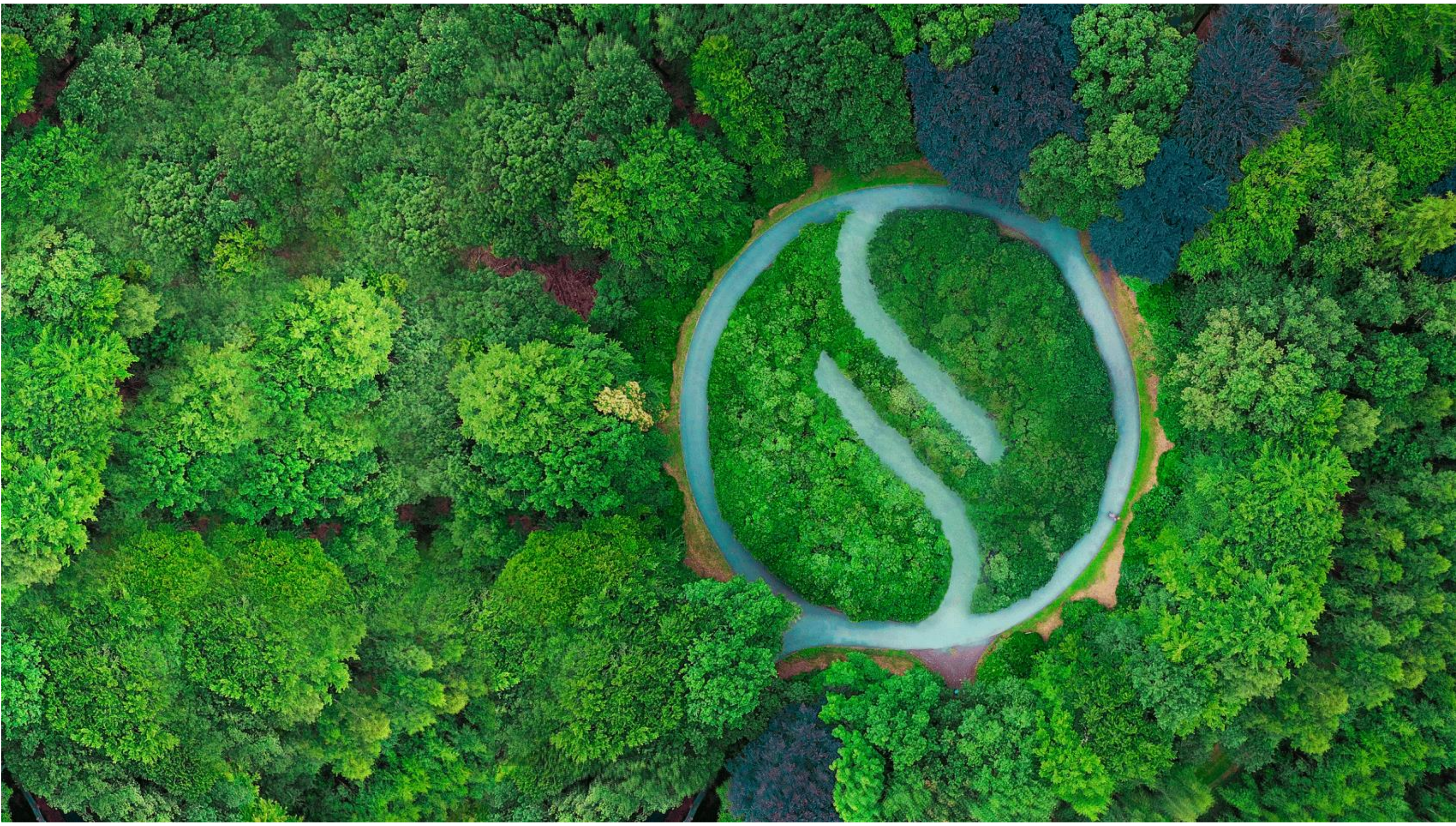

On behalf of Husky

Comparative LCA on 500 mL Beverage Packaging Products

Client:	**Husky Injection Molding Systems Ltd.**
Title:	**Comparative LCA on Beverage Packaging Products**
Report version:	v1.0
Report date:	August 10, 2023

On behalf of Sphera Solutions, Inc. and its subsidiaries

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List of Acronyms

ADP	Abiotic Depletion Potential
AP	Acidification Potential
BWC	Blue Water Consumption
CML	Centre of Environmental Science at Leiden
CSD	Carbonated Soft Drinks
EF	Environmental Footprint
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
EPf	Eutrophication Potential Freshwater
EPm	Eutrophication Potential Marine
EPt	Eutrophication Potential Terrestrial
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCAFE	Life Cycle Assessment for Experts
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MLC	Managed LCA Content
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
PEDt	Primary Energy Demand total
PEDnr	Primary Energy Demand non-renewable
PEDrr	Primary Energy Demand renewable
PET	Polyethylene Terephthalate

POCP	Photochemical Ozone Creation Potential
SFP	Smog Formation Potential
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile Organic Compound

Glossary

Life Cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life Cycle Interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Functional Unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Closed-loop and Open-loop Allocation of Recycled Material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, section 4.3.4.3.3)

Foreground System

"Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study." (JRC 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background System

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, section 3.45).

Executive Summary

Husky Technologies™, a pioneering technology provider enabling the delivery of essential needs to the global community. Helping customers reach their sustainability goals is a top priority for Husky. With today's circular economy driving package design, they work closely with customers to ensure that their packaging and other end products meet specific regional design requirements, particularly with regard to recycling and recycled content in the packaging itself.

Husky's vision is to be among the world's most valued technology and service industrial manufacturing companies. Using our innovation, collective expertise, and personal commitment, they endeavor to lead the way in developing new technologies, environmentally responsible products, and higher-efficiency manufacturing solutions that respond to and deliver the essential needs of people around the globe. Husky seeks to constantly challenge their assumptions and themselves to ensure they are on the path to the lowest overall environmental impact.

As part of their sustainability goals, Husky wants to assess the environmental impact of 500 mL PET bottles and compare it to the impacts associated with current alternatives. They would also like to assess current and potential future pathways for PET bottles. The client commissioned Sphera Solutions, Inc ("Sphera") to develop an LCA model to study various 500 mL carbonated beverage packaging solutions including PET bottles, aluminum cans, and glass bottles in the US and the EU.

The main audience for this study includes internal stakeholders, Husky's customers, and the investor community. The results will be used to identify hotspots in the manufacturing processes and facilitate informed decision-making related to raw materials, supply chain, energy use, and unit processes and operations by Husky's internal stakeholders. Husky is also looking to report the environmental performance of PET bottles compared to aluminum cans and glass bottles for marketing purposes. The life cycle impact assessment results of this study are therefore intended to be used in comparative assertions to be disclosed to the public. Husky is also interested in understanding how future changes (i.e., materials, lightweighting, recycling rate, recycled content, and energy sources) to PET bottles will affect the environmental performance of future PET bottles for carbonated soft drinks (CSD) and flat water. It should be noted that the goal is not to compare future PET bottles to current alternatives (i.e., aluminum cans and glass bottles) but instead to understand how the environmental performance of PET bottles may improve in the future.

The study has been conducted according to the requirements of the International Organization for Standardization (ISO) 14044 (ISO, 2006) and has undergone an independent critical panel review in accordance with ISO/TS 14071:2014. The panel of reviewers consisted of

- Tom Gloria (chair), Managing Director, Industrial Ecology Consultants
- Terrie Boguski, President, Harmony Environmental LLC
- Angela Schindler, Environmental Services Specialist

The functional unit is defined as a container holding up to 500 mL of carbonated soft drinks for consumer use. The system boundary is cradle-to-grave and includes life cycle phases from raw material extraction, manufacturing, distribution and retail, and end-of-life stage of the product. Inventory data was obtained from HUSKY, Sphera's previous study of aluminum cans for the Aluminum Association (Sphera, 2021), and Sphera's Managed LCA Content. Cradle-to-grave life cycle results are based on the following inventory and impact categories for the US and EU:

- GWP: Global Warming Potential (GWP100) excluding biogenic CO_2 (kg CO_2 eq.) – IPCC AR6
- PEDt: Primary Energy Demand from Non-Renewable and Renewable Resources (MJ net caloric value)
- PEDnr: Primary Energy Demand from Non-Renewable Resources (MJ net caloric value)
- PEDrr: Primary Energy Demand from Renewable Resources (MJ net caloric value)
- AP: Acidification Potential (kg SO_2 eq.) – US EPA TRACI 2.1
- AP: Acidification Potential (mole H+ - eq) – EF 3.0
- EP: Eutrophication Potential (kg N eq.) – US EPA TRACI 2.1
- EPf: Eutrophication Potential Freshwater (kg P-eq) – EF 3.0
- EPm: Eutrophication Potential Marine (kg N eq.) – EF 3.0
- EPt: Eutrophication Potential Terrestrial (Mole of N eq.) – EF 3.0
- PM2.5: Human Health Particulate Air (kg PM2.5 eq.) – US EPA TRACI 2.1
- PM: Particulate Matter (Disease Incidences) – EF 3.0
- ODP: Ozone Depletion Potential (kg CFC-11 eq.) – US EPA TRACI 2.1/ EF 3.0
- SFP: Smog Formation Potential (kg O_3 eq.) – US EPA TRACI 2.1
- SFP: Photochemical Ozone Formation Potential (kg NMVOC – eq) – EF 3.0
- BWC: Blue Water Consumption (kg water)

An overview of LCIA results for 500 mL beverage container can be seen in Figure ES-1 for the US and Figure ES-2 for the EU. In both geographic regions, glass bottles lead to the largest impacts in every category except PEDrr, ODP, and BWC, where aluminum cans have the largest impact. The PEDrr and BWC results are both due to the large amount of hydroelectric power used to produce aluminum, while the larger ODP impact is primarily driven by the emission of dichlorotetrafluoroethane (CFC-114) during the production of aluminum ingots.

PET bottles lead to the lowest impacts in every category except for PEDnr and EP in the US and EPf in the EU. The PEDnr result is due to the fact that the PET bottle itself is made from crude oil and natural gas and again because a large amount of the power used to produce aluminum comes from hydro. The energy content of the crude oil and natural gas used to make the PET bottles are included in the non-renewable primary energy demand. Since aluminum cans and glass bottles are made from mineral resources, they do not carry a similar PEDnr burden. The EP results in the US are primarily due to NO_x emissions from the incineration of PET bottles at the end of life. While the greater EPf results in the EU are due to freshwater P-eq (Phosphorus equivalent) emissions from scrap cleaning and disposal at end-of-life. The GWP from the packaging alternatives is 25 to 36% lower in the EU than the US due to improved recycling and a cleaner electricity grid.

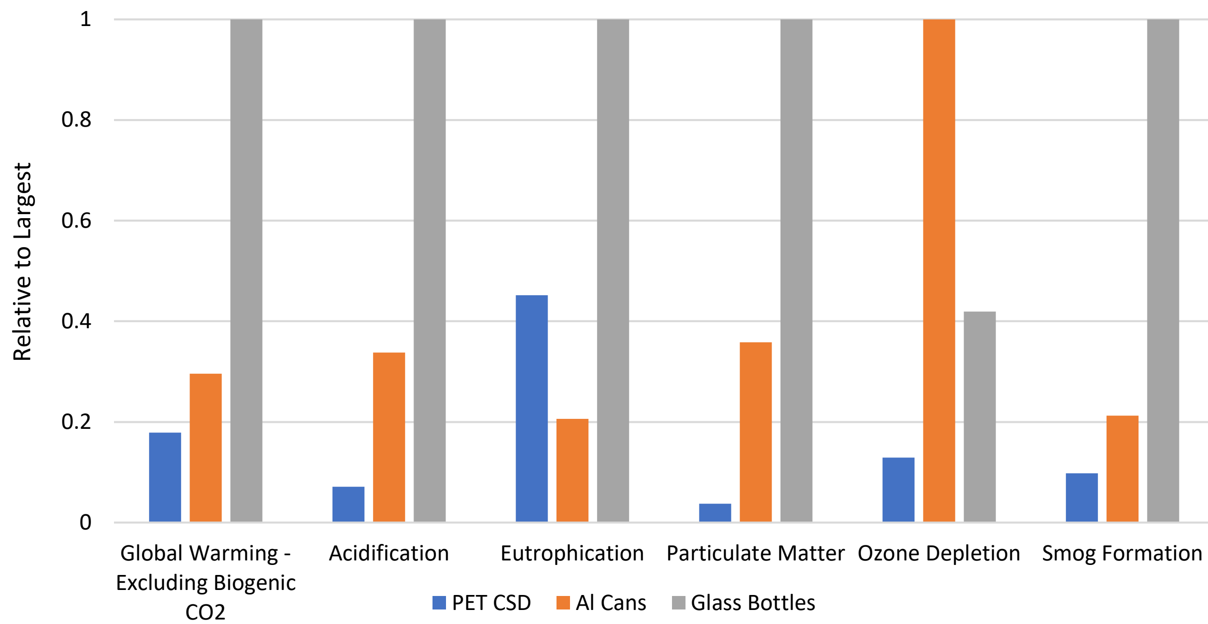

Figure ES-1: Comparison of cradle-to-grave impacts for 500 mL beverage containers in the US (TRACI 2.1).

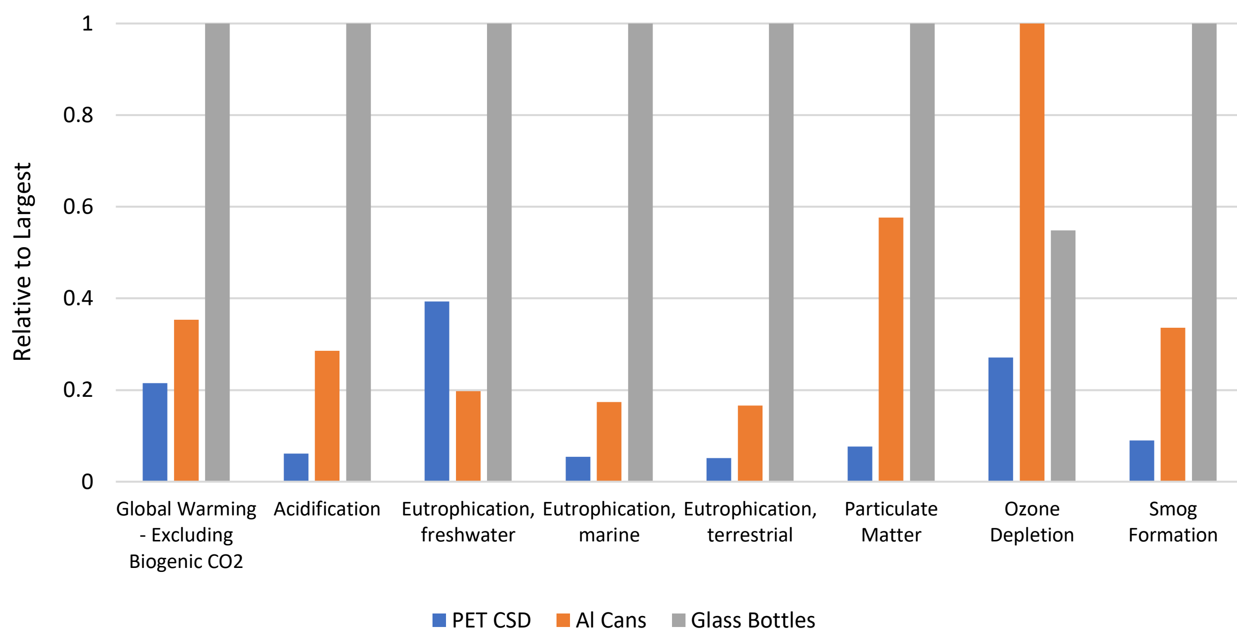

Figure ES-2: Relative comparison of cradle-to-grave impacts for 500 mL beverage containers in the EU (EF 3.0).

Finally, future PET bottle scenarios showed that continued efforts to lightweight PET bottles, increase their use of recycled content, and increase their recycling rate at end-of-life can continue to offer significant reductions in all environmental impacts. Figure E-3 and Figure E-4 show the LCIA results for the future flat water PET bottles for the US and EU, respectively. The lightweighting and improved recycling of the 2025 scenario reduces all impacts by 7 to 39%, while the 2030+ scenario reduces all impacts except PEDrr by 33 to 76% in the US and 62 to 92% in the EU. PEDrr increases in the 2030+ scenario for both regions due to the use of renewable resources (e.g., wind, hydro, solar, biomass) to produce electricity. The relative changes for the PET CSD bottle are similar.

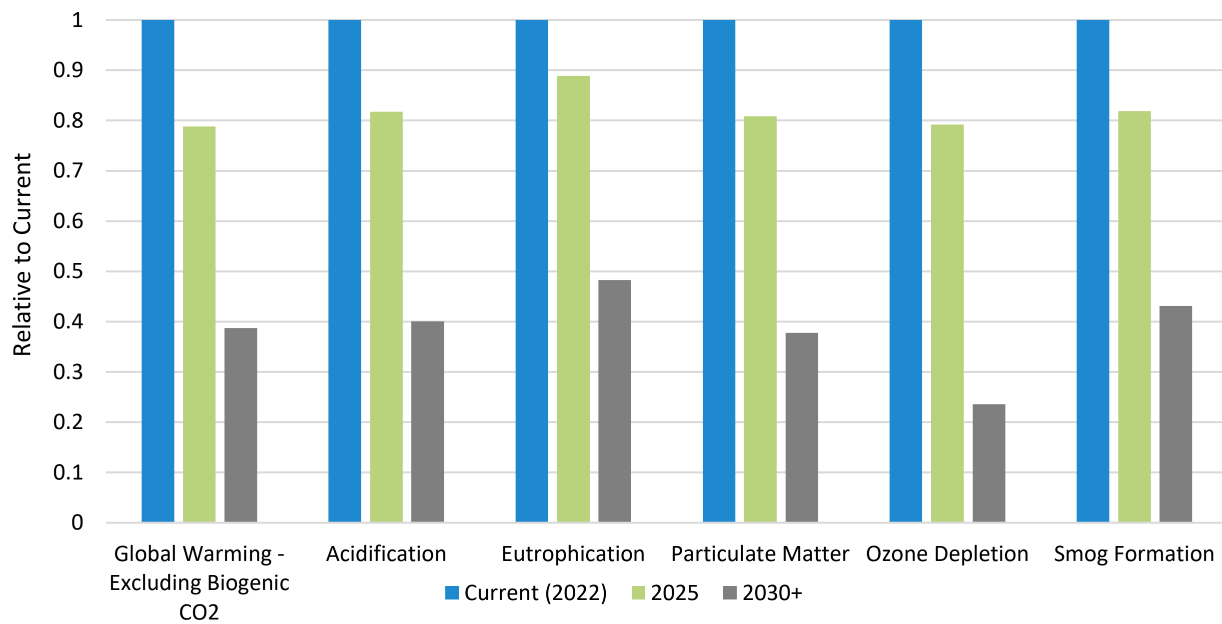

Figure ES-3: Comparison of cradle-to-grave impacts for future PET flat bottle scenarios in the US (TRACI 2.1).

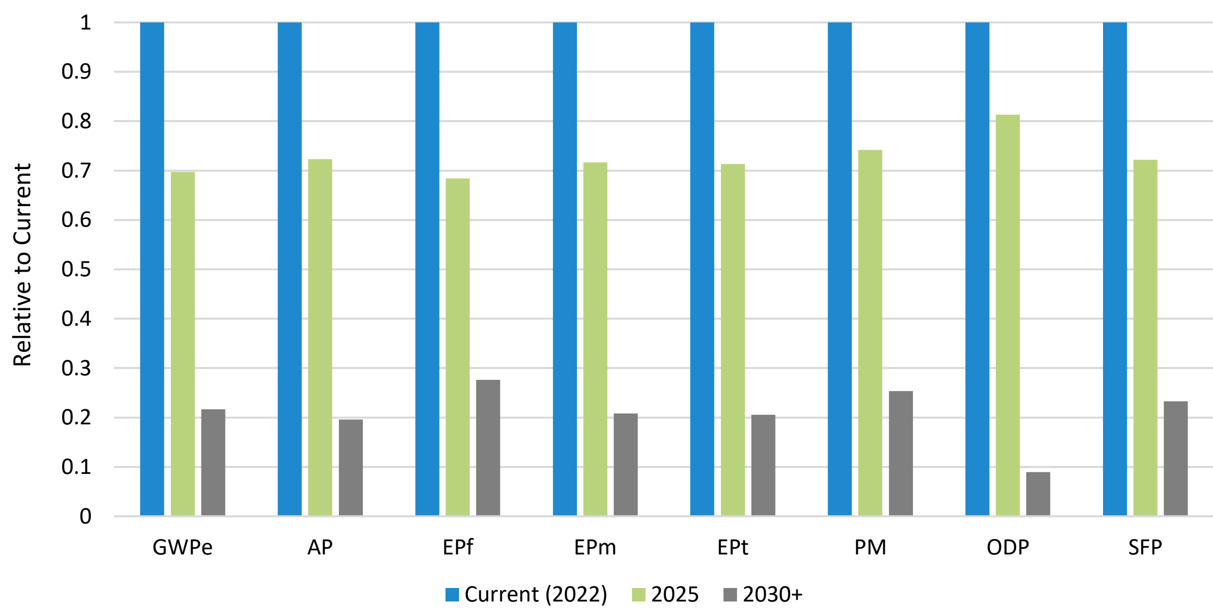

Figure ES-4: Comparison of cradle-to-grave impacts for future PET flat bottle scenarios in the EU (EF 3.0).

Based on the results of the study, we make the following recommendations:

- Continue improvements in lightweighting and the use of post-consumer recycled materials.
- Promote policies and programs that increase recycling rates.
- The use of renewable electricity could significantly improve most impacts
- The study could be improved by including additional primary data for glass bottles.

1. Goal of the Study

Husky Technologies™, a pioneering technology provider enabling the delivery of essential needs to the global community. Helping customers reach their sustainability goals is a top priority for Husky. With today's circular economy driving package design, they work closely with customers to ensure that their packaging and other end products meet specific regional design requirements, particularly with regard to recycling and recycled content in the packaging itself.

Husky's vision is to be among the world's most valued technology and service industrial manufacturing companies. Using their innovation, collective expertise, and personal commitment, they endeavor to lead the way in developing new technologies, environmentally responsible products, and higher-efficiency manufacturing solutions that respond to and deliver the essential needs of people around the globe. Husky seeks to constantly challenge their assumptions and themselves to ensure they are on the path to the lowest overall environmental impact.

As part of their sustainability goals, Husky wants to assess the environmental impact of 500 mL PET bottles and compare it to the impacts associated with current alternatives. They would also like to assess potential future pathways for PET bottles. The client commissioned Sphera Solutions, Inc ("Sphera") to develop an LCA model to study various 500 mL carbonated beverage packaging solutions including PET bottles, aluminum cans, and glass bottles in the US and the EU.

The main audience for this study includes internal stakeholders, Husky's customers, and the investor community. The results will be used to identify hotspots in the manufacturing processes and facilitate informed decision-making related to raw materials, supply chain, energy use, and unit processes and operations by Husky's internal stakeholders. Husky is also looking to report the environmental performance of PET bottles compared to aluminum cans and glass bottles for marketing purposes. The life cycle impact assessment results of this study are therefore intended to be used in comparative assertions to be disclosed to the public. Husky is also interested in understanding how future changes (i.e., materials, lightweighting, recycling rate, recycled content, and energy sources) to PET bottles will affect the environmental performance of future PET bottles for carbonated soft drinks and flat water. It should be noted that the goal is not to compare future PET bottles to current alternatives (i.e., aluminum cans and glass bottles) but instead to understand how the environmental performance of PET bottles may improve in the future.

The study has been conducted according to the requirements of the International Organization for Standardization (ISO) 14044 (ISO, 2006) and has undergone an independent critical panel review in accordance with ISO/TS 14071:2014. The panel of reviewers consisted of

- Tom Gloria (chair), Managing Director, Industrial Ecology Consultants
- Terrie Boguski, President, Harmony Environmental LLC
- Angela Schindler, Environmental Services Specialist

The critical review statement can be found in Annex A.

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2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product Systems

The product systems analyzed in the comparative study of current alternatives are 500 mL beverage packaging alternatives for carbonated soft drinks (CSD) and include PET bottles, aluminum cans, and glass bottles in the US and the EU. Additionally, lighter weight flat water PET bottles are assessed for benchmarking purposes, but their results are not comparable to the CSD alternatives because the lack of internal pressure allows less material to be used in the bottle.

2.2. Product Function and Functional Unit

The function of the compared products is to contain 500 mL of liquid beverages, enabling transportation, and protecting beverages against mechanical stress and material loss up to their consumption. The minimum legal standards applicable to products coming in direct contact with food and beverage for human consumption are fulfilled by all studied products.

The functional unit of the study is 500 mL of CSD packages. References flows for the masses of the containers, labels, and closures for each alternative are provided in Table 2-1.

Table 2-1: Reference flows for each alternative.

	PET Bottles CSD	Aluminum Cans	Glass Bottles	PET Bottles Flat
Container Volume (mL)[a]	500	500	500	500
Container Mass (g)[b]	19	11.99	330	6.91
Closure Mass - US (g)[c]	1.8	2.44	2	0.72[d]
Closure Mass – EU (g)[c]	1.8	2.44	2	1.25
Label Mass (g)[e]	0.86	N/A	1.39	0.86

a. Databases for CSD volumes (Independent Commodity Intelligence Services, 2021)
b. PET for PET bottles, aluminum for Al cans, glass for glass bottles (PETnology, 2022) (Ball Corporation, 2020)
c. HDPE for PET bottles tinplated steel for glass bottles, and Al for cans, based on (Ball Corporation, 2020),
d. PET flat water closure mass of 0.72 g based on currently available caps.
e. LDPE for PET bottles and paper for glass bottles (Ball Corporation, 2020)

The packaging alternatives are assumed to be functionally equivalent regarding the mechanical protection of the beverage during transport, storage, and sale. However, they do differ in terms of UV-transmittance and air-tightness. Transparent glass or PET bottles will allow UV-transmittance, while tinted bottles and aluminum cans will not. Aluminum cans are also more airtight that screw cap closures. While these factors may have some effect on shelf life, these differences are not expected to affect waste or loss of product given the relatively long shelf life of these beverages in all these containers.

2.3. System Boundary

The system boundary for this study is cradle-to-grave and includes life cycle phases from raw material extraction, manufacturing, distribution and retail, and end-of-life stage of the product. Table 2-2 lists the processes that are included and excluded from system boundary for the comparative study. Secondary and tertiary packaging have been excluded because the products are assumed to be sold individually, so there is no secondary packaging at point-of-sale. There is also significant variation in secondary and tertiary packaging. Additionally, previous studies have shown that secondary and tertiary packaging have minor contributions to impact results (Ball Corporation, 2021 and NAPCOR, 2023). This exclusion likely benefits glass bottles, which may require additional packaging to avoid breakage, whereas PET bottles and aluminum cans can both be held with simple LDPE rings, cartons, or cardboard trays, or LDPE wraps.

Table 2-2: Processes included and excluded in the model

Included	Excluded
✓ Raw materials production ✓ Upstream electricity generation for production ✓ Inbound transportation of raw materials ✓ Product manufacturing ✓ Use of auxiliary materials, water, and energy during manufacturing ✓ Emissions to air, water, and soil during manufacturing ✓ Transport of finished products to distribution centers, and application of product ✓ Disposal and recycling credits ✓ Deconstruction, transport to EoL, and waste processing ✓ Substitution credit for recycling in future product systems	× Construction of capital equipment × Maintenance and operation of support equipment (e.g., employee facilities, etc.) × Packaging of raw materials × Human labor and employee commute × Use stage × Secondary and tertiary packaging

2.3.1. Time Coverage

The data are intended to represent beverage containers produced in the year 2022. The primary data for PET bottle production are from 2022, and the reference year for the datasets used for other processes and raw materials are documented in Chapter 3, and the implications are discussed in Chapter 5.

2.3.2. Technology Coverage

The study is intended to cover current technologies for producing each beverage container. The use of technological proxies are documented in Chapter 3, and the implications of the use of those proxies is discussed in Chapter 5.

2.3.3. Geographical Coverage

The study is intended to represent beverage packaging distributed and sold in the US and EU, and the datasets used represent these geographical locations. The use of geographical proxy datasets have been documented in Chapter 3, and the implications are discussed in Chapter 5.

2.4. Allocation

2.4.1. Multi-output Allocation

Multi-output allocation follows the requirements of ISO 14044, section 4.3.4.2. When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Chapter 3.

For this study, multi-output allocation is not necessary in foreground except in end-of-life, which is described in the section 2.4.2.

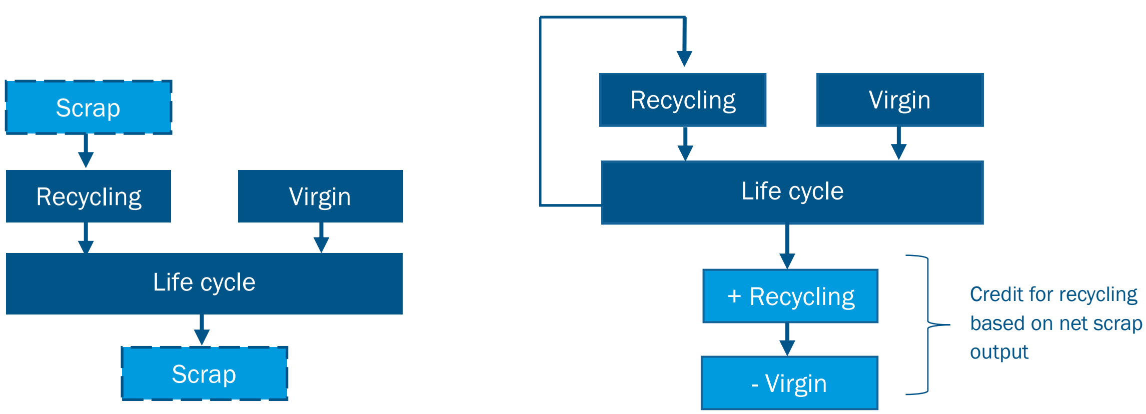
Allocation of background data (energy and materials) taken from Sphera Managed LCA Content (MLC) databases is documented online at https://sphera.com/life-cycle-assessment-lca-database/.

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3. Such allocation approaches address the question of how to assign impacts from virgin production processes to material that is recycled and used in future product systems.

Two main approaches are commonly used in LCA studies to account for end of life recycling and recycled content:

- Substitution approach (also known as 0:100, closed-loop approximation, recyclability substitution or end of life approach) – this approach is based on the perspective that material that is recycled into secondary material at end of life is technically able to substitute an equivalent amount of virgin material. Hence, a credit is given to account for this substitutability. To avoid double-counting the benefits of recycled content, waste materials collected for recycling in EoL are first used to satisfy the scrap demand of the manufacturing phase before being sent to recycling and crediting in EoL. This 'net scrap' approach rewards both end of life recycling as well as the use of recycled content.
- Cut-off approach (also known as 100:0 or recycled content approach) – burdens or credits associated with material from previous or subsequent life cycles are not considered i.e., are "cut-off". Therefore, scrap input to the production process is considered to be free of upstream virgin material burdens but, equally, no credit is received for scrap available for recycling at end of life. This approach rewards the use of recycled content but does not reward end of life recycling.



