Life Cycle Assessment of Packaging Materials in relation to Extended Producer Responsibility

Report for the Danish Environmental Protection Agency

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Contents

1. Abstract

Packaging products play a crucial role in protecting, preserving, and promoting products. However, the rapid growth in packaging material consumption and single-use packaging designs contribute significantly to waste generation. To address this issue, the European Union has established targets and directives for reducing packaging waste and increasing reusable packaging in the market through a set of measures to promote a circular economy through targets on waste reduction, reuse, and minimum recycled content; an example is the Revision of Directive 94/62/EC on Packaging and Packaging Waste . Denmark also aims for faster implementation of circularity and reusability by introducing Extended Producer Responsibility (EPR) programs. Implementing EPR policies requires systematic assessments of a product's environmental impact. Life Cycle Assessment (LCA) is a tool that evaluates a product's impact throughout its entire life cycle. Conducting an LCA for a product is essential for identifying the most impactful alternatives, encouraging sustainable design, recycling and reuse, and tracking progress in reducing overall environmental impacts. This study provides an LCA of selected packaging materials considering three end-of-life scenarios: i) multiple-loop reuse, ii) multiple-loop recycling and iii) incineration as a reference. The aim is to support the Danish EPA in implementing EPR policies.

The study found that reuse is the most favourable option for all selected materials and packaging types. Recycling was the second-best option, with the highest benefits observed for energy-intensive materials like metals and glass. The incineration scenario was found to be the least desirable option, presenting the highest emissions on the environment for all materials and scenarios. The report provides comparable impact calculations for the three scenario types across the selected materials.

Keywords: Life Cycle Assessment, packaging, reuse, recycling, Circular Footprint Formula, Extended Producer responsibility

2. Introduction

2.1 Background

Packaging products, such as boxes, bottles, and bags, are essential in everyday life. The term "packaging" refers to the material used to contain a product or item (EC, 2021; EEA, 2018); some examples are bottles, boxes and bags. The main functionalities of packaging include protecting the product from damage, tampering, and contamination, e.g. during transportation, distribution and storage (Williams et al., 2020). Even if packaging often eases our daily challenges, the rapid and continuous growth in material consumption, such as plastics, paper, and metals, and material complexity significantly contribute to waste generation (EMF, 2021). In addition, most of the packaging today is designed for single-use, or in other words, to be disposed of after a single use-phase.

According to data from the Danish Environmental Protection Agency (EPA, 2019), in 2019, households in Denmark generated approximately 474,000 tonnes of packaging waste (EPA, 2020). This accounted for about 31% of the total household waste generated in Denmark that year. With a recycling rate of packaging waste of 69% in 2019, Denmark performed slightly better than the European average recycling rate, estimated at around 64% (Eurostat, 2019).

Packaging waste has been addressed in Europe through international, national and local directives and legislation (EEA, 2022). The recent revision of the European Union's Packaging and Packaging Waste Directive encourages the reduction of packaging waste and the share increase of reusable packaging in the market (EC, 2022). The directive also includes recycling rate targets for packaging waste which all Member States should attain: by 2025, a minimum of 65% by weight of all packaging waste must be recycled, and a minimum of 70% by 2030 (EU, 2018; EC, 2022).

Denmark, among other countries, advocates for fast implementation of reusability and circularity in packaging. Currently, the focus is on implementing Extended Producer Responsibility (EPR) programs, which require manufacturers and retailers to take responsibility for the end-of-life management, such as recycling or incineration, of their packaging products (Andreasi Bassi et al., 2020). For a practical application of the EPR policy, systematic assessments for quantification of environmental impacts are needed from production to end-of-life to avoid rebound effects, e.g. implementing measures that only shift the impact to another product chain.

An LCA is a standardized methodology for quantifying the environmental impacts of products, systems and services within the system boundaries, for example, from raw material extraction to end-of-life management, providing a comprehensive understanding of its associated impacts and opportunities for reduction (ISO, 2006a, 2006b). In this context, one life cycle or single loop refers to the material being extracted, the product manufactured, used by the customer after purchase at the point of being discarded, and entering the end-of-life stage. The concept of multiple loops or cycles considers all stages of a product's existence and the potential for materials to be reused or recycled in subsequent cycles. The number of cycles or loops in the reuse scenario indicates the number of times a product can be used before it breaks and becomes unusable. Similarly, in the recycling scenario, the number of cycles reflects the number of times a material can be processed into a new product before it becomes too degraded to be recycled again. Recycling and reuse are crucial end-of-life scenarios as they promote the recirculation of materials and products. By minimizing waste and environmental damage, such as CO_2 emissions and resource depletion, these scenarios aim to extend the life of materials as much as possible. This circular approach recognizes that the available materials are finite, and their continued use is essential for sustainable development.

In the context of EPR programs, conducting an LCA that assesses the multiple cycles of a product is essential for several reasons: 1) Identifying the hotspots, as a consequence, where the most significant improvements can be made; 2) encouraging sustainable design, such as including durability, reparability, and recyclability; 3) tracking progress and evaluate the effectiveness of the programs in reducing the environmental impact of a product.

2.2 Objectives

The overall goal of this study is to provide the Danish EPA with the potential life cycle environmental impacts associated with the production, use and disposal of selected packaging products made from various materials. Three end-of-life scenarios are considered, i.e., multiple-loop reuse, multiple-loop recycling and incineration. The results are intended for internal decision support at the Danish EPA as part of a broader range of assessments to define EPR recommendations.

In particular, this study aims to:
- Collect and review life cycle inventory data for selected packaging products type purchased, used and discarded in a Danish context;
- Estimate the number of times the selected packaging products can be reused and recycled;
- Model the life cycle scenarios for each packaging product in the LCA modelling software EASETECH adopting a multiple-loop approach;
- Analyse the potential environmental impacts of each packaging product's end-of-life scenarios.

The study is based on a life cycle assessment (LCA) modelling framework for packaging materials provided in a previous EPA project from 2021, "Environmental profiles of packaging materials".

3. Packaging overview

3.1 Materials

In this report, the selected packaging is from the post-consumer stage after the use phase. Two types of post-consumer packaging are studied: 1) primary packaging representing packaging in direct contact with the product, and 2) secondary packaging representing additional packaging used to protect and contain individual units during storage, transport, and distribution (Miljø- Og Fødevareministeriet, 2015).

Packaging comprises various materials, from cellulose fibres to plastic or other alloys. The project includes the most frequently used packaging materials in Danish households and alternative packaging materials as biomaterials.

More specifically:
- Fossil plastic (PET, PE, PP, PS);
- Bio-based plastic (PLA);
- Metals (aluminium, steel);
- Fibre-based materials (paper, cartonboard, corrugated board);
- Glass

The included materials associated with each packaging group are shown in Table 1.

Table 1 - Overview of packaging groups and included materials assessed in this study.

Packaging group	Material	Full name	Description
Fossil-based plastic	PET	Polyethylene terephthalate	PET plastic is a durable, lightweight material commonly used in primary packaging products such as bottles, food containers (Andreasi Bassi et al., 2021).
	PE	Polyethylene	PE plastics are included in the polyolefin polymer, a broad family of polymers with moisture barrier and toughness properties (Bauer et al., 2021). Low-Density Polyolefin (LDPE) is used in flexible applications, e.g. in food bags, whereas High-Density Polyolefin (HDPE) is a stiff material often used in applications where rigidity is required, e.g. boxes (Bauer et al., 2021; Cecon et al., 2021).
	PP	Polypropylene	PP plastic is included in the polyolefin polymers. It is often used in primary packaging for flexible and rigid applications (Chappell et al., 2022; Horodytska et al., 2018)
	PS	Polystyrene	PS can be rigid or expended as foam. This study assesses the rigid PS used for packagings, such as food trays or cups (Ingrao et al., 2015).
Bio-based plastic	PLA	Polylactide Acid	Bio-based plastic is made from a feedstock derived from a renewable resource (Ali et al., 2023). It is a niche market representing an emerging alternative to fossil-based plastics (Rosenboom et al., 2022).
Metals	Aluminium	-	Aluminium packaging comprises>90% aluminium alloys with other metals, such as copper, zinc, and

			manganese (Zink et al., 2018). Cans and trays made of aluminium are commonly found in household packaging.
	Steel	-	Steel cans are produced from tin-coated steel, tinplate, or electrolytic chromium-coated steel (Zink et al., 2018). Steel packaging is resistant material mainly used for canned goods (Van Caneghem et al., 2019).
Fibre-based materials	Paper	-	Paper packaging consists of cellulosic fibres forming the structure of the material. Various additives are used during production for customizing the technical properties, e.g., fillers, coatings, biocides, and synthetic binders (Hage, 2007; Ma et al., 2023; Zambrano et al., 2021). Paper is a flexible material often used for dry foods, e.g. pastries.
	Cartonboard	-	Paper and board consist of cellulosic fibres forming the structure of the material. Various additives are used during production and for customizing the technical properties of paper and board, e.g., fillers, coatings, biocides, and synthetic binders. (Hage, 2007; Ma et al., 2023; Zambrano et al., 2021) Cartonboard is often used as secondary packaging, e.g. cartonboard boxes containing a plastic bag.
	Corrugated board	-	Creating a corrugated board involves combining multiple sheets of paper, which are corrugated before being adhered to a sturdy board and trimmed into the desired shape (FEFCO, 2019). A corrugated board is broadly applied as secondary packaging, for example, for product storage, transport, and delivery.
Glass	-	-	Glass consists of a random structure of silicon dioxide and metal oxides (Zero Waste Europe, 2022). It is commonly used in packaging, e.g., jars, bottles, and containers.

3.2 Packaging type

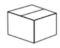
This study assesses post-consumer primary and secondary packaging, with no specified usage or application, which can be found in the form of rigid or flexible packaging:

- Rigid packaging: solid, firm and not easily distorted or deformed. It is typically made from glass, metal, cartonboard, plastic, or paperboard. Examples include cans, bottles, jars, and boxes – see Table 2.

- Flexible packaging: soft and pliable packaging can be easily bent, folded and twisted. It is typically made from plastic, paper, or foil. Often a layer of plastic film or coating is included, but this product-specific option is not considered in this study. Examples include bags and films – see Table 2.

Table 2 - Illustrative example of rigid and flexible packaging.

Packaging design type	Category	Product type examples	Illustration
Rigid	Bottle/jar/ can/brick	Bottle	
		Jar	

		Can	
	Container (tray/tub/box)	Tray	
		Tub	
		Box	
Flexible	Bag/film	Bag	
		Film	

Note that not all materials are considered to be used to produce both rigid and flexible products. The combination of packaging design type-material, as considered in this study, is presented in Table 3.

Table 3 - Materials included in the study for flexible and rigid packaging types.

	Rigid	**Flexible**
PET	☑	☒
PE	☑	☑
PP	☑	☑
PS	☑	☑
PLA	☑	☑
Aluminium	☑	☑
Steel	☑	☒
Paper	☒	☑
Cartonboard	☑	☒
Corrugated board	☑	☒
Glass	☑	☒

Both rigid and flexible packaging has the potential to be used multiple times or recycled multiple times. Examples of reusable packaging are refillable water bottles or reusable shopping bags, which can undergo many uses, whereas examples of single-use packaging are disposable coffee cups designed to be used once and then disposed of. Typically, reusable packaging is heavier than the corresponding single-use option made of the same material, as it is designed to be durable and withstand multiple uses; therefore, more material is needed to make the same packaging product (Greenwood et al., 2021).

4. LCA goal and scope

This study aims to provide the potential impacts on the environment associated with the production, use and waste management of selected design options for packaging. As mentioned above, the considered materials are fossil-based plastic (PET, PE, PP, PS), bio-based plastic (PLA), fibre-based materials (paper, cartonboard, corrugated board), metals (aluminium, steel), and glass. Only the primary material constituting the packaging is considered, while other packaging components, such as labels, ink and glue, are not included in the assessment.

The target audience of the study is the Danish EPA. The study aims to be used for internal decision support at the Danish EPA as part of the background material for implementing Extended Producer Responsibility of packaging materials. Note that the results presented in the report provide an overview of the environmental performance of selected packaging materials; they are intended as "baseline results" to support decision-making.

The scope of this LCA includes all stages of the packaging life cycle, from raw material extraction to end-of-life management. More specifically, the considered life cycle phases are:

- Raw material extraction: includes all the extraction activities of any raw material constituting the packaging product, like metal ore mining and oil drilling;
- Manufacturing: includes all processes required to convert the raw materials into packaging, such as assembling;
- Use: includes the usage of packaging by the end-user, in this case, consumers. No process or activity is included in this stage, as the packaging does not require any resource or energy consumption during the use stage.
- End-of-life: includes three end-of-life scenarios, i.e. reuse, recycling, and incineration.

While raw material extraction, manufacturing and use are the same for each product within the material and the packaging type selected, the end-of-life considers one option at a time, making three different LCA comparable pathways.

4.1 Functional unit

In LCA, the Functional Unit (FU) represents the object of the assessment and provides the basis for a fair and quantitative comparison of alternative ways of providing a function or service (ISO, 2006a, 2006b). This unit defines the function's qualitative and quantitative aspects, like temporal and geographical scope.

This study considers a wide range of materials which can provide different functionalities in terms of the number of cycles (see Section 6.2), preservation of mechanical properties after recycling, etc. Moreover, packaging of the same volume has different weights according to their material (see Section 6.3). Reusable packaging is usually heavier than the corresponding single-use one made of the same material, as it has been designed to be durable and to withstand multiple uses; hence, more material is required to satisfy the same functionality. Single-use products are sent to recycling or incineration.

This assessment intends to compare the potential environmental impacts of different packaging materials and types. The functional unit is defined as:

The amount of rigid and flexible packaging material, expressed in kilograms (kg), needed to contain 1 liter (L) of volume of an available product used in Denmark between 2020 and 2030.

The above-described functional unit allows for a functionally equivalent comparison across packaging materials, e.g., a 700 g aluminium can serve the same functionality as a 500 g plastic bottle; thus, the results of the LCA can be compared and aggregated.

4.2 Reference flow

The reference flow represents the amount of material required to fulfil the defined functional unit. The reference flow varies depending on the material (e.g. steel, PET), the type of packaging design (rigid or flexible), and whether the packaging is intended for reuse. The reference flows defined in this study are presented in Section 6.3 as the amount of packaging material required to contain 1 liter of a product used in Denmark between 2020 and 2030.

4.3 Consequential modelling

This LCA follows a consequential modelling approach for evaluating the environmental consequences of changing the management of the selected materials from the reference scenario representing the current system to several alternative scenarios (Brandão et al., 2022). It allows for identifying opportunities to reduce those impacts through product design or selecting more sustainable materials and production processes. Multi-functionality in the model is handled by system expansion when co-products are used in specific markets and for specific applications (Ekvall and Weidema, 2004; Weidema, 2003) under the assumption of unconstrain and fully elastic markets (Wernet et al., 2016).

