Carbon footprint screening of Fire-Eater fire extinction system

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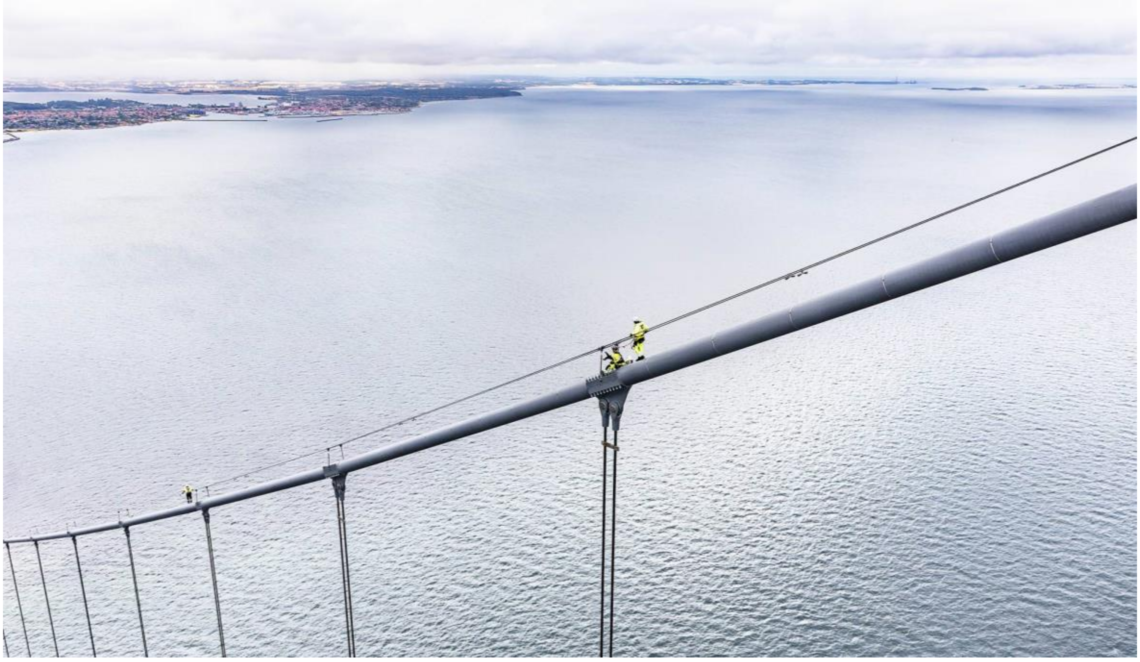

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1. Introduction

Fire Eater A/S (henceforth Fire Eater) is a company that delivers fire extinction systems for companies, private as well as public entities. Their specialty is a fire extinguishing system with Inergen gas. When the system is in use it works by automatically activating when an incipient fire is detected, followed by immediately spreading out Inergen throughout the room via nozzles. This reaction rapidly reduces the oxygen percentage to a level where fire is no longer possible. According to Fire Eater, the reduced oxygen level remains safe for people to stay in the room. The system can be dimensioned to a specific room or building in which it shall be installed. Rooms of application could be server rooms, datacenters, museums, rooms linked to pharmaceutical production and many more. Check https://fire-eater.com/ for more information.

Fire Eater wants to quantify the carbon footprint of an average system utilizing their product in a screening study. The study will include three main scenarios and different End-of-Life (EoL) scenarios in Europe and Denmark, respectively, with different waste treatment scenarios from cradle-to-grave. The study is on screening level and follows the overall guidelines in ISO 14067 but deviates as it is not subject to third party review, and certain aspects are not subject to further analysis. The study includes the life cycle of an average system from cradle-to-grave, however, the installation phase and consumption of materials and energy during the use phase have not been included as primary data was not available. Otherwise, raw material extraction and processing into components, production (assembly of system), transport, maintenance of system during use and EoL are included.

1.1. Aim of study

The study is conducted by FORCE Technology (FT), and commissioned by Fire Eater, with the aim of assessing the carbon footprint linked to the manufacturing, transport, packaging, and waste management of an average Fire Eater extinction system. The study will quantify the emissions of greenhouse gasses in kg CO_2-eq.

1.2. Target audience

The target audience is the management of Fire Eater with the primary aim of qualifying the audience to assess potential optimizations of their system. Secondly, the study may be used in B2B communication. The study is not directly suited for communication to the public, as it requires carbon footprint and life cycle assessment (LCA) knowledge to understand the technical aspects and as it is conducted on screening level it is only following the overall guidelines of ISO 14067.

2. Method

2.1. Carbon footprint method

The study aims to measure the carbon footprint of as much of the lifecycle of a Fire Eater system as possible (cradle-to-grave). However, the study does not include the installation phase and parts of the use phase. Thus, resulting in a partial carbon footprint of the Fire Eater system but in the following referred to as carbon footprint for simplicity. It is based on the general principles of carbon footprint studies, described in ISO 14067, which is based on principles and guidelines for conducting LCA studies in the ISO series (14040 and 104044). However, the study is on screening level as it is not subject to third party review, and certain aspects are not subject to further analysis, such as data quality and sensitivity analysis. Thus, the processes with high uncertainty or low data quality have not been subject to sensitivity analysis to quantify their impact on the results and the robustness of the study. The overall method is attributional, meaning it estimates what share of global environmental burdens are attributed to the products.

The primary data received from Fire Eater is modelled in SimaPro 9.5 LCA-software and results are calculated using the LCIA method: Environmental Footprint (EF) 3.1 method which divides the greenhouse gas emissions in three categories, see Table 1.

The results are presented as characterized results: kg CO_2-equivalents describing emission of greenhouse gasses. The characterized results are also normalized to Person Equivalents (PE), where the Climate change midpoint impact (kg CO_2-equivalents) is expressed as a contribution to the average global emissions of greenhouse gasses per European per year. The results are presented using French notation where the decimal separator is comma ",".

Table 1: Overview of the EF 3.1 impact categories (midpoint).

Impact category	Unit
Climate Change	kg CO_2 eq
Climate Change, biogenic	kg CO_2 eq
Climate Change, fossil	kg CO_2 eq
Climate Change, land use and land use change	kg CO_2 eq

It shall be emphasized that the study is only looking at climate change and no other environmental impact categories such as resource use of minerals and metals, ozone depletion potential, eutrophication that are a part of LCIA methods such as EF 3.1. Thus, there is a risk of environmental burden shifting when solely focusing on climate change.

2.2. Definition of goal and functional unit

The study quantifies the carbon footprint of an average Fire Eater system using a hotspot analysis to determine which aspects of the system's life cycle contribute the most to the carbon footprint emissions. Fire Eater produces fire extinction systems of various sizes at their site in Denmark. Therefore, the average Fire Eater system in scope is based on yearly production numbers for the year 2022. Thus, materials, energy use, waste generation and more was collected for the year 2022 and compared with the number of Fire Eater system produced in the same year.

The functional unit (FU) is defined as *one Fire Eater system that can extinguish an ordinary fire in less than 40 seconds without damaging the indoor environment, in an indoor area of 120 m^3 in both Denmark and Europe for 20 years.*

The transport from factory to user, installation and use of the system are not included. Thus, carbon footprint emissions linked to the fire extinction are not considered. To fulfill the FU a reference flow includes the raw materials extraction, manufacturing, transport and waste treatment at EoL for one Fire Eater system including all components. Otherwise, to fulfill the FU there are also legal obligations and certifications, details on this matter can be found on https://fire-eater.com/en/approvals/.

In general, all processes and flows that are attributable to the analyzed system are included in the study. However, assumptions have been made when data was missing or limited. This has not been subjected to a sensitivity analysis.

2.3. System boundaries

The considered system depicted in Figure 1 is from cradle-to-grave and includes extraction and processing of raw materials into components, manufacturing (assembly), packaging, maintenance, waste management at EoL which depend on the scenario, and lastly, transportation between the supplier and factory, and average transport to waste management facility. Energy consumption during use and installation are not included in the study, however, maintenance during the use phase is considered. The maintenance included is replacements of components with a lifetime shorter than the lifetime of the entire system (20 years) and their average transport. In future studies, the installation and the entire use phase can be included if data is available on energy consumption when the system is in use, along with data regarding consumption of energy and materials as well as generation of waste during the installation.

The geographical scope of the raw materials extraction and manufacturing stages is European as majority of the materials for the components that make up the system in scope originate from European countries. However, there are some exceptions where some materials originate from Taiwan or China. The geographical scope of the maintenance during the use stage and the EoL stage depends on the scenario and is either Denmark or Europe. The secondary process data is thus aimed at being European as best as possible but with few exceptions where global secondary process data is used. The technology scope applied, in this relation, is considered the best available. The temporal scope is long starting now as the production data is from 2022 and the system has an average lifetime of 20 years.

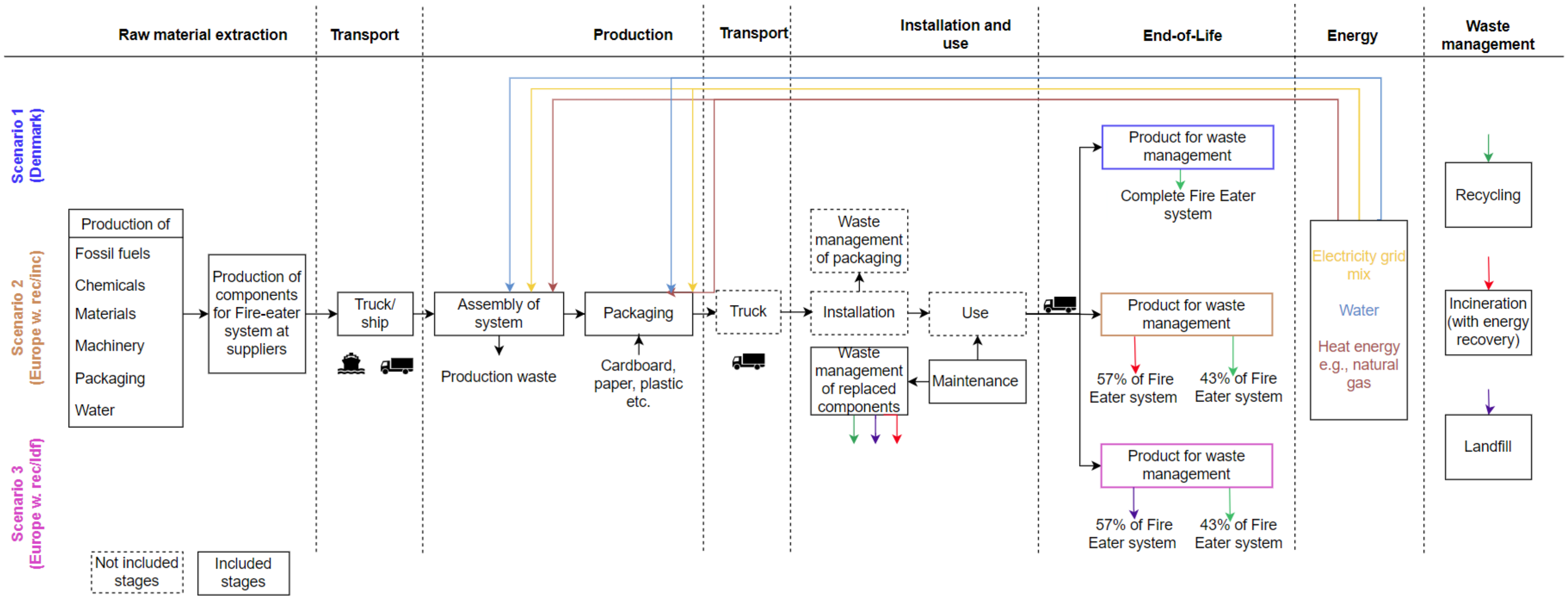

Figure 1: System boundaries for carbon footprint screening of a Fire Eater system.

2.4. *Scenarios*

As visualized in Figure 1, The study includes three scenarios in which the geographical region at the EoL is either Denmark or Europe, thereby including different waste management technologies. In Denmark, Fire Eater handles maintenance of the system during its use, and Fire Eater also takes back the system at the EoL to ensure all components are recycled. In Europe, Fire Eater is not in control of the maintenance or the EoL of the system and instead two average European scenarios are included in which the components are partly recycled and partly incinerated or landfilled. This is based on waste statistics on electronic waste (e-waste) in Europe (Forti et al., 2020). Thus, the raw material extraction, manufacturing and packaging in Denmark are the same for all three scenarios.

The differences in the three scenarios are summarized below:

- *Scenario 1:* the maintenance and EoL stages take place in Denmark where Fire Eater is in control of the maintenance of the system during its life cycle and takes back the system at the EoL stage. All components which are replaced during the system's lifetime or discarded at the EoL are send for recycling in Denmark.
- *Scenario 2:* the maintenance and EoL stages take place in Europe where Fire Eater does not control and maintain the system. Thus, the components are not necessarily recycled. Instead, an average European e-waste treatment scenario is applied. Here it is considered that 43% is recycled and 57% is incinerated both for components replaced during the system's lifetime and discarded at the EoL stage.
- *Scenario 3:* the maintenance and EoL stages take place in Europe where Fire Eater does not control and maintain the system. Thus, the components are not necessarily recycled. Instead, an average European e-waste treatment scenario is applied. Here it is considered that 43% is recycled and 57% is landfilled both for components replaced during the system's lifetime and discarded at the EoL stage.