(i) Cut-off approach (scrap inputs and outputs are not considered)

(ii) Substitution approach (credit given for net scrap arising)

Figure 2-1: Schematic representations of the cut-off and substitution approaches

In the baseline analysis, we used the substitution approach. However, a scenario analysis was performed using the cut-off approach as well.

Material recycling (substitution approach): Open scrap inputs from the production stage are subtracted from scrap to be recycled at end of life to give the net scrap output from the product life cycle. This remaining net scrap is then sent to material recycling. The original burden of the primary material input is then allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modeled using industry average inventories.

Energy recovery (substitution approach): In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. Credits are assigned for power and heat outputs using the regional grid mix and thermal energy from natural gas. The latter represents the cleanest fossil fuel and therefore results in a conservative estimate for the credit.

Landfilling (substitution approach): In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix. This credit refers to the energy produced from captured landfill gas and is given in cases where the material landfilled is biodegradable. It is therefore not applicable to the primary materials for the containers in this study.

Material recycling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary at end of life is drawn after scrap collection to account for the collection rate, which generates an open scrap output for the product system. The processing and recycling of the scrap is associated with the subsequent product system and is not considered in this study.

Energy recovery & landfilling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary includes the waste incineration and landfilling processes following the polluter-pays-principle. In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). No credits for power or heat production are assigned.

2.5. Cut-off Criteria

As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes included within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts for PET bottles and using best case assumptions for the alternatives.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analyzed and is discussed in Chapter 5.

2.6. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-3 and Table 2-4. For the US, TRACI 2.1 was selected as it is currently the only impact assessment methodology framework that incorporates US average conditions to establish characterization factors (Bare, 2012) (EPA, 2012). For impact categories where TRACI characterization factors are not available (e.g., water footprinting) or where they are not considered to be the most current (e.g., global warming potential), alternative methods have been used and are described in more detail below. For the EU, Environmental Footprint (EF) 3.0 impacts (ILCD, 2019) were selected as the most relevant for the current European context.

Global Warming Potential and Primary Energy Demand were chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be one of the most pressing environmental issues of our time. The global warming potential impact category is assessed based on the current IPCC characterization factors taken from the 6th Assessment Report (IPCC, 2022) for a 100-year timeframe (GWP100) as this is currently the most commonly used metric.

The global warming potential results are provided excluding and including the photosynthetically bound carbon (also called *biogenic carbon*) as well as the release of that carbon during the use or end-of-life phase as CO_2 and/or CH_4. Global warming potential results further include emissions from direct land use change which are calculated using the *Direct Land Use Change Assessment Tool*[1] developed by Blonk Consultants using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), which is consistent with PAS 2050-1:2012 (BSI, 2012) and WRI GHG Protocol Product Life Cycle Accounting and Reporting Standard (WRI, 2011). For more information, please refer to https://sphera.com/wp-content/uploads/2020/04/Modeling-Principles-GaBi-Databases-2021.pdf.

Eutrophication, Acidification, and Smog Formation/Photochemical Ozone Creation Potentials were chosen because they are closely connected to air, soil, and water quality and capture the environmental burden associated with commonly regulated emissions such as NO_x, SO_2, VOC, and others.

Ozone depletion potential was chosen because of its high political relevance, which eventually led to the worldwide ban of more active ozone-depleting substances; the phase-out of less active substances is due to be completed by 2030. Current exceptions to this ban include the application of ozone depleting chemicals in nuclear fuel production. The indicator is therefore included for reasons of completeness.

Water consumption, i.e., the anthropogenic removal of water from its watershed through shipment, evaporation, or evapotranspiration, was selected due to its high political relevance. The UN estimates that roughly a billion people on the planet don’t have access to improved drinking water, which entails a variety of problems around ecosystem quality, health, and nutrition. All the selected methodologies, categories, and indicators are internationally accepted.

[1] http://blonkconsultants.nl/en/tools/land-use-change-tool.html

Table 2-3: Impact category descriptions

Impact Category	Description	TRACI Units/ EF Units	Reference
Global Warming Potential (GWP100)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	AR6 (IPCC, 2022)
Eutrophication Potential / Eutrophication Potential (freshwater, marine, terrestrial)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg N equivalent/ (kg P equivalent, kg N equivalent, mole of N equivalent)	(Bare, 2012) (EPA, 2012) (European Commission, 2012)
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	kg SO_2 equivalent/ mol H^+ equivalent	
Smog Formation Potential/ Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg O_3 equivalent / kg NMVOC equivalent	
Ozone Depletion Potential (ODP)	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants.	kg CFC-11 equivalent	
Human Health Particulate Air (PM2.5)/ Particulate Matter	A measure of emissions of small particles that can have negative effects on human health when inhaled. Particulate matter is a major cause of respiratory problems and asthma and can also contribute to cardiac disorders.	kg PM2.5 equivalent/ Disease Incidences	

Table 2-4: Other environmental indicators

Indicator	Description	Unit	Reference
Primary Energy Demand (PED)	A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) including when used as a raw materials and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ (lower heating value)	(Guinée, et al., 2002)
Blue Water Consumption	A measure of the net intake and release of fresh water across the life of the product system. This is not an indicator of environmental impact without the addition of information about regional water availability.	kg of water	(Sphera, 2020)

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

As this study intends to support comparative assertions to be disclosed to third parties, no grouping or further quantitative cross-category weighting has been applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

2.7. Interpretation to be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

Note that in situations where no product outperforms all other alternatives in each of the impact categories, some form of cross-category evaluation is necessary to draw conclusions regarding the environmental superiority of one product over the other. Since ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, this evaluation will take place qualitatively and the defensibility of the results therefore depend on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.8. Data and Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modeling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in section 5 of this report.

2.9. Type and Format of the Report

In accordance with the ISO requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Software and Database

The LCA model was created using the LCA for Experts Software system for life cycle engineering, developed by Sphera Solutions, Inc. The 2022.2 Sphera Managed LCA content provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.11. Critical Review

The international standard ISO 14044 (ISO, 2006) outlines that an independent expert of the LCA shall perform the critical review. The primary goals of such a critical review are to provide an independent evaluation of the LCA study and to provide input to the study authors on how to improve the quality and transparency of the study. The benefits of employing a critical review are to ensure that:

- the methods used to carry out the LCA are consistent with ISO 14040 and 14044,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

For this study, the critical review was conducted by

- Tom Gloria (chair), Managing Director, Industrial Ecology Consultants
- Terrie Boguski, President, Harmony Environmental LLC
- Angela Schindler, Environmental Services Specialist

The reviewers were contracted to perform the critical review as independent experts. Their review comments shall not be construed to represent the positions of their affiliated organizations.

The review was performed according to section 6.3 of ISO 14044 on critical reviews. The independent experts provided feedback on the methodology, assumptions, and interpretation. The draft report was subsequently revised, and a final copy submitted to the reviewers along with responses to comments.

The Critical Review Statement can be found in Annex A.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

All primary data for PET bottle blow/injection molding energy were collected using data collection spreadsheets, which were received by email from Husky. Upon receipt, the spreadsheets were cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

The 2022.2 Sphera Managed LCA content was used for raw material, manufacturing (except PET bottle injection/blow molding energy), transportation and end-of-life.

Table 3-1 shows the recycling rate and recycled content for each alternative. The values were selected to best represent current industry data.

Table 3-1: Recycling rate and recycled content for alternate case

	PET Bottles CSD	Aluminum Cans	Glass Bottles	PET Bottles Flat
Recycling Rate (US/EU)	28.4%[a]/61%[b]	45.2%[c]/72.8%[d]	39.6%[e]/79%[f]	28.4%[a]/61%[b]
Recycled Content (US/EU)	10%[a]/17%[b]	73%[c]/55%[g]	40%[h]/52%[i]	10%[a]/17%[b]

a. NAPCOR, 2022 (NAPCOR, 2022)
b. PETCORE, 2022 (PETCORE, 2022)
c. AA, 2021 (The Aluminum Association, 2021)
d. MPE, 2021 (Metal Packaging Europe (MPE), 2021)
e. US EPA, 2020 (US Environmental Protection Agency, 2020)
f. Close the Glass Loop, 2022 (Close the Glass Loop, 2022)
g. Sphera, 2020 (Sphera, 2020)
h. Ardagh Group, 2023 (Ardagh Group, 2023)
i. EC, 2018 (European Commission, 2018)

3.2. PET Bottles

Figure 3-1 shows the process flow for the 500 mL PET bottles. Virgin PET starts from a mix of ethylene glycol (~30%) and terephthalic acid (~70%) that is primarily produced from natural gas. The virgin PET is then mixed with recovered PET granulate and molded into bottles. Molding inputs and outputs are shown in Table 3-2 based on measured primary data from Husky.

Both the HDPE cap and LDPE are compounding prior to being further processed, and Table 3-3 shows the related input and output data. Table 3-4 shows the inputs and outputs for HDPE cap molding, and Table 3-5 shows the inputs and outputs for the extrusion of the LDPE label. The data provided in Table 3-3 through Table 3-5 are based on default MLC datasets for compounding, injection molding, and plastic film extrusion.

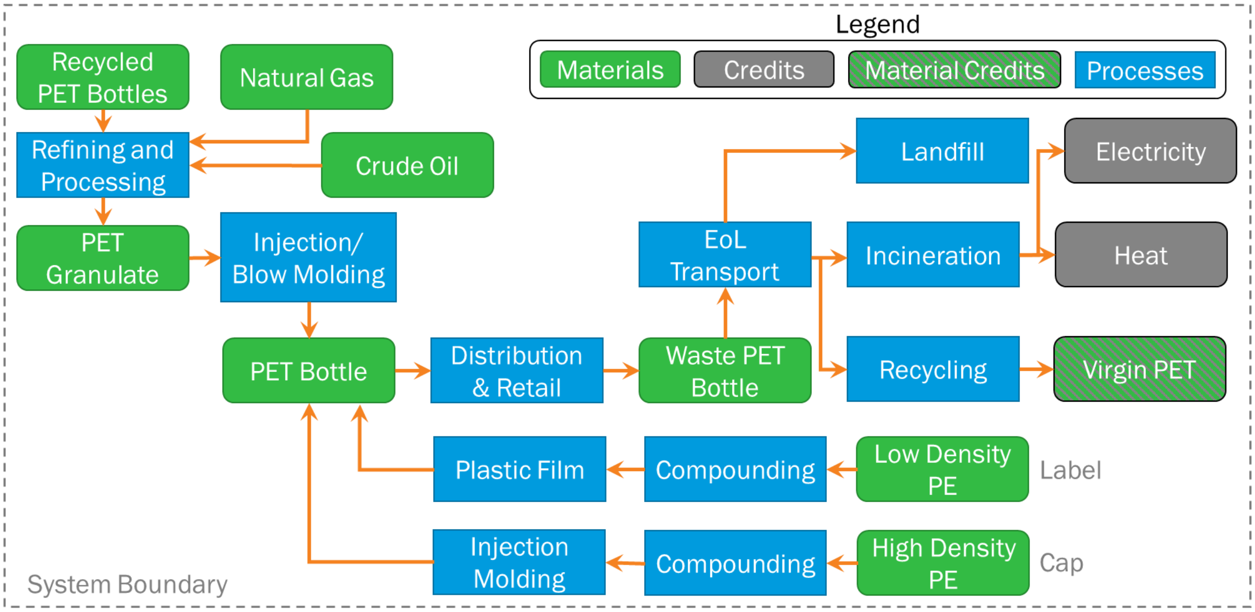


Figure 3-1: Process flowchart of PET bottlesCan you please independently confirm this numebr

Table 3-2: Inputs and outputs from bottle molding

	Material/ Process	Units	Amount
Inputs	PET	kg	1.003
	US/EU Grid Electricity	MJ	3.28
Outputs	PET Bottle	kg	1
	PET Loss (recycled)	kg	0.003

Table 3-3: Inputs and outputs from PE compounding for cap and label

	Material/ Process	Units	Amount
Inputs	PE	kg	1.01
	US/EU Grid Electricity	MJ	1.73
	Water	kg	0.636
Outputs	PE Cap\Label	kg	1
	PE Loss (recycled internally)	kg	0.01
	Wastewater	kg	0.636
	Dust (PM2.5 - PM10)	kg	0.00333

Table 3-4: Inputs and outputs from HDPE cap molding

	Material/ Process	Units	Amount
Inputs	HDPE	kg	1.03
	US/EU Grid Electricity	MJ	4.5
Outputs	HDPE Cap	kg	1
	HDPE Loss (recycled internally)	kg	0.03

Table 3-5: Inputs and outputs from LDPE label extrusion

	Material/ Process	Units	Amount
Inputs	LDPE	kg	1.04
	US/EU Grid Electricity	MJ	1.67
	Lubricating oil	kg	0.000201
	Thermal energy from natural gas	MJ	0.208
Outputs	LDPE Label	kg	1
	LDPE Loss (recycled internally)	kg	0.04

3.3. Aluminum Cans

Figure 3-2 shows the process flow for the 500 mL aluminum cans. Aluminum can production starts with the mining and smelting of aluminum. The virgin aluminum and recovered aluminum cans are then remelted and rolled into sheets and shaped into cans. The aluminum can is also coated and printed before distribution and retail which is described in section 3.5 for all alternatives, and end-of-life management is described in section 3.6. The modeling of the aluminum cans is based on Sphera's LCA report on aluminum cans for the Aluminum Association (2021). Datasets representative of the EU were added where appropriate to represent the EU as shown in Table 3-6.

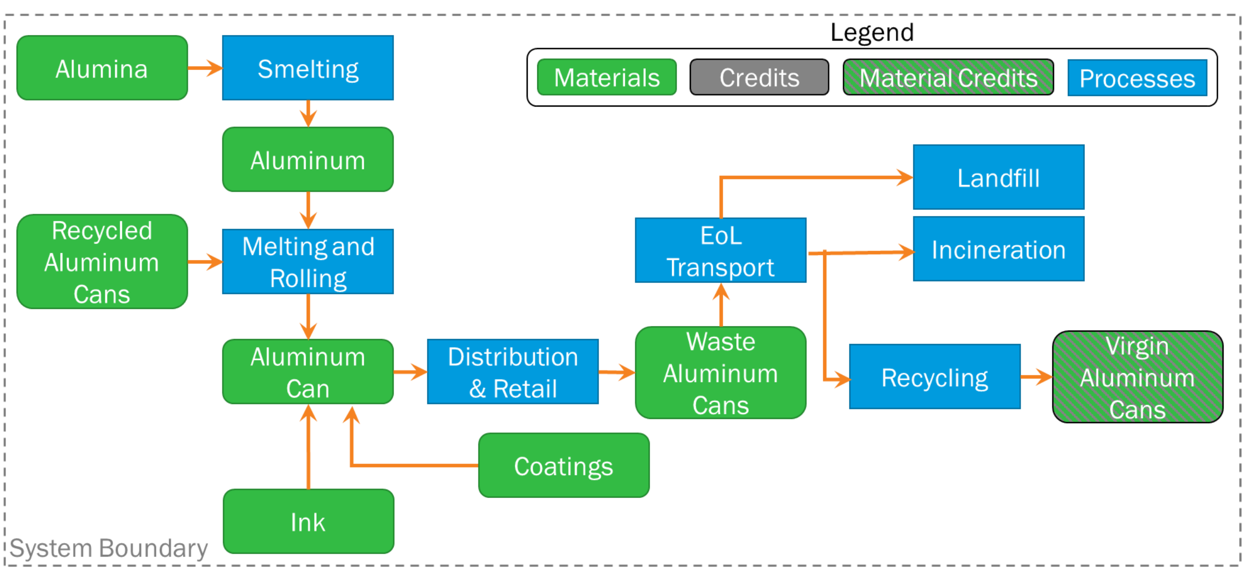


Figure 3-2: Process flowchart of aluminum cans

Table 3-6: Additional Datasets Representative of EU for Aluminum

Geographical Reference	Datasets Used	Data Origin	Reference Year
EU-28	Aluminium ingot (AlSi9Mg)	Sphera	2022
EU-28	Aluminium ingot mix	Sphera	2022
DE	Argon (gaseous)	Sphera	2022
EU-28	Chlorine mix	Sphera	2022
EU-28	Diesel mix at filling station	Sphera	2022
EU-28	Electricity grid mix	Sphera	2022
EU-28	Ferro metals on landfill	Sphera	2022
EU-28	Gasoline mix (regular) at filling station	Sphera	2022
EU-28	Inert matter (Glass) on landfill	Sphera	2022
EU-28	Inert matter (Unspecific construction waste) on landfill	Sphera	2022
EU-28	Lime (CaO; quicklime lumpy) (EN15804 A1-A3)	Sphera	2022
EU-28	Lubricants at refinery	Sphera	2022
EU-28	Municipal waste water treatment (mix)	Sphera	2022
EU-28	Nitrogen (gaseous)	Sphera	2022
EU-28	Polyethylene Film (PE-LD) without additives	Sphera	2022
EU-28	Potassium chloride (agrarian)	Sphera	2022
EU28+EFTA	Primary aluminium ingot consumption mix (2015)	European Aluminium	2022
EU-28	Sodium chloride (rock salt)	Sphera	2022
EU-28	Sodium hydroxide (caustic soda) mix (100%)	Sphera	2022
EU-28	Sulphuric acid (96%)	Sphera	2022
EU-28	Sulphuric acid mix (96%) (consumption mix)	Sphera	2022
EU-28	Talcum powder (filler)	Sphera	2022
EU-28	Tap water from groundwater	Sphera	2022
EU-28	Thermal energy from diesel (direct)	Sphera	2022
EU-28	Thermal energy from LPG	Sphera	2022
EU-28	Thermal energy from natural gas	Sphera	2022
EU-28	Thermal energy from natural gas (direct)	Sphera	2022
US	Truck - TL/dry van (EPA SmartWay)	Sphera	2022
GLO	Truck, Euro 6, 28 - 32t gross weight / 22t payload capacity	Sphera	2022

3.4. Glass Bottles

Figure 3-3 shows the process flows for the 500 mL glass bottles. The virgin components of glass bottles start with sand, limestone, and soda. These materials are melted down with recovered glass bottles to create new bottles. The bottles are then filled, capped, and labeled prior to distribution and retail which is described in section 3.5 for all alternatives, and end-of-life management is described in section 3.6. The mass data in Table 2-1 is used with the raw material datasets listed in Table 3-9 to model the production of the glass bottles, the labels, and steel caps. There is no separate manufacturing data used as the datasets listed in Table 3-9 include the manufacturing of the individual products used in the glass bottles.

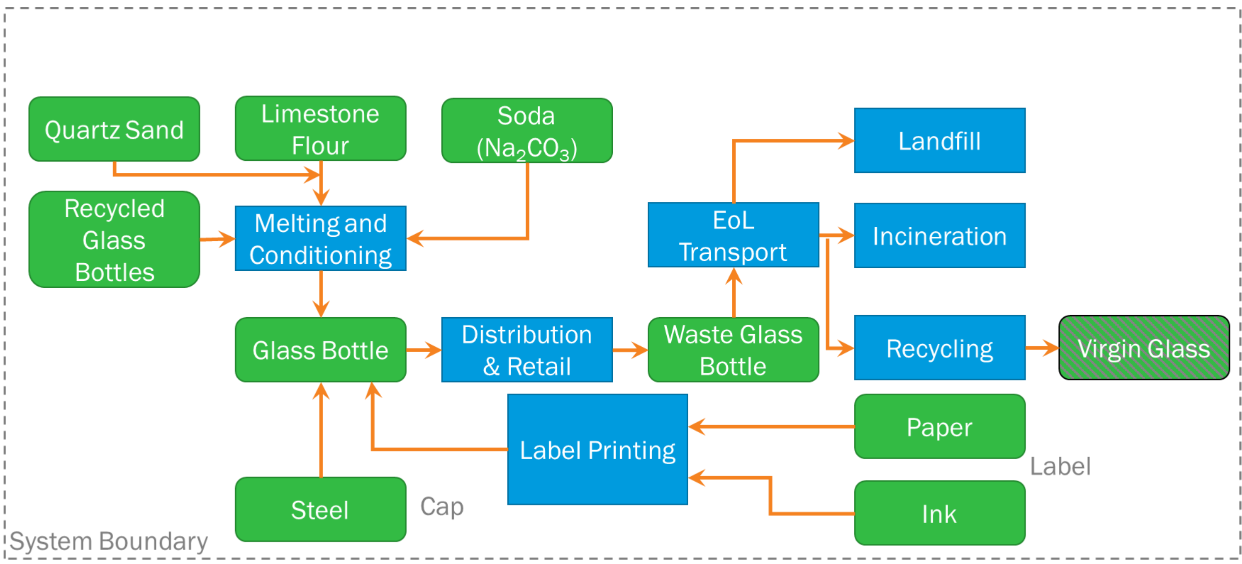


Figure 3-3: Process flowchart of glass bottles

3.5. Distribution and Retail

After the containers are manufactured, they are distributed by truck an assumed 1000 km in the US (500 km in the EU) to a grocery store where they are stored until purchase. After they are purchased at the grocery store, they are driven by a gasoline-powered personal vehicle 6.4 miles (10.3 km) to the home of the consumer. Since the beverages may or may not be cooled, refrigeration-related energy use is not included. However, aluminum cans are likely to require the least cooling during the retail and use phase due to the thinness of the can and the relatively high thermal conductivity of aluminum compared to PET and glass. Same US grocery dataset was used for the US and EU for all three alternatives and is further described in Table 3-8 and Table 3-9.

3.6. End-of-Life

Table 3-7 shows how each of the beverage containers is managed at end-of-life. The latest industry data was used to define the recycling rate as described in Table 3-1, and the split between incineration and landfill was based on US EPA (2020) for the US and Eurostat (2022) for the EU. The rate of recycling is based on industry values shown in Table 3-1. The transportation distance at end-of-life is 20 miles (32.2 km) based on the US EPA's WAste Reduction Model (WARM) (US EPA, 2022). Distance to recycling from there is the same as the distribution distances outlined in section 3.5 (i.e., 1000 km in the US and 500 km in the EU).

When using the baseline net scrap substitution approach, material that is recycled at end-of-life is cycled back to supply the recycled content used as a raw material. If there is more material recycled than recycled content required, a net credit of primary raw material production is provided. If there is more recycled content required than recycled material available at end-of-life, then additional primary raw material burdens are applied to supply the raw material. The same primary raw material datasets are used for the credit as for the initial burden.

When using a cut-off approach, recycled content is provided burden free and recycling activities are excluded from the system boundary at end-of-life.

Table 3-7: Final disposition of each container alternative at end-of-life

Geo Ref.	Management Alternative	PET Bottles	HDPE Caps for PET Bottles	Aluminum Cans	Glass Bottles	Steel Cap for Glass Bottles
US[a]	Incineration	14%	14%	11%	12%	15%
	Landfill	58%	58%	44%	49%	60%
	Recycling	28%	28%	45%	40%	25%
EU[b]	Incineration	21%	21%	14%	11%	10%
	Landfill	18%	18%	13%	10%	10%
	Recycling	61%	61%	73%	79%	80%

a. Recycling rates are based on sources shown in Table 3-1, while landfilling and incineration rates are based on US EPA (2020).
b. Recycling rates are based on sources shown in Table 3-1, while landfilling and incineration rates are based on Eurostat (2020).

3.7. Background Data

3.7.1. Fuels and Energy

National/regional averages for fuel inputs and electricity grid mixes were obtained from the Sphera MLC 2022.2. The reason for using national grid mixes is the lack of information regarding the exact locations as to where in the US or EU the production is occurring. Table 3-7 shows the most relevant fuels and energy LCI datasets used in modeling the product systems. Electricity consumption was modeled using national/regional grid mixes that account for imports from neighboring countries/regions. Process steam is used as a credit when waste incineration is used for PET, LDPE, HDPE, or paper with a substitution EoL allocation approach. It is used as a burden when aluminum, glass, or steel or sent to incineration. Thermal energy is used as a credit from landfill when the paper glass label is landfilled.

Documentation for all Sphera MLC datasets can be found at https://sphera.com/life-cycle-assessment-lca-database/.

Table 3-8: Fuels and Energy Background Data

Material/Process	Location	Dataset	Data Provider	Reference Year	Proxy?
Fuels and Energy					
Electricity	US	Wind electricity[a]	Sphera	2022	No
	EU-28	Electricity grid mix	Sphera	2022	No

Material/Process	Location	Dataset	Data Provider	Reference Year	Proxy?
	EU-28	Wind electricity[a]	Sphera	2022	No
	US	Electricity grid mix	Sphera	2022	No
Process Steam	EU-28/US	Process steam from natural gas 90%	Sphera	2022	No
Thermal Energy	EU-28/US	Thermal energy from natural gas	Sphera	2022	No

a. Wind electricity was only used in the 2030+ future PET bottle scenario.

3.7.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the MLC 2022.2 database. Table 3-9 and Table 3-9 show the most relevant LCI datasets used in modeling the product systems. Documentation for all MLC datasets can be found at https://sphera.com/life-cycle-assessment-lca-database/.

Table 3-9: Key Material and Process Background Data for PET

Material/Process	Location	Dataset	Dataset Provider	Reference Year	Proxy?
Plastic raw material	US/EU-28	Polyethylene Linear Low Density Granulate (LLDPE/PE-LLD)	Sphera	2022	No
Plastic raw material	US/EU-28	Polyethylene terephthalate bottle grade granulate (PET) via PTA	Sphera	2022	No
Plastic raw material	EU-28	Polyethylene terephthalate bottle grade granulate (PET) via PTA (partially biobased, sugar beet)	Sphera	2022	No
Plastic raw material	US	Polyethylene terephthalate bottle grade granulate (PET) via PTA (partially biobased from wheat)	Sphera	2022	No
Plastic raw material	EU-28/US	Polyethylene high density granulate (HDPE/PE-HD)	Sphera	2022	No
Molding process	GLO	Plastic injection molding (parameterized)	Sphera	2022	Yes
Label Process	GLO	Plastic Film (PE, PP, PVC)	Sphera	2022	Yes
Label raw material	DE	Polyethylene (HDPE/PE-HD) blow molding	Sphera	2022	No
Label Process	GLO	Compounding (plastics)	Sphera	2022	Yes
Lubricant for label	EU-28/US	Lubricants at refinery	Sphera	2022	No
Compressed air	GLO	Compressed air 7 bar (medium power consumption)	Sphera	2022	Yes
Water	EU-28/US	Tap water from groundwater	Sphera	2022	No
Grocery process	US	Grocery retail - open input warehouse product	Sphera	2022	No
Recycling, Landfill, waste and incineration					No
Plastic scrap	US	Plastic recycling (clean scrap)	Sphera	2022	No
Waste incineration	US/EU-28	Polyethylene terephthalate (PET) in waste incineration plant	Sphera	2022	No
Waste incineration	US/EU-28	Polyethylene (PE) in waste incineration plant	Sphera	2022	No

Material/Process	Location	Dataset	Dataset Provider	Reference Year	Proxy?
Waste on landfill	US	Plastic waste on landfill, post-consumer	Sphera	2022	No
Waste on landfill	EU-28	Plastic waste on landfill	Sphera	2022	No
Wastewater treatment	US	Municipal waste water treatment (60% agric. sludge appl., 22% sludge incin., 18% landfill, cut-off)	Sphera	2022	No
Wastewater treatment	US/EU-28	Municipal waste water treatment (mix)	Sphera	2022	No
Wastewater treatment	EU-28	Municipal waste water treatment (50% agricultural sludge appl.,50% sludge inciner., cut-off)	Sphera	2022	No

Table 3-10: Key Material and Process Background Data for Glass

Material/Process	Location	Dataset	Data Proovider	Reference Year	Proxy
Production process	US/EU-28	Production of container glass (100% batch)	Sphera	2022	No
Production process	US/EU-28	Production of container glass (100% cullet)	Sphera	2022	No
Steel cap	GLO	Steel tinplated	worldsteel	2022	Geo
Steel Cap	EU	Steel tinplated	worldsteel	2022	No
Label process	US	Inks (for can manufacturing)	Sphera	2022	No
Paper Label	US/EU-28	Kraftliner 2018; by-products: tall oil, turpentine; cut-off EoL; [mass allocation]; input: wood	Sphera/FEFCO	2022	No
Paper Label	DE	Timber spruce (65% moisture)	Sphera	2022	Geo/No
Raw Material	US	Container glass 100% virgin	Sphera	2022	No
Raw Material	EU-28	Glass cullet, sorted	Sphera	2022	No
Grocery process	US	Grocery retail - open input warehouse product	Sphera	2022	No/Geo
Recycling, Landfill, waste and incineration					
Landfill	EU-28	Inert matter (Glass) on landfill	Sphera	2022	No
Landfill	US	Glass/inert on landfill	Sphera	2022	No

3.7.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities.

The MLC 2022.2 database was used to model transportation. Transportation of materials within the United States were modeled using the MLC US transportation datasets listed in Table 3-11.

The vehicle types, fuel usage, and emissions for these transportation processes were developed using an MLC model based on the US EPA SmartWay program and the GREET model which, in turn, uses the EPA MOVES model to calculate emission factors. Fuels were modeled using US datasets as shown in Table 3-11. Documentation for all MLC datasets can be found at https://sphera.com/product-sustainability-gabi-data-search/.

Table 3-11: Key Transport Background Data

	Location	Dataset	Data Provider	Reference Year	Proxy
Truck	US	Truck - TL/dry van (EPA SmartWay)	Sphera	2022	No
	GLO	Truck, Euro 6, 28 - 32t gross weight / 22t payload capacity	Sphera	2022	Yes
Passenger Car	US	Grocery transport by car	Sphera	2022	No
Fuel	EU-28	Diesel mix at filling station	Sphera	2022	No
	US	Diesel mix at filling station	Sphera	2022	No
	EU-28	Gasoline mix (regular) at filling station	Sphera	2022	No
	US	Gasoline mix (regular) at filling station	Sphera	2022	No

3.8. Life Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory (LCI) analysis result as the “outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment”. As the complete inventory comprises hundreds of flows, the below table only displays a selection of flows based on their relevance to the subsequent impact assessment in order to provide a transparent link between the inventory and impact assessment results. LCI results for the EU alternatives are shown in Table B-1 to Table B-4 of Annex B.