4.4 Geographical and temporal scope

The production of both primary and secondary raw materials and the manufacturing of packaging products depend on the market situation of a country. This depends on market factors such as the demand for the materials, pricing, the accessibility of resources, and the level of technological advancements. In this study, raw material production is assumed to happen in Europe. In line with the project scope, processes related to converting virgin raw materials into packaging products, sorting before recycling, reuse and incineration are assumed to happen in Denmark. Reprocessing in the recycling pathway is handled in Europe except for glass packaging, which is assumed to occur in Denmark.

An overview of the specific geographical scope for each modelled scenario option for all packaging materials is presented in Table 5.

Table 4 - Geographical scope of production and end-of-life scenarios for the selected packaging materials.

Material	Raw material production	Conversion into packaging	Reuse	Sorting	Recycling-reprocessing	Incineration
PET	Europe	Denmark	Denmark	Denmark	Europe	Denmark
PE	Europe	Denmark	Denmark	Denmark	Europe	Denmark
PP	Europe	Denmark	Denmark	Denmark	Europe	Denmark
PS	Europe	Denmark	Denmark	Denmark	Europe	Denmark
PLA	Europe	Denmark	Denmark	Denmark	Europe	Denmark
Paper	Europe	Denmark	Denmark	Denmark	Europe	Denmark
Cartonboard	Europe	Denmark	Denmark	Denmark	Europe	Denmark
Corrugated board	Europe	Denmark	Denmark	Denmark	Europe	Denmark
Aluminium	Europe	Denmark	Denmark	Denmark	Europe	Denmark

Steel	Europe	Denmark	Denmark	Denmark	Europe	Denmark
Glass	Europe	Denmark	Denmark	Denmark	Denmark	Denmark

The temporal scope of the study has been set to cover the period from 2020 to 2030. To ensure that the LCA accurately reflects this time frame, the current and future technology data has been specifically adapted for this period.

4.5 Data collection

The modelling and input data are based on the life cycle assessment modelling framework for packaging materials included in the EPA project "Environmental profiles of packaging materials" (EPA, 2022), including a thorough data quality assessment of the input data. Most external processes are imported from the Ecoinvent database, version 3.6, and updated to version 3.8 for use in this study. Data for material composition and the incineration process are obtained from the library of the LCA software EASETECH (Section 4.7).

Several assumptions are made due to insufficient data availability in literature, mainly about multiple-loop information on recycling and reuse (see Chapter 6 about Life Cycle Inventory).

4.6 Circular Footprint Formula (CFF) formula

When modelling multiple product cycles, the distribution of the environmental impacts among the individual cycles may be relevant (Rigamonti et al., 2020). Although the modelling in this study assesses the packaging product life cycle in its entity, the Circular Footprint Formula (CFF) developed by the European Commission is applied to distribute impacts between individual parts of the product life cycle and to avoid double-counting (EC, 2018). The circular footprint formula involves a range of parameters, including the “A” factor distributing the environmental impacts between the upstream production and the downstream end-of-life phases. Thus the impacts are modelled in two parts (upstream part, i.e. production scenario, and downstream parts, i.e. end-of-life scenario) according to the A factor (following the recommendations from European Commission for its values):

- **0.2** is used when there is a greater demand for high-quality secondary material than what is being produced. This study uses this value for metals, fibre-based packaging and glass.

- **0.5** is used when there is an equilibrium between offer and demand. This study uses this value for plastic (fossil and bio-based).

- **0.8** is used when less high-quality secondary material is demanded than produced.

For more information regarding applying the CFF formula in this project, refer to Section 3.3 in the EPA project "Environmental profiles of packaging materials – LCA model documentation".

4.7 Modelling tool - EASETECH

This study uses the software EASETECH (Environmental Assessment System for Environmental Technologies) for the LCA modelling (Clavreul et al., 2014). EASETECH is a process-oriented tool developed at the Technical University of Denmark to support LCA studies in waste management. When modelling environmental technologies, the material flows can consist of a very heterogeneous mix of materials; it is crucial to maintain this information throughout the modelling process. EASETECH is a material flow-based tool where the material flow is defined as different fractions having physical, chemical, biochemical and nutritional properties associated and tracked in the model across the entire system, considering material transformation and transition from one process to another within the system boundaries (Lodato et al., 2021). Recently, more features have been implemented into EASETECH, expanding the application of LCA on more complex systems within waste management (Lodato et al., 2021).

4.8 Impact categories

The potential environmental results are generated in EASETECH using the Environmental Footprint (EF) 3.0 methodology without Long Term impacts, thereby focusing only on the impacts that occur during the life cycle of the products, i.e. short-term impacts.

The final results of the LCA are presented as characterized impacts, i.e., direct and indirect emissions associated with the modelled scenarios are converted into standard units and aggregated within each impact category. The short name and characterized unit for each impact category are listed in Table 5.

A non-zero characterisation factor is applied for biogenic CO_2-emissions to reflect the temporal effects from an instant release of CO2 in the case of waste incineration of biogenic materials such as wood relative to the much slower uptake of CO_2 from regrowing of the corresponding biomass (e.g. through forestry). For details, please refer to Faraca et al., 2019.

Table 5 - Overview of selected impact categories included in the EF 3.0 methodology.

Impact category	Short name	Characterized unit (CU)
Climate change	CC	kg $CO_{2\ eq}$
Ozone depletion	OD	kg $CFC^{-11}\ _{eq}$
Human toxicity, cancer effects	HT-C	CTUh
Human toxicity, non-cancer effects	HT-nC	CTUh
Particulate matter/respiratory inorganics	PM	Disease incidences
Ionizing radiation, human health	IR	kBq $U^{235}\ _{eq}$(to air)
Photochemical ozone formation, human health	POF	mol $H^{+}\ _{eq}$
Acidification	TA	mol N_{eq}
Eutrophication terrestrial	ET	kg N_{eq}
Eutrophication freshwater	EF	kg P_{eq}
Eutrophication marine	EM	kg N_{eq}
Ecotoxicity freshwater	EcoF	CTU_e
Land use	LU	-
Resource use, minerals and metals	RUMM	kg SB $_{eq}$
Resource use, energy carrier	RUEC	MJ

5. Model set-up

An overview of the process flow diagram for the selected packaging products is illustrated in Figure 1 and described in more detail in the sections hereafter. Primary raw material extraction and production (light green) and secondary raw material production (blue) are followed by the conversion into packaging step (dark green). After the use stage, the model considers three end-of-life scenarios: the reuse scenario (yellow), the recycling scenario (violet) and the incineration scenario (red). Note that the transportation of the products is not included in this assessment.

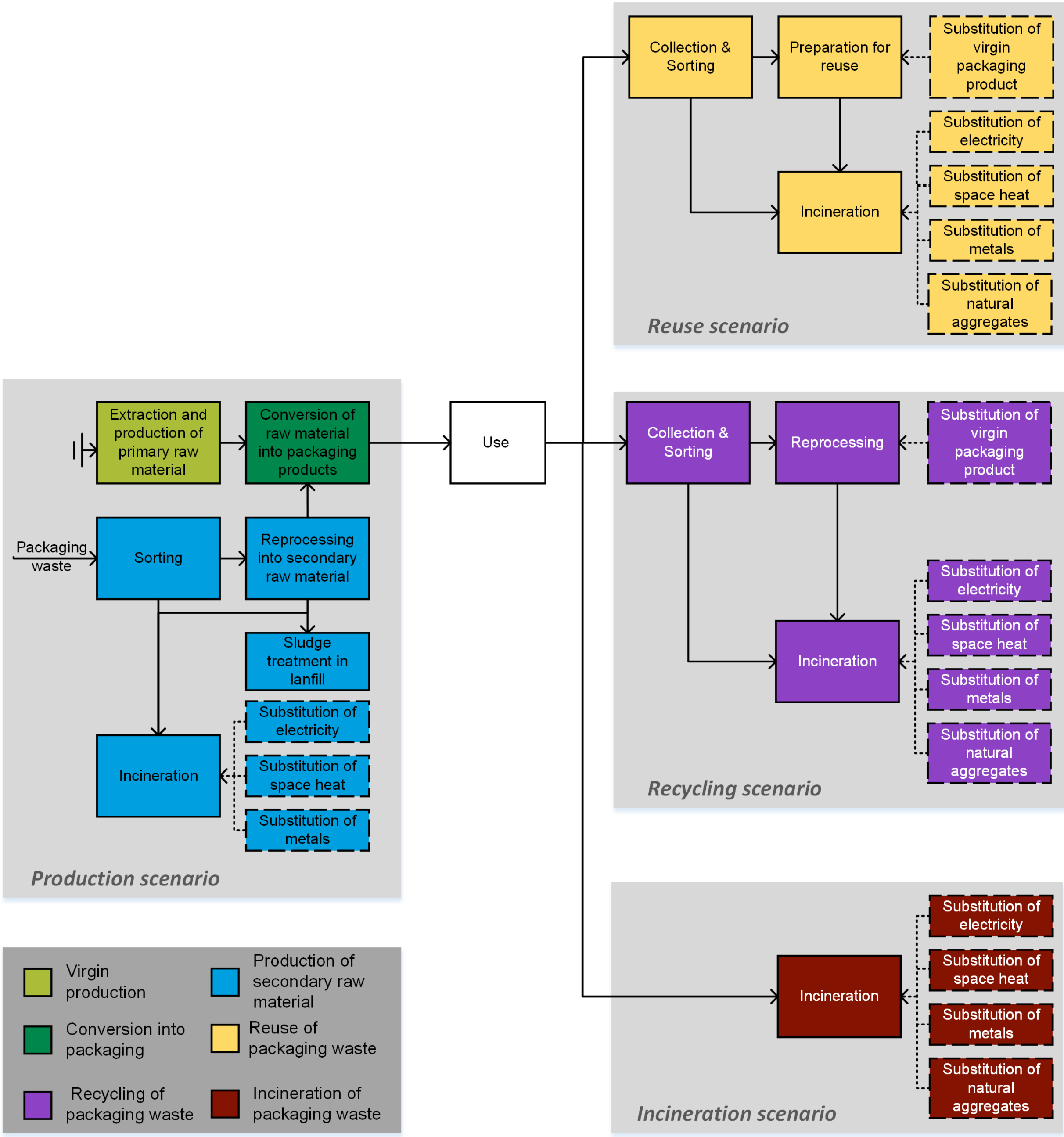


Figure 1 - Process flow diagram for selected packaging products: production scenario, use stage, and end-of-life scenarios. Dotted lines refer to material and energy substitution.

5.1 Production Scenario

The processes modelled in the production scenario are presented in Figure 2**Error! Reference source not found.**.

The model includes the following production scenario alternatives:

- Primary raw material production (light green in Figure 2**Error! Reference source not found.**): refers to the extraction and production of plastic from virgin resources;
- Secondary raw material production (light blue in Figure 2**Error! Reference source not found.**): refers to the recovery process of materials from existing products, i.e. in this study, packaging products, through mechanical recycling. For example, when a plastic bottle reaches its end of life can be processed into plastic pellets. More information related to the recycling process can be found in Section 4.3.2.

Primary and secondary raw materials are then converted into finished packaging products (dark green in Figure 2).

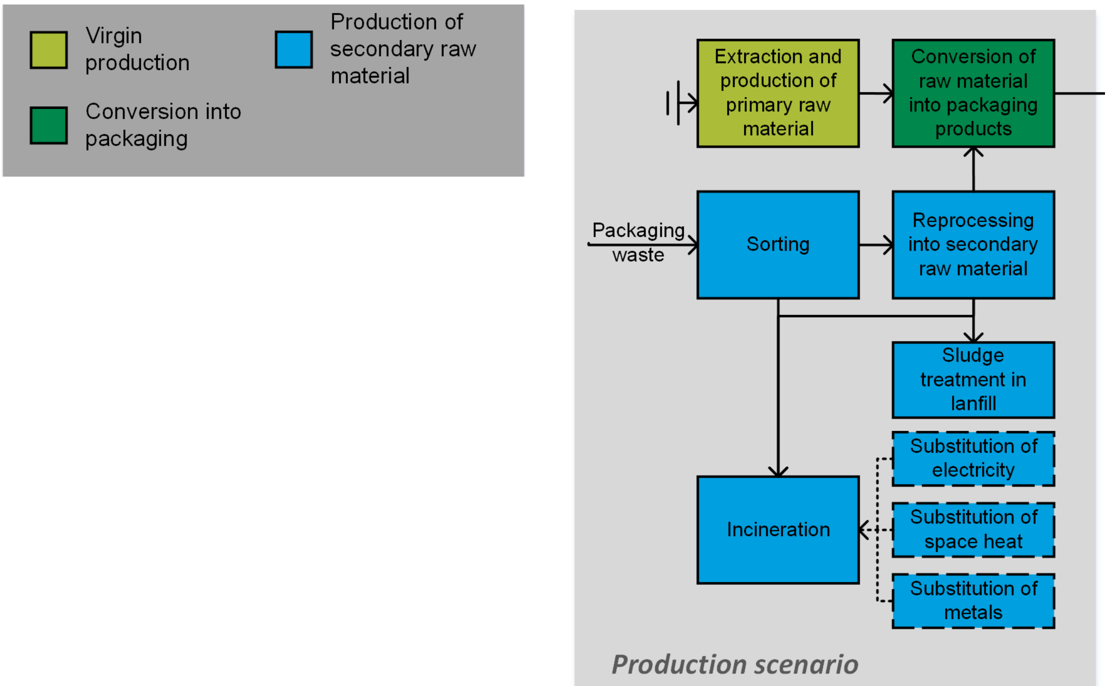


Figure 2 - Overview of processes modelled in the production scenario. Dotted lines refer to material and energy substitution.

The recycled content (RC) at the "conversion of raw material into packaging products" in Figure, when the virgin production flow merges with the secondary material production flow, varies between 0% and 100%, with RC=0% indicating a product made only of virgin materials, and RC=100% indicating a product entirely made of recycled materials. In this study, in order to display an intermediate situation, the final results are presented for a recycled content of 50%, i.e. half from virgin and half from recycled materials (EU, 2018). In reality, the share of recycled content in a packaging product varies depending on the material type and its end-of-use, e.g. for safety and hygiene reasons, packaging for certain products, such as medical supplies or food, may require higher levels of recycled content to be excluded to ensure the safety of the end user (Franz and Welle, 2022). On the other hand, products with less stringent requirements may use a higher percentage of recycled content without compromising product quality or safety (BRF, 2020). Therefore, the share of recycled content in a packaging product may vary depending on the specific end use of the product.

5.2 Use stage

The use stage is assumed to be burden free. No processes are associated with this stage.