In all three scenarios, some components require replacement and/or maintenance after 10 years of use. The full list of components and their requirements after 10 years can be found in Appendix 3. The replaced components are handled with the waste management technologies relating to the geographical scope of the scenario. Thus, replaced components in scenario 1 are handled through 100% recycling, whereas for scenario 2 and 3 replaced components are handled through a mixture of recycling and incineration as well as recycling and landfilling, respectively.

2.5. *Life cycle stages*

For the life cycle stages and the processes involved, some of the main considerations and choices made are described in the following. In relation to this, it needs to be emphasized that the study focuses on the operational aspect of processes, meaning that capital goods (e.g., building the factory or manufacturing the machinery used in the production) are excluded. The geographical, temporal, and technical representativity (described in section 2.4) are as representative as possible, but assumptions were made when data was insufficient or not available.

2.5.1. Materials

To manufacture the Fire Eater system various raw materials are used and processed to produce the components which are finally assembled as the full system. Replacements of individual components during the lifetime of the system and thereby the production of new components have been considered. The components have been modelled accordingly in the LCA software, but assumptions are made when materials and/or processes were not available, see complete overview in Appendix 1 for the secondary data and Appendix 2 specifically for the assumption on the materials.

The fire extinction systems produced by Fire Eater vary in size. The consumption of materials for producing components per average system has been estimated by Fire Eater (2023). The system is very complex and consists of more than 800 sub-components of various materials (Fire Eater, 2023). Therefore, grouping of the sub-components into main components was necessary to have an overview of the product and be able to assess what materials in the individual components and overall, what components in the system that drive the carbon footprint. The grouped components and their materials can be viewed in the Excel Appendix A. The grouping required some materials to be added together e.g., stainless steel is summed up for one component. The grouping of components was done in collaboration with Fire Eater.

2.5.2. Production and energy

At the factory in Hillerød, Denmark, some components are produced, and the complete system is assembled. The factory only produces Fire Eater fire extinction systems (Fire Eater, 2023). Packaging of the final product also takes place at the factory in Hillerød. Electricity for general lighting and machinery as well as heating are estimated for a full year to account for seasonal variations. The same is the case for any waste generated at the site. The data is collected for the year 2022. It should be noted that energy consumption includes other activities than the production e.g., use of computers and lighting as well as heating in the offices.

The electricity used is based on the Danish grid mix. For the thermal energy in Denmark, a mixture using different thermal energy sources is applied according to Danish Energy Agency (2022). The consumption of water at the facility is from groundwater as is the case for 99% of the tap water in Denmark.

2.5.3. Packaging

Packaging of final products is done with polyethylene (PP) film, cardboard, paper, steel and wooden pallets. The collected information on materials and weights of packaging is based on Fire Eater (2023). The modelling of packaging is based on the corresponding secondary data for production of materials, along with production processes of the packaging, if needed (e.g. extrusion of PP granulates to produce PP foil).

The wooden pallet is assumed to be a standard EUR pallet with an average weight of 25 kg with moisture content of 17% of that is assumed to be used 25 times before being discarded[1]. For the production and disposal of the wooden pallet, the product is only loaded with the part that this use-cycle represents.

2.5.4. *Transport*

Transportation from supplier to the factory site in Hillerød, Denmark is estimated. The grouping of components and adding together materials affects transportation, as some of the materials originate from different locations. This is solved by using weighted averages of the transportation considering weight of materials and transportation distances. The transportation distance is calculated using EcoTransIT when the specific distance was not given (EcoTransIT, 2023).

The truck type for transportation of raw materials to manufacturing site is "Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}"[2] to represent both transport within and outside Europe. For truck transport outside Europe this mainly concerns China and Taiwan. In China, the most common truck type for transport is China V which is equivalent to a Euro V truck[3] according to Zheng et al. (2022). For truck transport inside Europe, it varies depending on the country, in Denmark Euro VI trucks are largely implemented but in other European countries the Euro V truck dominates. As the transportation is based on weighted averages, the Euro V truck type is applied as a conservative assumption. The average freight load factor of the 16-32 metric ton truck is 5,79 tons, whereof the gross vehicle weight is 15,79 tons.

Also ship transport for some components is included. This is the case for materials originating from China or Taiwan. The dataset used is "Transport, freight, sea, container ship {GLO}".

For transport of replaced components between customer and factory, the dataset used is: "Transport, freight, lorry 16-32 metric ton, EURO5 {RER}", which is assumed to be a distance of 500km between the customer and the factory. When the transportation distance of raw materials to the factory was not known e.g., for packaging, then the same truck dataset and distance of 500km was applied.

For transport at the EoL, average transportation distances to waste treatment facilities in either Denmark or Europe. Transportation by truck is considered and the dataset "Transport, freight, lorry 16-32 metric ton, EURO6 {RER}" are used to match the typical size of garbage trucks in Europe and Denmark, respectively. The average freight load factor is 5,79 tons, as applied above.

The consumption of heavy fuel oil for ships and diesel for trucks are included in the datasets.

2.5.5. *Installation and use*

As mentioned, the installation and parts of the use phase are not included in the study. According to Fire Eater (Fire Eater, 2023), when the system is put into use and on standby, the consumption of energy is

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[1] https://environment.ec.europa.eu/system/files/2021-12/Annexes%201%20to%202.pdf

[2] According to Eurostat, majority of EU road freight transport in 2021 was carried out by trucks with a maximum gross weight of over 30 tonnes, thus, a truck with gross weight of 28-34t were chosen as best estimate - also for countries outside Europe (Eurostat, 2022).

[3] https://www.transportpolicy.net/standard/china-heavy-duty-emissions/

low, but this has not yet been measured. When the system is active due to an incipient fire, it consumes a significant portion of energy for spreading the Inergen gas around the room. This also includes the release of the Inergen gas that contains a mixture of different gasses, see Table 2. The only consumption of raw materials and generation of waste during the use phase that has been included is the replaced components.

2.5.6. Waste treatment

Waste is generated in several life cycle stages and is handled through different waste management technologies. Different waste fractions have been grouped together e.g., PET, PP, ABS are grouped into one overall plastics category that is handled either through recycling, incineration or landfilling as mixed plastic. The grouping requires assumptions to be made e.g., regarding heating value for incineration. However, the grouping is only made on comparable materials handled through comparable waste management technologies and it is not expected to have a significant influence on the results. See Appendix 3 for details on the groupings and assumptions.

Starting with the waste treatment of manufacturing waste, different metals e.g., steel, stainless steel, brass, aluminum, copper, electronics, batteries and various plastics are sent for recycling by an external waste treatment facility. It shall be noted that the waste from manufacturing also includes some Fire Eater systems that have reached the EoL and are disassembled and returned to Fire Eater. The amount of waste generated in the production vs waste generated from disassembled Fire Eater systems that have reached the EoL was not possible to separate. Therefore, a conservative estimation is made to consider the entire waste fraction as waste generated during manufacturing.

Next life cycle stage is the installation and use which are not included in the study, neither is the waste management of the packaging waste. According to Fire Eater (2023) all packaging waste (cardboard, PP foil, steel, wood pallets) can be recycled. Some components are replaced during the use phase and are either recycled, incinerated or landfilled depending on the scenario in scope. The components replaced are listed in Appendix 3.

Lastly, there is waste management when the system has reached the EoL. The system is dismantled, and the resulting waste components are sent for waste management. The dataset chosen for dismantling the system is "Manual dismantling of used electric passenger car GLO", dismantling an electronic car with a weight of 1200kg. The system weighs almost 1000 kg in total and is therefore comparable to the weight of the car. Therefore, the dataset is used and scaled to the weight of the system. According to the description of the dismantling dataset, it is a general process including a manual treatment facility for electric and electronic equipment into components, hence not specific for electric cars[4]. Therefore, the dataset is chosen as best representative considering the limited data availability.

Depending on the scenario, the resulting waste after dismantling is either recycled, incinerated or landfilled, see section 2.4. For the Danish scenario, 100% recycling is considered according to information

[4] https://ecoquery.ecoinvent.org/3.9.1/cutoff/dataset/8722/documentation

from Fire Eater (2023). For the European scenarios, only 43% of the waste is recycled according to waste statistics on electronic waste (e-waste) in Europe (Forti et al., 2020). The remaining e-waste is discarded in waste bins and subsequently landfilled or incinerated depending on waste management in the specific country. Therefore, a scenario considering 43% recycling and 57% incineration as well as a scenario considering 43% recycling and 57% landfilling are considered. It is likely that the real-life waste management includes a mixture of landfilling and incineration, but data was not available to support this.

Plastics are recycled through shredding, washing, compounding and pelletizing. Electronics are recycled through shredding, followed by grinding with separation technology. Recycling processes for metals involves sorting, then shredding and purification. Some materials such as lubricants and adhesives are treated as hazardous waste as a conservative assumption because the content is unknown and data availability on their waste management is limited. No recycling is considered for these fractions. Volatile materials such as ethanol are evaporated before reaching the EoL stage. The Inergen is reused in the Danish scenario as a part of the take-back system from Fire Eater, but Inergen is released into the atmosphere in the European scenarios. Paper and cardboard packaging from incoming materials arriving at the factory are sent to incineration in all scenarios.

2.5.7. Avoided production (crediting)

When materials are recycled, they carry the potential to replace virgin materials on the market if the quality has not been significantly degraded, and thereby avoid the production of new virgin material. The avoided production of virgin material can be credited. The quality loss of material due to recycling shall be considered. Along with a fair distribution of the burdens and benefits of recycling between the party recycling the waste and the party using the recycled material to avoid double counting. The quality loss and full details on the recycling processes are available from waste handling companies, but as this study is on screening level, the Circular Footprint Formula (CFF)[5] is used instead. The waste treatment and crediting of avoided virgin material are based on Danish and European processes as well as global processes when neither Danish nor European processes are available. The recycling datasets chosen are presenting the materials as best as possible, however, for the recycling of plastics which include many different types, a recycling process for recycling PP is chosen as there were no recycling of mixtures of plastic and as the PP stands for a significant share among the various plastic types.

The incineration of the waste fractions also brings credits to the system by producing electricity and thermal energy that replaces the average aggregated electricity grid mix and thermal energy mix across Europe, respectively, see Section 2.5.2 for the energy mixes in scope. The crediting is included through system expansion.

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[5] The CFF includes several parameters with one being the A parameter, the allocation factor, that ensures that a share of the burdens and benefits from recycling is allocated to the next life cycle in which the recycled material is utilized, hence not exclusively to the recycling process. Values for the A parameter along with the other parameters can be found in PEF's Annex C (EC, 2018).

According to Equanimator in a study for Zero Waste Europe (2023), the heat and energy efficiency from incineration facilities across Europe is 14,9% electricity and 34,6% heat produced as weighed average across South-Western, Central and Northern Europe. Note that the electricity vs heat efficiency varies significantly across the geographical regions in Europe, see Equanimator study for Zero Waste Europe (2023). These percentages are used to estimate the heat and electricity production from the incineration processes of the raw materials including the lower heating values (LHV) of the materials that can be found in Appendix 2, along with assumptions made in case a LHV was not possible to be estimated.

Example of calculation of heat and electricity production when incinerating 1 kg polypropylene using LHV listed in Pommer et al. (2001):

1kg-PP * 40 MJ/kg-PP * 34,6% = 13,84 MJ heat per kg-PP.
1kg-PP * 40 MJ/kg-PP * 14,9% = 5,96 MJ electricity per kg-PP.

3. Life cycle data

The data used in the study is based on primary data from Fire Eater, including raw materials, manufacturing, transport, and EoL, and secondary data (upstream processes) from Ecoinvent 3.9.1 database available through the LCA-software SimaPro, see Appendix 1 for details on datasets used. When secondary data was not available in the LCA databases, assumptions and data from literature have been used, see section 2.4 and Appendix 1 for details. The primary life cycle inventory data used in the study is summarized in Table 2 for the life cycle of the Fire Eater system.

3.1. *Resource consumption*

The primary data in Table 2 contains all the flows that are identified by Fire Eater in 2022. However, improvements to processes may occur in the future and thus new data shall be collected. In potential follow-up studies the primary data, and secondary data, can be improved and verified, to further substantiate the carbon footprint results. This will improve and minimize the applied assumptions described in section 2.4.

Table 2: Primary data for the life cycle of one Fire Eater system.