Table 3-12: LCI results for PET CSD bottle in US (kg/500 mL container)

Type	Flow	Raw Material	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	9.66E+00	9.29E+00	5.96E-01	-9.78E-01	-7.51E-01	1.78E+01
	Wood	4.94E-17	1.59E-17	1.36E-18	-2.64E-18	-7.01E-18	1.47E-17
	Crude oil	1.98E-02	1.74E-04	1.35E-03	1.38E-04	-3.67E-03	1.66E-03
	Hard coal	2.18E-03	2.38E-03	9.11E-05	-2.90E-04	-1.40E-04	2.18E-03
	Natural gas	1.61E-02	1.32E-03	2.20E-04	-4.11E-04	-2.69E-03	1.13E-03
	Uranium	6.57E-08	7.78E-08	3.18E-09	-9.87E-09	-3.65E-09	7.11E-08
Emissions to air	CO_2	4.48E-02	1.07E-02	4.74E-03	5.41E-03	-6.48E-03	2.08E-02
	CH_4	1.87E-04	2.40E-05	1.88E-05	-4.35E-06	-3.07E-05	3.85E-05
	N_2O	3.94E-07	1.47E-07	1.51E-07	-1.33E-08	-5.29E-08	2.84E-07
	NO_x	6.21E-05	8.49E-06	1.72E-06	1.51E-07	-1.03E-05	1.04E-05
	SO_2	1.66E-05	7.30E-06	1.45E-06	-1.01E-08	-2.21E-06	8.73E-06
	NMVOC	2.06E-05	9.47E-07	4.16E-06	2.28E-08	-3.60E-06	5.13E-06
	CO	2.40E-05	4.14E-06	4.76E-05	1.38E-06	-3.82E-06	5.31E-05
	PM10	5.33E-08	4.67E-09	6.00E-07	-7.76E-10	-9.03E-09	6.04E-07
	PM2.5	1.26E-06	3.20E-07	2.54E-07	1.85E-08	-1.90E-07	5.93E-07
Emissions to water	NH_3	1.44E-07	4.59E-08	9.54E-08	-1.14E-09	-1.76E-09	1.40E-07
	NO_3^{1-}	1.00E-06	7.39E-07	6.91E-07	-5.58E-08	-1.57E-08	1.37E-06
	PO_4^{3-}	7.06E-08	1.84E-08	5.24E-08	3.14E-09	-1.04E-08	7.39E-08

Table 3-13: LCI results for PET Flat bottle in US (kg/500 mL container)

Type	Flow	Raw Material	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	1.25E+01	1.73E+01	2.30E-01	-2.35E+00	-4.46E+00	2.33E+01
	Wood	-3.70E-17	1.72E-17	5.13E-19	2.67E-18	1.73E-17	6.62E-19
	Crude oil	7.67E-03	7.93E-05	3.76E-04	1.33E-05	-3.09E-03	5.05E-03
	Hard coal	3.03E-04	3.79E-04	3.44E-05	-4.94E-05	1.06E-04	7.74E-04
	Natural gas	4.38E-03	3.28E-04	6.86E-05	-4.62E-04	-1.59E-03	2.73E-03
	Uranium	3.01E-08	4.56E-08	1.23E-09	-6.08E-09	-5.36E-09	6.55E-08
Emissions to air	CO_2	1.60E-02	4.13E-03	1.54E-03	3.85E-03	-5.09E-03	2.04E-02
	CH_4	5.53E-05	5.40E-06	7.31E-06	-2.11E-06	-1.93E-05	4.66E-05
	N_2O	3.07E-07	1.05E-07	6.81E-08	-2.45E-08	-1.10E-07	3.46E-07
	NO_x	1.88E-05	3.86E-06	5.99E-07	-7.77E-07	-6.74E-06	1.58E-05
	SO_2	1.05E-05	3.35E-06	5.75E-07	-3.70E-07	-3.56E-06	1.05E-05
	NMVOC	1.53E-05	4.24E-07	1.65E-06	-1.33E-07	-5.89E-06	1.14E-05
	CO	1.02E-05	2.76E-06	1.92E-05	-7.69E-08	-3.80E-06	2.82E-05
	PM10	6.89E-09	1.56E-09	2.50E-07	-1.02E-09	-2.14E-09	2.55E-07
	PM2.5	3.79E-07	1.16E-07	7.64E-08	-2.23E-08	-1.23E-07	4.26E-07
Emissions to water	NH_3	1.53E-07	1.90E-08	3.97E-08	-1.42E-09	-3.57E-08	1.75E-07
	NO_3^{1-}	5.73E-07	6.82E-07	2.48E-07	-8.66E-08	-9.65E-08	1.32E-06
	PO_4^{3-}	3.83E-08	2.71E-08	1.44E-08	-3.19E-09	-1.40E-08	6.26E-08

Table 3-14: LCI results for Glass bottle in US (kg/500 mL container)

Type	Flow	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	4.58E+01	9.17E+00	5.58E+00	-3.02E-01	6.02E+01
	Wood	2.07E-16	2.09E-17	1.16E-17	1.43E-17	2.54E-16
	Crude oil	7.76E-03	2.07E-02	2.17E-03	1.48E-05	3.07E-02
	Hard coal	1.17E-02	1.40E-03	8.43E-04	-1.84E-04	1.38E-02
	Natural gas	5.91E-02	3.39E-03	1.97E-03	5.14E-04	6.50E-02
	Uranium	3.27E-07	4.89E-08	2.21E-08	2.47E-09	4.01E-07
Emissions to air	CO_2	2.48E-01	7.29E-02	1.44E-02	1.65E-03	3.37E-01
	CH_4	5.60E-04	2.89E-04	5.36E-05	4.85E-06	9.08E-04
	N_2O	1.18E-06	2.32E-06	1.65E-07	1.24E-08	3.68E-06
	NO_x	1.17E-04	2.65E-05	2.69E-05	5.71E-07	1.71E-04
	SO_2	3.28E-04	2.23E-05	1.60E-05	1.38E-06	3.67E-04
	NMVOC	3.29E-05	6.41E-05	4.98E-06	3.01E-07	1.02E-04
	CO	9.78E-05	7.32E-04	2.19E-05	-1.13E-05	8.40E-04
	PM10	2.75E-06	9.24E-06	9.03E-09	-3.56E-07	1.16E-05
	PM2.5	6.82E-05	3.92E-06	2.05E-06	1.20E-06	7.53E-05
Emissions to water	NH_3	3.69E-07	1.47E-06	4.15E-07	-4.72E-09	2.25E-06
	NO_3^{1-}	4.90E-06	1.06E-05	7.94E-07	-9.13E-10	1.63E-05
	PO_4^{3-}	3.16E-07	8.07E-07	7.86E-08	-8.70E-10	1.20E-06

Table 3-15: LCI results for Al can in US (kg/500 mL container)

Type	Flow	Raw Material	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	3.42E+02	6.74E+01	3.97E-01	2.71E-01	2.42E+02	6.51E+02
	Wood	7.82E-15	-5.35E-16	9.04E-19	6.88E-19	5.61E-15	-5.33E-16
	Crude oil	2.21E-03	6.25E-04	8.98E-04	2.50E-04	1.56E-03	1.77E-03
	Hard coal	2.68E-03	2.21E-03	6.07E-05	3.22E-05	1.86E-03	2.30E-03
	Natural gas	3.13E-03	6.88E-03	1.47E-04	8.01E-05	1.77E-03	7.11E-03
	Uranium	1.43E-08	2.12E-07	2.12E-09	8.88E-10	6.87E-09	2.15E-07
Emissions to air	CO_2	3.82E-02	3.40E-02	3.16E-03	8.94E-04	2.55E-02	3.81E-02
	CH_4	5.03E-05	6.01E-05	1.25E-05	1.96E-06	3.28E-05	7.46E-05
	N_2O	4.38E-07	7.44E-07	1.00E-07	1.01E-08	2.85E-07	8.54E-07
	NO_x	6.25E-05	2.62E-05	1.15E-06	1.05E-06	4.33E-05	2.84E-05
	SO_2	1.38E-04	1.41E-05	9.64E-07	6.10E-07	9.74E-05	1.57E-05
	NMVOC	4.77E-06	7.88E-05	2.77E-06	2.48E-07	3.01E-06	8.18E-05
	CO	1.21E-05	2.00E-05	3.17E-05	1.28E-06	8.03E-06	5.30E-05
	PM10	3.23E-06	1.88E-07	4.00E-07	5.24E-10	2.20E-06	5.88E-07
	PM2.5	9.67E-06	1.75E-06	1.69E-07	8.43E-08	6.69E-06	2.01E-06
Emissions to water	NH_3	3.26E-07	2.48E-07	6.36E-08	1.41E-07	2.28E-07	4.52E-07
	NO_3^{1-}	8.94E-07	3.13E-06	4.60E-07	7.15E-08	5.48E-07	3.66E-06
	PO_4^{3-}	2.05E-08	1.24E-07	3.49E-08	9.77E-09	1.09E-08	1.69E-07

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Overall Results

Table 4-1 and Table 4-2 show the total impact results for the US and EU, respectively, using the baseline substitution EoL allocation approach described in section 2.4.2. Figure 4-1 and Figure 4-2 show a relative comparison for the LCIA results and LCI indicators, respectively, in the US, and Figure 4-3 and Figure 4-4 show the same results in the EU. In both geographic regions, glass bottles lead to the largest impacts in every category except PEDrr, ODP, and BWC, where aluminum cans have the largest impact. The PEDrr and BWC results are both due to the large amount of hydroelectric power used to produce aluminum, while larger ODP impact is primarily driven by the emission of dichlorotetrafluoroethane (CFC-114) during the production of aluminum ingots. The emissions of dichlorotetrafluoroethane from aluminum production are responsible for over 90% of the ODP from aluminum cans. The effect of this single emission is larger than the difference between aluminum cans and glass bottles or PET CSD bottles.

PET bottles lead to the lowest impacts in every category except for PEDnr and EP in the US and EPf in the EU. The PEDnr result is because the PET bottle itself is made from crude oil and again because a large amount of the power used to produce aluminum comes from hydro because aluminum smelters in North America are frequently located near hydroelectric facilities to reduce energy costs due to their large energy demand. The EP results in the US are primarily due to NO_x emissions from the incineration of PET bottles at the end of life. While the greater EPf results in the EU are due to freshwater P-eq emissions from scrap cleaning and disposal at end-of-life. The next section further explores the primary contributors to the baseline results.

The GWP from the packaging alternatives is 25 to 36% lower in the EU than the US due to improved recycling and a cleaner electricity grid. Comparable impacts are generally lower in the EU. One exception is ODP due to the larger use of renewables. Specifically, the use of polyvinylidene fluoride in the production of photovoltaic solar cells is a large driver of ODP from renewable electricity.

While they cannot be directly compared due to their different functions, the PET flat water bottle has lower impacts compared to the PET CSD bottle by 35 to 62% due to the 64% reduction in bottle mass. This shows the importance of packaging functionality in the evaluation of environmental impacts.

Table 4-1: Impact results for 500 mL beverage containers in the US.

Impact Category	Unit	PET CSD	Al Can	Glass Bottles	PET Flat[a]
IPCC, AR6					
Global Warming Potential (GWP 100, excluding biogenic CO2) (GWPe)	kg CO2 eq.	6.40E-02	1.06E-01	3.58E-01	2.52E-02
Global Warming Potential (GWP 100, including biogenic CO2) (GWPi)	kg CO2 eq.	6.40E-02	1.06E-01	3.59E-01	2.52E-02
TRACI v2.1					
Acidification Potential (AP)	kg SO2 eq.	7.80E-05	3.71E-04	1.10E-03	3.11E-05
Eutrophication Potential	kg N eq.	3.20E-05	1.46E-05	7.08E-05	1.51E-05
Smog Formation Potential	kg O3 eq.	1.76E-03	3.81E-03	1.79E-02	7.08E-04
Particulate Matter (PM)	kg PM2.5-eq	4.15E-06	3.96E-05	1.11E-04	1.64E-06
Ozone Depletion Potential (ODP)	kg CFC 11 eq.	1.49E-15	1.16E-14	4.86E-15	5.79E-16
Resource Use Indicators					
Primary Energy Demand – Total (PEDt)	MJ LHV	1.44E+00	1.85E+00	4.82E+00	5.74E-01
Primary Energy Demand – Non-renewable (PEDnr)	MJ LHV	1.38E+00	1.26E+00	4.57E+00	5.53E-01
Primary Energy Demand – Renewable (PEDrr)	MJ LHV	5.99E-02	5.88E-01	2.52E-01	2.12E-02
Blue Water Consumption (BWC)	kg	4.44E-01	1.69E+00	7.96E-01	1.71E-01

a. Presented for benchmarking only. PET Flat is not directly comparable to the CSD containers.

Table 4-2: Impact results for 500 mL beverage containers in the EU.

Impact Category	Unit	PET CSD	Al Can	Glass Bottles	PET Flat[a]
IPCC, AR6					
Global Warming Potential (GWP 100, excluding biogenic CO2) (GWPe)	kg CO2 eq.	4.78E-02	7.83E-02	2.22E-01	2.07E-02
Global Warming Potential (GWP 100, including biogenic CO2) (GWPi)	kg CO2 eq.	4.78E-02	7.84E-02	2.24E-01	2.07E-02
EF 3.0					
Acidification potential (AP)	mol H+-eq.	6.10E-05	2.84E-04	9.97E-04	2.67E-05
Eutrophication Potential, Freshwater (EPf)	kg P-eq	1.96E-07	9.84E-08	4.98E-07	8.34E-08
Eutrophication Potential, Marine (EPm)	kg N eq.	1.56E-05	4.98E-05	2.87E-04	6.80E-06
Eutrophication Potential, Terrestrial (EPt)	Mole of N eq.	1.69E-04	5.40E-04	3.25E-03	7.34E-05
Photochemical Ozone Formation Potential (SFP)	kg NMVOC-eq	5.97E-05	2.23E-04	6.64E-04	2.67E-05
Particulate Matter (PM)	Disease Incidences	5.32E-10	4.01E-09	6.95E-09	2.32E-10
Ozone Depletion Potential (ODP)	kg CFC11-eq	1.56E-13	5.75E-13	3.15E-13	6.74E-14
Resource Use Indicators					
Primary Energy Demand – Total (PEDt)	MJ LHV	1.01E+00	1.51E+00	3.31E+00	4.38E-01
Primary Energy Demand – Non-renewable (PEDnr)	MJ LHV	9.12E-01	1.12E+00	3.04E+00	4.01E-01
Primary Energy Demand – Renewable (PEDrr)	MJ LHV	9.84E-02	3.93E-01	2.67E-01	3.66E-02
Blue Water Consumption (BWC)	kg	3.26E-01	8.12E-01	5.31E-01	1.35E-01

a. Presented for benchmarking only. PET Flat is not directly comparable to the CSD containers.

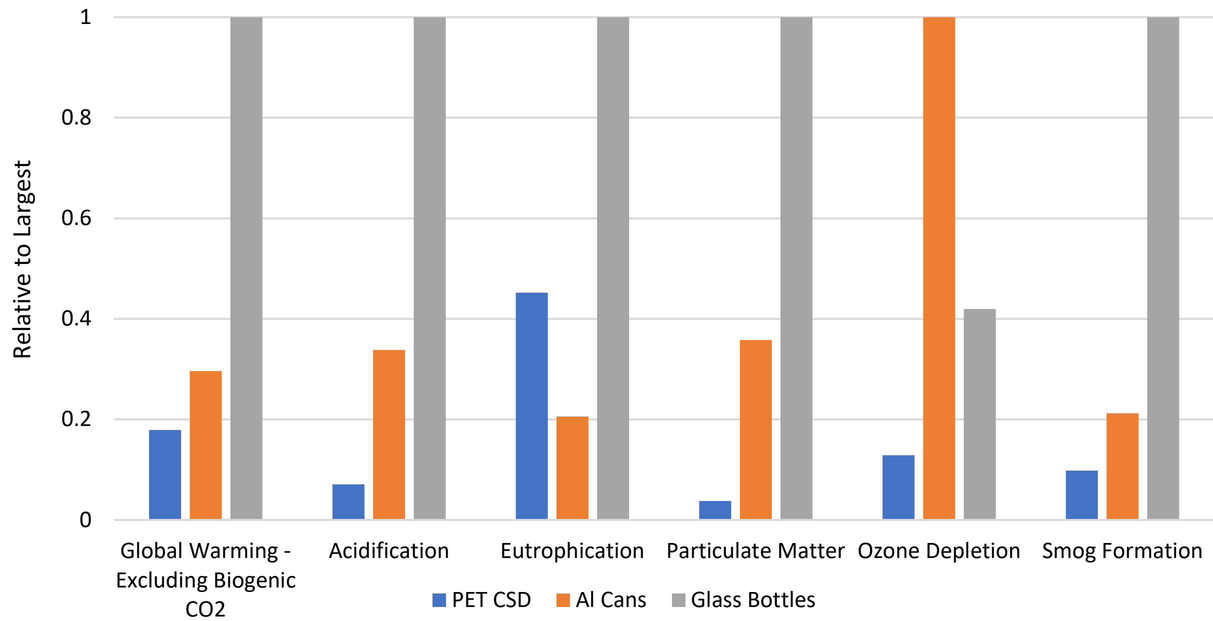


Figure 4-1: Comparison of impacts for 500 mL beverage containers in the US.

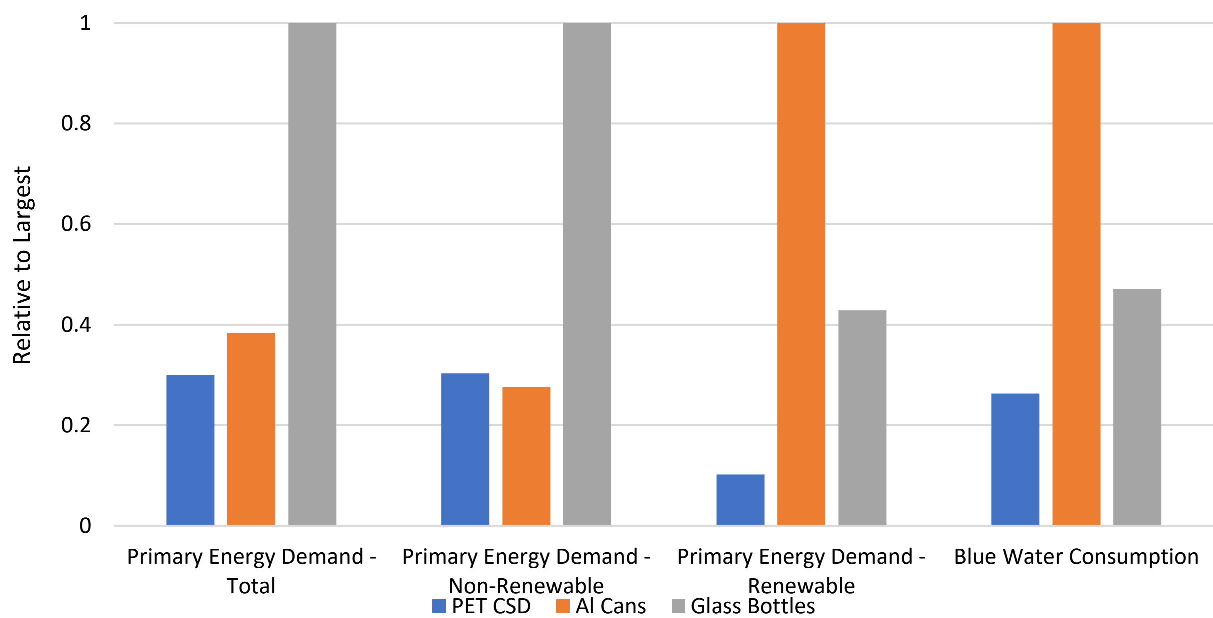


Figure 4-2: Comparison of resource use indicators for 500 mL beverage containers in the US

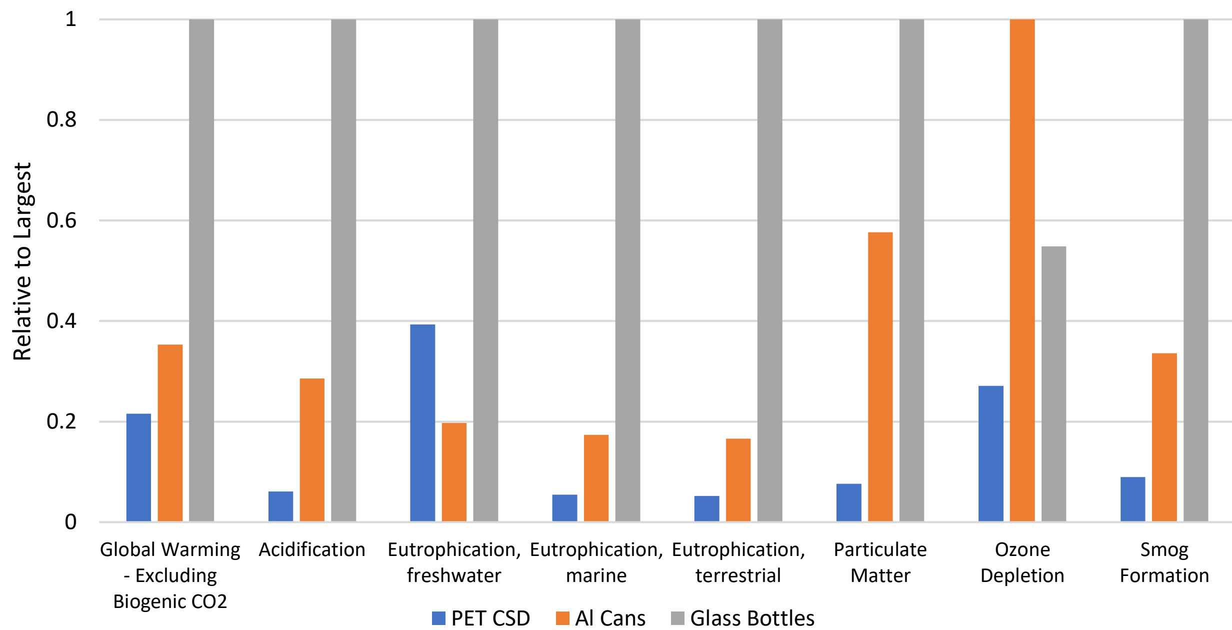


Figure 4-3: Relative comparison of impacts for 500 mL beverage containers in the EU.

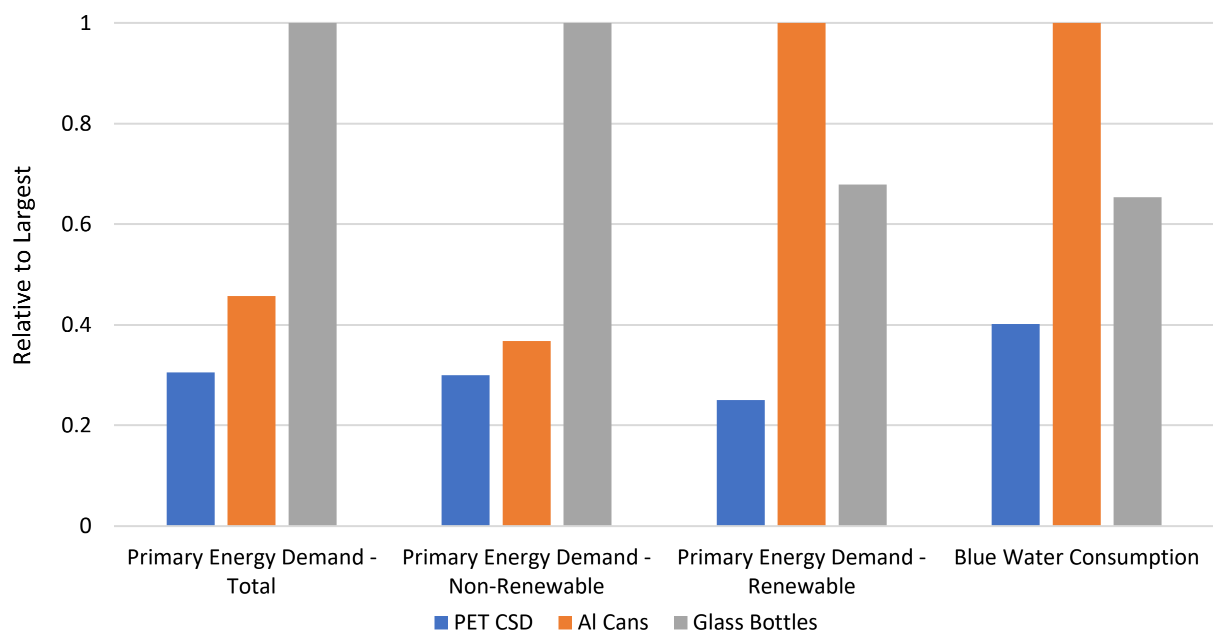


Figure 4-4: Comparison of resource use indicators for 500 mL beverage containers in the EU

4.2. Contribution Results

In this section we explore the key contributors to the baseline impact results for each of the beverage alternatives.

4.2.1. PET CSD Bottles

Figure 4-5 through Figure 4-8 show the contribution results for the PET CSD bottles in the US and EU. In the US, Raw Materials account for 61 to 84% of every impact except for PEDrr and ODP. Raw Materials account for 35% of both PEDrr and ODP. PEDrr (41%) and ODP (41%) results are both primarily associated with electricity from manufacturing. Distribution and retail only contribute 1 to 10% of impacts in the US and 0.7 to 11% in the EU. These results are partially driven by the relatively low weight of PET bottles.

The general trends in the EU are similar to the US, except EPf, which is only associated with freshwater emissions, while the other LCIA results are dominated by airborne emissions. In both the US and EU, there are net scrap benefits because the recycling rate (28.4% and 61% in the US and EU, respectively) is greater than the recycled content of the bottles (10% and 17% in the US and EU, respectively). The scrap benefits are larger in EU as seen by the scrap credits in Figure 4-5 through Figure 4-8.

Although the EU and US PET bottles serve different markets, it is important to acknowledge that EU bottles have 26.4% lower GWP impacts than PET bottles across the board and this is due to higher recycled content and rate, and a less carbon intensive grid. This serves as an example as to how different supply chain conditions and manufacturing practices can lead to overall impact reductions.

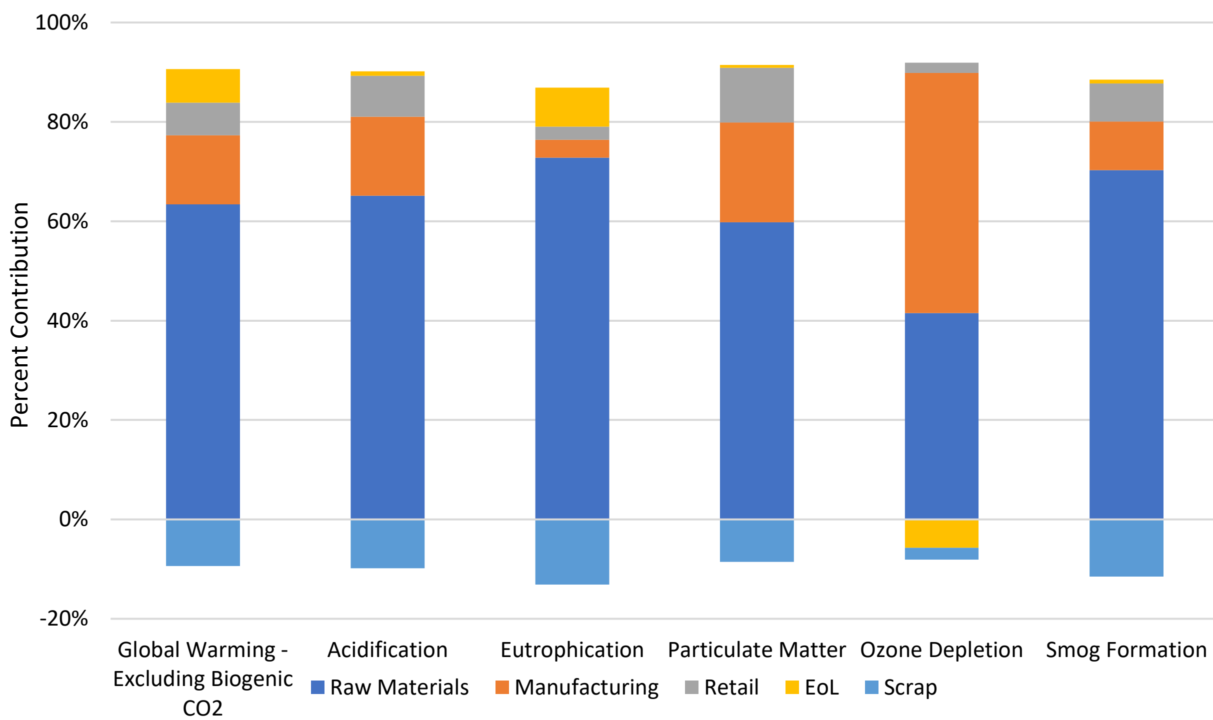


Figure 4-5: Contribution results for each impact for 500 mL PET CSD bottles in the US.

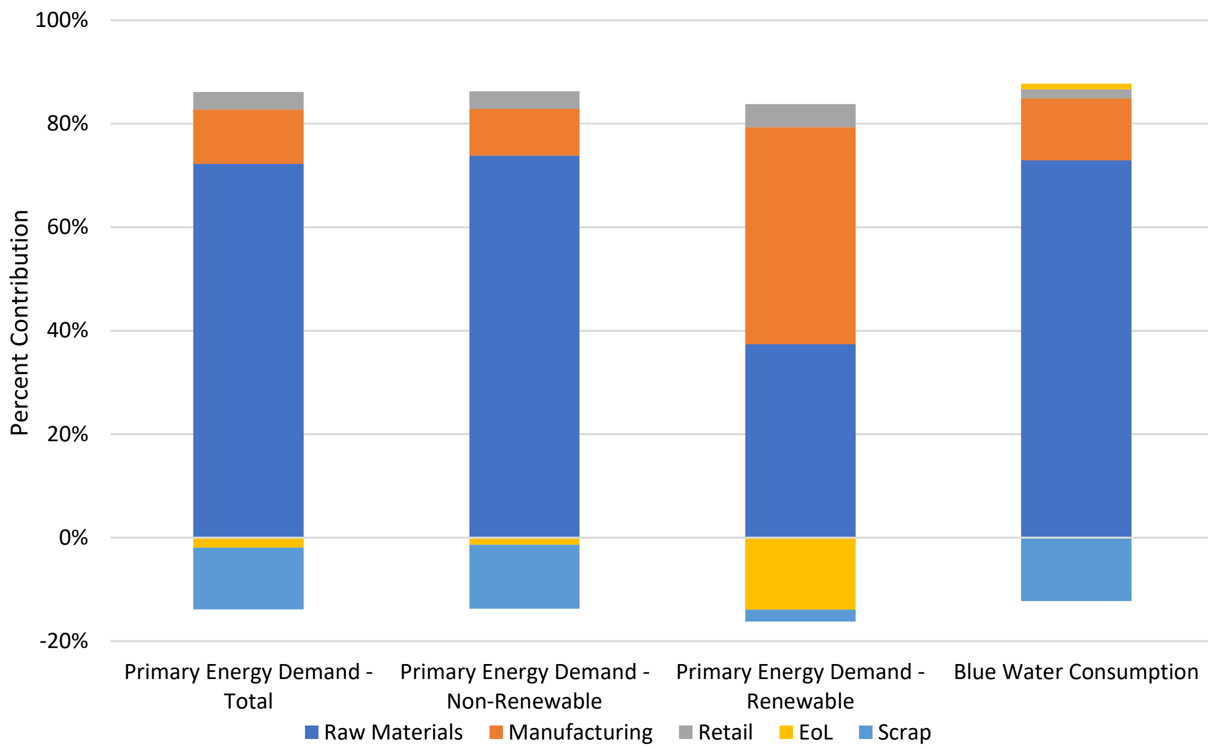


Figure 4-6: Contribution results for each resource use indicator for 500 mL PET CSD bottles in the US.