5.3 End-of-life Scenarios

The model includes the following end-of-life scenarios:

- Reuse
- Recycling
- Incineration

5.3.1 Reuse Scenario

After being used, the packaging waste undergoes a sorting activity at Material Recycling Facilities (MRFs), where the broken or deformed packaging is discarded and sent to incineration (see Section 0). The remaining waste can be prepared for being used again through cleaning and sanitizing processes. This process can slightly differ from one material to another. For instance, the washing activity is performed for most products while not included in paper and cartonboard. Moreover, differences may occur in the kind of detergent and solvent used to clean and sanitize the types of packaging. However, for simplicity, such variations are not considered in this study.

The reuse scenario has the main advantage of reducing waste and conserving resources by avoiding production of the virgin raw materials and the activities involved in the conversion into packaging, which in this study are assumed to be substituted at every cycle.

The packaging product could be sent for recycling when packaging reuse is impossible. This option is not considered, as the three end-of-life scenarios are compared directly in this study. Consequently, the residues from the sorting and preparation for reuse stages are sent to incineration.

The above-described processes, represented in Figure 3Figure 3 - Overview of processes modelled in the reuse scenario. Dotted lines refer to material and energy substitution.

, are referred to in this report as the "Reuse" scenario.

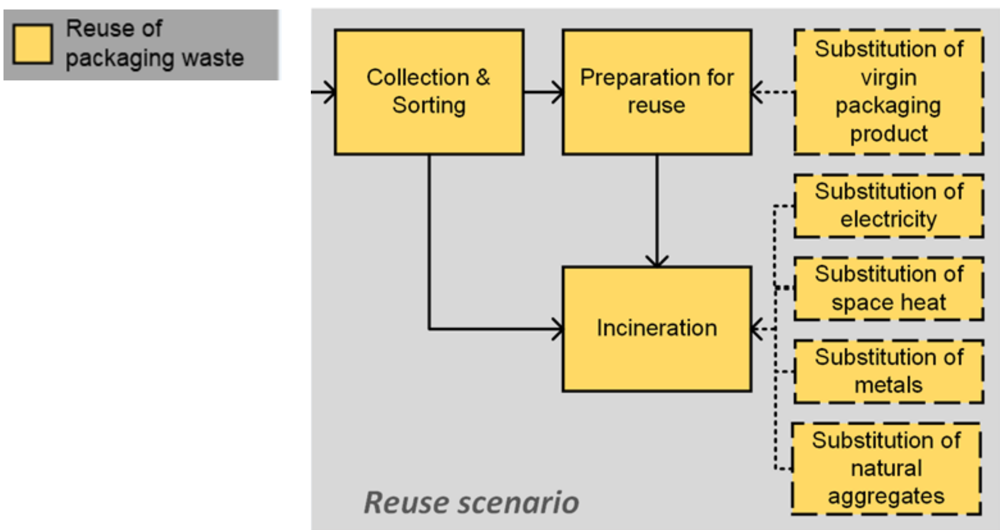


Figure 3 - Overview of processes modelled in the reuse scenario. Dotted lines refer to material and energy substitution.

5.3.2 Recycling Scenario

Packaging recycling refers to handling packaging waste and converting it into raw materials. The recycling process can change depending on the type and material being treated; however, it generally includes the following steps: collection and sorting, reprocessing and treatment of the residues.

After being used for its primary function, the packaging is collected from households, businesses, and other sources and brought to MRFs, where material types separate the waste, such as metals, paperboard and plastics, either manually or through sorting machines. The sorted materials are then reprocessed and, in this study, assumed to substitute virgin raw material to produce single-use packaging. This work considers mechanical recycling as a reference for reprocessing the selected packaging materials; therefore, activities like grinding and shredding are the main modelled processes.

The residues from the sorting and reprocessing activities are treated through incineration. Section 0 provides more information.

The processed materials are then used to manufacture new products, such as other packaging, distributed to consumers and businesses. These two last steps are out of the scope of this study and thus not included in the model set-up.

The above-described processes, graphically represented in Figure 4, are referred to in this report as the "Recycling" scenario.

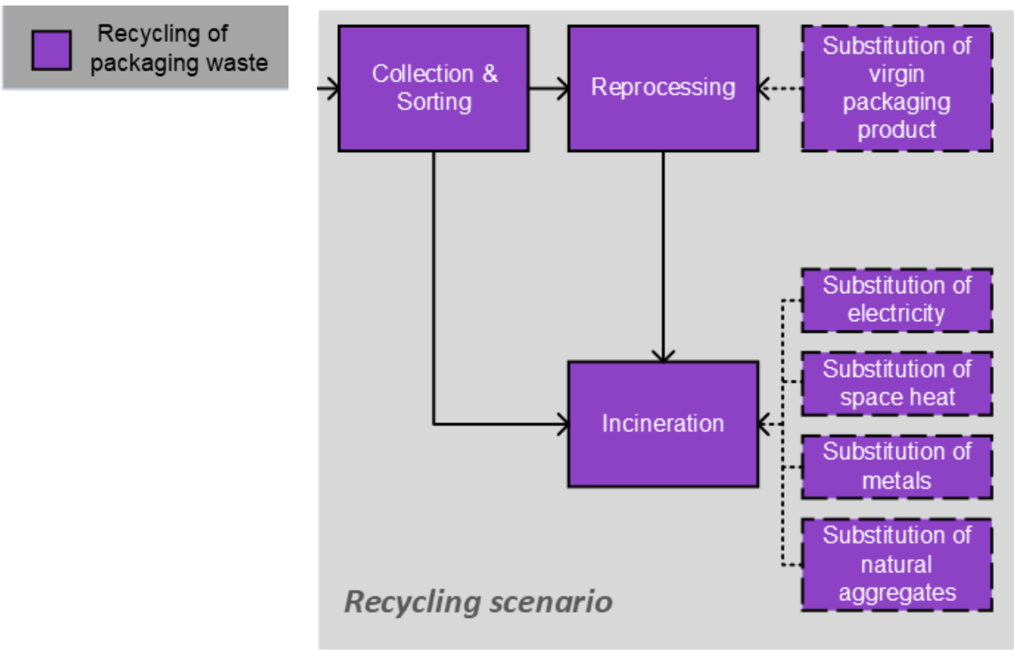


Figure 4 - Overview of steps modelled in the recycling scenario. Dotted lines refer to material and energy substitution.

5.3.3 Incineration Scenario

Packaging products and their residues from other processes can be disposed of through incineration. The incineration process involves combusting waste materials at high temperatures in incineration plants, typically within the temperature range of 850 to 1100°C (EC, 2020). This converts the heat produced into electricity and heat (Ekvall et al., 2021). Once the waste is combusted, it is possible to recover metals from the ashes through manual sorting, magnetic separation, and eddy current separation (Christensen, 2010). Furthermore, incinerator ash can be recovered as natural aggregates, substituting for filler materials used in road construction or aggregates in building materials (Christensen, 2010).

Incineration with energy recovery is a well-established waste treatment in Denmark with Amager Bakke in Copenhagen as a recent example. The plant has high energy recovery efficiencies and uses advanced air pollution control technology to minimize emissions of pollutants such as nitrogen oxides, sulfur dioxide, and dioxins (ARC, 2020).

The above-described processes, graphically represented in Figure 5, are referred to in this report as the "Incineration" scenario.

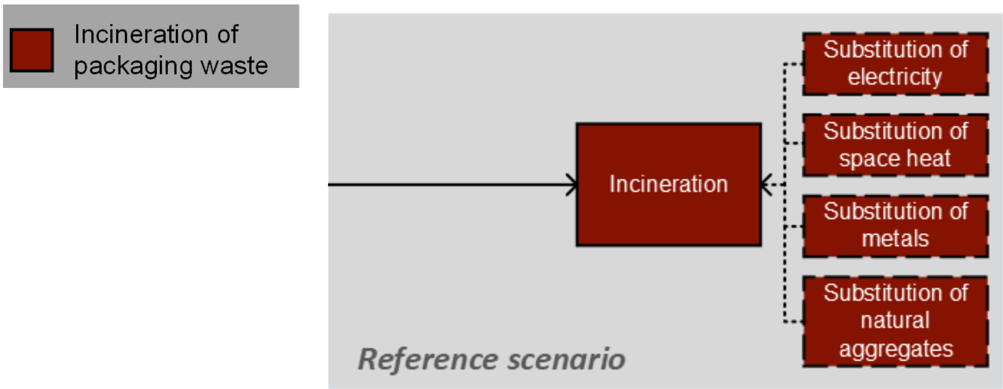


Figure 5 - Overview of processes modelled in the incineration scenario. Dotted lines refer to material and energy substitution.

5.3.4 Current end-of-life practices

An outline of the present state of technology development for all packaging materials' three end-of-life options is provided in the following table.

Table 6 - An overview of the current practices for managing the end-of-life of the chosen packaging materials - adapted from the EPA project "Environmental profiles of packaging materials"

Material	Reuse	Recycling	Incineration
Fossil plastic types (PET, PE, PP, PS) (Abbasi et al., 2022; EPA, 2019)	Packaging made from fossil plastic is not currently reused	Source separation is still maturing in Denmark. Recycling in Europe with established technologies	Incineration is the default treatment, if not directed to recycling through source-separation
Biobased plastic types (PLA) (Razza et al., 2020; Rosenboom et al., 2022)	Biobased plastic packaging is not currently reused	PLA: Neither source separation nor recycling is well-established	Incineration is the default treatment, if not directed to recycling through source-separation

Fibre-based materials (Paper, cartonboard, corrugated board) **(**EPA, 2019; Hage, 2007)	Fibre-based packaging is not currently reused	Well-established source separation and technologies for recycling fibre-based materials	Incineration is the default treatment, if not directed to recycling through source-separation
Metals (aluminium, steel) **(V**an Caneghem et al., 2019)	Metal packaging is not currently reused	Well-established technologies for recycling metals. Source separation is still growing in Denmark	Incineration is the default treatment, if not directed to recycling through source-separation
Glass (Agnusdei et al., 2022)	From unbroken glass packaging collected at glass cubes	Well-established source separation and technologies for recycling glass	Incineration is the default treatment, if not directed to recycling through source-separation

6. Life Cycle Inventory

6.1 Data sources, inventory data and uncertainties

Data and processes are modelled predominantly based on primary data, when available, or data from literature. While extensive data collection has not been part of this study, the inventory data are primarily based on a previous EPA report "Environmental profiles of packaging materials - LCA model documentation" (EPA, 2022), including appendices with relevant data for the selected packaging materials in context of the three end-of-life scenarios. Production and conversion of raw materials into packaging were modelled mainly based on processes from the Ecoinvent database, amended with data from other sources, such as literature and primary data, if data were not available in Ecoinvent.

End-of-life options were modelled as distinct processes, relying on data from literature or primary sources. As outlined in the documentation, these flow values were either added as individual values or data ranges based on the available data (EPA, 2022). The values presented as ranges allow for the inclusion of potential variations in flow values, e.g., sorting and reprocessing efficiency for the packaging products and different process/technology uses. Data on material composition and incineration processes were obtained from the library of the LCA model EASETECH.

In this study, additional focus was placed on estimating the number of cycles for the reuse and recycling scenario (see Section 6.2) as well as the packaging product weight (see Section 6.3). Additionally, the Ecoinvent data were updated to version 3.8 relative to version 3.6 in the previous EPA report (EPA, 2022). Changes were applied primarily to marginal electricity in Europe and a few other processes, as outlined in Appendix I.

The EASETECH modelling software uses parameters with defined data intervals assigned a uniform probability distribution for equal probability within the data range. For the uncertainty analysis, 1000 Monte Carlo simulations were included: at every simulation, the model extracts a value for each parameter within the defined data interval following the assigned probability distribution. The results are presented with a 95% confidence interval.

6.2 Number of cycles

The number of cycles or loops is identified for the reuse and the recycling end-of-life scenarios. In the reuse scenario, the number of cycles indicates the number of times a product can be used before it breaks and becomes unusable. Similarly, in the recycling scenario, the number of cycles reflects the number of times a material can be processed into a new product before it becomes too degraded to be recycled again. These two values refer to different life cycle stages of a product.

In both cases, the number of cycles varies depending on factors related to the product or the involved processes (Geueke et al., 2018). Generally, packaging made of metals or specific types of plastic has a lower integrity loss than packaging made of other materials, such as paper (Rigamonti et al., 2020). This is highly affected by the product's intended use and how this is used and maintained. For instance, paper and cartonboard are relatively durable materials but easily weakened by moisture, while UV rays can cause the plastic to degrade over time (Albrecht et al., 2022). Another critical parameter to consider is the thickness of the packaging. Overall, heavier packaging is more durable than lightweight products of the same type and material as they can withstand repeated uses with more limited damage (Schroeer et al., 2020). The quality and efficiency of the reuse system and the recycling plants also play an essential role in the lifespan. For example, if poorly maintained or handled, reusable products may experience fewer loops than better-preserved products. Thus, variations in the number of cycles depend on a wide range of factors affecting the product's life (Lu et al., 2022). Recycling often involves "breaking down" the product through shredding, washing and extruding it into flakes and reprocessing its materials to make new packaging (Berg et al., 2016; Spinacé and De Paoli, 2001). On the contrary, reusing a product often involves extensive washing, drying and decontamination processes which have fewer degradation effects at the material level (Coelho et al., 2020).

Very few studies in literature, based on experimental data, have defined the potential number of cycles that a packaging product could undergo both in the reuse and recycling scenario; however, in most of the cases, the main focus has been on plastic packaging and often not all the combinations of parameters affecting the condition of the product are considered (Bø et al., 2013; Simon et al., 2016). Due to substantial uncertainties and variability, the number of cycles for the reuse and recycling option is included as ranges in this study (Bradley and Corsini, 2023). The model considers "default" ranges for rigid and flexible packaging products are defined. However, these might vary slightly depending on the material (Zink et al., 2018). For assessment of specific packaging products the number of cycles needs to be addressed in detail for the case-study in question.

For this study, a uniform distribution is applied in the model with the ranges representing the minimum and maximum number of cycles for every packaging material reported in Table 8.

Table 7 – The potential number of cycles a packaging product assumed for reuse and recycling as represented by a minimum and maximum limit for the selected packaging type and materials. The minimum of two cycles represents a first cycle followed by a single reuse/recycling phase.