Life cycle stage	Component/process	Material/input	Scenarios				Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
Raw material extraction and processing into components	Sigma	Stainless steel	6,810	6,810	6,810	kg	543	5143
		Galvanized steel	0,030	0,030	0,030	kg	356	0
		Copper	0,010	0,010	0,010	kg	814	0
		LDPE film	0,010	0,010	0,010	kg	96	0
		ABS	0,114	0,114	0,114	kg	256	0
		Paper	0,123	0,123	0,123	kg	0	0
		PA6	0,010	0,010	0,010	kg	1000	18000
		PU rubber	0,120	0,120	0,120	kg	752	12000
		Cable, wire	0,250	0,250	0,250	kg	591	0
	Alarm	ABS	0,135	0,135	0,135	kg	0	0
		PET	0,020	0,020	0,020	kg	422	0
	SV22	Brass	14,71	14,71	14,71	kg	987	12938
		EPDM	0,110	0,110	0,110	kg	1298	7200
		Stainless steel	7,170	7,170	7,170	kg	696	1800
		Adhesive for metal	0,265	0,265	0,265	kg	769	0
		Lubricant	0,010	0,010	0,010	kg	883	0
	Cable	Cable, wire	1,431	1,431	1,431	kg	353	6000
		ABS	1,380	1,380	1,380	kg	800	0
		Stainless steel	0,020	0,020	0,020	kg	1000	18000
		Paper	0,010	0,010	0,010	kg	1000	18000
	Ci Junction	PCB	0,047	0,047	0,047	kg	654	0
		ABS	0,155	0,155	0,155	kg	733	0
		PA6	0,080	0,080	0,080	kg	256	0
		LDPE film	0,020	0,020	0,020	kg	204	0
		Paper	0,010	0,010	0,010	kg	0	0
		Brass	0,088	0,088	0,088	kg	1000	18000

Life cycle stage	Compo-nent/process	Material/input	Scenarios				Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
	CI MT Pres-sure	EPDM	0,010	0,010	0,010	kg	1000	18000
		Galvanized steel	0,081	0,081	0,081	kg	445	0
		PU rubber	0,115	0,115	0,115	kg	214	0
		LDPE film	0,010	0,010	0,010	kg	850	0
		Paper	0,010	0,010	0,010	kg	0	0
		Adhesive for metal	0,104	0,104	0,104	kg	1874	0
	Compression fit	Stainless steel	0,061	0,061	0,061	kg	1324	0
	Cylinder**	Steel	317	317	317	kg	256	0
		Brass	1,600	1,600	1,600	kg	1027	0
		Inergen	84	84	84	kg	256	0
	Fitting, clamp, pipe and pres-sure	Galvanized steel	451	451	451	kg	1012	0
		Stainless steel	8,800	8,800	8,800	kg	256	0
	Endcover	PVC	0,010	0,010	0,010	kg	1416	0
	Hose**	EPDM	10,40	10,40	10,40	kg	1039	13500
	IS8B	EPDM	0,120	0,120	0,120	kg	1000	18000
		Neodymium	0,036	0,036	0,036	kg	829	7500
		Stainless steel	0,286	0,286	0,286	kg	1000	18000
		Copper	0,147	0,147	0,147	kg	814	13500
		Steel	1,044	1,044	1,044	kg	1168	9000
		Brass	0,588	0,588	0,588	kg	931	14400
		Epoxy resin	0,050	0,050	0,050	kg	1000	18000
		LDPE film	0,020	0,020	0,020	kg	128	0
		Paper	0,020	0,020	0,020	kg	633	9000
		Cardboard	0,100	0,100	0,100	kg	256	0
		PP	0,020	0,020	0,020	kg	1015	0
		Cable, wire	0,745	0,745	0,745	kg	907	9000
		Silicone	0,020	0,020	0,020	kg	560	9000
		Ethanol	1,126	1,126	1,126	kg	758	13500
		Adhesive for metal	0,172	0,172	0,172	kg	1437	9000
		Lubricant	0,046	0,046	0,046	kg	661	9000
		Isopropyl	0,020	0,020	0,020	kg	942	9000
		Disinfectant wipes/PET cloth	1,842	1,842	1,842	kg	1000	18000
		PA6	0,020	0,020	0,020	kg	1874	0
	IV8	Adhesive for metal	0,000	0,000	0,000	kg	863	0
		Silicone	0,057	0,057	0,057	kg	1149	4500
		Stainless steel	0,860	0,860	0,860	kg	1104	14400
		PU rubber	0,400	0,400	0,400	kg	991	12000
		PVC	0,160	0,160	0,160	kg	1000	18000
		EPDM	0,120	0,120	0,120	kg	1000	18000
		Brass	2,988	2,988	2,988	kg	1000	18000
		Copper	0,020	0,020	0,020	kg	1000	18000
		LDPE film	0,002	0,002	0,002	kg	256	0
		Paper	0,100	0,100	0,100	kg	932	9000

Life cycle stage	Compo-nent/process	Material/input	Scenarios				Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
		Cardboard	0,144	0,144	0,144	kg	1000	18000
		PP	0,020	0,020	0,020	kg	1000	18000
		Nickel	0,020	0,020	0,020	kg	271	0
	Label & sign**	Paper	0,140	0,140	0,140	kg	445	6000
		LDPE film	0,160	0,160	0,160	kg	0	0
	PA INLET	Brass	0,670	0,670	0,670	kg	1355	0
		EPDM	0,500	0,500	0,500	kg	913	9000
		Paper	0,010	0,010	0,010	kg	356	0
		LDPE film	0,016	0,016	0,016	kg	0	0
	Rail	Galvanized steel	4,958	4,958	4,958	kg	1416	0
	Seal**	LDPE film	0,130	0,130	0,130	kg	0	0
		Paper	0,120	0,120	0,120	kg	850	0
		PCB	0,052	0,052	0,052	kg	171	0
		Brass	0,085	0,085	0,085	kg	256	0
		Stainless steel	0,020	0,020	0,020	kg	309	0
		Copper+zinc+gold plated	0,010	0,010	0,010	kg	1027	0
	Seal wire**	Stainless steel	0,170	0,170	0,170	kg	155	0
		ABS	0,160	0,160	0,160	kg	195	0
	Silencer	Aluminum	8,550	8,550	8,550	kg	1011	9000
		Stainless steel	0,870	0,870	0,870	kg	265	0
		Cardboard	1,500	1,500	1,500	kg	816	0
		Lubricant	0,216	0,216	0,216	kg	128	0
		Paper	0,060	0,060	0,060	kg	1000	18000
	SV CIV + port	EPDM	2,271	2,271	2,271	kg	0	0
		Stainless steel	1,275	1,275	1,275	kg	632	0
		Brass	0,185	0,185	0,185	kg	1054	15750
		Paper	0,020	0,020	0,020	kg	566	3600
		LDPE film	0,020	0,020	0,020	kg	0	0
		Adhesive for metal	0,186	0,186	0,186	kg	676	9000
		Copper	0,010	0,010	0,010	kg	649	6000
		Nickel	0,010	0,010	0,010	kg	1810	1286
		PP	0,010	0,010	0,010	kg	256	0
	SV22	LDPE film	0,090	0,090	0,090	kg	1000	18000
		Nickel	0,010	0,010	0,010	kg	1232	0
		Copper	0,010	0,010	0,010	kg	840	3600
		Galvanized steel	0,151	0,151	0,151	kg	921	12000
		Cable, wire	0,028	0,028	0,028	kg	0	0
		Cardboard	0,062	0,062	0,062	kg	204	0
		PA6	0,010	0,010	0,010	kg	1874	0
		PU rubber	0,030	0,030	0,030	kg	2312	0
		Paper	0,130	0,130	0,130	kg	730	0
		PP	0,150	0,150	0,150	kg	778	0
	SM22	Adhesive for metal	0,534	0,534	0,534	kg	638	10800

Life cycle stage	Compo-nent/process	Material/input	Scenarios			Unit	Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
		Cardboard	1,000	1,000	1,000	kg	730	0
		EPDM	0,040	0,040	0,040	kg	2312	0
		Silicone	0,020	0,020	0,020	kg	782	0
		Galvanized steel	0,020	0,020	0,020	kg	1022	0
		PU rubber	0,240	0,240	0,240	kg	265	0
		Stainless steel	6,190	6,190	6,190	kg	1000	18000
		Paper	0,100	0,100	0,100	kg	1874	0
		Lubricant	0,160	0,160	0,160	kg	265	0
		LDPE film	0,060	0,060	0,060	kg	1000	18000
		Brass	7,713	7,713	7,713	kg	256	0
		PP	0,100	0,100	0,100	kg	22	0
	Tableau	Stainless steel	0,010	0,010	0,010	kg	356	0
		PP	0,106	0,106	0,106	kg	591	0
		PCB	0,048	0,048	0,048	kg	403	0
		LDPE film	0,020	0,020	0,020	kg	925	9000
		Paper	0,010	0,010	0,010	kg	0	0
	Tube	Stainless steel	0,118	0,118	0,118	kg	1000	18000
		PP	0,400	0,400	0,400	kg	256	0
Production (packaging)		PP foil	0,2	0,2	0,2	kg	500	0
		Cardboard	56	56	56	kg	500	0
		Paper	2,2	2,2	2,2	kg	500	0
		Wooden pallet	54	54	54	kg	500	0
		Steel	2	2	2	kg	500	0
Manufacturing/assembly (utilities)		Electricity	795	795	795	kWh	-	-
		Water	1228	1228	1228	L	-	-
		District heating	4610	4610	4610	MJ	-	-
Waste manage-ment (man-ufacturing waste)	Recycling	Steel (incl. galva-nized and stainless steel)	150	150	150	kg	100	0
		Aluminum	0,888	0,888	0,888	kg	100	0
		Copper and brass	5,39	5,39	5,39	kg	100	0
		Battery	5,24	5,24	5,24	kg	100	0
		Electronics	2,30	2,30	2,30	kg	100	0
	Avoided pro-duction (cred-iting)	Steel (incl. galva-nized and stainless steel)	120	120	120	kg	-	-
		Aluminum	0,710	0,710	0,710	kg	-	-
		Copper and brass	4,31	4,31	4,31	kg	-	-
		Battery	4,19	4,19	4,19	kg	-	-
		Electronics	1,84	1,84	1,84	kg	-	-
Waste manage-ment (EoL)	Recycling	ABS	1,94	0,836	0,836	kg	100	0
	Incineration		0	1,11	0	kg	100	0
	Landfilling		0	0	1,11	kg	100	0
	Incineration	Adhesive for metal	1,26	1,26	1,26	kg	100	0
	Evaporated before EoL	Ethanol	1,13	1,13	1,13	kg	100	0

Life cycle stage	Compo-nent/process	Material/input	Scenarios				Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
	Recycling	Aluminum	8,55	3,68	3,68	kg	100	0
	Incineration		0	4,87	0	kg	100	0
	Landfilling		0	0	4,87	kg	100	0
	Recycling	Brass	28,6	12,3	12,3	kg	100	0
	Incineration		0	16,3	0	kg	100	0
	Landfilling		0	0	16,3	kg	100	0
	Recycling	Cable, wire	2,45	1,05	1,05	kg	100	0
	Incineration		0	1,40	0	kg	100	0
	Landfilling		0	0	1,40	kg	100	0
	Incineration	Cardboard	2,81	2,81	2,81	kg	100	0
	Released into atmosphere	Inergen	84,0	84,0	84,0	kg	100	0
	Recycling	Copper	0,197	0,085	0,085	kg	100	0
	Incineration		0	0,112	0	kg	100	0
	Landfilling		0	0	0,112	kg	100	0
	Recycling	Copper+zinc+gold plated	0,010	0,004	0,004	kg	100	0
	Incineration		0	0,006	0	kg	100	0
	Landfilling		0	0	0,006	kg	100	0
	Recycling	Disinfectant wipes/PET cloth	1,84	0,792	0,792	kg	100	0
	Incineration		0	1,05	0	kg	100	0
	Landfilling		0	0	1,05	kg	100	0
	Recycling	EPDM	13,6	5,84	5,84	kg	100	0
	Incineration		0	7,74	0	kg	100	0
	Landfilling		0	0	7,74	kg	100	0
	Incineration	Epoxy resin	0,050	0,050	0,050	kg	100	0
	Recycling	Galvanized steel	456	196	196	kg	100	0
	Incineration		0	260	0	kg	100	0
	Landfilling		0	0	260	kg	100	0
	Evaporated before EoL	Isopropyl	0,020	0,020	0,020	kg	100	0
	Recycling	LDPE film	0,558	0,240	0,240	kg	100	0
	Incineration		0	0,318	0	kg	100	0
	Landfilling		0	0	0,318	kg	100	0
	Incineration	Lubricant	0,432	0,432	0,432	kg	100	0
	Recycling	Neodymium	0,036	0,015	0,015	kg	100	0
	Incineration		0	0,021	0	kg	100	0
	Landfilling		0	0	0,021	kg	100	0
	Recycling	Nickel	0,040	0,017	0,017	kg	100	0
	Incineration		0	0,023	0	kg	100	0
	Landfilling		0	0	0,023	kg	100	0
	Recycling	PA6	0,120	0,052	0,052	kg	100	0
	Incineration		0	0,068	0	kg	100	0
	Landfilling		0	0	0,068	kg	100	0
	Incineration	Paper	0,863	0,863	0,863	kg	100	0
	Recycling	PCB	0,147	0,063	0,063	kg	100	0