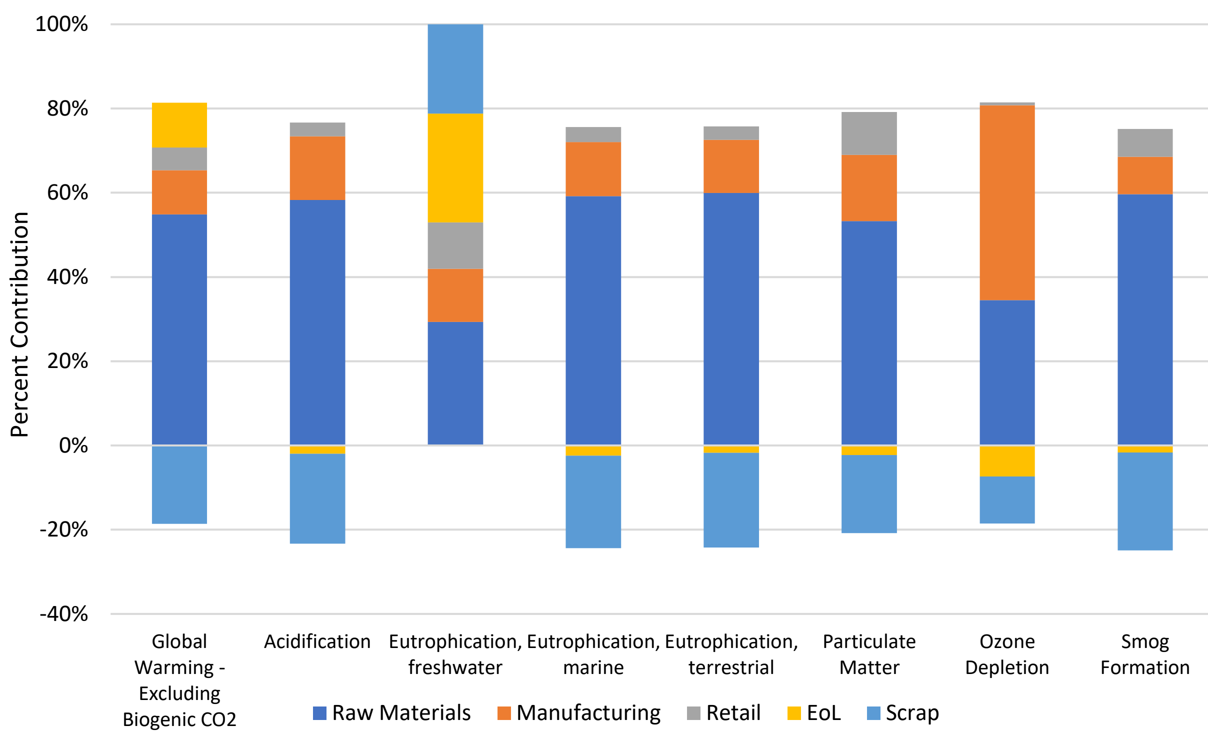


Figure 4-7: Contribution results for each impact for 500 mL PET CSD bottles in the EU.

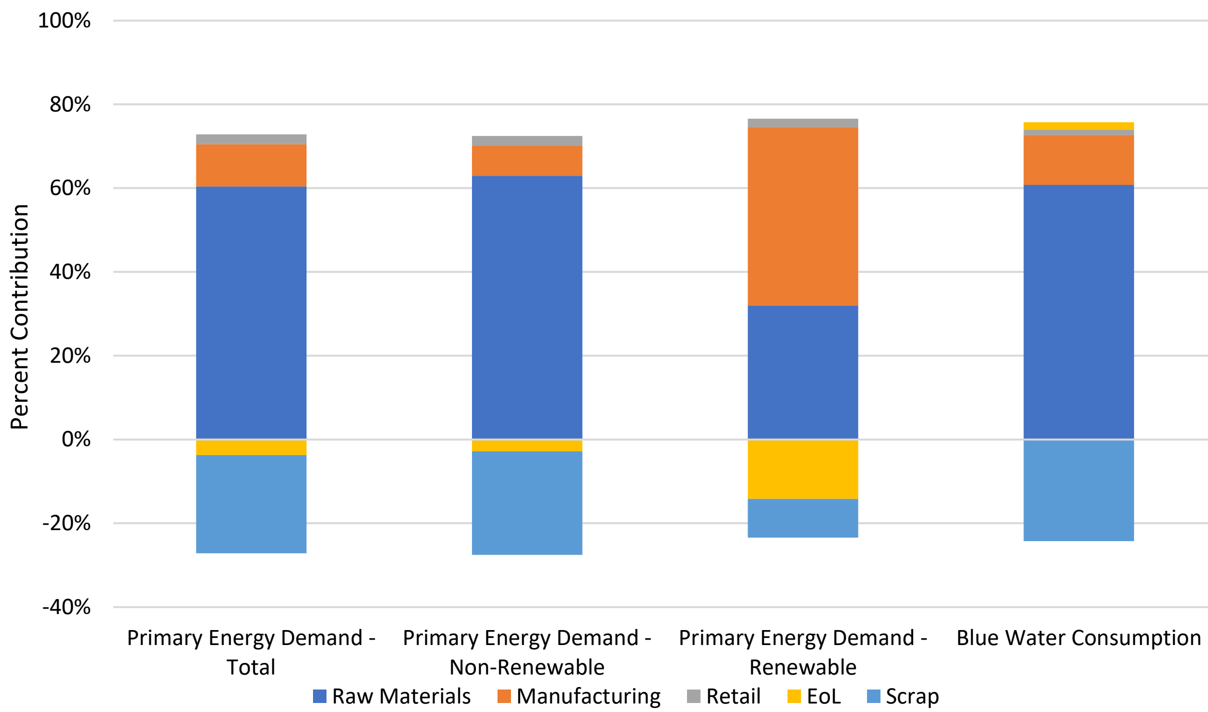


Figure 4-8: Contribution results for each resource use indicator for 500 mL PET CSD bottles in the EU.

4.2.2. Aluminum Cans

Figure 4-9 through Figure 4-11 show the contribution results for the aluminum cans in the US and EU. A major difference between the US and EU for aluminum cans is that in the US, scrap management creates a net burden because there is not enough recycled material (45.2%) to meet the recycled content demand (73%). The scrap burden in the US accounts for 21 to 37% of every impact except ODP, which is almost entirely driven by energy use during manufacturing. In the US, raw materials and the scrap input account for 53 to 91% of every impact except for ODP, while manufacturing accounts for 8 to 44% of every impact except ODP, to which it contributes 98% of the impact.

In the EU, the recovered scrap provides a net credit of 10 to 27%, and raw materials are the largest contributor to every impact (48 to 65%) of every impact except EPf (27%). EPf is primarily driven waterborne P emissions from the production of electricity used for can manufacturing.

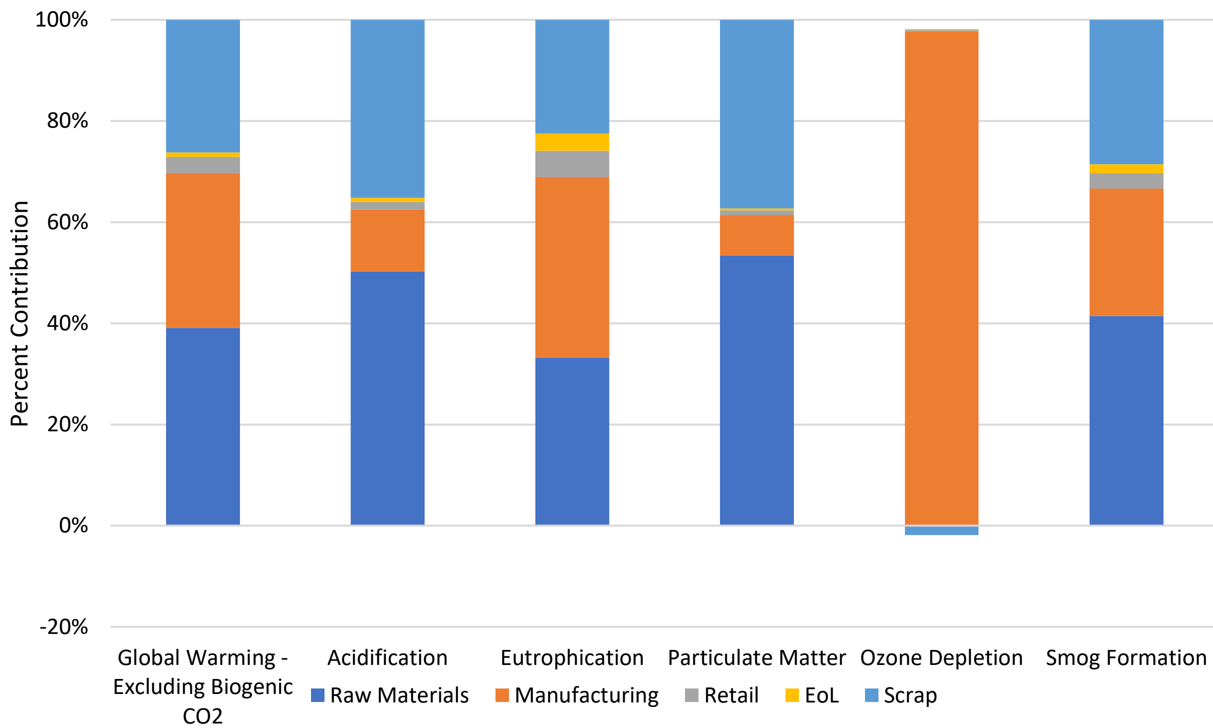


Figure 4-9: Contribution results for each impact for 500 mL aluminum cans in the US.

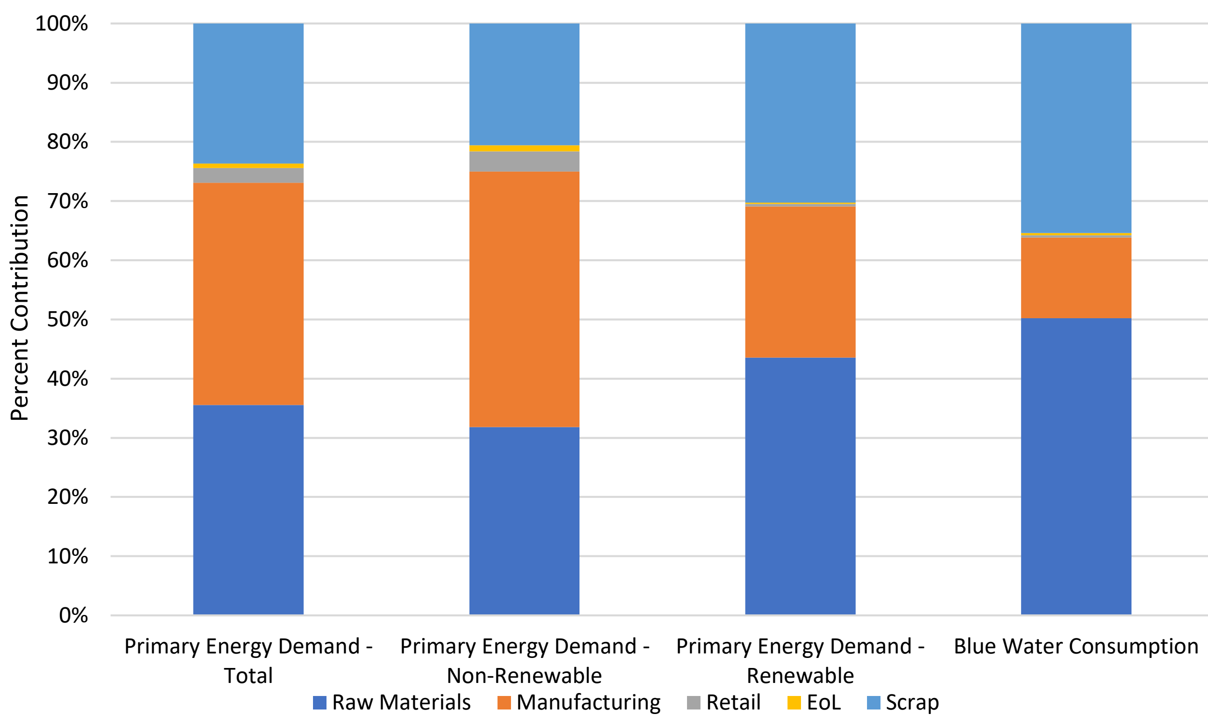


Figure 4-10: Contribution results for each resource use indicator for 500 mL aluminum cans in the US.

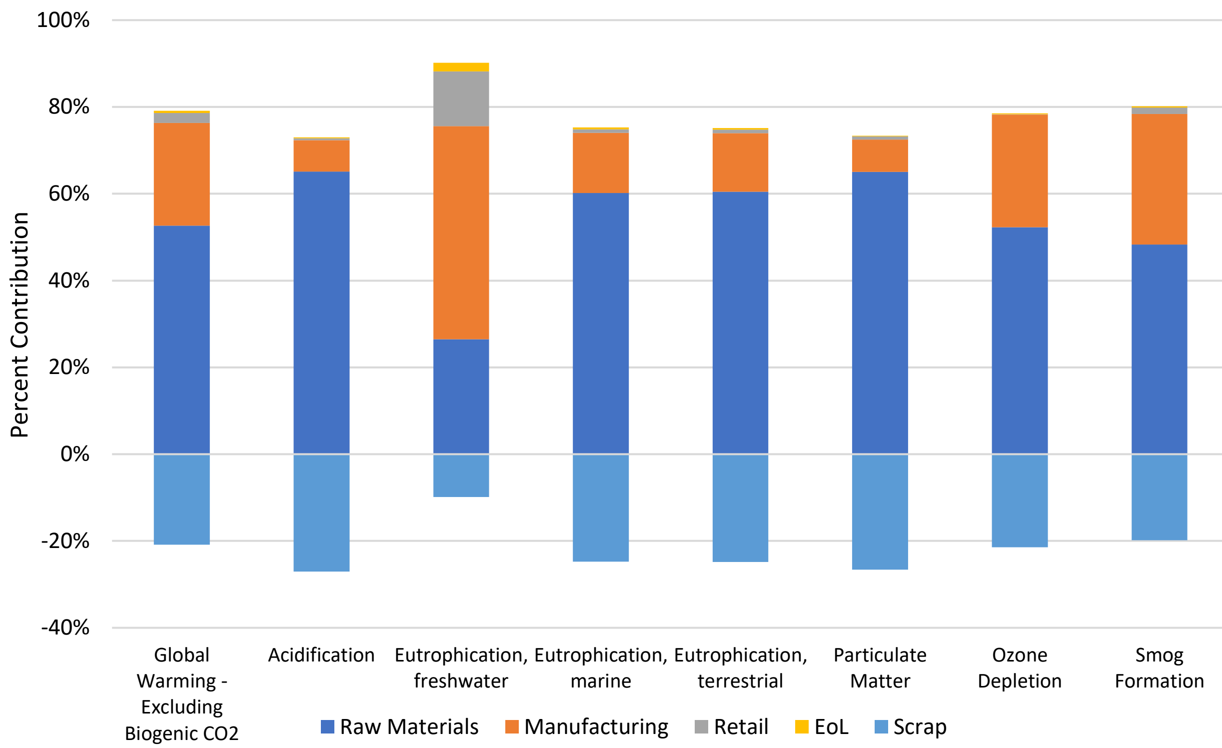


Figure 4-11: Contribution results for each impact for 500 mL aluminum cans in the EU.

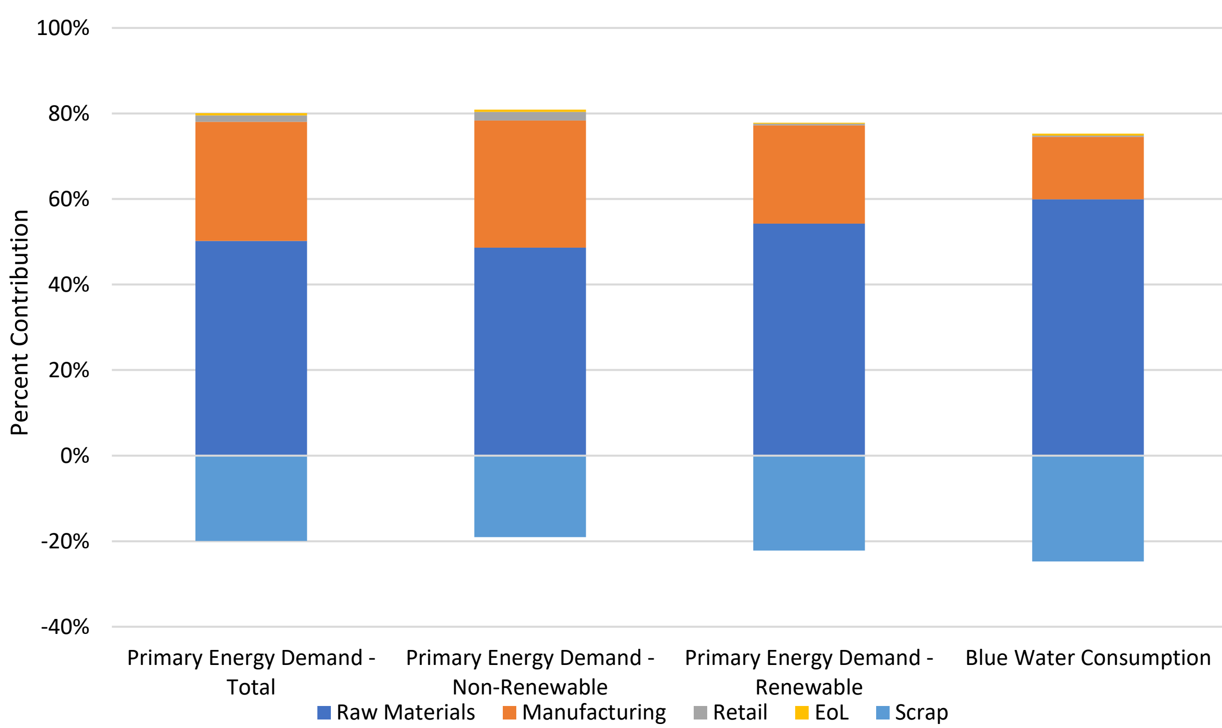


Figure 4-12: Contribution results for each resource use indicator for 500 mL aluminum cans in the EU.

4.2.3. Glass Bottles

Figure 4-13 through Figure 4-16 show the contribution results for the glass bottles in the US and EU. For glass bottles, contributions from raw materials and manufacturing were necessarily combined because the datasets used for the bottles could not be disaggregated to present the contributions separately. The dataset includes the raw materials and the energy used to melt and form the bottles. Raw materials and manufacturing contributes 72 to 90% of all impacts in the US, and 63 to 79% for all impacts in the EU except EPf (26%). EPf (65%) is primarily driven by freshwater P emissions during gasoline production for passenger vehicles for taking the bottles home. Distribution and retail contribute 5 to 21% of impacts in the US, and 3 to 18% of impacts in the EU (excluding EPf), which is a larger contribution than for PET bottles and aluminum cans due to the added weight of the glass bottles. Additionally, the production of the paper label used on the glass bottles was shown to contribute <0.6% to every impact category in both regions, while the steel cap had a maximum contribution of 2.9% and 2.3% to PM in the US and EU, respectively.

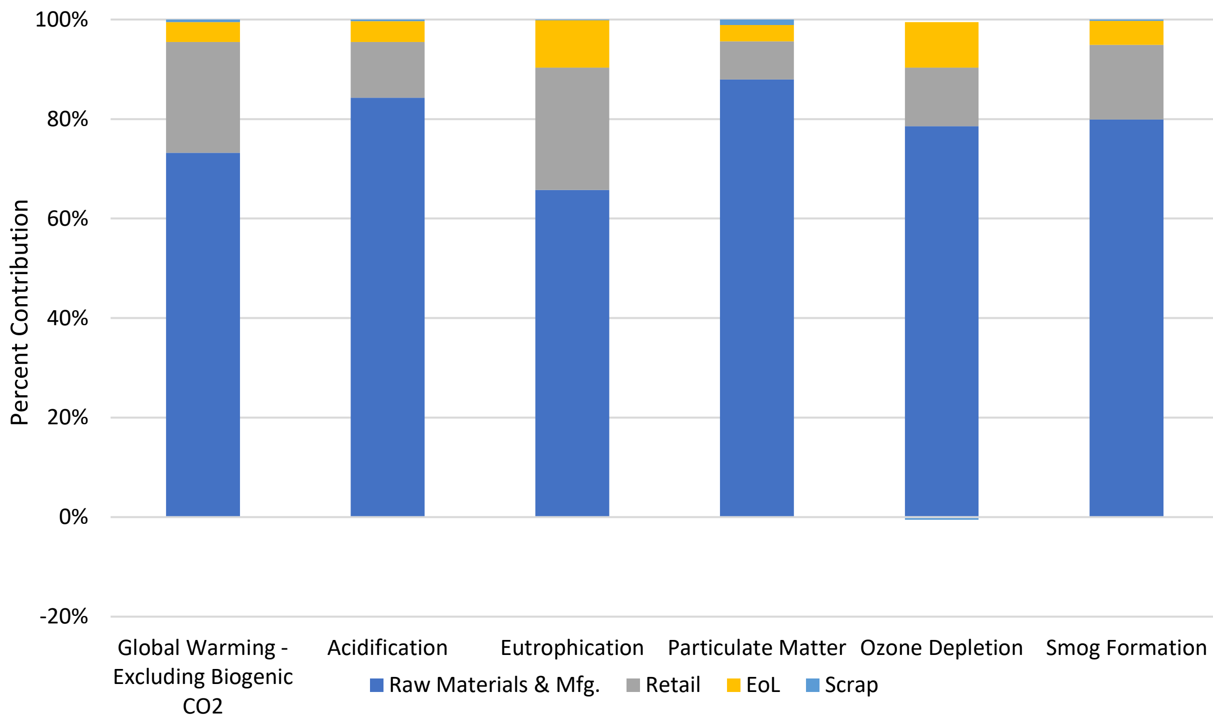


Figure 4-13: Contribution results for each impact for 500 mL glass bottles in the US.

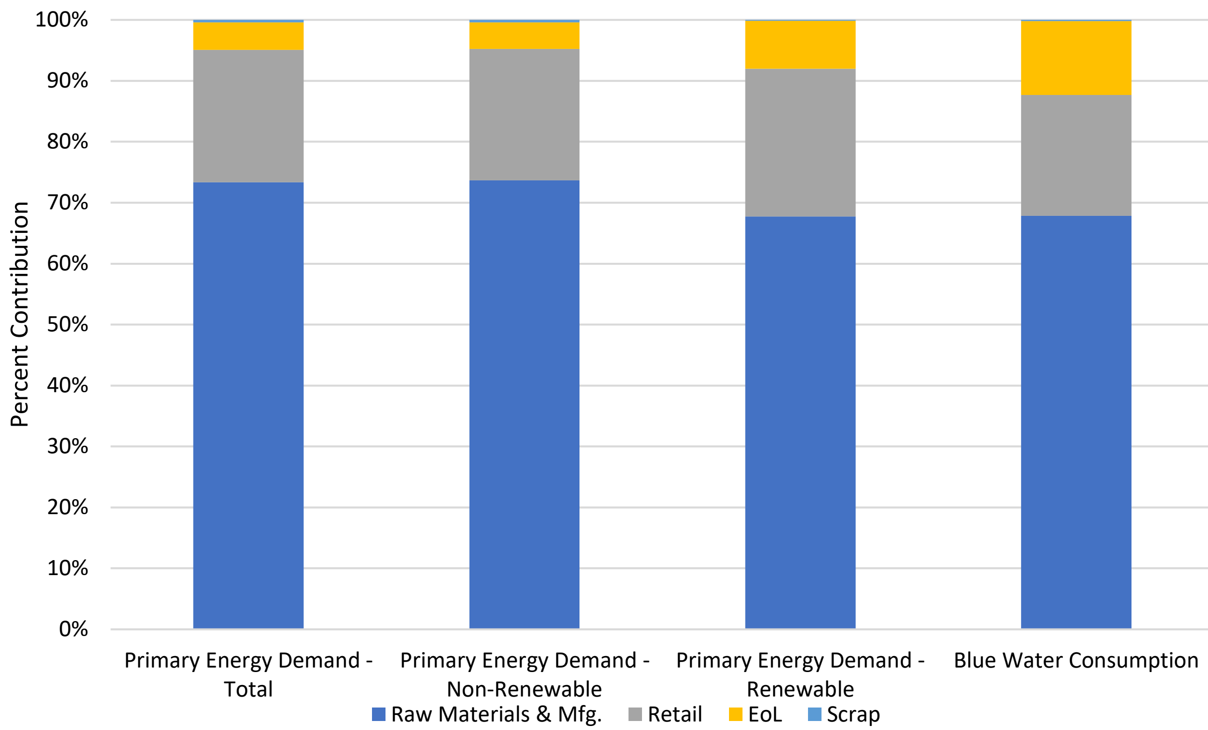


Figure 4-14: Contribution results for each resource use indicator for 500 mL glass bottles in the US.

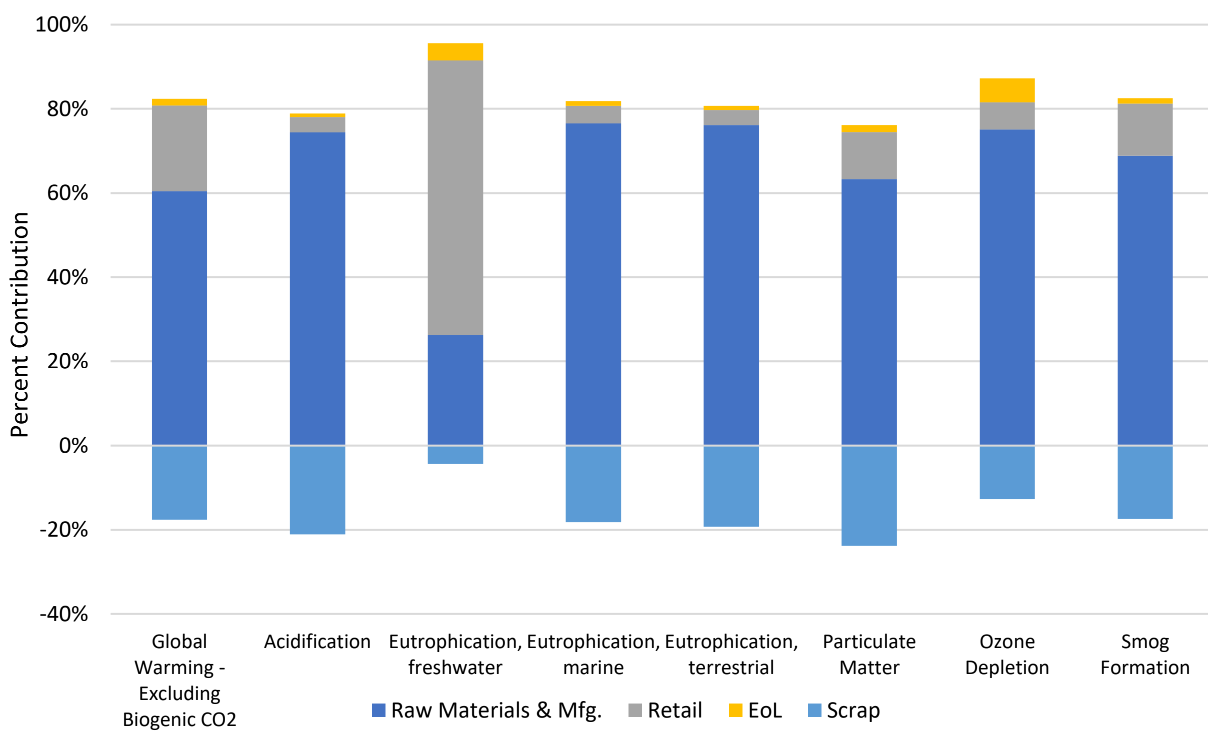


Figure 4-15: Contribution results for each impact for 500 mL glass bottles in the EU.

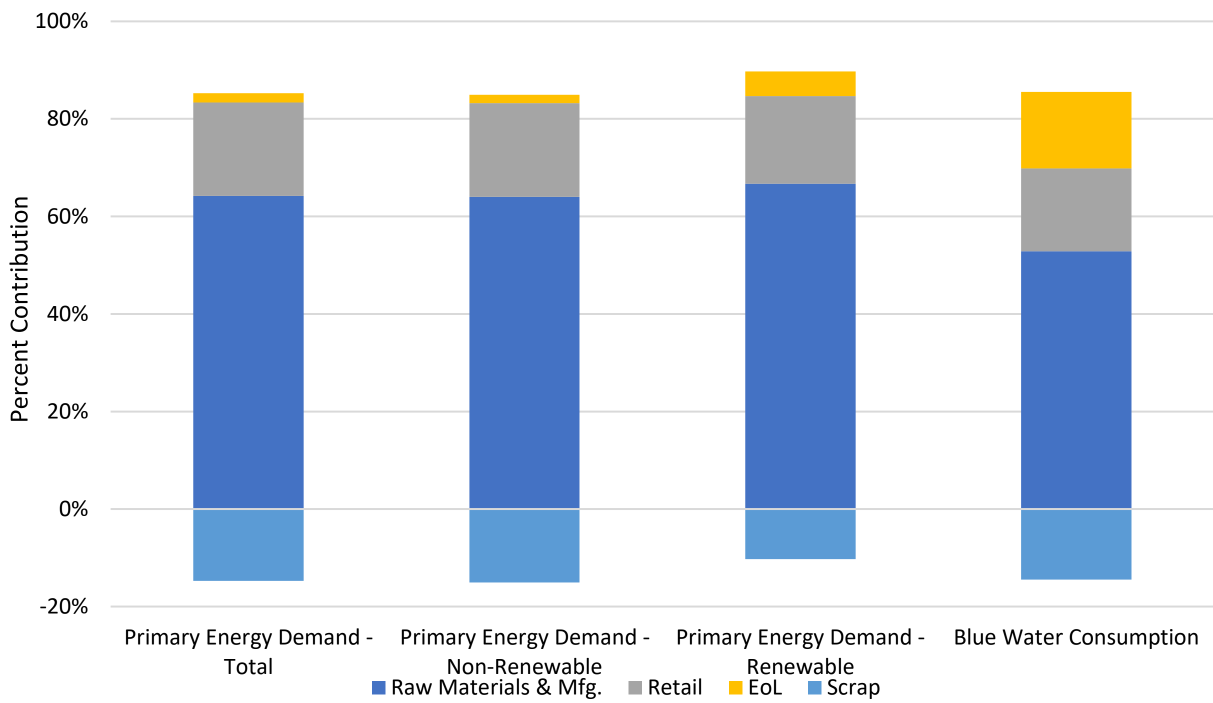


Figure 4-16: Contribution results for each resource use indicator for 500 mL glass bottles in the EU.