Packaging material	Packaging type	Reuse	Recycling
		Cycles (min – max)	Cycles (min – max)
Plastic (conventional, bio-based)	Rigid	2 - 50	2 – 25
	Flexible	2 - 25	2 – 5
Fibre-based materials (paper, cartonboard, corrugated board)	Flexible	2 - 5	2 – 5
	Rigid	2 - 25	2 – 15
Metal (steel, aluminium)	Rigid	2 - 50	2 – 50
	Flexible	2 - 25	2 – 25
Glass	Rigid	2 - 50	2 – 50

Every reuse and recycling phase is assumed to be associated with a mass loss, e.g. from discarding broken packaging in the reuse scenario and processing losses in the recycling scenario. Thus the mass loss rate refers to the rate at which a product losses mass over its life, in this case, quantified through the number of cycles. The loss rate value is expressed in percentage and is assumed constant for every cycle. Moreover, being a function of the number of cycles, it is included in the model as a variable parameter. Therefore, the mass loss rate at the individual cycles is determined as follows:

$$\text{Mass loss rate} = \frac{100\%}{number\ of\ cycles}$$

6.3 Weight of packaging products

In this study, data on the packaging weight was obtained from the literature and supplemented with sample measurements of packaging products from Danish retail. To determine the weights of the selected packaging products, a regular kitchen scale was used, and only the weight of the main material was considered while excluding other packaging components such as lids and labels. The weights were then scaled linearly to correspond with a standard volume of 1 litre following the defined FU. The scaling for packaging containing liquids was done based on a linear correlation between material weight and volume. If the volume was not expressed in litres, the packaging dimensions were measured to determine its capacity, which was then scaled to 1 liter. This method ensured accurate and comparable estimates of the weight of the selected packaging products. Five packaging products, e.g., bottle, jar, bag, per packaging type, were weighed per packaging material. The weight of a product can vary due to its material and the manufacturing process. Therefore, the weight data are provided in ranges.

In general, reusable packaging tends to be heavier than single-use packaging as it is designed to withstand multiple uses and thus requires manufacturing with more material. Moreover, the estimated mass for single-use packaging is an input for the recycling and incineration scenario, whereas the estimated mass for the multi-use packaging is considered for the reuse scenario.

Table 8 outlines the weight data for packaging in line with the functional unit defined in this assessment, as referenced in Chapter 4.1. The weight is expressed in kilograms per liter of contained packaging product.

Table 8 - Overview of packaging weight expressed in kg/L of contained packaging product.

	Flexible		**Rigid**	
	Recycling and Incineration	Reuse	Recycling and Incineration	Reuse
Packaging Material	kg/L (min-max)	kg/L (min-max)	kg/L (min-max)	kg/L (min-max)
Plastic	0.01 – 0.08	0.01 – 0.1	0.02 – 0.2	0.02 – 0.4
Paper	0.01 – 0.05	0.01 – 0.08	-	-
Cartonboard	-	-	0.02 – 0.08	0.02 – 0.1
Corrugated board	-	-	0.02 – 0.1	0.02 – 0.2
Aluminium	0.01 – 0.08	0.01 – 0.1	0.1 – 0.3	0.1 – 0.4
Steel	-	-	0.1 – 0.3	0.1 – 0.4
Glass	-	-	0.4 – 1.7	0.4 – 2

7. Interpretation of the results

This chapter presents the potential environmental impacts, focusing on climate change impacts expressed as kg CO_{2_eq} / FU by individual materials. The potential impacts for the other impact cathegories are presented in tables in Appendix II, using characterized units.

In this chapter, the results are presented as intervals, one for each of the three end-of-life scenarios. These results intervals represent 95% confidence intervals based on Monte Carlo simulations of the model with the included parameter data and probability distributions. As such, the “bars” representing results for reuse and recycling in the following figures are reflecting the ranges in potential number of cycles, i.e. if only a few reuse cycles take place then the corresponding climate change impact will be in the higher end of the “bar” (see Table 7 for the included ranges in number of cycles). No additional cycles (or loops) are included in the incineration scenario.

For each packaging material, the results are presented, comparing reuse, recycling, and incineration, with a recycled content of 50%. This means that 50% of the plastic in the packaging is assumed from primary material, while the other 50% is from recycled material. The green and orange bars represent rigid and flexible packaging types, respectively. Moreover, note that numerically negative values in the LCA results indicate environmental benefits or avoided environmental impacts, while positive values indicate environmental loads.

While evaluating the results in the following sections, it is important to note that potential savings or impacts related to energy in all scenarios are limited due to the renewable energy sources applied in the modelled energy mix, in alignment with the electricity and heat targets and forecasts for the temporal scope of 2020-2030 in the study.

7.1 PET

The impact of climate change caused by the full life cycle of rigid packaging products made of PET plastic is depicted in Figure 6. The result intervals of the life cycle assessment indicate that both reuse and recycling result in environmental benefits, while incineration represents an environmental load.

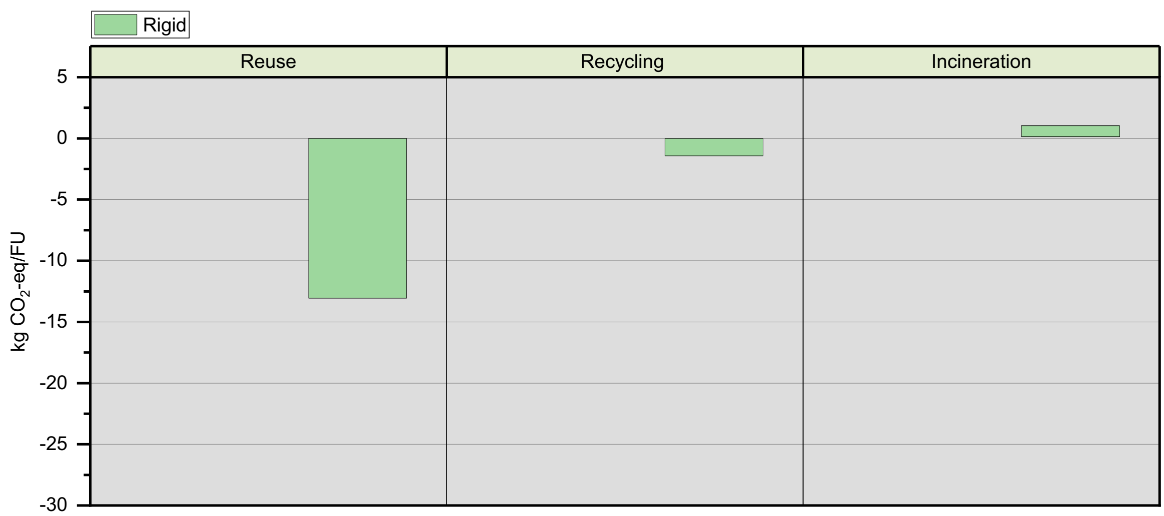


Figure 6 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid packaging products made of PET. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

Reusing rigid PET plastic packaging leads to the highest climate change impact savings, as this scenario reduces the need for resource extraction and production of virgin PET packaging within every cycle. The high savings observed in this reuse scenario can be attributed to the efficient recovery rate, which ranges between 89% to 93%. Moreover, the preparation activities for reuse have a limited contribution to climate change.

Recycling rigid PET plastic packaging also results in climate change savings by avoiding the production of virgin PET plastic due to the net benefits from recycling of secondary raw materials relative to the sorting and reprocessing activities. Reprocessing requires more energy and resources than those involved in the reuse scenario, resulting in lower overall environmental benefits. This difference in the results can be also attributed to the fact that PET packaging has potential for more reuse cycles (2 to 50) than recycling cycles (2 to 25); the lowest end of the result intervals illustrate the impact savings associated with the highest number of cycles in the two scenarios.

Incineration of PET plastic packaging is the least favourable option causing net climate change loads to the environment, mainly due to the relatively high concentration of fossil carbon converted into CO_2 during incineration.

7.2 PE

The environmental impact on climate change of the full life cycle of both rigid and flexible packaging products made of PE plastic is presented in Figure 7. Overall, the results indicate that reusing the packaging benefits the environment the most, for both flexible and rigid plastic packaging. Recycling flexible packaging results in net-positive impacts on the climate change potential score, and net-negative impacts for rigid packaging. The incineration scenario has a harmful effect on climate change potential for both packaging types.

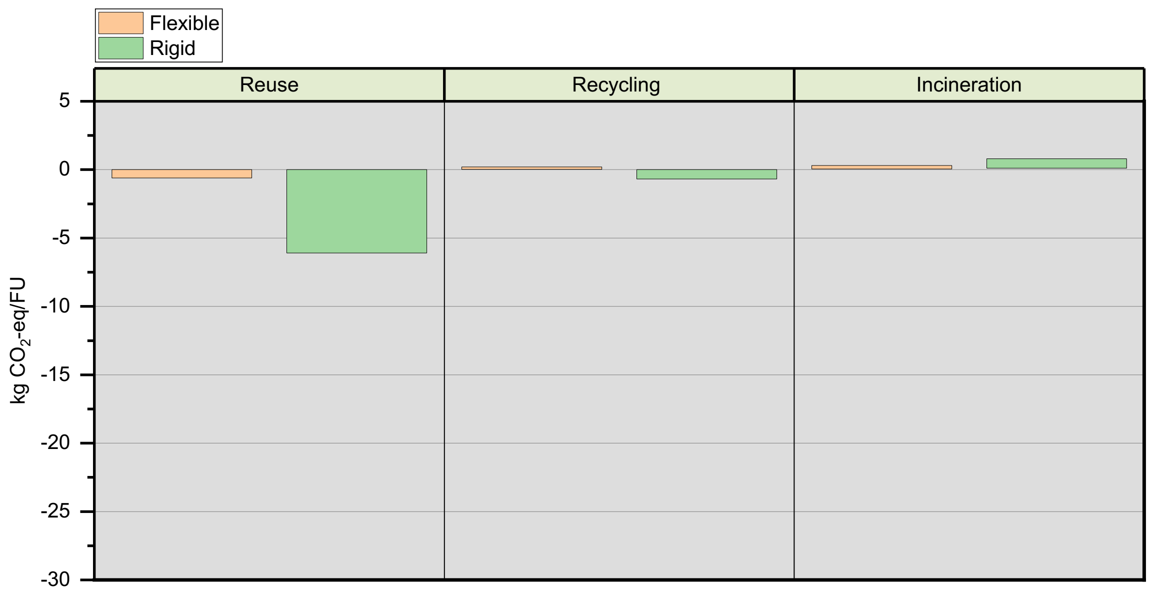


Figure 7 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid and flexible packaging products made of PE. The result intervals represent a 95% confidence interval and are presented as kg CO_2 equivalent per functional unit (FU).

Reusing PE packaging has a preferable climate change performance than recycling, both for rigid and flexible due to: 1) reusing PE packaging is assumed to replace the production of new packaging from virgin materials at every rotation, while recycling only avoids producing raw materials. In recycling, secondary materials are combined with primary materials to produce new products, avoiding using only primary materials, promoting material circulation, and partially lowering environmental emissions; 2) reuse has a higher recovery rate than recycling, ranging between 89% and 93% for reuse versus 36% to 81% for recycling. With this regard, note that PE has a high fossil carbon content, meaning that significant amounts of CO_2 are potentially released during the incineration of recycling residues, reducing even more the benefits of recycling; 3) the CO_2 emissions released during the washing and preparation processes are less than those for PE recycling. Recycling flexible packaging results in impacts on the climate change score, while it is beneficial for rigid packaging. Although the production of flexible packaging has an overall lower environmental impact compared to rigid packaging, rigid PE packaging is associated with the lowest climate change potential due to its higher assumed number of cycles both in reuse (2 to 50 cycles) and recycling (2 to 25 cycles) scenarios, compared to flexible packaging (2 to 25 cycles are assumed for the reuse scenario and 2 to 5 cycles for the recycling scenario).

A significant distinction between the impacts caused by flexible and rigid PE packaging in every scenario also lies in the amount of material required to fulfil the functional unit of this study. Specifically, less material is required for flexible PE products resulting, depending on the scenario, in reduced climate change impacts or savings at every rotation.

7.3 PP

The impact of climate change caused by the full life cycle of both rigid and flexible packaging products made of PP plastic is depicted in Figure 8. The results show that the reuse of PP packaging offers the largest contribution to avoiding climate change impacts for both rigid and flexible plastic packaging. While recycling contributes with net climate change impacts for flexible PP packaging, rigid PP packaging represents net benefits. The incineration scenario results in climate change loads for both types of packaging.

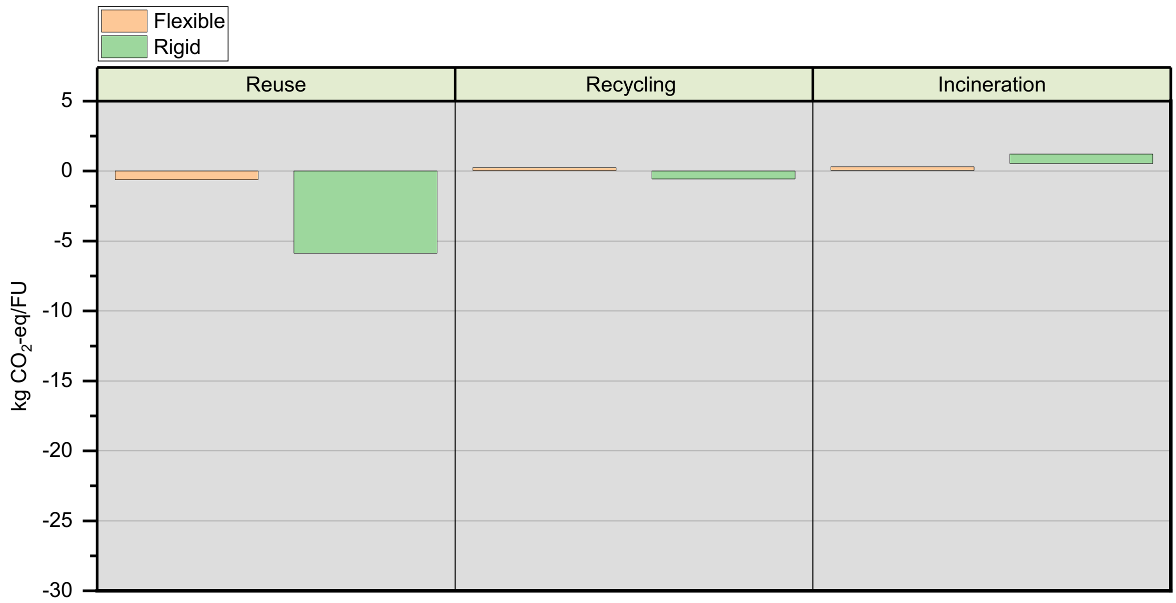


Figure 8 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid and flexible packaging products made of PP. The result intervals represent a 95% confidence interval and are presented characterized expressed as kg CO_2 equivalent per functional unit (FU).