Life cycle stage	Compo-nent/process	Material/input	Scenarios				Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
	Incineration		0	0,084	0	kg	100	0
	Landfilling		0	0	0,083961	kg	100	0
	Recycling	PET	0,020	0,009	0,009	kg	100	0
	Incineration		0	0,011	0	kg	100	0
	Landfilling		0	0	0,011	kg	100	0
	Recycling	PP	0,806	0,347	0,347	kg	100	0
	Incineration		0	0,459	0	kg	100	0
	Landfilling		0	0	0,459	kg	100	0
	Recycling	PU rubber	0,905	0,389	0,389	kg	100	0
	Incineration		0	0,516	0	kg	100	0
	Landfilling		0	0	0,516	kg	100	0
	Recycling	PVC	0,170	0,073	0,073	kg	100	0
	Incineration		0	0,097	0	kg	100	0
	Landfilling		0	0	0,097	kg	100	0
	Recycling	Silicone	0,097	0,042	0,042	kg	100	0
	Incineration		0	0,055	0	kg	100	0
	Landfilling		0	0	0,055	kg	100	0
	Recycling	Stainless steel	32,7	14,0	14,0	kg	100	0
	Incineration		0	18,6	0	kg	100	0
	Landfilling		0	0	18,6	kg	100	0
	Recycling	Steel	318	137	137	kg	100	0
	Incineration		0	181	0	kg	100	0
	Landfilling		0	0	181	kg	100	0
Avoided production (crediting)	Recycling***	ABS	0,972	0,418	0,418	kg	-	-
		Aluminum	6,84	2,94	2,94	kg	-	-
		Brass	22,9	9,85	9,85	kg	-	-
		Cable, wire	1,96	0,844	0,844	kg	-	-
		Copper	0,158	0,068	0,068	kg	-	-
		Copper+zinc+gold plated	0,008	0,003	0,003	kg	-	-
		Disinfectant wipes/PET cloth	0,921	0,396	0,396	kg	-	-
		EPDM	6,79	2,92	2,92	kg	-	-
		Galvanized steel	365	157	157	kg	-	-
		LDPE film	0,279	0,120	0,120	kg	-	-
		Neodymium	0,029	0,012	0,012	kg	-	-
		Nickel	0,032	0,014	0,014	kg	-	-
		PA6	0,060	0,026	0,026	kg	-	-
		PCB	0,118	0,051	0,051	kg	-	-
		PET	0,010	0,004	0,004	kg	-	-
		PP	0,403	0,173	0,173	kg	-	-
		PU rubber	0,453	0,195	0,195	kg	-	-
		PVC	0,085	0,037	0,037	kg	-	-
		Silicone	0,049	0,021	0,021	kg	-	-
		Stainless steel	26,1	11,2	11,2	kg	-	-

Life cycle stage	Compo-nent/process	Material/input	Scenarios				Transport*	
			1: DK-REC	2: EU-REC/INC	3: EU-REC/LDF	Unit	Truck transport (km)	Ship transport (km)
		Steel	255	109	109	kg	-	-
	Energy recov-ery from incin-eration****	Electricity (grid mix)	133	76	0	MJ	-	-
		Thermal energy (steam) (natural gas)	310	177	0	MJ	-	-

*Transportation vehicle and type depends on the life cycle stage in scope, check Appendix 1 and section 2.4 for details. Also see section 2.5 for details on weighted average for transportation of components vs assumed distances for transportation of other materials.
**These components are replaced once during the lifetime of the system and therefore production of new components is considered. This also affects the materials handled at EoL that will be handled according to the geographical area in scope.
*** The recycled content and avoided virgin material is related to the PEF formula, and the A factor in circular footprint formula (split between “upstream” and “downstream” crediting). Here an A factor of 0,5 for plastic, 0,8 for paper and cardboard and 0,2 for metals and electronics are applied according to Annex C.
**** The energy recovered from incineration is electricity substituting the consumption grid mix and steam substituting natural gas.

4. Results

The carbon footprint results due to emissions of greenhouse gasses are presented in characterized form as kg CO_2-equivalents for all scenarios. The characterized results are then translated into normalized form, hence person equivalents (PE), as explained in section 2.1. The detailed results are also listed in Appendix 4 and Appendix 5 for characterized and normalized results, respectively.

4.1. Characterized results (carbon footprint)

The characterized results are presented in Figure 2 where the overall life-cycle stages are visible, namely extraction of raw materials and production of components, manufacturing/assembly (use of utilities), packaging, transportation, and EoL, to quantify which part of the lifecycle that contribute the most to the carbon footprint. The results are presented for the three scenarios 1, 2 and 3. The overall carbon footprints of the life cycle of the system are 3107-, 3932- and 3902-kg CO_2-eq (3,1-, 3,9- and 3,9-ton CO_2-eq) as shown in Figure 2 for scenario 1, 2 and 3, respectively. Note that the total carbon footprint includes both carbon footprint emissions from activities such as manufacturing (positive contributions) as well as avoided carbon footprint emissions from recycling of waste fractions (negative contributions).

The production of components (incl. extraction of raw materials and upstream processes) is the largest contributor and responsible for 58-67% of the carbon footprint in absolute numbers[6] out of the total carbon footprint in Figure 2. The characterized results are also presented in Figure 3, where the individual components of the Fire Eater system can be viewed. In Table 2, the components and their composition are listed.

The components of main importance for the total carbon footprint are the *Cylinder* containing the Inergen and the grouped component termed *Fitting, clamp, pipe and pressure*. These two components are responsible for 81% of the carbon footprint of the extraction of raw materials and production of all components (for all scenarios). Both components contain a large amount of steel, stainless steel and galvanized steel, see Table 2, that are driving the carbon footprint. In fact, 80% of the total weight of the entire system comes from the steel materials in the *Cylinder* and the pipes in the grouped component named *Fitting, clamp, pipe and pressure* (for all scenarios). There are many other components listed in Table 2 which consist of various materials but in much smaller amounts compared to the steel in the *Cylinder* and *Fitting, clamp, pipe and pressure*. This explains why the carbon footprint of the remaining components are not as significant as the *Cylinder* and *Fitting, clamp, pipe and pressure*, see Figure 3. This is also despite the fact that some of the components have been replaced during the maintenance of the system. The full list of replaced components is available in Appendix 3.

Thus, an important aspect is that the maintenance of the system also requires the replacement of the *Cylinder* after 10 years of use. The replacement of a component requires the production of another. Thus,

[6] The absolute value | x | of a real number x is the non-negative value of x without regard to its sign. Thus, the credited processes such as recycling of waste and avoided production of electricity and heat are expressed in absolute terms, hence non-negative values, and the total carbon footprint for all life cycle stages is corrected accordingly. All percentage values stated in the report are calculated based on the absolute values.

the amount of steel in Table 2 for the *Cylinder* component corresponds to the production of two *Cylinder* components as two are needed to fulfill the FU.

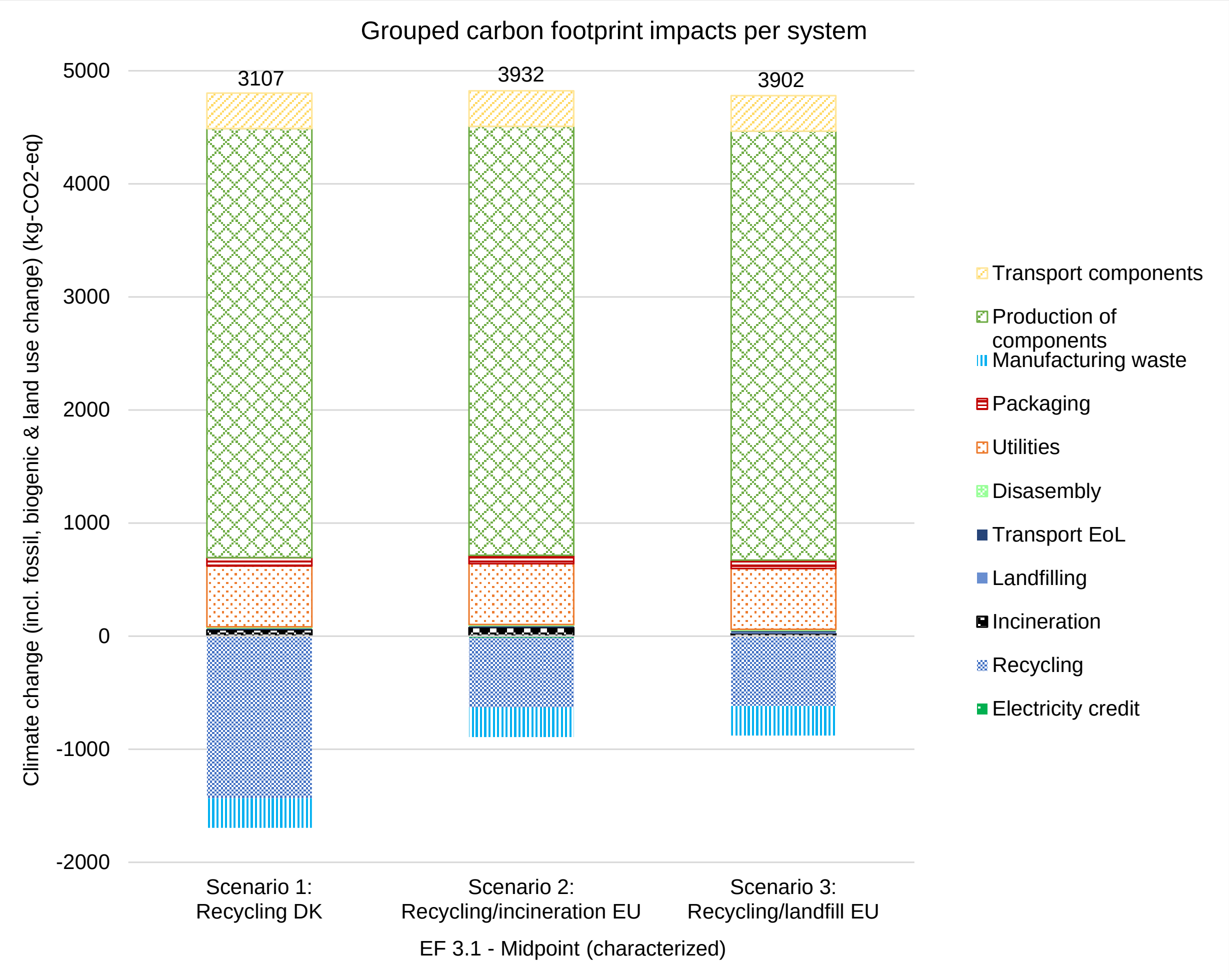

Figure 2: Characterized carbon footprint results for the three scenarios covering the life cycle of 1 Fire Eater system from cradle-to-grave. However, please note that parts of the lifecycle are not included, see section 2.2.

The second most contributing process to the carbon footprint is the recycling that contributes to 11-22% of the total carbon footprint in absolute numbers. Note that the contribution is negative as recycled materials are credited for the avoided production of virgin materials. For further elaboration see section 4.1.1.

Concerning the other processes in the life cycle of the system, they are to a lesser extent important. This concerns the utilities (energy and water use) being responsible for 8-10% of the overall carbon footprint followed by transport (both from cradle-to-gate and from gate-to-grave) responsible for 5-6%, manufacturing waste responsible for 4-5% (note that this is a negative contribution due to recycling of manufacturing waste) and packaging responsible for 1%. Lastly, depending on the scenario, the disassembly and either landfilling or incineration (including energy recovery) are responsible for 1-2%. The incineration process requires energy input (why a positive impact can be observed). Modern incineration plants have high energy recovery, meaning less heat and electricity are produced elsewhere and results in a credit (negative impact). Thus, the carbon footprint of the incineration process depends both on energy input for incineration, efficiency and potential energy recovery which is further elaborated in section 4.1.1.