4.2.4. PET Flat Water Bottles

Figure 4-17 through Figure 4-20 show the contribution results for the PET flat water bottles in the US and EU, respectively. The contributions are essentially the same as for the PET CSD bottle, although as discussed, the total magnitude of the impacts are lower due to the lower weight bottle.

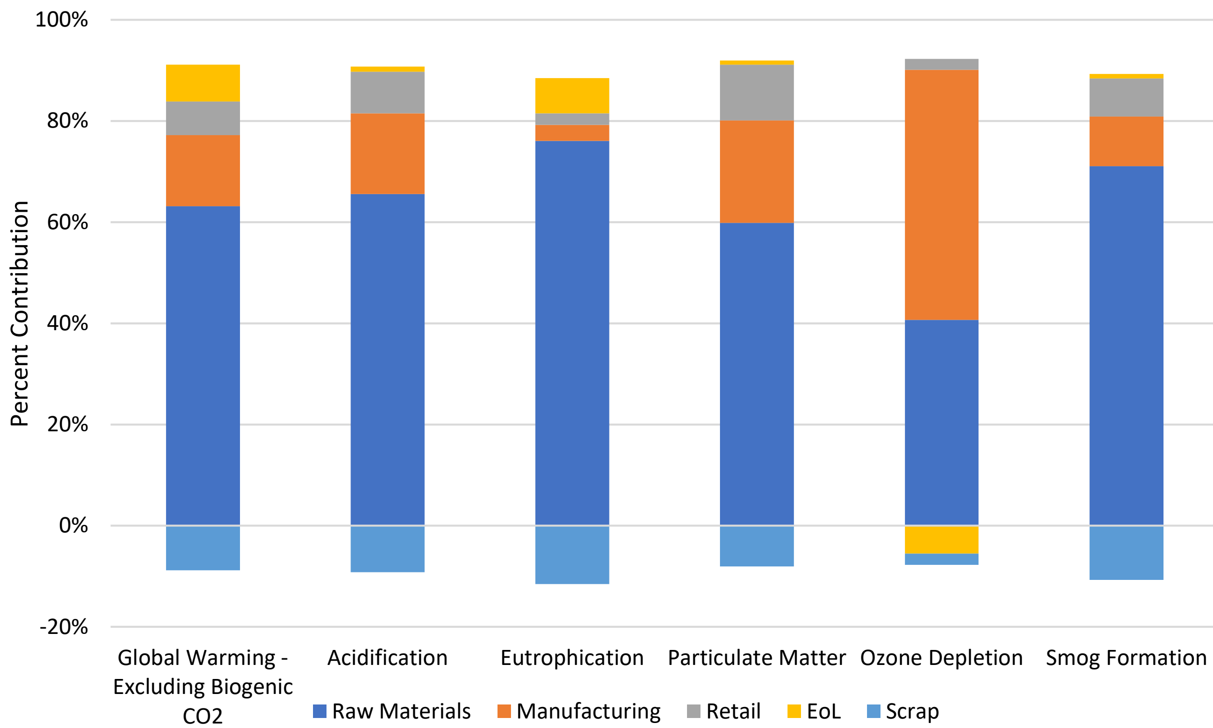


Figure 4-17: Contribution results for each impact for 500 mL PET flat bottles in the US.

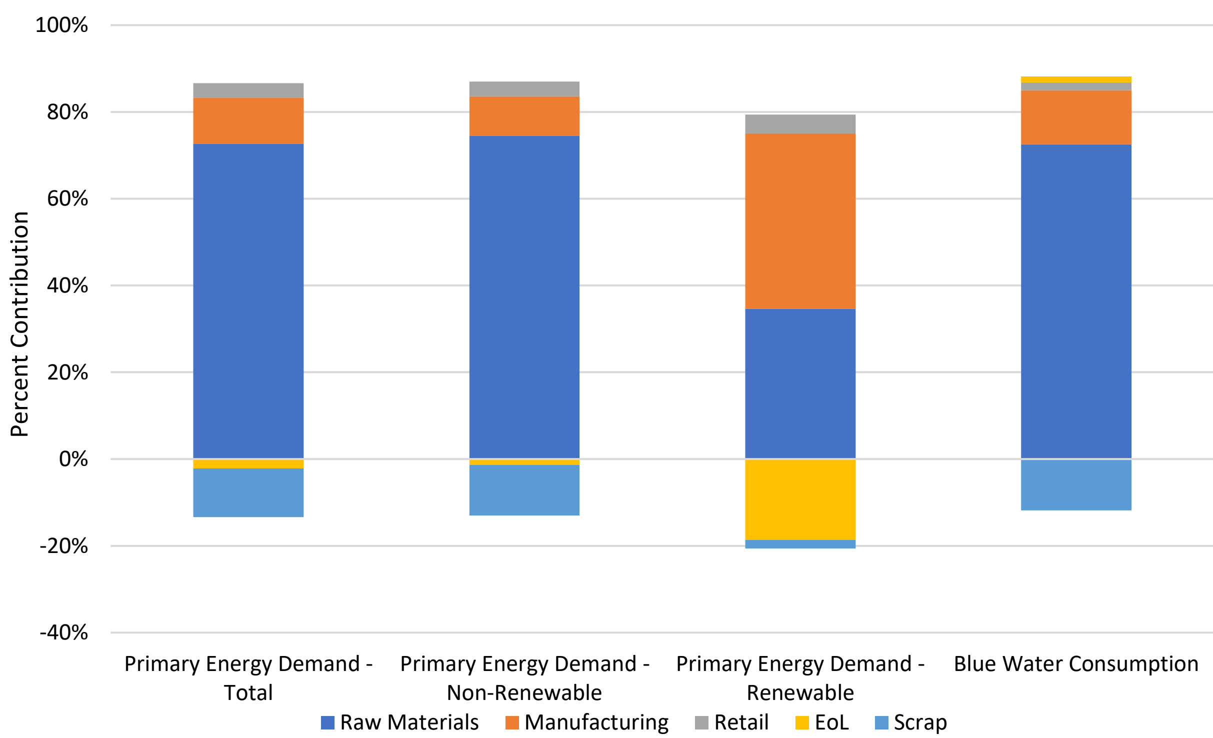


Figure 4-18: Contribution results for each resource use indicator for 500 mL PET flat bottles in the US.

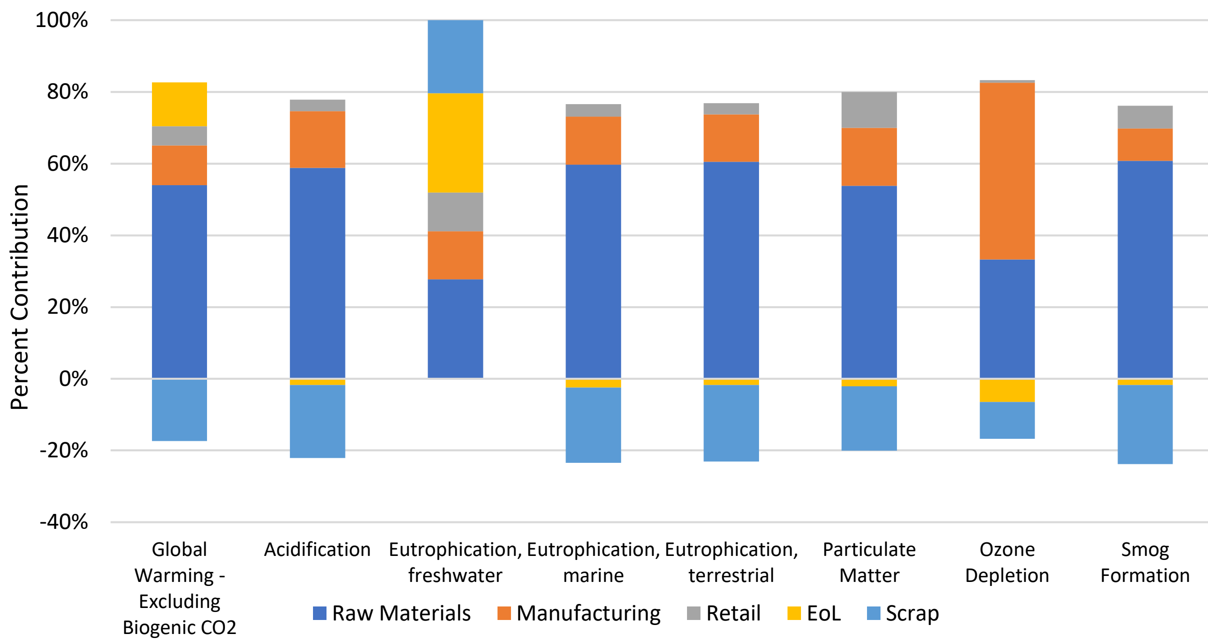


Figure 4-19: Contribution results for each impact for 500 mL PET flat bottles in the EU.

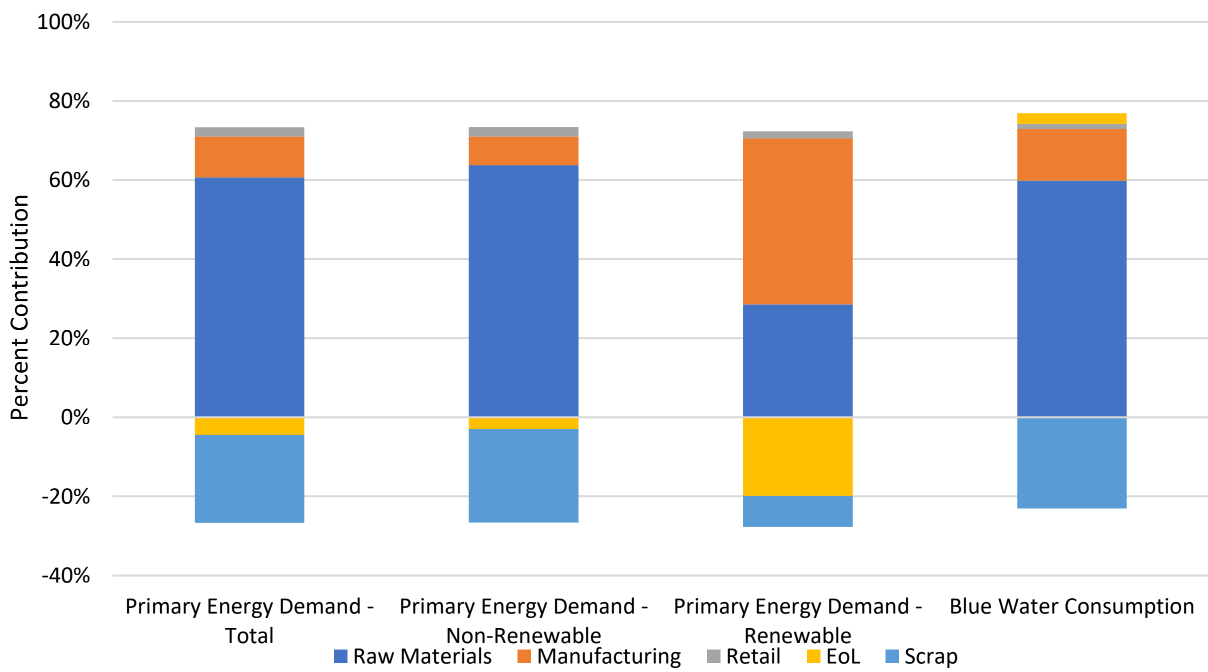


Figure 4-20: Contribution results for each resource use indicator for 500 mL PET flat bottles in the EU.

4.3. Scenario Analysis

Two different sets of scenario analyses were assessed. The first explored how the use of a cut-off EoL allocation approach affects the relative results, and the second set of scenarios consist of future PET scenarios to explore how different changes to PET bottles have affect their future environmental performance.

4.3.1. Cut-Off End-of-Life Allocation

Figure 4-21 through Figure 4-23 show relative comparisons of the beverage container alternatives in the US and EU, when using a cut-off EoL allocation approach. The rankings for every impact category remain the same in both regions regardless of EoL allocation approach. However, when using the cut-off approach in the US, aluminum cans have a PEDt that is 18.7% lower than PET CSD bottles, while when using the baseline substitution approach, the PEDt from PET CSD bottles is 21.9% lower than aluminum cans. These changes are because PET CSD bottles lose their PEDt scrap credits from substitution and aluminum cans lose their PEDt scrap burdens. Similarly, in the EU, aluminum cans have a PEDnr that is 1.6% lower than PET CSD bottles, while when using the baseline substitution approach, the PEDnr from PET CSD bottles is 19.2% lower than aluminum cans.

Figure 4-25 shows the change in PEDt for the PET bottles and aluminum cans for the US. Glass bottles are not shown because their PEDt is several times larger and they changed by less than 1% when switching allocation methods in the US. The figure clearly shows how the loss of net scrap credits adds burdens to the PET bottles, while the loss of the net scrap burdens leads to improved performance for the aluminum cans. This scenario analysis shows how the advantage of a packaging solution over another can depend on the methodological approach for modeling multifunctionality at end-of-life. For the PET bottle results to remain lower than aluminum under the cut-off perspective, the PET would have to reduce their weight or increase their recycled content, above current 10%, or recycling rate, above current 28.4%, as is demonstrated in the EU scenario with higher current recycled contents and recycling rates.

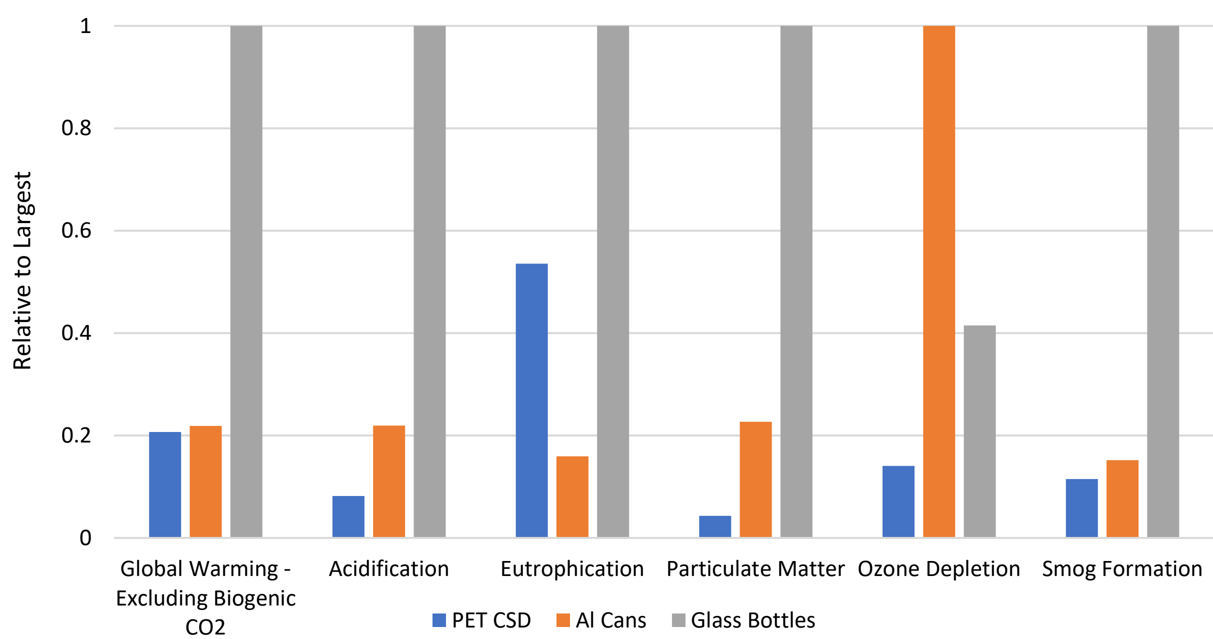


Figure 4-21: Relative comparison of impacts for 500 mL beverage containers in the US using a cut-off EoL allocation approach.

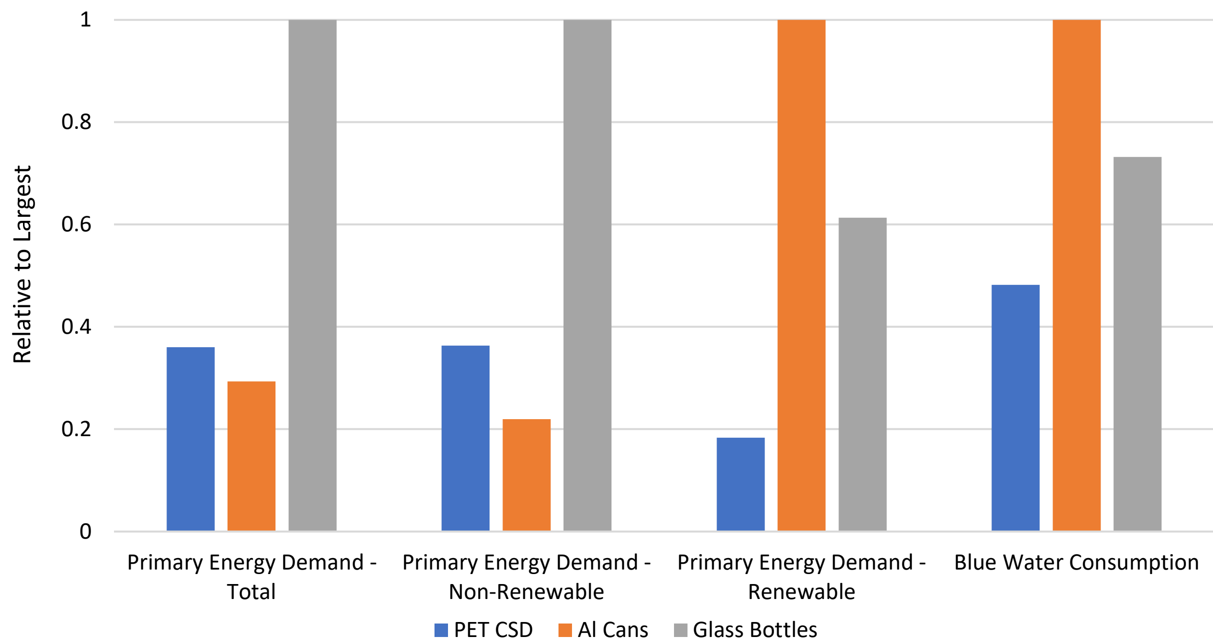


Figure 4-22: Relative comparison of resource use indicators for 500 mL beverage containers in the US using a cut-off EoL allocation approach.

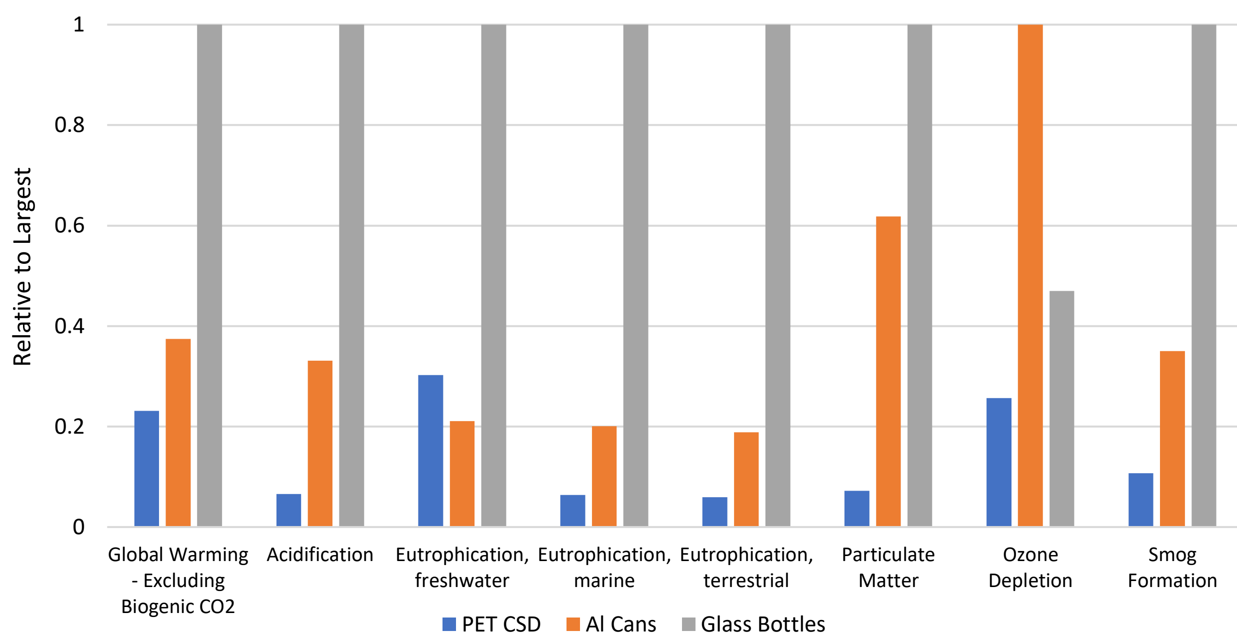


Figure 4-23: Relative comparison of impacts for 500 mL beverage containers in the EU using a cut-off EoL allocation approach.

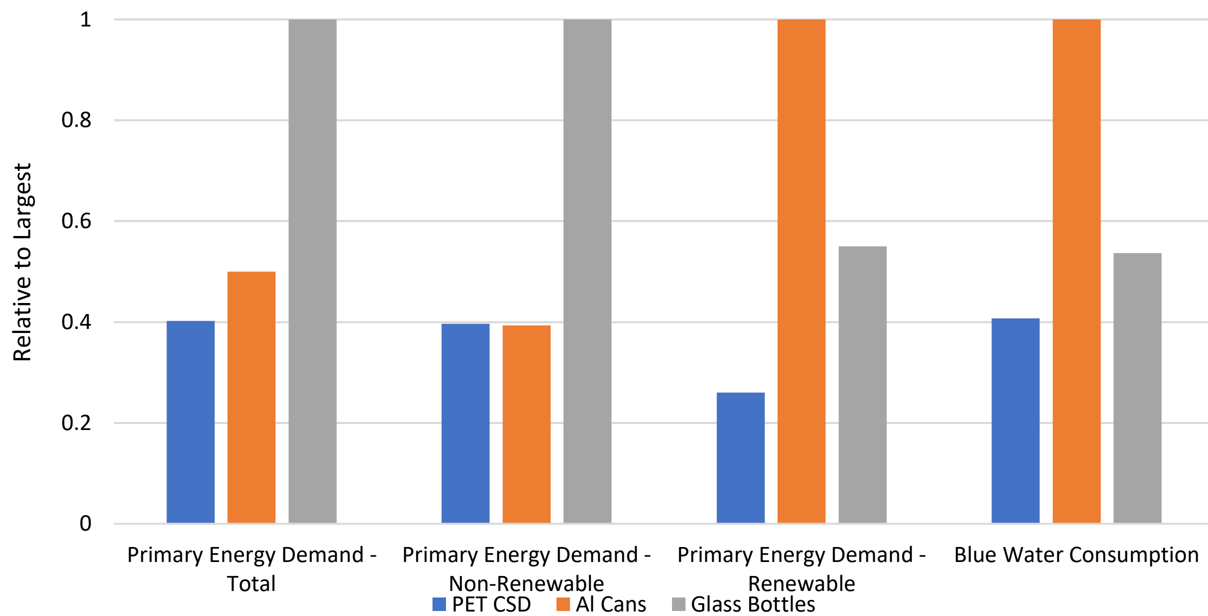


Figure 4-24: Relative comparison of resource use indicators for 500 mL beverage containers in the EU using a cut-off EoL allocation approach.

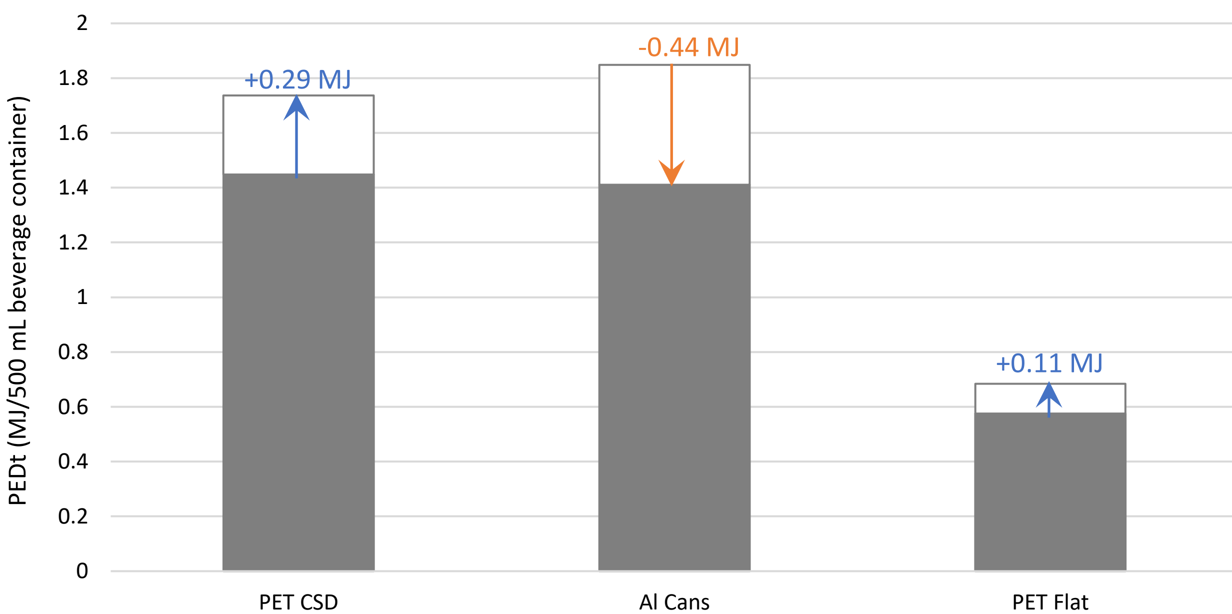


Figure 4-25: Changes in PEDt when switching from substitution to cut-off for EoL allocation in the US. Glass bottles are not shown because their PEDt is several times larger and they changed by less than 1% when switching allocation methods in the US.

4.3.2. Future PET Scenarios

Table 4-3 and Table 4-4 and show current and future scenarios for PET bottles for flat water and CSDs, respectively. In the 2025 and 2030+ scenarios the weight of the bottle decreases as recycling increases. In the 2030+ scenarios, a switch is also made from grid electricity to wind electricity.

Table 4-3: Future scenarios for PET bottles for flat water

	Current	2025	2030+
Material	Fossil PET	Fossil PET	Fossil PET
Bottle Mass (g)	6.91	6.2	5
Cap Mass – US (g)	0.72	0.72	0.8 [a]
Cap Mass – EU (g)	1.25	0.95	0.8 [a]
Label Mass (g)	0.86	0.86	0
Recycling Rate (US/EU)	28.4%/61%	38.4%/76%	48.4%/90%
Recycled Content (US/EU)	10%/17%	50%/50%	70%/70%
Electricity Source	US/EU Grid Mix	US/EU Grid Mix	US/EU Wind

a. Closure contains 25% recycled HDPE.

Table 4-4: Future scenarios for PET bottles for CSDs.

	Current	2025	2030+
Material	Fossil PET	Fossil PET	Fossil PET
Bottle Mass (g)	19	18	9.9
Cap Mass (g)	1.8	1.8	1.65[a]
Label Mass (g)	0.86	0.86	0
Recycling Rate (US/EU)	28.4%/61%	38.4%/76%	48.4%/90%
Recycled Content (US/EU)	10%/17%	50%/50%	70%/70%
Electricity Source	US/EU Grid Mix	US/EU Grid Mix	US/EU Wind

b. Closure contains 25% recycled HDPE.

Figure 4-26 through Figure 4-29 show the relative change in impacts for the US and EU for the flat water PET bottle in the US (Figure 4-25 and Figure 4-26) and the EU (Figure 4-27 and Figure 4-28). The relative changes for the PET CSD bottle are similar, and those figures are presented in Annex B. The lightweighting and improved recycling of the 2025 scenario reduces all impacts by 7 to 39%, while the 2030+ scenario reduces all impacts except PEDrr by 33 to 76% in the US and 62 to 92% in the EU. PEDrr increases in the 2030+ scenario for both regions due to the use of renewable resources (e.g., wind, hydro, solar, biomass) to produce electricity.

Also in 2030+ US case, tethered closures are introduced. That addition causes a slight increase in weight, and associated, LCIA, in order to improve recovery and overall circularity of the package.

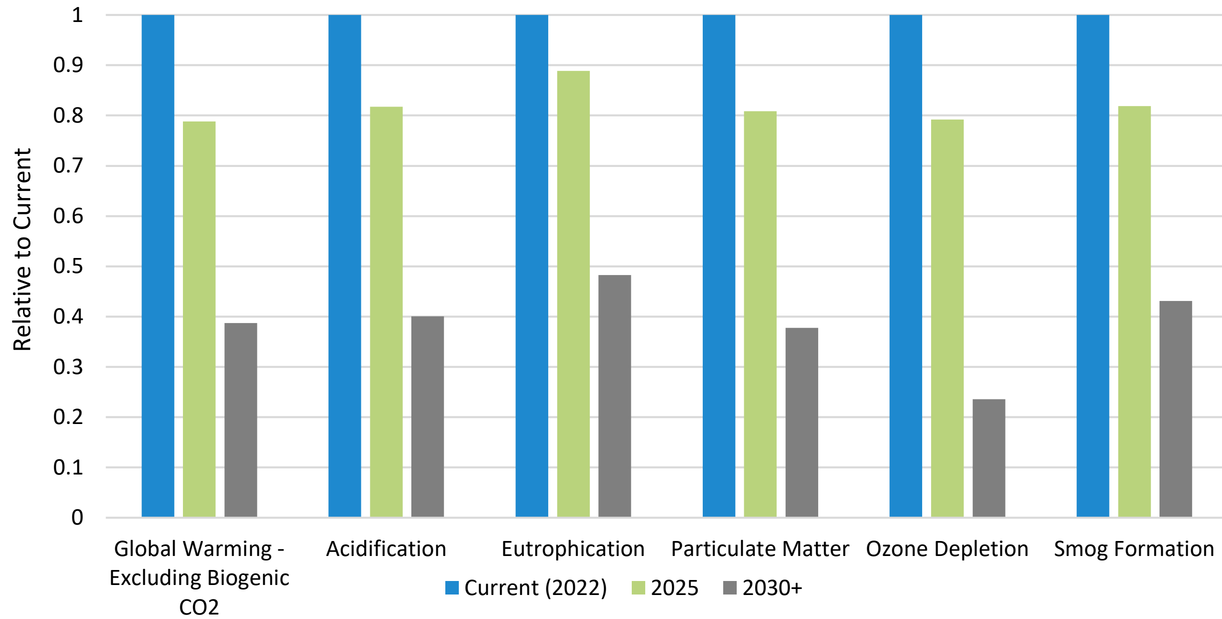


Figure 4-26: Comparison of impacts for future PET flat bottle scenarios in the US.