Reusing PP packaging has the highest climate change savings among the three scenarios due to the high estimated recovery rate of 89% to 93%, versus 48% to 86% for recycling, and the low climate change potential associated with washing and preparation activities. Recycling PP packaging results in savings in the case of rigid products and in net positive impacts in case of flexible products, due to the different number of cycles. Both in the reuse and recycling scenarios, PP rigid packaging has the lowest potential score for climate change due to its higher estimated number of cycles, i.e. 2 to 50 for reuse and 2 to 25 for recycling of rigid PP packaging, compared to 2 to 25 for reuse and 2 to 5 for recycling of flexible PP packaging. In addition, PP also has a high fossil carbon content, meaning that significant amounts of CO_2 are potentially released during the incineration of recycling residues, reducing the benefits of recycling. Reusing packaging avoids the need for producing new packaging while recycling only reduces the demand for virgin raw materials. In the incineration scenario, PP rigid packaging is found to result in a greater climate change potential emissions..

A significant distinction between the impacts caused by flexible and rigid PP packaging in every scenario also lies in the amount of material required to fulfil the functional unit of this study. Specifically, less material is required for flexible PP products resulting, depending on the scenario, in reduced climate change impacts or savings at every rotation.

7.4 PS

The environmental impact on climate change of the full life cycle of both rigid and flexible packaging products made of PS plastic is presented in Figure 9. Overall, the results indicate that the reuse of packaging has the most significant savings on the climate change score, both for flexible and rigid plastic packaging. Recycling has net positive emissions for flexible packaging, and net-negative emissions for rigid packaging regarding climate change. The incineration of PS packaging has a damaging effect on the climate change potential for both types of packaging.

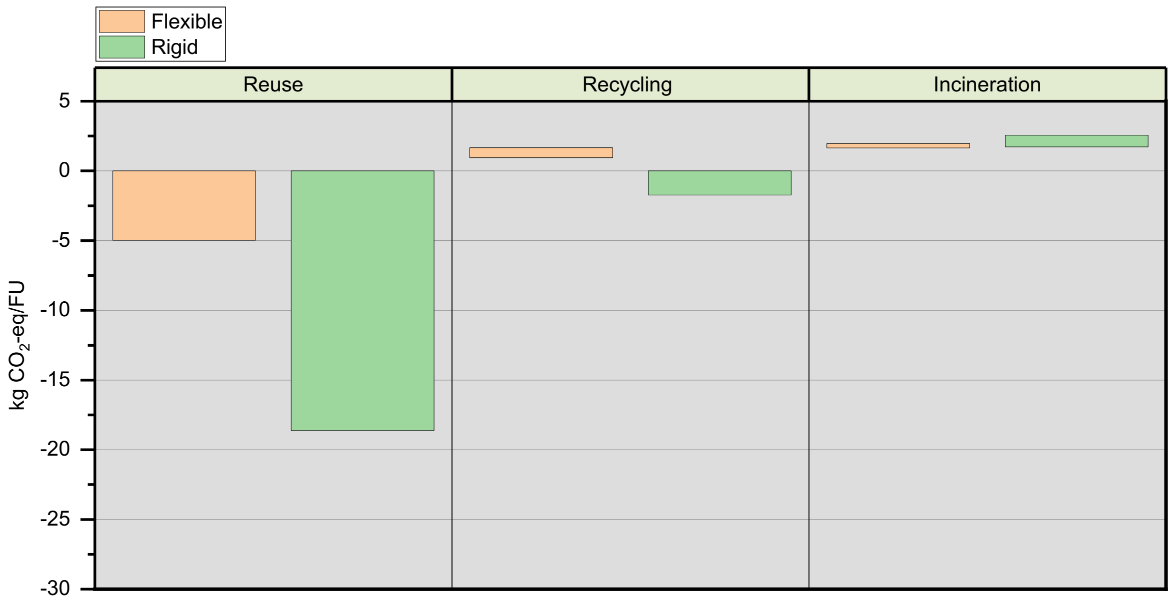


Figure 9 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid and flexible packaging products made of PS. The result intervals represent a 95% confidence interval and are presented characterized expressed as kg CO_2 equivalent per functional unit (FU).

Reusing both rigid and flexible PS packaging has the highest climate change savings compared to the other two scenarios, due to the high estimated recovery rate, ranging from 89% to 93%, %, versus 34% to 64% for recycling, and the limited climate change impacts associated with washing and preparation activities. Recycling PS packaging results in net- negative impacts in the case of rigid products and in net positive impacts in the case of flexible products. Both in the reuse and recycling scenarios, PP rigid packaging has the lowest potential score for climate change due to its higher number of cycles, estimated to range between 2 and 50 for reuse and between 2 and 25 for recycling of rigid PS packaging, compared to 2 and 25 for reuse and 2 and 5 for recycling of flexible PS packaging. In addition, PS has a high fossil carbon content, so a significant amount of CO_2 is released during the incineration of the recycling residues, significantly reducing the benefits of recycling. Reusing also replaces the need for producing new packaging, while recycling only reduces the demand for virgin raw materials. In the incineration option, PS rigid packaging is observed to cause larger climate change impacts than flexible PS packaging.

A significant distinction between the impacts caused by flexible and rigid PS packaging in every scenario also lies in the amount of material required to fulfil the functional unit of this study. Specifically, less material is required for flexible PS products resulting, depending on the scenario, in reduced climate impacts or savings at every rotation.

7.5 PLA

The environmental impact on climate change of the full life cycle of both rigid and flexible packaging products made of PLA plastic is presented in Figure 10. Overall, the results indicate that reusing bio-based PLA packaging represents climate change savings for both flexible and rigid types, while recycling of flexible packaging results in net impacts on climate change, and savings for recycling of rigid packaging. Incineration of PLA packaging causes burdens on the environment, albeit limited.

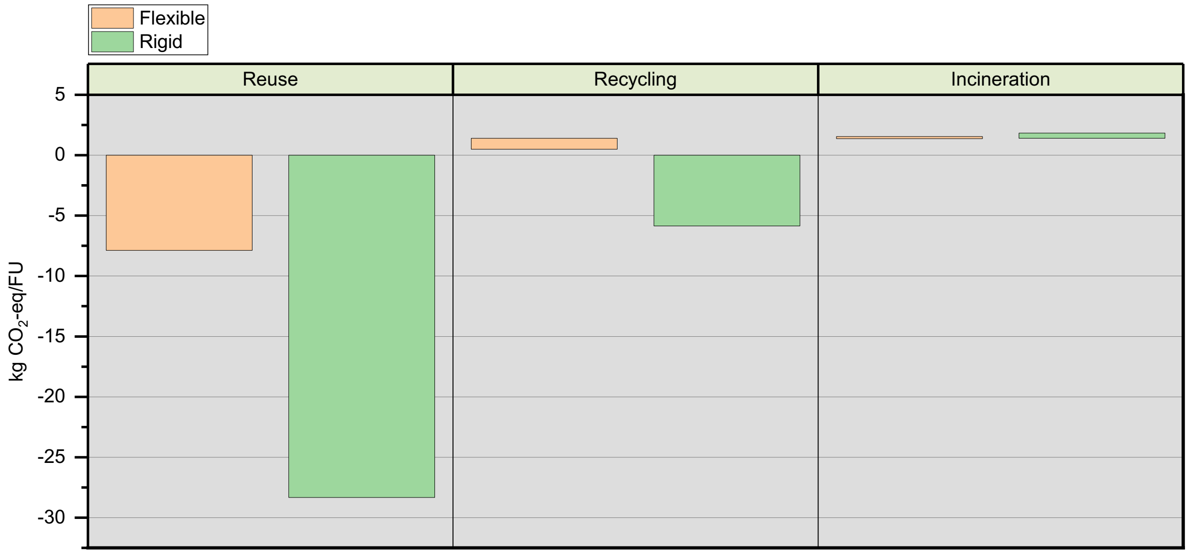


Figure 10 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid and flexible packaging products made of PLA. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

Reusing PLA plastic packaging, both rigid and flexible, leads to the highest savings in the climate change, as it reduces the need for resource extraction and production of PLA packaging at every cycle. Moreover, the preparation activities for reuse have a limited impact on climate change.

Compared to flexible PLA packaging, PLA rigid packaging has the highest net-negative potential for climate change. One of the reasons is its higher assumed number of cycles in both reuse and recycling scenarios (2 to 50 and 2 to 25, respectively) compared to flexible packaging (2 to 25 for the reuse scenario and 2 to 5 for the recycling scenario).

PLA packaging is assumed to contain only biogenic carbon; no fossil CO_2 is released during incineration. Thus, the benefits are associated with substituting marginal electricity and heat generated during incineration. However, the net climate change impacts of the incineration scenario are still positive due to the impacts from producing the PLA packaging.

A significant difference between the impacts of flexible and rigid PLA packaging in each scenario is related to the quantity of material necessary to meet the functional unit criteria of this study. In particular, flexible PLA packaging needs less material, which can lead to a cumulative decrease in climate change effects or savings at every rotation.

7.6 Cartonboard

The environmental impact on climate change of the full life cycle of rigid packaging products made of cartonboard is presented in Figure 11. Overall, the life cycle analysis findings indicate that reusing and recycling cartonboard packaging provide net-negative climate change potential emissions while the incineration of cartonboard packaging causes burdens on the climate change score, albeit limited.

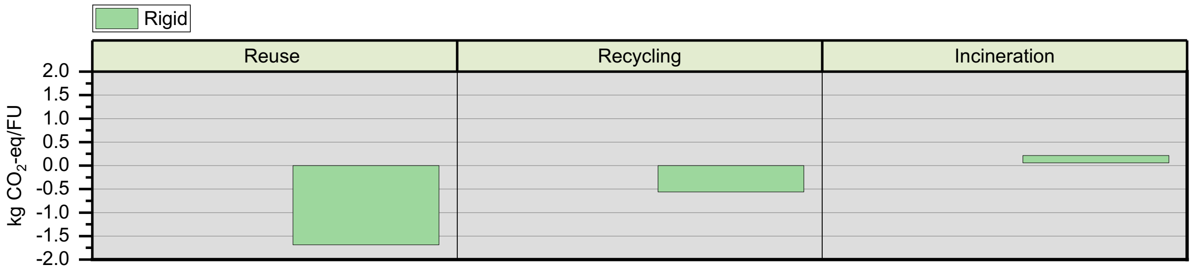


Figure 11 - Potential environmental impacts of climate change related to the production and end-of-life management of rigid packaging products made of cartonboard. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

The repeated use of cartonboard packaging significantly reduces climate change, as it prevents consequtive emissions from the production activities of virgin cartonboard packaging, such as deforestation and virgin pulp, production and conversion into packaging processes. Recycling cartonboards has environmental benefits, as the CO_2 emissions from the recycling processes are lower than producing new cartonboard packaging. Note that the results between these two waste management options can vary due to the fact that corrugated packaging can be reused more frequently (2 to 25 times) than it can be recycled (2 to 15 times).

7.7 Corrugated board

The impact of the full life cycle of rigid packaging products made of the corrugated board on climate change is illustrated in Figure 12. The analysis shows that reusing and recycling corrugated board packaging results in climate change savings, while incineration of corrugated packaging has a relatively small impact on climate change.

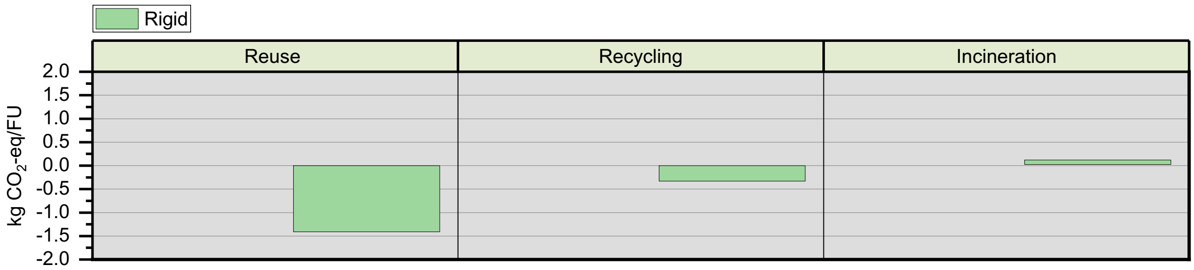


Figure 12 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid packaging products made of corrugated board. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

The repeated use of corrugated packaging significantly reduces climate change, as it avoids multiple times production of new corrugated packaging, more specifically, the emissions from the production activities of virgin cartonboard packaging, such as deforestation and virgin pulp, production and conversion into packaging processes. Recycling corrugated packaging is also environmentally beneficial as the CO_2 emissions from recycling machinery and equipment are lower than producing virgin materials for corrugated packaging. It is noteworthy that the results between these two waste management options can vary because corrugated packaging can be reused more frequently (2 to 25 times) than it can be recycled (2 to 15 times).

7.8 Aluminium

The climate change potential for aluminium packaging products is presented in Figure 13. The life cycle assessment results indicate that reusing and recycling rigid and flexible aluminium packaging has environmental benefits, whereas incineration causes net climate change impacts.

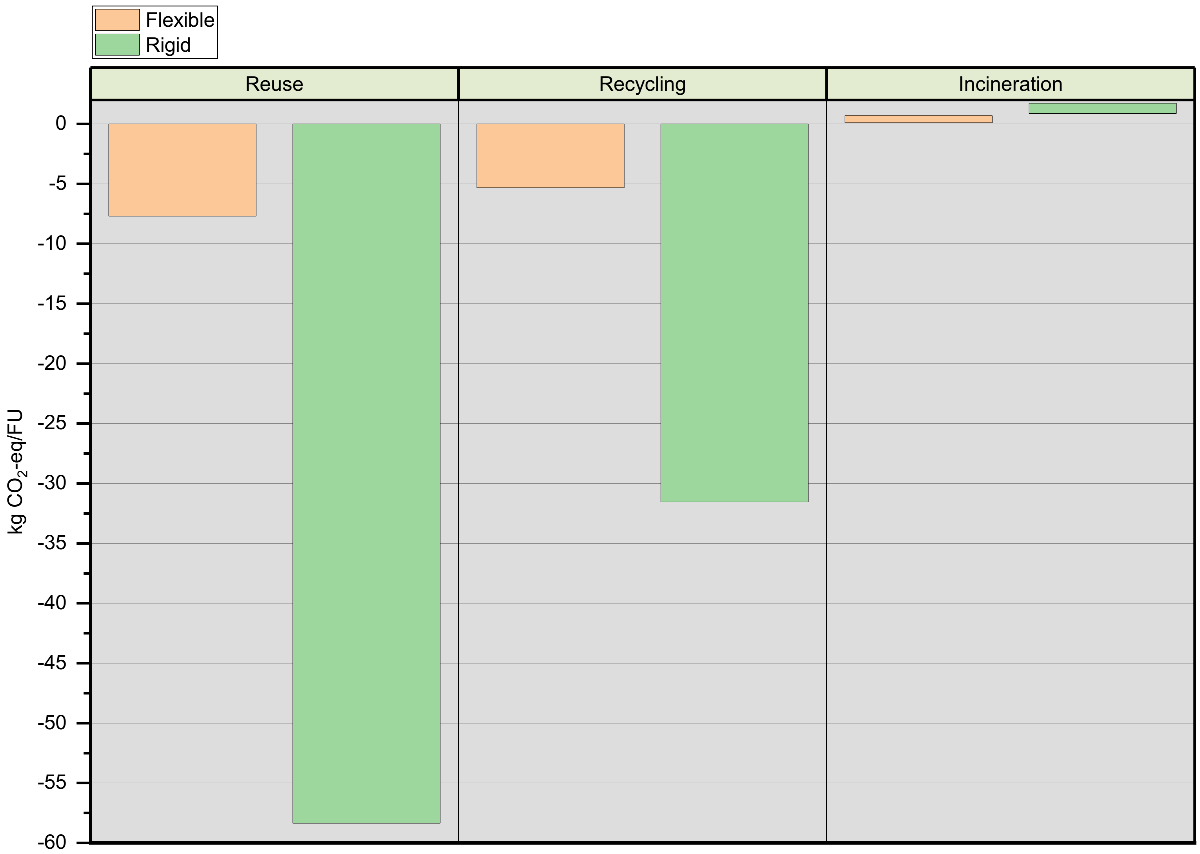


Figure 13 - Potential environmental impacts of climate change related to the production and waste management of flexible and rigid aluminium packaging products made of aluminium. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

Reusing rigid and flexible aluminium packaging leads to the highest savings in climate change potential due to its high recovery rate ranging between 89% and 93% versus 60% and 99% for recycling and the limited environmental impact associated with washing and preparation activities. Reusing both types of aluminium packaging replaces the need for new virgin packaging, which typically involves energy-intensive processes.