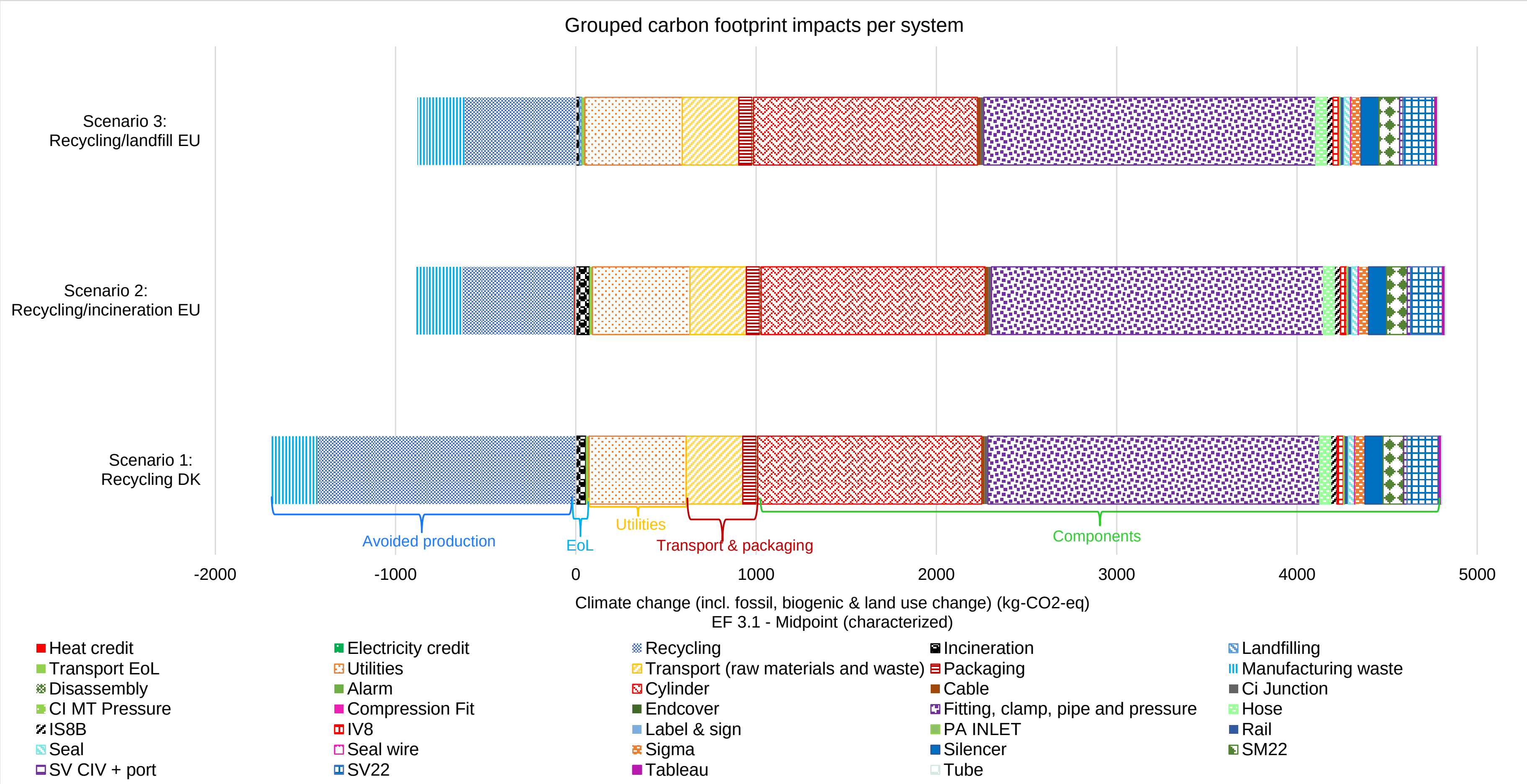

Figure 3: Characterized carbon footprint results with individual components visible for the three scenarios covering the life cycle of one Fire Eater system from cradle-to-grave. However, please note that parts of the lifecycle are not included, see section 2.2.

4.1.1. *Scenario comparison*

The difference in the three scenarios lie in the EoL stage, where the geographical scope and waste management technologies differ, see section 2.4 for details. The results in both Figure 2 and Figure 3 clearly illustrate the benefits of sending the entire system to recycling as is the case for scenario 1 with 100% recycling in Denmark. The overall carbon footprint is significantly lower for scenario 1 compared to scenario 2 and 3. This is because of the avoided production of new materials such as steel (incl. stainless, galvanized) which is the dominating material and is responsible for 84% of the weight of the entire product.

Loss of materials during recycling have been considered. Also, the CFF is applied to all recycling processes ensuring that a share of the burdens and benefits from recycling is allocated to the next life cycle in which the recycled material is utilized, hence not exclusively to the recycling process.

In scenario 2, 57% of the product (incl. components replaced during maintenance) at EoL is sent for incineration with energy recovery that results in credit due to avoided production of electricity and heat. As seen in Figure 2 and Figure 3, the credit for energy recovery is not significant. This is because most of the waste materials generated when disassembling the system are metals e.g., 84% are steel. Metals are not combustible and as a result incineration of metals is not a feasible EoL practice (Pommer et al., 2001). Therefore, when the system primarily consists of metals (84% steel, 3% copper, 1% aluminum and <1% of other metals), no energy will be recovered from incineration of these materials. Thus, the energy recovered in scenario 2, i.e. heat and electricity credited in Figure 2 and Figure 3, from scenario 2 come from plastics, rubber, paper and cardboard sent for incineration which combined constitute about 10% of the total weight of the system. Thus, further strengthening the benefits of recycling the system.

In scenario 3, 57% of the product (incl. components replaced during maintenance) at EoL is sent to landfill. Landfilling does not lead to significant greenhouse gas emissions of the present carbon footprint as it appears from the results in Appendix 5 hence, the landfilling is not visible in Figure 2 and Figure 3. When landfilling waste, the organic materials in the waste e.g., in paper and cardboard, will decompose and produce greenhouses gasses that are released into the atmosphere. However, it is metals that are responsible for the largest part of the Fire Eater system and metals do not decompose like organic materials and will therefore not contribute to the carbon footprint in landfills. However, discarding metals onto landfills will have several other impacts on the environment due to the release of toxins. This is not a part of the carbon footprint study as it is not measured in kg CO_2-eq. but can be seen if conducting a complete LCA study with several environmental impact categories and not exclusively climate change.

Lastly, it shall be noted that the EoL scenarios are based on statistical and average values. Thus, they quantify the potential impact and not necessarily the actual impact. Thereby, the carbon footprint depend on how the actual user of the system handles at the at the EoL stage. If the user ensures that more or less of the product is sent for recycling, incineration or landfill it will influence the carbon footprint.

4.2. Normalized results (person equivalents)

The normalized results for scenarios 1, 2 and 3 are presented in Figure 4 and detailed results can be viewed in Appendix 5. The normalized carbon footprint is compared to the average person equivalents (PE) which is a quantification of the environmental impact caused annually by the activities of an average European. Normalization of results is a measure to compare environmental impact to something comprehensible and is done for all three scenarios. The results show that the climate change impact category expressed in carbon footprint ranges within 0,41-0,52 PE in the three scenarios. Thus, the carbon footprint of the life cycle of the Fire Eater system corresponds to 41-52% of the greenhouse gas emissions that an average European is responsible for in one year , depending on the scenario.

The normalized results reveal the same trend as the characterized results presented in section 4.1, where scenario 1 has a lower carbon footprint of 0,41 PE than scenario 2 and 3 with 0,52 PE (for each) due to higher share of recycling at the EoL which is credited.

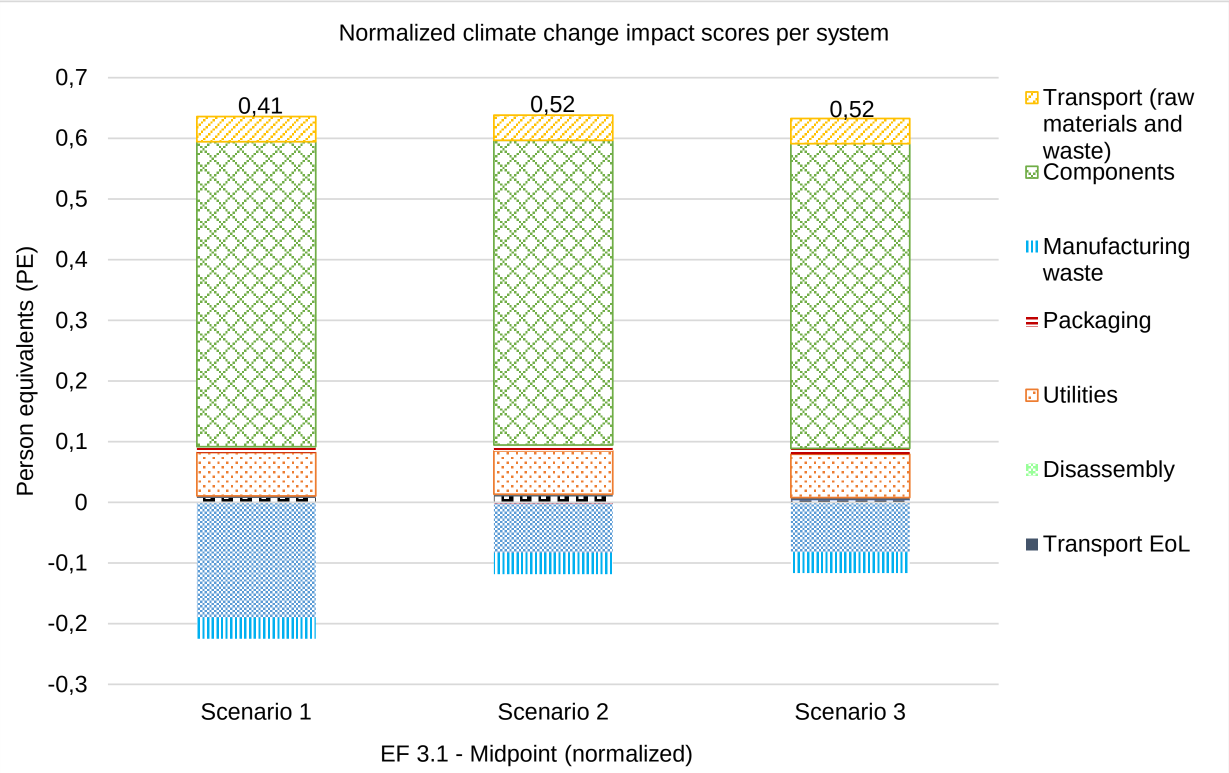

Figure 4: Normalized climate change impact scores for the three scenarios covering the life cycle of one Fire Eater system from cradle-to-grave. However, please note that parts of the lifecycle are not included, see section 2.2.

4.3. Future considerations

It is important to be aware that assumptions have been made throughout the study and the results shall be handled with care, see section 2.4 and Appendix 1, 2 and 3. This is primarily regarding the raw materials that are used to produce the components which resemble the Fire Eater system. For future studies the primary data can be improved, however, this requires in-depth work with suppliers and processes and can be complicated.

Additionally, the robustness of the assumptions made such as the choice of datasets have not been assessed. This can be investigated through sensitivity and uncertainty analyses which is a part of the ISO 14040/14044 guidelines when conducting a complete LCA.

Another consideration for future studies is including the remaining parts of the life cycle, namely installation phase and the entire use phase, i.e. the consumption of energy and other materials when the system is in use both when it is on standby mode and when it is activated. Thereby completing the cradle-to-grave carbon footprint and ensuring all activities in all life cycle stages are covered. This will change the results and could potentially alter the conclusions.

Also, other LCA environmental impacts could be quantified, along with greenhouse gas emissions such as eutrophication and resource use of minerals and metals. Thereby investigating the risk of environmental burden shifting.

Lastly, comparing the carbon footprint of the Fire Eater system with other currently applied fire extinction methods e.g., using water could be another aspect to consider in future studies.

5. Conclusion

This study quantifies the potential carbon footprint of a Fire Eater fire extinction system over its lifetime of 20 years, including extraction and processing raw materials into components, manufacturing and assembly of system, packaging, transport, maintenance and different EoL waste management. Three EoL scenarios are included that investigates different waste treatment technologies: recycling in Denmark (scenario 1) and a mixture of recycling and incineration or landfilling in Europe (scenario 2 and 3).

The results show that the greenhouse gas emissions related to scenarios 1, 2 and 3 are 3107-, 3932- and 3902-kg CO_2-eq, respectively. Scenario 1 has the highest recycling percentage at the EoL stage and also the lowest carbon footprint among the scenarios due to the credit gained from avoided production of raw materials. Thus, it clearly shows the benefits of Fire Eater being in control of the maintenance and EoL of the system by ensuring the materials are sent for recycling.

The life cycle stage that contributes the most to the carbon footprint is the extraction of raw materials that are processed into components before the system is assembled. Assumptions are made for some raw materials when the data availability is limited, however, this is not expected to have significant impact on the conclusions of the study. The high amount of steel in some components are dominating the carbon footprint. The maintenance of the system also plays an important role as it requires the replacement of some components and thereby the need to produce several of the same components. Thus, the choice of raw materials and need for maintenance can be beneficial for Fire Eater to investigate. This can be by looking into extending the lifetime of the *Cylinder* to avoid replacements of the component before the system has reach the EoL and thereby reduce the carbon footprint.

The EoL scenarios and in particular the share of recycling is the second most important life cycle stage to the carbon footprint. Whereas, the remaining life cycle stages including manufacturing (utilities), packaging and transport are to a lesser extent important for the overall carbon footprint.

The use stage of the life cycle is not completely covered as the consumption of electricity during the use of the system was not available. This can be further investigated by Fire Eater, so the carbon footprint of all activities during the entire life cycle of the fire extinction system is covered. Thereby Fire Eater has a more robust and better basis for making decisions on what life cycle stage to focus on if wanting to reduce the total carbon footprint. It could also be necessary to collect more detailed primary data, so the basis for the results and assumptions can be strengthened. A future follow-up study could also quantify more LCA environmental impact categories and thereby unveil more benefits and/or burdens.