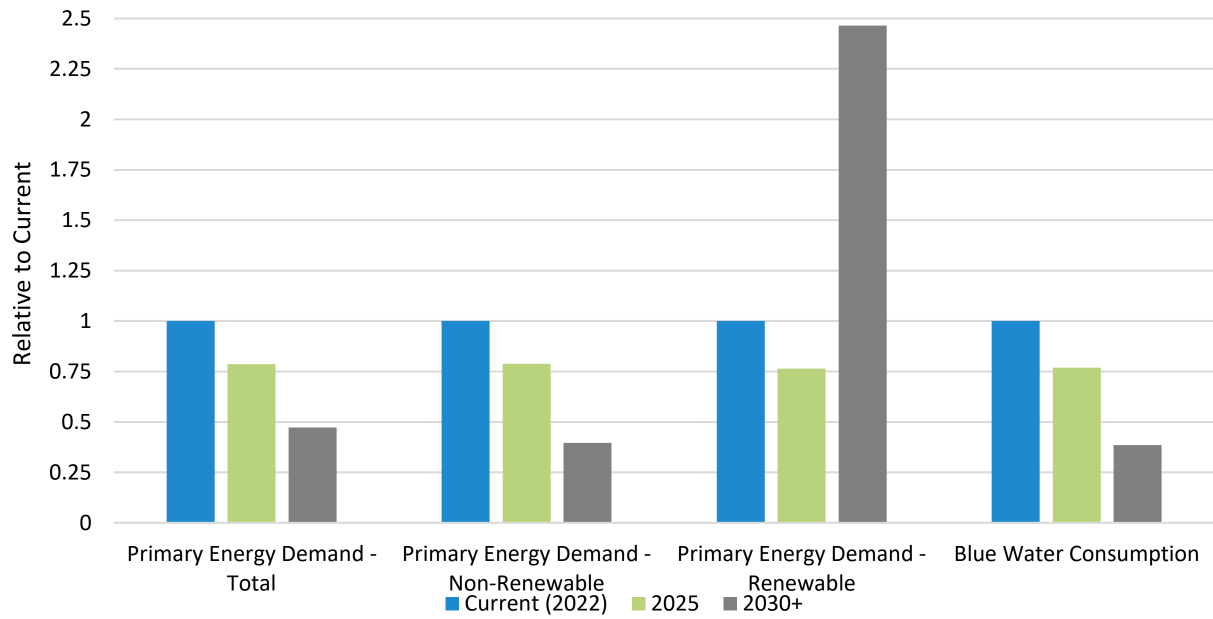


Figure 4-27: Comparison of resource use indicators for future PET flat bottle scenarios in the US.

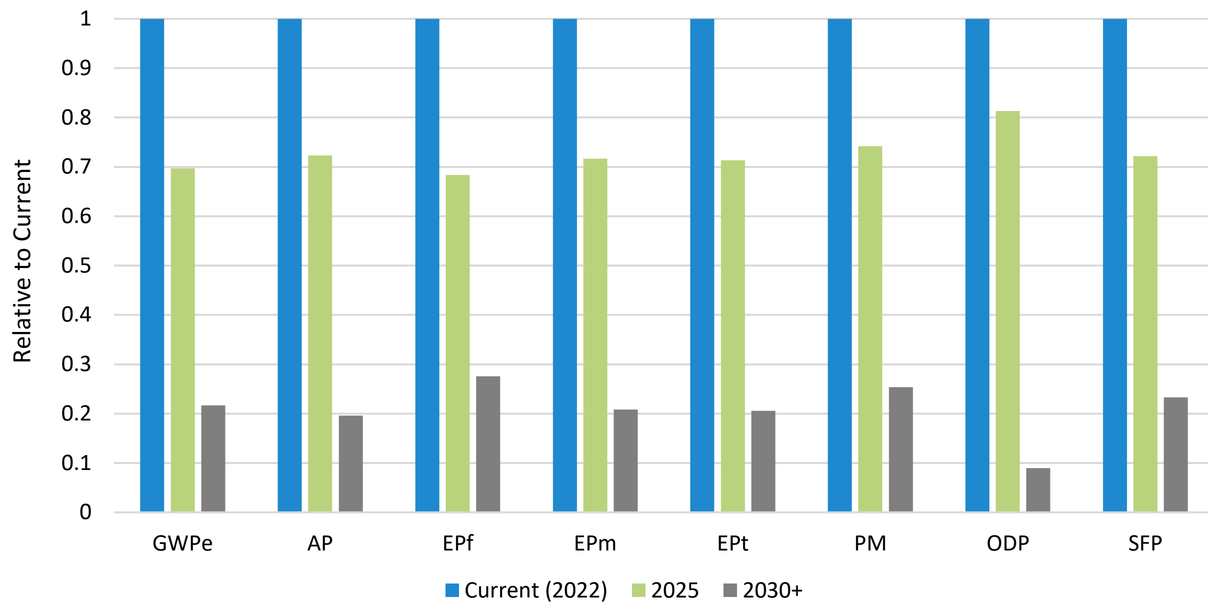


Figure 4-28: Comparison of impacts for future PET flat bottle scenarios in the EU.

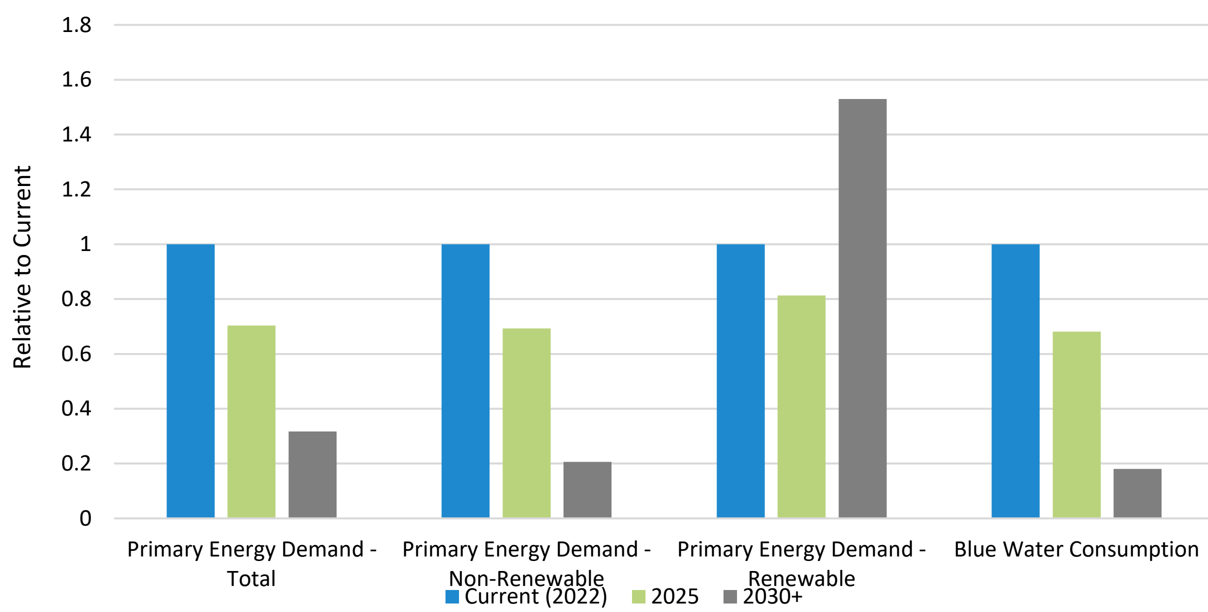


Figure 4-29: Comparison of resource use indicators for future PET flat bottle scenarios in the EU.

For the 2030+ scenarios, we also tested different levels of biogenic material in the PET. The 2030+ 30% represents the case where the ethylene glycol in the PET is from biogenic sources, and the 2030+ 100% represents the case where both the ethylene glycol and terephthalic acid are from biogenic sources. The model for the production of the biogenic p-xylenes used in the terephthalic acid is based on Chen et al. (2016), while everything downstream of the p-xylene and ethylene glycol production are based on the existing MLC datasets for primary PET granulate production. Figure 4-30 through Figure 4-33 show the relative results of the different PET formulations. The results indicate that except for GWP and PEDrr, all the impacts and indicators increase as the fraction of biogenic material increases. However, it should be noted that the GWPi is actually negative for the 100% biogenic case in the US due to the biogenic C that is stored in the landfill. In the EU, GWPi is reduced by 66%

compared to fossil PET. So there are meaningful trade-offs when sourcing PET materials. In the future, it is also possible that increases in efficiency and/or emission reductions could improve the other impacts of biogenic PET compared to conventional fossil PET.

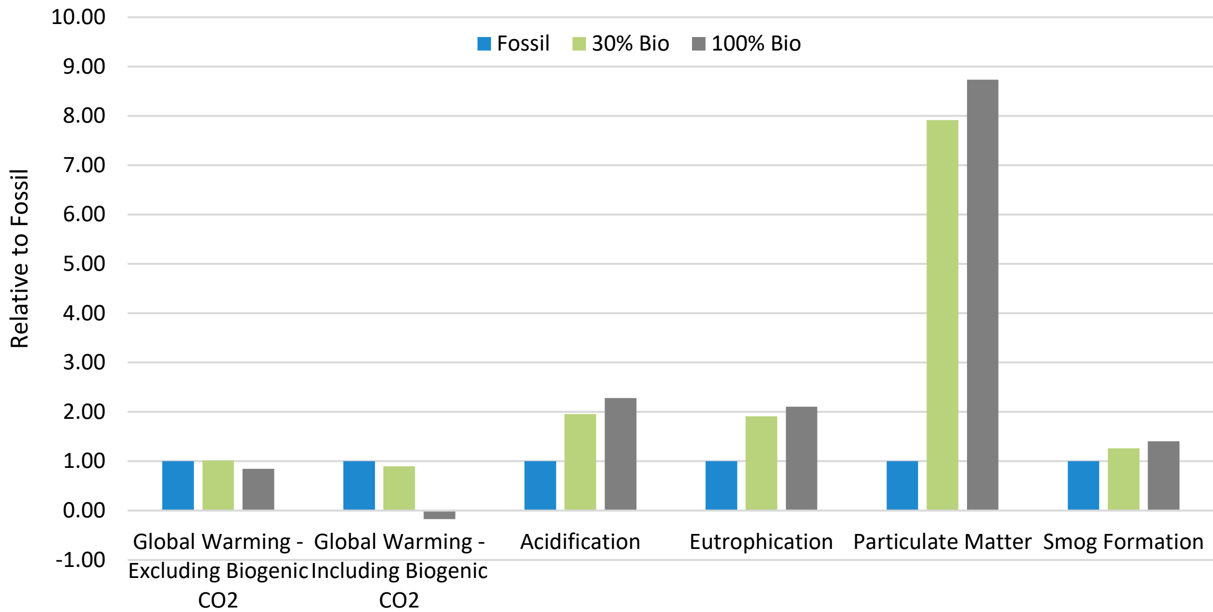


Figure 4-30: Relative impact results for 2030+ flat water PET bottles with different amounts of biogenic content in the US.

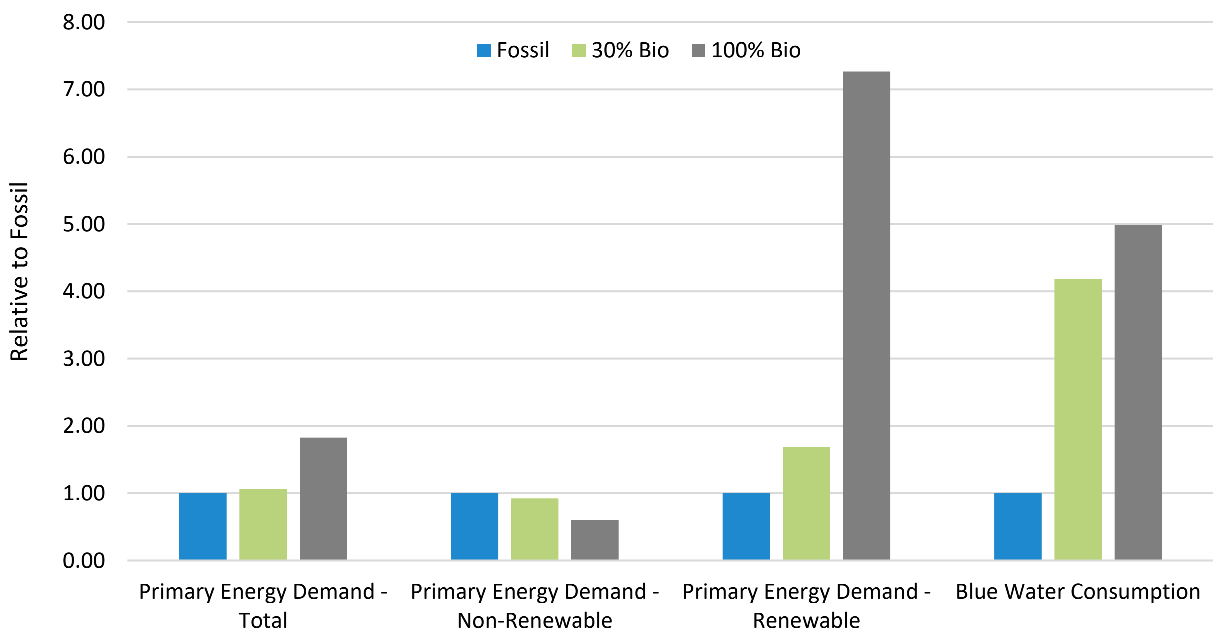


Figure 4-31: Relative resource indicator results for 2030+ flat water PET bottles with different amounts of biogenic content in the US.

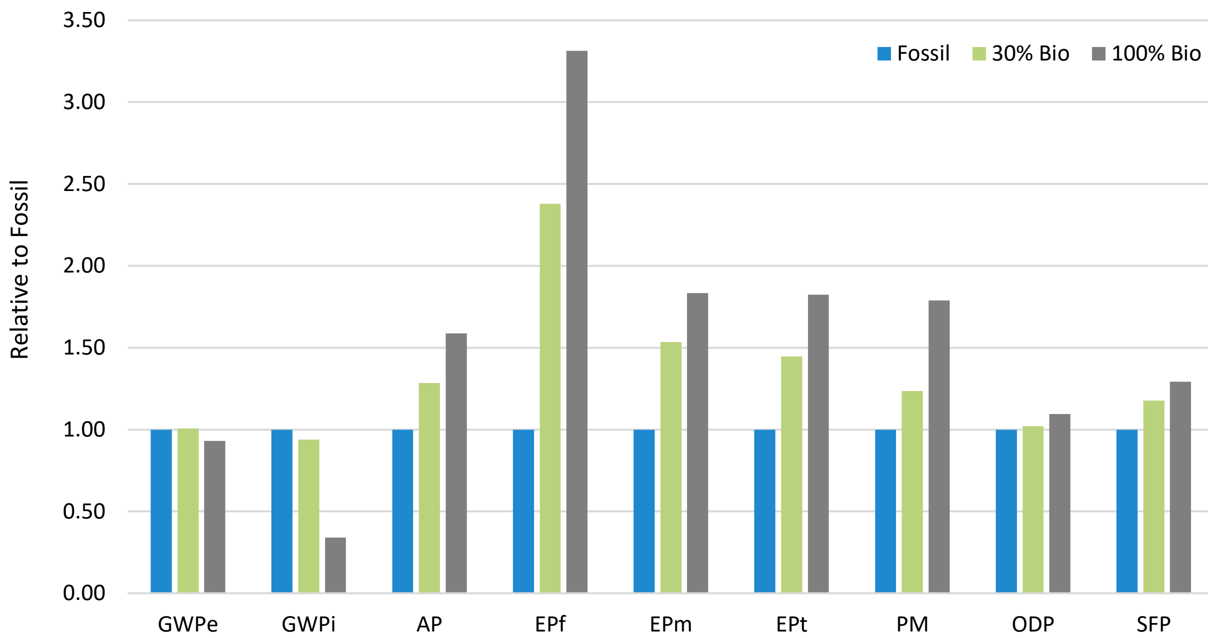


Figure 4-32: Relative impact results for 2030+ flat water PET bottles with different amounts of biogenic content in the EU.

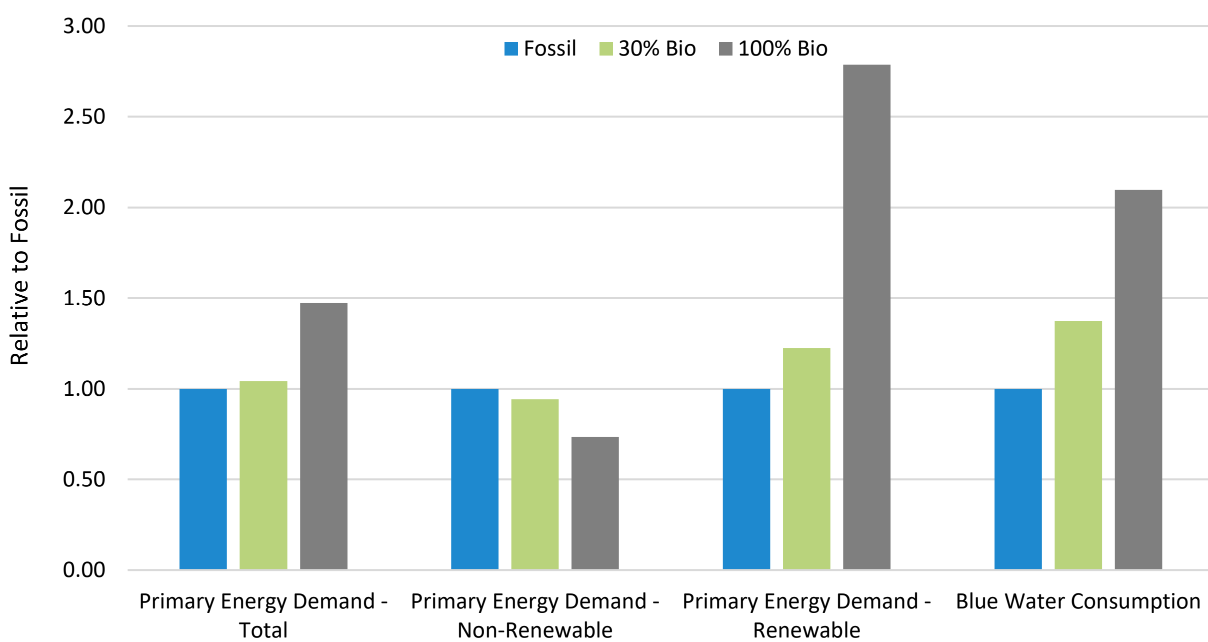


Figure 4-33: Relative resource indicator results for 2030+ flat water PET bottles with different amounts of biogenic content in the EU.

4.4. Sensitivity Analysis

4.4.1. Recycled Content

Figure 4-34 represents the change in GWP for PET bottles, Al cans and glass bottles in the US, as the recycled content is varied from 0 to 100%. Glass and PET bottles can be made from 100% recycled material . There are PET and glass bottles on the market with 100% recycled content, but there are limits depending on collection method and feedstock quality. Aluminum cans are usually limited to a maximum of ~90% recycled content due to the different alloys used in the body and closure. So, some caution should be used when looking at the upper ends of these results as it would be difficult for most beverage containers to achieve such high levels of recycled content without significant changes in production and recycling systems. The default parameter values were used for every parameter except the percent recycled content. It is observed that GWP for glass bottles is the most sensitive to the recycled content whereas the sensitivity of the GWP for PET bottles and Al cans is much lower (indicated by a less steep slope). Between Al cans and PET bottles, the GWP for the latter is more sensitive to the recycled content. As the recycled content varies from 0% to 100%, the GWP for glass bottles, PET bottles and Al cans drop by approximately 45%, 23% and 13% respectively. While the actual recycled content may be higher in the EU, this trend in the sensitivity of the GWP remains unchanged for the EU for the three products. Trends for the other impacts are generally similar to GWP. This sensitivity analysis also shows that in the event of 100% recycled content, glass containers still have a higher impact.

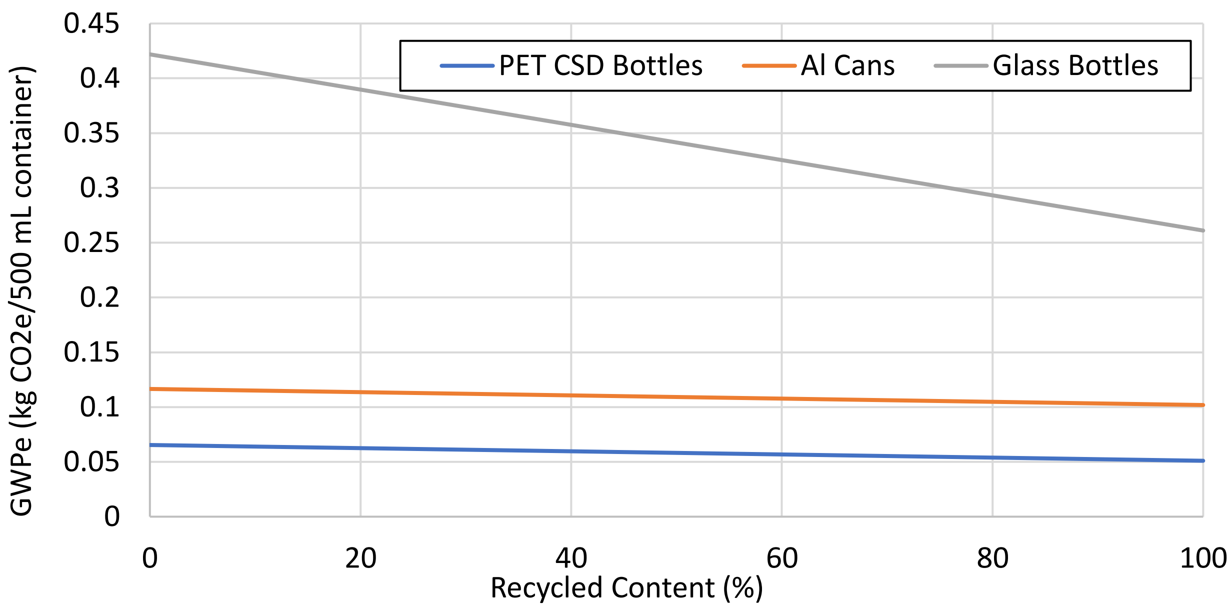


Figure 4-34: Sensitivity analysis of global warming potential to recycled content in the US for PET CSD bottles, Al cans and glass bottles

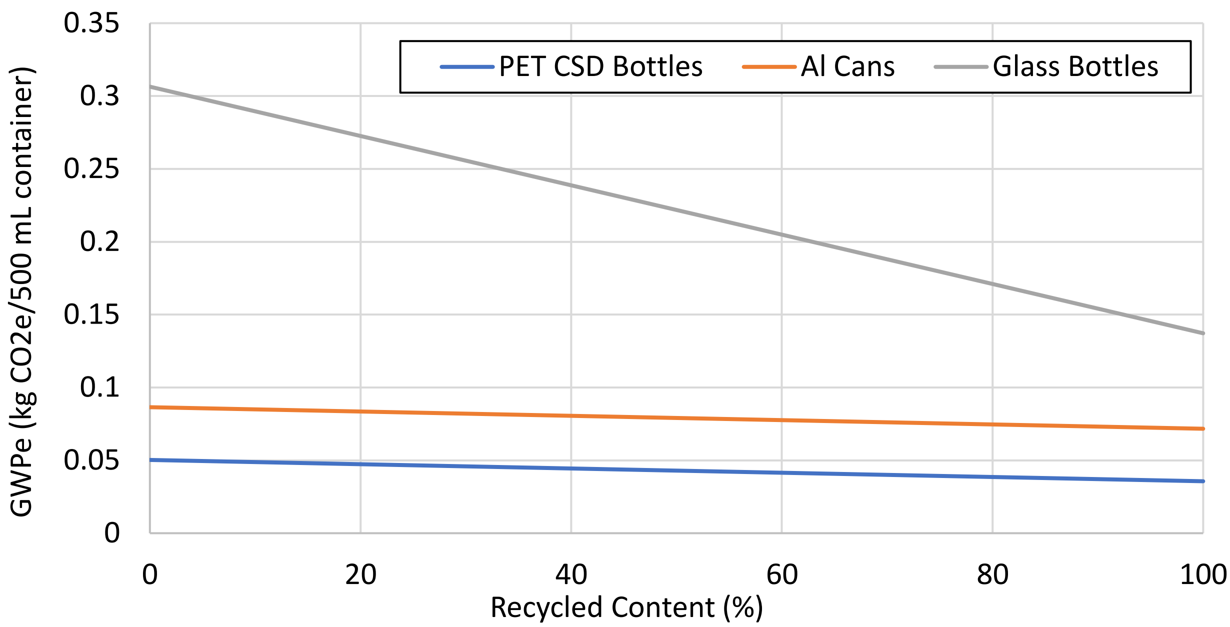


Figure 4-35: Sensitivity analysis of global warming potential to recycled content in the EU for PET CSD bottles, Al cans and glass bottles

4.4.2. Recycling Rate

Figure 4-36 represents the change in GWP for PET bottles, Al cans and glass bottles in the US, as the recycling rate varies from 0 to 100%. %. The default parameter values were used for every parameter except the recycling rate. It is observed that GWP for glass bottles is the most sensitive to the recycled rate whereas the sensitivity of the GWP for PET bottles and Al cans is much lower (indicated by a less steep slope). Between Al cans and PET bottles, the GWP for the former is more sensitive to the recycling rate. As the recycling rate varies from 0% to 100%, the GWP for glass bottles, Al cans and PET bottles drop by approximately 57%, 71% and 57% respectively. It is interesting to note here that while the percentage change in the GWP for fully recycled Al cans is largest relative to their completely non-recycled versions, the rate at which this occurs is much lesser than for glass bottles. Therefore, in terms of percentage reduction in GWP, glass bottles tend to gain more when the change in recycling content is small and Al cans tend to gain more when the change is larger. While the actual recycled content may be higher in the EU, this trend in the sensitivity of the GWP remains unchanged for the EU for the three products. Trends for the other impacts are generally similar to GWP. These analyses shows the importance of material sourcing (recycled content) and encouraging and/or facilitating recycling in managing environmental impacts of beverage packaging.

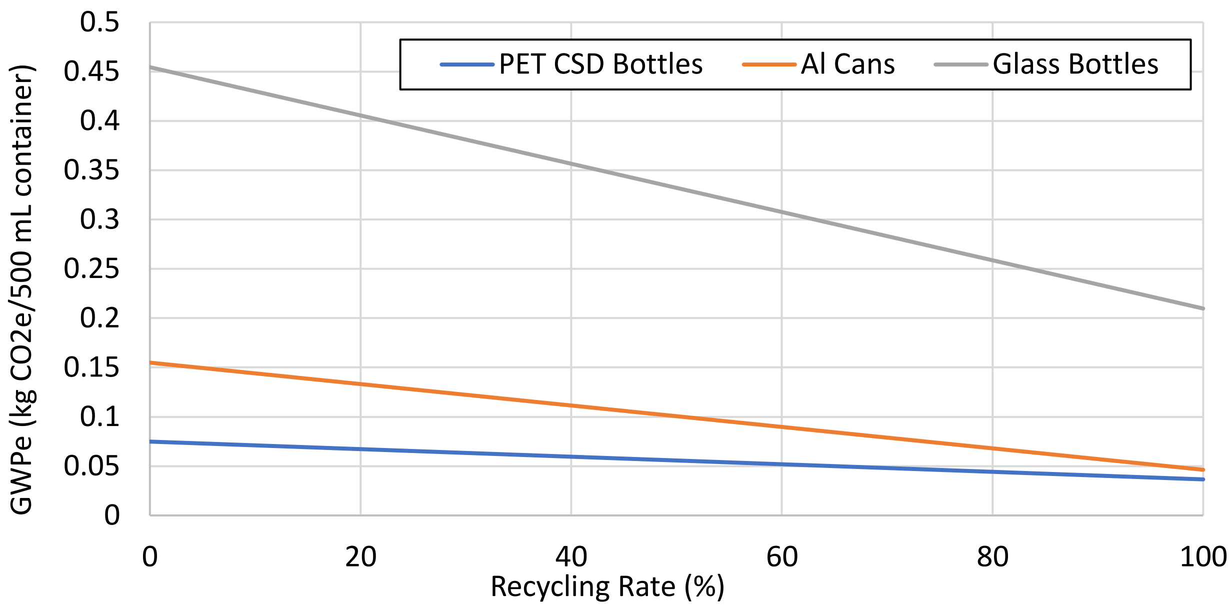


Figure 4-36: Sensitivity analysis of global warming potential to recycling rate in the US for PET CSD bottles, Al cans and glass bottles

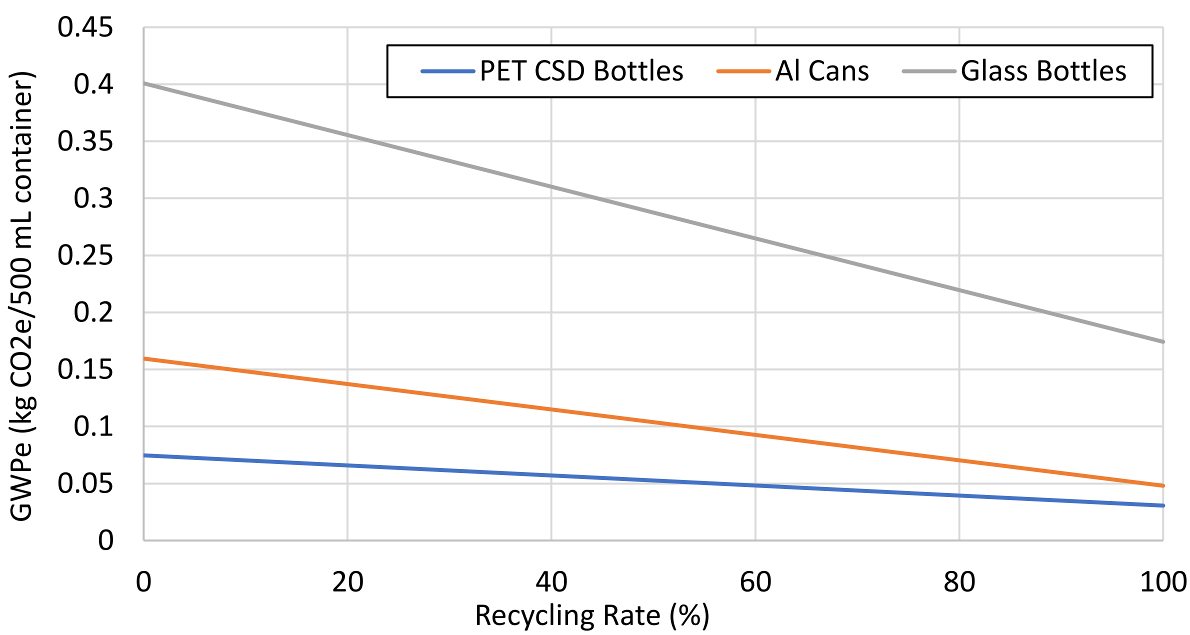


Figure 4-37: Sensitivity analysis of global warming potential to recycling rate in the EU for PET CSD bottles, Al cans and glass bottles

4.4.3. Distribution and Recycling Transportation Distances

Given the potential uncertainty in the distance traveled for distribution and recycling, and therefore a sensitivity analysis was performed that simultaneously varied the distribution and recycling distances from 0 to 2000 km in both the US and EU. Figure 4-38 and Figure 4-39 show the GWP results for this sensitivity analysis for the US and EU, respectively. The results show that changes in distribution and recycling distance have a small effect on PET bottles and aluminum cans. GWP from PET CSD bottles change by less than 6% over the entire range, while aluminum cans changed by less than 3%. While glass bottles, due to their much larger weight, change by 16.5%

and 17.8% in the US and EU, respectively. However, regardless of the distribution and recycling distance, the rankings among the scenarios do not change.

