be updated during its validity period. The follow-up can be organized entirely by the EPD owner or together with the original verifier via an agreement between the two parties. In both approaches, the EPD owner is responsible for the procedure being carried out. If a change that requires an update is identified, the EPD shall be re-verified by a verifier.

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

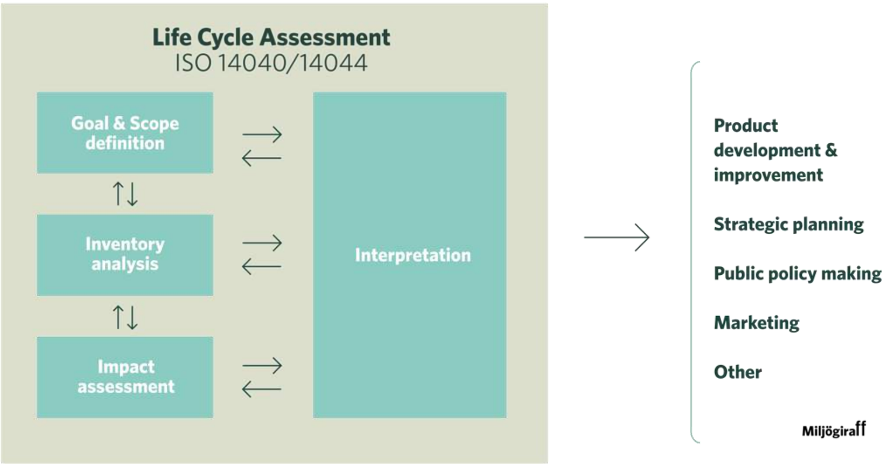


Figure 19. The four phases of the Life Cycle Assessment

## 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.

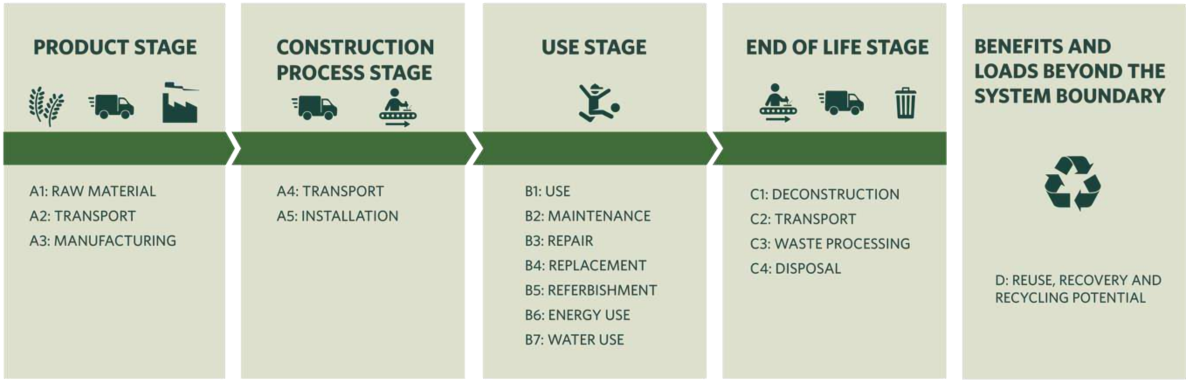


Figure 20: General summary of the modules included in an LCA, based on EN 15804.

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 21). 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.

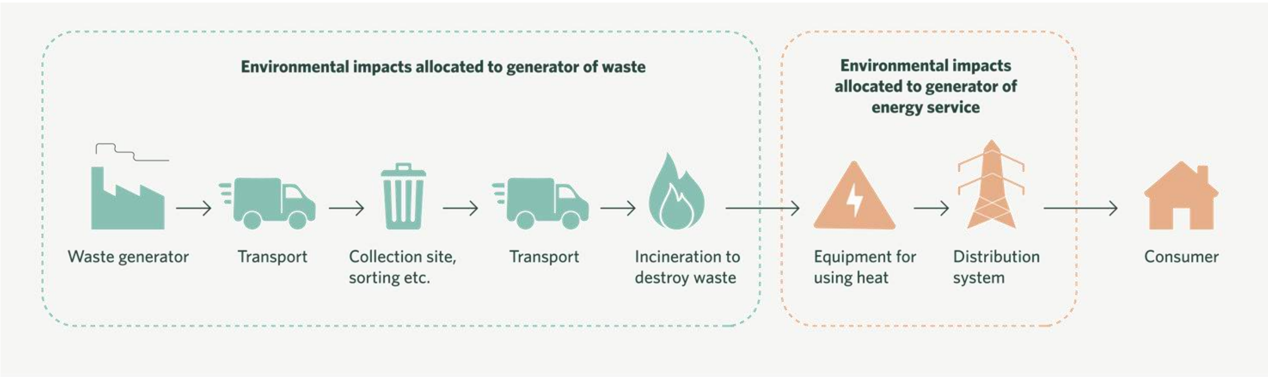


Figure 21: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here in regard to the incineration of waste and resulting energy products.

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

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

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

### ii. Cut-off

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

### iii. Allocation

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

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

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

### iv. Data requirements (DQR)

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

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

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

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

Generic data
1. Public and verified libraries with LCI data

2. Trade organisations' libraries with LCI data

Sector-based IO data, national

## B. Inventory analysis (LCI)

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

## C. Impact assessment (LCIA)

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

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

Classification, characterisation and weighting will here be briefly explained.

### i. Classification and characterisation

The process of determining what effects an environmental aspect can contribute to is called classification, e.g. that the use of water contributes to the environmental effect of water depletion, see Figure 22 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.