6. References

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7. Appendix

7.1. Appendix 1: Secondary process data applied in the study

Life cycle stage	Material/action modelled	Process in tool	Source	Geographical coverage	Year (validity)	Comment
Raw materials extraction and pre-processing (production of components)	Halogen-free plastic + ABS plastic	Acrylonitrile-butadiene-styrene copolymer {RER}| acrylonitrile-butadiene-styrene copolymer production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	PC/ABS blends are used as alternatives for halogen free cable ducts (no flour, chloride, bromide). ABS is therefore used
	ABS extrusion	Extrusion, plastic film {RER}| extrusion, plastic film | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Brass	Brass {RoW}| brass production | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	
	Brass shaping	Metal working, average for metal product manufacturing {RoW}| metal working, average for metal product manufacturing | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	
	Adhesive for metal	Adhesive, for metal {DE}| adhesive production, for metal | Cut-off, S	Ecoinvent 3.9.1	Germany	2022	No European dataset, therefore German is chosen as best representative
	Alcohol, 80%	Ethanol {GLO} | technology mix | production mix, at plant | 100% active substance | LCI result	Ecoinvent 3.9.1	Global	2022	Alcohol used in cleaning agent spray
	Aluminum	Aluminium alloy, AlMg3 {RER}| aluminium alloy production, AlMg3 | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	Most of the aluminium are produced from aluminium alloys
	Aluminum shaping	Metal working, average for aluminium product manufacturing {RER}| metal working, average for aluminium product manufacturing | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Cable, wire	Cable, unspecified {GLO}| cable production, unspecified | Cut-off, S	Ecoinvent 3.9.1	Global	2022	
	Cardboard	Corrugated board box {RER}| corrugated board box production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Copper	Copper, cathode {GLO}| cobalt production | Cut-off, S	Ecoinvent 3.9.1	Global	2022	The cathode is the basic product of copper production.
	Copper shaping	Metal working, average for copper product manufacturing {RER}| metal working, average for copper product manufacturing | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	CuZn gold-plated	Copper concentrate, sulfide ore {CN}| copper mine operation and beneficiation, sulfide ore | Cut-off, S	Ecoinvent 3.9.1	China	2022	Copper with gold and zinc
	Disinfectant wipes	Textile, nonwoven polyester {RoW}| textile production, nonwoven polyester, needle-punched | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	Disinfectant wipes are made of non-woven material
	EPDM and rubber	Synthetic rubber {RoW}| synthetic rubber production | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	Different rubbers and various EPDM types are all assumed to be EPDM, petrochemical based, due to limited options. No steel reinforced rubber was available. Therefore, EPDM is chosen as it is often used as reinforced rubber material. The synthetic rubber is EPDM
	Epoxy hardener and primer	Epoxy resin, liquid {RoW}| epoxy resin production, liquid | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	No hardener available. The amount is small therefore resin is used as proxy
	Galvanized steel	Steel, low-alloyed, hot rolled {RER}| steel production, low-alloyed, hot rolled | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	

Life cycle stage	Material/action modelled	Process in tool	Source	Geographical coverage	Year (validity)	Comment
	Galvanization process	Zinc coat, coils {RER}| zinc coating, coils | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	the unit is in m2, but we consider the use of 64 m2/t from the description
	Shaping galvanized steel	Metal working, average for steel product manufacturing {RER}| metal working, average for steel product manufacturing | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	Galvanized steel includes zinc plated steel
	Isopropyl alcohol	Isopropanol {RER}| isopropanol production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	LDPE film	Packaging film, low density polyethylene {RER}| packaging film production, low density polyethylene | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	In the primary data descriptions, the LDPE is film/foil/bags which corresponds to the production of packaging film. Also, labels are considered to be LDPE film, as plastic laminate labels are often made of PE or LDPE
	Paste + gear lube	Lubricating oil {RER}| lubricating oil production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	Different types of lubricants
	Neodymium	Neodymium oxide {GLO}| market for neodymium oxide | Cut-off, S	Ecoinvent 3.9.1	Global	2022	
	Nickel	Nickel, class 1 {GLO}| processing of nickel-rich materials | Cut-off, S	Ecoinvent 3.9.1	Global	2022	
	PA6	Nylon 6-6 {RoW}| nylon 6-6 production | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	There is a small part in a single component that is PA6, glassfilled. It is assumed that PA66 is appropriate. The production of PA66 is considered appropriate for PA6
	Paper	Kraft paper {RER}| kraft paper production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	PCB	Printed wiring board, surface mounted, unspecified, Pb free {GLO}| printed wiring board production, surface mounted, unspecified, Pb free | Cut-off, S	Ecoinvent 3.9.1	Global	2022	Surface Mount is used more frequently than Through Hole since it is more reliable and less expensive
	PET	Polyethylene terephthalate, granulate, amorphous {Europe without Switzerland}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	PET granulates extrusion to foil	Extrusion, plastic film {RER}| extrusion, plastic film | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	PP	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	PP injection molding	Injection moulding {RER}| injection moulding | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	PU rubber	Thermoplastic polyurethane rubber (TPR) {GLO} | extrusion of a blend of thermoplastic polyurethane (TPU) pellets and rubber granulates | production mix, at plant | petrochemical based | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Global	2020-2024	Different kinds of PU rubbers are combined into one
	PVC	Polyvinylchloride, suspension polymerised {RoW}| polyvinylchloride production, suspension polymerisation | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	About 80% of production involves suspension polymerization.
	Silicone	Silicone product {RER}| silicone product production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Steel	Steel, low-alloyed, hot rolled {RER}| steel production, low-alloyed, hot rolled | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Steel shaping	Metal working, average for steel product manufacturing {RER}| metal working, average for steel product manufacturing | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	

Life cycle stage	Material/action modelled	Process in tool	Source	Geographical coverage	Year (validity)	Comment
	Stainless steel	Steel, chromium steel 18/8, hot rolled {RER}| steel production, chromium steel 18/8, hot rolled | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	Stainless steel is an iron and chromium alloy.
	Stainless steel shaping	Metal working, average for chromium steel product manufacturing {RER}| metal working, average for chromium steel product manufacturing | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
Packaging	EUR pallet	EUR-flat pallet {RER}| EUR-flat pallet production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	The dataset doesn't include the production of the pallet but only the materials. It is not considered to have significant impact
	PP plastic film	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, S. Incl. Extrusion, plastic film {RER}| extrusion, plastic film | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Cardboard	Corrugated board box {RER}| corrugated board box production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Paper	Kraft paper {RER}| kraft paper production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
	Steel	Steel, low-alloyed, hot rolled {RER}| steel production, low-alloyed, hot rolled | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
Manufacturing (utilities)	Electricity	Electricity, medium voltage {DK}| electricity, medium voltage, residual mix | Cut-off, U	Ecoinvent 3.9.1	DK	2022	
	District heating	District heating mix	Ecoinvent 3.9.1	DK	2022	Danish Energy Agency (2022). Heating mix includes natural gas, fuel oil, hard coal, waste, biogas, biomass.
	Tap water	Tap water {Europe without Switzerland}| tap water production, underground water without treatment | Cut-off, U	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
Transport	Ship transport (raw materials)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, S	Ecoinvent 3.9.1	Global	2022	Process includes heavy fuel oil consumption
	Truck transport (raw materials)	Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	Process includes diesel consumption
	Truck transport (waste management)	Transport, freight, lorry 16-32 metric ton, EURO6 {RER}| transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	
Waste management (dismantling system)	Dismantling system	Manual dismantling of used electric passenger car {GLO}| manual dismantling of used electric passenger car | Cut-off, S	Ecoinvent 3.9.1	Global	2022	Dismantling an electronic car with a weight of 1200kg. The system in scope weighs around 1000 kg. The dismantling dataset is a general process including a manual treatment facility for electric and electronic equipment (which main material composition is of metals) into components, hence not specific for electric cars. Therefore, the dataset is chosen as best representative for the dismantling due to limited data availability.
Waste management (recycling)	Aluminum waste	Recycling of aluminium into aluminium ingot - from pre-consumer {EU+EFTA+UK} | collection, transport, pretreatment, remelting | production mix, at plant | aluminium waste, efficiency 99% | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Europe	2015-2024	
	Battery waste (from manufacturing only)	Used Li-ion battery {GLO}| treatment of used Li-ion battery, hydrometallurgical treatment | Cut-off, S	Ecoinvent 3.9.1	Global	2022	One of the two most common recycling processes for batteries
	Cable waste	Used cable {GLO}| treatment of used cable | Cut-off, S	Ecoinvent 3.9.1	Global	2022	According to Ecoinvent process, 66% of the cable consist of copper and 34% of plastic that is credited when recycled.

Life cycle stage	Material/action modelled	Process in tool	Source	Geographical coverage	Year (validity)	Comment
	Copper and brass waste	Recycling of copper from electronic and electric waste {EU+EFTA+UK} | collection, transport, dismantling, shredding, separation, remelting | production mix, at plant | copper electronic waste, 95% efficiency | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Europe	2015-2024	
	Mixed electronic waste (from manufacturing but also including non-ferro metals as neodymium and nickel)	Waste electric and electronic equipment {GLO}| treatment of waste electric and electronic equipment, shredding | Cut-off, U	Ecoinvent 3.9.1	Global	2022	No specific processes were available for the non-ferro metals and some electronic materials. Therefore, the dataset is best representative as it includes a mixture of electronic waste incl. cables. Recycling output is considered to place cables. According to Ecoinvent process, 66% of the cable consist of copper and 34% of plastic that is credited when recycled.
	PCB waste	Used printed wiring boards {RoW}| treatment of scrap printed wiring boards, shredding and separation | Cut-off, S	Ecoinvent 3.9.1	Rest of World	2022	Average composition of PCB according to Arshadi et al. (2018) is used for recycling PCB. Here 23% iron, 18.5% copper, 10.5% aluminium and 20% plastics are considered, the remaining 28% is considered lost.
	Plastic waste (PP, PET, PET-cloth/disinfectant wipes, PA6, LDPE, PVC, ABS, PU rubber, silicone, EPDM)	Recycling of polypropylene plastic (PP) {EU+EFTA+UK} | from post-consumer waste, via washing, granulation, pelletization | production mix, at plant | 90% recycling rate | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Europe	2015-2024	PP plastic was chosen as representative for recycling of various plastic types. PP represent
	Steel and iron waste (incl. galvanized and stainless steel)	Recycling of steel into steel billet {EU+EFTA+UK} | collection, transport, pretreatment, remelting | production mix, at plant | steel waste, efficiency 95% | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Europe	2015-2024	
Waste management (incineration)	Aluminum waste	Scrap aluminium {Europe without Switzerland}| treatment of scrap aluminium, municipal incineration | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Cable waste	Residue from mechanical treatment, industrial device {CH}| treatment of residue from mechanical treatment, industrial device, municipal waste incineration | Cut-off, S	Ecoinvent 3.9.1	Switzerland	2022	No cable incineration process available. The dataset chosen includes incineration of cables.
	Cardboard and paper waste	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration | Cut-off, S	Ecoinvent 3.9.1	Switzerland	2022	
	Copper and brass waste	Scrap copper {Europe without Switzerland}| treatment of scrap copper, municipal incineration | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Hazardous waste (lubricants, epoxy resin, adhesives)	Hazardous waste, for incineration {Europe without Switzerland}| treatment of hazardous waste, hazardous waste incineration | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Non-ferro metals (nickel, neodymium)	Waste incineration of non-ferro metals, others {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pretreatment | production mix, at consumer | non-ferro metal waste | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Europe	2015-2024	
	PCB waste	Residue from mechanical treatment, industrial device {CH}| treatment of residue from mechanical treatment, industrial device, municipal waste incineration | Cut-off, S	Ecoinvent 3.9.1	Switzerland	2022	No PCB incineration process available. The dataset chosen includes incineration of pcbs.
	Plastic waste (PP, PET, PET-cloth/disinfectant wipes, PA6, LDPE, PVC, ABS)	Waste plastic, industrial electronics {CH}| treatment of waste plastic, industrial electronics, municipal incineration | Cut-off, S	Ecoinvent 3.9.1	Switzerland	2022	