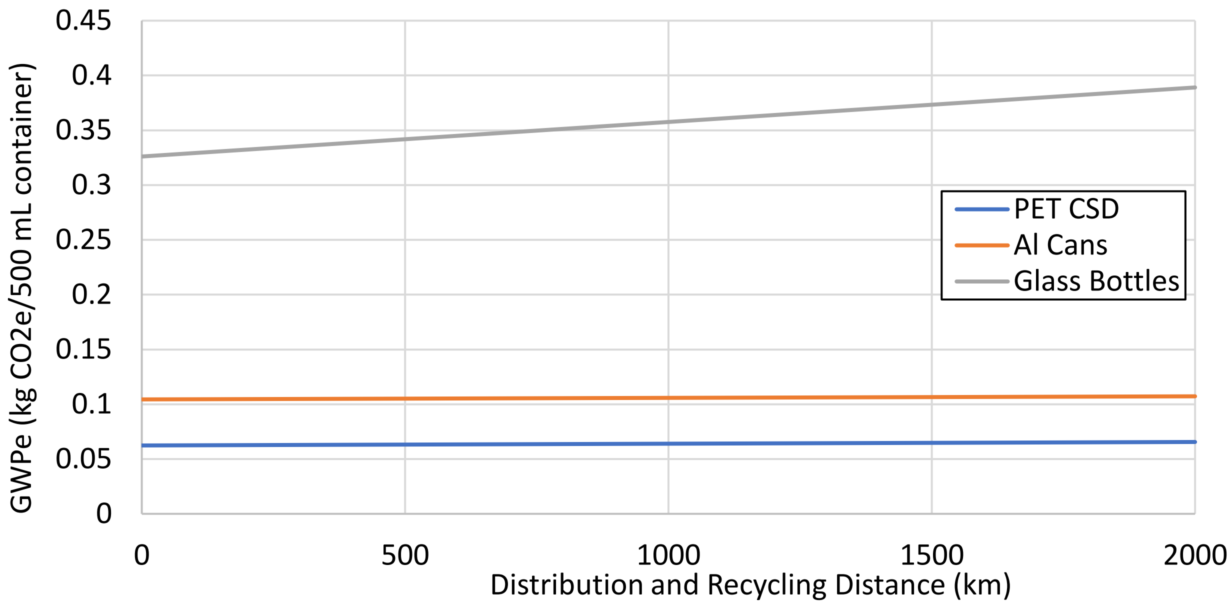


Figure 4-38: Sensitivity analysis of global warming potential to distribution and recycling distance in the US.

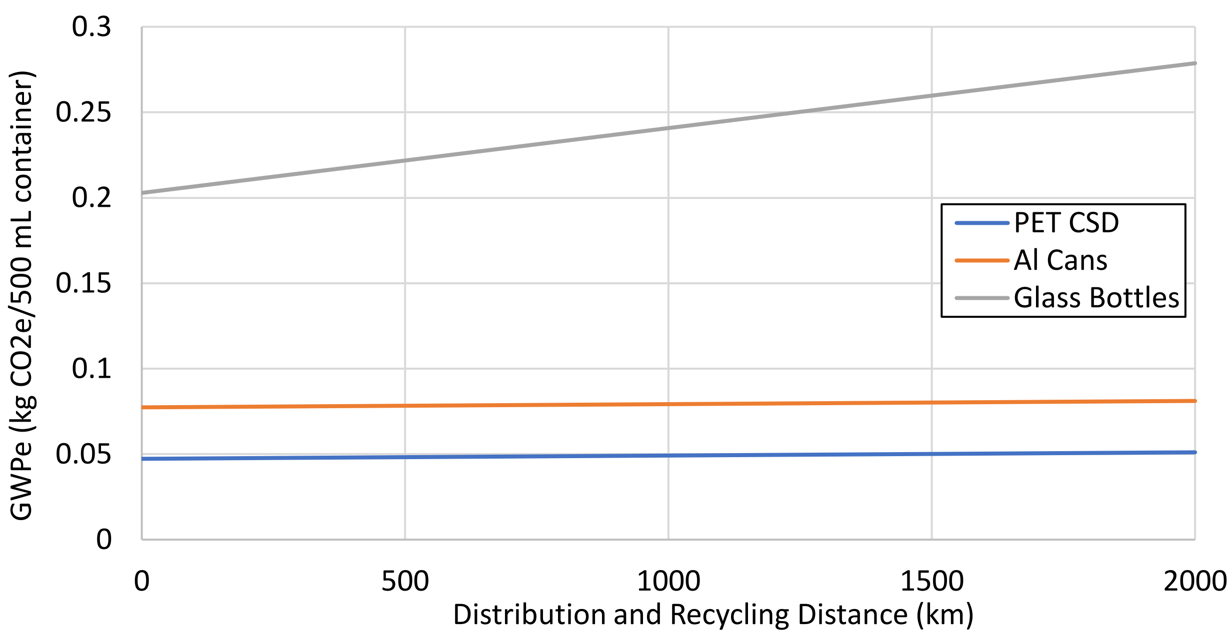


Figure 4-39: Sensitivity analysis of global warming potential to distribution and recycling distance in the EU.

5. Interpretation

5.1. Identification of Relevant Findings

The baseline results indicated that PET bottles performed the best in all the impact categories in both regions except for EP (EPf in the EU) and PEDnr in the US. In those categories, PET bottles were outperformed by aluminum cans. PET bottles performed worse in EP due to NOx emissions from incineration at the end-of-life. PET bottles performed worse in PEDnr in the US due to the large amount of hydropower used to produce aluminum cans instead of the US grid mix used to produce PET bottles which uses more coal and natural gas. Additionally, the crude oil and natural gas used to produce the PET bottles is included in the PEDnr, while aluminum cans and glass bottles have no such material burden. The large use of hydropower in North American aluminum production is also why aluminum cans perform the worst in terms of PEDrr and BWC in the baseline case. Glass containers had the largest impact in all categories except ODP, PEDrr, and BWC primarily due to the manufacturing stages. However, the glass bottles also had larger distribution and retail impacts than PET bottles and aluminum because the glass bottles are over ten times heavier.

While the baseline results used a substitution approach for EoL allocation, a cut-off approach was also explored. The rankings of the impact categories remained consistent, but aluminum cans outperformed in terms of PEDt in the US, and in PEDnr in the EU. The change in PEDt result in the US was driven by the loss of scrap credits for PET CSD bottles, and the loss of scrap burdens for aluminum cans. These results indicate that methodological assumptions can affect the rankings of the alternatives.

5.2. Assumptions and Limitations

There are several assumptions and limitations associated with the data and models. These assumptions and limitations include:

- Primary data was limited to that from Sphera (2021) for aluminum cans, and for bottle molding for PET bottles.
- Refrigeration of the beverages was not included.
- Transportation distances were generally assumed.
- Potential shelf-life differences were assumed to not affect waste or loss.
- Secondary and tertiary packaging were excluded.
- Reusable glass and PET bottles, which are common in the EU region are not covered.
- The results cannot necessarily be extrapolated to other container sizes.

5.3. Discussion of Sensitivity and Scenario, and Uncertainty Analysis

5.3.1. Scenario Analysis

The scenario exploring the effects of using a cut-off EoL allocation approach found that the rankings for every impact category remain the same in both regions regardless of EoL allocation approach (Figure 5-1 and Figure 5-2). However, when using the cut-off approach in the US, aluminum cans have a PEDt that is 18.7% lower than

PET CSD bottles, while when using the baseline substitution approach, the PEDt from PET CSD bottles is 21.9% lower than aluminum cans. These changes are because PET CSD bottles lose their PEDt scrap credits from substitution and aluminum cans lose their PEDt scrap burdens. Similarly, in the EU, aluminum cans have a PEDnr that is 1.6% lower than PET CSD bottles, while when using the baseline substitution approach, the PEDnr from PET CSD bottles is 19.2% lower than aluminum cans.

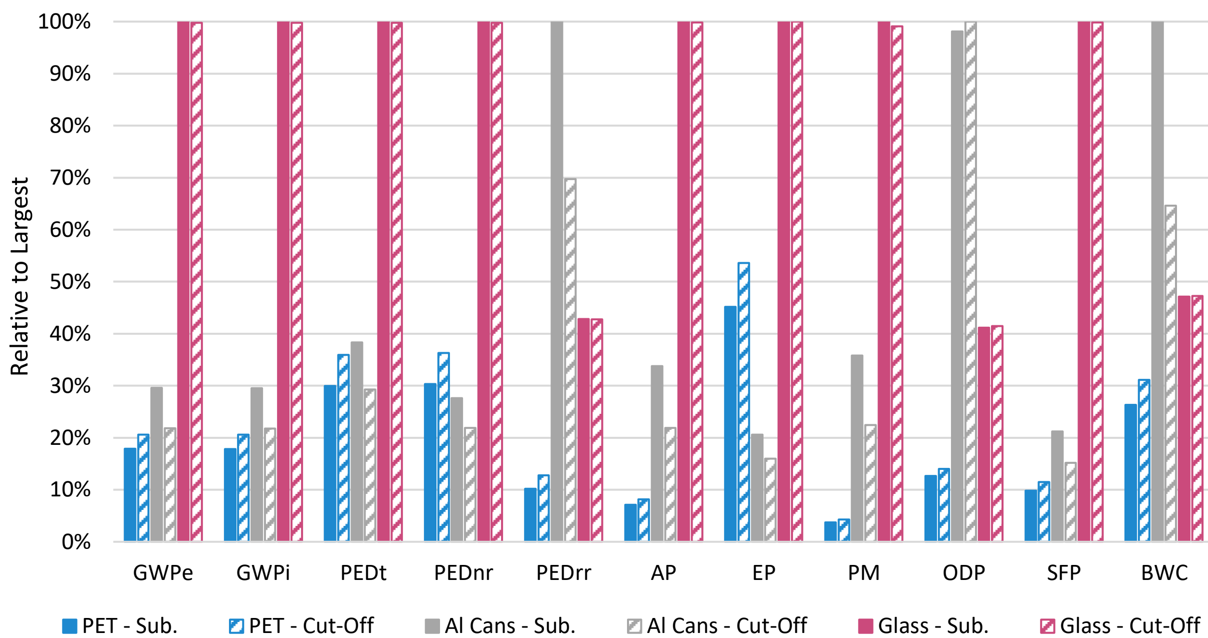


Figure 5-1: Relative results for substitution and cut-off EoL allocation methods in the US.

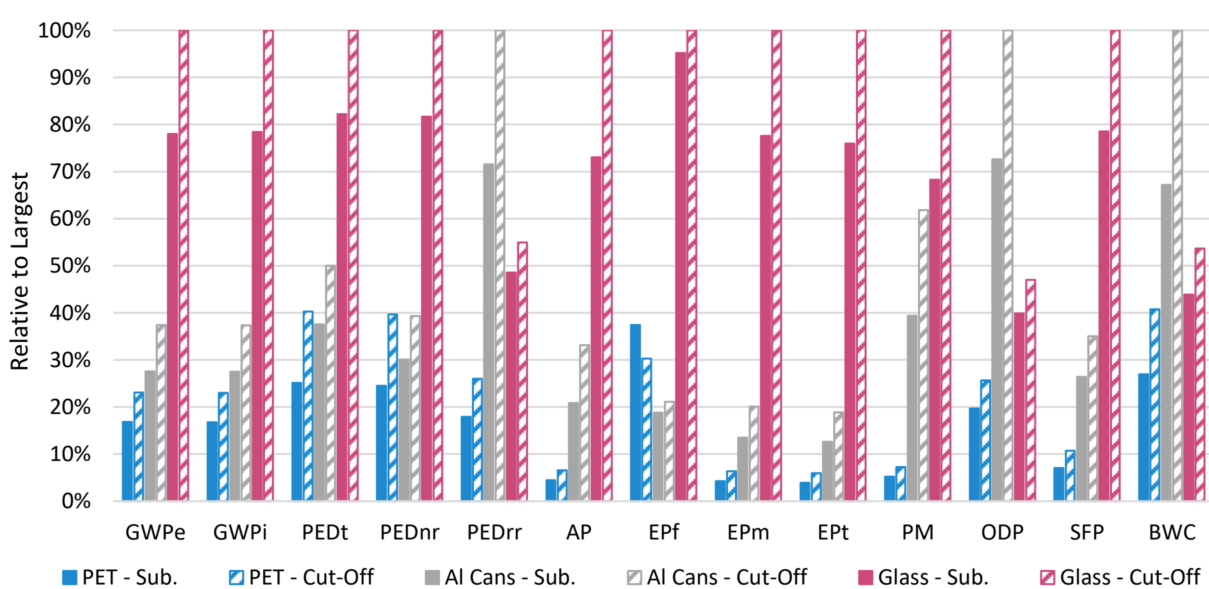


Figure 5-2: Relative results for substitution and cut-off EoL allocation methods in the EU.

The other scenarios explored how future changes to PET bottle sizes, materials, recycling rate, and electricity source could change their performance. Lightweighting and improved recycling in the 2025 scenario was shown to reduce all impacts in both regions. And all impacts except PEDrr were further reduced in the 2030+ scenario in both regions. PEDrr increased in both regions due to the use of wind electricity instead of the standard electricity grid mix.

5.3.2. Sensitivity Analysis

Sensitivity analyses focused on the recycling rate, recycled content, and transportation distances of the containers because these parameters are dynamic and uncertain. Each of these container alternatives is currently made with a wide range of recycled contents, and the recycling rate varies considerably across these regions. Distribution distances also can vary considerably depending on the location of the consumer.

Figure 5-3 and Figure 5-4 show the relative impact and indicator results for the US and EU, respectively, for the current amount of recycled content and for a recycled content of 90% for each container. In the US, there are no changes in rankings of any impact or indicator due to the amount of recycled content. However, in the EU, at a recycled content of 90%, PET bottles outperform Al cans in terms of EPf, and glass bottles outperform PET bottles in terms of ODP.

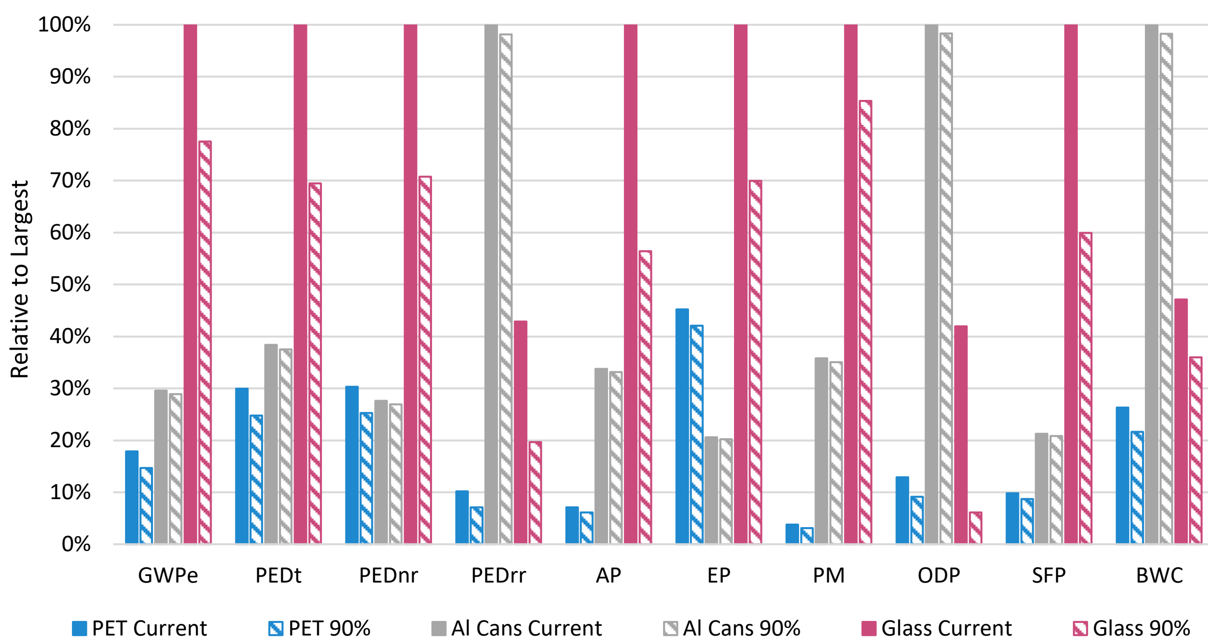


Figure 5-3. Comparison of current and 90% recycled content for each container in the US.

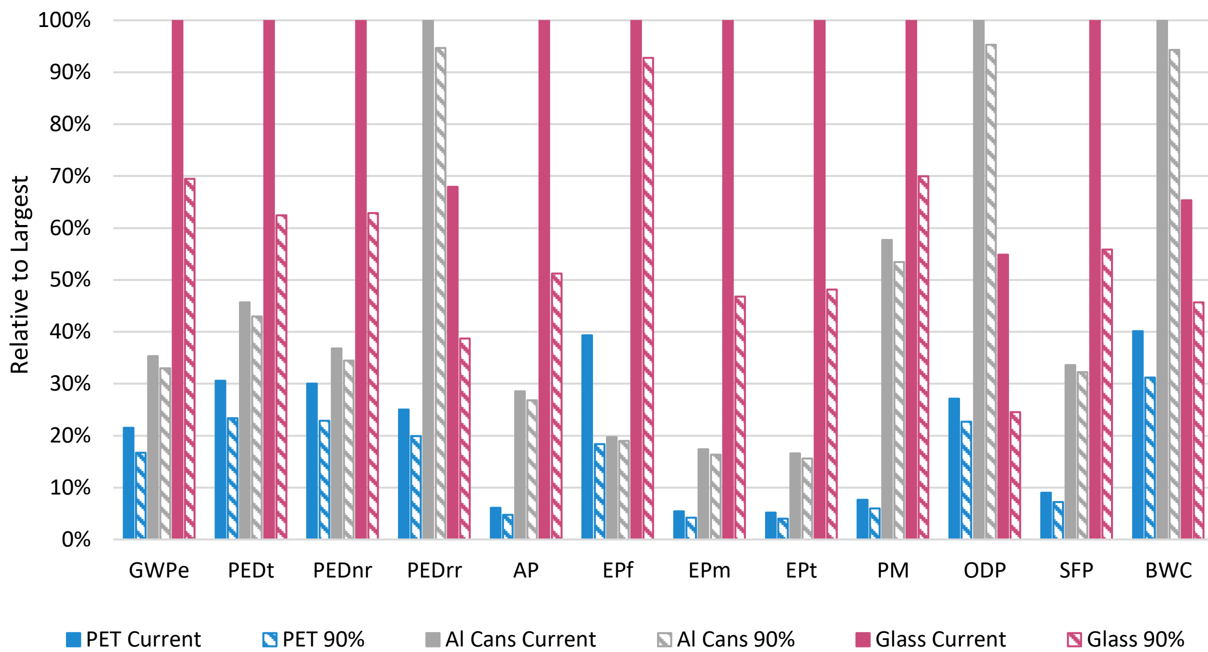


Figure 5-4. Comparison of current and 90% recycled content for each container in the EU.

Figure 5-5 and Figure 5-6 show the relative impact and indicator results for the US and EU, respectively, for the current recycling rate and for a recycling rate of 90% for each container. The relative rankings are relatively robust regardless of recycling. However, in the US if the PET recycling rate remained at its current rate of 28%, while the Al can recycling rate increased to 90%, then Al cans would outperform PET bottles in terms of GWPe, PEDt, and PEDnr. In the EU, this would only switch the rankings of PEDnr. If the recycling rate of PET bottles remained constant, then Al cans would have a lower GWPe than PET bottles at a recycling rate of 84%. This represents an increase of over 38 percentage points. It is therefore unlikely for Al cans to outperform PET bottles in GWPe due to uncertainty or variability in recycling rate. Changing distribution and recycling transportation distances from 0 to 2000 km did not affect the rankings of any impacts or indicators.

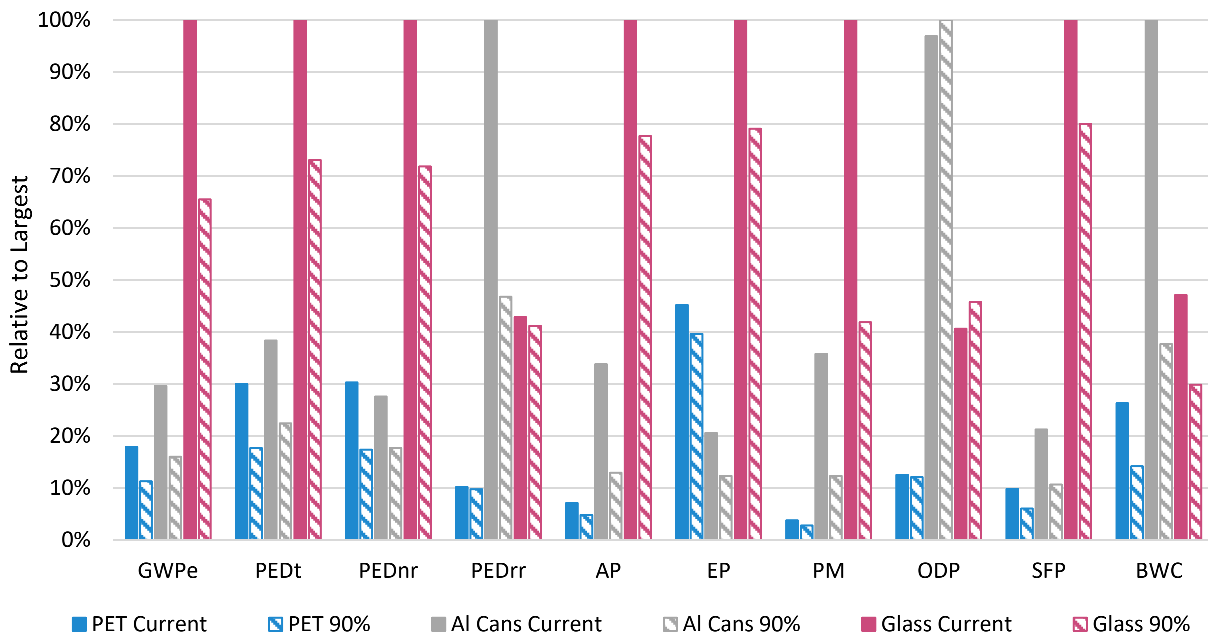


Figure 5-5. Comparison of current and 90% recycling rate for each container in the US.

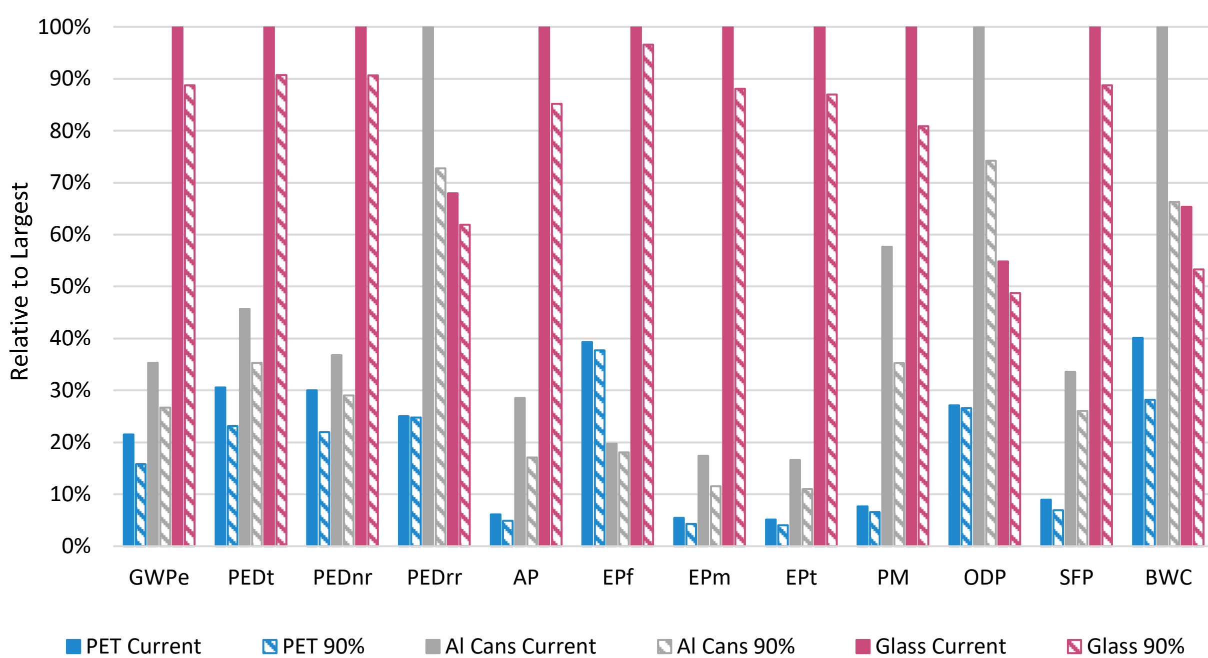


Figure 5-6. Comparison of current and 90% recycling rate for each container in the EU.

5.3.3. Uncertainty Analysis

The contribution, scenario, and sensitivity analyses provide an understanding of the key uncertain parameters, models, and assumption used in the model. The contribution results showed that the environmental performance was primarily driven by the raw material inputs. The overall effect of the raw material inputs on the outputs was significantly affected by the net difference in the recycling rate when using a substitution approach and by the recycled content when using the cut-off approach. However, under both approaches, PET CSD bottles were found to be the best in all metrics in both geographies, except for PEDnr and EP in the US, and EPf under both EoL allocation approaches. The effect of recycled content and recycling rate were both also explored, and the relative rankings did not change as they changed simultaneously for all the alternatives. However, if the PET recycling rate remains constant, while the Al can recycling rate increased to 84% in the US, then Al cans would outperform PET bottles in terms of GWPe. This large increase for one type of single-use container and not for another does not seem likely. An additional sensitivity analysis explored the effect of distribution and recycling transport distances and found not effect on the rankings of the alternatives for any of the considered metrics. Therefore, the results of the analysis appear to be relatively robust in light of the uncertainty in key modeling parameters and assumptions. The differences between the alternatives appear to be outside the range of uncertainty in the model parameters, assumptions, and data.

5.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the MLC 2022.2 database were used. The LCI datasets from the MLC 2022.2 database are widely distributed and used with the LCA FE 10 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.4.1. Precision and Completeness

- ✓ **Precision:**. Primary data was limited to that from Sphera (2021) for aluminum cans, and for bottle molding for PET bottles. Additionally, glass melting and forming energy can vary. Therefore, precision is considered to be acceptable. All background data are sourced from MLC 2022.2 databases with the documented precision.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from MLC 2022.2 databases with the documented completeness.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the MLC 2022.2 databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

5.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2022. All secondary data come from the MLC 2022.2 databases and are representative of the years 2018-2022. As the study intended to compare the product systems for the reference year 2022, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.5. Model Completeness and Consistency

5.5.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regard to the goal and scope of this study.

5.5.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimized by exclusively using LCI data from the MLC 2022.2 2020 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6. Conclusions, Limitations, and Recommendations

5.6.1. Conclusions

In the base case and the cut-off scenario, glass bottles have the largest impacts in all impact categories except ODP, PEDnr, and BWC in both the US and EU. In the base case, the GWP from glass bottles is over five times greater than PET bottles and over three times greater than aluminum cans. In the cut-off scenario, glass leads to approximately five times the GWP of PET bottles and aluminum cans. Raw materials and manufacturing are the main driver of impact categories for all three packaging materials. The sensitivity analyses showed that when using a substitution EoL allocation approach, PET bottles outperform glass bottles and aluminum cans regardless of the recycling rate, the amount of recycled content, or the distribution and recycling distance.

While the PEDt from PET CSD bottles is 22% lower than aluminum cans in the base case using a substitution EoL allocation approach, when using a cut-off approach, aluminum cans are associated with 18.7% lower GWP than PET CSD bottles. This results shows how methodological choices can significantly affect the results.

Finally, the future scenarios showed that continued efforts to lightweight PET bottles, increase their use of recycled content, and increase their recycling rate at end-of-life can continue to offer significant reductions in all environmental impacts. The use of renewable electricity in the manufacture and recycling of bottles can further reduce these impacts.

5.6.2. Recommendations

- Continue improvements in lightweighting and the use of post-consumer recycled materials.
- Promote policies and programs that increase recycling rates.
- The use of wind electricity could significantly improve most impacts, but there could be trade-offs in terms of PEDrr.
- The study could be improved by included additional primary data for glass bottles.

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Annex A: Critical Review Statement

- Critical Review Statement -

Comparative LCA on 500 mL Beverage Packaging Products

Commissioned by:	Husky Injection Molding Systems Ltd.
Conducted by:	James Levis
Reviewers:	Tom Gloria – Industrial Ecology Consultants Terrie Boguski – Harmony Environmental Angela Schindler – Umweltberatung
References:	ISO 14044:2006 – Environmental Management – Life CycleAssessment – Requirements and Guidelines ISO 14067:2018 Greenhouse gases – Carbon Footprint of Products – Requirements and Guidelines for Quantification ISO/TS 14071:2014 — Environmental management — Life cycle assessment — Critical review processes and reviewer competencies:Additional requirements and guidelines to ISO 14044:2006

Scope of the Critical Review

In accordance with ISO 14044:2006, section 6.1, the goal of the Critical Review was to assess whether:

- the methods used to carry out the LCA are consistent with the internationalstandards ISO 14040 and ISO 14044,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

As the study is intended to support comparative assertions intended to be disclosed to the public, the review was performed by a panel of independent experts following ISO 14044:2006, section 6.3.