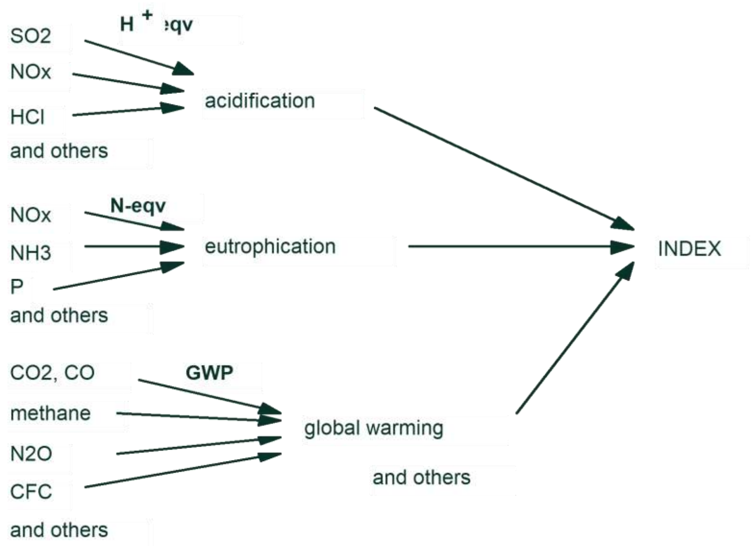


Figure 22: An illustration of the Impact Assessment of an LCA.

### 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. As an example, the method EF 3.1 uses normalization first, to set each impact category on a comparable scale, and then applies weighting factors according to an expert panel. Weights per impact category are then summarised to reach a single score.

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

## D. Interpretation

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

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

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

### i. Evaluation of the results

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

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

# Appendix 2 Environmental footprint 3.0

One of the most commonly used LCIA methods is the Environmental footprint 3.0 (EF3.0) method (European Commission, 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 32 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 32: Planetary boundaries and mid-point environmental impact indicators in LCA recommended by EF3.0. Adapted from (Tillman et al., 2020).

<table>
<tr><th>Planetary boundaries</th><th>Mid-point indicators in LCA as per EF3.0</th><th>Level of correspondence between impact categories</th></tr>
<tr><td>Climate change</td><td>Climate change</td><td rowspan="6">High level of correspondence</td></tr>
<tr><td>Stratospheric ozone depletion</td><td>Ozone layer depletion</td></tr>
<tr><td>Biogeochemical flows (nitrogen and phosphorus cycles)</td><td>Freshwater, marine and terrestrial eutrophication</td></tr>
<tr><td rowspan="2">Novel entities (chemical pollution)</td><td>Freshwater ecotoxicity</td></tr>
<tr><td>Human toxicity (cancer and noncancer)</td></tr>
<tr><td rowspan="2">Atmospheric aerosol loading</td><td>Photochemical ozone creation</td></tr>
<tr><td>Respiratory effects, inorganic</td><td rowspan="3">Some correspondence</td></tr>
<tr><td>Ocean acidification</td><td>Freshwater acidification</td></tr>
<tr><td>Biospheric integrity (biodiversity loss)</td><td>Resources land use</td></tr>
</table>

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

# Appendix 3 Cumulative Energy Demand, CED

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

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

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

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

# Appendix 4 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! Recycling rate of copper in photovolataic panel is 0. |
| [MG] Brass (waste treatment) {GLO}\| recycling of brass \| Cut-off, U | Non-ferro | 95 | In PEF Annex: Metals > Copper alloys > building - water supply pipes |
| 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 uninterruptible 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 | | 99 | 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 | | 1 | Share going to landfill based on EU27 statistics for 2013, as found in PEF Annex C (See documentation tab). For Sweden, it is 1% |

# Appendix 5 DQA of individual datasets

Data quality assessment of individual datasets covering more than 80% of impact across all impact categories, according to Annex E, table E.1 in EN 15804.

| **Processes cumulatively contributing >80% of GWP-GHG indicator** | Representativeness | | |
|---|---|---|---|
| | Geographical | Technical | Temporal |
| Ferronickel {GLO}\| market for ferronickel \| Cut-off, U | Good | Fair | Very good |
| Ferrochromium, high-carbon, 68% Cr {GLO}\| market for ferrochromium, high-carbon, 68% Cr \| Cut-off, U | Good | Fair | Very good |
| Metal working, average for steel product manufacturing {RER}\| metal working, average for steel product manufacturing \| Cut-off, U | Good | Fair | Good |
| Copper, cathode {GLO}\| market for copper, cathode \| Cut-off, U | Good | Fair | Very good |
| Electricity, medium voltage {RER}\| market group for electricity, medium voltage \| Cut-off, U | Good | Very good | Very good |
| Pig iron {RER}\| market for pig iron \| Cut-off, U | Good | Fair | Good |
| Heat, district or industrial, natural gas {Europe without Switzerland}\| heat production, natural gas, at boiler modulating >100kW \| Cut-off, U | Good | Good | Very good |
| Transport, freight, lorry, unspecified {RER}\| transport, freight, lorry, all sizes, EURO6 to generic market for transport, freight, lorry, unspecified \| Cut-off, U | Good | Good | Fair |
| Waste rubber, unspecified {Europe without Switzerland}\| treatment of waste rubber, unspecified, municipal incineration \| Cut-off, U | Good | Fair | Fair |
| Synthetic rubber {RER}\| synthetic rubber production \| Cut-off, U | Good | Fair | Very good |
| Energy and auxilliary inputs, metal working factory {RER}\| market for energy and auxilliary inputs, metal working factory \| Cut-off, U | Good | Fair | Good |
| Quicklime, in pieces, loose {CH}\| market for quicklime, in pieces, loose \| Cut-off, U | Fair | Fair | Fair |
| Metal working, average for copper product manufacturing {RER}\| metal working, average for copper product manufacturing \| Cut-off, U | Good | Fair | Good |