From Figure 13, it can also be observed that rigid packaging has a higher net-negative potential for climate change than flexible packaging due to its higher assumed number of cycles in both the reuse and recycling scenarios. The number of potential cycles for the reuse and recycling scenario ranges between 2 and 50 for rigid packaging and between 2 and 25 for flexible packaging.

In the incineration option, aluminium packaging causes an environmental burden, although limited due to recycling of aluminium scrap recovered from bottom ashes.

Finally, consider that the amount of material required to fulfil the functional unit of this study also varies between flexible and rigid aluminium packaging, with flexible products requiring less material and resulting at every rotation, in reduced climate change impacts or savings depending on the scenario.

7.1 Paper

The environmental impact on climate change of the full life cycle of flexible packaging products made of paper is presented in Figure 14. Overall, the life cycle analysis results show that the reuse and recycling of paper packaging contribute to decreased emissions with a net positive impact on climate change, while the incineration of paper packaging has a limited impact on climate change.

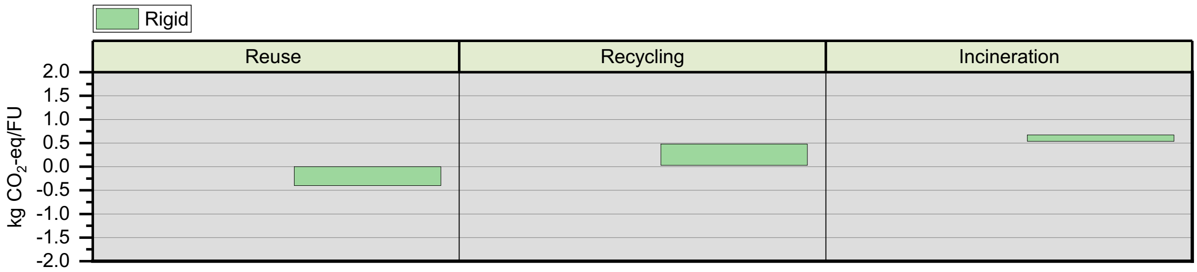


Figure 14 - Potential environmental impacts within climate change related to the production and end-of-life management of flexible packaging products made of paper. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

Reusing paper packaging results in the highest savings in the climate change potential, as it prevents repeated emissions from the production activities of virgin cartonboard packaging, such as deforestation and virgin pulp production and related processes. Recycling cartonboard also has environmental benefits, as the CO_2 emissions from using processing equipment during recycling are lower than producing new paper. Despite having the same cycles (ranging between 2 and 5) for both the reuse and recycling scenarios, recycling still requires energy and resources to process, thus leading to higher impacts on climate change potential than the reuse scenario.

7.2 Steel

The impact of the entire life cycle of rigid packaging products made of steel on climate change is illustrated for three end-of-life scenarios in Figure 15. The analysis results show that both reusing and recycling steel packaging result in savings on the climate change potential score, while the incineration scenario has only few impacts within climate change.

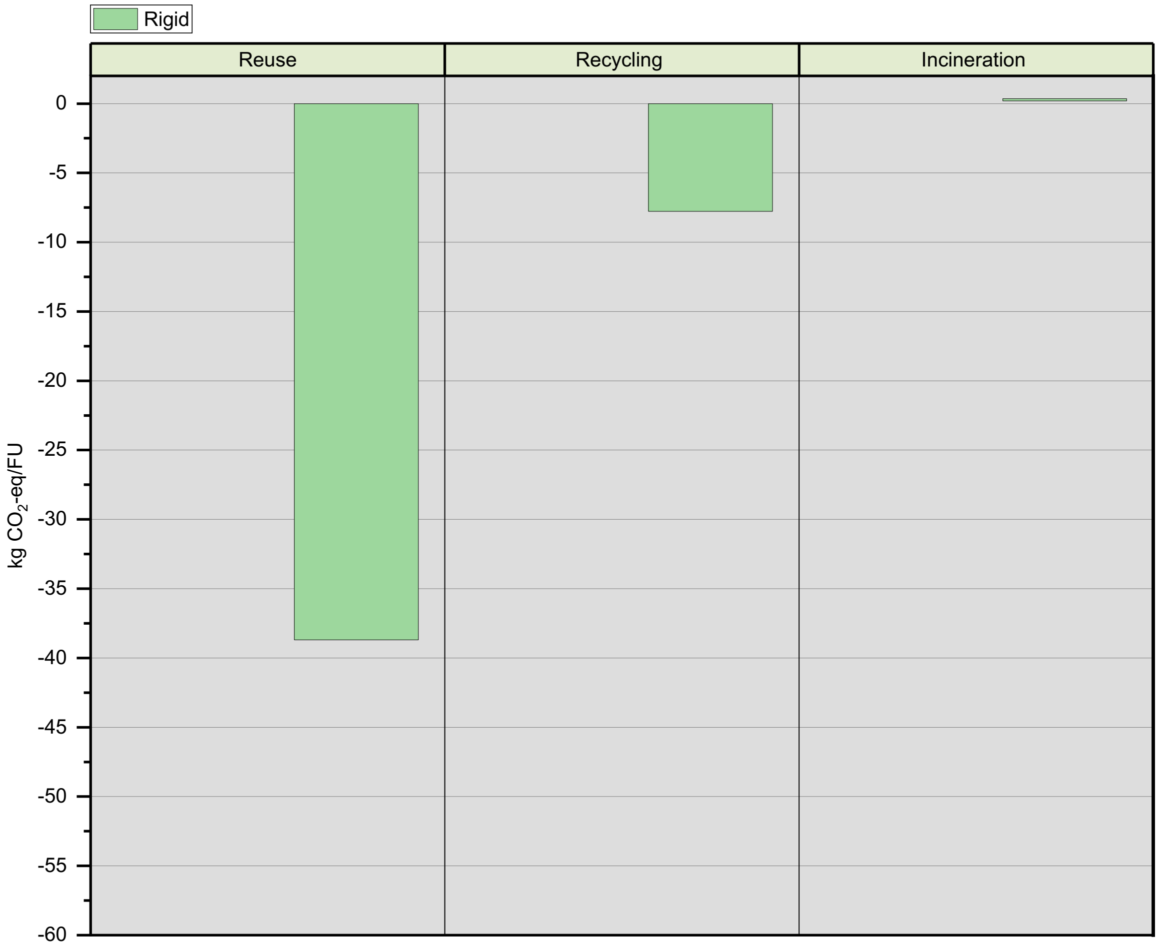


Figure 15 - Potential environmental impacts within climate change related to the production and end-of-life management of rigid packaging products made of steel. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

Reusing steel has the most significant impact on reducing climate change because each reuse cycle is assumed to substitute the need for resource extraction and manufacturing of steel packaging, which involves significant energy-intensive activities. Recycling steel also saves the climate change potential score, as the emissions during sorting and processing are lower than those from producing new steel. However, even though the potential number of cycles is the same for both reuse and recycling scenarios, i.e. ranging between 2 and 50, recycling requires more energy and other resources to reprocess the materials, resulting in lower savings on climate change compared to reusing steel packaging. Additionally, the recovery rate for reused steel packaging is generally higher, of 89% to 93%, compared to recycling, which typically has a recovery rate of 77% to 81%. Efficient recycling, however, may still result in more significant savings than reusing steel packaging with a lower recovery rate.

7.3 Glass

The environmental impact on climate change of the entire life cycle of rigid packaging made of glass is depicted in Figure 16. Overall, the life cycle analysis findings indicate that the reuse and recycling of glass packaging result in savings on the climate change potential score, while the incineration scenario results in climate change potential emissions.

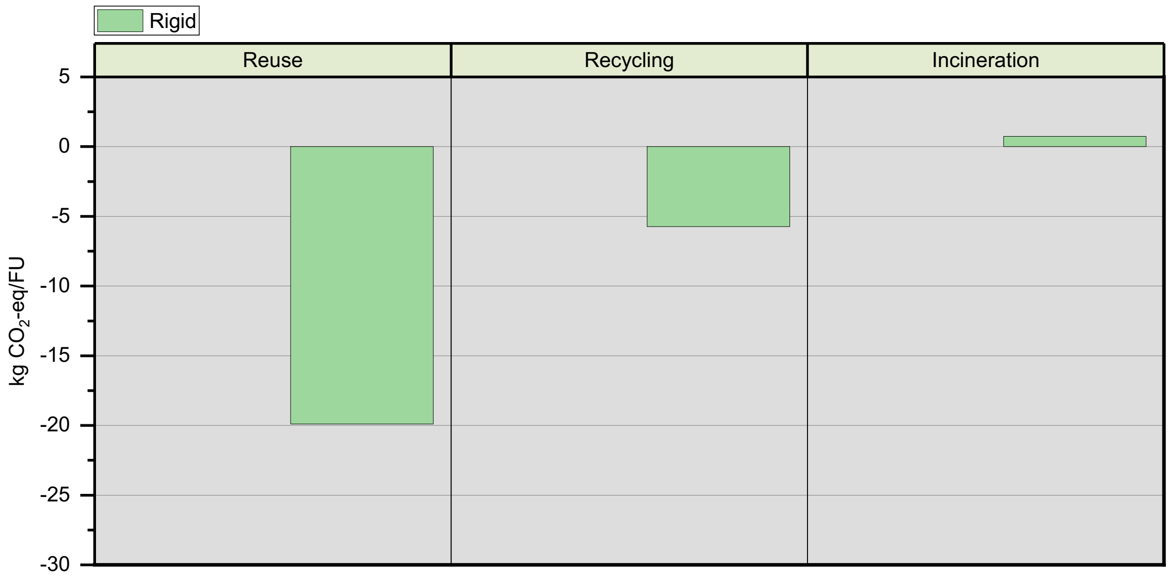


Figure 16 - Potential environmental impacts within climate change related to the production and waste management of rigid packaging made of glass. The result intervals represent a 95% confidence interval and are presented characterized as kg CO_2 equivalent per functional unit (FU).

Glass packaging that is reused has the lowest climate change impact due to the limited climate change potential associated with the sorting process and the washing and preparation activities compared to the production activities. Indeed, reusing glass packaging avoids the need to extract new virgin minerals and the potential global emissions associated with melting and conversion into packaging processes. Savings in the potential global score are also observed in the recycling scenario. However, recycling is assumed to substitute only the demand for virgin raw materials within every cycle.

The potential number of cycles is the same for the reuse and recycling scenario, i.e. between 2 and 50. The significant differences in the results are attributed to the processes associated with the two waste management options and the relative substitution assumptions.

Overall, glass packaging contains minimal amounts of carbon; therefore, causing few CO_2 emissions when incinerated. However, since glass contribute with no net energy production, no savings in climate change impacts can be associated with incineration. As a result, incineration of glass packaging results in a small burden.

8. Conclusion

This study provides a comparative LCA of selected packaging materials, from raw material production to different end-of-life options. The considered end-of-life scenarios are multiple-loop reuse, multiple-loop recycling and incineration. The results are intended for internal decision support at the Danish EPA as part of a broader range of evaluations about implementing the Extended Producer Responsibility (EPR) system.

Environmental impacts throughout the life cycle of various packaging products, considering different packaging materials and types, are modelled. The selected packaging materials are fossil plastics (PET, PE, PP, PS), bio-based plastic (PLA), metals (aluminium, steel), fibre-based materials (paper, cartonboard, corrugated board), and glass. The environmental impacts of packaging products, among other aspects, depending on the material, the packaging type and the end-of-life scenarios options.

The LCA results show that multiple-loop reuse and multiple-loop recycling are environmentally beneficial relative to the incineration of the same packaging products. The reuse scenario for all materials and packaging types always provided the most significant potential climate change savings. Reuse extends a product's life, reducing the need for resource extraction and conversion into packaging processes at every cycle and the overall amount of waste sent to incineration. The higher the environmental impacts associated with resource extraction and packaging product manufacturing, the more significant the potential savings from reuse. The reusability of aluminium and steel packaging offered the most significant potential for savings.

Generally, recycling provides fewer climate change benefits than reuse, partly because only the material conversion into the packaging product was substituted. As for the reuse scenario, the most significant benefits are observed for energy-intensive materials. However, the quality degradation of recycling packaging materials is essential to consider. Each time a material is recycled, it undergoes some degree of degradation, which can decrease its strength, flexibility, and overall quality. Some materials, like glass and aluminium, can be recycled multiple times with relatively little degradation in quality, while others, like some types of plastic, may degrade more quickly with each recycling cycle.

The LCA results highlight that for most materials, reusing packaging products only a few times may be less environmentally beneficial than recycling the same materials many times. Thus, the number of product cycles can be decisive for the overall environmental impacts of the packaging product, albeit with some uncertainty. Similarly, reuse systems should be associated with some level of documentation for the number of cycles, as recycling systems should document the recycling rate of the materials.

Product-specific LCA modelling is necessary to quantify and understand the environmental impacts associated with packaging products in an EPR context. The results provided in this study evaluate a range of generic packaging products in the context of a range of generic end-of-life scenarios. For specific implementation of EPR regulations, further aspects should be considered, e.g., compliance with product-specific regulations, type and combinations of materials, amounts of recycled content in packaging products, reprocessing methods, and the presence of labels, lids, and caps. These aspects have not been addressed in this study, and their end-of-life management may affect the overall environmental impacts of the packaging products.