Life cycle stage	Material/action modelled	Process in tool	Source	Geographical coverage	Year (validity)	Comment
	Rubber waste (EPDM, silicone, PU rubber)	Waste rubber, unspecified {Europe without Switzerland}| treatment of waste rubber, unspecified, municipal incineration | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Steel and iron waste (incl. galvanized and stainless steel)	Scrap steel {Europe without Switzerland}| treatment of scrap steel, municipal incineration | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
Waste management (landfilling)	Aluminum waste	Waste aluminium {CH}| treatment of waste aluminium, sanitary landfill | Cut-off, S	Ecoinvent 3.9.1	Switzerland	2022	
	Cable waste	Inert waste {Europe without Switzerland}| treatment of inert waste, sanitary landfill | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Cardboard and paper waste	Waste paperboard {CH}| treatment of waste paperboard, sanitary landfill | Cut-off, S	Ecoinvent 3.9.1	Switzerland	2022	
	Copper and brass waste	Inert waste {Europe without Switzerland}| treatment of inert waste, sanitary landfill | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Hazardous waste (lubricants, epoxy resin, adhesives)	Industrial waste, average, not hazardous, to residual landfill {EU+EFTA+UK} | LCI result	EF Database 3.1 - Plastics (Ecoinvent)	Europe	2015-2024	Best available process on mixed waste on landfill without knowing the specific composition
	Non-ferro metals (nickel, neodymium)	Inert waste {Europe without Switzerland}| treatment of inert waste, sanitary landfill | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	PCB waste	Inert waste {Europe without Switzerland}| treatment of inert waste, sanitary landfill | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
	Plastic waste (PP, PET, PET-cloth/disinfectant wipes, PA6, LDPE, PVC, ABS, PU rubber, silicone, EPDM)	Waste plastic, consumer electronics {GLO}| treatment of waste plastic, consumer electronics, sanitary landfill, wet infiltration class (500mm) | Cut-off, S	Ecoinvent 3.9.1	Global	2022	
	Steel and iron waste (incl. galvanized and stainless steel)	Scrap steel {Europe without Switzerland}| treatment of scrap steel, inert material landfill | Cut-off, S	Ecoinvent 3.9.1	Europe w/o Switzerland	2022	
Avoided production (crediting)	Aluminum	Aluminium, cast alloy {GLO}| aluminium ingot, primary, to aluminium, cast alloy market | Cut-off, S	Ecoinvent 3.9.1	Global	2022	A factor 0,8 applied
	Nickel	Nickel, class 1 {GLO}| processing of nickel-rich materials | Cut-off, S	Ecoinvent 3.9.1	Global	2022	A factor 0,8 applied
	Polypropylene	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, S	Ecoinvent 3.9.1	Global	2022	A factor 0,5 applied
	Steel	Steel, low-alloyed {GLO}| market for steel, low-alloyed | Cut-off, S	Ecoinvent 3.9.1	Global	2022	A factor 0,8 applied
	Copper	Copper, cathode {GLO}| copper production, cathode, solvent extraction and electrowinning process | Cut-off, S	Ecoinvent 3.9.1	Global	2022	A factor 0,8 applied
	Manganese from battery (from manufacturing)	Manganese {RER}| manganese production | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	By weight percentage, an average Li-ion battery is composed of 7% Co, 7% Li (Li2CO2), 4% Ni, 5% Mn, 10% Cu, 15% Al, 16% graphite, and 36% other materials (Pagliaro & Meneguzzo, 2019). According to the Ecoinvent process only the Cu, Al and Mn are recovered, hence 20% of the battery (weight percentage). A factor 0,8 applied.
	Heat	Heat, district or industrial, natural gas {RER}| market group for heat, district or industrial, natural gas | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	Average incineration efficiency in Europe considered, see section 2.5
	Electricity	Electricity, low voltage {RER}| electricity, low voltage, European attribute mix | Cut-off, S	Ecoinvent 3.9.1	Europe	2022	Average incineration efficiency in Europe considered, see section 2.5

7.2. Appendix 2: Material assumptions

Original material description (Fire Eater)	Modelled material (FT)	Comment/assumption	Lower heating value (LHV) (MJ/kg)*
ABS Plastic	ABS		40
Halogenfree plastic	ABS	PC/ABS blends are used as alternatives for halogen free cable ducts (no flour, chloride, bromide). ABS is therefore used	40
Halogen free plastic	ABS	PC/ABS blends are used as alternatives for halogen free cable ducts (no flour, chloride, bromide). ABS is therefore used	40
Ethyl SI1500	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Alcohol 80%	Ethanol		-
Aluminium	Aluminium		0
Brass	Brass		0
Brass	Brass		0
Plated Brass	Brass	Metal forming process is included in all brass processes, however, no specific for plating is available.	0
Wire	Cable, wire		0
Carboard	Cardboard		20
Cardboard	Cardboard		20
Cardboard	Cardboard		20
Co2 8%	CO2 and more	Inergen gas including CO2, N2 and Ar	-
copper	Copper	Copper cathode is modelled as the cathode is the basic product of copper production.	0
Cu	Copper	Copper cathode is modelled as the cathode is the basic product of copper production.	0
Copper	Copper	Copper cathode is modelled as the cathode is the basic product of copper production.	0
CUZN Gold plated	Copper+zinc+gold plated	Copper with gold and zinc was the best available dataset considering the information.	0
Alcohol wipes X70	Disinfectant wipes/PET cloth	Wipes are often made of non-woven PET material	30
EPDM 70	EPDM		46
FPM90 green	EPDM	No fluororubber available, therefore EPDM is chosen as best representative	46
Steel inforced rubber	EPDM	No steel reinforced rubber available. Therefore, EPDM chosen as it is often used as reinforced rubber material	46
EPDM	EPDM		46
EPDM	EPDM		46
EPDM Cell	EPDM		46
Rubber EPDM	EPDM		46
FPM75	EPDM	No fluororubber available, therefore EPDM is chosen as best representative	46
P5001	EPDM	O-ring but material not stated. Assumed to consist of EPDM as the other o-rings. Fine assumption given the small amounts	46
Epoxy base Primer 90	Epoxy resin		40
Epoxy hardener Primer 90	Epoxy resin	No hardener available. The amount is small therefore resin is used as proxy	40
Epoxy 50 mm2 35Um Cu	Epoxy resin		40
AISL303	Galvanized steel	In primary data from Fire Eater, it says Nipple sock 1/8-1/4", which is a steel bolt. Bolts are typically made of steel and plated with several coatings	0
Galvanized steel	Galvanized steel		0
Zinc plated Steel	Galvanized steel		0
Galv. Stål	Galvanized steel		0

Original material description (Fire Eater)	Modelled material (FT)	Comment/assumption	Lower heating value (LHV) (MJ/kg)*
Galv Stål	Galvanized steel		0
Gavl stål	Galvanized steel		0
Isopropyl Alc. 99%	Isopropyl		-
LDPE 50	LDPE film		40
Foiled plastic	LDPE film		40
Krytox GPL205	Lubricant	Type of lubricant, average process chosen	40
Molykote D Paste	Lubricant	Type of lubricant, average process chosen	40
Gear lube	Lubricant	Type of lubricant, average process chosen	40
Neodymium	Neodymium		0
Nickel	Nickel		0
Nickel	Nickel		0
Nylon	PA6		30
PA12GF30	PA6	Due to low amounts PA6 is chosen instead of glass-filled PA6.	30
paper	Paper		20
paper	Paper		20
foiled paper	Paper		20
PBT	PCB	Small amounts of PBT as a part of a PCB, therefore PCB is chosen as conservative assumption	0
Printplate	PCB		0
PCB	PCB		0
Laminated plast	LDPE film	Plastic laminate labels are often made of PE or LDPE	40
Foiled 2 layer plastic	LDPE film		40
Polyethylenterephthalat	PET		30
Polypropylen	PP		40
Plastic PP	PP		40
PU75	PU rubber		30
PU90	PU rubber		30
PU	PU rubber		30
Rubber PU 90	PU rubber		30
Rubber PU 75	PU rubber		30
Rubber PU751E1	PU rubber		30
pur	PU rubber		30
crimp pur	PU rubber		30
PVC	PVC		20
Plastic BSPT	PVC	British Standard Pipe Taper. Assumed PVC pipe material	20
Thread Loctite 2700	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Loctite 276	Adhesive for metal	Product use online, is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Loctite 7400	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Loctite 2700	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Dimethacrylate	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Thread Seal Loctite 248	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40

Original material description (Fire Eater)	Modelled material (FT)	Comment/assumption	Lower heating value (LHV) (MJ/kg)*
Thread seal Loctite276	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Loctite 290	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Loctite 276	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
loctite 5400	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Loctite 276 HARD	Adhesive for metal	Product use online is as adhesive for metals, electronics or others. Therefore, average dataset is chosen	40
Rubber P5001	PU rubber	Assumed PU rubber	30
Silicone 3140 RTV	Silicone		46
OHA O-ring lube	Lubricant	Type of lubricant, average process chosen	40
Steel	Stainless steel		0
Stainless Steel	Stainless steel		0
Stainless steel	Stainless steel		0
Powderpainted steel	Stainless steel		0
Stainless Steel aisi316	Stainless steel	g	0
Stål 34CrM04 EN 10 083	Steel		0
Plated steel	Steel		0

*According to values listed in Pommer et al. (2001). The same LHV is assumed for metals and electronics as only a few of the materials were listed and the same LHV value is considered for adhesives, lubricants and epoxy resin. When it is marked '-' then the LHV is not relevant because the material is not incinerated, this is the case for the Inergen, ethanol and isopropyl, see section 2.4 for details.

7.3. Appendix 3: List of components and their maintenance after 10 years

Component name	Status after 10 years of use
Alarm	Controlled and maintained
Cable	Maintained
Ci Junction	Maintained
CI MT Pressure	Maintained
Compression Fit	Replaced if worn out
Cylinder	Replaced and re-certified
Endcover	Maintained
Fitting, clamp, pipe and pressure	Maintained
Hose	Replaced
IS8B	Maintained
IV8	Reset and maintained
Label & sign	Replaced
Nozzel	Maintained
PA INLET	Maintained
Rail	Maintained
Seal	Maintained
Seal wire	Replaced
Sigma	Controlled and maintained
Silencer	Maintained
SM22	Maintained
SV CIV + port	Reset and maintained
SV22	Maintained
SV22 MT KIT	Maintained
SV22 Zone	Reset and maintained
Tableau	Controlled and maintained
Tube	Maintained

7.4. Appendix 4: Characterized impact results (midpoint) using EF 3.1

	Characterized results - scenario 1				Characterized results - scenario 2				Characterized results - scenario 3			
Process	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**
Total	**3,12E+03**	**5,38E+01**	**3,06E+03**	**3,98E+00**	**3,94E+03**	**5,45E+01**	**3,88E+03**	**4,73E+00**	**3,91E+03**	**5,87E+01**	**3,85E+03**	**4,73E+00**
Manufacturing utilities	5,39E+02	1,10E+00	5,38E+02	1,62E-01	5,39E+02	1,10E+00	5,38E+02	1,62E-01	5,39E+02	1,10E+00	5,38E+02	1,62E-01
Transport (raw materials and waste)	3,14E+02	7,85E-02	3,14E+02	1,71E-01	3,14E+02	7,85E-02	3,14E+02	1,71E-01	3,14E+02	7,85E-02	3,14E+02	1,71E-01
Packaging	7,26E+01	4,56E+00	6,71E+01	1,02E+00	7,26E+01	4,56E+00	6,71E+01	1,02E+00	7,26E+01	4,56E+00	6,71E+01	1,02E+00
Manufacturing waste	-2,62E+02	2,15E-01	-2,62E+02	-2,51E-01	-2,62E+02	2,15E-01	-2,62E+02	-2,51E-01	-2,62E+02	2,15E-01	-2,62E+02	-2,51E-01
Alarm	6,96E-01	3,73E-03	6,92E-01	1,75E-04	6,96E-01	3,73E-03	6,92E-01	1,75E-04	6,96E-01	3,73E-03	6,92E-01	1,75E-04
Cylinder	1,24E+03	1,74E+01	1,22E+03	1,03E+00	1,24E+03	1,74E+01	1,22E+03	1,03E+00	1,24E+03	1,74E+01	1,22E+03	1,03E+00
Cable	1,60E+01	5,24E-02	1,60E+01	1,72E-02	1,60E+01	5,24E-02	1,60E+01	1,72E-02	1,60E+01	5,24E-02	1,60E+01	1,72E-02
Ci Junction	1,59E+01	3,11E-02	1,59E+01	2,85E-02	1,59E+01	3,11E-02	1,59E+01	2,85E-02	1,59E+01	3,11E-02	1,59E+01	2,85E-02
CI MT Pressure	2,12E+00	3,53E-02	2,08E+00	2,97E-03	2,12E+00	3,53E-02	2,08E+00	2,97E-03	2,12E+00	3,53E-02	2,08E+00	2,97E-03
Compression Fit	4,56E-01	3,69E-03	4,52E-01	4,85E-04	4,56E-01	3,69E-03	4,52E-01	4,85E-04	4,56E-01	3,69E-03	4,52E-01	4,85E-04
Endcover	2,48E-02	6,81E-05	2,47E-02	2,27E-05	2,48E-02	6,81E-05	2,47E-02	2,27E-05	2,48E-02	6,81E-05	2,47E-02	2,27E-05
Fitting, clamp, pipe and pressure	1,84E+03	2,49E+01	1,82E+03	1,58E+00	1,84E+03	2,49E+01	1,82E+03	1,58E+00	1,84E+03	2,49E+01	1,82E+03	1,58E+00
Hose	6,33E+01	1,01E-01	6,31E+01	5,90E-02	6,33E+01	1,01E-01	6,31E+01	5,90E-02	6,33E+01	1,01E-01	6,31E+01	5,90E-02
IS8B	3,18E+01	2,34E-01	3,12E+01	4,22E-01	3,18E+01	2,34E-01	3,12E+01	4,22E-01	3,18E+01	2,34E-01	3,12E+01	4,22E-01
IV8	3,46E+01	5,23E-01	3,40E+01	6,21E-02	3,46E+01	5,23E-01	3,40E+01	6,21E-02	3,46E+01	5,23E-01	3,40E+01	6,21E-02
Label & sign	1,13E+00	9,42E-03	1,11E+00	1,82E-03	1,13E+00	9,42E-03	1,11E+00	1,82E-03	1,13E+00	9,42E-03	1,11E+00	1,82E-03
PA INLET	7,05E+00	8,96E-02	6,95E+00	1,21E-02	7,05E+00	8,96E-02	6,95E+00	1,21E-02	7,05E+00	8,96E-02	6,95E+00	1,21E-02
Rail	1,95E+01	2,68E-01	1,93E+01	1,67E-02	1,95E+01	2,68E-01	1,93E+01	1,67E-02	1,95E+01	2,68E-01	1,93E+01	1,67E-02