This review statement is only valid for the specific report titled "**Comparative LCA on 500 mL Beverage Packaging Products**", dated July 24, 2023, v5 but not to any other report versions, derivative reports, excerpts, press releases, and similar documents.

The review was performed exclusively on the LCA study report. No software models were shared or requested during the review.

Critical Review process

The review was conducted by exchanging comments and responses using an Excel spreadsheet based on Annex A of ISO/TS 14071:2014.

The critical review was carried out between May 22, 2023 (delivery of the first draft of the report) and August 2, 2023 (delivery of the final review statement). There was one formal round of comments on the first draft version of the report as well as email conversations in-between. A copy of the final review report containing all written comments and responses has been provided to the study commissioner along with this review statement, and shall be made available to third parties upon request.

The overall review was conducted in an equitable and constructive manner. The reviewers would like to highlight the constructive collaboration with the author of the report. All comments were addressed and all open issues were resolved. There were no dissenting opinions held by any of the involved parties upon finalization of the review.

General evaluation

The study is well scoped, and the analysis is capable of supporting the goal of the study. It shows a high level of technical knowledge and methodological proficiency.

Conclusion

Based on the final study report, it can be concluded that the methods used to carry out theLCA are consistent with the international standard ISO 14044, that they are scientifically and technically valid, that the data used are appropriate and reasonable in relation to the goal of the study, and that the interpretations reflect the limitations identified and the goal of the study. The study report is considered sufficiently transparent and consistent.

When communicating results to third parties outside of Husky, ISO 14044, section 5.2 requires that a third-party report be made available to any such parties. The third-party report shall be made available by the study commissioner and should contain all required information as specified in ISO 14044, section 5.2. Any confidential or otherwise sensitive contents can be removed or blacked out prior to sharing the report with third parties.

The reviewers sign this review statement as individual experts. Their signatures do not constitute an endorsement of the study's scope or results by the affiliated organizations.

Thomas Gloria	Terrie Boguski	Angela Schindler

Valid as of August 9, 2023

Annex B: Additional Results

Table B-1: LCI results of PET CSD Bottle in EU (kg/500 mL container)

Type	Flow	Raw Material	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	3.15E+01	3.98E+01	5.53E-01	-6.46E+00	-1.17E+01	5.37E+01
	Wood	-8.79E-17	3.95E-17	1.23E-18	3.80E-18	4.33E-17	4.45E-17
	Crude oil	1.75E-02	1.84E-04	9.02E-04	2.83E-05	-7.55E-03	1.11E-03
	Hard coal	7.67E-04	8.70E-04	8.27E-05	-1.36E-04	2.50E-04	8.17E-04
	Natural gas	1.06E-02	7.52E-04	1.65E-04	-9.29E-04	-4.03E-03	-1.21E-05
	Uranium	7.62E-08	1.05E-07	2.96E-09	-1.68E-08	-1.49E-08	9.07E-08
Emissions to air	CO_2	3.91E-02	9.43E-03	3.69E-03	7.94E-03	-1.31E-02	2.11E-02
	CH_4	1.30E-04	1.24E-05	1.76E-05	-4.50E-06	-4.80E-05	2.54E-05
	N_2O	7.54E-07	2.42E-07	1.63E-07	-5.73E-08	-2.84E-07	3.48E-07
	NO_x	4.46E-05	8.84E-06	1.44E-06	-1.78E-06	-1.69E-05	8.50E-06
	SO_2	2.48E-05	7.69E-06	1.38E-06	-1.02E-06	-8.91E-06	8.05E-06
	NMVOC	3.34E-05	9.74E-07	3.97E-06	-2.83E-07	-1.40E-05	4.66E-06
	CO	2.53E-05	6.32E-06	4.60E-05	-3.47E-07	-9.87E-06	5.20E-05
	PM10	1.66E-08	3.56E-09	5.99E-07	-1.76E-09	-5.46E-09	6.01E-07
	PM2.5	8.67E-07	2.66E-07	1.84E-07	-5.26E-08	-2.84E-07	3.97E-07
Emissions to water	NH_3	3.08E-07	4.19E-08	9.53E-08	-4.04E-09	-7.37E-08	1.33E-07
	NO_3^{1-}	1.45E-06	1.56E-06	5.96E-07	-2.40E-07	-2.69E-07	1.91E-06
	PO_4^{3-}	9.33E-08	6.22E-08	3.45E-08	-8.92E-09	-3.57E-08	8.78E-08

Table B-2: LCI results of PET Flat Bottle in EU (kg/500 mL container)

Type	Flow	Raw Material	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	1.25E+01	1.73E+01	2.30E-01	-2.35E+00	-4.46E+00	2.33E+01
	Wood	-3.70E-17	1.72E-17	5.13E-19	2.67E-18	1.73E-17	6.62E-19
	Crude oil	7.67E-03	7.93E-05	3.76E-04	1.33E-05	-3.09E-03	5.05E-03
	Hard coal	3.03E-04	3.79E-04	3.44E-05	-4.94E-05	1.06E-04	7.74E-04
	Natural gas	4.38E-03	3.28E-04	6.86E-05	-4.62E-04	-1.59E-03	2.73E-03
	Uranium	3.01E-08	4.56E-08	1.23E-09	-6.08E-09	-5.36E-09	6.55E-08
Emissions to air	CO_2	1.60E-02	4.13E-03	1.54E-03	3.85E-03	-5.09E-03	2.04E-02
	CH_4	5.53E-05	5.40E-06	7.31E-06	-2.11E-06	-1.93E-05	4.66E-05
	N_2O	3.07E-07	1.05E-07	6.81E-08	-2.45E-08	-1.10E-07	3.46E-07
	NO_x	1.88E-05	3.86E-06	5.99E-07	-7.77E-07	-6.74E-06	1.58E-05
	SO_2	1.05E-05	3.35E-06	5.75E-07	-3.70E-07	-3.56E-06	1.05E-05
	NMVOC	1.53E-05	4.24E-07	1.65E-06	-1.33E-07	-5.89E-06	1.14E-05
	CO	1.02E-05	2.76E-06	1.92E-05	-7.69E-08	-3.80E-06	2.82E-05
	PM10	6.89E-09	1.56E-09	2.50E-07	-1.02E-09	-2.14E-09	2.55E-07
	PM2.5	3.79E-07	1.16E-07	7.64E-08	-2.23E-08	-1.23E-07	4.26E-07
Emissions to water	NH_3	1.53E-07	1.90E-08	3.97E-08	-1.42E-09	-3.57E-08	1.75E-07
	NO_3^{1-}	5.73E-07	6.82E-07	2.48E-07	-8.66E-08	-9.65E-08	1.32E-06
	PO_4^{3-}	3.83E-08	2.71E-08	1.44E-08	-3.19E-09	-1.40E-08	6.26E-08

Table B-3: LCI results of Glass Bottle in EU (kg/500 mL container)

Type	Flow	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	1.07E+02	8.97E+00	7.75E+00	-2.28E+01	1.01E+02
	Wood	-3.93E-16	2.11E-17	3.73E-18	1.02E-16	-2.66E-16
	Crude oil	9.36E-03	1.57E-02	5.66E-04	-2.24E-03	2.34E-02
	Hard coal	1.16E-02	1.28E-03	2.29E-04	-6.04E-03	7.08E-03
	Natural gas	4.29E-02	2.68E-03	6.32E-04	-8.53E-03	3.76E-02
	Uranium	2.58E-07	4.62E-08	1.88E-08	-3.57E-08	2.87E-07
Emissions to air	CO_2	2.03E-01	6.31E-02	6.14E-03	-5.75E-02	2.15E-01
	CH_4	2.93E-04	2.79E-04	3.30E-05	-7.59E-05	5.29E-04
	N_2O	2.49E-06	2.90E-06	1.53E-07	-5.07E-07	5.03E-06
	NO_x	2.11E-04	2.43E-05	1.15E-05	-8.90E-05	1.58E-04
	SO_2	4.15E-04	2.29E-05	3.86E-06	-1.31E-04	3.11E-04
	NMVOC	2.80E-05	6.34E-05	1.30E-06	-6.83E-06	8.59E-05
	CO	2.18E-04	7.10E-04	6.12E-06	-1.26E-04	8.08E-04
	PM10	5.08E-07	9.23E-06	2.58E-09	-1.29E-06	8.45E-06
	PM2.5	1.34E-05	2.92E-06	7.36E-07	-6.03E-06	1.10E-05
Emissions to water	NH_3	1.49E-05	1.47E-06	1.40E-07	-7.49E-06	9.02E-06
	NO_3^{1-}	5.97E-06	9.60E-06	4.78E-07	-1.08E-06	1.50E-05
	PO_4^{3-}	3.23E-07	5.97E-07	2.49E-08	-3.11E-08	9.14E-07

Table B-4: LCI results of Aluminum Can in EU (kg/500 mL container)

Type	Flow	Raw Material	Manufacture	Use Phase	End-of-Life	Scrap	Total
Resources	Water use	9.36E+02	7.04E+01	3.88E-01	5.23E-01	-3.93E+02	6.14E+02
	Wood	0.00E+00	2.75E-17	9.15E-19	4.38E-19	-8.29E-19	2.89E-17
	Crude oil	3.50E-03	5.75E-04	6.81E-04	1.41E-04	-1.45E-03	1.40E-03
	Hard coal	1.05E-02	1.77E-03	5.56E-05	1.69E-05	-4.39E-03	1.84E-03
	Natural gas	7.06E-03	6.82E-03	1.16E-04	6.07E-05	-2.52E-03	7.00E-03
	Uranium	2.40E-07	2.08E-07	2.00E-09	1.22E-09	-9.85E-08	2.12E-07
Emissions to air	CO_2	6.34E-02	3.40E-02	2.73E-03	7.19E-04	-2.50E-02	3.75E-02
	CH_4	1.20E-04	5.01E-05	1.21E-05	1.89E-06	-4.74E-05	6.41E-05
	N_2O	8.99E-07	8.55E-07	1.26E-07	3.29E-08	-3.51E-07	1.01E-06
	NO_x	1.51E-04	2.73E-05	1.05E-06	7.67E-07	-6.24E-05	2.91E-05
	SO_2	2.22E-04	1.47E-05	9.92E-07	3.20E-07	-9.24E-05	1.60E-05
	NMVOC	1.23E-05	7.82E-05	2.74E-06	2.10E-07	-4.78E-06	8.12E-05
	CO	2.67E-05	2.02E-05	3.07E-05	3.93E-07	-1.06E-05	5.13E-05
	PM10	2.28E-09	2.38E-07	3.99E-07	2.04E-10	1.17E-07	6.38E-07
	PM2.5	1.49E-05	1.85E-06	1.26E-07	4.64E-08	-6.07E-06	2.02E-06
Emissions to water	NH_3	1.83E-07	2.52E-07	6.36E-08	3.74E-09	-7.17E-08	3.20E-07
	NO_3^{1-}	1.69E-06	3.40E-06	4.15E-07	5.89E-08	-6.21E-07	3.87E-06
	PO_4^{3-}	4.46E-08	1.40E-07	2.58E-08	5.53E-09	-1.51E-08	1.71E-07

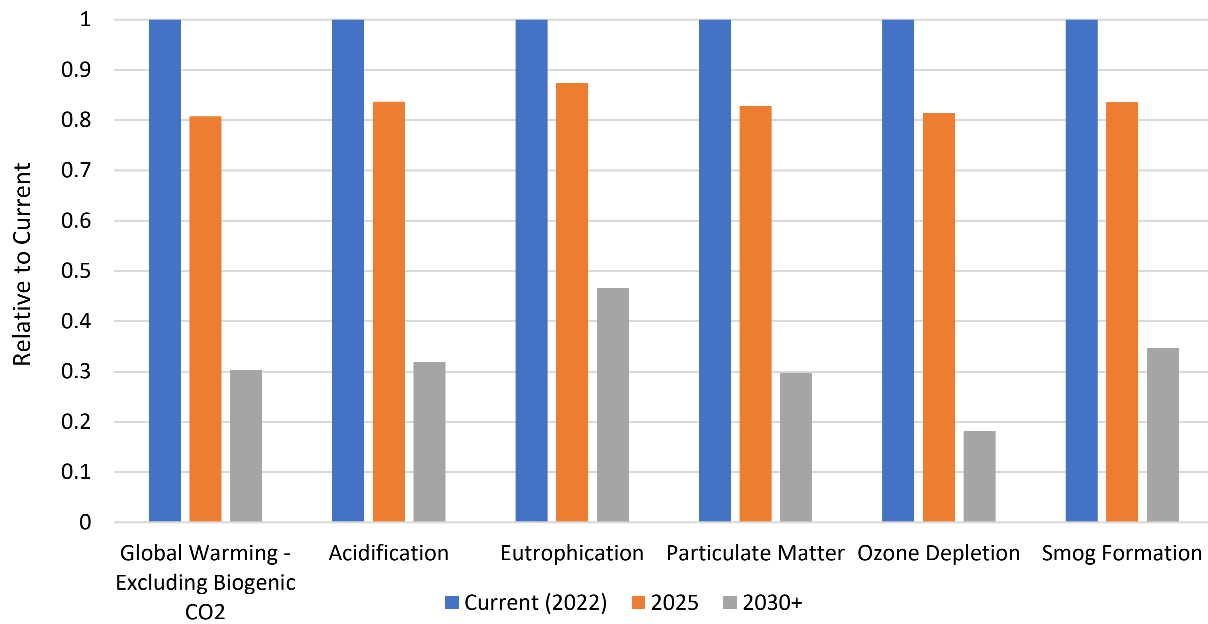

Figure B-7: Comparison of impacts for future PET CSD bottle scenarios in the US.

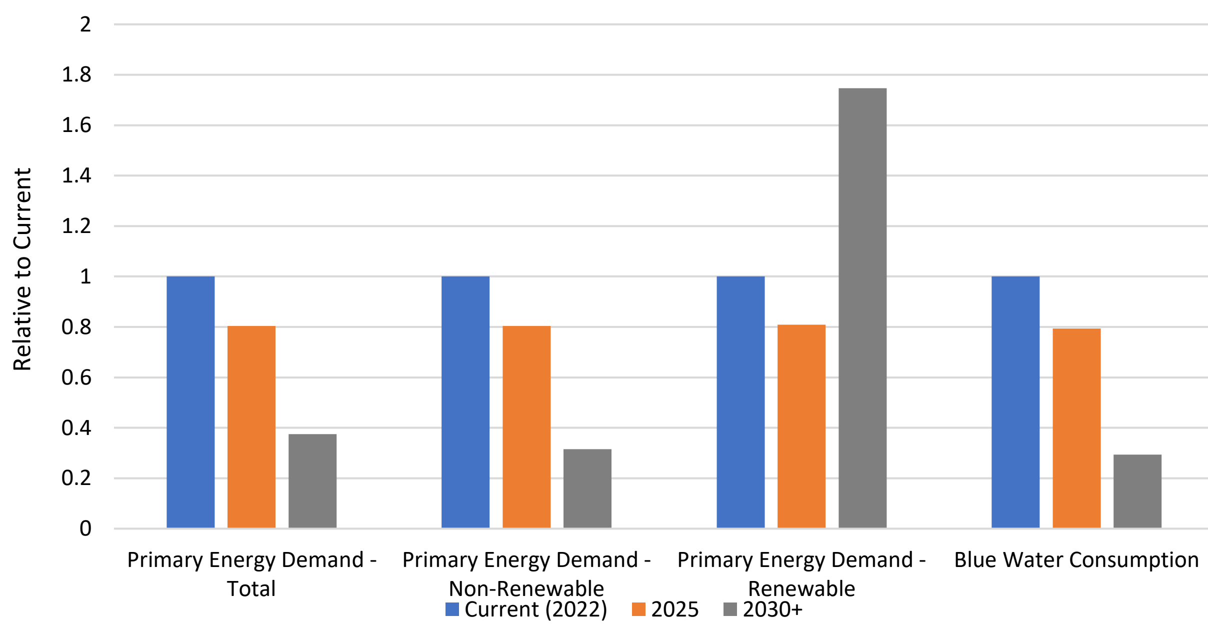

Figure B-8: Comparison of resource use indicators for future PET CSD bottle scenarios in the US.

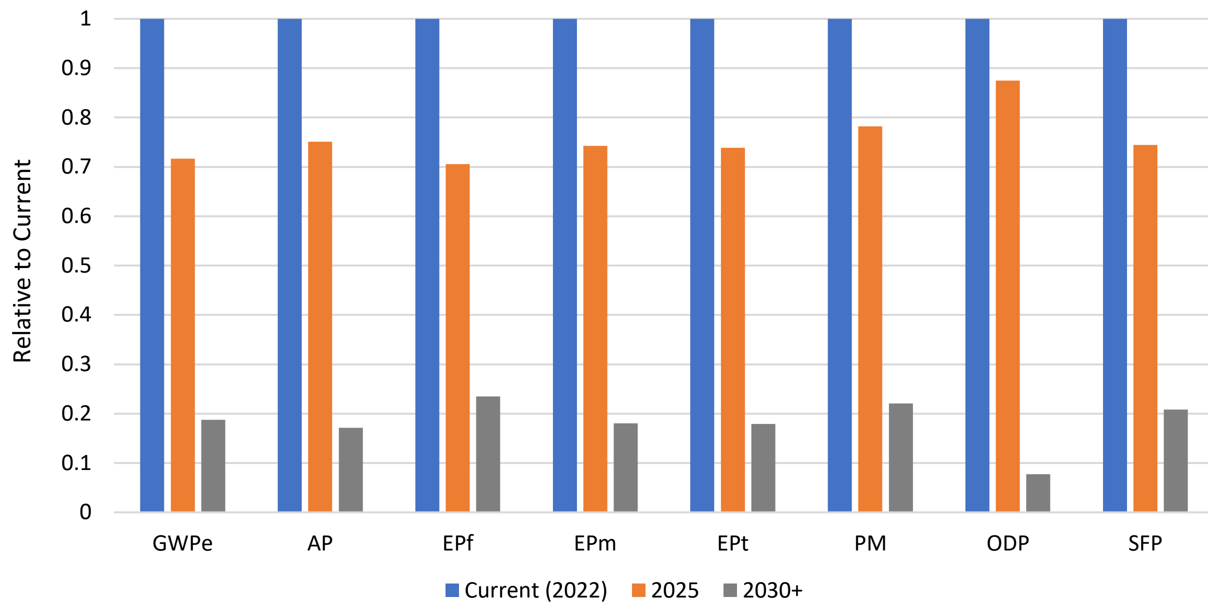

Figure B-9: Comparison of impacts for future PET CSD bottle scenarios in the EU.

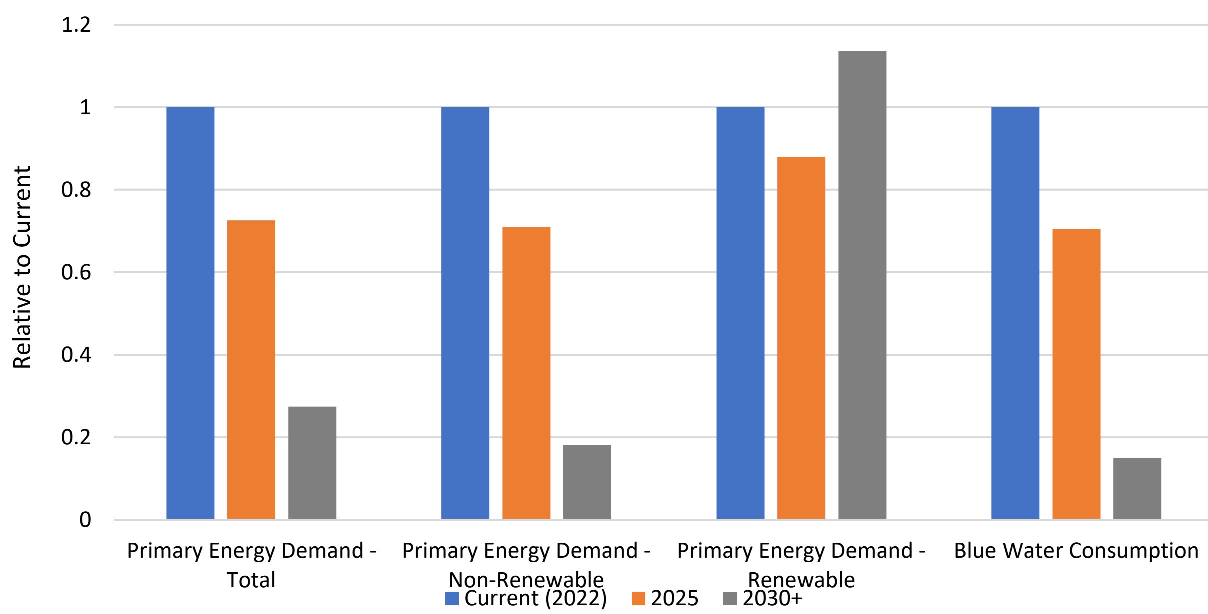

Figure B-10: Comparison of resource use indicators for future PET CSD bottle scenarios in the EU.

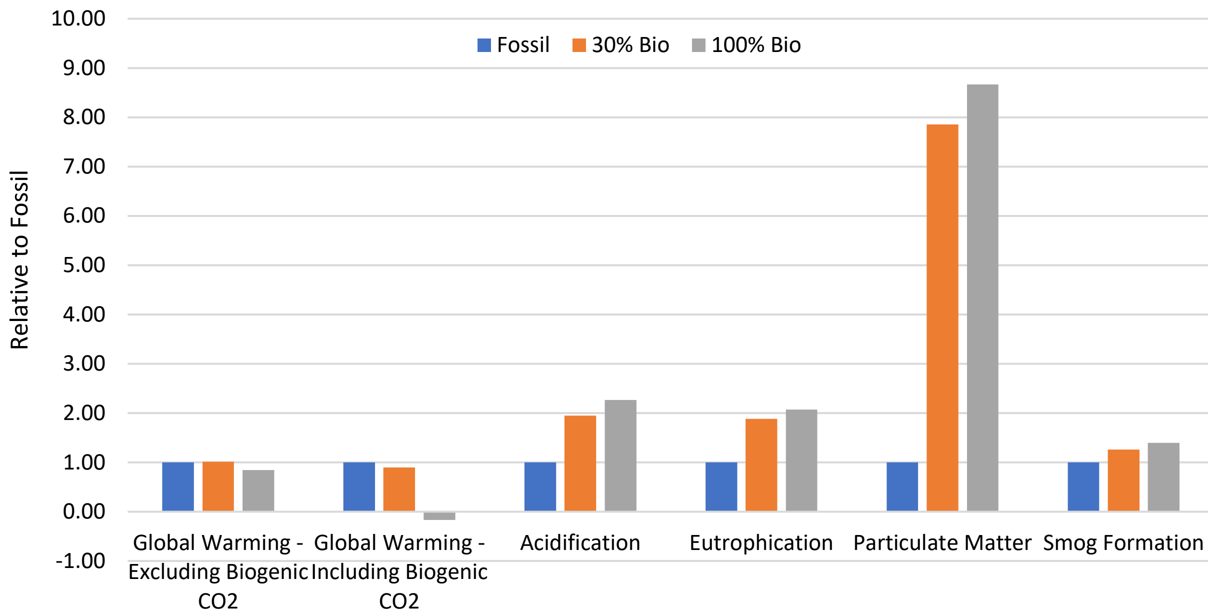

Figure B-11: Relative impact results for 2030+ PET CSD bottles with different amounts of biogenic content in the US

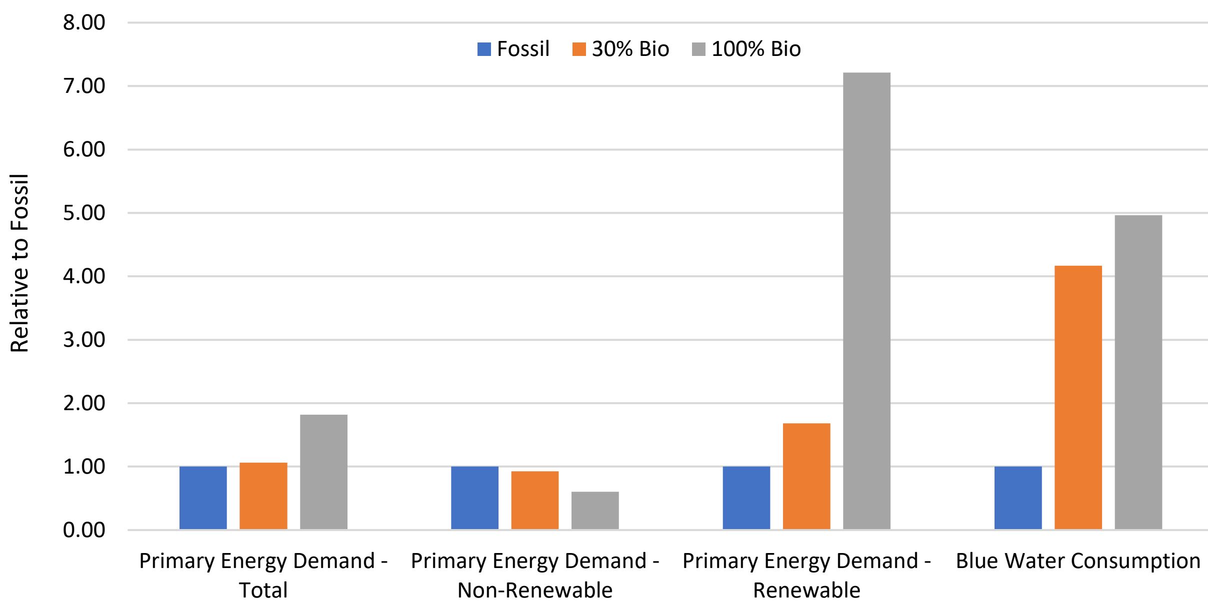

Figure B-12: Relative resource use indicator for 2030+ PET CSD bottles with different amounts of biogenic content in the US

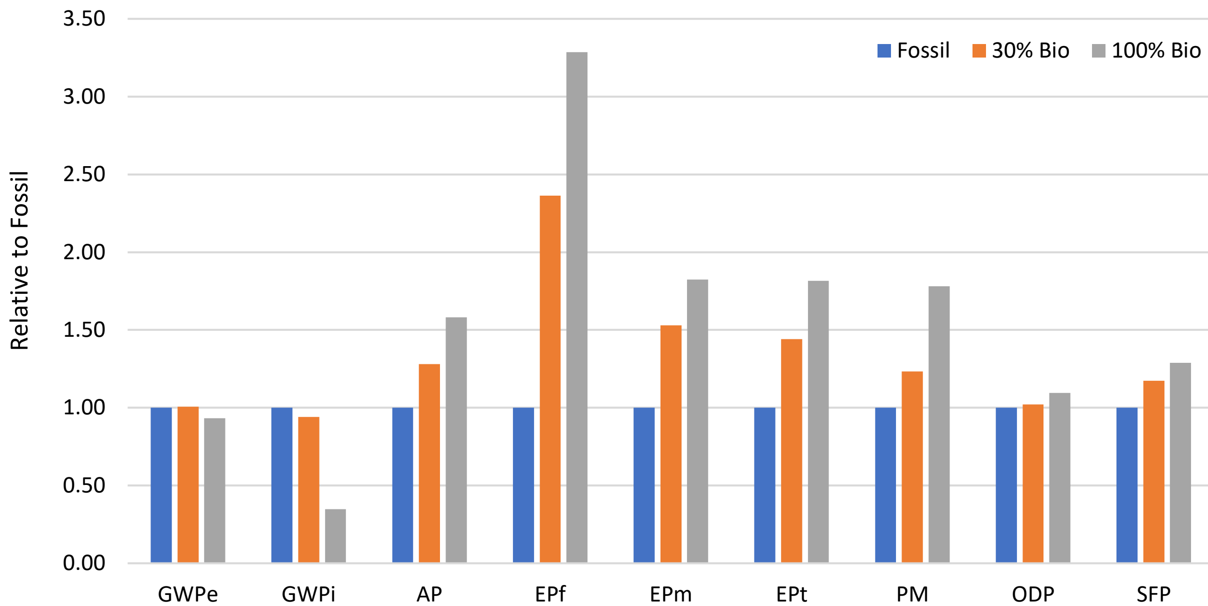

Figure B-13: Relative impact results for 2030+ PET CSD bottles with different amounts of biogenic content in the EU

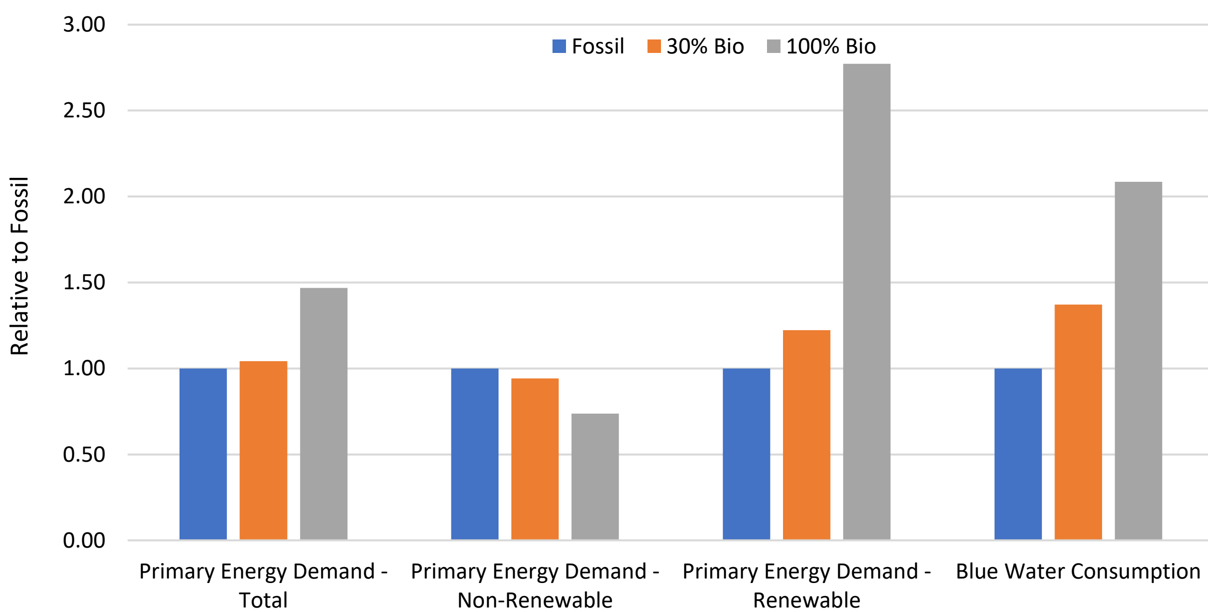

Figure B-14: Relative resource use indicator for 2030+ PET CSD bottles with different amounts of biogenic content in the EU