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10. Appendix I

10.1 LCI – Electricity modelling update

Table A 1 – Marginal electricity for Europe update: the left column displays the processes used in the EPA report 'Environmental profiles of packaging materials', while the right column presents the updates made to these processes for this study.

Marginal Electricity for Europe	
Process name as modelled in the EPA report “Environmental profiles of packaging materials”	Process update in this study (source: Ecoinvent)
electricity, high voltage,electricity production, wood, future,GLO	
electricity, hard coal, RER	electricity, high voltage,electricity production, hard coal,RoW
electricity, lignite, RER	electricity, high voltage,electricity production, lignite,RoW
electricity, geothermal, RER	electricity, high voltage,electricity production, deep geothermal,RoW
electricity, hydro-lakes, RER	electricity, high voltage,electricity production, hydro, reservoir, alpine region,RoW
electricity, hydro-river, RER	electricity, high voltage,electricity production, hydro, run-of-river,RoW
electricity, natural gas conventional, RER	electricity, high voltage,electricity production, natural gas, conventional power plant,RoW
electricity, natural gas combined, RER	electricity, high voltage,electricity production, natural gas, combined cycle power plant,RoW
electricity, nuclear, RER	electricity, high voltage,electricity production, nuclear, pressure water reactor,RoW
electricity, oil, RER	electricity, high voltage,electricity production, oil,RoW
electricity, solar panels, RER	electricity, low voltage,electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted,RoW
electricity, solar plant, RER	electricity, high voltage,electricity production, solar tower power plant, 20 MW,RoW
electricity, wind onshore, RER	electricity, high voltage,electricity production, wind, >3MW turbine, onshore,RoW
electricity, wind offshore, RER	electricity, high voltage,electricity production, wind, 1-3MW turbine, offshore,RoW

10.2 LCI – Process modelling update

Table A 2 - Process update: the left column displays the processes used in the EPA report 'Environmental profiles of packaging materials', while the right column presents the updates made to these processes for this study.

Process name as modelled in the EPA report “Environmental profiles of packaging materials”	Process update in this study (source: Ecoinvent)
diesel, low-sulfur,diesel production, low-sulfur,Europe without Switzerland	diesel production, low-sulfur, petroleum refinery operation_Europe without Switzerland
chromite ore concentrate,chromite ore concentrate production,GLO	chromite ore concentrate, market for chromite ore concentrate
steel, chromium steel 18/8,steel production, converter, chromium steel 18/8,RER	steel production, electric, chromium steel 18_8_RER_2023_Consequential
ammonia, liquid,market for ammonia, liquid,RER	market for ammonia, anhydrous, liquid
iron scrap, sorted, pressed,market for iron scrap, sorted, pressed,GLO	iron scrap, sorted, pressed,market for iron scrap, sorted, pressed,RER

11. Appendix II

11.1 Overview of the climate change potential results

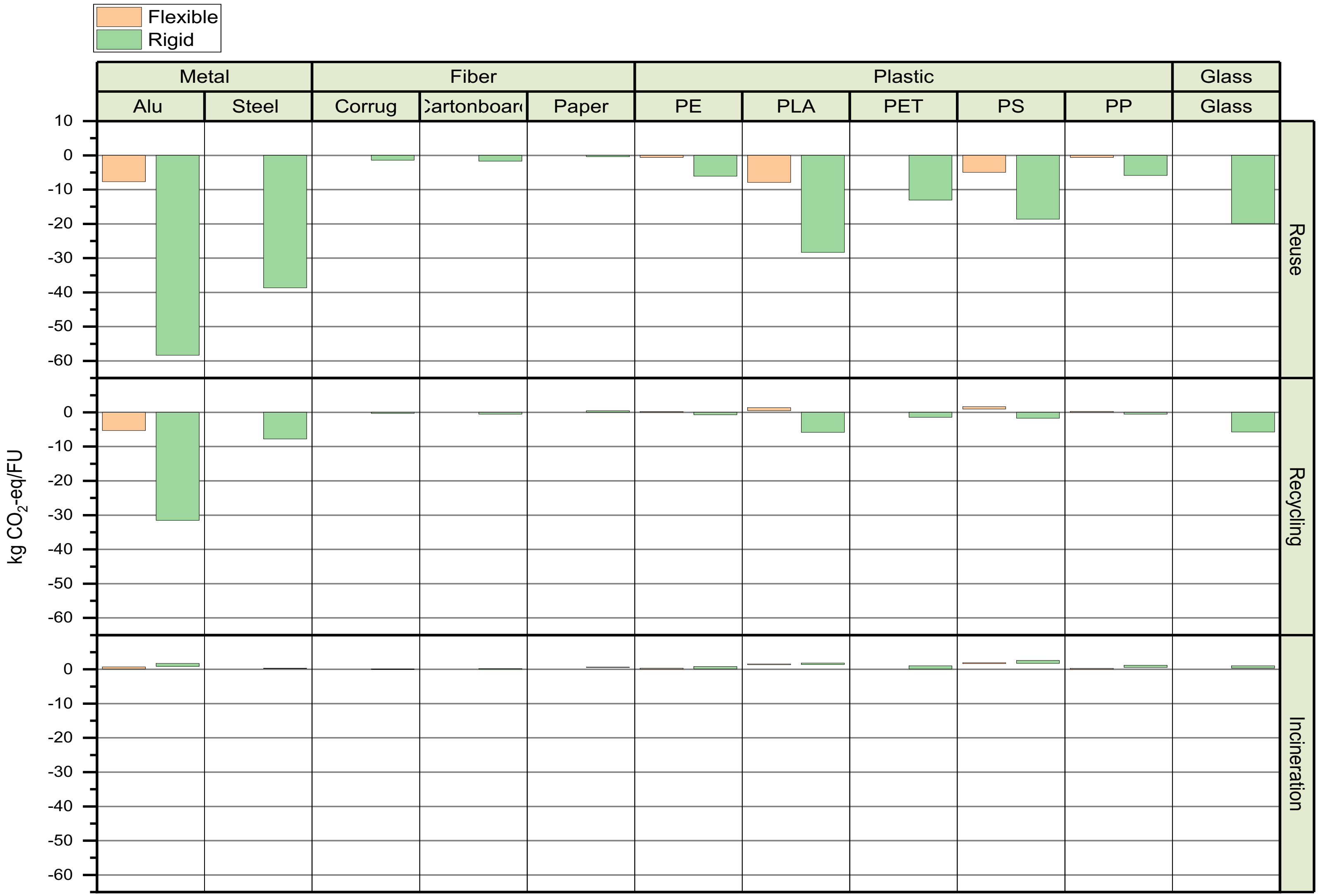

Figure A 1 - Comparison of the climate change potential results for all selected materials for rigid packaging

11.2 Characterised results for all impact cathegories

Table A 3 - Impact categories considered in this model and their corresponding short names used in the following tables.

Impact category	Short name
Climate change	CC
Ozone depletion	OD
Human toxicity, cancer effects	HT-C
Human toxicity, non-cancer effects	HT-nC
Particulate matter/respiratory inorganics	PM
Ionizing radiation, human health	IR
Photochemical ozone formation, human health	POF
Acidification	TA
Eutrophication terrestrial	ET
Eutrophication freshwater	EF
Eutrophication marine	EM
Ecotoxicity freshwater	EcoF
Land use	LU
Resource use, minerals and metals	RUMM

11.2.1 PET

Rigid packaging - Reuse scenario

Table A 4 - Characterized result scores for all the selected impact categories - Reuse scenario of PET rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-3.15	0.00	0.00	0.00	0.00	-0.03	-0.01	-0.01	-0.03	0.00	0.00	-51.95	-27.49	-2.47	0.00	-75.71
Mean	-4.23	0.00	0.00	0.00	0.00	-0.04	-0.01	-0.02	-0.03	0.00	0.00	-69.89	-37.73	-3.36	0.00	-101.39
5%	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	3.76	0.30	0.00	6.92
95%	-13.06	0.00	0.00	0.00	0.00	-0.11	-0.04	-0.05	-0.11	0.00	-0.01	-214.42	-116.59	-11.09	0.00	-311.50

Table A 5 - Characterized result scores for all the selected impact categories - Recycling scenario of PET rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.48	0.80	-0.07	0.00	-5.20
Mean	-0.21	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-2.64	0.91	-0.13	0.00	-8.34
5%	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.90	6.85	0.38	0.00	8.67
95%	-1.43	0.00	0.00	0.00	0.00	-0.02	0.00	-0.01	-0.01	0.00	0.00	-16.38	-4.60	-0.89	0.00	-38.71

Table A 6 - Characterized result scores for all the selected impact categories - Incineration scenario of PET rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.65	2.88	0.24	0.00	7.92
Mean	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.62	2.87	0.25	0.00	7.88
5%	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.92	5.49	0.51	0.00	13.87
95%	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.70	0.05	0.00	1.93

11.2.2 PE

Table A 7 - Characterized result scores for all the selected impact categories - Reuse scenario of PE flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,78	-1,15	-0,17	0,00	-6,12
Mean	-0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-2,27	-1,44	-0,22	0,00	-7,97
5%	0,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,26	0,21	0,05	0,00	1,36
95%	-0,61	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-6,82	-4,46	-0,71	0,00	-25,04

Table A 8 - Characterized result scores for all the selected impact categories - Recycling scenario of PE flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,10	-0,25	0,06	0,00	0,99
Mean	0,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,12	-0,39	0,06	0,00	1,09
5%	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,56	1,03	0,13	0,00	2,62
95%	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,81	-2,27	0,02	0,00	0,12

Table A 9 - Characterized result scores for all the selected impact categories - Incineration scenario of PE flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,03	-0,12	0,04	0,00	1,89
Mean	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,04	-0,19	0,04	0,00	1,90
5%	0,31	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,26	0,20	0,08	0,00	3,26
95%	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,97	-0,84	0,01	0,00	0,50

Table A 10 - Characterized result scores for all the selected impact categories - Reuse scenario of PE rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-1.44	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	0.00	0.00	-14.06	-4.92	-1.38	0.00	-55.75
Mean	-1.94	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	0.00	0.00	-18.69	-6.71	-1.90	0.00	-73.55
5%	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.34	0.15	0.00	2.27
95%	-6.09	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.02	-0.04	0.00	0.00	-57.24	-25.31	-6.81	0.00	-221.17

Table A 11 - Characterized result scores for all the selected impact categories - Recycling scenario of PE rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.25	-1.29	0.01	0.00	-6.48
Mean	-0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.73	-1.73	0.01	0.00	-8.68
5%	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	1.50	0.28	0.00	3.98
95%	-0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-8.01	-6.38	-0.26	0.00	-32.96

Table A 12 - Characterized result scores for all the selected impact categories - Incineration scenario of PE rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.60	-0.67	0.08	0.00	4.78
Mean	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.56	-0.85	0.09	0.00	4.73
5%	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.52	0.15	0.24	0.00	8.41
95%	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.81	-2.58	0.01	0.00	1.08

11.2.3 PP

Table A 13 - Characterized result scores for all the selected impact categories - Reuse scenario of PP flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0,12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,38	-0,53	-0,11	0,00	-5,63
Mean	-0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,73	-0,71	-0,15	0,00	-7,36
5%	0,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,16	0,58	0,05	0,00	1,80
95%	-0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-5,29	-2,81	-0,49	0,00	-23,61

Table A 14 - Characterized result scores for all the selected impact categories - Recycling scenario of PP flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,32	-0,11	0,05	0,00	1,36
Mean	0,12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,41	-0,17	0,05	0,00	1,44
5%	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,27	0,67	0,12	0,00	3,06
95%	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,34	-1,34	0,01	0,00	0,33

Table A 15 - - Characterized result scores for all the selected impact categories - Incineration scenario of PP flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,00	0,13	0,03	0,00	1,99
Mean	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,03	0,18	0,03	0,00	2,00
5%	0,31	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,26	0,62	0,06	0,00	3,53
95%	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,88	0,01	0,01	0,00	0,54

Table A 16 - Characterized result scores for all the selected impact categories - Reuse scenario of PP rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-15.62	-7.93	-1.72	0.00	-51.06
Mean	-1.78	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	0.00	0.00	-20.32	-10.99	-2.57	0.00	-66.25
5%	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	1.41	0.19	0.00	6.48
95%	-5.87	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.04	0.00	0.00	-63.24	-39.56	-9.88	0.00	-207.82

Table A 17 - Characterized result scores for all the selected impact categories - Recycling scenario of PP rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.16	-0.70	0.04	0.00	-2.60
Mean	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.42	-0.96	0.05	0.00	-5.09
5%	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1.19	0.28	0.00	5.82
95%	-0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.22	-4.31	-0.14	0.00	-28.72

Table A 18 - Characterized result scores for all the selected impact categories - Incineration scenario of PP rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.35	0.13	0.08	0.00	5.01
Mean	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.35	0.22	0.10	0.00	4.91
5%	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.47	1.37	0.28	0.00	8.64
95%	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.48	-0.37	0.01	0.00	1.12

11.2.4 PS

Table A 19 - Characterized result scores for all the selected impact categories - Reuse scenario of PS flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-2.08	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	0.00	0.00	-3.55	-3.62	-1.62	0.00	-48.04
Mean	-2.05	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	0.00	0.00	-3.50	-3.62	-1.61	0.00	-47.62
5%	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.96	0.53	0.00	13.98
95%	-4.97	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.03	0.00	0.00	-7.45	-8.32	-3.80	0.00	-111.91

Table A 20 - Characterized result scores for all the selected impact categories - Recycling scenario of PS flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.57	-2.92	0.66	0.00	17.42
Mean	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.55	-3.18	0.66	0.00	17.00
0,05	1.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.57	0.68	0.80	0.00	20.80
0,95	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-7.35	-8.16	0.54	0.00	11.65

Table A 21 - Characterized result scores for all the selected impact categories - Incineration scenario of PS flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8.77	-0.80	0.63	0.00	20.89
Mean	1.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8.79	-0.88	0.63	0.00	20.90
5%	1.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-7.25	-0.39	0.69	0.00	22.21
95%	1.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-10.49	-1.68	0.58	0.00	19.68

Table A 22 - Characterized result scores for all the selected impact categories - Reuse scenario of PS rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-7.44	0.00	0.00	0.00	0.00	0.00	-0.02	-0.03	-0.05	0.00	0.00	-13.35	-2.55	-4.47	0.00	-167.56
Mean	-7.58	0.00	0.00	0.00	0.00	0.00	-0.02	-0.03	-0.05	0.00	0.00	-13.68	-3.41	-4.59	0.00	-172.05
5%	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.49	4.13	0.38	0.00	13.98
95%	-18.62	0.00	0.00	0.00	0.00	-0.01	-0.05	-0.07	-0.11	0.00	-0.01	-30.98	-15.43	-11.32	0.00	-419.27