	Characterized results - scenario 1				Characterized results - scenario 2				Characterized results - scenario 3			
Process	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**
Seal	3,46E+01	9,54E-02	3,44E+01	6,71E-02	3,46E+01	9,54E-02	3,44E+01	6,71E-02	3,46E+01	9,54E-02	3,44E+01	6,71E-02
Seal wire	4,12E+00	2,38E-02	4,09E+00	3,01E-03	4,12E+00	2,38E-02	4,09E+00	3,01E-03	4,12E+00	2,38E-02	4,09E+00	3,01E-03
Sigma	5,40E+01	4,41E-01	5,35E+01	5,83E-02	5,40E+01	4,41E-01	5,35E+01	5,83E-02	5,40E+01	4,41E-01	5,35E+01	5,83E-02
Silencer	1,00E+02	7,45E-01	9,94E+01	2,53E-01	1,00E+02	7,45E-01	9,94E+01	2,53E-01	1,00E+02	7,45E-01	9,94E+01	2,53E-01
SM22	1,14E+02	1,50E+00	1,13E+02	1,93E-01	1,14E+02	1,50E+00	1,13E+02	1,93E-01	1,14E+02	1,50E+00	1,13E+02	1,93E-01
SV CIV + port	1,88E+01	1,15E-01	1,87E+01	2,07E-02	1,88E+01	1,15E-01	1,87E+01	2,07E-02	1,88E+01	1,15E-01	1,87E+01	2,07E-02
SV22	1,77E+02	2,36E+00	1,74E+02	2,95E-01	1,77E+02	2,36E+00	1,74E+02	2,95E-01	1,77E+02	2,36E+00	1,74E+02	2,95E-01
Tableau	1,49E+01	3,00E-02	1,48E+01	2,91E-02	1,49E+01	3,00E-02	1,48E+01	2,91E-02	1,49E+01	3,00E-02	1,48E+01	2,91E-02
Tube	1,24E+00	8,41E-03	1,23E+00	1,51E-03	1,24E+00	8,41E-03	1,23E+00	1,51E-03	1,24E+00	8,41E-03	1,23E+00	1,51E-03
Transport EoL	1,77E+01	5,17E-03	1,77E+01	8,73E-03	1,77E+01	5,17E-03	1,77E+01	8,73E-03	1,77E+01	5,17E-03	1,77E+01	8,73E-03
Recycling	-1,43E+03	-1,35E+00	-1,43E+03	-1,31E+00	-6,17E+02	-5,80E-01	-6,16E+02	-5,62E-01	-6,17E+02	-5,80E-01	-6,16E+02	-5,62E-01
Recycling copper & brass	-1,75E+02	-5,50E-01	-1,74E+02	-2,50E-01	-7,52E+01	-2,37E-01	-7,49E+01	-1,08E-01	-7,52E+01	-2,37E-01	-7,49E+01	-1,08E-01
Recycling aluminum	-1,41E+02	-1,61E-01	-1,41E+02	-4,23E-01	-6,08E+01	-6,94E-02	-6,06E+01	-1,82E-01	-6,08E+01	-6,94E-02	-6,06E+01	-1,82E-01
Recycling steel	-1,12E+03	-6,39E-01	-1,12E+03	-6,34E-01	-4,81E+02	-2,75E-01	-4,80E+02	-2,73E-01	-4,81E+02	-2,75E-01	-4,80E+02	-2,73E-01
Recycling mixed electronics	-1,00E-01	-4,36E-05	-1,00E-01	-3,41E-04	-4,32E-02	-1,87E-05	-4,30E-02	-1,47E-04	-4,32E-02	-1,87E-05	-4,30E-02	-1,47E-04
Recycling plastic	-2,10E+00	-2,00E-03	-2,10E+00	9,42E-05	-9,02E-01	-8,61E-04	-9,01E-01	4,05E-05	-9,02E-01	-8,61E-04	-9,01E-01	4,05E-05
Recycling PCB	4,64E-03	9,09E-06	4,62E-03	9,00E-06	2,00E-03	3,91E-06	1,99E-03	3,87E-06	2,00E-03	3,91E-06	1,99E-03	3,87E-06
Recycling cable	2,43E+00	2,65E-03	2,42E+00	8,82E-04	1,04E+00	1,14E-03	1,04E+00	3,79E-04	1,04E+00	1,14E-03	1,04E+00	3,79E-04
Incineration	5,54E+01	2,89E-03	5,53E+01	1,50E-03	7,53E+01	1,29E-02	7,53E+01	5,22E-03	2,17E+01	2,27E-04	2,17E+01	1,22E-04
Incineration hazard (lubricant, adhesive, resin)	4,73E+00	1,55E-03	4,73E+00	1,13E-03	4,52E+00	1,48E-03	4,52E+00	1,08E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Incineration rubber	5,05E+01	5,28E-04	5,05E+01	2,84E-04	5,05E+01	5,28E-04	5,05E+01	2,84E-04	2,17E+01	2,27E-04	2,17E+01	1,22E-04
Incineration cardboard and paper	9,28E-02	8,07E-04	9,19E-02	8,58E-05	9,28E-02	8,07E-04	9,19E-02	8,58E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00

	Characterized results - scenario 1				Characterized results - scenario 2				Characterized results - scenario 3			
Process	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**	**Climate change total (incl. Fossil, biogenic & land use change) (kg CO_2-eq)**	**Climate change – Biogenic (kg CO_2-eq)**	**Climate change – Fossil (kg CO_2-eq)**	**Climate change - Land use & LU change (kg CO_2-eq)**
Incineration plastic	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,02E+01	1,04E-04	1,02E+01	7,10E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Incineration aluminium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,24E-02	1,10E-04	8,22E-02	4,87E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Incineration copper	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,76E-01	3,71E-04	2,76E-01	1,64E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Incineration steel	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,85E+00	9,41E-03	5,84E+00	3,45E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Heat credit	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-1,07E+01	-1,20E-03	-1,07E+01	-9,32E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Electricity credit	0,00E+00	0,00E+00	0,00E+00	0,00E+00	-2,29E+00	-8,14E-03	-2,28E+00	-4,32E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Incineration Nickel + neodynium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,36E-03	1,72E-05	6,33E-03	9,87E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Incineration PCB + cable	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,75E+00	4,07E-05	3,75E+00	2,76E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Landfilling	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,12E+01	4,17E+00	7,08E+00	2,82E-03
Landfilling hazard (lubricant, adhesive, resin)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,97E+00	8,15E-01	2,16E+00	6,19E-04
Landfilling cardboard and paper	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,42E+00	3,35E+00	6,70E-02	4,36E-05
Landfilling plastic	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,47E+00	7,98E-04	1,47E+00	1,15E-04
Landfilling aluminium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,11E-02	2,35E-04	8,09E-02	2,35E-05
Landfilling copper, nickel, pcb, cable	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,32E-01	5,91E-04	2,31E-01	1,68E-04
Landfilling steel	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,07E+00	1,21E-03	3,07E+00	1,85E-03
Disassembly	8,84E+00	1,09E-01	8,72E+00	9,65E-03	8,84E+00	1,09E-01	8,72E+00	9,65E-03	8,84E+00	1,09E-01	8,72E+00	9,65E-03

7.5. Appendix 5: Normalized impact results in PE using EF 3.1

Process	Climate change (person equivalents)		
	Scenario 1	**Scenario 2**	**Scenario 3**
Total	**4,11E-01**	**5,21E-01**	**5,17E-01**
Top	1,78E-03	1,78E-03	1,78E-03
Manufacturing/assembly utilities	7,14E-02	7,14E-02	7,14E-02
Transport (raw materials and waste)	4,16E-02	4,16E-02	4,16E-02
Packaging	9,62E-03	9,62E-03	9,62E-03
Manufacturing waste	-3,47E-02	-3,47E-02	-3,47E-02
Alarm	9,21E-05	9,21E-05	9,21E-05
Cylinder	1,64E-01	1,64E-01	1,64E-01
Cable	2,12E-03	2,12E-03	2,12E-03
Ci Junction	2,11E-03	2,11E-03	2,11E-03
CI MT Pressure	2,81E-04	2,81E-04	2,81E-04
Compression Fit	6,04E-05	6,04E-05	6,04E-05
Endcover	3,28E-06	3,28E-06	3,28E-06
Fitting, clamp, pipe and pressure	2,44E-01	2,44E-01	2,44E-01
Hose	8,38E-03	8,38E-03	8,38E-03
IS8B	4,21E-03	4,21E-03	4,21E-03
IV8	4,58E-03	4,58E-03	4,58E-03
Label & sign	1,49E-04	1,49E-04	1,49E-04
PA INLET	9,33E-04	9,33E-04	9,33E-04
Rail	2,59E-03	2,59E-03	2,59E-03
Seal	4,58E-03	4,58E-03	4,58E-03
Seal wire	5,45E-04	5,45E-04	5,45E-04
Sigma	7,15E-03	7,15E-03	7,15E-03
Silencer	1,33E-02	1,33E-02	1,33E-02
SM22	1,51E-02	1,51E-02	1,51E-02
SV CIV + port	2,49E-03	2,49E-03	2,49E-03
SV22	2,34E-02	2,34E-02	2,34E-02
Tableau	1,97E-03	1,97E-03	1,97E-03
Tube	1,64E-04	1,64E-04	1,64E-04
Top	0,00E+00	0,00E+00	0,00E+00
Transport EoL	2,34E-03	2,34E-03	2,34E-03
Recycling	-1,90E-01	-8,17E-02	-8,17E-02
Recycling copper & brass	-2,32E-02	-9,96E-03	-9,96E-03
Recycling aluminum	-1,87E-02	-8,05E-03	-8,05E-03
Recycling steel	-1,48E-01	-6,37E-02	-6,37E-02
Recycling mixed electronics	-1,33E-05	-5,72E-06	-5,72E-06
Recycling plastic	-2,78E-04	-1,19E-04	-1,19E-04
Recycling PCB	6,15E-07	2,64E-07	2,64E-07
Recycling cable	3,21E-04	1,38E-04	1,38E-04
Incineration	7,33E-03	9,97E-03	2,88E-03

Process	Climate change (person equivalents)		
	Scenario 1	Scenario 2	Scenario 3
Incineration hazard (lubricant, adhesive, resin)	6,26E-04	5,99E-04	0,00E+00
Incineration rubber	6,69E-03	6,69E-03	2,88E-03
Incineration cardboard and paper	1,23E-05	1,23E-05	0,00E+00
Incineration plastic	0,00E+00	1,34E-03	0,00E+00
Incineration aluminium	0,00E+00	1,09E-05	0,00E+00
Incineration copper	0,00E+00	3,66E-05	0,00E+00
Incineration steel	0,00E+00	7,74E-04	0,00E+00
Heat credit	0,00E+00	-1,42E-03	0,00E+00
Electricity credit	0,00E+00	-3,03E-04	0,00E+00
Incineration Nickel + neodynium	0,00E+00	8,41E-07	0,00E+00
Incineration PCB + cable	0,00E+00	4,97E-04	0,00E+00
Landfilling	0,00E+00	0,00E+00	1,49E-03
Landfilling hazard (lubricant, adhesive, resin)	0,00E+00	0,00E+00	3,93E-04
Landfilling cardboard and paper	0,00E+00	0,00E+00	4,52E-04
Landfilling plastic	0,00E+00	0,00E+00	1,95E-04
Landfilling aluminium	0,00E+00	0,00E+00	1,07E-05
Landfilling copper, nickel, pcb, cable	0,00E+00	0,00E+00	3,07E-05
Landfilling steel	0,00E+00	0,00E+00	4,06E-04
Disassembly	1,17E-03	1,17E-03	1,17E-03