Table A 23 - Characterized result scores for all the selected impact categories - Recycling scenario of PS rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.36	-5.56	-0.02	0.00	-2.35
Mean	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.35	-5.98	-0.09	0.00	-5.46
5%	1.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.38	-0.74	0.63	0.00	22.83
95%	-1.72	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.02	0.00	0.00	-10.40	-13.98	-1.26	0.00	-50.92

Table A 24 - Characterized result scores for all the selected impact categories - Incineration scenario of PS rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-10.27	-3.22	0.51	0.00	23.86
Mean	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-10.40	-3.43	0.51	0.00	23.87
5%	2.57	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	-7.34	-1.62	0.62	0.00	27.72
95%	1.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-13.97	-6.20	0.42	0.00	20.49

11.2.5 PLA

Table A 25 - Characterized result scores for all the selected impact categories - Reuse scenario of PLA flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-3.27	0.00	0.00	0.00	0.00	0.04	-0.01	-0.01	-0.06	0.00	0.00	-81.49	-15.46	-3.68	0.00	-26.20
Mean	-3.27	0.00	0.00	0.00	0.00	0.04	-0.01	-0.01	-0.06	0.00	0.00	-81.41	-15.39	-3.68	0.00	-26.20
5%	0.99	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.02	0.00	0.00	23.88	5.28	1.19	0.00	7.74
95%	-7.88	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.03	-0.14	0.00	-0.01	-195.85	-37.58	-8.91	0.00	-63.06

Table A 26 - Characterized result scores for all the selected impact categories - Recycling scenario of PLA flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	1.12	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.02	0.00	0.00	26.08	7.62	1.40	0.00	8.55
Mean	1.07	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.02	0.00	0.00	25.43	7.95	1.36	0.00	8.29
5%	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	33.34	12.25	1.73	0.00	10.86
95%	0.50	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.01	0.00	0.00	13.42	4.97	0.83	0.00	4.30

Table A 27 - Characterized result scores for all the selected impact categories - Incineration scenario of PLA flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	1.45	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	30.17	5.31	1.66	0.00	10.25
Mean	1.45	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	30.27	5.31	1.66	0.00	10.27
5%	1.54	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	32.47	6.04	1.77	0.00	11.02
95%	1.36	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	28.44	4.56	1.55	0.00	9.64

Table A 28 - Characterized result scores for all the selected impact categories - Reuse scenario of PLA rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-10.14	0.00	0.00	0.00	0.00	0.11	-0.02	-0.03	-0.18	0.00	-0.01	-253.00	-42.16	-11.88	0.00	-79.80
Mean	-11.12	0.00	0.00	0.00	0.00	0.12	-0.03	-0.04	-0.20	0.00	-0.02	-277.97	-45.78	-12.90	0.00	-87.60
5%	0.95	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.02	0.00	0.00	23.27	4.32	1.31	0.00	7.12
95%	-28.32	0.00	0.00	0.00	0.00	-0.01	-0.07	-0.09	-0.51	0.00	-0.04	-705.11	-113.17	-32.39	0.00	-221.87

Table A 29 - Characterized result scores for all the selected impact categories - Recycling scenario of PLA rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.79	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-0.01	0.00	0.00	-22.14	-0.63	-0.46	0.00	-6.89
Mean	-1.22	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-0.02	0.00	0.00	-32.11	-1.49	-0.87	0.00	-10.15
5%	1.46	0.00	0.00	0.00	0.00	0.07	0.00	0.01	0.03	0.00	0.00	33.96	10.16	1.93	0.00	10.31
95%	-5.85	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.02	-0.11	0.00	-0.01	-147.78	-17.48	-5.77	0.00	-46.21

Table A 30 - Characterized result scores for all the selected impact categories - Incineration scenario of PLA rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	1.60	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	32.64	4.16	1.89	0.00	10.89
Mean	1.60	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	32.86	4.12	1.91	0.00	10.94
5%	1.83	0.00	0.00	0.00	0.00	-0.02	0.00	0.01	0.03	0.00	0.00	37.94	6.32	2.40	0.00	12.56
95%	1.40	0.00	0.00	0.00	0.00	-0.03	0.00	0.01	0.03	0.00	0.00	29.20	1.44	1.51	0.00	9.65

11.2.6 Paper

Table A 31 - Characterized result scores for all the selected impact categories - Reuse scenario of a rigid paper packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.24	9.95	-0.03	0.00	-1.33
Mean	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.31	9.14	-0.03	0.00	-1.45
5%	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.19	60.74	0.06	0.00	1.25
95%	-0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.98	-43.24	-0.14	0.00	-4.57

Table A 32 - Characterized result scores for all the selected impact categories - Recycling scenario of rigid paper packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.03	27.98	0.25	0.00	2.82
Mean	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.05	27.97	0.25	0.00	2.83
5%	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	8.29	72.00	0.29	0.00	3.77
95%	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.93	-18.69	0.20	0.00	1.93

Table A 33 - Characterized result scores for all the selected impact categories - Incineration scenario of rigid paper packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	1.17	96.47	0.05	0.00	2.11
Mean	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	1.16	96.45	0.05	0.00	2.11
5%	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	1.62	98.70	0.07	0.00	2.67
95%	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.68	94.25	0.03	0.00	1.53

11.2.7 Cartonboard

Table A 34 - Characterized result scores for all the selected impact categories - Reuse cartonboard rigid packaging product scenario.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-13.26	-42.67	-0.44	0.00	-5.58
Mean	-0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-16.09	-50.52	-0.54	0.00	-6.87
5%	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	5.62	0.06	0.00	0.74
95%	-1.69	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.01	-0.02	0.00	0.00	-46.69	-142.47	-1.69	0.00	-21.70

Table A 35 - Characterized result scores for all the selected impact categories - Recycling cartonboard rigid packaging product scenario.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.23	-14.48	-0.13	0.00	-0.90
Mean	-0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-4.07	-18.02	-0.17	0.00	-1.34
5%	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.96	6.25	0.11	0.00	1.37
95%	-0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-15.20	-56.22	-0.65	0.00	-6.25

Table A 36 - Characterized result scores for all the selected impact categories - Incineration scenario of cartonboard rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.85	10.14	0.10	0.00	1.26
Mean	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.87	10.23	0.10	0.00	1.31
5%	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.88	16.57	0.18	0.00	2.36
95%	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.26	4.58	0.04	0.00	0.51

11.2.8 Corrugated board

Table A 37 - Characterized result scores for all the selected impact categories - Reuse scenario of corrugated board rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.64	-47.46	-0.13	0.00	-3.75
Mean	-0.47	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-7.48	-61.00	-0.16	0.00	-4.86
5%	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	6.27	0.02	0.00	0.51
95%	-1.41	0.00	0.00	0.00	0.00	-0.02	0.00	-0.01	-0.01	0.00	0.00	-24.54	-184.08	-0.50	0.00	-14.81

Table A 38 - Characterized result scores for all the selected impact categories - Recycling scenario of corrugated board rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8.43	-13.62	-0.01	0.00	-0.88
Mean	-0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-10.01	-16.52	-0.01	0.00	-1.07
5%	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.17	5.38	0.05	0.00	0.49
95%	-0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-25.81	-50.08	-0.08	0.00	-3.41

Table A 39 - Characterized result scores for all the selected impact categories - Incineration scenario of corrugated board rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	8.09	0.01	0.00	0.52
Mean	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	8.12	0.01	0.00	0.52
5%	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	13.22	0.02	0.00	0.85
95%	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	3.09	0.01	0.00	0.19

11.2.9 Aluminium

Table A 40 - Characterized result scores for all the selected impact categories - Reuse scenario of aluminium flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-2.07	0.00	0.00	0.00	0.00	0.01	-0.01	-0.01	-0.03	0.00	0.00	-73.40	-120.58	-0.29	0.00	-29.64
Mean	-2.61	0.00	0.00	0.00	0.00	0.01	-0.01	-0.01	-0.04	0.00	0.00	-93.50	-154.45	-0.36	0.00	-37.27
5%	0.19	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	3.83	-0.01	0.02	0.00	2.54
95%	-7.69	0.00	0.00	0.00	0.00	0.00	-0.03	-0.04	-0.11	0.00	-0.01	-274.26	-465.44	-1.06	0.00	-109.00

Table A 41 - Characterized result scores for all the selected impact categories - Recycling scenario of aluminium flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-1.46	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-0.01	0.00	0.00	-25.33	20.20	-0.15	0.00	-21.13
Mean	-1.79	0.00	0.00	0.00	0.00	0.01	0.00	-0.01	-0.01	0.00	0.00	-30.85	22.40	-0.19	0.00	-25.88
5%	0.23	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	8.64	50.69	0.02	0.00	2.78
95%	-5.32	0.00	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.03	0.00	0.00	-95.47	5.10	-0.57	0.00	-76.23

Table A 42 - Characterized result scores for all the selected impact categories - Incineration scenario of aluminium flexible packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.29	9.24	0.04	0.00	5.28
Mean	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.51	9.40	0.04	0.00	5.38
5%	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	18.86	16.71	0.08	0.00	9.68
95%	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.92	2.59	0.01	0.00	1.49

Table A 43 - Characterized result scores for all the selected impact categories - Reuse scenario of aluminium rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-21.02	0.00	0.00	0.00	0.00	0.07	-0.08	-0.10	-0.28	0.00	-0.02	-720.47	-1136.53	-2.87	0.00	-302.49
Mean	-22.99	0.00	0.00	0.00	0.00	0.07	-0.09	-0.11	-0.31	0.00	-0.02	-784.67	-1238.60	-3.20	0.00	-329.63
5%	0.33	0.00	0.00	0.00	0.00	0.19	0.00	0.00	-0.01	0.00	0.00	-8.06	-49.93	0.01	0.00	4.35
95%	-58.35	0.00	0.00	0.00	0.00	0.00	-0.23	-0.28	-0.78	0.00	-0.06	-2007.20	-3074.54	-8.30	0.00	-845.98

Table A 44 - Characterized result scores for all the selected impact categories - Recycling scenario of aluminium rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-12.51	0.00	0.00	0.00	0.00	0.07	-0.04	-0.04	-0.07	0.00	-0.01	-231.09	102.03	-1.28	0.00	-180.45
Mean	-13.31	0.00	0.00	0.00	0.00	0.08	-0.04	-0.05	-0.08	0.00	-0.01	-245.76	107.87	-1.38	0.00	-191.81
5%	0.53	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.01	0.00	0.00	12.69	223.32	0.02	0.00	6.36
95%	-31.54	0.00	0.00	0.00	0.00	0.00	-0.09	-0.11	-0.19	0.00	-0.02	-593.08	30.90	-3.44	0.00	-456.60

Table A 45 - Characterized result scores for all the selected impact categories - Incineration scenario of aluminium rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	1.29	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	0.01	0.00	0.00	33.05	23.01	0.12	0.00	18.02
Mean	1.29	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	0.01	0.00	0.00	32.99	23.09	0.13	0.00	18.02
5%	1.74	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.00	44.08	31.39	0.21	0.00	24.13
95%	0.88	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.01	0.00	0.00	22.41	15.38	0.07	0.00	12.23

11.2.10 Steel

Table A 46 - Characterized result scores for all the selected impact categories - Reuse scenario of steel rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-16.56	0.00	0.00	0.00	0.00	0.12	-0.08	-0.05	-0.19	0.00	-0.02	-531.27	-165.10	-5.68	0.00	-181.80
Mean	-16.86	0.00	0.00	0.00	0.00	0.12	-0.08	-0.05	-0.19	0.00	-0.02	-540.70	-170.64	-5.93	0.00	-185.97
5%	0.77	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00	11.71	8.09	0.25	0.00	7.74
95%	-38.69	0.00	0.00	0.00	0.00	0.00	-0.18	-0.12	-0.44	0.00	-0.04	-1229.02	-399.67	-14.01	0.00	-430.95

Table A 47 - Characterized result scores for all the selected impact categories - Recycling scenario of steel rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-3.50	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.03	0.00	0.00	-77.16	-4.24	-0.49	0.00	-42.63
Mean	-3.44	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.03	0.00	0.00	-75.47	-5.03	-0.48	0.00	-42.02
5%	0.25	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	10.42	6.12	0.21	0.00	2.58
95%	-7.77	0.00	0.00	0.00	0.00	0.00	-0.04	-0.03	-0.06	0.00	-0.01	-173.58	-21.43	-1.30	0.00	-93.78

Table A 48 - Characterized result scores for all the selected impact categories - Incineration scenario of steel rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.79	5.74	0.20	0.00	2.26
Mean	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.84	5.75	0.20	0.00	2.27
5%	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	12.77	7.58	0.26	0.00	3.06
95%	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.19	4.12	0.15	0.00	1.58

11.2.11 Glass

Table A 49 - Characterized result scores for all the selected impact categories - Reuse scenario of glass rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-6.11	0.00	0.00	0.00	0.00	0.00	-0.02	-0.04	-0.11	0.00	-0.01	-311.22	-209.42	-5.95	0.00	-90.71
Mean	-7.32	0.00	0.00	0.00	0.00	0.01	-0.02	-0.05	-0.13	0.00	-0.01	-380.08	-262.42	-7.26	0.00	-114.11
5%	0.37	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	16.49	17.55	0.46	0.00	6.44
95%	-19.89	0.00	0.00	0.00	0.00	0.00	-0.06	-0.14	-0.37	0.00	-0.02	-1049.16	-811.76	-20.24	0.00	-349.29

Table A 50 - Characterized result scores for all the selected impact categories - Recycling scenario of glass rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	-2.08	0.00	0.00	0.00	0.00	0.04	0.00	-0.02	-0.05	0.00	0.00	-169.93	-57.62	-3.67	0.00	-19.26
Mean	-2.23	0.00	0.00	0.00	0.00	0.05	-0.01	-0.02	-0.05	0.00	0.00	-180.48	-61.24	-3.90	0.00	-21.02
5%	0.34	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	12.49	15.37	0.17	0.00	7.90
95%	-5.73	0.00	0.00	0.00	0.00	0.01	-0.01	-0.05	-0.13	0.00	0.00	-443.52	-163.27	-9.52	0.00	-58.38

Table A 51 - Characterized result scores for all the selected impact categories - Incineration scenario of glass rigid packaging product.

RC = 50%	CC	OZ	HTc	HTnc	PM	IR	POM	Ac	ET	EF	EM	Eco	LU	WU	Rumm	Ruec
Median	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	30.53	20.83	0.57	0.00	8.96
Mean	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	31.28	21.73	0.59	0.00	9.70
5%	1.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	48.39	36.98	0.90	0.00	18.69
95%	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	17.69	10.80	0.34	0.00	3.78